EFFECT OF RETAINED SCOTS PINE TREES ON REGENERATION, GROWTH, FORM, AND YIELD OF FOREST STANDS

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SUMMARY

Green tree retention is predominantly motivated by the increasing complexity of objectives in forest management. It is one of the major methods for the creation of structurally complex stands for ecological and amenity benefits. Retention may promote regeneration in terms of regular seed tree, shelterwood, planting, or direct seeding methods. The effect of retaining Scots pine trees to various degrees and in varying stand structures was assessed, with emphasis on regeneration results, development of the juvenile stand, tree quality and economic results were assessed. Group retention seems to be the simplest way to practise retention with Scots pine for ecological and amenity purposes. Considerable difficulties can be expected when trying to regenerate pine under a dense shelter, naturally or artificially. After the regeneration phase, residual trees have adverse effects on the young generation. Sustainable uneven-aged structures are hard to create and maintain with Scots pine.

KEY WORDS: Tree retention
Growth
Yield
Regeneration
Quality

INTRODUCTION

Retained trees are left more or less permanently on a forest regeneration area. One of their potential functions is to assist regeneration in terms of regular seed tree, shelterwood, planting, or direct seeding methods. Some trees may be removed at a later date or lost through damage, but most are retained for life and beyond.

Tree retention is predominantly motivated by the increasing complexity of objectives in forest management, including harvesting and regeneration. It is one of the approaches proposed for creation of structurally complex stands that should help maintain specific ecological processes and aesthetic values (Franklin *et al.,* 1997). Live retained trees are also a source for snags and woody debris on the forest floor, which are key elements in maintaining biodiversity (Franklin *et al.,* 1997; Annila, 1998).

Retention is now widely applied in regeneration areas in Scandinavia. There are additional challenges to meet in the Scots pine *(Pinus sylvestris* L.) forests of Western Europe where it has been widely planted, often in single species stands. Retention can play a significant role in the application of «close-to-nature» management of Scots pine forests, with the following principles and objectives given for Northern Flanders by Lust and Geudens (1998):

1. Minimise the rate of change. Apply long transformation periods and regenerate under cover.
2. Use native tree species. Scots pine must be maintained, with a compromise sought between native broadleaf species and Scots pine. Oak and birch are given special consideration in current Scots pine forests.
3. Avoid clearcuts.
4. Encourage natural regeneration.
5. Development of a complex structure. A mosaic structure with complexity in vertical and horizontal plane is the goal.
6. Increase dead wood. Old big trees should be left standing or lying in the forest.

Early observations, survey results and conclusions of the effect of large Scots pine trees on the regeneration and development of a seedling stand have varied between extremely detrimental to beneficial. Aaltonen (1919) studied poorly stocked gaps around large old pines on poor sites in Lapland. The results, confirmed later over a range of site conditions, advocated the early removal of seed trees after successful regeneration. This became the standard procedure in Finland. In Germany, the famous and much debated «Dauerwald» concept of applying a selection system for Scots pine management is based on variable (single tree to patch) retention and use of small regeneration gaps (Möller, 1922, Wiedemann, 1925). One of its cornerstones was the remarkably good shade tolerance of Scots pine seedlings under a Scots pine overstorey in the famous Bärenthoren forest district.

This review deals with tree retention in terms of regeneration harvest methods in the context of even-aged management systems. Connections with selection or uneven-aged management are obvious, especially within the basic biological framework. However, the concept of tree retention would be irrelevant in silvicultural systems where high stocking levels are sustained perpetually.

The purpose of this review is to examine the effects of retained Scots pine trees on:

*   regeneration of Scots pine and admixture species in terms of seedling emergence, vigour and survival;
*   growth and mortality of trees of the new generation;
*   resulting stand structure and its development;
*   external quality of trees of the new generation in terms of branching and defects;
*   growth of the retained Scots pine trees and their contribution in volume and value growth;
*   resulting economics.

At the stand level, the result of a regeneration effort and precommercial stage management regime can be assesed from the estimated future wood production of the stand,

and the costs in money and time until successful regeneration. Commercial and noncommercial utilities other than wood, as well as ecological sustainability, should also be assessed.

Tree and stand parameters such as stocking, spatial distribution, size distribution, species composition and vigour provide the foundation for the assessment. Tree recruitment, mortality, and growth processes determine their development in time and are controlled by a multitude of biological, environmental and technical factors, often as complex interactions. Some treatments like cleaning, thinning, and overstorey removal manipulate the tree stand directly. Unforeseen complications can arise, such as damage through logging operations.

This review will assess the effect of retained Scots pine trees on the individual tree and stand parameters, the processes, and results. Finally, a summary and practical implications will be presented.

MATERIAL AND METHODS

Information sources

Relevant information on Scots pine retentions was concentrated in Finland, Sweden, and Germany with their extensive Scots pine forests and intensive research efforts in the past and present. North American research results and application guidelines may be helpful but not directly applicable in Europe due to differences in species composition and environmental parameters.

The principal sources used in this review were:

1. Niemistö *et al.* (1993). Growth of Scots pine seed bearers, and regeneration and development of seedlings during a protracted regeneration period was studied with empirical material from temporary sample plots in 69 stands on infertile mineral soils in Northern Finland. Up to 200 stems ha^{-1} of Scots pine seed trees had been retained for 8-35 years after seed tree cutting. Models describing density and growth of the seedling cohort, and growth of the overstorey pines were constructed and used in simulations.

2. Valkonen and Ruuska (1999). Empirical models have been constructed to describe the effect of retained Scots pine trees on stand structure, and growth and external quality of young Scots pine and birch *(Betula pendula* Roth, *Betula pubescens* Ehrh.) trees and growth of retained trees in Southern Finland. Because the study and its results have not been published yet, the material and methods are outlined briefly in Appendix I.

3. Kuuluvainen and Pukkala (1989a). The effect of Scots pine seed trees on the density of ground vegetation and tree seedlings was modeled using a spatial competition index and empirical data from one regeneration area in Eastern Finland with 50 Scots pine seed trees ha^{-1} retained for three years prior to the field measurements.

4. Kubin (1994, 1998). Optimal length of seed tree retention period was studied based on results from a permanent experiment with 1-8 year retention periods in northeast Finland on an average site stocked with 26-42 stems ha^{-1} of pine seed trees.

5. Valtanen (1998). A study on the results of the seed tree method for Scots pine in Central Finland, including the effect of retention of 20-80 seed trees ha^{-1} for 3-15 years. Data from a series of permanent experiments at 5 locations were utilized.

6. Basic Finnish studies on the seed tree and shelterwood methods with highly relevant information (Heikinheimo, 1937, Sarvas, 1949, Kalela, 1954, Lehto, 1956, 1969, Valtanen, 1994).

7. Major Swedish studies with a high degree of relevance (Hagner, 1962, Björkman and Lundeberg, 1971, Ackzell and Lindgren, 1992, Persson, 1992, Sundkvist, 1993, 1994a, 1994b, Ståhl and Karlmats, 1995, Karlmats *et al.,* 1996).

8. Major studies from other European countries

    - Geudens *et al.* (1998). A study on the effect of soil treatment, heavy thinning and deer fencing on regeneration in a 70-year old Scots pine stand in Northern Flanders, based on one experiment with a 7-year observation period.
    - An overview from Flanders with information on regeneration (Lust and Geudens, 1998).
    - A survey of six 45-69 year old Scots pine stands in Northern Flanders with understories composed of red oak *(Quercus rubra* L.) and black cherry *(Prunus serotina* Ehrh.) (Maddelein *et al.,* 1990).
    - A survey of 15-70 year old Scots pine stands stands in Northern Flanders with a spontaneous ingrowth of a mixture of broadleave species (Lust, 1987).
    - A review and experimental results on the use of pine shelterwood for oak *(Quercus robur* L., *Quercus petraea* Liebl.) and beech *(Fagus sylvatica* L.) in Germany (Ebeling and Hanstein, 1988).
    - Wiedemann (1925). Results from studies in the famous «Dauerwald» selection forests in Northern Germany with a very long regeneration period (25-35 years) with 60-150 Scots pine ha$^{-1.}$ Additional results from nearby Eberswalde from various kinds of gap, patch, retention, and shelterwood retention in 0.05 to 0.5 ha constellations in direct seeding of Scots pine with a lot of beech.
    - Heinsdorf (1994). A review of the history, concepts, methods, results and conclusions on the natural regeneration of Scots pine in Northern Germany, including the controversy around the «Dauerwald» selection concept.
    - Preuhsler and Costa (1994). Results from an experimental study on combined natural regeneration for Scots pine, direct seeding of oak, and planting of beech *(Fagus sylvatica* L.) and some additional broadleaf species in Nürnberg, Germany.

RESULTS

Recruitment

Retained pines are a natural seed source that can restock a regeneration area in part or in whole. Heikinheimo (1937) reported that the average seed production of seed tree stands [N=40-100 stems ha^{-1}, T (age of retained trees)=90-120 years, T_r (retention period)=4-17 years] was 19.3 seeds m^{-2} on poor *Calluna* site types (CT) and 39.9 seeds m^{-2} on average pine *Vaccinium* site types (VT) in Southern Finland. Sarvas (1949) showed similar results with similar seed tree parameters (18 seeds m^{-2} for CT sites and 61.2 seeds m^{-2} for VT sites). Lehto (1956) also reported fairly similar seed tree stands (N=10-50 ha^{-1}, age=90-150 years) and results (CT:16.6 seeds m^{-2}, VT: 30.7 seeds m^{-2}). Sarvas (1962) concluded that seed production is greatest with 100-200 stems ha^{-1} in seed tree stands in Southern Finland.

The average seed production of a retained Scots pine tree stays the same, or even decreases, for 3-4 years after the regeneration cutting. Then it increases dramatically, depending on tree vigour, size, and age. After levelling out in about 10 years it may be several times the original production (Heikinheimo, 1937). Large climatically induced annual variations in seed crop (amount and maturation level) are typical for Scots pine in Finland, and more so in the north. An abundant seed crop can be expected once in a 100 years at the northern timberline (close to 70°N), but every 2-5 years in the South (60°N). Some viable seed is produced by isolated seed trees during most years even in extreme climatic conditions (Heikinheimo, 1937, Numminen, 1982).

Annual seed crop variations are generally smaller in seed tree stands than in fully stocked stands in Finland, and the advantage is greatest in years with low seed production (Heikinheimo, 1937).

Consequently, 30-50 Scots pine trees ha^{-1} are usually enough to restock a regeneration area in Finland. Even 20 trees ha^{-1} are enough if an effective soil treatment (mineral soil exposed on 50 % of area) coincides with good seed crops (Valtanen, 1994, 1998). To allow for variations in wind throw hazard, annual seed crop, soil treatment effect, and site conditions, stockings between 50-150 stems ha^{-1} are currently recommended in Finland. Valtanen (1998) concluded that the upper limit is far too high and may produce adverse effects if retained too long. An adjoining pine stand with sufficient seed production capacity can often regenerate areas up to 50 m distance without any retention on the area itself, other factors permitting (Valkonen, 1992). Seed dispersal from a sparse seed tree stand as an edge can extend further than from a closed stand, probably due to higher wind speed. Ackzell (1992) recorded an average 5,200 Scots pine seedlings per hectare at a distance of 30-70 m from the edge of a seed tree stand, and 2,462 ha^{-1} at 70-110 m distance.

Germination, survival, and growth of a seedling at a given site depends on a multitude of factors. The most important are temperature, and the availability of light, water, and nutrients. Retained trees generally decrease the resource availability for seedlings through light and rainfall interception and nutrient uptake. Some favourable effects of retained trees on germination and seedling survival may also be involved. Leaching of nutrients from the crown and stem throughflow can increase nutrient availability in close to a tree. Shading can help reduce excessive soil temperature and evaporation and competition from ground vegetation in particular.

Kuuluvainen and Pukkala (1989a) found that Scots pine seed trees reduced the abundance of grasses and herbs 3 years after regeneration cut in the experimental stand in Eastern Finland. At a distance of 8 m from the nearest tree there were 4-5 times as many grasses or herbs compared to that in the immediate vicinity of a seed tree. Mosses with low resource requirements can thrive better in zones under the influence of the retained tree. Consequently, moss coverage decreased from 80 % near the tree to about 55 % at 13 m distance from it, while the number of pine seedlings increased from about 5,000 ha^{-1} to about 9,000 ha^{-1}, respectively. Hagner (1962) found that the ground vegetation colonised scarified patches significantly slower on patches near retained pines than those further away from them. The average coverage four years after treatment was only 20 % at one metre distance from a retained pine, compared to 55 % at eight metres. Based on German literature, Heinsdorf (1994) concluded that the moss layer is a far better vegetation type for regeneration in Scots pine stands than grass or dwarf shrubs.

Although critical for regeneration success and seedling numbers in general, root competition may have only a limited effect in the germination phase, in which temperature and moisture of the uppermost soil surface are crucial factors. Lehto (1956) noticed a marked advantage in germination rate and germinant weight a few days after germination on experimental plots in a sparse Scots pine seed tree stand (N=16 ha^{-1}) over a dense shelterwood stand (N=252 ha^{-1}). In a direct seeding experiment in Scots pine seed tree stands (N=60-70 ha^{-1}), Lehto (1956) found considerably more pine seedlings (20.0 m^{-2}) on plots where the root competition was artificially eliminated than on control plots (9.3 m^{-2}) after one year. The ratio did not change during the next one year of observations.

However, root competition from trees and ground vegetation commences immediately after germination. Later on, a seedling must continuously expand its root system to grow and survive, and competition for below ground growing space increases in importance. Stocking and duration of retention, as well as soil treatment effects, play major roles in their growth and survival.

Many research reports indicate that the effect of soil treatment (exposure of mineral soil) far exceeds those of any other practical means of improving seedbed properties in the boreal forests. Very few voluntary seedlings emerge outside the cultivated zone, e.g. only 0.0-4.3 % by species (Kubin, 1994, 1998). Disc trenches had an average 48,000 pine seedlings ha^{-1} but on the untreated strips there were only 5,000 ha^{-1} in a survey study in Central Finland (Valtanen, 1994). In an experiment in Central Finland, untreated plots had an average 2,940, disc trenched plots 4,540 and ploughed plots 7,580 seedlings ha^{-1} 5 years after regeneration felling (Valtanen, 1998). Ackzell (1994) found 74 % of natural seedlings on Scots pine seed tree areas growing in scarified tracks in Northern Sweden. Some of the driest Scandinavian Scots pine sites should not have soil treatment as it may adversely raise temperatures and reduce soil moisture.

Cultivation resulted in increased number and height of Scots pine regeneration in an experiment in a 70 years old Scots pine stand in Northern Flanders (Geudens *et al.,* 1998). However, there was no effect on other species such as rowan *(Sorbus aucuparia L.),* larch *(Larix decidua* Mill.), birch *(Betula* spp.), sessile oak *(Quercus petraea)* and red oak. Based on an inventory of seedlings on a bared extraction track in a Scots pine selection forest, Bergmann (1994) concluded that pine and birch could be regenerated through cultivation but without it they would have not much chance due to intensified grass competition. 18,000 ha^{-1} pine seedlings and 75,000 ha^{-1} birch seedlings emerged after 2 years on the bared track.

Seedbed properties start to change soon after a thinning or a soil treatment operation, most often becoming less favorable for regeneration. Hagner (1962) found that the density of a pine overstorey had a very pronounced effect on the recolonization of scarified patches by ground vegetation. With 50 retained pines ha^{-1} the average coverage in the patches four years after treatment was about 50 % but with 400 ha^{-1} only 10 %.

Almost all pine seedlings (about 15,000 ha^{-1}) emerged in the first year after disc trenching in the experiment conducted in Northeastern Finland (Kubin, 1994, 1998). At the end of the monitoring period there was virtually no difference in pine stocking between seed tree retention periods of 1, 2, 4 or 8 years. There were significantly less hairy birch *(B. pubescens)* seedlings in the 2, 4 and 8 year retention treatments (3,060, 4,500, 1,480 ha^{-1}) than in the 1-year retention plots (6,240 ha^{-1}). There were also somewhat less silver birch *(B. pendula)* seedlings, and birch sprouts, but the differences were not significant. A low number (260-340 ha^{-1}) of spruce *(Picea abies* Karst.) seedlings appeared in all treatments. Retention periods of 1, 2 and 4 years resulted in almost equal mean heights for Scots pine seedlings (52, 42, and 45 cm respectively), but an 8-year retention had a significant detrimental effect (20 cm). The same pattern appeared for birch and spruce seedlings but not for sprouts. It was concluded that a Scots pine seed tree stand can be abundantly stocked in one good regeneration year when a large seed crop and cultivation coincide.

In the experiment of Valtanen (1998) all but one of 3 experimental locations were fully stocked in 2-3 years after the regeneration cut (10,000-25,000 pines ha^{-1}). The fourth site was fully stocked after 5 years and the fifth, at the most unfavorable climatic location, only after 10 years. Prolonged retention did not further increase the stockings.

Failure in seedling emergence was one of the primary reasons for poor or patchy stocking in the Bärenthoren selection plots (Wiedemann, 1925). Patches with poor initial regeneration shortly soon became unfavorable for further regeneration.

Growth and survival

Apart from inherent factors, the growth and mortality of young trees is controlled by resource availability (site, competition and physical growing space) and both stochastic and deterministic damage. In a Scots pine retention with low overstorey stocking levels, often poor site fertility and water supply, it is frequently below ground competition that is responsible for competition effects. Niemistö *et al.,* (1993) concluded that poor stocking close to the retained trees was a result of root competition rather than light or rain interception, given the very small crown coverage and light interception in the seed tree stands. According to Tamm (1991), nitrogen is normally the limiting factor for tree growth in Scots pine stands on the meagre soils in Northern Sweden. This could also explain some of the overstorey effect as being competition for nitrogen. Heinsdorf (1994) and Olberg (1957) named water supply as the critical factor for pine regeneration on the poor diluvial sites of Northern Germany, and that an overstorey may aggravate the problem.

The roots of retained trees completely dominate the upper soil layer over a distance of 5-7 m from the stem, draining the nutrient and water resources (Björkman and Lundeberg, 1971). Kalela (1954) studied the root density and its distribution around approximately 100 year old Scots pine seed trees on fairly poor sites with a sandy soil in Southern Finland 3-10 years after the regeneration felling. It was estimated that a significant effect on

seedling growth extends for up to a distance of 3.5-5 m from the base, representing 200 m m^{-2} in total root density (Fig. 1). A critical value of 65-70 m m^{-2} root density in the humus layer would be a more relevant variable for small seedlings than the total value.
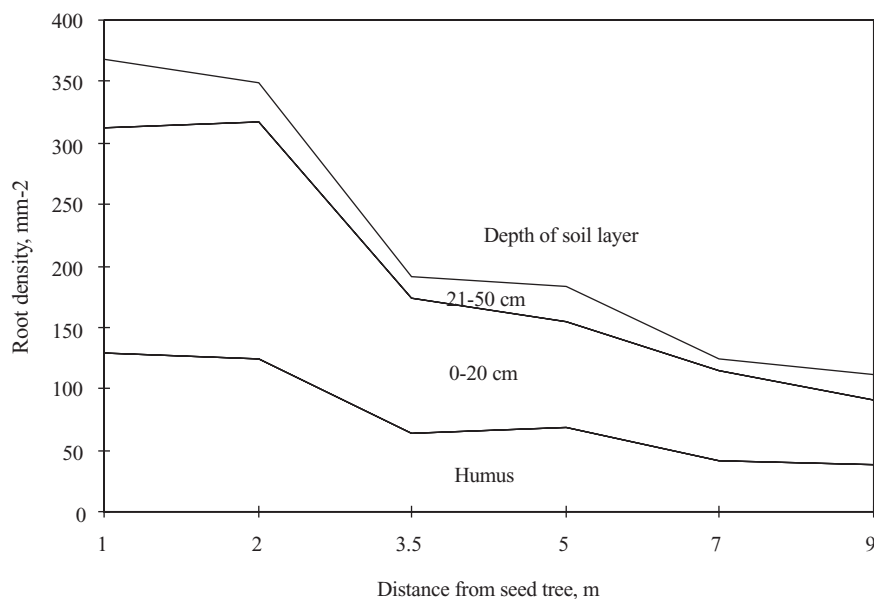

Fig. 1.–Average cumulative root density in soil layers and distance from Scots pine seed trees in Southern Finland (Kalela, 1954)
Densidad media acumulada de raíces en las capas del suelo, y distancia desde los árboles semilleros de Pino silvestre en el Sur de Finlandia (Kalela, 1954)

The root distribution pattern of a tree is generally irregular and asymmetrical. In the study of Kalela (1954) the area of highest density (>500 m m^{-2}) generally showed an oval shape clearly elongated in one direction away from the tree base (length 3-7 m, width about 1-2 m). Examination of the positions of the removed trees indicated that the shape and extension of the root systems was a result of past competition prior to regeneration. Old retained trees do not increase their root systems into newly released growing space as readily as young trees. According to Kalela (1949), a managed pine stand on a Vaccinium site type in Finland will start to show gaps between the root systems of individual trees beyond the age of 80-90 years. Prior to that, remaining trees rapidly fill in the spaces left by removed trees. Beyond 80-90 years, the root systems will not expand much and a reducton in stand density creates more growing space, allowing advance growth to emerge.

Wiedemann (1925) divided the gap, patch, retention, and shelterwood regeneration experiments in Eberswalde according to regeneration success of Scots pine and analyzed

what factors had contributed to the results. He identified soil properties and competition response as the decisive factors for any differences, as follows:

1. Good regeneration on layered soils. Scots pine tolerated a high degree of shading (or competition) well and showed good growth, vitality, and form. The site factors were favourable with good water and nutrient supply and little grass competition on sites with a layer of coarse sand on the surface, and a clay moraine layer with high water conductivity and nutrient supply underneath. Tree roots could reach the favourable layer but superficial grass roots could not.

2. Unsatisfactory regeneration or total failures on fertile sites. Most pine regeneration died due to heavy grass competition. With adequate water and nutrient supplies, broadleaved species dominated. Shading suppressed young Scots pines but did not suppress the grass. A very high degree of competition resulted from the combined overstorey and grass influences.

3. Unsatisfactory patchy stocking on poor sites. Young Scots pine trees were still mostly alive but suffering from overstorey competition, with a pronounced height and stocking gradient (or even empty space) around the overstorey trees. There were low numbers of broadleaves, possibly due to the very intensive overstorey competition for water and nutrients on these very poor sandy soils without a favourable lower soil horizon. Wiedemann (1925) also concluded that rain interception by the overstorey played a significant role.. The stand edge effect was also very pronounced so that full stocking was achieved only beyond 8 - 15 m from the outer edge of the crowns.

Light interception is probably not the principal reason for any growth reduction of Scots pine trees on poor sites in Northern Finland. The radiation regime at the ground level is comparatively uniform, and the light interception of a sparse retention stand is small. A stocking of 10-100 Scots pine retained trees ha^{-1} represent an average basal area of 1-10 m²ha^{-1} (Niemistö *et al.,* 1993, Valkonen and Ruuska, 1999). Estimates, using the direct radiation extinction models of Kuuluvainen and Pukkala (1989b), indicate that their shading probability at ground level would be about 3-35 % at 45 degrees sun elevation angle. Greater shading probabilities would result for smaller sun elevations and smaller for higher elevations. Pukkala *et al.* (1993) found that the correlation between seedling number per unit area and solar irradiation (both modelled and measured) in a mature Scots pine stand in Eastern Finland was near zero. Correlation between the radiation parameters and seedling growth was significantly positive. The stand was part open, part fully stocked, so that the variation in the radiation regime was very much greater than in a retention.

A model by Niemistö *et al.* (1993) indicated that the number of pine seedlings decreased drastically towards the bases of the retained Scots pine trees in seedling stands of 0.5-1.2 m mean height in Northern Finland (Fig. 2). Preliminary results from the study of Valkonen and Ruuska showed a much less steep decline for pine on more fertile sites in Southern Finland, but a stronger effect on birch seedlings (Fig. 2).

The same authors (Niemistö *et al.* 1993) showed that the height of pine seedlings decreased towards the bases of the retained Scots pine trees in seedling stands of 0.5-1.2 m mean height in Northern Finland (Figure 3). This finding was supported by Valkonen and Ruuska(1999), who also found no differential influence of retained trees upon diameter growth.
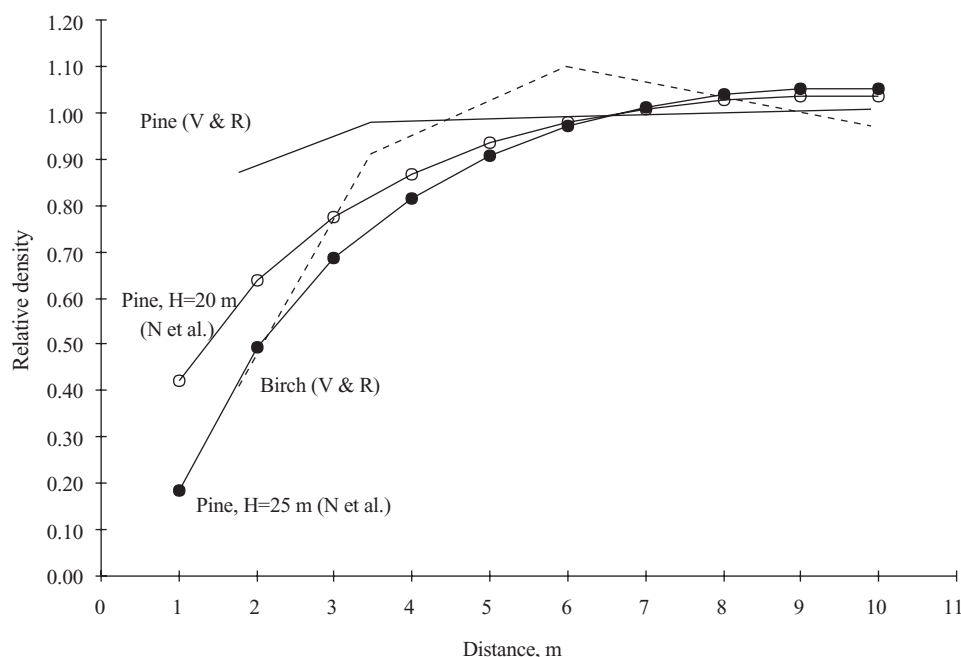
Fig. 2.–Relative average stocking of pine and birch seedlings by distance from a retained Scots pine tree. N *et al.*: Estimated using a model for pine by Niemistö *et al.* (1993) with mean height of retained trees (H$_{ret}$)= 20 and 25 m, thickness of the humus layer=3 cm. V & R: preliminary average results for pine and birch from the study of Valkonen and Ruuska (1999)

Existencias medias relativas de brinzales de pino y abedul según la distancia de un árbol retenido de Pino silvestre. N et al.: Estimado usando un modelo para pino por Niemistö et al. (1993) con una altura media de los árboles retenidos (H$_{ret}$)= 20 y 25 m, espesor de la capa de humus=3 cm. V & R: resultados medios preliminares para pino y abedul del estudio de Valkonen y Ruuska (1999)

In an experiment in Northern Sweden, planted 13-year old Scots pine seedlings had smaller height (1.6 m) on retention plots with 60 Scots pine trees per hectare compared to those on clearcuts (2.2 m) (Ackzell and Lindgren, 1992). There were also more living plants (4,074 ha^{-1}) on the clearcut than on the retention plots (3,311 ha^{-1}) six growing seasons after planting or direct seeding. The number of retained pine trees had a significant effect on seedling growth in Hagner's (1962) study in Sweden.

Competition increases the probability of mortality for a seedling through decreased vigour. There are also mortality processes of more random character that do not depend on the competition status of individuals. In this respect, a pine shelterwood can have beneficial effects such as sheltering oak and beech regeneration from late frosts (Ebeling and Hanstein, 1988).

Sundkvist (1994a) conducted a study on the extent and causes of initial mortality of Scots pine seedlings after a partial or total overstorey removal in Northern Sweden. He found that both injuries and mortality increased with increasing overstorey removal.
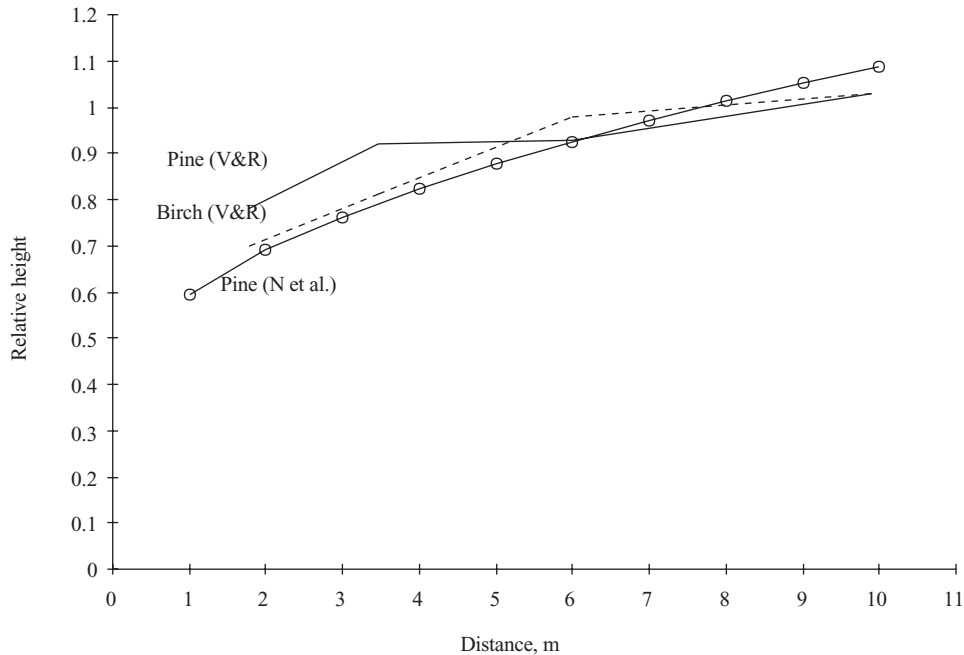
Fig. 3.–Relative height of pine and birch seedlings by distance from a retained Scots pine tree. (N *et al.*): Estimated with model by Niemistö *et al.* (1993) with time from seed tree cutting (Δt)=15 years, temperature sum (TS)=1,000 dd, N=50 stems ha^{-1}, thickness of the humus layer =3 cm. V & R: preliminary average results from the study of Valkonen and Ruuska (1999)

Altura media relativa de brinzales de pino y abedul según la distancia de un árbol retenido de Pino silvestre

About 80 % of the seedlings were dead or injured on the plots with total removal after 3 growing seasons, but only 25 % on control plots (no removal). Removals of 65 and 80 % caused intermediate effects. Most of the mortality and damage were caused by the pine weevil *(Hylobius abietis* L.) and Pissodes weevils *(Pissodes* spp.), e.g. 73 % of mortality and 91 % of injuries on total removal plots. The weevils probably responded to lowered concentrations of volatiles, caused by the removal. The second most important cause was fungi, mainly *Lachnellula pini.*

Retaining a dense pine overstorey for too long resulted in structural unstability and wide-spread, severe snow damage in Scots pine understories in the Bärenthoren forst district in Germany (Flöhr and Pietschmann, 1984).

As for physical growing space, trees will not grow through crowns of vital retained pines. In a closed stand they will not have much free space to evade the crowns. Consequently, the crown projection of a retained tree forms a patch where straight trees can grow only up to crown limit. In the data of Valkonen and Ruuska (1999), the average crown diameter was 5.2 m, representing 21.2 m^2 in crown projection area. A stocking of 10 retained trees per hectare represents 2.1 % of area, and 100 trees 21.2 %. Trees over 40

cm in diameter had an average 6.3 m crown diameter, representing 31.2 % of area with 100 trees ha^{-1}.

In addition to permanent retention, the possibility for later felling also needs attention. Scots pine advance growth released from a mature overstorey usually start to increase its height increment after a 1 to 3 year period of unchanged or slightly decreased growth (Vaartaja, 1951, Koistinen and Valkonen, 1993, Sundkvist, 1994b). The acceleration was greatest with 100 % removal, smaller for 60 and 85 % of initial basal area of 10.4-19.9 m^2 ha^{-1} in the study of Sundkvist (1994b) in Northern Sweden. Retention of about 2-6 m^2 ha^{-1} thus decreased seedling growth. However, the increase in increment was only about 2 mm year^{-1} on the second growing season after release, compared with the initial increment of 13.7-15.0 mm year^{-1}.

Regeneration results and stand structure

Seedling stands developing under an overstorey will develop a more heterogeneous size and spatial distribution than free grown stands (Vaartaja, 1951, Koistinen and Valkonen, 1993). The degree of heterogeneity is a result of the recruitment, mortality and growth processes and depends on density and spatial distribution of the retained trees, and tolerance of the seedling species. More tolerant trees may have a wider height distribution than intolerant trees that die more readily. Heterogeneous size structures may be desirable or not, depending on the regeneration and management goals. Unstocked patches are generally judged undesirable in young stands in commercial forestry.

In the experiment of Valtanen (1998), retention of Scots pine seed trees for 8-10 and 14-17 years resulted in a reduction in the stocking of pine seedlings (Table 2). The effect was greatest on plots with no soil treatment. A key factor was the infection by *Phacidium infestans,* a fungus that operates under snow cover. The faster growing trees on the plots with cultivation and short retention period were better able to survive. The average mean heights for pine at 15 years were 107 cm for a 3-5 year retention, 90 cm for 8-10, and 85 cm for a 14-17 year retention.

TABLE 2

RELATIVE STOCKING OF SCOTS PINE AND LENGTH OF SEED TREE RETENTION PERIOD IN CENTRAL FINLAND (VALTANEN, 1998). SHORTEST RETENTION BY SOIL TREATMENT = 100

Existencias relativas de Pino silvestre y duración del período de retención del árbol semillero en el Centro de Finlandia (Valtanen, 1998). La retención más corta, en cada tratamiento del suelo = 100

Soil treatment	Retention period	years	
	3-5	8-10	14-17
Untreated	100	70	48
Disc trench	100	90	98
Plow	100	96	87

In a survey study in Central Finland, Valtanen (1994) concluded that a 10-14 year retention of Scots pine seed trees (average 33 stems ha^{-1}, range 0-66) had resulted in unstocked patches of 100-200 m^2 in area. Average seedling height was 1.1 m, compared with 1.7 m with removal immediately after successful restocking. Valtanen (1994) suggested that 5 years would be the maximum retention period after successful restock that would not show substantial harmful effects to the seedling stand.

At the age of 80-90 years the Scots pine stands in Northern Flanders typically consist of an irregular cover of ageing pine standards, with an ingrowth generation of several species, already reaching into the middle, and sometimes, the upper storey (Lust and Geudens, 1998). A survey in 70-year stands confirmed that broadleaved trees (mainly red and sessile oak, and black cherry) are able to grow in these Scots pine stands with no need for heavy thinnings in the upper storey. Basal area retention between 20-30 m^2 ha^{-1} is quite feasible. Even the poorest sites can sustain a good understorey. However, survival of Scots pine seedlings is doubtful, and requires intensive and continuous assistance (Lust, 1987).

Based on an experiment with mixed species and methods (Scots pine: natural; oak: direct seeding; beech and some other broadleaves: planting) Preuhsler and Costa (1994) concluded that the density of the Scots pine upper layer can be utilised to regulate the species composition in such stands. Less tolerant species like pine and oak can be favoured by reducing the overstorey density. However, the very high density of oak was a much more decisive factor for pine survival than overstorey density which ranged between 55-89 % crown coverage.

The corner-stone of the German Dauerwald concept was that, in terms of natural succession, Scots pine had regenerated and thrived in stands with an overstorey of variable density and structure, and in coexistence with broadleaves, especially beech (Möller, 1922). Wiedemann (1925) held a contrasting view. In natural stands, Scots pine has survived only on special sites where the competition was minimal or where large scale disturbances had occurred, often through fire. A successful admixture with tolerant species like beech in uneven-aged or selection type structures was not common. In contemporary forests, human influence had favoured Scots pine through site degradation, and artificial regeneration. Such sites tended to develop a beech understorey and slowly crowd out the pine regeneration. Wiedemann (1925) concluded that prolonged shelterwood retention was undesirable with pine as it resulted in uneven size and spatial structure of the regeneration.

Bergmann (1994) reported large variations in pine regeneration underneath a 176 year old Scots pine overstorey of 99 m^3 ha^{-1} in eastern Germany. It had been thinned to emulate the famous Dauerwald management in Bärenthoren in the 1920s but left practically unmanaged thereafter. A second story of Scots pine, oak *(Q. robur, Q. petraea),* beech and hornbeam *(Carpinus betulus* L.) developed after the regeneration felling, comprising 84 m^3 ha^{-1}. A third layer of regeneration with variable height up to 10 m had emerged almost everywhere. It was overwhelmingly dominated by oak with 82-93 % of stems. Pine was a minority species amongst beech, silver birch *(Betula pendula* Roth) and rowan. The 40 hectare forest area had become a structured mixed stand developing towards a more natural structure and species composition than the old pure pine stand that had emerged on a site degraded by litter raking.

Natural regeneration of deciduous trees occurred under 70-year old pine canopies in Northern Flanders, with an average density of 7,000 saplings ha^{-1}, but 80 % was black

cherry *(Prunus serotina* Ehrh.), an undesirable exotic species. It was concluded that the regeneration of several broadleaved species was feasible under the cover of Scots pine, but that the regeneration of Scots pine was limited and restricted to stands where black cherry had been removed (Lust 1987, Lust and Geudens 1998). In a survey of 45-69 year old Scots pine stands, 3 out of 4 mature stands had a vigorous dense understorey composed of red oak and black cherry (Maddelein *et al.,* 1990). Heavy thinning of the Scots pine upper storey resulted in an increased number and height of Scots pine seedlings older than 1 year in Northern Flanders (Geudens *et al.,* 1998). It also increased the number and height of rowan and larch *(Larix decidua* Mill.), but had no effect on birch, oak and red oak.

Logging damage

Fellings of retained trees may affect survival and growth of regeneration through logging damage. Extraction can cause serious wounds to the root systems of trees adjacent to the tracks if ground damage occurs. Root rot through infections by *Heterobasidion annosum* often result in Finland.

Most studies and practical experience in Finland indicate that logging damage is not a serious problem in well stocked seedling stands (review by Hyppönen, 1996). However, it may shift the balance to unacceptably low stocking if the initial stocking level is low. Damage percentages of 15-20 % may be expected in labour intensive methods (chainsaw cutting, forwarder transportation) (Maukonen, 1987, Hyppönen, 1996) although excessive damage (45- 57 %) did occur in a few stands. The damage percentage increased with increasing removal volume and length of extraction tracks in a stand, since breakage under a felled tree or a forwarder wheel are the dominant damage mechanisms. Damage may be more serious in advance growth stands with greater seedling height (Vaartaja, 1951), but there are contrasting results, too, reviewed by Hyppönen (1996). Wide and deep crowns formed after a long retention period could cause greater damage than normal seed trees. Logging damage was one of the primary reasons for patchy regeneration in the «Dauerwald» selection stands of Bärenthoren (Wiedemann, 1925).

Growth of retained trees

Trees are often retained for life and longer. However, some are only temporarily retained, so that their contribution to wood production and income deserves some attention. In addition, retained tree size and probably growth rate are important predictors for seedling growth and survival.

Tree age, size, vigour and crown dimensions are key factors of retained tree growth, in addition to site factors. Isolated retained trees are often far apart and free of competition from each other, whilst in groups or denser overstories they may influence each other. Initially, emerging regeneration does not reduce the resource availability of retained trees, but competition increases with growing density.

The mixed linear model by Niemistö *et al.* (1993) for cross-sectional increment at breast height indicated dependence on tree size, tree age, and time from the felling that removed inter-tree competition.

According to the model, diameter growth at breast height increased substantially during the first 15 years after being released from neighbouring competition in the regeneration felling (Figure 4). Diameter growth was even greater (15-20 %) in lower parts of the stem (15-20 % more at 0.5 m height than at breast height), and slower higher up on the stem. Consequently, the height to diameter ratio fell considerably. After 15 years the average tree volume increment was 3.0 % or almost double that before the cut.
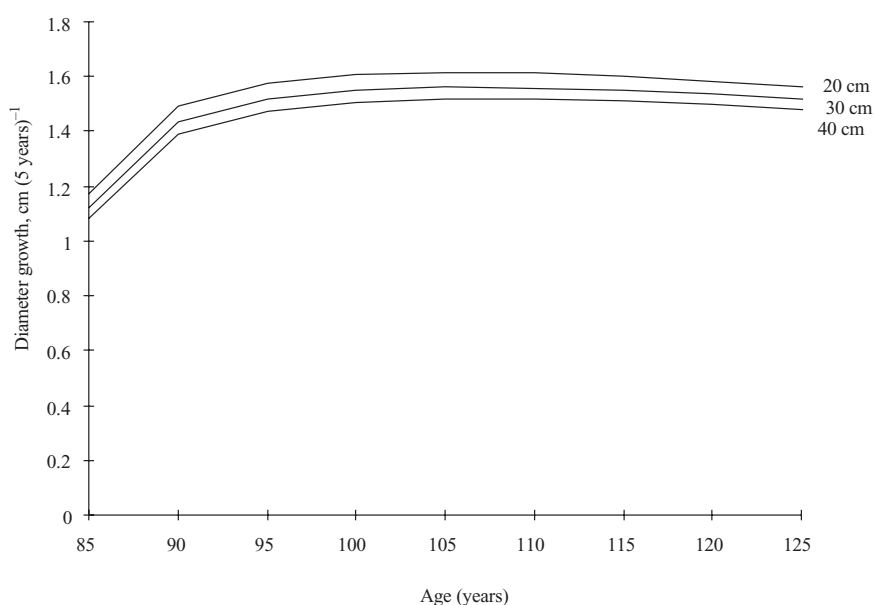

Fig. 4.–Diameter growth at breast height of retained Scots pine trees 20 30, and 40 cm in diameter after being retained at 85 years of age (Niemistö *et al.,* 1993)
Crecimiento en diámetro a la altura del pecho de árboles de Pino silvestre de 20, 30 y 40 cm de diámetro tras ser retenidos a los 85 años de edad (Niemistö et al., 1993)

Despite an increase of 100 % in 15 years, volume increment at the stand level remained very low in stands with a low stocking level (Niemistö *et al.,* 1993). According to the stand level volume growth model, a stand with 100 stems ha^{-1} would grow at 1.2-1.5 % of volume in Southern Finland with a temperature sum TS=1200 dd, and at 0.8-1.1 % at TS= 900 dd in Southern Lapland over 35 years of regeneration cut. A stocking of 60 stems ha^{-1} would show 0.75-0.9 and 0.5-0.7 % volume growth rates, respectively.

Sarvas (1949) reported similar volume growth rates for seed tree stands (N= average 72 ha^{-1}, range 12-180, T=81-148 years) in Southern Finland after a 4-35 year retention period: 0.6 m^3 ha^{-1} for the poorest Calluna type, 0.9 for Vaccinium type and 1.3 for Myrtillus type, or 1.9 %, 1.9 % and 1.7 %, respectively. It was concluded that long-term retention was not economically profitable, since the same diameter and quality level can be achieved in fully stocked stands with much higher volume growth rates.

In contrast, Karlmats *et al.* (1996) estimated that after a period of growth acceleration, a shelterwood stand would produce about 89 % of the fully stocked stand, and a seed tree stand about 75 %. Results based on model studies (Persson, 1992) indicted the possibility of increasing the dimensions and value of high quality trees without adverse effects on their wood properties.

Form

Tree form in retentions can apply to the retained trees or the seedling stand. The best trees of the stand, in terms of external quality, were retained as seed bearers in the study of Niemistö *et al.* (1993). They were generally straight, free of defects, and free of branches up to considerable height. Consequently, the additional growth that they accumulated after the regeneration cut could be assigned to the highest quality category. However, the potential yield per log of equal volume decreased as a consequence of the greater taper.

Trees retained in solitary positions or at edges stop reducing their crown length as would happen in closed stands. In south Finland, seed trees retained for 10-15 years had an average crown ratio of 0.42-0.51 according to the site (Sarvas, 1949). Comparable figures would be 0.30-0.33 in old unthinned natural stands and about 0.4 in mature managed stands (Hynynen, 1995, Hynynen and Siipilehto, 1996). A crown ratio of 0.5 would mean there would be living branches from about 9.5-11.9 m and upwards in height in trees d>25 cm.

Retained trees can affect the vitality, form and branching of the seedling stand. Based on German experience, Valkonen and Ruuska (1999) hypothesised that the branch thickness of surrounding seedlings would be reduced and this expectation was confirmed by initial modelling (Figure 5). The effect would be about 2.5 mm for 5 m high trees within 1 m distance of a 40 cm retained Scots pine tree compared to a similar tree over 10 m away. Less fertile sites and greater density of the seedling stand also resulted in smaller branches.

Lust (1987) found that understorey broadleaves (red and sessile oak, black cherry, and a few minor species) in old Scots pine stands were of good morphological quality. Pine shelter of about 40-60 % relative stocking (of maximum) and 48-80 % relative radiation level is utilised in oak and beech regeneration areas in the forest district of Sellhorn in the Lüneburger Heide, northern Germany. This is used as additional competition to promote good quality development in the young broadleaves. As a result, stocking can be reduced in planting or seeding from 8,000-9,000 ha^{-1} to 5,000-6,000 ha^{-1} (Ebeling and Hanstein, 1988).

Although young trees in the Bärenthoren selection stands showed smaller branches and smaller stem diameters for equal height with greater overstorey competition and stand density, there were often poor quality «wolf trees» in patches with no overstorey competition (Wiedemann, 1925). Stem defects are typical for Scots pine seedlings under a dense understorey. Crooked stems with forks and dense branch groups are typical, as well as bark wounds, asymmetrical growth rings and reaction wood. Most stem deformations result from damage to the terminal bud, which is common in understories due to insects, and pathogens which often wound the stem. Logging damage is also common. The defects generally have little effect on yield and quality of the crop trees as they are over-
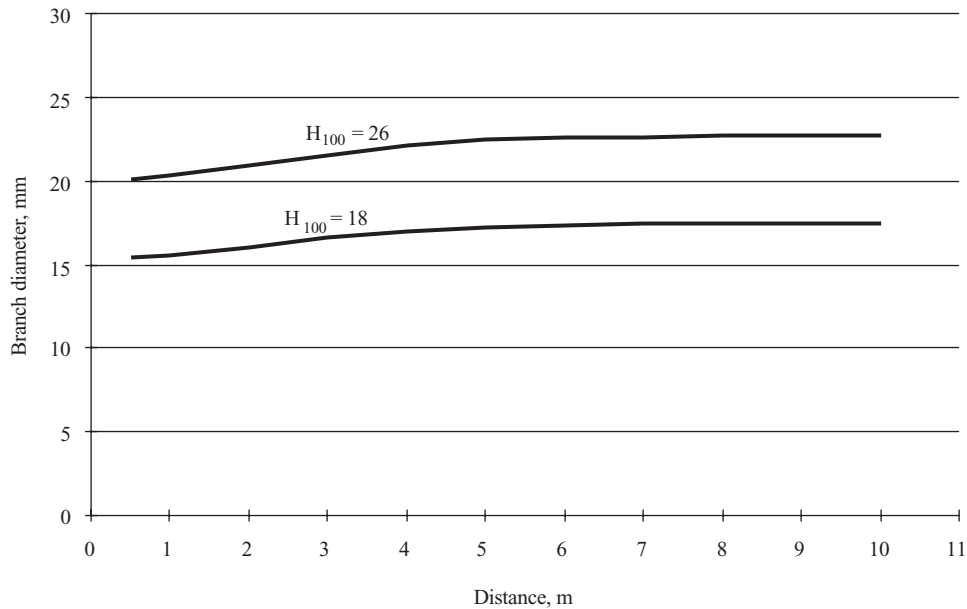
Fig. 5.–Diameter of the thickest branch of a 5 m high dominant Scots pine by distance from a retained Scots pine (d=40 cm) and site (H$_{100}$) in an average density seedling stand from the data of Valkonen and Ruuska (1999)
Diámetro de la rama más gruesa de un pino dominante de 5 m de altura, según la distancia desde un árbol retenido de Pino silvestre (d=40 cm) y calidad de estación (H$_{100}$), en un rodal de densidad media, a partir de los datos de Valkonen y Ruuska (1999)

grown by normal wood when the trees are released (Vaartaja, 1951). Ackzell and Lindgren (1992) found that in a 13-years old Scots pine plantation, the proportion of straight stems was greater (50.7 % vs. 42.1 %) and the average number of branches per whorl was smaller (4.41 vs. 4.97) on plots with 60 retained Scots pines ha^{-1} than on clearcut controls.

Total yield and economics

Niemistö *et al.* (1993) concluded that, despite the high quality produced in Scots pine seed tree stands, the interest on capital employed is too low to make it profitable to retain the seed trees any longer than is necessary for restocking. This is accentuated when permanent retention is projected for most or all trees. The negative effects on regeneration and growth of seedlings, logging damage, increased logging costs through repeated low-yield operations, and windthrow risk further decrease the attraction of long retention periods. However, these results were based on the Finnish price structure in the early 1990s and different conclusions could apply in areas with higher prices for top quality

material. For instance, based on long-term observations and analysis on volume and quality production in Scots pine stands in lower Saxony, Junack (1980) was convinced of the advantages of a two-storied system over a clearcutting system.

The understorey competes with the retained trees for resources limiting their growth depending on density and vitality of both. A dense (N=2,800 stems ha^{-1}, H= 0.8 m) spruce understorey grew to H=8 m in an experiment lasting 25 years and reduced the overstorey Scots pine volume growth by 1.03 m^3 ha^{-1} year^{-1} or 17.8 % (Isomäki, 1979).

Wiedemann (1925) reported that retained pines generally showed very rapid diameter growth rates for 2-3 decades after the cut, but slowed substantially after the younger understorey closed and was very slow thereafter. For about 30 years, the combined volume growth of the regeneration and the overstorey was higher than that of a regenerated clearcut of the same age. Beyond that, the clearcut and regenerated stand grew faster

Karlmats *et al.* (1996) compared the profitability of clearcutting, seed tree and shelterwood methods in the regeneration of two stands in terms of yield and wood quality. They concluded that the retention of seed trees or shelterwood is less profitable than clearcutting, due mainly to the smaller volume removal per cutting, the need for at least one extra entry, and lesser quality. However, advantages of regeneration were not considered.

The value of an improvement in quality is hard to estimate. However, if the stocking required for quality establishment can be reduced through overstorey retention, costs are immediately reduced. A total cost reduction of 10-20 % over clearcutting of about 5,200-7,300 Euros was cited by Ebeling and Hanstein (1988) for north German oak regeneration under a Scots pine overstorey.

CONCLUSIONS

Green tree retention is now an integral part of the regeneration and management practices in Scots pine forests in Scandinavia. The principal objective is to maintain elements that are important for ecological sustainability and to increase the aesthetic value of regeneration areas and young stands. In central and western Europe, retention is applied as an integral part of «close to nature» management of Scots pine forests. Long transformation periods, avoidance of clearcuts, and natural regeneration are favoured in order to create structurally complex mixed stands where Scots pine can be maintained in a desirable proportion. The practice can have both beneficial and detrimental effects on regeneration, growth, yield and net returns of a forest enterprise. Achieving good results depends on the density, duration, and spatial distribution of retention. The optimal regime varies according to biological and ecological factors, and management objectives and constraints. However, an effort is made here to evaluate a few simplified alternatives in order to summarise the review.

The hypothetical alternatives compared range from least to most intensive retention as follows:

1.   Retain a few trees per hectare in a compact group
2.   Use seed trees for regeneration and retain all or a major part for life

3. Use a shelterwood for regeneration and retain all or major part until the succeeding generation requires partial removal
4. Transform to selection management, creating selection structures through single tree and group cuttings and continuous regeneration

Group retention (1) is the simplest way to practise retention for ecological and amenity purposes. Potential adverse effects on regeneration and development of the young stand will be limited to the immediate vicinity of the retained group.

The seed tree method (2) with 20 to 150 seed trees ha^{-1} is an established regeneration method in Scandinavia. Originally, retained trees served as seed sources only. A shelterwood (3) with 150-500 trees ha^{-1} is used if a dense overstorey is assumed to provide some benefits in addition to seed sources. A shelterwood can probably help improve the seedbed properties in terms of the species composition, structure and biomass of the ground vegetation and shrubs, and the avoidance of temperature extremes and drought. The sparse stocking in a seed tree stand (2) has a similar kind of influence but is much less productive in terms of volume growth. In comparison, the effect of cultivation is much greater, at least in Scandinavia. In summary, considerable difficulties can be expected when trying to regenerate pine under a dense shelter, naturally or artificially.

After restocking has been completed, residual trees mainly have an adverse effect on the young generation by limiting resource availability through competition. It is logical to assume that the effect of a certain sized retained tree is smaller on a site with greater resource availability because it can draw the same amount of resources from a smaller physical growing space (Oliver and Larson, 1990). Consequently, the magnitude of the competition effect may vary between geographical areas along with differences in site productivity. However, there are very few research results available to evaluate or quantify this hypothesis.

Root competition for water, nutrients, and growing space seems to have a greater importance than the relatively small amount of light interception by retained Scots pines. The zone of influence of retained seed trees extends further than 10 m and the shapes of the root competition zone around a retained Scots pine tree are irregular, resulting in patchy spatial and size distributions of the next generation. Poorly stocked gaps are typical. Ultimately, fully developed trees can not be produced under the canopies of retained trees. Using average Scandinavian Scots pine crown dimensions of old retained trees, every solitary retained tree would make about 0.2-0.3 % of the stand growing space virtually unavailable to the next generation trees. The loss per tree should be smaller in group retention.

In principle, retained tree competition can be used to regulate the species composition of the regeneration since the influence varies between species as well as the environmental conditions of a site. There is not enough information available to draw conclusions for practical application. Competition from the retained trees can reduce branching in Scots pine regeneration, but preliminary research results seem to indicate that the effect is too small to have practical importance compared to selection of a suitable site and adequate stocking levels (Varmola, 1996).

In management alternatives 2 (seed trees) and 3 (shelterwood), partial removal and commercial utilisation of the retained trees is an option. The production of large dimension, high quality Scots pine timber is a possible objective. Due to their slow volume growth and their adverse effects on the juvenile stand and the limited differential in wood prices for quality, this seems unprofitable under large scale Scandinavian conditions. However, niche markets for high quality timber can often create price differences that can greatly improve the profitability of this option. The long production time is a disadvan-

tage, especially when high discount rates are applied in management planning. Salvage cuttings can become obligatory as a result of windthrow or other damage.

Scots pine is poorly suited to selection systems (4). Structures with a temporary pine domination in the large diameter classes are feasible, but pine regeneration in single tree or small group structures is very problematic. Uneven-aged structures with pine do exist in the high altitude and high latitude forests in Northern Scandinavia, but they are the result of a slow regeneration process, very low growth rate, large gaps and the fire regimes of the nineteenth century. As such, they are not suited for management guidelines in productive forests. A parallel exists in western North America with *Pinus ponderosa* Laws, a species somewhat similar to Scots pine in ecological and physiological characters, for which a successful uneven-aged management system is currently being tested (O'Hara and Valappil, 1995). However, experiences from the «Dauerwald» selection system seem to indicate that uneven-aged structures are difficult to create and maintain with Scots pine (Wiedemann, 1925). The Dauerwald forests have been been converted to broadleaved stands with Scots pine gradually disappearing as the old overstorey pines succumb (Flöhr and Pietschmann, 1984). This could be the goal in many forest stands in Europe that are currently occupied by artificially introduced Scots pine monocultures.

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RESUMEN

Efecto de la retención de pies de Pino silvestre sobre la regeneración, crecimiento, forma y producción

La retención de árboles vivos está principalmente motivada por la cada vez mayor complejidad de los objetivos en la gestión forestal. Es uno de los métodos más importantes para crear masas estructuralmente complejas, con el fin de obtener beneficios ecológicos y de recreo. La retención puede promover la regeneración por la disposición regular de árboles semilleros, por proporcionar cubierta, o por medio de plantación o semillado. Se han evaluado los efectos de retener pies de Pinos silvestres a distintos niveles y en varias tipos de estructura de masa, con énfasis en los resultados de la regeneración, desarrollo del rodal en el estado juvenil, calidad del árbol y resultados económicos. La retención en grupos parece ser el método más sencillo de practicar la retención en Pino silvestre con objetivos ecológicos y de recreo. Se espera una gran dificultad en la regeneración de pino bajo una cubierta densa, tanto natural como artificial. Tras la fase de regeneración, los árboles residuales tienen efectos adversos sobre el regenerado. Las estructuras irregulares sostenibles son difíciles de crear y mantener en Pino silvestre.

PALABRAS CLAVE: Retención de árboles
Crecimiento
Producción
Regeneración
Calidad

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APPENDIX I

MATERIALS AND METHODS IN THE STUDY OF VALKONEN AND RUUSKA (1999)

Candidate stands for inclusion in the study had to be at least 1 ha in area with a Scots pine seedling stand of 1-5 m dominant height with at least 20 large Scots pine trees retained for about 10 years or more without significant removals of trees through cutting or mortality. 35 stands were identified for consideration of which only 9 were accepted. The rest were disqualified for being too small in area or too irregular in shape for a plot to be located, or because of site and stand heterogeneity, or youth of the regeneration ($H_{dom} < 1$ m). The selected stands were situated in southern Finland between 60°00 N-62° 45′N and 23°00 E- 28°45′E, and below 100 m elevation. Stand parameters are shown in Table 1.

TABLE 1

STAND PARAMETERS AT MEASUREMENT IN THE STUDY OF VALKONEN AND RUUSKA (1999)

Parámetros de los rodales medidos en el estudio de Valkonen y Ruuska (1999)

Stand	Est.	T	T_r	H_{100}	Nr	Hr	Gr	Ns_{sp}	Ns_{bi}	Hs_{sp}	Hs_{bi}
1	pl	150	10	25.8	32	22.0	4.0	4,054	14,363	3.45	1.80
2	nt	75	8	21.6	70	17.6	6.0	3,773	4,144	1.08	1.17
3	nt	110	9	20.2	77	23.3	7.8	13,728	2,573	0.79	1.51
4	nt	105	18	18.4	117	20.7	10.9	37,156	743	1.27	2.38
5	nt	140	16	21.2	59	22.1	6.0	6,908	1,185	1.41	2.74
6	pl	105	8	23.5	49	24.0	4.6	30,337	13,837	0.21	0.64
7	pl	130	12	23.0	59	22.8	5.9	6,033	756	2.11	2.38
8	nt	115	12	24.4	38	23.7	3.7	7,805	4,445	1.24	1.02
9	nt	100	12	25.3	71	24.3	7.2	5,252	677	1.27	2.25

Est.   = Regeneration method: pl = planted, nt = natural
T   = Age of retained trees, years
T_r = Length of retention period, no. of growing seasons
H_{100} = Site index (dominant height at T=100 years), m
Nr   = Number of retained trees, ha^{-1}
Hr   = Average height of retained trees, m
Gr   = Basal area of retained trees, m^2 ha^{-1}
Ns   = Number of seedlings, ha^{-1}
Hs   = Mean height of seedlings, m
sp   = Scots pine
bi   = birch

All retained trees were mapped and measured for breast height diameter (d) and height (h). Scots pine trees at least 20 m from the stand edge were accepted as Sample Retained Trees (SRT). They were additionally measured for stump diameter (d_k), crown height (ch; height of the lowest contiguous branch whorl), crown width (cw), and other

dimension parameters, and an increment core was taken at breast height to determine tree age ($t_{1.3}$) and annual radial increments (i_r).

A systematic sample of 10 SRT was selected in each stand. Sampling points were systematically placed at 1, 3, 6, and 10 m distances from each SRT. Sample points within 20 m of a stand edge were omitted. At each sample point, the closest healthy dominant or codominant pine seedling was selected as a Sample Crop Tree (SCT) which was measured for coordinates, trunk and crown dimensions, height increment (i_h) and diameter increment (i_d), and age. Branch dimensions were measured from three whorls containing the thickest branch of the tree. All Additional Trees (AT, with h≥0.5*h of the SCT) at a 2 m radius around each SCT were measured for height. One of them per SCT was selected as a Sample Additional Tree (SAT)and measured for the same parameters as the SCT. All Additional Noncrop Trees (ANT, with h<0.5*h of the SCT) were counted at a 2 m radius from the SCT and their number (n) and mean height were recorded per species. Five Dominant Height Seedlings (DHS) that had grown virtually free of edge, overstorey, or seedling competition were also measured for the same parameters as the SCT.

Stand site index (H_{100}) was calculated as the average value of the estimates of the enlarged intercept method (Varmola, 1993), the dominant height curves of Varmola (1993), and dominant height model of Gustavsen (1980).

A modelling and simulation approach was applied in the study. Linear and nonlinear regression models and mixed linear models were fitted to the data using various parameter estimation methods. Generally applicable guidelines (Searle, 1971, Draper and Smith, 1981, Clutter *et al.,* 1983, Ranta *et al.,* 1989, Lappi, 1993) were applied for testing of the distribution hypotheses, model fitting and examination and the examination of residuals. The models were tested with an independent data set (Niemistö *et al.,* 1993) as far as relevant data were available.

Competition from retained trees and between seedlings was described using a numerical competition index, based on the concept of ecological fields (Wu *et al.,* 1985), in the manner of Kuuluvainen and Pukkala (1989a) with modifications. Growth potential (GPOT) value 1 at a point in a stand indicated full availability of growth resources with no tree interference, and value 0 indicated the minimum level where no growth resources are available. Growth potential is reduced by tree interference (ϕ). The maximum interference value ($\phi=1$) was achieved at the standpoint of the largest tree for stump diameter in the study material ($d_k=60$ cm). The interference value of each retained tree and seedling at its standpoint was $\phi=d_k/60$ cm and dimished with increasing distance according to a nonlinear function given in Kuuluvainen and Pukkala (1989a). Alternative parameter values were tested against height, diameter, and increment data, but the original values performed best and were retained.

The Growth Potential (GPOT) at the standpoint of a seedling was obtained by reducing its initial value of 1 by ϕ values of all trees in its vicinity according to a multiplication function as in Kuuluvainen and Pukkala (1989a). The final competition index used in the models was the Influence Potential value IPOT =1-GPOT.