Aspects of Precommercial Thinning - Private Forest Owners' Attitudes and Alternative Practices

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Abstract

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Precommercial thinning (PCT) in young forests in Sweden has been an important part of the silvicultural system since the 1950s. However, the annual area treated with PCT has decreased since the 1990s. At the same time the relative cost of PCT compared to both harvesting and regeneration has increased. The objectives of the work underlying this thesis were to examine the attitudes to PCT among private forest owners, and to evaluate alternative and potentially more cost-effective methods for PCT.

The private forest owners' attitudes to PCT were assessed by a questionnaire, which showed that they were interested in their forest and wanted to perform PCT. However, it was often neglected or postponed, usually because lack of time and secondly the cost of the operation. The forest owners seem to have many objectives for their forestry in addition to financial considerations. There were also significant differences between male and female forest owners, for instance the female forest owners claimed to have less knowledge regarding forestry and PCT-issues than male forest owners.

Several alternative PCT-methods were evaluated by field experiments, all with a randomised complete block design. One study focused on PCT through topping i.e. cutting the secondary stems at a higher level above ground than in traditional PCT, in a naturally regenerated birch (*Betula*)-dominated stand. Topping proved to be an attractive alternative, since the main stems in the topped treatments grew as well as the main stems on traditionally treated plots. Furthermore, it gave better results in terms of stem and branch properties. A point cleaning experiment (cutting competing trees within a certain radius of each main stem) in a planted Scots pine (*Pinus sylvestris*) stand showed that a single point cleaning operation gave worse results in terms of growth and stem quality variables, then a single traditional PCT. The findings are consistent with traditional recommendations to perform a subsequent PCT operation after point cleaning. The last study examined the effects of several variants of PCT, with differing tree selection criteria, in a typical planted Scots pine young stand in northern Sweden. The results showed that PCT was a profitable measure even if all planted stems were removed, raising the possibility that silvicultural cost-effectiveness could be optimised by retaining some of the natural regeneration and reducing the number of seedlings that are planted accordingly.

Keywords: *Betula* sp., cleaning, growth, growth simulation, *Pinus sylvestris*, *Picea abies*, stem quality, young stand

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Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Fällman, K., Albrektson, A. & Karlsson, A. 2005. Private forest owners in Sweden and their attitude towards precommercial thinning (Manuscript).

II. Fällman, K., Ligné, D., Karlsson, A. & Albrektson, A. 2003. Stem quality and height development in a *Betula* dominated stand seven years after precommercial thinning at different stump heights. Scandinavian Journal of Forest Research 18: 145-154.

III. Fällman. K., Albrektson, A. & Karlsson, A. 2005. Development of *Pinus sylvestris* main stems nineteen years after three different precommercial thinning methods in a mixed stand (Manuscript).

IV. Fällman, K. & Nenzén, A. 2005. Efficiency of planting and precommercial thinning in a representative mixed stand of Scots pine, Norway spruce and birch in Northern Sweden (Manuscript).

Introduction

Precommercial thinning

Precommercial thinning (PCT), or cleaning, is a silvicultural activity, in order to benefit the future crop trees (main stems), that is not linked to the extraction of merchantable timber (Smith et al. 1997; Anon. 2000a). The operation has financial costs but is expected to raise profits from subsequent harvests, mainly by increasing the diameters and timber quality in the retained trees (Andersson 1975; Savill et al. 1997). The aims of PCT are: to leave trees adapted to the site conditions (Björkman 1877; Zellén 1904; Eberling 1955; Söderström 1980; Jäghagen & Sandström 1994), to concentrate growth in trees expected to be most valuable in the future (Ström 1822; Smith et al. 1997), to decrease the risk of natural disasters such as damage by wind and snow (Ström 1822; Eberling 1955; Persson 1972); to increase the financial returns from future harvests by increasing stem diameter (Ström 1822; Eberling 1955; cf. Brunberg 1997), to decease the length of the rotation (Eberling 1955; Jäghagen & Sandström 1994); and, more recently to maintain and enhance conservation value (Bäcke & Liedholm 2000; cf. Kardell 2004).

The history of precommercial thinning in Sweden

An early description of PCT, found in Swedish forestry textbooks, is by Israel Adolf af Ström (1822), writing about an early silvicultural activity without financial profit. This is also described by Obbarius (1857) who emphasizes that it is important to extract not just larger trees that are suitable to get fuel wood. The recommended tree selection order was as follows; (i) to cut all dead or dying trees; (ii) all suppressed trees; and (iii) all trees of unwanted species (Obbarius 1857). The same author also recommended that the first thinning should be performed within the first 10-20 years, depending on the price of fuel wood, since the income from the wood should pay for the work; the better the price, the earlier the thinning.

The Swedish word for PCT - "röjning" - is early found in Björkman (1877), who defines it as removing seedlings of unwanted species, such as birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.), aspen (*Populus tremula* L.) or alder (*Alnus glutinosa* (L.) Gaertner and *Alnus incana* (L.) Moench) from stands of the desired species, usually Scots pine (*Pinus sylvestris* L.) or Norway spruce (*Picea abies* (L.) Karst). Af Zellen (1904) suggested cutting not only unwanted species, but also "wolf-trees" (dominant wide-crowned and highly-branched trees) of the desired species. To reduce the cost of PCT, he also recommended that the stems should be top-broken or girdled instead of being cut close to the ground (Zellén 1904). According to Wahlgren (1914), the aim of PCT is to decrease competition among young stems, irrespective of species of the species of trees cut. Wahlgren (1914) mentioned birch, aspen and alder as undesirable species, but he also emphasized that it is sometimes good to retain a mixture of broadleaved trees within the coniferous stand. Possible benefits of a mixed stand, according to Wahlgren (1914), are: fuel wood production; improving the topsoil; protecting the stand from damage by snow, draughts, cold winds and insects; and decreasing damage by browsers, both wild and domesticated.

The dominant forestry system in Sweden has changed over time. The early foresters in Sweden, such as af Ström and Obbarius, studied forestry in Germany, and brought the idea of clear felling systems, in which PCT and thinning are important parts, part back to Sweden (Ström 1822; Obbarius 1857; Brynte 2002; Kardell 2004). In the 1920s in Sweden, the merits of clear cutting began to be questioned, with different selection systems being favoured; these new ideas also came from Germany (Lindblad 1937; Ekelund & Hamilton 2001). After 1950, forestry systems were re-evaluated and clear cutting became the standard method once again (Ekelund & Hamilton 2001; Kardell 2004).

Since the 1950s, when the government changed official forest policies (cf. Höjer 1950), clear cutting systems, including shelterwood and seed tree systems, have dominated the Swedish forestry and PCT has been a standard management technique ever since. One of the key foresters associated with reintroducing the clear cutting system was Joel Wretlind. His recommendation was to remove "wolf-trees", in order to maintain a good genetic stock, and to create single-storied stands (Hjort 1947).

Private forest owners

All the large forestry companies have a PCT-policy and their guidelines are all similar (Anon. 1997; Anon. 1998; Anon. 2000b; Anon. 2001). In addition, there are more than 350 000 private forest owners in Sweden, who own more than half of the productive forest land. The mean size of a private forest holding is 33 ha (Anon. 2004a), and the holders of approximately half of the land in private ownerships are affiliated to one of the forest owners' associations (Anon. 2004a). Private forest owners have differing objectives for their holdings, depending on factors such as where the forest owner lives and how much he or she relies on income generated by forestry (Lönnstedt 1989; Carlén 1990). PCT and planting are the most common silvicultural activities for private forest owners to carry out themselves (Anon. 2004a).

The characteristics of private forest owners have changed over time. For example, during recent decades, the proportion of forest owners who are full- time or part- time farmers has decreased considerably (Lönnstedt & Roos 1990; Törnqvist 1995). The relative proportion of gender of owners has also changed (Lidestav 1998); today, there are more female owners than ever, amounting 38 % (Anon. 2004a). In addition, men and women interact differently with their forests (Sennblad 1996; Lidestav 1998; Lidestav & Ekström 2000), for example. PCT is more likely to be performed if the owner is male (Lidestav & Ekström 2000).

Methods and technology

The standard method of PCT in coniferous forests in Sweden is to cut all undesired stems within a stand, close to the ground, when the stand has reached a height of 2-4 meters, aiming to leave approximately 2000-3000 main stems (future crop trees) ha^{-1} to grow and develop. If necessary, further PCT can be conducted in subsequent years (Jäghagen & Sandström 1994). PCT can be performed schematically or selectively. Schematic PCT, also known as geometric PCT, is uncommon in Swedish forestry, except from in young forests of beech (*Fagus sylvatica* L.) (Almgren et al. 2003), but is more common in North America (Ryans 1988; Ryans & Cormier 1994). Experimental schematic corridor-PCT in Sweden has been described by Pettersson (1986) and Bergkvist & Glöde (2004).

Selective PCT is the standard technique in Sweden. Two different approaches to selective PCT are described in the literature; cutting unwanted species or thinning the target species. The former could be described as a form of negative selection, i.e. removing the unwanted species (cf. Wahlgren 1914), whereas the latter is a form of positive selection, i.e. selecting the trees that should be left as main stems and removing the other stems (Söderström 1980; Smith et al. 1997).

From early literature, it appears that fast growing deciduous species in young coniferous stands were not perceived to be a problem. The first measure to be applied in a stand's life was an early thinning at the age of 20-30 years (Ström 1822; Ström 1846; Obbarius 1857). According to Söderström (1971) this was probably because in the 19th century the greatest problem in a young forest was not the presence of birch and other deciduous species, but the wild and domesticated animals that browsed the young trees. Goats and sheep were a problem in young forests until the 1940s (Ronge 1949; cf. Fahlgren 1995). In the 19th century, the extracted material from PCT was considered to be a valuable source of fuel wood (Obbarius 1857) and small timber (Björkman 1877).

To reduce the numbers of unwanted species it was recommended that birch should be cut and aspen girdled some years before the clear cut (Björkman 1877; Wahlgren 1914; Amilon 1923). In the early 1950s, chemical treatment was recommended to reduce the number of deciduous trees (Rennerfelt 1948). The first compounds used for this purpose (e.g. sodium chlorate and arsenic) were known to be poisonous not only to trees but also to humans and animals (cf. Juhlin Dannfelt 1947; Rennerfelt 1948). Soon the use of hormone derivatives became the standard method of chemical cleaning (Fransson 1952; Eberling 1955). The use of chemicals peaked in 1969, when 92 000 hectares in Sweden were treated (Ekelund & Hamilton 2001), amounting to almost a third of the annual clear felled area (cf. Anon. 2004a). Subsequently, there was a debate in Sweden during the 1970s about the use of hormone derivatives (Anon. 1978a; Andrée & Kylander 1979; Löf 1993), in 1971 the first ban on hormone derivatives was introduced (Ekelund & Hamilton 2001) and such herbicides have been practically prohibited in Swedish forestry since 1983 (Bäckström 1984; Ekelund & Hamilton 2001). In other parts of the world, they are still in use in forestry management to control unwanted tree species and other vegetation (see for instance, Lindgren & Sullivan 2001).

Today, the attempts in PCT are to both remove unwanted species and to ensure that trees of the desired species are appropriately spaced simultaneously (cf. Jäghagen & Sandström 1994; Bäcke & Liedholm 2000). There are today, also recommendations to leave a mixture of broadleaves in the conifer stands, for various reasons including: broadleaves can complement and replace conifers (Bäckström 1984); high levels of competition promotes better timber quality in conifers (Hägg 1990; Valkonen & Ruuska 2003); broadleaves can increase forest yield (Mielikäinen 1980; Tham 1994); and they can enhance conservation value (http://www.pefc.se/english/;050804; http://www.fsc-sverige.org/; 050804). It has also been suggested that trees cut in late PCT could be used for biofuel (Claesson et al. 2001). There have been numerous studies of the potential benefits of two-storied stands of birch and Norway spruce - a birch shelter with an understory of spruce – including the enhanced protection (i.e. decrease the risk of frost damage on Norway spruce) and yield they can provide (e.g. Örlander 1993; Tham 1994; Mård 1996; Bergqvist 1999). There are also nature conservation reasons for maintaining some broadleaved trees in coniferous stands (Bäcke & Liedholm 2000; Ekelund & Hamilton 2001). Today in Sweden, 14 million hectares are registered by one of two forest certification systems: PEFC (http://www.pefc.se/english/; 050804) or FSC (http://www.fsc-sverige.org/; 050804). These require a certain proportion of broadleaved trees to be maintained in coniferous forests. In Finland, birch (mainly *Betula pendula*) has been valued as a timber species for a long time (cf. Raulo 1987). In Sweden today the industry requires a certain amount of birch, and birch is the most common species to import to Sweden (Anon. 2004a). Fahlvik (2005) recently stated that a better understanding of silviculture in young heterogeneous forests is required in order to maintain the mixtures for a long period.

Various recommendations have been made regarding the number of stems that should be left after PCT. These recommendations are often based on a compromise between volume growth, and timber quality (cf. Persson 1977; Andersson 1984). Eberling (1955) recommended 4000 stems ha^{-1} should be left after PCT where the site index is T24 (i.e. sites where the 100 dominant Scots pines ha^{-1} attain a mean height of 24 m at an age of 100 years, cf. Hägglund & Lundmark 1987). Today the recommendations are to leave c. 2300-2700 stems ha^{-1} in areas with this site index (Anon. 1997; Bäcke & Liedholm 2000). However, some foresters recommend leaving only 1500 stems ha^{-1} (Nellbeck 1969; Söderström 1980; Fryk 1984). The recommendations reflect the prevalent attitudes and economics factor related to forestry. In the 1970s, the forest industry's economic status was poor, with low prices, especially for pulpwood. (Anon. 1971; Anon. 1978b; Ekelund & Hamilton 2001) and the recommendation was to prepare the stand for the clear cutting at the time of PCT in order to avoid subsequent thinnings, which would yield no positive return but would have associated financial costs (cf. Anon. 1967; Nellbeck 1969).

When PCT is performed by the standard method, all unwanted stems in a stand are cut close to the ground (Jäghagen & Sandström 1994). There are alterative methods, however. A recommendation by Wahlgren (1914) was to top-break stems of birch in order to protect the ground from direct sunlight whilst reducing competition (Wagenknecht & Henkel 1962; Karlsson & Albrektson 2000; Ligné 2004). This topping treatment could also increase the timber quality of the main stems, since the topped trees remain alive and continue to compete which may promote better branch quality in the main stems (Wahlgren 1914; Karlsson & Albrektson 2000; Karlsson & Albrektson 2001; Ligné 2004; Ligné et al. 2005). Topping may also increase the abundance of attractive fodder for browsers (cf. Danell et al. 1985; Löyttyniemi 1985).

One simple and cheap way to perform the PCT simple and cheap could be to cut only trees that are in direct competition with the main stems (Smith et al. 1997). Andersson (1993) showed that birches compete strongly with Scots pine trees only if they are within one meter of them and are taller than them. Point cleaning is one possible method, in which all trees within a certain radius (often < 1 m) from the main stem are removed and the rest are left for a later complete PCT, or another point cleaning with a larger radius (Andersson 1985). Point cleaning is recommended for the production of high quality timber (Andersson 1985).

Another way to improve forest economics is to decrease the regeneration cost. The most expensive measure is planting (Anon. 2004a). Several studies have demonstrated that a naturally regenerated stand produces timber of equal or better quality than that from a planted stand (Agestam et al. 1998; Valkonen & Ruuska 2003).

The first equipment used for PCT included knives, axes and brush hooks (Björkman 1877; Wahlgren 1914), but at the beginning of the 1950s, the motor-manual brush saw was introduced and came into common usage (Callin 1957; Andrén 1992). There have been some attempts to fully mechanise the PCT operations (Berg et al. 1973; Ryans 1988; Freij 1991) but the brush saw is still the most commonly used tool for PCT (cf. Ligné 2004). PCT is the only forestry operation that has been associated with little productivity development over the last 50 years (cf. Perlinge 1992). Today other methods for performing PCT are being studied. One of these new ideas is to cut the stems at a higher level, which would result in fewer obstacles and improve visibility for the operator (Ligné 2004). There are also suggestions that PCT operations could be autonomous, using robots, for example (Vestlund 2005).

Browsing

In Swedish forestry today, browsing by herbivores, especially moose (*Alces alces*), is a significant problem in young Scots pine forests (Bergqvist et al. 2003; Glöde et al. 2004). In one study as much as 10 % of young Scots pine main stems showed fresh damage by moose (Bergqvist et al. 2001). Growth rate and future timber quality are badly affected by browsing (Karlmats & Pettersson 2001; Lavsund 2003). If browsing is expected to be a problem, it is recommended that PCT be postponed until the trees have reached a height where the moose cannot reach the leading shoot or break the stem (Anon. 2000b; Bäcke & Liedholm 2000). The moose population in Sweden peaked in 1982/1983 and has been decreasing ever since, mainly due to hunting (Hörnberg 2001). Hörnberg (2001) found a significant correlation between the total moose population in Sweden and the browsing pressure on young Scots pine stems.

Forest policy

The first national Forestry Act in Sweden dates from 1903; the main goal was to oblige the forest owners to regenerate the forest after logging (Enander 2000). In later Forestry Acts (1923 and 1948), the main objective was to protect young forests from excessive thinnings (Enander 2001). In the Forestry Act of 1979, the forest owners were obliged to perform PCT in dense stands (Anon. 1978b). Between 1975 and 1984 subsidies were available for performing PCT (Ekelund & Hamilton 2001). In 1994, the Forestry Act of 1979 was revised (Ekelund & Hamilton 2001; Enander 2003). There was a change in forest policy and nature conservation and timber production were given equal importance (Anon. 1992; Ekelund & Hamilton 2001). The requirements for PCT were removed (cf. Anon. 1992). According to the current national forestry policy (Anon. 2002), forest owners have the freedom to select and take responsibility for silvicultural activity, treatments, and there is no intention to control their activities through subsidies or legislation.

Some years before 1994, the annual area that was subjected to PCT decreased (Figure 1), probably partly because foresters foresaw the cessation of compulsory PCT. In 2002, the National Board of Forestry investigated the effects of forest policies and found an alarming decline in the annual PCT-treated area (Anon. 2002). The national goal is to reduce the area in urgent need of PCT to below 700 000 ha by the year 2010. In order to fulfil this goal, the annual PCT-treated area needs to be at least 345 000 ha (Anon. 2004b). However, since the beginning of the 1990s, the PCT-treated area has been less than 175 000 ha per year (Anon. 2004a) (Figure 1).

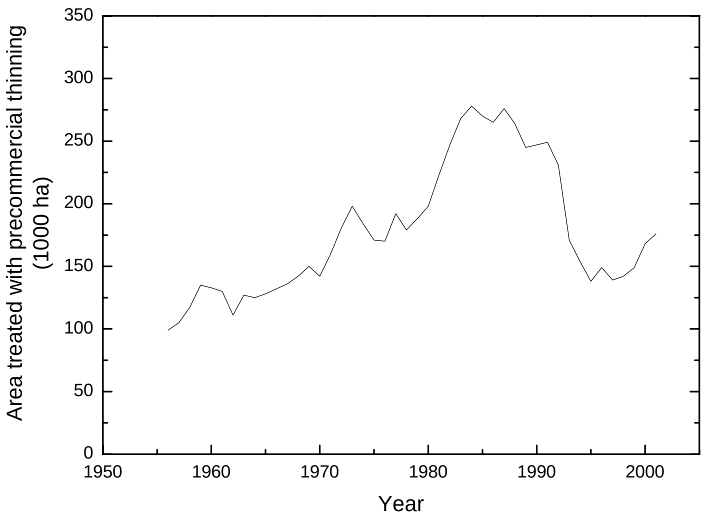

Figure 1. Annual area treated with precommercial thinning in Sweden, 1955-2000; 1000 ha (Anon. 2004a).

Objectives

Precommercial thinning is an economic investment for private forest owners. New PCT-methods can reduce the cost and increase the return, thus increasing the profit resulting from it. In order to improve the situation for private forest owners it is important to understand their thinking and attitudes towards PCT. However, for PCT to be effective, it is important that new ideas associated with it are accepted and applied by forest owners.

The objectives of the work underlying this thesis were:

- to increase understanding regarding private forest owners and their attitudes towards PCT
- to evaluate methods that have a potential to make PCT cheaper and simpler, especially for the private forest owner

The objectives of Study I were to analyse characteristics of private forest owners and their behaviour and attitudes towards PCT.

In Study II the objectives were to: evaluate whether topping secondary stems (compared to cutting them close to the ground and no PCT) resulted in better quality main stems; to determine whether the topped secondary stems could attain the same height as the main stems; and to examine how the different methods affect the survival rates among main and secondary stems.

The objectives of Study III were: to compare the effects of two different point cleaning regimes with conventional PCT and no PCT and to evaluate how stem and branch properties and stem development were affected by the different regimes.

Study IV was a case study aiming to evaluate the efficiency of planting and different PCT treatments from a forest yield and economic perspective.

Materials and Methods

Geographic areas of Sweden

In Study I, a questionnaire was sent out to private forest owners in the counties of Västernorrland, Jämtland and Jönköping. The experimental sites for Studies II and III were located in the county of Västerbotten in northern Sweden. Study IV was conducted in the county of Norrbotten (Figure 2, Table 1).

Study I

The study was based on a questionnaire sent to private forest owners in the counties of Jönköping (Southern Sweden, Figure 2), Jämtland and Västernorrland (Northern Sweden, Figure 2). The sample consisted of 1000 forest owners, 500 in each region; the population comprised all the forest management units in the selected counties. The questionnaire was sent out in March 2001 and reminders with another copy of the questionnaire enclosed, were sent after one and two month.

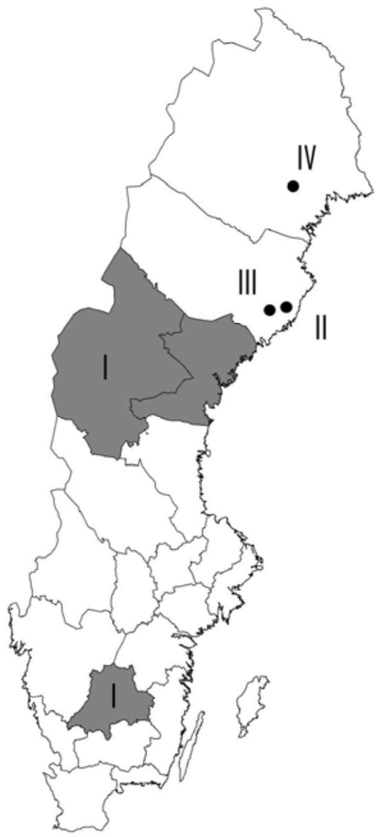

Figure 2. Locations of the studies described in the thesis. Roman numerals signify Studies I-IV.

The questionnaire consisted of a total of 40 questions about the forest owner's background, knowledge base, residence and habits related to forestry in general. The main part of the questionnaire examined the forest owners' attitude and behaviour with respect to PCT.

The answers were analysed using summary statistics. Responses from men/women, owners living on the holding/owners living off the holdings and owners from the Northern region/owners from the Southern region were compared using chi-square (χ^2) analyses.

Study II

A field experiment was established in June 1994 in a seven-year-old, naturally regenerated stand on former farmland in northern Sweden consisting of birch, mainly downy birch (*Betula pubescens*) mixed with a few silver birch (*B. pendula*) and willows (*Salix sp.*)(Figure 2, Table 1). A randomized complete block design was used, with 12 gross plots of 15 × 15 m, each with a net plot of 8 × 8 m in the centre. The plots were separated into blocks on the basis of stand density (17 000 to 41 000 stems ha^{-1}). Main stems were chosen subjectively at a spacing of 1.8 m (c. 3100 stems ha^{-1}).

Table 1. *General description of Studies II-IV, for geographical locations see Figure 2*

Study	Species	Years after establishment	Factors studied:	No of blocks	Treatments	Abbreviations
II	Naturally regenerated downy birch (*Betula pubescens*) with *Salix* and silver birch (*B. pendula*)	7	Mortality Stem and branch properties Growth Damage	3	Traditional precommercial thinning (PCT) Topping at 40% of mean height Topping at 70% of mean height No PCT	TRAD TO40 TO70 NOTH
III	Planted Scots pine (*Pinus sylvestris*) with naturally regenerated Norway spruce (*Picea abies*) and birch (silver and downy)	19	Mortality Stem and branch properties Growth Damage	3	Traditional PCT Point cleaning of all stems Point cleaning of stems taller than the main stem No PCT	CO PA PH NO
IV	Planted Scots pine with naturally regenerated Norway spruce and birch (silver and downy)	0	Simulation of volume growth and economics up to the time of the first commercial thinning	4	Traditional PCT i.e. leaving the best stems regardless of species and origin Leave only planted stems Leave only naturally regenerated stems No PCT	ALL PLANT NAT NOPCT

Four different treatments were randomly applied between the plots. The treatments were: traditional PCT close to the ground (TRAD), topping at 40 % of the mean height of the main stems (TO40), topping at 70 % of the mean height of the main stems (TO70) and no PCT at all (NOTH) (Table 1). The mean height of the main stems was 179 cm at the time for the treatment. After the treatments, sample trees for measuring were selected from the main stems and the (treated) secondary stems.

The experiment was inventoried on five occasions from 1994 to 1997 (Karlsson & Albrektson 2000) and once again in September 2000. The height, the green crown height, diameter at breast height, diameter of the thickest branch, stem straightness, number of forks and number of spike knots were recorded. The treatment effects were evaluated using analysis of variance (ANOVA) for main and secondary stems. Height in spring 1994 was used as a covariate in the model in some cases. Tukey's studentised range test was used to determine differences between treatments. To determine differences in response variables within treatments, between main stems and secondary stems of either birch or willow, a paired-sample t-test was used.

Study III

A field experiment was established in June 1983 in Northern Sweden (Figure 2) in a stand that had been planted with Scots pine seedlings in 1972, and also contained naturally regenerated birch and Norway spruce (Table 1). A randomised complete block design was used with 12 gross plots of 30 × 35 m with the inner 20 × 25 m formed the net plots. The plots were sorted into three different blocks according to stand basal area, which varied between 1.02 and 4.02 m^2 ha^{-1} (Karlsson et al. 2002).

Main stems of, mainly Scots pine, were selected at a spacing of 2.2 × 2.2 m (*c.* 2100 stems ha^{-1}). The following four treatments were randomly distributed among the plots: no PCT (NO); conventional PCT (CO); point cleaning of all secondary stems within a radius of 0.8 m from each main stem (PA), and point cleaning within a radius of 0.8 m of only stems taller than the each main one (PH) (Table 1).

The experiment was inventoried in 1995 (Karlsson et al. 2002) and again in May 2002, when the diameter (at breast height) and species were recorded for all stems taller than 1.3 m in the net plots. The original main stems were enumerated and recorded as either living or dead. Whether or not they were still a main stem was recorded together with: diameter (at breast height), diameter of the thickest branch (on the lower 4 m of the stem), height, green crown height, stem crookedness, number of spike knots and visible damage.

The effects of the treatments were evaluated using analysis of variance (ANOVA), Tukey's studentised range test was used to determine differences between treatments.

Study IV

The experiment was established in August 2002 in Norrbotten (Figure 2), in a stand with 18-year-old planted Scots pine mixed with naturally regenerated Norway spruce and birch (downy and silver) (Table 1). The stand was chosen to be representative for a PCT-stand in north Sweden from the perspective of species composition, stem number, mean height, site index, soil texture and soil moister. A randomised block design was used with 16 gross plots of 30 × 30 m, each net plot consisting of a circular plot with a radius of 3 m, resulting in an area of 28 m^2 in the middle of each gross plot. All trees were counted and their species recorded inside the gross plots. Within the net plots, the diameter, height and damage to the butt log were also recorded for all trees. For Scots pines, the origin of the stems was also recorded. The plots were divided into four different blocks; the blocking factor was number of stems, varying between 2857 and 15714 stems ha^{-1}.

The following four treatments were randomly distributed between the plots in each block: leaving only planted pines as the main stems (PLANT); leaving the best trees, i.e. trees without serious injuries with the potential to belong to the dominant height class. The different species were preferred in the following order: pine > spruce > birch (ALL), leaving the best naturally regenerated stems irrespective of species as the main stems (NAT), and no PCT at all (NOPCT) (Table 1). The stem number after PCT was expected to be 1500 stems ha^{-1}. After the treatments had been applied, the plots were measured again.

To analyse the differences between planted and naturally regenerated stems before PCT, paired sample t-tests were used. The effects of the treatments were evaluated using analysis of variance (ANOVA), and Tukey's studentised range test was used to determine differences between treatments.

The tree sample data, following the treatments, were used as input for a model to simulate the stand development up to the first commercial thinning, and current costs and prices were input to evaluate the yield and economic returns from the different treatments. The net profit from PCT was calculated with an interest rate of 0 and 3 %.

Results

Study I

The return frequency of the questionnaire was 66 %, and 29 % of the respondents were women. There were some more respondents from the southern region than the northern region; 53 % and 47 %, respectively. The majority of the respondents (55 %) said that they had acquired their holding for a lower price than the open market value, and 59 % lived permanently on their holding. A third claimed that they were had their occupation in their own forests but the most common occupation category was "employed" (44 %).

The majority of respondents (81 %) claimed that PCT is a common measure in their young forests, and 74 % said that they had performed PCT during the last five years. More than half of the respondents (56 %) claimed that they had areas in need of PCT in their forests, 65 % considered PCT to be profitable and 47 % said they would increase their PCT activities if government subsidies were available. Most commonly, PCT was undertaken by the forest owner (61 %) with a motor manual brush saw (53 %). The most common structural goal for PCT was a mixed forest of conifers and deciduous trees (69 %).

The most common reason cited by the respondents for performing PCT was “to get good timber quality in the future” (90 %), and the most common reason for not undertaking perform PCT was lack of time (54 %). Of the respondents, 60 % considered the number of moose on their holdings to be not excessive, while 44 % indicated that the risk of browsing damage had an influence on the timing of the treatment.

There were some differences between respondents from the two regions, since respondents from the south indicated that they were more active and, thus, the respondents from the northern region said they had a greater need for PCT. The southern owners considered PCT to be profitable and that subsidies would increase their PCT activities to a greater extent than the northern owners.

Owners of large holdings performed more PCT, had larger PCT requirements and considered PCT to be profitable at a greater extent. Owners of small holdings used the wastes from the PCT more often. It was also more likely for owners of large holdings to consider the amount of moose to be too large.

The gender of the respondents had a strong influence on their answers. Women tended to rate their silviculture knowledge lower, and were more likely to answer “I don’t know” to almost all the questions about PCT.

There were fewer differences between the respondents who lived on their holdings permanently and those who did not. The respondents who lived on their holdings performed PCT more often, and tended to undertake it themselves. More of them thought that PCT was profitable, and they tended to use the waste generated by PCT for fuel wood. More of them also thought that the moose population was too large.

Study II

In general the main birch stems in the topped treatments (TO40 and TO70) indicated better stem quality than the main stems in the traditionally cut plots (TRAD) and the untreated plots (NOTH). The main stems in the TO70-treated plots had the highest live crown height, the thinnest branches, the straightest stems and fewest forks. For the main stems, no significant differences in height were found between treatments. For diameter (dbh) and height/diameter ratio, the NOTH-treatment produced the lowest and highest results, respectively. The survival of the main stems was high (96 %) and there was no significant difference between the treatments. The main stems were taller and had a greater height increment than the secondary stems of birch and willow. For the secondary stems, the willow showed a higher survival rate (ca 75 %) over all the treatments; no significant differences between treatments were observed. For secondary stems of birch there was a strong treatment effect on survival, NOTH giving higher survival rates than TO40 and TRAD. With respect to damage, there was no significant difference between willow and birch, or between treatments for secondary stems except on the TO70 plots where the willows suffered more damage than the birches.

Study III

A high mortality was recorded for the main stems: eighteen years after PCT, 31 % of all the original main stems were dead. The frequency of dead main stems was lowest on the conventionally treated PCT plots (CO plots) (16 %). There was no treatment effect on main stems mortality of the different species, but Scots pine exhibited highest rate (41 %). In comparison 1.2 % of the spruces and 18 % of the birches had died.

Only half of the original main stems of Scots pine since 1983 continued to be classified as such in 2002; the highest proportion which was statistically significant, was found in the CO plots. The diameter (dbh) for Scots pine main stems showed statistically significant differences between treatments and was greatest in the CO plots. There were no statistically significant differences for height or relative green crown height. However, the H/D-ratio for the main stems of Scots pine showed a statistically significant treatment effect, and it was highest on the untreated plots (NO plots). There were, on average, 1.2 spike knots per tree and 31 % of the stems were damaged; no statistically significant differences were recorded between the treatments.

The greatest total basal area (including all main and secondary stems) was found in the plots where point cleaning of higher stems had been performed (PH plots) and the NO plots. Scots pine had the greatest basal area in the CO plots, and birch was the dominant species in all other plots. The mean stem diameter for Scots pine was greatest in the CO plots. For birch the largest diameter was found in the NO plots while for Norway spruce no significant difference was found between the treatments. The mean total number of stems was 10 233 stems ha^{-1}, of which Scots pine, Norway spruce, birch and other broadleaved species accounted for 9, 30, 58 and 3 %, respectively. There were no statistically significant differences between treatments for total number of stems, which varied between 8186 stems ha^{-1} (CO) and 12460 stems ha^{-1} (PH).

Study IV

Before PCT-treatment, the planted Scots pine trees were significantly taller and had greater mean diameter than the naturally regenerated pines. Scots pine was the dominant species: 63.5 % of the pine stems were planted and 36.5 % were naturally regenerated.

After the PCT-treatment there were statistically significant differences in the number of stems between treatments: the untreated plots (NOPCT) had the highest total number of stems and the highest number of Scots pine stems. Scots pine was the most common species in all treatments, both in numerically and with respect to basal area. Scots pine stems had the greatest mean diameter and stand basal area in the plots where only planted stems were left after PCT (PLANT) (although only the differences in basal area were statistically significant). If birch and Norway spruce stems were included, the mean diameter and height were still largest in the PLANT plots, while the stand basal area (dbh) was largest in the NOPCT plots. There were no statistically significant differences in damage frequencies but there was a tendency towards more damaged trees in the PLANT and NOPCT plots than in the ALL and NAT plots, in which the best stems irrespective of species and origin were left, and only the best naturally regenerated stems were left after PCT, respectively.

The simulation up to (and including) the first commercial thinning, at the age of 52 years, showed that differences at the time of PCT will increase until the first thinning. Mean stem diameter and height were largest in the PLANT plots while the basal area was largest in the NOPCT plots. The diameter distribution showed that 90 % of the stems in the PLANT treatments were thicker than 13.5 cm in diameter (dbh) while the corresponding value for the NOPCT treatment was only 2 %. In terms of economic returns, the mean thinning cost was greatest, by far, for the NOPCT plots. All the PCT treatments resulted in a net profit and the PCT cost was recovered in the first thinning with both 0 and 3 % interest rate. The greatest net profit as a result of PCT was found in the PLANT and ALL plots.

Discussion

Private forest owners and forest policies

There have been many studies in which the attempts have been made to categorize private forest owners (Hyder et al. 1994; Kline et al. 2000; Kurttila et al. 2001). The emphasis during the late 1980s was on surveying forest owners' logging activities (Sennblad 1988; Lönnstedt 1989; Kärhä & Oinas 1998), while later there were studies on the gender perspective of private forest owners (Brandth & Haugen 1998; Lidestav 1998; Lidestav & Ekström 2000), and others on behaviour of non-resident forest owners (Carlén 1990; Lönnstedt & Roos 1990; Törnqvist 1995). An examination of the relationship between private forest owners and PCT can be found in a few studies (e.g. Sennblad 1988; e.g. Karppinen 1998; Lidestav & Ekström 2000).

Most of the forest owners considered in Study I were aware of the effects of PCT. They wished to perform PCT but also had areas of land where PCT was needed. This situation has also been identified in other studies (Erlandsson 2001; Eriksson 2004a). Forest owners believed that PCT is a profitable treatment (cf. Jonsson 2001; cf. Svensson 2004), and would perform more PCT if there were government subsidies for the operation (cf. Eriksson 2004a). Between 1975 and 1984, subsidies were available for PCT, at least in some parts of the country (cf. Brännlund et al. 1985; Ekelund & Hamilton 2001). According to Hultkranz (1986) the existence of subsidies increased PCT activity. Torvelainen and Ripatti (2000) also demonstrated a correlation between subsidies and activity in Finland. It has been shown that the "advice and recommendations" distributed by the Regional Boards of Forestry between 1979 and 1993 had a positive impact on the extent of forest that was subjected to PCT (Anon. 2002). In a recent questionnaire study from the county of Västernorrland, the Regional Board of Forestry used satellite imagery to identify areas in need of PCT and advisory letters were sent out to the forest owners. This was an efficient way of making the forest owners aware of the need for PCT, and the majority of respondents said that the information would lead to an increase in the area of PCT they would undertake in the future (Erlandsson 2001).

The most common responses explaining the absence of PCT were lack of time and the high cost of PCT. The majority of respondents said that they usually performed PCT themselves. Together with planting, PCT is the most common forestry activity performed by the owners themselves (Anon. 2004a). To explain these findings it has been hypothesised that private forest owners traditionally considered that they should perform any necessary PCT themselves.

One way to increase the extent of PCT could be to change the attitude that it should be performed by the family. The number of silvicultural contractors is increasing, mainly because large forest companies prefer to engage contractors rather than retain employees to do the work (Eriksson 2004b). This increases the opportunities for private forest owners to engage contractors. Forest owners' associations and forest companies often offer PCT free or at a reduced rate as a part of the contract when they buy timber from private forest owners (Björn Johansson pers. comm.). In addition, the development of new mechanized equipment for PCT (cf. Bergkvist et al. 2004; Ligné 2004) could increase the profitability of the operation for silvicultural entrepreneurs, since mechanised PCT-equipment may increase the contractors' efficiency (Bergkvist et al. 2004). In addition, the topping treatment described in Study II allows PCT to be performed during the winter (cf. Ligné 2004).

Many respondents performed PCT in order to leave valuable forests for future generations. This could either reflect the traditional mentality, based on the likelihood that subsequent generation will own the farm (cf. Törnqvist 1995), or that of a new type of forest owner, who appreciates the value of forests in more than purely economic terms (Carlén 1990). The fact that as many as 70 % of the respondents performed PCT because "It looks nice" supports this hypothesis. According to Carlén (1990), the most common non-financial incentive was what he referred to as "roots" i.e. having contact with the family and the family farm.

Respondents who lived on their holdings were more likely than non-residents to perform PCT and to think that it was a profitable activity. It has been found that residents and non-residents have different aims for their forests (Rudqvist & Törnqvist 1986; Lönnstedt & Roos 1990). Non-residents are less likely to be dependent on the income from forestry. This means, for example, that harvesting intensity is low and that loggings, when performed, is done on a large scale (Lönnstedt 1989; Lönnstedt & Roos 1990).

There were many differences between the responses from men and women. The number of female forest owners is increasing, perhaps because of new inheritance traditions, i.e. all children are increasingly likely to take over the holding after the previous generation, rather than just the oldest son (Lidestav 1997). Other studies have shown that both knowledge of forestry and silvicultural behaviour of male and female forest owners differ, for example are men more likely than women to perform PCT themselves (Clauss 2004) and are less familiar with silvicultural operations (Sennblad 1996).

The results from Study I show the importance of awareness of the differences between different groups of forest owners when informing them of the necessity and advantages of PCT.

Yield and timber quality after PCT

The forest owners included in Study I were aware that PCT is a profitable activity and 73 % of the respondents claimed that "getting thicker stems" was important to them with respect to PCT. In both Studies II and III, traditional PCT resulted in main stems with statistically significant larger diameters than when there had been no PCT. In addition, the main stems in all the treated plots had a greater mean diameter than the main stems in the non-treated plots (cf. Sjolte-Jorgensen 1967; Pettersson 1986; Niemistö 1995a; Varmola & Salminen 2004). In Study IV the mean diameter was greatest after the PLANT treatment (main stems sampled from the planted seedlings). This could be due to the planted Scots pines being thicker than naturally regenerated ones. The diameter was smaller in the ALL plots (where all species could be sampled) than in the PLANT plots. This may be because the population suitable for main stems was larger, and when the instruction was to choose the best stem the increase in technical quality was assumed to compensate for the reduction in diameter (cf. Pettersson 2001). It is clear from Study II that the topped treatments gave more options during subsequent thinnings than traditional PCT.

There was no treatment effect on height in Studies II and III, as found in previous investigations (Salminen & Varmola 1990; Spellmann & Nagel 1992; Niemistö 1995a). The H/D-ratio was, however, affected by the treatments in both studies. This is probably because trees allocate resources differently under strong competition, and height increment is prioritised (Oliver & Larson 1990). Valinger (1992) showed that height growth for Scots pine decreases after release from competition, while the diameter increases. A high H/D-ratio is associated with high technical timber quality (Spellmann & Nagel 1992; Anon. 1999), but also increases the risk of damage by snow (Persson 1972; Valinger et al. 1994).

In Study IV, the simulation up to (and including) the first commercial thinning demonstrated that the differences in diameter, height and basal area recorded at the time of PCT persisted and increased. The simulated total volume at the first thinning in Study IV was highest in the NOPCT plots, in accordance with other studies (cf. Andersson 1975; Söderström 1980; Salminen & Varmola 1990). The stems however, were more slender and, therefore, were more prone to snow and wind damage (cf. Persson 1972; Valinger et al. 1994). The most important reason for the negative return from thinning for the NOPCT plots was the harvesting cost, which increases per unit volume with decreasing diameter (Brunberg 1997).

Most respondents in Study I did performed PCT in order to increase the quality of their stands.

In Study II almost all of the quality variables tested for the main stems of birch were better in the topped plots than in the traditionally cut and plots with no PCT. This may be a result of heavier competition in the topped plots which influences the diameter of the thickest branch (Persson 1977 (Scots pine); Niemistö 1995b (silver birch)), the live crown height (Cameron et al. 1995 (silver birch); Niemistö 1995b (silver birch); Fahlvik et al. 2005 (Scots pine)), the proportion of straight stems (cf. Huuri & Lähde 1985 (Scots pine)), and the number of forks (Erdman et al. 1981 (yellow birch); Collet et al. 1998 (sessile oak (*Quercus petrea* (Matt.) Liebl.)). There was also a tendency for the main stem quality variables to be better in plots were the secondary stems were topped at 70 % of the mean height compared to plots where the topping height was 40 % of the mean height. This can also be explained by competition (Niemistö 1995b (silver birch)). Salminen and Varmola (1990) showed that a stand density of 3000-4000 stems ha^{-1} after PCT provided the best quality in Scots pine, and that there was a slight decrease in timber quality, in terms of numbers of branches, crooks and forks etc. after intensive PCT. This decrease, however, was small and if the PCT was delayed until the dominant height was 6-7 m, the reduction in quality almost disappeared.

For the main stems of Scots pine in Study III there were no statistically significant differences for the relative green crown height or the diameter of the thickest branch. Both green crown height and diameter of the thickest branch are good timber quality indicators (cf. Petersson 1997) and are affected by stand density (Persson 1977; Mäkinen 1999; Varmola & Salminen 2004; Fahlvik et al. 2005). Stem straightness in Study III did not show any clear trends, but the frequency of straight stems was generally low. It is believed that stem straightness for Scots pine is controlled mainly by genetic factors rather than silvicultural ones (cf. Prescher & Ståhl 1986; cf. Ståhl et al. 1990; Persson 1994). However, Agestam et al. (1998) found a planting effect on straightness in Scots pine trees i.e. planted trees were more crooked then naturally regenerated ones. Explanations for this could either be from the planting method or due to limited selection alternatives in the planted plots.

Trees in the unthinned plots, where competition was greatest, did not exhibit the best timber quality in either Study II or in Study III. This may be because of the existence of a threshold, beyond which competition has a negative impact on timber quality (cf. Ruha & Varmola 1997; Karlsson et al. 2002). When there is no PCT, wolf-trees often survive natural thinning. Such trees are, by nature, highly-branchy, with a low green crown height (cf. Pettersson 2001).

Natural regeneration in combination with PCT

The aim of PCT for most of the forest owners in Study I was to create a mixed forest, of either conifers or conifers and deciduous trees. This is in accordance with today's forest policy, where more than 60 % of the productive forest area in

Sweden is associated with some kind of certification program (www.svo.se; 050804). According to such programmes (http://www.pefc.se/english/; 050804; http://www.fsc-sverige.org/; 050804) the forest owner is obliged to maintain a proportion of deciduous trees within their coniferous forests.

The planted Scots pines in Study IV were significantly taller and thicker than the naturally regenerated pines prior to PCT. Ackzell (1993) showed that planted seedlings, eleven years after planting, had a height advantage corresponding to 5.6 years of growth over naturally regenerated seedlings. The artificially propagated material has advantages over naturally regenerated counterparts: a high nutrient load from the nursery (Troeng 1988; cf. Timmer & Munson 1991) the benefit of genetic improvement (Hägglund 1983; Ackzell & Lindgren 1994) and appropriate provenance (Ackzell 1993). Despite this, the ALL treatments, containing naturally regenerated stems, were as profitable as the PLANT treatment. Natural regeneration, if successful, is often better than planting, for the owners, from an economical point of view (cf. Streyffert 1949; Kardell 1986; 2005), and is more likely to induce high timber quality (Agestam et al. 1998). There are also studies showing that natural regeneration could complement planting and make it possible to obtain high quality timber with less intensive regeneration methods (Hägg 1990; Ackzell & Lindgren 1994; Valkonen & Ruuska 2003). In the ALL treatment in study IV (main stems chosen irrespective of origin), 48 % of the main stems were planted. Most PCT advice describes the ALL treatment as the "normal" way to perform PCT, i.e. to cut the wolf trees and then choose main stems from all the remaining ones (Anon. 1997; Anon. 1998; Bäcke & Liedholm 2000). However, there are conflicting ideas about the optimum method of PCT, including leaving the thickest "wolf-trees" and creating a multi-storied stand. Such an approach could be economically optimal since the largest "wolf-trees" could be cut in the first commercial thinning and thus increase the thinning income, and the stems that are released will have a high timber quality because of heavy competition from above (Anon. 1997; Hagner 2004). Fahlvik (2005) showed in a simulation that only removing "wolf-trees" during PCT results in a financial loss associated with the first commercial thinning.

The treatment NAT (were only naturally regenerated stems in the stand is considered for main stems) could hypothetically substitute a naturally regenerated stand. In that case the planting cost could be withdrawn from the model and, most likely, the PCT cost would be lowered. In that case the economic simulation would result in highest net profit in NAT.

Mixed forests of Scots pine and birch produce equal or more growth and yield then pure Scots pine stands (Mielikäinen 1980; Frivold & Frank 2002) or only a slightly reduced yield (Agestam 1985). The results of Study IV suggest that there is some doubt whether a planting density of 2500 seedlings ha^{-1} is necessary for acceptable timber quality (cf. Persson 1977; Hägg 1990), raising the possibility of using natural regeneration to develop a high quality stand. The target stand before final cutting often consists of only 500 to 700 stems ha^{-1} (Jäghagen & Sandström 1994). It is also concluded that a regime without PCT in this type of stand results in a large economic loss at the time of the first thinning. Several studies on two-storied stands of birch and Norway spruce have shown that the volume yield loss in the understory of spruce is compensated for by the yield from the overstory of birch (Tham 1994; Bergqvist 1999; Valkonen & Valsta 2001). Sometimes natural regeneration is considered to be a problem in a plantation. However, Studies III and IV show that natural regeneration often is a complement to get a fully stocked stand (cf. Ackzell 1995).

Damage and mortality

Moose browsing is considered to be a problem in young forests in Sweden (Bergqvist et al. 2001; Glöde et al. 2004). Most respondents in Study I were content with the number of moose on their holdings. There were no big differences between the different categories of forest owners, but forest owners with holdings larger than 400 ha expressed more concern: half of them considered that there were too many moose. Many forest owners rank opportunities higher than the losses from damage by browsing (cf. Lönnstedt & Roos 1990). Almost 45 % of the forest owners claimed that the risk of browsing influenced their PCT activites. The general recommendation for PCT is to wait until the stand reaches "moose-safe height", i.e. a height of 4-5 m, to avoid severe moose damage to the stems left after PCT (Anon. 1997; Anon. 1998; Anon. 2000b; Bäcke & Liedholm 2000). According to Lavsund (2003), this recommendation is questionable, since Scots pine trees with vigorous growth are less likely to be browsed and PCT encourages such growth. Rebrowsing of birch and Scots pine trees by moose is high (Danell et al. 1985; Löyttyniemi 1985; Bergqvist et al. 2003), probably because the chemistry of the shoots is affected and differences in shoot morphology encourage browsing (Danell et al. 1985; Löyttyniemi 1985). Ligné (2004) suggests that the topping treatments in Study II could induce browsing of the topped stems and thus reduce browsing on the main stems.

The topped secondary stems in Study II did not attain the same height as the main stems, indicating that the height differential was sufficient. The fact that there were significant differences in height between the main and secondary stems also in the NOTH plots supports this hypothesis (cf. Oliver & Larson 1990; cf. Nilsson & Albrektson 1994). The survival of the topped secondary stems had decreased dramatically at the time of the last inventory, indicating that the topped secondary stems may all be dead by the time of the first commercial thinning (cf. Kvaalen 1989). This would be beneficial for operating the machinery used during thinning.

In Study III, the mortality of the main stems of Scots pine was high, and there was a tendency for less intensive treatments to be associated with higher mortality, in accordance with the findings of Ikäheimo and Norokorpi (1986). Consequently, there were more remaining main stems of Scots pine in the plots with the lowest competition (CO plots). In Study IV the number of damaged stems was lowest in the ALL and NAT treatments, which could be explained by the larger population of main stems in these treatments.

Methods

Using a questionnaire for a survey of silvicultural behaviour is rather unorthodox. A questionnaire provides various opportunities to assess the practices of the surveyed population, especially amongst divers groups such as private forest owners there are also limitations (cf. Trost 2001). It is difficult to frame the correct questions and to interpret the answers (Japec 1997). It is also important to remember that many factors influence how respondents answer the questions (Japec 1997; Trost 2001). The questionnaire should be easy to understand, not too rigorous and it should be sent out at an appropriate time of the year, i.e. not close to holidays or annual festivals. (Japec 1997). In Study I, the aim was to obtain a representative sample of private forest owners' attitudes in the target regions, therefore the sample was taken from the holding register, with size class as the only weighting. This guaranteed that even respondents with very large holdings were sampled.

Study II-IV had a more orthodox silvicultural approach, but there were some disadvantages. The studies are case studies, all situated in the north of Sweden and the results cannot be extrapolated to the whole of the country. Nevertheless, the studies, if interpreted with care, do provide valuable information.

In Study II the species studied was downy birch. Less than 5 % of land, however, is dominated by deciduous species (Anon. 2003) and birch has limited commercial value in Sweden today (cf. Anon. 2004a). The study does, however provide valuable information on how pioneer species react to topping. Since the survey was a reinventory it was possible to compare the present data with the previous results (Karlsson & Albrektson 2000), adding a further dimension to the study.

Study III was also a reinventory (Karlsson et al. 2002) and in the present assessments the results were expected. The stand consisted of planted Scots pine and naturally regenerated Norway spruce and birch: a common forest type in northern Sweden (Anon 2003). There were generally poor stem and branch characteristics and the survival rates of the main stems of the Scots pine trees were low. Lähde (1991) concluded that point-cleaning in Norway spruce provided better economy and yield then conventional PCT so the method might be better for other species, less sensitive to be overtopped than pine (cf. Andersson 1983). Voorhis (1990) discusses the possibilities to vary the radius with species in a mixed stand. According to Persson (1977) there are differences in the timber quality effects of spacing between the north and south of Sweden. This implies that the results are primarily applicable only to forests in the northern region.

Study IV is a case study of a selected typical North Swedish site and showing the results if one and the same site is treated with different PCT intentions. The models that were used for the simulations were designed for young trees and may be unreliable up to the first commercial thinning (Kenneth Nyström pers. comm.). The yields and the economic outputs should be seen as a relative comparison between the different treatments inside this stand. In addition, the comparison between ALL and NAT could also be seen as indicating the efficiency of planting. It is likely that a pure natural regenerated stand, without competing planted stems would have been even more vigorous and thereby would have produced more significant results in the study.

Conclusions

Private forest owners are, in general, aware of effective silvicultural measures for their young forests, but PCT activities are limited by the time and cost involved. There are differences between male and female forest owners: the women tend to claim that they have little knowledge and exhibit less interest then men in forestry issues. In order to educate forest owners about silviculture, female forest owners and forest owners that do not live permanently on their holdings are important groups to target. There is also a need to understand that private forest owners are less dependent on the income from forestry today than they were in the past, so they may have other goals than just timber production.

Topping is an alternative to conventional PCT (close to the ground). The results from Study II show that, at least for birch, topping induces better timber quality and does not reduce the growth too much. Since both Scots pine and birch are pioneer species and therefore, exhibit similarities in their growth pattern, this method should be studied also for other species and for mixed stands, for example stands containing Scots pine and birch.

The results from Study III demonstrate that if point cleaning is the chosen PCT technique, it is not enough merely to remove the trees that are taller than the main stems on one single occasion. Although not considered in this research, the recommendation must be to conduct a subsequent complete PCT if point cleaning has been employed. If this is the method used, point cleaning should no be regarded as a way to reduce the cost of PCT, but a maybe method for enhancing the timber quality.

According to Study IV, PCT is a profitable silvicultural measure. A combination of planting and natural regeneration with subsequent PCT may be the most profitable way for the forest owners to improve their returns from forestry. Optimizing such behaviour demands a much better knowledge of where and how rich natural regeneration can be achieved.

Future research

Many aspects of the behaviour of private forest owners with respect to PCT still need to be elucidated. The differences between different categories of owners could be better understood if more background variables were studied. In-depth interviews could be an method of achieving this.

The topping method needs to be evaluated for species of greater commercial interest (e.g. Scots pine and Norway spruce in Sweden). There is also a need to examine whether the topping treatment can direct browsing (especially by moose) away from the main stems and towards the topped secondary stems. Whether the topped stems present an obstacle to harvesting at the first commercial thinning also needs to be considered. It is possible, in addition, that the remnants of the topped stems could be used as biofuel. Another interesting aspect would be to study topping in mixed stands, consisting of species with different growth pattern.

Different kinds of “quick PCT” still need to be evaluated, from economic, time, yield, and quality perspectives. There need to be more trials based on point cleaning and other types of "quick PCT" in different types of stands. Further research is also required to determine how extensive PCT can be in order to maintain the positive effects of reduced competition.

Combining early management activities could maximise the value of future forests. The economics of these possibilities should be evaluated, particularly combining artificial and naturally regeneration. There is a poorly evaluated experiment of Elfving and Näslund (cf. Sjögen & Näslund 1996) that needs to be revised in order to elucidate these aspects.

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References

Ackzell, L. 1993. A comparison of planting, sowing and natural regeneration for *Pinus sylvestris* (L.) in boreal Sweden. *Forest Ecology and Management 61*: 229-245.

Ackzell, L. & Lindgren, D. 1994. Some genetic aspects of human intervention in forest regeneration: considerations based on examples from an experiment in Northern Sweden. *Forestry 67*: 133-148.

Agestam, E. 1985. A growth simulator for mixed stands of pine, spruce and birch in Sweden. *Swedish University of Agricultural Sciences, Department of Forest Yield, Report 15*. 150 pp. ISBN 91-576-2528-X.

Agestam, E., Ekö, P.-M. and Johansson, U. 1998. Timber quality and volume growth in naturally regenerated and planted Scots pine stands in S.W. *Sweden. Studia Forestalia Suecica 204*. 17pp.

Almgren, G., Jarnemo, L. & Rydberg, D. 2003. *Våra ädla lövträd.* Skogsstyrelsen, Jönköping. 319 pp. (In Swedish). ISBN 91-88462-60-9.

Amilon, J. A. 1923. *Skogsskötseln och dess förutsättninga*r. Albert Bonniers förlag, Stockholm. 574 pp. (In Swedish).

Andersson, B. 1993. The influence of broad-leaved trees on survival, height and diameter of small Scots pine (*Pinus sylvestris* L.) trees. *Swedish University of Agricultural Sciences, Department of Silviculture, Report 36.* 36 pp. (In Swedish with English summary).

Andersson, S.-O. 1975. Röjning i tall- och granskog. *Skogsfakta nr. 4 1975*. 4 pp. (In Swedish).

Andersson, S.-O. 1985. Treatment of young mixed stand with birch and conifers. In: Broadleaves in boreal silviculture – an obstacle or an asset? Eds: B. Hägglund & G. Petersson, *Swedish University of Agricultural Sciences, Department of Silviculture, Reports, No. 14*: 127-161.

Andersson, S.-O. 1984. *Röjning och sågtimmerkvalitet.* In: Kvalitet-behöver vi det? (Eds. Eriksson, A., Wünsche, G. & Zimmerman, J.) Skogsfakta konferens, Uppsala. 33-38 (In Swedish).

Andrée, G. & Kylander, B.-M. 1979. Fosterskador i norra Värmland, *Miljöhäften no. 2*. Miljöförbundet, Uppsala. 32 pp. (In Swedish). ISSN 0348-534X.

Andrén, T. 1992. *Från naturskog till kulturskog.* CW-förlaget, Bjästa. 326 pp. (In Swedish). ISBN 91-7542-197-6.

Anon. 1967. *Skogsstyrelsens röjningsrekommendationer*, Kungl. Skogsstyrelsen: 12 pp (In Swedish).

Anon. 1971. *Lönsammare skog.* Skogsstyrelsen, Stockholm. 124 pp. (In Swedish).

Anon. 1978a. *Frågor och svar om fenoxisyror: en information från SCA:s skogsdivision*. SCA, Sundsvall. 15 pp (In Swedish).

Anon. 1978b. Skog för framtid. *SOU 1978:6.* Jordbruksdepartementet, Stockholm. 194 pp. (In Swedish with English summary). ISBN 91-38-03836-6.
Anon. 1992. Skogspolitiken inför 2000-talet. *SOU 1992:76,* Allmänna förl., Stockholm. 343 pp. (In Swedish.). ISBN 91-38-13131-5.
Anon. 1997. *Röjningshandbok-virkeskvalité-ståndortsanpassning-naturvård.* AssiDomän, Stockholm. 58 pp. (In Swedish).
Anon. 1998. *Röjning.* Stora Skog, Falun. 34 pp. (In Swedish).
Anon. 1999. Regulations for measurements of round wood. *Circular VMR 1-99*. Swedish Timber Measurement Council. 42 pp.
Anon. 2000a. *Skogsencyklopedien.* Sveriges skogsvårdsförbund, Stockholm. 567 pp. (In Swedish). ISBN 91-7646-041-x.
Anon. 2000b. *Röjningshandledning.* Holmen skog, Örnsköldsvik. 15 pp. (In Swedish).
Anon. 2001. *Så här ska du röja.* SCA Skog, Sundsvall. 15 pp. (In Swedish).
Anon. 2002. *Skogsvårdsorganisationens utvärdering av skogspolitikens effekter SUS 2001.* Skogsstyrelsens förlag, Jönköping. 275 pp. (In Swedish). ISSN 1100-0295
Anon. 2003. *Forestry statistics 2003.* Swedish University of Agricultural Sciences, Department of Forest Resource Management and Geomatics, Umeå. 114pp. (In Swedish with English summary). ISSN 0280-0543
Anon. 2004a. *Skogsstatistisk årsbok 2004.* Skogsstyrelsens förlag, Jönköping. 329 pp. (In Swedish with summary and glossary in English). ISBN 91-88462-61-7.
Anon. 2004b. *Skogliga sektorsmål.* Skogsstyrelsen, Jönköping. 21 pp (In Swedish).
Bäcke, J.-O. & Liedholm, H. 2000. *Röjning.* Skogsstyrelsens förlag, Jönköping. 34 pp. (In Swedish).
Bäckström, P.-O. 1984. Ungskogsröjning och lövbehandling. *Sveriges skogsvårdsförbunds tidskrift 3-4: 5-14.* (In Swedish).
Berg, H., Bäckström, P.-O., Gustavsson, R. & Hägglund, B. 1973. Några system för ungskogsröjning - en analys. *Forskningsstiftelsen Skogsarbeten, Redogörelse 5.* 78 pp. (In Swedish).
Bergkvist, I. & Glöde, D. 2004. Corridor cleaning – a method with great potential. *SkogForsk, Results 3 2004*. 4 pp
Bergkvist, I., Johansson, F. & Glöde, D. 2004. Tredje generationens röjningsteknik - Maskinell röjning i stråk kombinerad med motormanuell mellanzonsröjning. *SkogForsk, Arbetsrapport 566*. 27pp. (In Swedish). ISSN 1404-305X
Bergqvist, G. 1999. Wood volume yield and stand structure in Norway spruce understory depending on birch shelterwood density. *Forest Ecology and Management 122:* 221-229.
Bergqvist, G., Bergström, R. & Edenius, L. 2001. Patterns of stem damage by moose *(Alces alces)* in young *Pinus sylvestris* stands in Sweden. *Scandinavian Journal of Forest Research 16*: 363-370.
Bergqvist, G., Bergström, R. & Edenius, L. 2003. Effects of moose (*Alces alces*) rebrowsing on damage development in young stands of Scots pine (*Pinus sylvestris*). *Forest Ecology and Management 176*: 397-403.
Björkman, C. A. T. 1877. Handbok i skogsskötsel, Stockholm. 312 pp. (In Swedish).
Brandth, B. & Haugen, M. S. 1998. Breaking into a masculine discourse: woman and farm forestry. *Sociologia Ruralis 38*: 427 - 442.
Brännlund, R., Göransson, M. & Löfgren, K.-G. 1985. The effects on the short-run supply of wood from subsidized regeneration measures: an econometric analysis. *Canadian Journal of Forest Research 15*: 941-948.
Brunberg, T. 1997. Basic data for productivity norms for single-grip harvesters in thinning. *SkogForsk, Redogörelse 8*. 18 pp. (In Swedish with English summary).
Brynte, B. 2002. C.L. Obbarius -en nydanare i Bergslagens skogar vid 1800-talets mitt. *Skogs- och lantbrukshistoriska meddelanden 24*. 248 pp. (In Swedish with summary in German). ISBN 91-89379-15-2.
Callin, G. 1957. An investigation on cleaning with brush motor saws. *Statens skogsforskningsinstitut, Uppsatser 56*: 501-524. (In Swedish with English summary).

Cameron, A. D., Dunham, R. A. & Petty, J. A. 1995. The effects of heavy thinning on stem quality and timber properties of silver birch (*Betula pendula*). *Forestry 68*: 275-285.

Carlén, O. 1990. Private Nonindustrial Forest Owners' management behaviour. An economic analysis based on empirical data. *Swedish University of Agricultural Sciences, Department of Forest Economics, Report 92.* 104 pp. ISBN 91-576-4043-2.

Claesson, S., Sahlén, K. & Lundmark, T. 2001. Functions for biomass estimation of young *Pinus sylvestris, Picea abies* and *Betula spp*. from stands in northern Sweden with high stand densities. *Scandinavian Journal of Forest Research 16*: 138-146.

Clauss, S. 2004. Testing a prototype of a safety knowledge test concerning the use of cleaning saw in pre-commercial thinning among forest owners in Sweden. *Swedish University of Agricultural Sciences, Department of Silviculture, Division of Forest Technology, Studentuppsatser 68.* 35 pp.

Collet, C., Ningre, F. & Frochot, H. 1998. Modifying the microclimate around young oaks through vegetation manipulation: Effects on seedling growth and branching. *Forest ecology and management 110*: 249-262.

Danell, K., Huss-Danell, K. & Bergström, R. 1985. Interactions between browsing moose and two species of birch in Sweden. *Ecology 66*: 1867-1878.

Eberling, F. 1955. *Norrländska skogsvårdsfrågor.* Kungl. Domänstyrelsen, Helsingborg. 146 pp. (In Swedish).

Ekelund, H. & Hamilton, G. 2001. Skogspolitisk historia. *Skogstyrelsens rapport 2001:8A.* 251 pp. (In Swedish). ISSN 1100-0295.

Enander, K.-G. 2000. Skogsvårdslagen 1903 - dess förhistoria och några huvuddrag i utvecklingen. *Swedish University of Agricultural Sciences, Department of Silviculture, Report 46.* 72 pp. (In Swedish with English summary).

Enander, K.-G. 2001. Skogsbrukssätt och skogspolitik 1900-1950. *Swedish University of Agricultural Sciences, Department of Silviculture, Report 48.* 125 pp. (In Swedish with English summary).

Enander, K.-G. 2003. Skogsbrukssätt och skogspolitik 1950-2000. *Swedish University of Agricultural Sciences, Department of Silviculture, Report 54.* 200 pp. (In Swedish with English summary).

Erdman, G. G., Peterson, R. M. J. & Goodman, R. M. 1981. Cleaning yellow birch seedlings stands to increase survival, growth, and crown development. *Canadian journal of forest research 11*: 62-68.

Eriksson, P. 2004a. Evaluation of a directed campaign for pre-commercial thinning. *Swedish University of Agricultural Sciences, Department of Silviculture, Examensarbete 2004-5*. 39 pp (In Swedish with English summary).

Eriksson, B. 2004b. Kraftig expansion - entreprenörer gör nu 90 procent av naturvården. *SkogForsk, Resultat 17.* 4 pp. (In Swedish with English summary).

Erlandsson, P. 2001. Private forest owners cleaning activities as a result from advisory service by the County Forestry Board, advises based on satellite image interpretation. *Swedish University of Agricultural Sciences, Skogsmästarskolan, Examensarbete 2001:11.* 33 pp. (In Swedish with English summary).

Fahlgren, S. 1995. Skogsbruket i Kramfors bolag. Några iaktagelsen och minnen från åren 1939-1951. *Skogshistorisk tidskrift 5*: 2-18 pp. (In Swedish).

Fahlvik, N. 2005. Aspects of precommercial thinning in heterogeneous forests in southern Sweden. *Acta Universitatis Agriculturae Sueciae 2005:68*. 38 pp. ISBN 91-576-6967-8

Fahlvik, N., Ekö, P.-M. & Pettersson, N. 2005. Influence of precommercial thinning grade on branch diameter and crown ratio in *Pinus sylvestris* in southern Sweden. *Scandinavian Journal of Forest Research 20*: 243-251.

Fransson, P. 1952. Control of birch in Northern Sweden with weed killers. *Statens skogsforskningsinstitut, Meddelanden från Statens skogsforskningsinstitut 41:1*. 20 pp. (In Swedish with English summary).

Freij, J. 1991. Röjningsteknik. *Forskningsstiftelsen Skogsarbeten, Redogörelse 2.* 56 pp. (In Swedish with English summary).

Frivold, L. H. & Frank, J. 2002. Growth of mixed birch-coniferous stand in relation to pure coniferous stands at similar sites in south-eastern Norway. *Scandinavian Journal of Forest Research 17*: 139-149.

Fryk, J. 1984. Wide spacing after cleaning of young forest stands - stand properties and yield. *Swedish University of Agricultural Sciences, Department of Forest Yield Research, Report 13*. 248 pp. (In Swedish with English summary). ISBN 91-576-1958-1.

Glöde, D., Bergström, R. & Pettersson, F. 2004. Intäktsförluster på grund av älgbetning på tall i Sverige. SkogForsk, Arbetsrapport 570. 30 pp. (In Swedish). ISSN 1404-305X.

Hägg, A. 1990. The profitability of using self-regenerated birch for shaping the quality of planted pine. *Swedish University of Agricultural Sciences, Department. of Forest Products, Report 214*. 26 pp. (In Swedish with English summary).

Hägglund, B. 1983. What can tree breeding give in reality? Examples från Västerbotten and Småland. *Sveriges skogsvårdsförbunds tidskrift 3/83*: 15-25. (In Swedish with English summary).

Hägglund, B. & Lundmark, J.-E. 1987. *Bonitering, Del 1. Definitioner och anvisningar.* Skogsstyrelsen, Jönköping. 53 pp. (In Swedish). ISBN 91-85748-64-1.

Hagner, M. 2004. *Naturkultur.* Mats Hagners Bokförlag, Umeå. 124 pp. (In Swedish). ISBN 91-631-5010-7.

Hjort, R. 1947. Förbundets exkursion i Malåtrakten år 1947. *Norrlands Skogsvårdsförbunds tidskrift 4/1947*: 389-480 (In Swedish).

Höjer, E. W. 1950. Domänverkets föryngringsarbete i Norrland. *Norrlands Skogsvårdsförbunds tidskrift 4/1950*: 425-446. (In Swedish).

Hörnberg, S. 2001. Changes in population density of moose (*Alces alces*) and damage to forest in Sweden. *Forest Ecology and Management 149*: 141-151.

Hultkrantz, L. 1986. Ger skogsvårdsbidrag bättre skogsvård? En utvärdering av bidragen till skogsvård i Norrland. *Swedish University of Agricultural Science, Department of Forest economics, Arbetsrapport 49.* 20 pp. (In Swedish).

Huuri, O. & Lähde, E. 1985. *Effect of planting density on the yield, quality and quantity of Scots pine plantations.* In: International conference on managing forest trees as cultivated plants (Eds. P. M. A. Tigerstedt, P. Puttonen and V. Koski). Department of plant breeding, University of Helsinki, Finland, pp. 295-304.

Hyder, A. S., Lönnstedt, L. & Penttinen, M. 1994. Outline of accounting for non-industrial private woodlots. *Silva Fennica 28*: 115-137.

Ikäheimo, E. & Norokorpi, Y. 1986. The effect of cleaning on the incidence of damage and the development and quality of Scots pine plantations in northern Finland. *Folia forestalia 647*. 49 pp. (In Finnish with English summary).

Jäghagen, K. & Sandström, J. 1994. *Alla tiders skog*. Skogsägarnas riksförbund, Stockholm. 197 pp. (In Swedish). ISBN 91-7446-043-9.

Japec, L. 1997. *Minska bortfallet.* Statistiska centralbyrån, Stockholm. 160 pp. (In Swedish.). ISBN 91-618-0908-X.

Jonsson, M. 2001. Increased cleaning area for members of Södra skog! *Swedish University of Agricultural Sciences, Skogsmästarskolan, Examensarbete 2001:2.* 46 pp. (In Swedish with English summary).

Juhlin Dannfelt, M. 1947. *Skogsskötsel: lärokurs för statens skogsskolor.* Kungliga domänstyrelsen, Stockholm. 176 pp. (In Swedish).

Kardell, L. 1986. Sowing, planting or natural regeneration? *Sveriges skogsvårdsförbunds tidskrift 1/86*: 3-15. (In Swedish with English summary).

Kardell, L. 2004. *Svenskarna och skogen-Från baggböleri till* naturvård. Skogsstyrelsen, Jönköping. 303 pp. (In Swedish). ISBN 91-88462-57-9.

Kardell, L. 2005. Ett försök med sådd, plantering och självföryngring i tall 1959-2002. *Swedish University of Agricultural Science, Department of Environmental Forestry, Report 95*. 58pp. (In Swedish).

Kärhä, K. & Oinas, S. 1998. Satisfaction and company loyalty as expressed by non-industrial private forest owners towards timber procurement organizations in Finland. *Silva Fennica 32*: 27-42.

Karlmats, U. & Pettersson, N. 2001. The effect of moose grazing on wood properties in Scots pine. *Dalarna University, Forest and timber, Report 12.* 17 pp. (In Swedish with English summary.). ISSN 1403-8188.

Karlsson, A. & Albrektson, A. 2000. Height development of *Betula* and *Salix* species following precommercial thinning at various stump heights: 3-year results. *Scandinavian journal of forest research 15*: 359-367.

Karlsson, A. & Albrektson, A. 2001. Height development of *Betula* and *Salix* species following pre-commercial thinning through breaking the tops of secondary stems: 3-year results*. Forestry 74*: 41-51.

Karlsson, A., Albrektson, A., Elfving, B. & Fries, C. 2002. Development of *Pinus sylvestris* main stems following three different precommercial thinning methods in a mixed stand. *Scandinavian Journal of Forest Research 17*: 256-262.

Karppinen, H. 1998. Values and objectives of non-industrial private forest owners in Finland. *Silva Fennica 32*: 43-56.

Kline, J. D., Alig, R. J. & Johnson, R. L. 2000. Fostering the production of nontimber services among forest owners with heterogeneous objectives. *Forest Science 46*: 302-311.

Kurttila, M., Hämäläinen, K., Kajanus, M. & Pesonen, M. 2001. Non-industrial private forest owners attitude towards the operational environment of forestry - a multinomial logit model analysis. *Forest policy and Economics 2*: 13-28.

Kvaalen, H. 1989. Virkning av forskjellig stubbehoyde på skuddskyting, stubbeoverlevelse og vekst av subbesskudd etter hogst av seks år gammel hengebjork (*Betula pendula* Roth.). *Norwegian Forest Research Institute, Seksjon skogbehandling, Research paper 5.* (In Norwegian with English summary).

Lähde. E., 1991. *Picea abies*-dominated naturally established sapling stands in response to various cleaning-thinnings. *Scand. J. For. Res. 6*, 499-508.

Lavsund, S. 2003. Skogsskötsel och älgskador i tallungskog. *SkogForsk, Results 6.* 4 pp. (In Swedish with English summary). ISSN 1103-4173

Lidestav, G. 1997. Female forest owners and female forest holdings - a structure analysis. *Swedish University of Agricultural Sciences, Department of Operational Efficiency, Uppsatser och Resultat 298.* 23 pp. (In Swedish with English summary).

Lidestav, G. 1998. Women as non-industrial private forest landowners in Sweden. *Scandinavian Journal of Forest Research 13*: 66-73.

Lidestav, G. & Ekström, M. 2000. Introducing gender in studies on management behaviour among non-industrial private forest owners. *Scandinavian journal of forest research 15*: 378-386.

Ligné, D. 2004. New technical and alternative silvicultural approaches to pre-commercial thinning. *Acta universitatis agriculturae sueciae, Silvestria 331.* 46 pp. ISBN 91-576-6715-2

Ligné, D., Karlsson, A. & Nordfjell, T. 2005. Height development of *Betula pubescens* following precommercial thinning by breaking or cutting the treetops in different seasons. *Scandinavian Journal of Forest Research 20*: 136-145.

Lindblad, O. 1937. Tyskland överger trakthuggningen. *Skogen 24*: 139-142. (In Swedish).

Lindgren, P. M. F. & Sullivan, T. P. 2001. Influence of alternative vegetation management treatment of conifer plantations attributes: abundance, species diversity, and structural diversity. *Forest Ecology and Management 142*: 163-182.

Löf, M. 1993. Relationer mellan miljörörelsen och skogsbolagen 1970-1993. *Swedish University of Agricultural Sciences, Department. of Forest Economy, Arbetsrapport 176.* 60 pp. (In Swedish with English summary).

Lönnstedt, L. 1989. Goals and cutting decisions of private forest owners*. Scandinavian Journal of Forest Research 4*: 259-265.

Lönnstedt, L. & Roos, A. 1990. The economy of the absentee non-farmers. *Swedish University of Agricultural Sciences, Department of Forest-Industry-Market Studies, Report 15.* 58 pp. (In Swedish with English summary).

Löyttyniemi, K. 1985. On repeated browsing of Scots pine sapling by moose (*Alces alces*). *Silva Fennica 19*: 387-391.

Mäkinen, H. 1999. Effect of stand density on radial growth of branches of Scots pine in southern and central Finland. *Canadian Journal of Forest Research 29*: 1216-1224.

Mård, H. 1996. The influence of Birch shelter (*Betula* spp) in the growth of young stands of *Picea abies*. *Scandinavian Journal of Forest Research 11*: 343-350.

Mielikäinen, K. 1980. Structure and development of mixed pine and birch stands. *Communicationes instituti forestalis Fenniae 99*: 82pp. (In Finnish with English summary).

Nellbeck, R. 1969. *Den nya skogen*. AB Iggesunds bruk, Iggesund. 43 pp. (In Swedish).

Niemistö, P. 1995a. Influence of initial spacing and row-to-row distance on the growth and yield of silver birch (*Betula pendula*). *Scandinavian journal of forest research 10*: 245-355.

Niemistö, P. 1995b. Influence of initial spacing and row-to-row distance on the crown and branch properties and taper of silver birch (*Betula pendula*). *Scandinavian Journal of Forest Research 19*: 235-244.

Nilsson, U. & Albrektson, A. 1994. Growth and selfthinning in two young Scots pine stands planted at different initial densities. Forest Ecology and Management 68: 209-215.

Obbarius, L. W. 1857. *Enkla reglor for praktisk skogsskötsel: till tjenst för skogwaktare och ägare af mindre skogslotter*. Lindh, Örebro. 108 pp. (In Swedish).

Oliver, C. D. & Larson, B. C. 1990. *Forest stand dynamics*. McGraw-Hill, New York. 467 pp. ISBN 0-07-047793-0.

Örlander, G. 1993. Shading reduces both visible and invisible frost damage to Norway spruce seedlings in the field. *Forestry 66*: 27-36.

Perlinge, A., (Ed.) 1992. *Skogsbrukes tekniska utveckling under 100 år*. Nordiska Museets förlag, Stockholm. 119 pp. (In Swedish). ISBN 91-7108-321-9.

Persson, A. 1977. Quality development in young spacing trials with Scots pine. *Royal College of Forestry, Department of forest yield, Research notes 45.* 152 pp. (In Swedish with English summary).

Persson, A. 1994. How genotype and silviculture interact in forming timber properties. *Silva Fennica 28*: 275-282.

Persson, P. 1972. Stand treatment and damage by wind and snow - survey of younger thinning experiments. *Royal College of Forestry, Department of Forest Yield Research, Research notes 23*. 205 pp. (In Swedish with English abstract).

Petersson, H. 1997. Functions for predicting crown height of *Pinus sylvestris* and *Picea abies* in Sweden. *Scandinavian Journal of Forest Research 12*: 179-188.

Pettersson, F. 2001. Impacts of different cleaning regimes on the development of Scots-pine in Sweden. *SkogForsk, redogörelse 4.* 28 pp. (In Swedish with English summary).

Pettersson, N. 1986. Line thinning in young natural regenerated pine stands. *Swedish University of Agricultural Sciences, Department of Forest Yield Research, Report 17.* 22 pp. (In Swedish with English summary).

Prescher, F. & Ståhl, E. G. 1986. The effect of provenance and spacing on stem straightness and number on spike knots of Scots pine in South and Central Sweden. *Studia Forestalia Suecica 172*: 12 pp.

Raulo, J. 1987. *Björkboken*. Skogsvårdstyrelsen, Jönköping. 87 pp. (In Swedish). ISBN 91-85748-61-7

Rennerfelt, E. 1948. Försök att med kemiska medel förhindra stubbskottsbildning hos björk på hyggen. *Sveriges skogsvårdsförbunds tidskrift 1948:* 119-139. (In Swedish).

Ronge, E. 1949. Kunna fåren och skogens intressen förenas? *Svenska fåravelsföreningens tidskrift 4*: 8 pp. (In Swedish).

Rudqvist, A. & Törnqvist, T. 1986. Forestry strategies and cutting decisions among private forest owners - 40 case studies. *Swedish University of Agricultural Sciences, Department of Operational Efficiency, Report 171.* 225 pp. (In Swedish with English summary).

Ruha, T. & Varmola, M. 1997. Precommercial thinning in naturally regenerated stands in northern Finland. *Silva Fennica 31*: 401-415.

Ryans, M. 1988. Mechanized precommercial thinning methods: experience to date. *Forest Engineering Research Institute of Canada. Special Report SR-56.* 17 pp.

Ryans, M. & Cormier, D. 1994. A review of mechanized brush-cutting equipment for forestry. *Forest Engineering Research Institute of Canada, Special Report SR-101.* 36 pp.

Salminen, H. & Varmola, M. 1990. Development of seeded Scots pine stands from precommercial thinning to the first commercial thinning. *Folia forestalia 752*: 29 pp. (In Finnish with English summary).

Savill, P., Evans, J., Auclair, D. & Falck, J. 1997. *Plantation silviculture in Europe*. Oxford University Press, Oxford. 297 pp. ISBN 0-19-854909-1.

Sennblad, G. 1988. Survey of logging and silviculture in non-industrial private forest in Sweden 1984. Part 1. Logging and silviculture and who performed the forest work. *Swedish University of Agricultural Sciences, Department on Operational Efficiency, Report 175.* 56 pp. (In Swedish with English summary).

Sennblad, G. 1996. An analysis of the logging behaviour of non-industrial private forest owners in Sweden. *Swedish University of Agricultural Sciences, Department of Forest Efficiency, Research notes 293.* 17 pp. (In Swedish with English summary).

Sjögren, H. & Näslund, B.-Å. 1996. Försök med olika skogsskötselintensitet, dokumentation av försöksanläggning 1984-1988. Swedish University of Agricultural Sciences, Department of Silviculture, Arbetsrapporter 117. 17pp. (In Swedish).

Sjolte-Jorgensen, J. 1967. The influence of spacing on the growth and development of coniferous plantations. *International Review of Forestry Research 2*: 43-94.

Smith, D. M., Larson, B. C., Kelty, M. J., Aschton, P. M. S. 1997. *The practice of silviculture, applied forest ecology*. 9th edition. John Wiley & sons, inc. New York. 537pp. ISBN0-471-10941-X.

Söderström, V. 1971. *Ekonomisk skogsproduktion.* 1st ed. LTs Förlag, Stockholm. 391 pp. (In Swedish). ISBN 91-36-27512-3.

Söderström, V. 1980. *Ekonomisk skogsproduktion.* 2nd ed. Lts förlag, Stockholm. 217 pp. (In Swedish). ISBN 91-36-01486-9.

Spellmann, v., H. & Nagel, J. 1992. Evaluating the NELDER-spacing experiment with Scots pine in Walsrode. *Allgemeine Forst- und Jagdzeitung 163*: 221-229. (In German with English summary).

Ståhl, E. G., Persson, B. & Prescher, F. 1990. Effect of provenance and spacing on stem straightness and number of stems with spike knots in *Pinus sylvestris* L. - Northern Sweden and countrywide models. *Studia Forestalia Suecica 184*: 16 pp.

Streyffert, T. 1949. Economy of artificial regeneration. Bulletin of the Royal School of Forestry, No 1. 54 pp. (In Swedish with English summary).

Ström, I. A. af 1822. *Förslag till en förbättrad skogshushållning i Sverige jemte utkast till dess systematiska verkställande*, Stockholm. 158 pp. (In Swedish).

Ström, I. A. af 1846. *Handbok för skogshushållare*, Stockholm. 303 pp. (In Swedish).

Svensson, J. 2004. Cleaning inspection in Karlskrona kommun, 2004. *Swedish University of Agricultural Sciences, Skogsmästarskolan, Examensarbete 2004:13*. 29 pp. (In Swedish with English summary). ISSN

Tham, Å. 1994. Crop plans and yield prediction for Norway spruce (*Picea abies* (L.) Karst.) and birch (*Betula pendula* Roth & *Betula pubescens* Ehrh.) mixtures. *Studia Forestalia Suecica 195*, 21 pp.

Timmer, V.R. & Munson, A.D. 1991. Site-specific growth and nutrition of planted Picea mariana in the Ontario clay belt. IV. Nitrogen loading response. *Canadian Journal of Forest Research 21*: 1058-1065.

Törnqvist, T. 1995. Inheritors of the woodlands - a sociological study of private, non-industrial forest ownership. *Swedish University of Agricultural Sciences, Department. of Forest-Industry-Market Studies, Report 41.* 442 pp. (In Swedish with English summary).
Torvelainen, J. & Ripatti, P. 2000. Public subsidies in promoting the tending of young stands. *Tyotehoseuran-Metsatiedote 621*: 4 pp. (In Finnish with English summary.).
Troeng, E. 1988. Växtnäringstyrda plantor II. Tillväxt i fält. Swedish University of Agricultural Science, Department of Forest Yield research, Stencil 45. 15 pp. (In Swedish).
Trost, J. 2001. *Enkätboken.* Studentlitteratur, Lund. 148 pp. (In Swedish). ISBN 91-44-01816-9.
Wagenknecht, H. E. & Henkel, W. 1962. *Rationelle dickungspflege*. Neumann verlag, Radebeul, Berlin. (In German).
Wahlgren, A. 1914. *Skogsskötsel- handledning vid uppdragande, vård och föryngring av skog.* P. A. Nordstedt och söners förlag, Stockholm. 728 pp. (In Swedish).
Valinger, E. 1992. Effects of thinning and nitrogen fertilization on stem growth and stem form of *Pinus sylvestris* trees. *Scandinavian Journal of Forest Research 7*: 219-228.
Valinger, E., Lundqvist, L. & Brandel, G. 1994. Wind and snow damage in a thinning and fertilisation experiment in *Pinus sylvestris*. *Scandinavian Journal of Forest Research 9*: 129-134.
Valkonen, S. & Ruuska, J. 2003. Effect of *Betula pendula* admixture on tree growth and branch diameter in young *Pinus sylvestris* stands in Southern Finland. *Scandinavian Journal of Forest Research 18*: 416-426.
Valkonen, S. & Valsta, L. 2001. Productivity and economics of a mixed two-storied spruce and birch stand in Southern Finland simulated with empirical models. *Forest Ecology and Management 140*: 133-149.
Varmola, M. & Salminen, H. 2004. Timing and intensity of precommercial thinning in *Pinus sylvestris* stands. *Scandinavian Journal of Forest Research 19*: 142-151.
Vestlund, K. 2005. Aspects of automation of selective cleaning. *Acta Universitatis Agriculturae Sueciae 2005:74*. 54 pp. ISBN 91-576-6973-2
Voorhis, N. G. 1990. Precommecial thinning in a mixed northern hardwood stand. *Northeastern Forest Experiment Station, Research paper NE-640*. 4pp.
Zellén, J. O. af 1904. *Den nya lagstiftningen angående vård af enskildes skogar med kommentarier jämte anvisningar för skogarnes skötsel*, Stockholm. 184 pp. (In Swedish).

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http://www.pefc.se/english/ accessed 050804

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http://www.fsc-sverige.org/ accessed 050804