Citation for the published paper:
Skovsgaard, Jens Peter, Nordfjell, Tomas and Sørensen, Ib Holmgård. (2006) Precommercial thinning of beech (Fagus sylvatica L.): Early effects of stump height on growth and natural pruning of potential crop trees. *Scandinavian Journal of Forest Research*. 21: 5, 380-387. ISSN 0282-7281.
http://dx.doi.org/ 10.1080/02827580600979817

Pre-commercial thinning of beech (*Fagus sylvatica* L.): Early effects of stump height on growth and natural pruning of potential crop trees

by
Jens Peter Skovsgaard, Tomas Nordfjell & Ib Holmgård Sørensen
Royal Veterinary and Agricultural University
Forest & Landscape Denmark
11 Hørsholm Kongevej
DK-2970 Hørsholm

Corresponding author: Jens Peter Skovsgaard, e-mail jps@kvl.dk

Manuscript for Scandinavian Journal of Forest Research
8 September 2004, revised 18 May 2005 and 23 January 2006

ABSTRACT

This paper reports early effects of stump height on the growth and natural pruning of potential crop trees after pre-commercial thinning of a young stand of naturally regenerated beech (*Fagus sylvatica* L.) in Denmark. The experiment comprises five treatments based on combinations of three grades of pre-commercial thinning and three stump heights. Treatments include the unthinned control, thinning only of whips and wolf trees (using low stumps), and thinning for potential crop trees using low, medium or high stumps. All treatments were replicated three times. Stump heights averaged 10, 90 or 230 cm, respectively. Pre-treatment stem number (live trees) varied from 17,500 to 41,000 per ha. In the potential crop tree treatment, post-treatment stem number ranged from 4,750 to 9,500 per ha. Following two growth seasons, the quantity of stump regrowth increased with increasing stump height, the rate of stump regrowth increased with increasing stump height, the diameter growth of potential crop trees increased with decreasing stump height, the increase in stand height did not depend on stump height or post-treatment stem number, and the natural pruning of potential crop trees increased with increasing stump height. It remains to be seen, whether these trends hold in the long run, and whether additional economic return from the increase in wood quality with increasing stump height compensates for the reduction in diameter growth.

Key words: stand density, stump regrowth, inter-tree competition, forest operations

INTRODUCTION

With a wide distribution, high growth rates and a good potential for high quality timber, beech (*Fagus sylvatica* L.) is one of the economically most important tree species in Europe. Natural regeneration is used extensively in beech. Due to the high number of trees in young stands, many foresters believe that pre-commercial thinning is needed to remove undesirable individuals, reduce inter-tree competition and promote the growth of the best trees.

The traditional approach to pre-commercial thinning comprises frequent and labour-intensive operations. These are carried out manually or motor-manually by skilled forest workers, who evaluate carefully the potential of each tree. With the current, high costs of labour and changing socio-economic and market conditions the general tendency is for thinnings to become profitable at a much later stage than previously, even when wood-for-energy options are considered. At the same time, forest administration staff is being reduced in number in many countries, in the private as well as in the public sector, leaving less time for on-site supervision.

This development has lead to the consideration whether pre-commercial thinning is really needed to ensure a satisfactory development of individual tree growth and wood quality, or whether new technologies should be developed to rationalize work operations. Cutting trees at a somewhat higher level than usual could possibly reduce the costs of pre-commercial thinning because trees are easier to cut or because the cutting operation is easier to mechanize (e.g., Bulley et al. 1997, Ligné et al. 2004, Fodgaard 2005).

Depending on site conditions, forest type and species characteristics, regrowth from high stumps and low branches, which remain alive, may create an understorey of short, bushy trees (e.g., Wahlgren 1914, Wagenknecht & Henkel 1962, Harris 1986, Savill & Beatty 1986, Karlsson & Albrektson 2000, 2001, Skovsgaard & Graversgaard 2004). This may help improve natural pruning on potential crop trees (e.g., Fällmann et al. 2003) and alleviate browsing pressure (e.g., Danell et al. 1985), but may also reduce crop tree growth due to continued competition for resources (e.g., Butcher 1980).

Depending on mortality, decomposition and available work technology high stumps may become obstacles for subsequent thinning operations. The additional costs due to this obstacle or re-cutting of stumps should be deducted from possible benefits such as improved wood quality on crop trees.

Alternatively, a technology, which can handle felling of inferior trees and pruning of crop trees more-or-less simultaneously, could provide an attractive solution. Moreover, this could allow for heavier thinning operations in youth and, consequently, a more rapid diameter growth for potential crop trees. For beech, the growth rate *per se* does not influence wood quality very much.

It is well-known that historical practices in Central Europe for girdling, breaking, pruning or decapitating inferior beech (e.g., Wagenknecht & Henkel 1962) did lead to improved wood quality on potential crop trees, but only little has been documented. While these methods were conceived during a period when cost of labour was not a major concern in forestry, they may still be attractive if each pre-commercial thinning operation can be heavy (i.e., decapitate many trees) without compromising wood quality. Next, in contrast to previous practices, there is a need for mechanized, more uniform solutions in hardwood silviculture, so that each tree will not be evaluated as carefully as in the past.

Unfortunately, no experimental evidence or experience from practice is available to provide indications of, which stump height and stand density would be optimal for tree growth and natural pruning in young stands of naturally regenerated beech. In line with these arguments and practices, this paper reports early effects of stump height on the growth and natural pruning of potential crop trees after pre-commercial thinning of a young stand of naturally regenerated beech in Denmark.

MATERIALS AND METHODS

All observations originate from experiment no. 1422 of *Forest and Landscape Denmark*.

The experiment

Experiment no. 1422 was set up during spring 2002 to study effects of stump height on the growth and wood quality of beech (Skovsgaard et al. 2004a,b). The experiment is part of a larger series of pre-commercial thinning experiments.

The experiment is located in Little Beech Forest on the island of Zealand, approx. 100 km southwest of Copenhagen. Local site conditions are close to optimal for beech. Summers are cool with mean temperature around 16°C, and winters are often mild with mean temperature around 0°C. Precipitation falls throughout the year, with a mean annual precipitation of 600-650 mm. The length of the growing season for beech amounts to 5-6 months (late April - early October). The soil is derived from calcareous moraine. Height above sea level is approx. 40 m.

The stand, where the experiment is located, originated 1987 from natural regeneration. The stand is somewhat irregular, at places with an admixture (less than 10 %) of sycamore (*Acer pseudoplatanus* L.), ash (*Fraxinus excelsior* L.) and other broadleaved tree species. Immediately prior to establishment of the experiment stand height varied from 3.0 to 4.2 m. Pre-treatment stem number (live trees) generally varied from 17,500 to 26,000 stems per ha, but in some parts of the experiment from 35,000 to 41,000 per ha.

Treatments

The layout of the experiment is a randomized complete block design with five treatments replicated in each of three blocks, yielding a total of 15 plots. Blocking was done at establishment of the experiment according to the average height of ten dominant trees in each plot. Blocking resulted in significant between-block differences in pre-treatment stand height ($p \leq 0.05$). The arguments for using stand height as a blocking criterion were that rate of height growth may influence natural pruning and that plot-specific site conditions may influence responses to stand treatment.

Each plot measures approximately 15 m x 15 m. Plot area ranges between 177 and 263 m^2, with an average area of 218 m^2. Plots are located at four different places in the stand, with groups of six, four, four and one plot in each location (the maximum distance between any two plots is 300 m). Note that blocking does not relate to the geographical distribution of plots. Each plot location is surrounded by an unthinned buffer zone.

The experiment comprises five treatments based on combinations of three grades of pre-commercial thinning and three stump heights (Table 1). All treatments were carried out at establishment of the experiment.

The pre-commercial thinning regimes include the unthinned control, thinning only of severe competitors such as whips and wolf trees, and thinning for a low number of potential crop trees. A whip is a slender tree, which through swaying may lacerate the crown of potential crop trees and thereby hamper their development (cf. Ford-Robertson 1971, term no. 6653). A wolf tree is a coarse tree with short stem, thick branches and widely spreading crown (cf. Ford-Robertson 1971, term no. 6702).

Due to the original, large variation between plots, the number of selected crop trees in the potential crop tree treatment varied between 4,750 and 9,500 per ha. All other trees in these plots were cut. Unfortunately, the number of remaining crop trees following the first pre-commercial thinning increased with decreasing stump height, but was uncorrelated with pre-treatment stem number.

The stump heights averaged approx. 10 cm (corresponding to common practice), approx. 90 cm (easy work position) or approx. 230 cm (maximum reach of a hand-held chain saw), respectively. Stump height was controlled experimentally only in those plots where pre-commercial thinning was carried out to specifically promote potential crop trees. In plots where only severe competitors are thinned, stumps were cut close to ground level.

Measurements

At installation of the experiment (spring 2002, before budburst) ten dominant trees in each plot were measured for total tree height. These trees were not permanently marked for re-measurement. All other measurements were carried out two growth seasons later (autumn 2003).

Apart from measuring plot area and counting of pre- and post-treatment stem numbers, measurements were carried out only for a sample of trees. The sample included the five best potential crop trees in each plot and all stumps and trees within a radius of 0.5 metre from each of these crop trees. Crop trees for measurement were selected based on visual assessment of size and exterior wood quality. This selection criterion was also applied in unthinned control plots and in plots with thinning only of whips and wolf trees. Trees and stumps for measurement were individually numbered and permanently marked for re-measurement.

Measurements on stumps included stump height, stump diameter at breast height (treatment 5) or at top of stump (treatment 4), number of regrowth shoots, and maximum height of regrowth above stump height (measured with regrowth in natural position). Measurements on crop and other trees included diameter at breast height, total tree height and the height to the base of the lowest live branch (indicating height to the live crown base). It was also noted, whether each stump, regrowth shoot or tree for measurement, was alive or dead. All diameter measurements were uni-directional. At this first re-measurement, all measured stumps, regrowth shoots and trees were alive, except for low stumps and some dead trees in the unthinned control plots. A total of 139 stumps and 75 crop trees were measured.

In addition to the field measurements, the growth response was quantified based on uni-directional measurements of annual ring width. For this purpose, stem discs were cut at breast height from trees that were felled as part of an adjustment of post-treatment stem numbers. Five trees, representing the range of tree sizes, were sampled in each of two plots of each treatment type, except in the whip and wolf tree plots. However, in one plot (treatment 3) ten trees were sampled. Trees to represent unthinned control plots were cut in the unthinned buffer zone areas. Unlike the permanent sample trees, these 45 stem discs represented the entire range of tree sizes in the experiment.

Statistical analyses

Data were analyzed and hypotheses tested based on analyses of co-variance, complemented with pairwise t-tests and tests based on least-squares means. Whenever relevant, initial stand height, as well as pre- and post-treatment stem numbers were used as co-variates.

Testing for significant terms was done with the elimination of possible interactions as a first concern, and other terms as a next. No three-factor or more complex interactions were included in the models. In all analyses the resulting models provided balanced residuals. A test level of p = 0.05 was used, unless otherwise stated.

Stumps

Possible between-plot variation in stump height and in number of regrowth shoots per stump was analyzed by comparing plot means based on a pairwise *t* test. The hypothesis that means are equal was rejected if $\left|\bar{y}_i - \bar{y}_j\right| / s\sqrt{1/n_i + 1/n_j} \geq t(\alpha, v)$, where $\bar{y}_i$ and $\bar{y}_j$ are the means, n_i and n_j are the number of observations in the two plots, s is the root mean square error based on v degrees of freedom, α is the significance level, and $t(\alpha,v)$ is the two-tailed critical value from the t distribution.

The amount and rate of stump regrowth was tested within each treatment type for possible effects of thinning grade as expressed through post-treatment stem number and stump density. The model may be specified mathematically as $y_{ij} = \mu_j + \beta_j X_{1ij} + \gamma_j X_{2ij} + \varepsilon_{ij}$, where y_{ij} denotes either number of regrowth shoots or annual increase in height of regrowth above stump height, X_1 is post-treatment stem number per ha, X_2 is number of stumps per ha, μ, β, γ and ε are parameters to be estimated, subscript i refers to stump identification (stump number), subscript j refers to plot identification (plot number), and the residuals ε_{ij} are normally and independently distributed with zero mean and common variance. It will turn out that, for all practical purposes, within-treatment plot differences can be ignored, and consequently subscript j disappears from the model. For obvious reasons, the interaction between post-treatment stem number and number of stumps is irrelevant.

Hypothesis testing for significant model terms was based on the usual F-test with $F_r = \left((RSS_r - RSS_f)/(df_r - df_f)\right)/(RSS_f / df_f)$, where RSS denotes the residual sum of squares, df denotes degrees of freedom, and subscripts f and r refer to the full and the reduced model, respectively. If the hypothesis provides as good a model as does the alternative, then F will be small. If the model is not adequate when compared to the full model, then F will be large when compared to the critical value of the $F(df_r - df_f, df_f)$ distribution.

Throughout, the tests were based on the assumptions of homogeneous variance and normal distribution of errors. These assumptions were justified by the observed data. More specifically, transformation of count data proved redundant, possibly because of very few zero observations.

Potential crop trees

Treatment effects on potential crop trees were analyzed in terms of diameter growth, diameter at breast height (dbh), stand height increase and height to live crown base. Independent variables included dbh spring 2002, dbh^2 spring 2002, dbh autumn 2003, individual tree height autumn 2003, pre-treatment stem number, post-treatment stem number and treatment type. The relevant combinations of dependent and independent variables appear in the results section below. Note that effects on diameter growth include a wider range of tree sizes than effects on dbh, stand height increase and height to live crown base.

The models may be specified in general mathematical terms as $y_{ij} = \mu_j + \sum(\beta_k X_{ijk}) + \varepsilon_{ij}$, where y is one of the four dependent variables mentioned above (identified by subscript j), X is one of the independent variables (identified by subscript k), μ, β and ε are parameters to be estimated, subscript i refers to potential crop tree number, subscript j identifies the dependent variable, subscript k identifies independent variables, and the residuals ε_{ij} are normally and independently distributed with zero mean and common variance.

The number of independent variables per dependent variable ranges up to five. Note that treatment is identified through inclusion as independent variable (treatment type (1, 2, 3, 4 or 5) or post-treatment stem number). Hypothesis testing for significant model terms was based on the usual F-test as outlined above. Comparing treatment means based on the pairwise t-test (also outlined above), is relevant only for diameter growth and height to live crown base.

RESULTS AND DISCUSSION

Results are presented with a main emphasis on qualitative rather than quantitative aspects.

Stumps

Stump measurements are summarized in Table 2. Treatment effects on stump regrowth were analyzed for number of regrowth shoots and maximum height of regrowth above stump height and summarized in Table 3. Clearly, the number of regrowth shoots and their growth rate increase with increasing stump height.

Low stumps

Average stump height was 9.3 cm and did not differ between plots. There was very little regrowth, and none of any biological significance. No regrowth occured on stumps sampled for this investigation.

Medium stumps

Average stump height was 88.7 cm. Based on statistical testing stump height differed between plots, but this is hardly of any biological significance. The number of regrowth shoots did not differ between plots.

The number of regrowth shoots depended on post-treatment stem number ($p = 0.065$), but not on the number of stumps per ha. Annual increase in height of regrowth above stump height was influenced by post-treatment stem number and the number of stumps per ha, but not by post-treatment stem number alone ($p = 0.165$).

High stumps

Average stump height was 231.8 cm and did not differ between plots. The number of regrowth shoots did not differ between plots.

The number of regrowth shoots did not depend on post-treatment stem number or on the number of stumps per ha. Post-treatment stem number or number of stumps per ha did not influence the annual increase in height of regrowth above stump height.

Potential crop trees

Treatment effects on potential crop trees were analyzed in terms of diameter growth, diameter at breast height, stand height increase and height to live crown base. Results are summarized in Table 4 and Table 5.

Diameter growth

The average annual growth of individual tree diameter at breast height on crop trees depended on treatment type, pre-treatment tree diameter and post-treatment stem number. More specifically, diameter growth increased with increasing tree size, decreasing post-treatment stem number and decreasing stump height.

Including only post-treatment stem number and initial diameter in the model resulted in an R-square value of 0.68, while treatment type and initial diameter provide a slightly better explanation with an R-square value of 0.78. Including both treatment type and post-treatment stem number together with initial diameter resulted in an R-square value of 0.80, $p = 0.0003$ for treatment type and $p = 0.103$ for post-treatment stem number. This indicates that stump height as well as residual stem number influenced individual tree growth, but a confounding effect remains.

There were no effects of pre-treatment stem number and no need for a quadratic term indicating individual tree basal area to adequately model post-treatment diameter growth. Disregarding three-factor interactions and the obvious interaction between treatment type and post-treatment stem number (due to limitations on degrees of freedom), there were no significant interactions.

Based on a pairwise *t*-test growth in the unthinned control plots differed significantly from growth in plots where pre-commercial thinning was carried out to specifically promote potential crop trees. While the three potential crop tree treatments did not differ, based on statistical testing, the tendency was clear. However, as demonstrated by intercept estimates, the difference between the effects of low and medium stumps was small.

As an example, consider a pre-treatment stem number of 20,000 per ha, a post-treatment stem number of 5,000 per ha, and a crop tree with a diameter of 30 mm. In an unthinned control plot such a tree is estimated to have grown to 39 mm two years after pre-commercial thinning (in the absence of self-thinning). In potential crop tree plots a similar tree is predicted to have grown to 53, 47 or 42 mm with low, medium or high stumps, respectively.

Diameter at breast height

Following two growth seasons after pre-commercial thinning diameter at breast height of potential crop trees depended positively on individual tree height and negatively on pre- and post-treatment stem number. There was no significant effect of pre-treatment stand height. Using treatment type as a substitute for post-treatment stem number yielded identical results (not shown in the tables).

More specifically, the diameter of potential crop trees averaged 42, 45, 51, 44 and 41 mm for treatment types 1, 2, 3, 4 and 5, respectively. Hence, the (best) potential crop trees were thickest in plots that were thinned with low stumps to specifically promote potential crop trees, followed by the whip and wolf tree plots, medium stump plots, unthinned control plots, and high stump plots. There was no big difference between treatments 1, 2, 4 and 5, but potential crop trees of treatment 4 were thicker than those of treatment 5.

Considering that post-treatment stem number was less in treatment 5 than in treatment 4, and less in treatment 4 than in treatment 3, this result supports the interpretation that stump regrowth reduced the growth of potential crop trees and increasingly so with increasing stump height. For an identical number of potential crop trees, the acceleration in the growth of potential crop trees would most likely have been even larger, all else being equal.

Stand height increase

The average annual change in stand height depended on initial height rather than on treatment type or on both. Interestingly, the change in stand height was dampened with increasing initial height (i.e., negative sign on coefficient). Nevertheless, annual height increase clearly reflected the original blocking, with block averages of 91, 82 and 67 cm, respectively.

Live crown base

Already at this early stage height to the live crown base of potential crop trees was influenced by treatment type ($p = 0.061$) as well as diameter and height of the individual tree, but unaffected by pre-treatment stand height (blocking variable) and pre-treatment stem number. The lack of effect of average pre-treatment stand conditions is unexpected. Using post-treatment stem number as a variable instead of treatment type resulted in a poorer model ($p = 0.188$ for post-treatment stem number).

More specifically, height to the live crown base averaged 233, 221, 207, 154 and 127 cm for treatment types 1, 2, 5, 4 and 3, respectively. Hence, height to the live crown base was largest in the unthinned control plots, followed by the whip and wolf tree thinning and the treatments that specifically aim to promote potential crop trees. For the three treatments that specifically aim to promote crop trees height to the live crown base decreased with decreasing stump height. While according to the statistical test some of the treatments were not significantly different at this stage, the tendency was clear.

In conclusion, these results imply that natural pruning is reduced with increasing amount of open space in the stand already shortly after the first pre-commercial thinning. However, considering the average length of regrowth shoots in plots with medium stump height, the difference in natural pruning to similarly thinned plots with low stumps may be due to chance (compare with photographs in Skovsgaard et al. 2004b).

CONCLUSION

In this study of pre-commercial thinning of beech, treatments include stump heights, which are within the reach of a hand-held chain saw and ranging from 2-3 % up to 55-77 % of pre-treatment stand height. Thinning grades include the unthinned stand, very light thinning (whips and wolf trees) with removal of only 5 % of the trees, and heavy to very heavy thinning with removal of 52 to 87 % of the trees. These limits essentially include the range of relevant options.

Within these ranges and following only two growth seasons after pre-commercial thinning, the quantity of stump regrowth increased with increasing stump height, the rate of stump regrowth increased with increasing stump height, the diameter growth of potential crop trees increased with decreasing stump height, the increase in stand height did not depend on stump height or post-treatment stem number, and the natural pruning of potential crop trees increased with increasing stump height. So far, these are our best hypotheses for the effect of stump height on the growth and natural pruning of young, naturally regenerated beech. It remains to be seen, whether these trends hold in the long run, and whether additional economic return from the increase in wood quality with increasing stump height compensates for the reduction in diameter growth.

Due to the very limited time of observation, results should not be used for long-term predictions of growth or natural pruning. However, based on the quite intense competition from high stumps and the relatively small increase in height to the live crown base with medium stumps, our current recommendation for forestry practice is to use low stumps and avoid heavy pre-commercial thinning in beech. Development of new technologies may alter this recommendation.

To our knowledge, the only other experiments on pre-commercial thinning in beech, which include a high stump treatment, are located at Bjersgaard Estate, Tönnersjöheden Experimental Forest and Trolleholm Estate in Southern Sweden. These have not been re-measured, yet. In time, experiment no. 1422 and the three experiments in Southern Sweden will help clarify, whether it is worthwhile to develop or apply such technology in beech.

ACKNOWLEDGEMENTS

The experiment and this report were supported by SNS - The Nordic Forest Research Cooperation Committee during 2001-03 under the project SNS-78 "Ny och effektiv röjning: syntes av biologi, teknik och ekonomi". Sorø Academy Trust most kindly agreed to host the experiment.

REFERENCES

Ford-Robertson, F.C. 1971: Terminology of forest science, technology, practice and products. Society of American Foresters, Washington D.C. XXI + 349 pp.

Bulley, B., C. Bowling & G. Niznowski 1997: Jack pine leader clipping trial: fifth-year results. Northwest Science & Technology, Ontario Ministry of Natural Resources, Thunder Bay; NWST Technical Report 106. 22 pp.

Butcher, T.B. 1980: Competitive effect of pine regrowth and woody weeds on the growth of *Pinus pinaster*. Australian Forestry 43: 75-80.

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

Fällman, K., D. Ligné, A. Karlsson & A. Albrektson 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.

Fodgaard, S. 2005: Ny sav til udrensning: Halvering af udrensningsomkostningerne? Skoven 37: 152-155.

Harris, E.H.M. (ed.) 1986: Oceanic forestry. Proceedings of a conference held in 1985. The Royal Forestry Society of England, Wales and Northern Ireland. 44 pp.

Karlsson, A. & A. Albrektson 2000: Height development of *Betula* and *Salix* species following pre-commercial thinning at various stump heights: 3-year results. Scandinavian Journal of Forest Research 15: 359-367.

Karlsson, A. & A. Albrektson 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.

Ligné, D., T. Nordfjell & A. Karlsson 2004: New techniques for pre-commercial thinning: time consumption and damage parameters. International Journal of Forest Engineering: Accepted for publication.

Savill, P.S. & M.H. Beatty 1986: Techniques, early growth and silvicultural considerations. In Harris (1986), pp. 12-18.

Skovsgaard, J.P. & H.C. Graversgaard 2004: Høje stød ved udrensning i blandingsbevoksninger af ask og rødel. Skoven 36: 384-385.

Skovsgaard, J.P., T. Nordfjell, I.H. Sørensen & L. Birck 2004a: Udrensning i bøg. Undersøgelse af stødhøjdens betydning for blivende bestands vækst og kvalitet. Forsøg nr. 1422, Stiftelsen Sorø Akademi, Lille Bøgeskov, afd. 332a. Anlægsrapport nr. 627. Skov & Landskab, Den Kgl. Veterinær- og Landbohøjskole.

Skovsgaard, J.P., T. Nordfjell & I.H. Sørensen 2004b: Udrensning i bøg. Stødhøjdens betydning for vækst og kvalitet. Skoven 36: 379-382.

Wagenknecht, E. & W. Henkel 1962: Rationelle Dickungspflege. Neumann Verlag; Radebeul, Berlin. 176 pp.

Wahlgren, A. 1914: Skogsskötsel. P.A. Norstedt & Söners Förlag, Stockholm. 729 pp.

TABLES

Table 1

Overview of treatments in experiment 1422.

Treatment type	Thinning regime	Stump height
1	Unthinned control	-
2	Removal of whips and wolf trees	Low
3	Thinning for potential crop trees	Low
4	Thinning for potential crop trees	Medium
5	Thinning for potential crop trees	High

Table 2

Summary of stump measurements in treatments 3, 4 and 5. No. indicates number of observed stumps.

Treatment			Stump height (cm)			Number of shoots			Max. growth above stump (cm/yr)		
Type	Stump	No.	Mean	Min.	Max.	Mean	Min.	Max	Mean	Min.	Max.
3	Low	30	9.3	6	14	0.0	0	0	-	-	-
4	Med.	68	88.7	15[1]	128	1.7	0	6	17.1	0.0	56.5
5	High	41	231.8	121	275	2.7	0	8	46.1	0.5	125.0

[1] Except for four lower stumps, minimum stump height was 69 cm.

Table 3

Statistical testing of treatment effects on number of regrowth shoots and maximum growth of regrowth above stump height. Legend: ** indicates $0.001 < p \leq 0.01$; n.s. indicates $p > 0.05$. In the case of p-values slightly above 0.05, the test value appears in the table.

	Medium stumps (treatment 4)		High stumps (treatment 5)	
Variable	Number of shoots	Shoot growth	Number of shoots	Shoot growth
Post-treatment stem number	0.065	**	n.s.	n.s.
Number of stumps	n.s.	**	n.s.	n.s.

Table 4

Statistical testing of treatment effects on annual diameter growth, diameter at breast height, annual stand height increase and height to the live crown base. Legend: * indicates $0.01 < p \leq 0.05$; ** indicates $0.001 < p \leq 0.01$; *** indicates $p \leq 0.001$; n.s. indicates $p > 0.05$; -- indicates that this variable was not tested. In the case of p-values slightly above 0.05, the test value appears in the table.

Variable	DBH growth	DBH	Stand height increase	Height to live crown base
Pre-treatment stand height	--	n.s.	**	n.s.
DBH spring 2002 (age 13)	***	--	--	--
DBH^2 spring 2002 (age 13)	n.s.	--	--	--
DBH autumn 2003 (age 15)	--	--	--	***
Tree height a. 2003 (age 15)	--	***	--	***
Pre-treatment stem number	n.s.	**	--	n.s.
Post-treatment stem number	0.103	***	--	see main text
Treatment type	*	see main text	n.s.	0.061
Two-factor interactions[1]	n.s.	n.s.	n.s.	n.s.

[1] No specific two-factor interactions are shown as they all proved to be not significant.

Table 5
Regression estimates for treatment effects on annual diameter growth, diameter at breast height, annual stand height increase and height to the live crown base. Legend: -- indicates that this variable was not included in the final model. Adj to intcpt = treatment-specific adjustment to intercept.

Variable	DBH growth (mm)	DBH (mm)	Stand height increase (cm)	Height to live crown base (cm)
Pre-treatment stand height	--	--	-0.326	--
DBH spring 2002 (mm)	0.194	--	--	--
DBH^2 spring 2002 (mm^2)	--	--	--	--
DBH autumn 2003 (mm)	--	--	--	-4.750
Tree height autumn 2003 (cm)	--	0.134	--	1.112
Pre-treatment stem no. (10^{-4})	--	-3.479	--	--
Post-treatmen stem no. (10^{-4})	-3.300	-3.044	--	--
Intercept	1.808	-12.878	201.3	-167.7
Adj to intcpt - type 1 treatment	3.514	--	--	-6.3
Adj to intcpt - type 2 treatment	--	--	--	-8.4
Adj to intcpt - type 3 treatment	2.455	--	--	-46.5
Adj to intcpt - type 4 treatment	2.352	--	--	-54.8
Adj to intcpt - type 5 treatment	0.000	--	--	0.0