An Analysis of Successful Natural Regeneration of Downy and Silver Birch on Abandoned Farmland in Sweden

Anders Karlsson, Arne Albrektson, Anders Forsgren and Lennart Svensson

Karlsson, A., Albrektson, A., Forsgren, A. & Svensson, L. 1998. An analysis of successful natural regeneration of downy and silver birch on abandoned farmland in Sweden. Silva Fennica 32(3): 229–240.

To improve our understanding of factors influencing the success of natural regeneration with downy birch (*Betula pubescens* Ehrh.) and silver birch (*Betula pendula* Roth) on abandoned farmlands, a survey was conducted to analyse the effects of site conditions and site preparation characteristics. The study was based on a sample plot inventory conducted in one northern and one southern district of Sweden, in which 29 successfully established, naturally regenerated stands, about to be cleaned or thinned, were assessed. Radical site preparation increased stand density and uniformity of established regeneration, and gave faster initial development, than establishment without site preparation on former leys or meadows. Large proportions of the total sample area were classified as moist, and soils consisting of sand–fine sand or peat were frequent. The frequency of birch stems was highest in mesic sites, and on soils consisting of sand, sand–fine sand or peat. Distances to seed-trees were generally shorter than 80 m, and downy birch was the dominant species in most stands.

Key words afforestation, arable land, *Betula pendula*, *Betula pubescens*, site conditions, site preparation

Authors´ address Swedish University of Agricultural Sciences, Department of Silviculture, S-901 83 Umeå, Sweden **E-mail** anders.karlsson@ssko.slu.se

Accepted 30 June 1998

1. Introduction

In Sweden there is considerable interest in using hardwood species for farmland afforestation (Elfving 1986, Karlsson 1994). Hardwoods are often preferred for reasons of aesthetics and biodiversity (Gustavsson 1991), and there is increasing industrial demand for them (Ekström 1987). Downy birch (*Betula pubescens* Ehrh.) and silver birch (*Betula pendula* Roth), the two most common hardwood species in Sweden (Kempe 1991), are attractive trees for farmland afforestation. However, birch planting has often been unsuccessful because of competing ground vegetation and foraging mammals (Bäcke 1991). Successful regeneration of planted birch requires intensive protection (Johansson 1991), which can significantly reduce financial incentives. Natural regeneration and direct seeding may be feasible low-cost regeneration methods. If successful, stands generated using these methods may be dense enough to withstand damage.

Although there is some experience of natural regeneration with birch on abandoned farmland (Kalela 1961, Hytönen 1991), knowledge of factors affecting the success of such regeneration on these sites is limited (Karlsson 1994). Almost all experiments dealing with natural regeneration of birch have been carried out on derelict land, e.g. mine spoils, or on forest sites (cf. Perala and Alm 1990a, 1990b). Competition from ground vegetation has been cited as a major inhibiting factor in recommendations advising against natural regeneration of birch on abandoned fields (Bjorkbom 1969) or abandoned agricultural peatland (Kaunisto and Päivänen 1985). However, appropriate site preparation has been shown to promote birch seedling emergence (Nash et al. 1951, Karlsson 1996a) and seedling establishment on abandoned fields (Karlsson 1996b), suggesting that in suitable conditions birch can successfully compete.

The aim of this study was to analyse successfully established, naturally regenerated birch stands on abandoned farmlands. The significance of site preparation, and site conditions, on density and uniformity of established regeneration, as well as on stand development after abandonment, were investigated. Furthermore, the extent and causes of damage to the birch were also studied.

2. Materials and Methods

2.1 The Survey

The survey was conducted in two districts, one in the north of Sweden, in the vicinity of Umeå (63°50'N, 20°15'E), and the other in the south, near Växjö (56°53'N, 14°49'E). It was considered impossible to sample the whole population of abandoned farmlands randomly for three reasons. Firstly, there are no registers of abandoned farmlands in Sweden, so their full extent and location are unknown. Secondly, some sites are difficult to assess due to changes in usage, i.e. over long periods they have been successively abandoned and re-used, depending on changes in agricultural demands. Thirdly, random sampling of all farmlands would require an enormous sample to obtain a sufficient number of successfully established, naturally regenerated birch stands on abandoned farmlands, and stand history (time since abandonment and site preparation methods used) would have to be known in detail for all stands evaluated.

Thus, instead of taking a random sample from the whole population, we selected samples solely from birch stands known to have been successfully established and naturally regenerated on abandoned farmlands. This method was chosen since afforested sites on former farmlands could easily be identified, using stand registers from the General Forest Inventory (General Forest Inventory... 1983), and advice from local foresters.

As a result, only stands that fulfilled the requirements of the Swedish Forestry Act were considered. Thus, a minimum of 1000 birch stems ha^{-1} was required (Skogsvårdslagen, handbok… 1987). In addition, only stands of at least 0.1 ha, where birch accounted for at least 50 % of the standing volume, were accepted. Stand history had to be known or deducible, and stands previously cleaned or thinned were excluded. Two of the selected stands had been cleaned shortly before the survey took place, but they could be reconstructed as all stumps and stems were left. They were, therefore, included.

The survey was conducted in late summer and autumn 1991 as a sample plot inventory. Circular plots, with an area of 10 m^2 were evaluated. At each site, the first plot was randomly laid out and the other plots were then systematically aligned using a compass and a measuring-tape. Plot spacing was calculated from estimated stand area, aiming to define 25 plots per stand and marking, in practice, 22–33 plots per stand. Since the direction of the survey lines was perpendicular to the direction of open drains (where present), plot spacings of the same size as the drain spacings were avoided. Plots lying partly across open drains were reduced in size, excluding the drain and associated trees, since trees growing in open drains may differ in both age and development from trees growing on the formerly cultivated area per se.

The following variables were described at stand level: altitude, in m a.s.l.; area, in ha; maximum stand age, i.e. time since abandonment, in years; site preparation method, i.e. the last treatment or use before abandonment; and percentage of plots with no birch (percentage zero plots: pzp). Data on time since abandonment and site preparation were obtained from landowners.

At plot level, the following site variables were described according to definitions by Hägglund and Lundmark (1977): soil material type, soil texture, soil moisture, surface/subsurface water flow, and dominant height. Dominant height was estimated as the mean height (dm) of the two largest trees, measured with a telescopic rod (heights < 12 m) or a height meter (Silva Production AB, Sollentuna, Sweden), in circular plots with a radius of 10 m.

In addition, the following variables were also noted: slope (%); depth of top-soil (plough pan), in cm-classes; the total number of stems taller than 0.2 m, the number of birch stems taller than 0.2 m (counting, where possible, downy birch and silver birch separately according to morphological characteristics, cf. Fries 1964), and numbers of other hardwoods and conifers. Furthermore, the extent and cause of damage either to all birch stems ($n \leq 10$) or a random sample of them ($n > 10$) on the plot was recorded, together with degree of damage, on a scale from 0 (no damage) to 3 (dead). Damage to the birches was detailed for all stands except for the two that had been cleaned. However, damage was not noted for plots without stems, since it was considered impossible to judge whether damage had caused the absence of birch in the zero plots. Where birches, which could have acted as seed-trees at the time of regeneration, could be identified, the distance to the nearest potential seed-tree (m) was measured.

In all, 29 birch stands (15 in the north and 14 in the south) were surveyed. Stand area varied between 0.2 and 1.2 ha in the north, and between 0.1 and 1.2 ha in the south. Altitude ranged between 5 and 135 m a.s.l. in the north, and between 150 and 220 m a.s.l. in the south. In the north, 32 % of the area was on peatland, 2 % on glacial till, and 66 % on sediment. Corresponding values in the south were 32 %, 55 % and 13 %, respectively. All stands in the northern district were on level ground while a quarter of the area in the southern district was on slopes of 5–15 %. Distances to seed trees were generally not greater than 80 m in either district.

Six different types of site preparation practice, or pre-abandonment use, could be identified: 1) potato cultivation; 2) ley (meadow), i.e. no site preparation; 3) stubble-field; 4) ploughed ley or field; 5) removal of top-soil; 6) ploughed and harrowed stubble-field. Types 1–5 were found in the north, while types 2–6 were found in the south. Three sites in the south, two on former leys and one on a ploughed field, had been grazed temporarily by cattle after abandonment. In four stands in the south, two on former leys and two on ploughed fields, the dominant height could not be estimated due to damage to the trees.

2.2 Calculations

Analyses were focused on identifying correlations between site characteristics, site preparation, and degree of establishment success. The distribution of the total area was calculated with regard to classes of different site factors and methods (types) of site preparation. For different methods of site preparation, the distribution of different classes of site factors was also calculated. In these calculations, all sample plots were given equal weight.

The number of trees, and frequency of zero plots, were also calculated with regard to classes of different site factors and methods of site preparation, while maximum stand age and dominant height of the trees were calculated only for the various methods of site preparation. To avoid bias due to reductions in plot size (where applicable), the mean number of stems ha^{-1} (N) for each stand was calculated so:

$$\mathrm{N} = \frac{\left(\sum \text{no. of stems on the plot}\right)}{\left(\sum \text{invented area of the plot}\right)} \qquad (1)$$

When means and standard errors (SE), for the numbers of birch stems ha^{-1}, for example, were computed for different classes of site factors, each district was considered to be a single area, and the rules for a ratio estimate (Raj 1968) were used in the calculations. For depth of top-soil, a median class was calculated for each stand. Two-sample t-tests were used to compare stands established without site preparation (i.e. stands established on former leys) with stands established after site preparation. The analysis was carried out with the SAS procedure TTEST (SAS 1988). When t-tests were performed, the folded F-statistic, F', was used to test the assumptions that the variances were equal:

$$F' = \frac{\left(\text{larger of } s_1^2,\ s_2^2\right)}{\left(\text{smaller of } s_1^2,\ s_2^2\right)} \qquad (2)$$

When the p-value for this test was greater than 0.10, the standard two-sample t-test was used, otherwise the approximate t-statistic with the Cochran and Cox (1957) approximation for the probability level was used.

3. Results

3.1 Site Conditions

On mineral soil, soil textures were dominated by sand–fine sand or sandy till while finer textures were rare (Table 1). Soil moisture was mostly classified as moist, with mesic sites not uncommon. A few sites were dry or slightly waterlogged (Table 1). Surface/subsurface water flow was found only in the southern district, where it occurred during brief intervals on 21 % of the area, and for longer periods on 13 % of the area.

3.2 Birch Species and Density of Birch Stems

In 25 of the stands, downy birch and silver birch could be distinguished. Downy birch was the dominant (≥ 70 % of number of birch stems) birch species in most stands. In the north, 92 % of the birches were downy birch, and in the south the corresponding value was 84 %. Silver birch was frequent (>30 % of number of birch stems) only in three stands, two in the south and one in the north. Two of these three stands grew on mesic sites, while the third stand grew on a moist site, but at all three sites the soil was dominated by sand–fine sand. In the following section, the two birch species are not separately considered.

There were more birch stems on sites where site preparation had been carried out than on former leys (p = 0.084, in the north; p = 0.016, in the south) (Fig.1). The total number of stems

Table 1. Distribution (%) of the total sample area, in the two districts, with regard to classes of different site factors (soil type and soil moisture, according to definitions of Hägglund and Lundmark 1977), and methods of site preparation (types of site preparation practice) found.

Soil type and soil moisture	Umeå (63°50'N, 20°15'E) Soil preparation[a]						Växjö (56°53'N, 14°49'E) Soil preparation[a]					
	PO	L	S	PL	RT	Total area	L	S	PL	RT	PH	Total area
Sand	12	–	–	–	1	2	16	4	10	–	–	8
Sand-fine sand	6	17	15	33	37	26	17	51	54	12	25	35
Sand-fine sand	70	32	–	58	28	38	25	13	3	88	21	20
Silt-clay	12	1	–	1	–	2	16	–	–	–	–	5
Peat	–	50	85	8	34	32	26	32	33	–	54	32
Dry	2	–	–	13	–	4	–	–	–	–	–	–
Mesic	94	29	46	23	9	34	19	63	30	88	48	40
Moist	4	68	54	64	72	57	79	31	70	12	52	58
Slightly water-logged	–	3	–	–	19	5	2	6	–	–	–	2
Total area	13	20	13	28	26	100	30	21	26	7	16	100

[a] PO = potato-field; L = ley; S = stubble-field; PL = ploughed ley or field; RT = removal of top-soil; PH = ploughed and harrowed field.

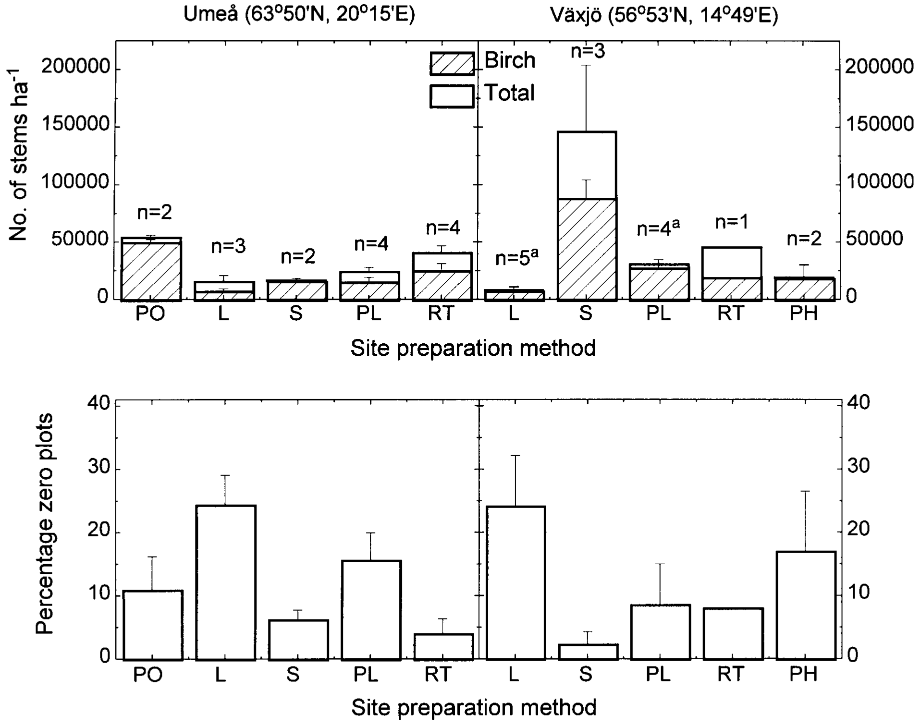

Fig. 1. Mean (+SE) for density of birch (*Betula pubescens* and *B. pendula*) stems ha^{-1}, density of stems of all species ha^{-1}, and percentage of zero plots for the stands, associated with different methods of site preparation (PO = potato-field; L = ley; S = stubble-field; PL = ploughed ley or field; RT = removal of top-soil; PH = ploughed and harrowed field). n = no. of stands.

[a] = one stand was treated as two different stands due to differences in site preparation.

was also higher on sites where site preparation had been carried out (p = 0.088, in the north; p = 0.055, in the south). In the north, the highest densities of birch stems were found on former potato-fields while former stubble-fields carried the highest densities in the south (Fig. 1). The other tree species found were mainly other hardwoods, not separated by species. In half of the stands there were also conifers, especially Norway spruce (*Picea abies* (L.) Karst.).

The frequency of plots at which birch establishment completely failed, was assessed by calculating pzp-values (percentage zero plots). On former leys, the frequency of plots without birch stems was higher than on sites where site preparation had been carried out (p = 0.018, in the north; p = 0.070, in the south) (Fig. 1). The lowest pzp-values were found after removal of top-soil in the north, and on former stubble-fields in the south.

Mesic sites carried the highest densities of birch stems (Fig. 2). In the south, pzp-values were high (29 %) on slightly waterlogged sites, intermediate on mesic sites (17 %) and low on moist sites (12 %). In the north, the highest pzp-values (43 %) were found on dry sites. On other types of site, pzp-values varied between 5 % (on slightly waterlogged sites) and 13 % (mesic sites).

Plots on silty mineral soil generally carried low densities of birch stems while plots on sand or sand–fine sand in the north, and plots on sand–fine sand in the south, were much better stocked (Fig. 2). The highest pzp-values (29 % in the south and 33 % in the north) were found on silty soil while the pzp-values on other soils ranged from 10 % to 18 %.

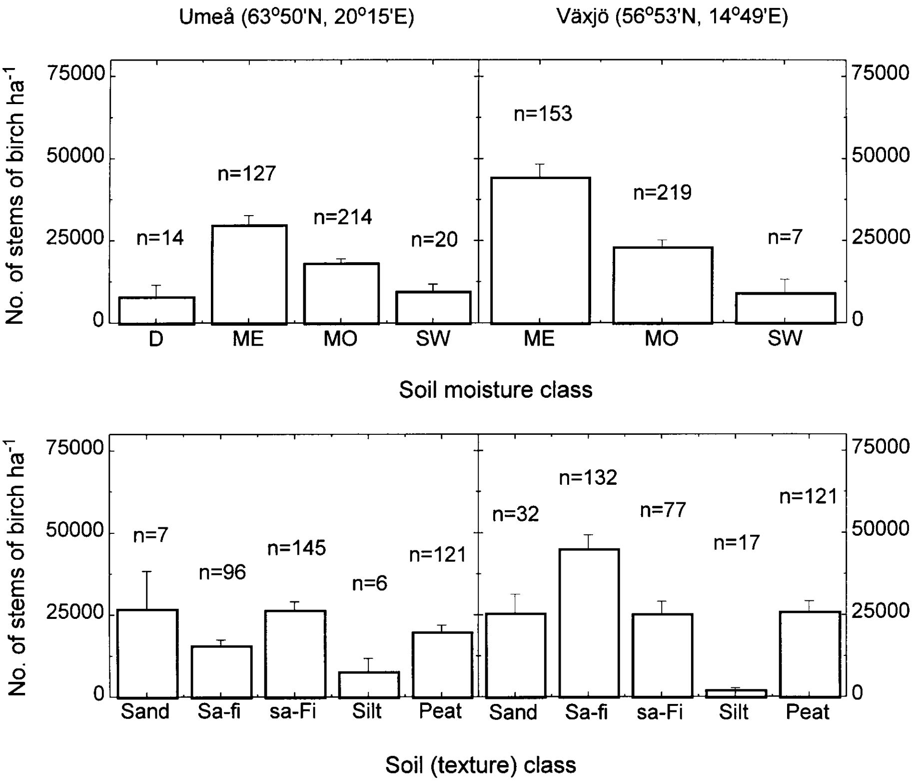

Fig. 2. Mean (+SE) for density of birch (*Betula pubescens* and *B. pendula*) stems ha^{-1} for all sample plots associated with different classes of soil moisture (first row), and types of soil (second row), soil moisture and texture were classified according to definitions of Hägglund and Lundmark (1977). The following abbreviations are used: dry (D), mesic (ME), moist (MO), slightly waterlogged (SW), sand–fine sand (Sa–fi), sand–fine sand (sa–Fi), no. of plots (n).

3.3 Maximum Stand Age and Dominant Height

Stands established without site preparation, i.e. on leys, showed higher maximum stand age than stands established after site preparation. The effect of site preparation was strong in the south ($p < 0.001$), but weaker in the north ($p = 0.099$). The highest maximum stand age in the south was found on leys, while leys and stubble-fields gave the highest maximum stand age in the north (Fig. 3). There was no effect of site preparation on dominant height in the north ($p = 0.512$) while there was a weak effect in the south ($p = 0.089$).

3.4 Damage

In the south, 45 % of the stocked plots were free from damage, 30 % were slightly damaged and 25 % were seriously damaged. Corresponding values in the north were 62 %, 34 % and 4 %, respectively. A few stems had been lethally damaged, but none of the stocked plots was ruined by damage. Damage in the south was mainly caused by browsing mammals, especially moose (*Alces alces* (L.)) and, to a lesser extent, roe deer (*Capreolus capreolus* (L.)). There were also many forked stems, indicating previous damage. In the north, damage was mainly caused by browsing moose and bark-eating voles, probably field voles (*Microtus agrestis* (L.)).

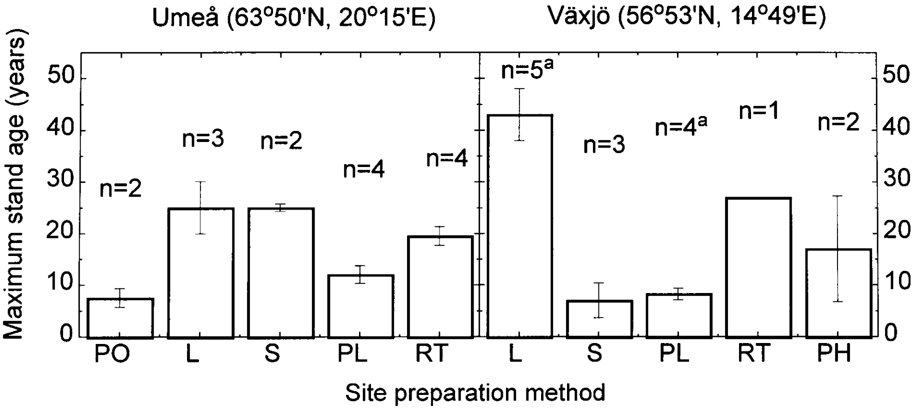

Fig. 3. Mean (±SE) of maximum stand age of birch (*Betula pubescens* and *B. pendula*) for the stands, associated with different methods of site preparation (PO = potato-field; L = ley; S = stubble-field; PL = ploughed ley or field; RT = removal of top-soil; PH = ploughed and harrowed field). n = no. of stands.

[a] = one stand was treated as two different stands due to differences in site preparation.

4. Discussion

4.1 Effects of Stand Selection

The restrictions for stand selection define a population that is not representative of all abandoned farmland in Sweden. For many reasons, it is impossible to perform an unbiased sampling of the whole population. In addition, the degree of success probably also depends on time since abandonment. However, it is possible to draw several general conclusions from the selected population. In our study, there are two variables indicating the degree of establishment success, or establishment quality: number of stems ha^{-1}, and pzp-values. The effects of site preparation on stand development, expressed as dominant height in relation to maximum stand age, also give an indication of the degree of success associated with pre-abandonment practices.

4.2 Site Preparation

In this study, most stands were established after site preparation. However, according to agricultural staff at the county administrative boards (personal communications with S. Lindegard, S-901 86 Umeå, and A. Fransson, Kungsgatan 8, S-351 86 Växjö), almost all (≥ 90 %) sites that are abandoned are leys. The derived relationships between radical site preparation, and both the highest stand densities and lowest pzp-values were significant and positive (Fig. 1; cf. Karlsson 1994). This is in accordance with reports showing that seed germination and seedling establishment are highest on disturbed ground (Kalela 1961, Miles 1973, Raulo and Mälkönen 1976, Karlsson 1996a, 1996b).

The best-stocked sites were found on former potato fields in the north, and on former stubble-fields in the south (Fig. 1). Potatoes and corn require radical site preparation and may also temporarily reduce competing vegetation. Competing vegetation may have been additionally checked by weed-control, most likely carried out when the crops were grown. In autumn, when birches disperse the bulk of their seed (Fries 1984), crops are harvested. The ground is disturbed and the top-soil is exposed after harvesting potatoes. In stubble-fields the top-soil is partly exposed and the stubble provides shade which, according to American studies (Marquis et al. 1964, Horsley and Abbott 1970), promotes seedling emergence.

Large numbers of stems and low pzp-values were obtained after removal of top-soil (Fig. 1). This practice suppresses ground vegetation for many years (Karlsson 1996b) since seeds and vegetative reproductive organs are removed together with the top-soil. Thus, removal has long-term effects that may promote germination and seedling establishment over several years. However, dominant height seems to be negatively correlated with complete removal of top-soil (Fig. 4). A certain minimal amount of top-soil, probably needs to be retained in the soil profile to obtain good dominant height development (Karlsson 1996b). According to Marquis et al. (1964) and Perala and Alm (1989), in studies of paper birch (*Betula papyrifera* Marsh.), organic matter in the seedbed is important for seedling growth. Removal of top-soil also increases the risk of frost heaving (Karlsson 1996b).

Although some stands were established on leys, they often carried few stems, and had high pzp-values and high maximum stand ages (Fig. 1, Fig. 3). This indicates slow and successive colonisation by birch. The low stand densities in these stands may partly be due to high maximum stand age, probably combined with natural thinning (cf. Kinnaird 1974). Competition from ground vegetation is a major problem in seedling establishment on abandoned farmland (cf. Ferm et al. 1994, Karlsson 1996b). However, both radical soil preparation (Karlsson 1996a, 1996b), and use of herbicides (Ferm et al. 1994), offer possibilities of suppressing ground vegetation during the first growing seasons.

Two stands on former leys in the southern district were established during years when cattle grazed the sites. Birches may be successful colonisers of fallow pastures (Blazkova 1988). According to Miles and Kinnaird (1979), grazing by large herbivores may provide favourable conditions for seed germination by keeping vegetation short, by exposing soil through uprooting plants while feeding, and by trampling. However, grazing of seedlings may prevent regeneration (Atkinson 1992).

4.3 Maximum Stand Age and Dominant Height

Maximum stand age was used as an indication of true age due to difficulties in assessing the latter. Age calculation based on ring count at stump height results in an underestimate since growth in height may be slow during the first growing seasons after germination. Both abiotic factors (e.g. frost heaving) and biotic factors (e.g. browsing mammals) may keep the seedlings short for many years (cf. Kinnaird 1974, Karlsson 1994). Some annual growth rings may also be absent in the lower part of the stem (Takaoka 1993).

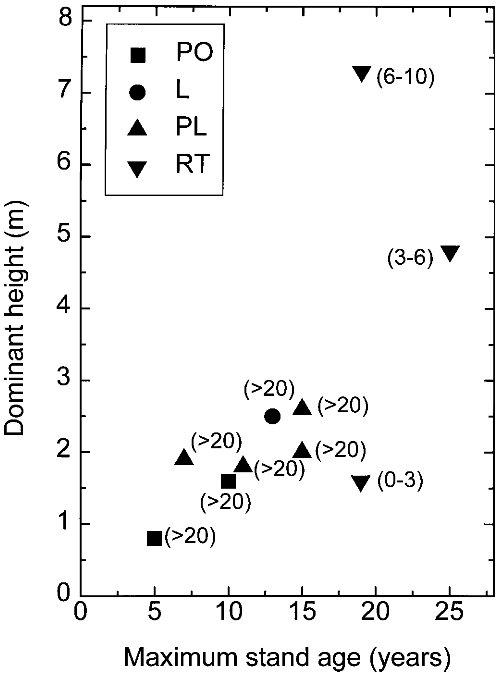

Fig. 4. Dominant height versus maximum stand age for birch stands established after different site preparation methods on mineral soil in the vicinity of Umeå (63°50'N, 20°15'E). Figures within parentheses show the (remaining) depth of top-soil in cm. The following abbreviations are used: potato-field (PO), ley (L), ploughed ley or field (PL) and removal of top-soil (RT).

Dominant height can also reflect stand age. Stands on former leys gave the highest maximum stand age values (Fig. 3), but they did not have significantly higher dominant heights. This may indicate successive colonisation by birch on former leys, leading to varying periods of "failure" until stand establishment. Alternatively, birch dominant height development may be slower on former leys than on appropriately prepared sites.

4.4 Site Conditions

Mesic and, especially, moist sites occupied large proportions of the total area in this study. Moist sites also gave low pzp-values while the highest pzp-values were observed at dry sites. Reliable and adequate soil moisture is crucial during seedling emergence (Mork 1944, Palo 1986). In this study, leys were mostly classified as moist (Table 2). The only stand that was established on ley on a mesic site had been grazed during seedling establishment. These results support the findings of Sarvas (1948) that moist or wet soils are prerequisites for successful seedling establishment on untreated ground. However, while soil preparation improves seedling establishment on moist sites, it also increases the risk of frost heaving (Pohtila 1977, Karlsson 1996b). On mesic sites, soil preparation is necessary (Sarvas 1948, Fries 1984), as it seems to improve soil moisture conditions (cf. Örlander et al. 1991). The highest densities of birch stems in this study were found on mesic sites (Fig. 2), established after soil preparation (Fig. 1).

Peat, sand–fine sand and sand–fine sand occupied large proportions of the total area in this study. Stands on these soils, and those on sand, were also well stocked with relatively low pzp-values. According to Palo (1986), these soils are favourable germination substrates if soil moisture is adequate, while more fine-grained soil textures such as silt and clay seem to be difficult media for rootlets to penetrate. In this study, regenerated plots on silty soil were also found to be poorly stocked and to have high pzp-values. Silty soils are also very susceptible to frost heaving (Penner 1957). There are some indications that coarser soil textures provide better conditions for seedling establishment (Palo 1986, Karlsson 1994).

Distances to seed trees were mostly short. Many sites probably received a high and uniform seedfall since quantity of seed dispersal is usually limited to a distance of about twice the height of the seed-producing trees (Heikinheimo 1944, cited in Sarvas 1948; Sarvas 1948).

4.5 Birch Species

In four stands, including the two that had been cleaned, downy birch and silver birch could not be distinguished. According to Lundgren et al. (1995), it may be difficult to distinguish between the two species, especially in mixed stands. However, according to morphological characterization, most of the stands included in this study were totally dominated by downy birch. The proportion of silver birch was unexpectedly low in the south (cf. Kempe 1991).

4.6 Damage

Moose were found to be an important cause of damage, in accordance with the findings of the Swedish young stand survey (Näslund 1986). In Sweden, moose feed to a large extent on birches and prefer silver birch to downy birch (Danell et al. 1985), which might have affected the proportions of downy birch and silver birch found in this study. In southern Sweden, roe deer also cause significant damage (Bäcke 1991). Voles may cause severe damage on former fields (Bärring 1967, Karlsson 1996b) but damage by voles is reduced if ground vegetation is removed (Bärring 1967, Karlsson 1996b) or checked (Ferm et al. 1994). Forked stems may be caused by abiotic factors, e.g. frost (cf. Langhammer 1982, Karlsson 1996b), or biotic factors such as grazing cattle and foraging wild mammals (cf. Kinnaird, 1974). The higher proportion of seriously damaged plots in the southern district is probably due to a higher pressure of browsing there than in the north.

4.7 Conclusions

This study shows that radical site preparation is important for obtaining uniformly well-stocked stands of birch. If seedfall occurs simultaneously with the last agricultural harvest, ground conditions may be favourable even without further soil preparation. Stands can also be established without preceding soil preparation, but by comparison these stands carry fewer birch stems, are less uniformly stocked, and require longer periods to be established. Further studies are needed on the effects of different site factors, e.g. different soil textures, on seedling emergence and establishment. In addition, soil preparation effects of cattle grazing on the sites, and changes in different seedbeds over time need further study.

Acknowledgements

This work was financed mainly by “Forskningsprogram Privatskogsbruk”. Grants from Södra Skogsägarna, Economic Association, financed field work in the southern district. We thank Dr. Tord Johansson, Dr. Lars Lundqvist, Dr. Olov Norgren, Prof. Per-Christer Odén and two anonymous reviewers for valuable comments on the manuscript, and the staff at the Regional Forestry Boards who helped us to find the stands. We are also grateful to Sören Holm for statistical advice and to Dr. John Blackwell for revising the English.

References

Atkinson, M.D. 1992. Biological flora of the British Isles: Betula pendula Roth (B. verrucosa Ehrh.) and Betula pubescens Ehrh. Journal of Ecology 80: 837–870.

Bäcke, J.O. 1991. Preliminära delresultat från Lövinventering 90. Skogsstyrelsen, Skogsvårdsenheten, Skogsvård 1/91, 4 p. Jönköping, Sweden. (In Swedish.)

Bärring, U. 1967. Studies of methods employed in the planting of Picea abies (L.) H. Karst. and Pinus silvestris L. on farm land in southern and central Sweden. Studia Forestalia Suecica 50. 332 p. (In Swedish with English summary.)

Bjorkbom, J.C. 1969. Seeding and planting birch. In: Larson, E. vH. (Editor), Proc. Birch Symp. Univ. of New Hampshire Durham NH 19–21 August 1969. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA. p. 79–82.

Blazkova, D. 1988. Succession on Nardus pastures in eastern Slovakia with invasion by woody plants. Preslia, 60(2): 127–132. (In Czech with English summary.)

Cochran, W.G. & Cox, G.M. 1957. Experimental designs. Second edition. John Wiley & Sons, Inc. New York. 611 p.

Danell, K., Huss-Danell, K. & Bergström, R. 1985. Interactions between browsing moose and two species of birch in Sweden. Ecology 66(6): 1867–1878.

Elfving, B. 1986. The value of growing birch, aspen and alder on abandoned fields in southern Sweden. Sveriges Skogsvårdsförbunds Tidskrift 5: 31–41. (In Swedish with English summary.)

Ekström, H. 1987. Hardwood. Supplies and industrial utilization. Swedish University of Agricultural Sciences, Department of Forest Products, Report 197. 123 p. ISSN 0348-4599. (In Swedish with English summary.)

Ferm, A., Hytönen, J., Lilja, S. & Jylhä, P. 1994. Effects of weed control on the early growth of Betula pendula seedlings established on an agricultural field. Scandinavian Journal of Forest Research 9: 347–359.

Fries, C. 1984. Den fråsådda björkens invandring på hygget. Sveriges Skogsvårdsförbunds Tidskrift 82 (3/4): 35–49. (In Swedish.)

Fries, J. 1964. Yield of Betula verrucosa Ehrh. in middle Sweden and southern north Sweden. Studia Forestalia Suecica 14. 303 p. (In Swedish with English summary.)

General Forest Inventory. Programme. 1983. 28 p. National Board of Forestry 1981. Revised 1983. Jönköping, Sweden.

Gustavsson, R. 1991. Lövträds inverkan på landskapsbilden. In: Lestander, T. (Editor), Björk och asp. Skogsfakta konferens 15: 107–109. Sveriges Lantbruksuniversitet. Uppsala. ISSN 0282-7360. (In Swedish.)

Hägglund, B. & Lundmark, J-E. 1977. Site index estimation by means of site properties. Scots pine and Norway spruce in Sweden. Studia Forestalia Suecica 138. 38 p.

Heikinheimo, O. 1944. Metsien luontainen uudistaminen. Toinen painos. Keskusmetsäseura Tapion käsikirjasia 22. Helsinki, Finland. 96 p. (In Finnish, cited in Sarvas 1948.)

Horsley, S.B. & Abbott, H.G. 1970. Direct seeding of paper birch in strip clearcutting. Journal of Forestry 68: 635–638.

Hytönen, J. 1991. Field afforestation in central Ostrobothnia, western Finland. In: Ferm, A. & Polet, K. (Eds.), Developing methods for afforestation of fields – Interim report. The Finnish forest research institute, Kannus. p. 22–28. ISBN 951-40-1175-9. (In Finnish with English abstract.)

Johansson, T. 1991. Beståndsanläggning av asp och björk. In: Lestander, T. (Editor), Björk och asp. Skogsfakta konferens 15: 67–72. Sveriges Lantbruksuniversitet, Uppsala. ISSN 0282-7360. (In Swedish.)

Kalela, E.K. 1961. Über die natürliche Bewaldung der Kulturböden im sog. Porkkala-Pachtgebiet. Acta Forestalia Fennica 74(2). 83 p.

Karlsson, A. 1994. Farmland afforestation by natural regeneration and direct seeding of hairy birch and silver birch. Dissertation. Swedish University of Agricultural Sciences, Department of Silviculture. Umeå, Sweden, 29 p. + papers. ISBN 91-576-4843-3.

— 1996a. Initial seedling emergence of hairy birch and silver birch on abandoned fields following different site preparation regimes. New Forests 11: 93–123.

— 1996b. Site preparation of abandoned fields and early establishment of naturally and direct-seeded birch in Sweden. Studia Forestalia Suecica 199. 25 p.

Kaunisto, S. & Päivänen, J. 1985. Forest regeneration and afforestation on drained peatlands. A literature review. Folia Forestalia 625. 75 p. (In Finnish with English summary.)

Kempe, G. 1991. Omfattningen av lövträd i Sverige. In: Lestander, T. (Editor), Björk och asp. Skogsfakta konferens 15: 60–66. Sveriges Lantbruksuniversitet, Uppsala. ISSN 0282-7360. (In Swedish.)

Kinnaird, J.W. 1974. Effect of site conditions on the regeneration of birch (Betula pendula Roth and B. pubescens Ehrh.). Journal of Ecology 62: 467–472.

Langhammer, A. 1982. Growth studies on silver birch (Betula verrucosa Ehrh.) in Norway. Meldinger fra Norges Landbrukshøgskole 61(23). 43 p. ISSN 0025-8946. (In Norwegian with English summary.)

Lundgren, L.N., Pan, H., Theander, O., Eriksson, H., Johansson, U. & Svenningsson, M. 1995. Development of a new chemical method for distinguishing between Betula pendula and Betula pubescens in Sweden. Canadian Journal of Forest Research 25: 1097–1102.

Marquis, D.A., Bjorkbom, J.C. & Yelenosky, G. 1964. Effect of seedbed condition and light exposure on paper birch regeneration. Journal of Forestry 62: 876–881.

Miles, J. 1973. Early mortality and survival of self-sown seedlings in Glenfeshie, Inverness-shire. Journal of Ecology 61: 93–98.

— & Kinnaird, J.W. 1979. The establishment and regeneration of birch, juniper and Scots pine in the Scottish Highlands. Scottish Forestry 33: 102–119.

Mork, E. 1944. Om bjørkefruktens bygning, modning og spirning. Meddelelser fra det Norske Skogsforsøksvesen 30: 423–471. (In Norwegian.)

Nash, R.W., Duda, E.J. & Gray, N.H. 1951. Studies on extensive dying, regeneration and management of birch. Maine Forest Service, Bulletin 15. 82 p. Augusta, Maine.

Näslund, B-Å. 1986. Simulation of damage and mortality in young stands and associated stand development effects. Sveriges Lantbruksuniversitet, Institutionen för Skogsskötsel. Rapport 18. 147 p. ISSN 0348-8969. (In Swedish with English summary.)

Örlander, G., Gemmel, P. & Hunt, J. 1990. Site preparation: A Swedish overview. B. C. Ministry of Forests. FRDA Report 105. 62 p. ISSN 0835-0752.

Palo, I. 1986. Vårtbjörkens fröspridning, frögroning och plantetablering. Sveriges Skogsvårdsförbunds Tidskrift 5: 21–27. (In Swedish.)

Penner, E. 1957. The nature of frost action. p. 234–243. In: Proc. Convention of the Canadian Good Road Association, Canada.

Perala, D.A. & Alm, A.A. 1989. Regenerating paper birch in the Lakes States with the shelterwood method. Northern Journal of Applied Forestry 6: 151–153.

— & Alm, A.A. 1990a. Reproductive ecology of birch: a review. Forest Ecology and Management 32: 1–38.

— & Alm, A.A. 1990b. Regeneration silviculture of birch: a review. Forest Ecology and Management 32: 39–77.

Pohtila, E. 1977. Reforestation of ploughed sites in Finnish Lapland. Communicationes Instituti Forestalis Fenniae 91(4). 98 p.

Raj, D. 1968. Sampling theory. Mcgraw-Hill, Inc., New York. 302 p.

Raulo, J. & Mälkönen, E. 1976. Natural regeneration of birch (Betula verrucosa Ehrh. and B. pubescens Ehrh.) on tilled mineral soil. Folia Forestalia 252. 15 p. (In Finnish with English summary.)

Sarvas, R. 1948. A research on the regeneration of birch in south Finland. Communicationes Instituti Forestalis Fenniae 35(4). 91 p. (In Finnish with English summary.)

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. Cary, NC: SAS Institute Inc. 1028 p. ISBN 1-55544-088-6.

Skogsvårdslagen, handbok. 1987. Skogsstyrelsen, Jönköping, Sweden. (In Swedish.)

Takaoka, S. 1993. The effect of missing rings on stand-age estimation of even-aged forests in northern Hokkaido, Japan. Ecological research 8: 341–347.

Total of 47 references