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Time Consumption of Planting after Partial Harvests

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Partial harvesting combined with underplanting may be a means to reduce the risk of regeneration failure when e.g. unfavourable microclimatic conditions or severe damage by bark-feeding insects may be expected after clear-cutting, and to maintain or establish certain stand structures or tree species mixture. In this study, we performed time studies of manual planting with and without prior site preparation (patch scarification, inverting) in partially harvested stands of Norway spruce (*Picea abies* (L.) Karst.). The harvest treatments included basal area removals of approx. 35, 45, and 55%, and a patch clear-cut treatment that was assumed to provide the same conditions for planting as conventional clear-cutting. Site preparation had a much larger influence on time consumption plant^{-1} (main time) than the harvest treatment. The lowest time consumption was found with inverting and the highest without site preparation. The time spent on walking between planting spots increased with decreasing harvest intensity, reflecting a lower density of planted seedlings in the partially harvested stands. A corresponding increase in main time per plant only occurred after site preparation, since the time spent on clearing the planting spot (removal of logging residue and humus) on untreated plots was higher at the higher harvest strengths. The variation in time consumption attributed to the six replicate stands was large and mainly due to the difference among stands planted by different workers.

Keywords mechanical site preparation, partial cutting, planting, scarification, work study
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1 Introduction

In Norway, clear-cutting and planting has been and still is the predominant way of regenerating Norway spruce (*Picea abies* (L.) Karst.) stands. However, during the entire period since the introduction of even-aged management around World War II, the use of partial harvesting methods has remained important in mountain forests, typically in the form of heavy selection cuttings (Nilsen 1988). This practice has primarily been motivated by the need to improve the conditions for regeneration establishment in a difficult climate. While natural regeneration is often aimed at in these low-productive forests, regeneration failure is not uncommon due to the generally poor conditions for seed ripening, germination and seedling establishment. Securing adequate recruitment by underplanting is a possible alternative, which has yielded good results from a production point of view under similar conditions in Sweden (Elfving 1990). Underplanting could also be a means to mitigate regeneration problems in more productive forests, for example when the risk of severe vegetation competition, waterlogging, or frost during the growing season, is unacceptably high (Groot and Carlsson 1996, Holgèn and Hånell 2000, Langvall and Örlander 2001). Combining partial cutting with underplanting could also be used to enhance tree species mixture (Freij 1990, Nilsson et al. 2006), or to maintain a continuous forest cover when this is an important management goal. Planting under the cover of residual trees also reduces damage to planted seedlings by the large pine weevil (*Hylobius abietis* L.) (von Sydow and Örlander 1994), and damage is further reduced if the stand is scarified (Pettersson and Örlander 2003).

In order to assess the economical outcome of different regeneration strategies, information on the biological effects as well as the associated costs are needed. While the biological results of underplanting in partially harvested spruce stands have been the subject of several studies from a broad range of forest conditions (Skoklefald 1989, Elfving 1990, Holgèn and Hånell 2000, Granhus et al. 2003), the time consumption of such treatment has, to our knowledge, not earlier been compared with that of conventional planting on clear-cuts. In contrast, there are numerous reports from planting on clear-cuts, in which the influence of site preparation, different planting tools and stock types, terrain difficulties and logging debris has been addressed and quantified (Callin 1971, Been 1972, Strømnes 1972, 1981, 1986, Hakkila 1973, Friberg 1975, Appelroth 1982, Häggblom and Kaila 1982). Although much of the knowledge gained from earlier studies can be extended to planting in partially harvested stands, some characteristic conditions call for further investigation. For example, fewer plants may be required for adequate stocking if partial harvesting makes it easier to take advantage of advance regeneration, due to lower mortality and damage rates during and after harvest (Alekseev 1973, Örlander and Karlsson 2000). Furthermore, with otherwise equal criteria for plant spacing, the growing space occupied by the residual trees could reduce the density of potential regeneration spots per area unit (Elfving 1990). The scattering of work associated with a reduction in the density of outplanted seedlings should in turn increase the time consumption plant^{-1}. In contrast, the lower amount of slash produced after partial harvests could make planting less time consuming (Hakkila 1973) and thus have the opposite effect.

There have been two types of forest work study traditions in the Nordic countries: comparison studies and correlation studies. In the comparative time study the researcher seeks the difference between various working methods under so equal working conditions as possible. In the correlation time study the intention is to find out how the time consumption varies, and the researcher studies the working method under so different working conditions as possible (Samset 1992). Normally the comparison time study takes a very short period of time to ensure equal conditions (climatic and otherwise). The relationship between effective, work place or total work time (NSR 1978) must be taken from other studies which have gone over longer periods of time. Correlation time studies normally go over a longer period and may be used to calculate both effective and work place time.

The goal of this study was to assess the time consumption of planting with and without prior site preparation after partial harvesting. This was accomplished by comparative time studies in six replicates of an experimental series that combine different basal area removal treatments, with three site preparation alternatives (untreated control, patch scarification, inverting). In connection with the study, we also assessed how the technical feasibility of the different site preparation treatments was affected by the stand-level treatments, by comparing the number of planting spots ha^{-1} that could be established.

2 Materials and Methods

2.1 Study Sites and Silvicultural Treatments

The study was conducted in six replicates of an experimental series located in uneven-sized Norway spruce stands in the counties of Hedmark (four replications) and Oppland (two replications) in southeast Norway. In each replicate stand, three uniform partial harvest treatments (UPC) with removals corresponding to approximately 35, 45, and 55% of pre-harvest basal area, were established in plots sized 0.216 ha (Fig. 1). These treatments are hereafter abbreviated as BA_{35}, BA_{45} and BA_{55}, respectively. Each UPC plot was split into six subplots sized 12×30 m (0.036 ha), in which three site preparation alternatives were applied: no site preparation, patch scarification and inverting. Of the two subplots assigned to each site preparation method within each UPC unit, one was planted whereas the other was left to regenerate by natural regeneration or sowing (see Granhus 2003 for further details). In this study, only planted subplots were used. Post-harvest stand data for the UPC plots are given in Table 1.

To emulate the conditions for planting on conventional clear-cuts, three additional plots sized 25×25 m, were subjected to 100% removal (BA_{100}; Fig. 1). These patch clear-cuts were treated with the same site preparation alterna-

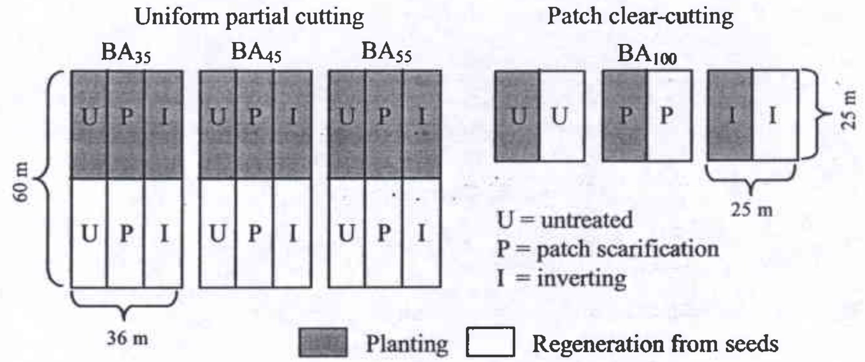

Fig. 1. Design of one replication of the experimental stands. Only planted subplots (shaded) were used in the present study.

Table 1. Post-harvest stand characteristics of the uniform partial harvest treatments for the replicate stands in Hedmark and Oppland, with minimum and maximum (range) in parentheses.

Harvest treatment	Hedmark (n = 4) Stem density[1)] >49 mm dbh (n ha^{-1})	Hedmark Stem density[1)] <50 mm dbh (n ha^{-1})	Hedmark Basal area (m^2 ha^{-1})	Oppland (n = 2) Stem density[1)] >49 mm dbh (n ha^{-1})	Oppland Stem density[1)] <50 mm dbh (n ha^{-1})	Oppland Basal area (m^2 ha^{-1})
BA_{35}	910 (860–1090)	870 (680–1290)	20 (12–24)	1220 (850–1560)	2760 (2240–3280)	20 (12–24)
BA_{45}	1020 (880–1150)	1000 (490–1950)	18 (13–21)	1000 (590–1420)	2280 (1810–2760)	18 (13–21)
BA_{55}	910 (760–1010)	1010 (240–1520)	13 (10–16)	970 (860–1090)	2270 (1960–2570)	13 (10–16)

[1)] The <50 mm dbh group represents saplings with height greater than 0.5 m and dbh less than 50 mm

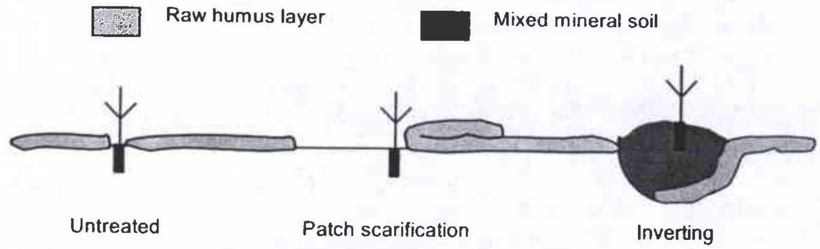

Fig. 2. Site preparation treatments and associated planting patterns.

tives as the UPC plots, with one site preparation alternative per plot. Subsequently, one half of each plot was planted while the other half was regenerated from seeds.

Trees to be felled within the UPC plots were selected primarily among the largest stems and trees of poor quality or vigour (high thinning). Harvesting took place in the winter of 1993–94, using the cut to length system with single-grip harvesters and forwarders at the four replicates in Hedmark County, and motor-manual felling and cable skidding in the two stand replicates in Oppland County. A striproad spacing of 24 m was used in the UPC plots. Site preparation was done the first autumn after harvest, using an excavator (Hymax 840) with a boom reach of 7.2 m and the same operator in all six stands. The excavator utilized the previously established striproads, and, when possible, the operator drove in between the residual trees to reach the area of the midzone that could not be scarified from the striproad. The instruction was to avoid site preparation within a distance less than 1–1.5 m to advance regeneration and 2–2.5 m to larger trees. In the patch clear-cuts, and in larger gaps in the UPC plots, a spacing of 2×2 m was aimed at, with preference for optimal regeneration spots rather than a regular spacing. The same instructions were applied for choosing regeneration spots when planting without prior site preparation.

All replicates were located on glacial till soils with a moderate stone content. Depth of the organic (LFH) layers typically varied from 3 to 10 cm. Surface structure and inclination correspond to surface evenness classes 1 to 2 and ground slope classes 1 to 3, respectively, according to the Skogsarbeten terrain classification system (Terrängtypsschema...1991). With this system, class 1 represents very easy conditions and class 5 very difficult conditions.

Planting took place in spring 1995; with two-year-old containerised seedlings of type M95 (root plug volume approx. 50 cm^3, mean plant height 18–20 cm). The planting was done by two professional forestry workers, both males. Worker 1 (Hedmark) was 25 years old, and had seven years of planting experience at an average of about two months per year. Worker 2 (Oppland) was 52 years old, and had been planting about one month per year over the last 20 years. Both used a Sandvik planting pipe (Strømnes 1986), and the plants were carried in a standard planting belt. On the plots without prior site preparation, hereafter referred to as "untreated", a small patch of the ground vegetation and humus layer was removed with the foot pedal of the planting pipe before the planting hole was created. This slight manual site preparation was done to secure proper contact between the root plug and the mineral soil (Fig. 2). In the patch scarified plots the seedling was usually planted in the mineral soil adjacent to the inverted humus turf. With inverting, the plant was put into the centre of the mineral soil spot, which formed a slightly elevated mound at the time of planting, which protruded up to 10 cm above ground level. The area of exposed mineral soil was about 0.3 m^2 for both the patch scarified and inverted spots (Granhus et al. 2003).

2.2 Time Studies

We used the comparison study approach to assess the effect of the treatments on time consumption. The time studies were restricted to main time as defined by the Nordic Forest Work Study Council (NSR 1978). The following sub-operations were separated: clearing of the planting spot (CLEAR), planting (PLANT), and walking between planting positions (WALK). The sub-operation CLEAR included the manual preparation of the planting spot and the occasional removal of tops and branches when needed. Thus, this sub-operation was not needed on plots that had been treated with mechanical site preparation. The PLANT sub-operation includes the following work cycle: creation of the planting hole, insertion of the plant into the soil, and a slight compaction of the soil around the base of the plant when needed. This was usually done by stepping slightly around the base of the seedling before walking to the next planting position. The sub-operation PLANT commenced when the worker inserted the planting pipe into the soil and ended as he began to walk towards, or search for, the next planting spot.

Data were recorded in cmin plant^{-1} on a Husky Hunter field computer (Husky Computers Ltd., UK), using SIWORK3 software (Kofman 1989). Of the 72 studied plots (three site preparation alternatives and four harvest treatments in six replicates); data from one plot in one of the Hedmark stands (untreated plot in BA_{35} harvest treatment) was lost due to a failure with the field computer. The data from another plot in Oppland (patch scarified plot in BA_{35} harvest treatment) were discarded since the value for this plot could be identified as an outlier (studentized residual >3) when walking time for all patch scarified plots was regressed against the planting density ha^{-1}. The total number of observations (planted seedlings) on the remaining 70 plots was 3220.

2.3 Statistical Methods

The applied statistical methods include analyses of variance and regression in SAS procedure GLM (Sas Institute...1989). Due to the unbalanced data, least square estimates of treatment means were calculated and used in subsequent comparisons of mean differences. Data pertaining to the planting result (planted seedlings ha^{-1}) and most of the time study data were analysed using split-plot analysis of variance, according to the model:

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \gamma_k + (\beta\gamma)_{jk} + (\tau\gamma)_{ik} + e_{ijk} \quad \text{(Model 1)}$$

where μ is the general mean, τ_i, = effect of the ith replicate stand (i = 1,..., 6), β_j = effect of the jth harvest treatment (j = 1,..., 4), γ_k = effect of the kth site preparation alternative (k = 1,..., 3), e_{ijk} = experimental error. The mainplot ($\tau\beta$) and subplot ($\tau\gamma$) mean squares were used as denominators for the F-tests on the effects of harvest treatments and site preparation, respectively, whereas the F-tests on the harvest treatment × site preparation interaction were based on the experimental error mean square.

The CLEAR data (untreated plots only) were analyzed according to a simper model:

$$y_{ij} = \mu + \tau_i + \beta_j + e_{ij} \quad \text{(Model 2)}$$

Here, y_{ij} = time in cmin per plant^{-1}, μ = general mean, τ_i, = effect of the ith replicate (i = 1, 2..., 6), β_j = effect of the jth harvest treatment (j = 1,...,4), e_{ij} = experimental error.

In all analyses of variance, parametric tests were chosen since Shapiro-Wilk tests did not indicate any violation of the assumption of normally distributed residuals ($p < W = 0.30–0.71$ for the different tested variables).

3 Results

3.1 Planting Result

The mean density of planted seedlings (density of site prepared spots for patch scarified and inverted plots) is shown in Fig. 3. The density declined with decreasing basal area removal (significant main effect of harvest treatment; $p < 0.0001$, $F_{3,15} = 143.90$), but due to a different pattern for untreated and site prepared plots the difference among the stand-level treatments depended on the site preparation method (significant interaction of harvest treatment × site preparation; $p = 0.0480$, $F_{6,28} = 2.47$). With patch scarification and inverting, the mean varied from 2460–2480 seedlings ha^{-1} in the BA_{100} harvest treatment, to 670–840 in the BA_{35}. On untreated plots, the relative reduction was less pronounced, with means ranging from 2100 (BA_{100}) to 1000 seedlings ha^{-1} (BA_{35}). With some minor exceptions, the stands in Hedmark and Oppland followed a similar pattern.

Table 2. Average time consumption (cmin plant^{-1}, lsmeans of n = 6 replicate stands) for the different sub-operations according to harvest treatments (BA_{35}–BA_{100}) and site preparation methods (U = untreated, P = patch scarification, I = inverting).

	BA_{35}			BA_{45}			BA_{55}			BA_{100}		
	U	P	I	U	P	I	U	P	I	U	P	I
CLEAR	7.8	–	–	7.8	–	–	10.9	–	–	10.3	–	–
PLANT	15.5	16.2	12.5	14.6	14.7	12.1	14.3	15.3	12.3	14.5	16.0	11.2
WALK	13.4	11.1	11.7	11.0	12.9	10.9	13.9	9.9	8.7	10.1	8.9	7.6

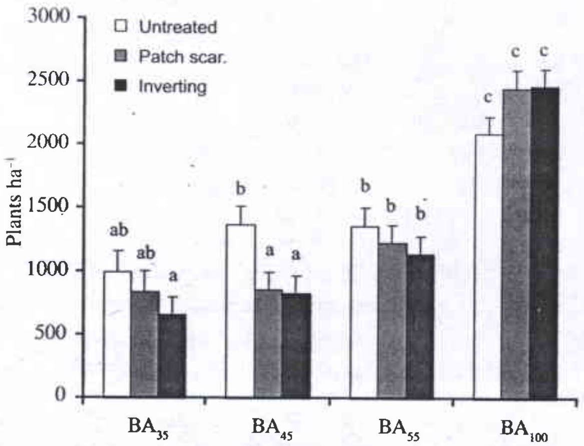

Fig. 3. Average planting density ha^{-1} (lsmeans) for the different harvest treatments and site preparation alternatives. Means in columns which do not share any letters were significantly different ($p < 0.05$).

One noticeable difference was a lower overall density of site prepared spots in Oppland, which was especially pronounced for the patch clear-cuts (1910 seedlings ha^{-1} in Oppland versus 2750 in Hedmark). Besides, for the untreated plots the reduction in planting density with increasing harvest intensity was greater in Oppland than in Hedmark (Oppland: from 2220 to 720 seedlings per ha^{-1}; Hedmark: from 2030 to 1180 seedlings ha^{-1}, for BA_{100} and BA_{35}, respectively).

3.2 Time Consumption – Major Sources of Variation

The average time consumption plant^{-1} associated with the different sub-operations are shown for each harvest treatment and site preparation alternative in Table 2 (all six replicate stands). An examination of the main time per plant^{-1} by ANOVA (Model 1) showed that the most influential sources of variation were the effects of the replicate stands ($p < 0.0001$; $F_{5,15} = 69.85$) and site preparation treatments ($p < 0.0001$; $F_{2,10} = 48.88$), as illustrated in Fig. 4. The majority of the variation between the replicate stands was due to the difference between the stands in Hedmark (worker 1) and those in Oppland (worker 2). The effect of harvest treatment ($p = 0.0201$; $F_{3,15} = 4.44$) was minor in comparison.

3.3 Effects of Site Preparation Treatments

The inverting method caused the lowest time consumption and the highest time consumption was found without any site preparation treatment (Table 2, Fig. 4). When summing up the sub-operations CLEAR + PLANT across all replicate stands and harvest treatments, the mean time consumption plant^{-1} was 12.0 cmin for inverted, and 15.6 and 23.9 cmin for patch scarified and untreated plots, respectively. Considering the sub-operation PLANT only, the highest and lowest time consumptions was found for patch scarification (15.6 cmin) and inverting (12.0 cmin). The untreated control (14.7 cmin) was intermediate and significantly different from both patch scarification and inverting (Model 1). The time consumption associated with the sub-operation PLANT did not differ among the harvest treatments (no significant effect of harvest treatment or harvest treatment × site preparation). For the sub-operation CLEAR, the time consumption tended ($p = 0.0508$; $F_{3,14} = 3.33$, Model 2) to be higher at the higher harvest strengths (Table 2). Although the time spent on these two sub-operations differed among the replicate stands, the overall ranking among site preparation treat-

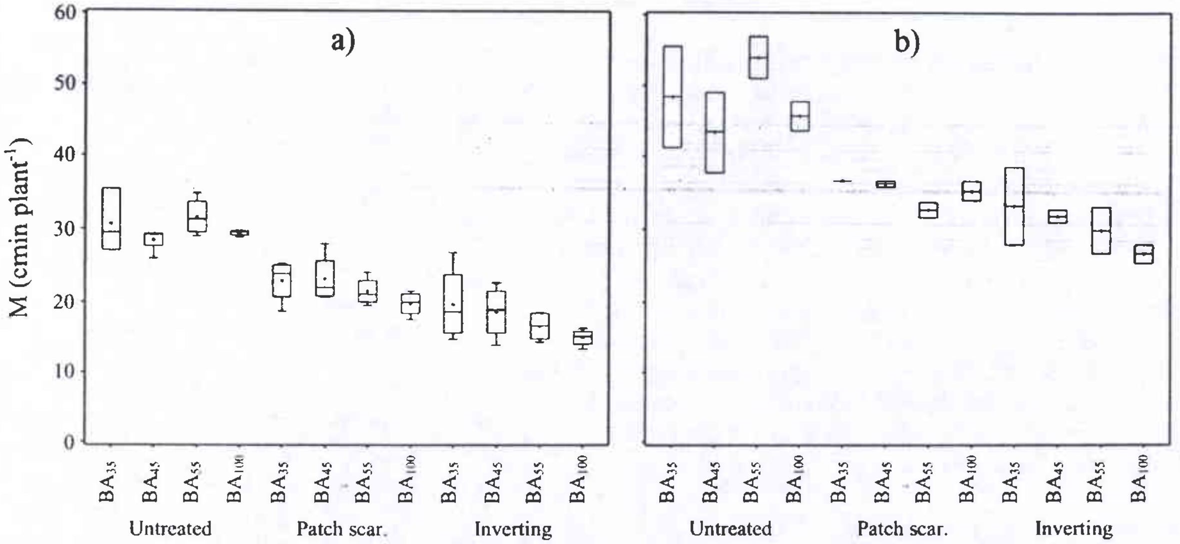

Fig. 4. Main time in cmin plant^{-1} for each experimental treatment in the replicate stands in a) Hedmark (worker 1, n = 4 replications) and b) Oppland (worker 2, n = 2 replications). The dot and horizontal line gives the mean and median, respectively, while the box frame delineates the upper (75 per cent) and lower (25 per cent) quartiles. The range ("error" bars) is shown for the Hedmark stands but could not be displayed for the stands in Oppland due to the low number of replications.

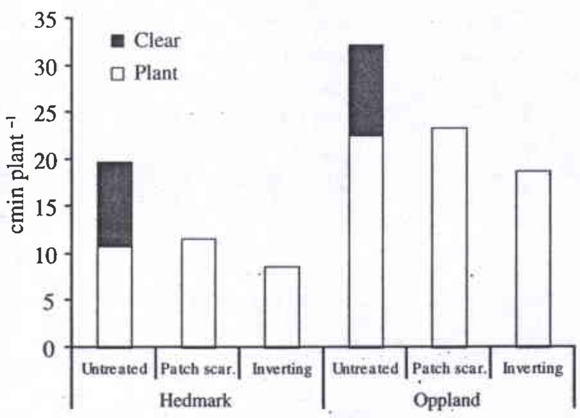

Fig. 5. Effects of site preparation methods on time consumption for the sub-operations CLEAR and PLANT, shown as means for the replicate stands in Hedmark (worker 1) and Oppland (worker 2).

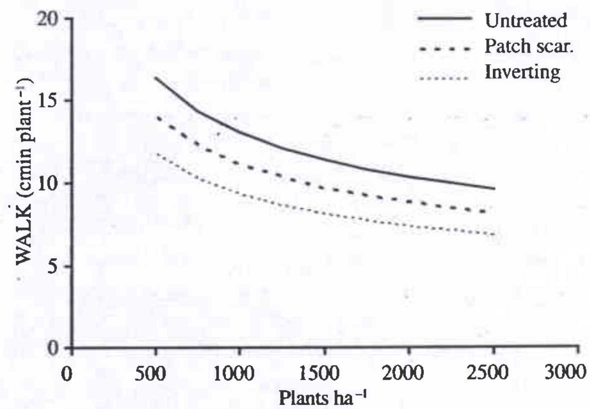

Fig. 6. Influence of planting density and site preparation treatment on time spent on walking between planting spots (WALK).

ments was consistent for the two groups of stands planted by the different workers (Fig. 5).

The summary data in Table 2 indicated differences among the site preparation alternatives in time consumption associated with the sub-operation WALK. This was tested by controlling for the variation in planting density among the site preparation treatments, by using the number of outplanted seedlings as an explanatory variable in regression analysis (log transformed model). The effect of the site preparation treatments was assessed by including dummy (1, 0) variables in the model. With similar planting density, the time spent on walking was lower with the inverting method than with the untreated alternative, whereas the patch scarification treatment was intermediate (Fig. 6). The three site preparation treatments differed significantly ($p < 0.01$) when all the replicate stands were analysed together, and for inverting the time spent on walking was also lower than for the untreated alternative when analyses were run separately for the stands planted by different workers (Hedmark $p = 0.0014$; Oppland $p = 0.0092$). For the stands in Oppland however, the difference between the untreated and patch scarified plots was not significant ($p = 0.1205$), and for the Hedmark stands, the difference between inverting and patch scarification was only marginally significant ($p = 0.0710$).

3.4 Effects of Harvest Treatments

In order to assess the impact of the different harvesting treatments, a comparison must account for the influence of operators and site preparation methods within which this effect is nested. This was done by calculating the relative time consumption plant^{-1} for each UPC treatment in relation to the patch clear-cut treatment within each combination of site preparation within each replicate stand. This gives a better picture of how the relative time consumption was influenced by the operator (worker) effect which is clearly confounded with the replicate stand effect. The result of this calculation (Table 3) showed that the average increase in relative time consumption per plant^{-1} (for all three site preparation treatments) was higher in the Hedmark stands than in the stands in Oppland. This difference reflects that the worker in Oppland spent a lower proportion of the main time on walking (mean 34% versus 44%). For all stands counted together, the relative increases in time consumption for the BA_{35}, BA_{45} and BA_{55} harvest treatments were 8.8, 10.6 and 15.3%, respectively.

This comparison successfully isolated the effects of harvest treatments from the operator effect but did not fully account for the differences in planting density associated with the site preparation treatments (cf. Fig. 3). To assess this influence, we calculated the relative planting density for the different experimental treatments in a similar way as for time consumption; that is, as the ratio between the planting density for each UPC plot and the corresponding planting density for the patch clear-cut of the same combination of site preparation and replicate stand. For each site preparation alternative, the values for relative planting density were plotted against the relative time consumption for main time and the sub-operation WALK (Fig. 7). These plots show that a reduction in planting density only translated into a corresponding increase in main time plant^{-1} on the patch scarified and inverted plots, whereas the main time for the untreated plots remained fairly constant despite an increase in walking time as the planting density was reduced. Moreover, for the patch scarification and inverting treatments, these calculations indicate that the average relative increase in time consumption when planting in partially cut stands is unlikely to exceed 50% as long as the corresponding relative planting density is greater than approximately 20 percent of that in the patch clear-cut.

Table 3. Per cent increase in time consumption plant^{-1} (main time) when planting in the different uniform partial harvest treatments in Hedmark (worker 1) and Oppland (worker 2), relative to planting in the patch clear-cuts (BA_{100}). The averages were calculated across all site preparation treatments.

Harvest treatment	Hedmark	Oppland
BA_{35}	18.2	9.4
BA_{45}	13.0	5.9
BA_{55}	9.3	7.9

4 Discussion

4.1 Planting result

With the exception of the patch clear-cut treatment, fewer plants were planted on site prepared plots than on untreated plots (Fig. 3). This result mainly reflects that the desired number of site prepared spots was not reached in the densest residual stand treatments, due to limited stand access for the excavators. With the high residual stem density in the UPC plots (Table 1), opportunities for the excavator to operate outside the previously established striproads were often limited, and with a striproad spacing of 24 m and a boom reach of slightly above 7 m, theoretically about 40% of the stand area could not be reached under the most difficult operating conditions. With increasing harvest strength, the opportunities to drive into

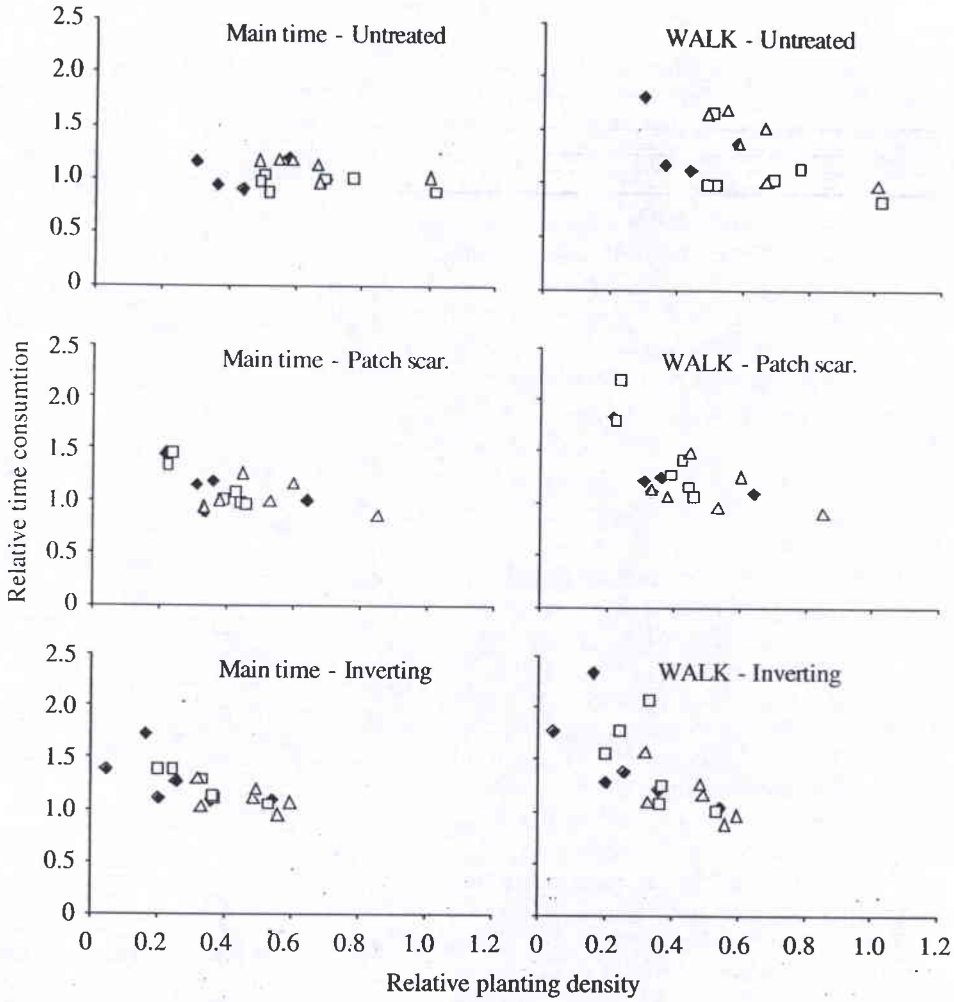

Fig. 7. Relative values for main time (left) and the sub-operation WALK (right) versus relative planting density. Data were calculated separately for untreated (upper), patch scarified (middle) and inverted (lower) plots. For each experimental treatment and replicate stand, the reference value (1) is the time consumption and planting density for the corresponding patch clear-cut (BA_{100}) plot. The relative values for the BA_{35}, BA_{45} and BA_{55} harvest treatments are indicated by filled diamonds, open squares and open triangles, respectively.

the remaining stand, and thereby reaching the area farthest away from the striproads, increased. This is also indicated by the finding that differences in planting density were relatively small in the BA_{55} treatment. However, a lower density of site prepared regeneration spots was established in all harvest treatments except the patch clear-cut. Accordingly, a residual stand density of about 900–1000 trees ha^{-1} with a total basal area of approximately 13 m^2 (BA_{55}, Table 1) was still too high to obtain the target density of regeneration spots in the site prepared plots.

4.2 Operator Effects in the Study

We expected that while the level of productivity could vary widely between workers in this study, the relative changes in time consumption between treatments was expected to be independent of the worker. This assumption was based on previous studies which have shown that the relative changes in time consumption are often nearly independent of the worker when conditions or work methods change, although the level of productivity may vary widely (Samset 1990). Our result did not fully confine with this assumption since the relative increase in time consumption with decreasing harvest strength varied among the two workers (Table 3). Harstela (1988) also noted that variation in relative time consumption between individual forest workers for a specific working method could be greater than the relative variation in time consumption between working methods or conditions. This is the one of the reasons for the attempted transfer of the performance rating principle from the manufacturing industry to forest operations research. Performance rating, however, has been used primarily in connection with correlation studies. At meetings of IUFRO Sec. 32 in the 1950's, subjective performance rating was judged as a helpful method but an unsatisfactory feature of scientific work studies (Samset 1990). Regardless of this historical criticism of the study method, Appelroth (1982) used it in his doctor dissertation on manual planting methods and had it accepted as a basis for piece rates in Finland (see also Appelroth 1989). Manual planting and other less complex operations may, therefore, be one of the suitable application areas for this technique. Given the observed differences in working speed between the two operators (Fig. 4), the performance rating approach could also have been a valid method for this study.

After the further advance of statistical methods in forest operations research in later years the difference between comparison studies and correlation studies has become increasingly difficult to see. Examples of statistical models for comparison time studies of mechanized operations have been suggested which may adjust study results for average operator differences (Bergstrand 1991). As well, comparison times studies must often adjust for at least one factor (for example harvested tree size) before direct comparison between alternative methods can be made (Harstela 1988). This was also the case in this study where the planting density had to be adjusted for to isolate the effects of both harvesting treatment and site preparation.

4.3 Effects of Experimental Treatments

The mechanical site preparation treatments greatly reduced the time consumption for planting. The greatest reduction occurred with the inverting method, which reduced the main time plant^{-1} by almost 50% on the BA_{100} plots (Table 2). The corresponding reduction with patch scarification was somewhat smaller, slightly below 30%. Although the reduction in time consumption associated with site preparation was mainly due to the greater ease of the planting work per se, i.e. less time spent on the sub-operations PLANT and CLEAR (Fig. 5), our data also showed that the site preparation treatment influenced the time spent on walking (Fig. 6). This probably reflects that the workers needed more time to search for suitable planting spots in the untreated plots, a task which was included in the sub-operation WALK in this study. It was somewhat surprising though, that time consumption for the sub-operation WALK was lower after inverting than with patch scarification. The reason for this pattern could be that the worker can easily approach the homogenous inverted spot from any direction, at least on fairly level ground, whereas the most appropriate direction of approach depends on patch orientation with the latter method, due to the upturned humus slice (Fig. 2). Although this difference was marginally significant for the stands which were planted by the fastest worker (Hedmark), the treatment ranking was similar in both groups of stands.

For comparison with operational site preparation, it should be noted, that excavators might produce a more homogenous planting substrate than the tractor-drawn aggregates that are more commonly used in the Nordic countries. Accordingly, for the patch-scarified spots the planting conditions may have been more optimal in our experiment than with the more commonly used equipment. However, using an excavator is the most suitable option for mechanical site preparation in partially harvested stands of similar density as in the current study, and at present also the only possible way to do inverting site preparation. Suadicani (2002), who performed time studies in a shelterwood stand in Denmark, compared the time consumption of planting in inverted spots with other site preparation techniques, including planting in untreated soil. While inverting reduced the time consumption by about 50% compared with no site preparation, a reduction which is comparable to the difference in our study, he found no significant differences between inverting and other mechanical site preparation methods which included harrowing and disc trenching. Suadicani (2002) also assessed the costs of the site preparation and found that the high costs of inverting by excavator were not compensated for by the lower planting costs.

The influence of harvest treatment was small compared with the effect of site preparation. Moreover, the effect depended on the site preparation method as the reduction in planting density that resulted from the different harvest treatments (Fig. 3) did not translate into a corresponding increase in main time on the untreated plots (Fig. 7). For the untreated plots, the greater time required for clearing of the planting spots at the higher harvest strengths (Table 2) apparently compensated for the increased walking time. It is likely that this pattern reflects an increasing amount of logging debris at the higher harvest strengths. In comparison, when site preparation was carried out prior to the planting, the influence of harvest treatments was solely due to an effect on the time spent on walking. Since the planting density varied among the harvest treatments, it was not possible to separate the effect of the longer average walking distance from the potential effect of other factors that might influence performance, like obstacles such as remaining trees and logging residue. With no obstacles present and a fairly even distribution of planting spots, it would be logical to anticipate a quadratic relationship between walking time and planting density ha^{-1}. Such a model assumption did, however, not fit well to the data, and in Fig. 6 the slope is in fact less steep than what one might expect from a quadratic relationship. This is at least partly a result of a clustered plant distribution in the UPC plots, with many seedlings being concentrated to larger gaps and striproads. The amount of logging residue will also influence work efficiency (Hakkila 1973, Strømnes 1986), and the amount of tops and branches will logically be smaller at lower harvest strengths. The overall effect of a clustered distribution of planting spots and less logging residue at the lower basal area removal levels, might have been to outweigh some of the increase in walking time $plant^{-1}$ that would result from a lower planting density ha^{-1}. The average walking time observed on the patch clear-cuts in this study (8.9 cmin $plant^{-1}$), is comparable to reported values from planting on clear-cuts in other studies, e.g. Callin (1971), Hakkila (1973) and Strømnes (1981, 1986).

While our results addresses the relative time consumption for different treatments, the limited range of stand conditions and the fact that only two workers were used limits their use in terms of the absolute values. Another uncertainty that a short-term study like this does not address is the relation between main time, effective and work place time, which needs to be taken from studies that have gone over longer periods of time. When planting, fetching and organizing of plants accounts for the largest proportion of the by-time (Strømnes 1986), which together with main time adds up to the effective time (E_0). The by-time may be split into a fixed and variable component, and could be influenced by terrain difficulties and the organization of the work (Strømnes 1981). With respect to delays, Strømnes (1986) found a 16.5% addition to E_0 when planting without mechanical site preparation and 16.7% when planting in site prepared spots, which suggest that the proportion of the work-place time lost due to delays is unaffected by site preparation, when using a similar planting tool as in this study. In an earlier study by the same author (Strømnes 1981), where the effect of terrain slope was investigated, delay times varied from 14.3% of effective time on level ground to 17.1% when the slope exceeded 90%. Hakkila (1973) studied the effects of logging residue and found delay times to vary from slightly below 15% when all the residues were removed to between 15–20% when it was left at the planting site. The fairly narrow variation observed across a vide range of planting conditions in these studies indicate that the delay time percentage can be estimated for other stand-level treatments than clear-cutting as well, without introducing unacceptably large errors.

The six experimental stands where the time studies were performed are part of a larger experimental series of nine identical replications, established to assess the result of different regeneration treatments. An earlier report (Granhus et al. 2003) on the survival and growth of the planted seedlings, which had been treated with permethrin against pine weevils (*Hylobius abietis* L.), showed that both seedling survival and seedling height six years after planting was significantly improved by inverting compared with planting in untreated soil, while patch scarification gave a result that was intermediate between inverting and no site preparation. The differences between the treatments were moderate however; less than 10 per cent units for mortality and about one year for height increment. Thus, although we do not have available data on the performance of the excavators in our stands, it is unlikely that the expenses for the site preparation will be justified unless e.g. further restrictions on insecticide use are implemented in the future. Suadicani (2002) also assessed the costs of site preparation with an excavator in a shelterwood stand and found that the high cost of such treatment was not compensated for by the lower planting cost.

5 Conclusion

Site preparation and the variation attributed to the replicate stands, which in this study was confounded with the operator (worker) effect, had a much larger effect on the time consumption plant^{-1} than the stand-level silvicultural treatments, despite considerable differences in average planting density among the harvest treatments. This conclusion is limited to planting densities higher than ca. 500 seedlings ha^{-1} since the data material was insufficient below this limit.

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