The use of small units in forest planning calculations and its effects in the forest management plan

Master's Thesis in Forest planning

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1 INTRODUCTION

1.1 Compartmentwise planning in Finland

Forest planning in Finland has traditionally been based on compartmentwise inventory (Poso 1983, Uuttera et al. 2002). Compartments are delineated visually on aerial photographs, and stand characteristics are measured in the field from relascope sample plots located subjectively on representative points in the stand. In seedling stands usually a circular plot is used. The number of sample plots on a stand is dependent on the size of the compartment and its homogeneity, as well as on the habits of the surveyor. Nowadays stand age, basal area, mean diameter and mean height are measured separately for each tree species, and also site characteristics and evaluation of wood quality are recorded (Ajosenpää et al. 2006).

The compartments should be at least 0.5 hectares of size because they are to be used as operational units. Eventually, their boundaries do not always follow the natural stand borders. In addition, especially in gradually changing sites the stand borders may be difficult to define, which emphasises the subjectivity in compartment delineation even more. The sample plot measurements are aggregated to average figures for each compartment. This single set of stand characteristics is then used for planning purposes for example in the common forest simulators MELA2002 (Hynynen et al. 2002) and MOTTI (Salminen et al 2005). In these mean figures there is no information of the within-stand variation left, but the stands are assumed as average in this respect. This is rarely true in reality.

1.2 Within-stand variation and its effects in forest planning

Variation within forest compartments occurs both in the spatial distribution of the trees as well as in the characteristics of single trees. Especially in young stands the origin of trees acts a major role in determining the spatial pattern of the trees: naturally-born stands form usually clustered spatial pattern, whereas planted stands
may appear quite regular (e.g. Nanos et al. 2003). Swampy patches, rocks or other variation in the soil may cause gaps in the canopy, and ditches or harvesting roads often leave quite distinctive open areas, too. Within-stand variation occurs also in the species composition: different tree species may form clusters within the compartment, but remain too small to be delineated as separate compartments. Among single trees, variation in growth and tree dimensions may be for example due to variation in genetics, site characteristics or in the position of the tree with respect to its competitors, the neighbouring trees. On very small compartments the stands may appear quite homogeneous, whereas on large compartments the variation in characteristics is more likely. The amount of within-stand variation thus depends on the size of the compartment: the larger the compartment, the greater is usually the within-stand variation of stand characteristics (Poso 1983).

Koivuniemi (2003, p. 123) compared several Finnish studies where the within-stand variation had been evaluated. For example the variation in basal area was 16-40 % within the compartments, and the average variation of standing volume, depending on the study, ranged from 20 % to more than 50 %. The estimates for the variation of median diameter and median height measured in different parts of the compartment varied from 9 % to 28 % and from 6 % to 25 % respectively. The size of the sample plots used in the studies was not reported, which complicates the direct comparison of the studies. This is because comparing small sample plots will result in a greater estimate of within-stand variation than the use of larger plots (Loetsch & Haller 1973, pp. 46-48).

If the within-stand variation is not taken into account, the estimations of stand growth may be biased when non-spatial growth models are used. Pukkala (1990) argued that as the dependence of growth on stand density is of concave type, the high density in some parts of the stand will not compensate the lack of trees on other parts, leading to a growth overestimate. This could be tackled using spatial growth models (e.g. Hegyi 1974, Tham 1989). In these models the location of the tree among other trees is included in the growth estimate, by for example creating indices for the number, size and proximity of neighbours. Pukkala (1989) tested a spatial growth model for Scots pine stands using the ratio between the size and distance of the competitor and the horizontal angle from the tree to competitor tree as spatial
indices. The spatial model appeared to decrease the relative standard error of growth estimate from 15 % to 30 % when compared to a non-spatial growth model. The spatial model worked especially well in considerably regular and clustered stands, as could have been expected. In general, however, spatial growth models have not become very popular. They usually require very detailed information of the stand including accurate coordinates of the individual trees, and this type of data has not been available in a larger scale.

Despite the growth overestimates, using average characteristics over the whole compartment may also lead to deviations in the thinning removal estimations. This was studied by Kilkki et al. (1985). In their study the attention was driven from the canopy gaps towards the densest parts of the stand. They argued that if a stand was very heterogeneous and the trees heavily clustered, its average basal area may not reach the thinning limit even though some parts of the stand were clearly too dense. The solution proposed was a grouping index that could be used to correct the estimate of the need for thinning and the amount of removal. Dense plots could then be thinned even though the stand-wise average would not yet indicate so. This measure would require some adjustments to the measurement of sample plots, as a group of small relascope plots would be needed to determine the spatial distribution of the trees.

1.3 Taking within-stand variation into account using sample plots as simulation units

One way to implement the within-stand variation into planning calculations using the traditional sample plot data is to keep the measured plots separate from each other. Pukkala (1990) used this method to study the biases in forest growth estimations and thinning removal caused by using only one data record per compartment. Forest planning calculations were carried out for simulated and empirical stands in two ways: by simulating stand growth and thinning treatments for each plot separately and alternatively based on only one field record per compartment. The predicted growth for the compartments was generally lower in the calculations based on
several individual plots, but the difference was very small. The thinning removal was considerably greater in the method where the sample plot data were kept separate, especially in irregular stands. This relates to the previously discussed study of Kilkki et al. (1985), as here each separate plot being dense enough could be thinned to a specified remaining basal area, independently of the compartmentwise average. The results of Pukkala (1990) also affirmed the presumption that an irregular stand is often harvested to a lower remaining basal area than a regular stand.

A similar simulation setup of independent sample plots versus only one data record per compartment was used by Sundström (2001). The outcome supported that of Pukkala (1990): the remaining basal area after thinning was lower in the simulations by separate sample plots, and also the growth prediction was slightly smaller. In this study the simulation of separate plots was also carried out in two ways: by allowing thinning on individual sample plots despite the compartmentwise average, as in Kilkki (1985) and Pukkala (1990), and not allowing this division of compartments. When the sample plots within each compartment were let to be treated differently in the simulation, this actually happened on each compartment, purportedly reflecting clustering of the trees. The correlation between the within-stand variation and the division of compartments was, however, found to be very weak.

Pukkala and Miina (2005) studied further the effect of the within-stand variation in a forestry plan when all the sample plots in the compartment were treated simultaneously. In their study the forestry plan was optimized as to maximize the soil expectation value using a treatment program of two thinnings. Heterogeneity of the stands was found to affect negatively in the soil expectation value. Also the net income and timber removal were decreased in increasingly heterogeneous stands. The study also supported the previous reckoning of heterogeneity decreasing the optimal thinning density and the remaining stand basal area of a tree stand.
1.4 Objectives of the study

The idea of utilizing the inventory data as such, including the information about within-stand variation and without calculating aggregate figures, is becoming an attractive option for future forestry calculations (e.g. Kangas et. al. 2006). The development of new inventory methods, such as radar, laser scanning and photogrammetry, may provide cost-efficient methods to attain detailed information from the forests in the future. Moreover, the increased amount of data is nowadays relatively easy to manage with the advanced computers used in forest planning, and small-scale data would enable specific operational planning as the location and amount of wood were known in more detail than in the traditional compartmentwise planning.

The planning tools used in Finland are based on compartmentwise data, where the management units are defined before growth simulations. What possibilities there are available to utilize the accurate data and how does the input data affect the forest management plan? This study investigates the application of more detailed field data into the simulation procedure using a quite similar approach as in Pukkala (1990) and Sundström (2001). Outcomes from two input data sets, compartmentwise data derived by averaging sample plot observations and plotwise data as such, are compared. The focus of the study is on the possible differences in the timing and yield of the first logging operation, attempting to evaluate whether the use of different input data will lead into different forestry plans. The study will also attempt to evaluate whether small simulation units are preferable to compartments using aggregate variables in forest simulations.

The initial expectations are that the growth estimate will be greater in the simulations using compartmentwise data as in Pukkala (1990). The difference in growth between the simulation setups is also expected to increase if the within-stand variation is increased. Following the greater growth, operations are expected to come earlier than in the simulation using separate values for each sample plot. In Pukkala (1990), the removal estimate was greater in the calculations where the sample plot data sets were
kept separate. Hence the income is supposedly greater in the analogous simulation of this study also.

2 MATERIALS AND METHODS

2.1 Field measurements

The study site of 71 hectares is located in the municipality of Juuka in Eastern Finland. The site is a typical representative of a forest in North Karelia: the stands are mostly Scots pine-dominated (75% of the standing volume), accompanied by some Norway spruce stands (15%), and few birch, or mixed stands (10%).

The area was divided in the field into 29 stand compartments in the ordinary manner of the compartmentwise inventory. Stand characteristics were, however, not collected from subjectively placed sample plots as usual, but using a systematic 30 m x 30 m sample plot grid instead (see Mustonen 2007 for further detail). A total of 682 relascope sample plots were measured (9.6 per hectare). The relascope factor used was 2. The measured characteristics were basal area (BA) in non-seedling stands or number of trees per hectare (N) in seedling stands, median diameter at breast height (DgM), median height (HgM) and age of the stand. The measurements were carried out separately for each tree species on the plot. For each plot, also site index, soil type and the existence of ditches or stony ground was determined.

2.2 Data processing

The aim of this thesis is to discuss the possible differences in the forest plan occurring because of the scale of the input data. Here, two separate data sets were formed from the field measurements, the compartments and a mosaic of subcompartments. The subcompartment-level data is derived directly from the field sample plots by forming Thiessen polygons around each sample plot.
In a Thiessen polygon the borderlines are placed in the middle of a line connecting two sample points. Thiessen polygons were chosen because with them it is possible to cover the whole study area. In other studies, a computing unit of regular shape has been more common, for example a pixel (Öhman and Eriksson 2002) or hexagons (Heinonen and Pukkala 2007). This was problematic here as areas near the boundaries of the planning area would have been omitted (figure 1).

Finally, the borderlines of the Thiessen polygons and compartments were compared. If one Thiessen polygon overlapped several compartments, it was divided by the compartment borderlines into a final mosaic. The measured sample plot data of each Thiessen polygon was kept intact in the respective subcompartments. After this, the compartmentwise data was aggregated from the subcompartmentwise data as area-weighted mean, or for stand variables such as the site index the mode of the respective subcompartments was used. The final subcompartment mosaic as well as the surveyor-derived compartments are presented in figure 1.

Figure 1. With Thiessen polygons (left) as subcompartments around each sample plot it is possible to cover the whole planning area, whereas using regular shapes (right), such as pixels, would result in black-denoted excluded areas near the site boundaries.
Figure 2. The study area divided into compartments (left) and a subcompartment mosaic (right). A dirt road dividing the area (10) as well as lakes and ponds within the area (12, 13, 31, 34 and 35) were excluded from the study area. Also the compartments where there were no operations suggested were not studied further.

2.3 Simulations

The simulations of forest growth and predicted forestry operations were carried out using recently developed, extendable software SIMO (Tokola et al. 2006). SIMO package currently includes two simulators for forest planning, a tree-level and a stand-level growth simulator (Mäkinen et al. 2008). In this study we used the tree-level simulator, which is based on the same growth models as common Finnish forestry simulators MELA2002 (Hynynen et al. 2002) and MOTTI (Salminen et al. 2005). These models predict the growth of single trees. The input data can thus consist of either individually measured trees or of a theoretical set of trees created by distribution model if only aggregate stand-level attributes are available. Some stand level attributes such as site class, soil type and temperature sum are also required. The operations proposed in the forest plan were conducted by the common Finnish
silvicultural guidelines (Hyvän metsänhoidon...2006). Thinning decisions are based on BA and dominant height (Hdom) of the stands, and final cuts are proposed based on age and DgM. Only those compartments on where there were operations were examined further.

From the field sample plots only median values for each tree species were measured. As tree-wise sample plot data was not available, the data for the tree-level simulator was obtained by distribution models for each tree species in both simulation data sets. For the compartment-wise data one diameter distribution was created to represent all trees of the same species in the compartment. For the mosaic simulations one diameter distribution for each species was derived for each subcompartment, resulting in several diameter distributions for every species on the compartment. The aggregate values of characteristics for the studied stands are presented in table 1.

Main species and site class are expressed as the mode of the sample plot records, weighed by the area of the corresponding subcompartment. Other characteristics are area-weighted averages, calculated from the diameter distributions of each (sub)compartment. Hdom was determined in the simulations as the mean height of 100 largest trees per hectare.

The within-stand variation with respect to the stand characteristics is expressed using the coefficient of variation (formula 1). This expression states the relative deviation of the variables from the mean value as a percentage.
\[ CoV_k = \frac{\sigma_k}{\bar{x}_k} = \sqrt{\frac{\sum_{j=1}^{n_i} (x_{ij} - \bar{x}_k)^2}{\sum_{i=1}^{n_j} a_i}} \]

where

\( \sigma_k \) = the standard deviation on compartment \( k \)
\( x_{ij} \) = observation \( j \) on subcompartment \( i \)
\( \bar{x}_k \) = the arithmetic mean of observations on compartment \( k \)
\( a_i \) = the area of subcompartment \( i \)

The variation in site index and tree species are illustrated in figures 3 and 4 (respectively) as the proportion of each site class or tree species within the compartments. The variation in site index is presented as the proportion of area covered by each site class on each compartment. The tree species variation shows the proportional volume of each species.
Table 1. Area-weighed aggregate characteristics and coefficient of variation (CoV) of the simulation data after one year of simulation before operations. (I) refers to the simulation computed with a single compartmentwise data set and (II) to the simulation computed with several subcompartmentwise (mosaic) data sets per each compartment. Area is measured in hectares and age in years. Site class is determined by the site fertility classification system of Cajander (1949) to MT (Myrtillus type), VT (Vaccinium type), CT (Calluna type) or CIT (Cladina type) and given here as the mode of the stand records. BA is stand basal area (m$^2$ ha$^{-1}$), $V$ is volume of trees (m$^3$ ha$^{-1}$), $N$ is number of trees ha$^{-1}$, DgM is diameter of the median tree (cm), HgM is height of median tree (m) and Hdom is the dominant height (m).

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<td>73.9</td>
<td>37.5</td>
<td>308.3</td>
<td>18.8</td>
<td>16.0</td>
<td>18.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CoV</td>
<td>16.3</td>
<td>57.2</td>
<td>71.8</td>
<td>13.8</td>
<td>21.8</td>
<td>23.3</td>
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<tr>
<td>29</td>
<td>4.24</td>
<td>(I) Pine</td>
<td>MT</td>
<td>64.0</td>
<td>23.6</td>
<td>132.8</td>
<td>14.1</td>
<td>11.1</td>
<td>13.8</td>
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<tr>
<td></td>
<td></td>
<td>(II) Pine</td>
<td>MT</td>
<td>60.8</td>
<td>23.4</td>
<td>147.8</td>
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<td>12.6</td>
<td>14.3</td>
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<td></td>
<td></td>
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<td>2.04</td>
<td>(I) Pine</td>
<td>VT</td>
<td>102.3</td>
<td>25.0</td>
<td>186.0</td>
<td>20.0</td>
<td>15.2</td>
<td>19.3</td>
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<tr>
<td></td>
<td></td>
<td>(II) Pine</td>
<td>VT</td>
<td>95.6</td>
<td>24.7</td>
<td>197.7</td>
<td>21.0</td>
<td>16.3</td>
<td>18.9</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>CoV</td>
<td>34.9</td>
<td>33.5</td>
<td>38.1</td>
<td>16.3</td>
<td>13.5</td>
<td>15.7</td>
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</table>
The compartmentwise diameter distribution for the traditional simulation was derived from the aggregate figures of the respective subcompartment characteristics, whereas the distributions for each subcompartment were derived from each sample plot. Hence there are differences in the compartmentwise mean figures for these two (table 2). On average, sim(I) that was based on only one diameter distribution presented the stands as 1.7 % denser and 1.9 % older than sim(II) that was based on several distributions per compartment (one for each subcompartment. The trees, in turn, were presented smaller in sim(I): the mean V was 8.9 % smaller than in sim(II), and DgM and HgM were 7.7 % and 9.2 % (respectively) smaller on an average compartment. However, Hdom was 0.1 % greater in sim(I), which implies that the largest trees on the compartments were slightly taller in sim(I) than in sim(II).

<p>| Table 2. The average differences between the mean values of initial data derived from one diameter distribution for the compartment (simI) or individual distribution for each subcompartment (simII). |</p>
<table>
<thead>
<tr>
<th>Age (yrs ha(^{-1}))</th>
<th>BA (m(^2) ha(^{-1}))</th>
<th>V (m(^3) ha(^{-1}))</th>
<th>DgM (cm ha(^{-1}))</th>
<th>HgM (m ha(^{-1}))</th>
<th>Hdom (m ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>sim(I)-sim(II)</td>
<td>2.0</td>
<td>0.4</td>
<td>-14.3</td>
<td>-1.3</td>
<td>-1.2</td>
</tr>
<tr>
<td>sim(I)-sim(II), % of sim(I)</td>
<td>1.9</td>
<td>1.7</td>
<td>-8.9</td>
<td>-7.7</td>
<td>-9.2</td>
</tr>
</tbody>
</table>

Figure 3. The proportions of area (%) of different site classes within the compartments.
The flexibility of SIMO in the forest planning calculations was advantageous in this study as we had to make some adaptations in the simulation hierarchy. In a tree-level simulator, traditional compartmentwise forest planning is usually formulated as three steps of simulation hierarchy. The growth models act on the tree-level data, the results of which are then summed up to the stratum-level, which contains the information of the stands by tree species. Due to these figures the strata variables, such as species distribution, are updated. The stratum level information is in turn summed up to the stand level where the possibility of harvests is determined. During the simulation process, this aggregation of data to upper levels of the hierarchy is carried out after every simulation time step. This set-up was used in the traditional compartmentwise calculations (simI) of this paper (figure 5).

For the mosaic calculations (simII) and (simIII) we needed to create an additional hierarchy level, subcompartment (figures 6 and 7). This level included similar variables to those of level ‘stand’. It was computed to act in two different ways to study the effects of input data extent to the expected yield from the operations (simII) and the timing of them (simIII). In both mosaic simulations the input data was derived as such from the individual sample plots, in contrast to mean compartmentwise values in the traditional simulation (simI). Growth simulations were conducted in both simulations in similar ways: growth was simulated for...
individual trees, and the results were aggregated to stratum and subcompartment levels.

The difference between the setup of the two mosaic simulations lies in the role of the hierarchy level ‘stand’. In the mosaic sim(II), same harvest decisions were suggested and at the same time as in the traditional sim(I). This was done to evaluate the difference in the income and yield estimations as well as in growth caused by different input data setups. In mosaic sim(III) the harvest decisions were applied independently, based on the average of the subcompartments. The main purpose of this simulation was to estimate possible differences in the suggested timing of harvesting operations.

**Figure 5.** Hierarchy levels and respective variables in the traditional simulation by average values for compartment (simI).
In the second simulation, sim(II), where growth and yield were under investigation, forest management operations were set according to the compartment-wise simulation. Growth simulations were continued on the three lowest levels until the date when there was a forest management task proposed for some compartment in the traditional plan (sim(I)). Then the same management operations were applied for the subcompartments of this simulation at the same time. The hierarchy level 'stand' was used only for recording the simulation results after each time step. After the operations, the estimated cash flows and cut volumes were compared between the compartment-level and subcompartment-level simulations to evaluate whether the scale of the input data affects on the estimated yield of the operations if the compartments are operated at the same time.

In the other mosaic simulation (simIII), the timing of the operations was of interest. The growth simulations were similar to those of the first simulation by
subcompartments, and after every time step the results were collected to the level ‘stand’ for records. In this simulation, however, the stand level also acted as a level of decision. That is, the characteristics aggregated to stand level figures were used to evaluate the timing of the operations. The compartments were then operated when the subcompartment results on average indicated so. The procedure was almost the same as in the traditional simulation, with the difference that growth simulations were done by subcompartments instead of the aggregate stand-level values.

Forest growth and forestry operations were simulated for a time period of ten years in one year steps. This simulation period corresponds to the usual planning period of forests in Finland. The time step in practice is usually 5 years, but in this study it was shortened to track the possible differences in the simulated operations' timing more precisely.

2.4 Interpretation of the results

The results of traditional sim(I) were compared to mosaic simulations sim(II) and sim(III). When calculating the differences between the simulations, sim(I) results were considered as the base values. The purpose was to evaluate possible differences in stand growth and yield and timing of the harvesting operations. As to stand growth, the correlation between the within-stand variation and possible differences in volume growth were evaluated visually and by the correlation coefficient. A more thorough statistical analysis was not used in this study, as the number of variables was considered too small.

The results were compared as total figures for the forest estate, as well as individually for each compartment. The simulations were made with SIMO, and all calculations and visualizations with MS Excel.
3 RESULTS

3.1 Growth

The volume growth prediction for the compartments was consistently lower when based on several plots (table 3). The differences between the simulations varied from 2 to 38 per cent between the respective compartments. The difference between the simulation setups was smallest, only 0.1 m$^3$ha$^{-1}$a$^{-1}$ (2 %), on compartments 25 and 27. In contrast, the growth was more than 25 % greater on traditional sim(I) on compartments 3, 6, 14, 18, 19 and 30. The annual volume growth differences were greatest on compartments 6 and 14, where the annual increment differences between the simulations were 1.8 m$^3$ha$^{-1}$ (38 %) and 2.0 m$^3$ha$^{-1}$ (37%) respectively.

Table 3. The average annual volume growth (m$^3$ha$^{-1}$a$^{-1}$) of the compartments until the simulated operation.

<table>
<thead>
<tr>
<th></th>
<th>Annual growth prediction</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One simulation unit (I)</td>
<td>Multiple simulation units (II)</td>
</tr>
<tr>
<td>1</td>
<td>4.2</td>
<td>3.4</td>
</tr>
<tr>
<td>3</td>
<td>5.7</td>
<td>4.0</td>
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<tr>
<td>6</td>
<td>4.8</td>
<td>3.0</td>
</tr>
<tr>
<td>7</td>
<td>4.9</td>
<td>4.0</td>
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<tr>
<td>14</td>
<td>5.3</td>
<td>3.4</td>
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<tr>
<td>15</td>
<td>4.0</td>
<td>3.4</td>
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<tr>
<td>18</td>
<td>4.7</td>
<td>3.5</td>
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<td>19</td>
<td>5.4</td>
<td>3.6</td>
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<tr>
<td>24</td>
<td>3.5</td>
<td>2.7</td>
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<tr>
<td>25</td>
<td>7.5</td>
<td>7.4</td>
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<td>26</td>
<td>6.9</td>
<td>6.3</td>
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<td>27</td>
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<td>7.5</td>
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<tr>
<td>29</td>
<td>6.9</td>
<td>5.9</td>
</tr>
<tr>
<td>30</td>
<td>5.0</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Reasons for the growth differences were examined from the viewpoint of two possible sources: the differences in the initial states of the two stands, and the within-stand variation. The correlations between the differences of initial stand characteristics and the growth estimate are presented in figures 8-12. None of the initial characteristics examined proved to explain very well the difference in the growth rates of the simulation. Even the best one, difference in initial age (figure 8),
only resulted in a coefficient of determination of 0.17. In other words, differences in initial age explained approximately 17% of the variation of the growth difference. The differences in initial volume did not appear to be correlated to the differences in the volume growth rate, and the correlation coefficient between these variables was 0.0 (figure 9). Initial basal area differences (figure 10) explained 10% of the variation of the growth rate, and initial diameter and initial height 8% and 7% respectively (figures 11 and 12).

Figure 8. The correlation between the difference in initial age (%) and the volume growth (iV, %) between simulations I and II.

Figure 9. The correlation between the difference in initial volume (V, %) and the volume growth (iV, %) between simulations I and II.
Figure 10. The correlation between the difference in initial basal area (BA, %) and the volume growth (iV, %) between simulations I and II.

Figure 11. The correlation between the difference in initial median diameter (DgM, %) and the volume growth (iV, %) between simulations I and II.

Figure 12. The correlation between the difference in initial median height (HgM, %) and the volume growth (iV, %) between simulations I and II.
The correlation between the within-stand variation and growth difference is illustrated in the graphs of figure 13. According to these results, the variation in site class seems to correlate best with the differences in growth rates between the two simulations, as approximately 41% of the variation in growth rate difference is explained by the proportion of main site class (figure 13; a). That is, the growth difference seems to be greater on compartments where the proportion of the main site class is smaller and the within-stand variation in site class greater.

Other measures of within-stand variation correlated considerably less with the growth difference. Variation of basal area (figure 13; d) explained 24% of the variation in growth difference, and variation in volume (figure 13; c) explained 16%. Variations in median diameter and median height explained only 8% and 6% of the growth difference respectively. Also variations in main tree species, age and dominant height were weak explainers of the growth differences, as their coefficients of correlation were 3% or less (figure 13; b, e and h).
Figure 13. The correlation of within-stand variation to the differences of annual volume growth rate (iV). Volume is denoted by V, basal area by BA, median diameter by DgM, median height by HgM and dominant height by Hdom.
3.2 Final cuts

3.2.1 Timing

In this subchapter the simulation by one unit per compartment (simI) is compared with the mosaic simulation (simIII) whose final cut decision was made based on the average of the subcompartments, independently of sim(I).

Final cuts were proposed for five compartments on the ten-year planning period (figure 14). For compartment 1 both simulation setups proposed a final cut at the same time, in the first planning year. For compartment 18 the final cut was proposed three years earlier in the simulation based on multiple units per compartment than on only one simulation unit. Conversely, for compartments 3, 5 and 30 the simulation by one unit proposed the felling one or two years before the mosaic simulation. The proposed final cut was a seedtree cut for all compartments the compartment 18 in the mosaic sim(III). The removal of seedtrees was always scheduled six years after the seedtree cut, and is not considered in this subchapter.

![Figure 14](image.png)

**Figure 14.** Simulation time until final cut on compartments where (I) only one simulation unit was used for the whole compartment and (III) several simulation units (subcompartments) were used to define compartmentwise forest planning schedule.

An analysis of the stand development in the two simulations was used to examine the reasons for timing differences. In the treatment program used, a final cut was applied
when either the mean age or the mean diameter of the stand exceeded the given limits. These limits depend on the temperature sum, site class and tree species, and are given in table 4. The limits used were based on the Finnish silvicultural recommendations (Hyvän metsänhoidon... 2006). In this study, the mid-values of the maximum and minimum limits in the recommendations were used.

Table 4. The diameter and age limits used in the study.

<table>
<thead>
<tr>
<th>Temperature sum</th>
<th>1000 d.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main species</strong></td>
<td></td>
</tr>
<tr>
<td>Site class</td>
<td></td>
</tr>
<tr>
<td><strong>Pine</strong></td>
<td></td>
</tr>
<tr>
<td>MT</td>
<td>26</td>
</tr>
<tr>
<td>VT</td>
<td>25</td>
</tr>
<tr>
<td>CT, CIT</td>
<td>23.5</td>
</tr>
<tr>
<td><strong>Spruce</strong></td>
<td></td>
</tr>
<tr>
<td>MT, VT, CT, CIT</td>
<td>26.5</td>
</tr>
<tr>
<td><strong>Birch</strong></td>
<td></td>
</tr>
<tr>
<td>MT, VT, CT, CIT</td>
<td>27</td>
</tr>
</tbody>
</table>

As there was variation in the site class within the compartments (see fig. 3), the average final cut limits differed from the tabular figures in the mosaic simulation. For example, when there were some subcompartments of site class MT and some of VT, the final cutting limit for the aggregate compartment was calculated as an area-weighted average of these compartments’ age and diameter limits. This difference in the decisive limits was clearly the most prominent feature describing the differences between the two simulation setups, which can be seen in table 5. The table presents the development of mean age and mean diameter in the two simulations till the felling, as well as the final cut limits for these figures.
Table 5. The average development of the compartments until final cut. The values of age and mean diameter (DgM) are given one year before the operation, except if the operation was carried in the first simulation year 2008, the figures are those right before harvest. The year of cutting is denoted in **bold** typing.

<table>
<thead>
<tr>
<th>Compartment ID</th>
<th>One simulation unit (I)</th>
<th></th>
<th>Multiple simulation units (III)</th>
<th></th>
</tr>
</thead>
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<tr>
<td></td>
<td><strong>Year</strong></td>
<td><strong>Regeneration limit</strong></td>
<td><strong>Age</strong></td>
<td><strong>DgM</strong></td>
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<tr>
<td></td>
<td><strong>Age</strong></td>
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<tr>
<td>30</td>
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</table>

In compartment 1 the final cut is proposed in the first simulation year in both setups, as the initial age met the cutting limits right away. The limits for operations were also quite close to each other as there was very little variation in site class or tree species. Nevertheless, on this compartment the within-stand variation did not have a clear effect as the stands exceeded the limits already in the beginning.
The effect of the within-stand variation is revealed on compartment 3, where the stand is harvested according to the simulation (I) a year before the mosaic simulation, even though the stand is considered more mature in the latter one. This is because the stand gradually grew towards the cutting limits, instead of being already above them in the first place. Hence even a slight difference in the decisive limits has an effect on the harvest schedule. This is also shown on the development of the average characteristics of compartment 15.

The effect of the within-stand variation is further emphasized in compartments 18 and 30, where the variation is notable with respect to site index as well as to tree species. For these compartments the age limits for final cut were considerably lower in the mosaic simulation. The site class for simulation (I) was chosen as the dominant (mode) site class on the compartment. However, a considerable proportion of the compartments were of better quality, as was seen in figure 3. The mosaic simulation takes this into account, which leads to a clear difference in the final cut age of compartment 18.

3.2.2 Income and yield

This subchapter studies the income from all three simulations: the usual method of using average figures for compartments (simulation I), a mosaic simulation where the operations were timed according to those in the previous simulation (simulation II), and a mosaic simulation where the operations were carried out according to the average of the mosaic variables (simulation III).

The results show that the income estimates for the ten-year period were always greater when the simulation units were the micro compartments of the mosaic (table 6). When the final cuts were simulated at the same time, total income estimates for the ten-year period were about 5% greater in the mosaic simulation (II) than in the simulation where only one data set per compartment was used (I). In mosaic simulation (III) the timings differed from those in simulation (I), and income was 9.5% greater without discounting. If interest rate is taken into account, however, the
difference in income diminishes and is only 0.7 % if interest rate was as high as 7 %. This reflects the delay in final cuts on three of the compartments when sim(III) is compared to sim(I), as income in the near future is valued higher than that gained later on.

Table 6. Net present value (€ ha\(^{-1}\)) of income from final cuts in the different simulation setups at different interest rates. The planning period was ten years in simulation by one simulation unit per compartment (I), and the respective operations in other simulations.

<table>
<thead>
<tr>
<th>Rate of interest</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>One simulation unit (I)</td>
<td>6058.7</td>
<td>5815.9</td>
<td>5595.8</td>
<td>5395.5</td>
<td>5212.8</td>
<td>5045.6</td>
<td>4892.2</td>
<td>4751.0</td>
</tr>
<tr>
<td>Multiple simulation units, same timing (II)</td>
<td>6373.6</td>
<td>6111.1</td>
<td>5873.8</td>
<td>5658.5</td>
<td>5462.5</td>
<td>5283.5</td>
<td>5119.8</td>
<td>4969.4</td>
</tr>
<tr>
<td>Difference to (I), %</td>
<td>5.2</td>
<td>5.1</td>
<td>5.0</td>
<td>4.9</td>
<td>4.8</td>
<td>4.7</td>
<td>4.7</td>
<td>4.6</td>
</tr>
<tr>
<td>Multiple simulation units (III)</td>
<td>6632.1</td>
<td>6303.7</td>
<td>6000.3</td>
<td>5719.6</td>
<td>5459.4</td>
<td>5218.0</td>
<td>4993.6</td>
<td>4784.7</td>
</tr>
<tr>
<td>Difference to (I), %</td>
<td>9.5</td>
<td>8.4</td>
<td>7.2</td>
<td>6.0</td>
<td>4.7</td>
<td>3.4</td>
<td>2.1</td>
<td>0.7</td>
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</tbody>
</table>

The reason for the income difference is found in table 7: the estimate in timber removal was on average 5.3 % greater in sim(II) than in sim (I), and 7 % greater in sim (III) than in sim(I). In sim(II), the yield estimate was only slightly greater for the main wood assortments, the difference being only 1.0 % and 0.4 % for pine logwood and pulpwood respectively. The estimate of the amount of other species, however, was different in the two simulations. For the other economically important species, spruce, the logwood estimation in sim(I) was only 0.6 m\(^3\)ha\(^{-1}\), whereas sim(II) estimated the yield to be 4.0 m\(^3\)ha\(^{-1}\). Also the amount of spruce pulpwood was smaller in sim(I). Birch was absent in sim(I) altogether, whereas in sim(II) there were on average 0.3 m\(^3\)ha\(^{-1}\) of birch logwood and 3.3 m\(^3\)ha\(^{-1}\) of birch pulpwood in the final cut yields.

The yield estimates in sim(III) revealed similar differences to sim(I) as the other mosaic simulation. Non-prominent species spruce and birch were estimated to
produce more than in sim(I), whereas the estimate of pine wood was nearly the same in both of the simulations. The differences between the two mosaic simulations are mostly explained by the timing difference: on three of the compartments the final cut came later in sim(III), and therefore the trees had grown a year or two more.

<table>
<thead>
<tr>
<th>Table 7. Average removal (m³/ha⁻¹) and the timber assortment from final cuts in the different simulation setups. The planning period was ten years in simulation by one simulation unit per compartment (I), and the respective operations in other simulations.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Removal, m³/ha⁻¹</strong></td>
</tr>
<tr>
<td><strong>One simulation unit (I)</strong></td>
</tr>
<tr>
<td>Birch, log</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td><strong>Multiple simulation units, same timing (II)</strong></td>
</tr>
<tr>
<td>Difference to sim1 (%)</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td><strong>Multiple simulation units (III)</strong></td>
</tr>
<tr>
<td>Difference to sim1 (%)</td>
</tr>
<tr>
<td>N/A</td>
</tr>
</tbody>
</table>

The most prominent difference between the simulations, however, was caused by the fact that on compartment 18 the operation was a seedtree cut in sim(I) and consequently in sim(II), but a clearcut in sim(III). This was a result of the variation in site class, which was not taken into account in sim(I): on this compartment 37 % of the area was relatively fertile soil of type MT. A seedtree cut of pine is not preferred for such fertile soil, as seedlings are usually suppressed by other vegetation, and sim(III) suggested a clearcut for the compartment. On the other hand, sim(I) did not take the variation in soil fertility into account, but assessed the compartment based on the mode forest type CT and chose seedtree cut as the treatment option. The different choice in final cut method led to different estimations in the relative proportions of logwood and pulpwood on compartment 18 (figure 15), sim(III) estimating relatively more pine logwood than the other simulations.
Figure 15. Final cut timber assortment by compartments in different simulations.
3.3 Thinnings

3.3.1 Timing

Altogether nine compartments were thinned during the planning period in this study (figure 16). Thinnings followed the silvicultural recommendations in Finland (Hyvänmetsänhoidon... 2006) where thinning limits are determined by the temperature sum, tree species, basal area and dominant height of the stands. In this study, there was also an age limit applied, which excluded the stands over 80 years of age from the thinning procedure. This makes the simulation more realistic as the stands that will soon be mature enough for final cutting are not thinned just a few years before.

Thinnings were mostly concentrated in the first years of the planning period. Three of the compartments (25, 26 and 27) were thinned right at the beginning of the simulation in both simulation setups. In compartments 7, 14 and 19 thinning was proposed in the mosaic simulation (simIII) before the simulation by one data unit. Of these, the compartment 19 was not thinned at all in the traditional simulation (simI) as it was over 80 years of age. In contrast, in compartments 6, 24 and 29 the thinning was proposed first in the traditional simulation, and compartment 6, in turn, got over 80 years old in the mosaic simulation before reaching the thinning limit.

![Figure 16. Simulation time until thinning on compartments where only one simulation unit was used for the whole compartment (simI) and several simulation units (subcompartments) were used to define forest planning schedule (simIII).](image-url)
Thinning models are stated in the silvicultural recommendations as graphs showing the boundaries for target basal area before and after the operation (Hyvänmetsänhoidon... 2006). When the stand is between the upmost boundaries, upper and lower harvesting limit, thinning is recommended. The lower two boundaries show the recommended basal area after thinning. In this study, thinning limit was set at the halfway of the harvesting limits, and the remaining basal area at the halfway of the target limits. In addition, the maximum removal was set to 40 % of the basal area as is the usual standard in the simulator. In sim(III), the thinning decision was made according to the compartmentwise average, but the operations were carried out separately for each subcompartment according to its site class, tree species and stand density, as in the final cut limits. Thus the BA and Hdom boundaries in mosaic simulations were not exactly those of the traditional simulation. In figures 17, 18 and 19 the development of each compartment's average basal area and dominant height are sketched with the thinning limits for simulation by one unit (I).

Graphs in figure 17 show the compartments where thinning was carried out in the first simulation year in both simulations. The basal area of the stands with respect to the dominant height exceeded the thinning limits clearly in the beginning of the planning period at all of these compartments, and the stands were harvested in the first year of simulation. On compartments 26 and 27 the maximum of 40 % removal from the basal area was effective, restricting thinnings to reach the target basal area levels. The remaining basal area of the compartments was slightly greater in the mosaic simulations than in the simulations using compartmentwise data, and always above the target limit.
Figure 17. Thinnings that were proposed at the same time in both simulation setups.

In the compartments in figure 18 thinnings were proposed earlier in the traditional simulation. In compartment 6 the age of the stand was over 80 in the mosaic simulation, and hence the stand was not thinned. In the other compartments the initial values for the decision variables were on a lower level in the mosaic simulation, and the stands needed to grow some years longer to meet the thinning limits than in the traditional simulation. On these compartments, too, the remaining basal area was greater in the mosaic simulation.
Figure 19 presents the compartments where the stands were thinned earlier in the mosaic simulation. In compartment 14 the basal area of the mosaic data reached the thinning limit in the beginning of the simulation, whereas in the traditional simulation thinning was suggested two years later. On this compartment the remaining basal area was smaller in the mosaic simulation, opposite to the other compartments. In compartment 19 the mean age in sim(I) exceeded the limiting 80 years, and prevented the compartment from being thinned. In mosaic sim(III) the age limit was not met, and a thinning was suggested. The interpretation of compartment 7 is not very straightforward as the basal area seems to meet the thinning limits clearly in the beginning of both simulations, but the traditional simulation suggests thinning a year later than sim(III). This is a result of the within-stand variation on the site.
class (fig. 4): as 28% of the stand was of other than the main site class, the thinning limits for mosaic simulations differed from those of the traditional simulation.

**Figure 19.** The development of basal area and dominant height on the stands thinned later in the simulation by one data unit.

### 3.3.2 Income and yield

In this subchapter compartments 6 and 19 are not included in the calculations of totals, as these compartments were not managed in all simulations.

As in final cuts, also in thinnings the income was greater in the mosaic simulations than in the simulation by one unit per compartment (table 8). In sim(II), where the
thinnings were dated according to sim(I), the income estimate was about 8 % greater than that in the single-unit simulation.

In the mosaic simulation sim(III) where the thinnings were dated independently, the income estimate was 11.6 % greater than in the single-unit simulation, when the interest rate was assumed zero. When the interest rate was applied, the income difference decreased and with the discount rate of 7 % the difference to simulation (I) would be 8.5 %.

Table 8. Net present value (€ ha\(^{-1}\)) of income from thinnings in the different simulation setups at different interest rates. The planning period was ten years in simulation by one simulation unit per compartment (I), and the respective operations in other simulations (excluding compartments 6 and 19).

<table>
<thead>
<tr>
<th>Rate of interest (%)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>One simulation unit (I)</td>
<td>801.5</td>
<td>793.2</td>
<td>785.3</td>
<td>777.6</td>
<td>770.1</td>
<td>762.9</td>
<td>755.9</td>
<td>749.1</td>
</tr>
<tr>
<td>Multiple simulation units, same timing (II)</td>
<td>865.1</td>
<td>856.3</td>
<td>847.8</td>
<td>839.5</td>
<td>831.6</td>
<td>823.9</td>
<td>816.4</td>
<td>809.2</td>
</tr>
<tr>
<td>Difference to (I), %</td>
<td>7.93</td>
<td>7.95</td>
<td>7.96</td>
<td>7.97</td>
<td>7.98</td>
<td>7.99</td>
<td>8.01</td>
<td>8.02</td>
</tr>
<tr>
<td>Multiple simulation units (III)</td>
<td>894.2</td>
<td>880.6</td>
<td>867.7</td>
<td>855.5</td>
<td>844.0</td>
<td>833.0</td>
<td>822.7</td>
<td>812.9</td>
</tr>
<tr>
<td>Difference to (I), %</td>
<td>11.57</td>
<td>11.01</td>
<td>10.50</td>
<td>10.02</td>
<td>9.59</td>
<td>9.20</td>
<td>8.84</td>
<td>8.52</td>
</tr>
</tbody>
</table>

The differences in removal were generally small between the simulations (figure 20). The largest removals were on compartments 25 and 27, on which the basal area and standing volume were also the largest in the input data. On these compartments the removal was considerably smaller in sim(I) than in the mosaic simulations. Sim(I) removal estimate was smaller also for compartment 6 (not included in the previous tables showing average figures), 7, 24 and 29, whereas it was greater than the mosaic estimations for compartments 14 and 26.
There were also some differences in the timber assortment of removal between the simulations (table 9). When sim(I) is compared to sim(II), the simulation using similar operation schedule but different data units, it can be seen that the estimated yield of logwood is greater in mosaic simulation sim(II), whereas the yield of pulpwood is slightly greater in sim(I). This balances out in the total figures, as sim(I) estimates just 0.6 % greater yield than sim (II). The difference is the greatest for spruce logwood (sim(II) 24.5 % greater yield than sim(I)) and pine logwood (17.7 %), whereas the difference in yield estimates for pulpwood was less than 10 % for pine and spruce. The yield of birch logwood was very small in both simulations, but for birch pulpwood sim(I) estimated 13.5 % greater yield.

In sim(III) the yield estimates were somewhat greater than in sim(II), resulting in a total yield estimate of 5.1 % greater than that of sim(I). There were differences in logwood and pulpwood amounts here as well, logwood estimates being almost a quarter greater in sim(III) than in sim (I). The pulp estimates were almost the same in these simulations. When comparing these three simulations, however, it has to be noted that the yield of each assortment was only few cubic meters, and even small differences in the estimated amounts result in large differences in the percentage figures. The average figures describe well also the individual compartments, as there were no major differences between the compartment timber assortments (figure 21).
Table 9. Average removal (m$^3$ha$^{-1}$) from thinnings in the different simulation setups at different interest rates. The planning period was ten years in simulation by one simulation unit per compartment (I), and the respective operations in other simulations (excluding compartments 6 and 19).

<table>
<thead>
<tr>
<th></th>
<th>Birch, log</th>
<th>Birch, pulp</th>
<th>Pine, log</th>
<th>Pine, pulp</th>
<th>Spruce, log</th>
<th>Spruce, pulp</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>One simulation unit (I)</td>
<td>0.0</td>
<td>4.7</td>
<td>3.5</td>
<td>7.9</td>
<td>3.2</td>
<td>9.2</td>
<td>28.5</td>
</tr>
<tr>
<td>Multiple simulation units, same timing (II)</td>
<td>0.2</td>
<td>4.1</td>
<td>4.1</td>
<td>7.5</td>
<td>4.0</td>
<td>8.5</td>
<td>28.3</td>
</tr>
<tr>
<td>Difference to sim1 (%)</td>
<td>N/A</td>
<td>-13.5</td>
<td>17.7</td>
<td>-5.0</td>
<td>24.5</td>
<td>-8.1</td>
<td>-0.6</td>
</tr>
<tr>
<td>Multiple simulation units (III)</td>
<td>0.2</td>
<td>4.6</td>
<td>4.3</td>
<td>7.9</td>
<td>4.1</td>
<td>8.8</td>
<td>29.9</td>
</tr>
<tr>
<td>Difference to sim1 (%)</td>
<td>N/A</td>
<td>-3.1</td>
<td>23.1</td>
<td>0.8</td>
<td>28.6</td>
<td>-4.5</td>
<td>5.1</td>
</tr>
</tbody>
</table>
Figure 21. Timber assortment in thinnings in different simulations.
3.3.3 Stands after thinning

The remaining basal area was generally smaller in sim(I) (figure 22). The reasons are found in figures 23 and 24 showing the development of basal area and dominant height in sim(I) and sim(II). The corresponding graphs for sim(III) were presented previously in figures 13, 14 and 15. In the mosaic simulation sim(III) the remaining basal area was smaller than that in sim(I) in all except compartment 14. In mosaic sim(II), where thinning were dated according to sim(I), remaining basal area was greater than in sim(I) on compartments 7, 24, 25, 26, 27 and 30, and smaller on compartments 6 and 14. As was discussed in chapter 3.3.1, the differences seem to result from differences in the data input and site class variation affecting the thinning limits of the mosaic simulations.

What is curious about the remaining stands, for most compartments both the removal and the remaining basal area are greater in the mosaic simulations. This relates to the formation of the input data: the average initial volume was greater in the mosaic tree distribution. Because of this, the removal estimate was greater for the mosaic simulations, and still also the basal area remained greater after the thinnings.

![Figure 22. Basal area after thinning.](image-url)
Figure 23. The development of basal area and dominant height in sim(I) and sim(III) before and after thinning.
Figure 24. The development of basal area and dominant height in sim(I) and sim(III) before and after thinning.
4 DISCUSSION AND CONCLUSIONS

This study compared three different simulations conducted on the same field data. Sim(I) represents the traditional compartmentwise planning: sample plots were used to aggregate single variables for each compartment to represent stand characteristics. This planning approach was then compared with two other simulations, which used the sample plot data itself in simulation instead of aggregate variables. In sim(II) the forestry operations were adopted from sim(I), enabling the assessment of the effect of data input on growth and yield. In sim(III) the operations were based independently on the development of simulation units, allowing the examination of data unit effect on operation timing.

The within-stand variation on the study area was quite large, but was still on the same range as in other Finnish studies compared in Koivuniemi (2003). For example, the average coefficient of variation for basal area in this study was 41.6 %, while it had in the previous studies been between 16 and 40 %. Likewise, the variation of volume was here 46.4 %, as in other studies it was reported as 20 – 50 %. In this study, the variation is increased because of the Thiessen polygons used to evaluate the compartment-level data. The polygons were first delineated around the sample plots, and after then cut with respect to the compartment boundaries. Hence near the boundaries of compartments there are small subcompartments whose values are based on the sample plot situated on the neighbouring compartment. On neighbouring compartments that are very different with respect to tree stands, for example a seedling stand next to a mature stand, the small subcompartments near the boundaries have very different values than the rest of the compartment. The data was delineated in this manner because the field data was collected independently of the compartment boundaries. That is, when a sample plot was placed near a compartment boundary, the measurement actually included characteristics from both sides of the boundary.

The differences between the simulations were seen already in the formation of the input data for the simulations. Sim(I), where only one diameter distribution was derived for the compartment, resulted in a denser data set and smaller trees on
average than sim(II) where a diameter distribution was derived for every sample plot data set (subcompartment) separately. Unfortunately, diameter distributions of the mosaic simulations were not available for manual inspection in this study, and further analysis of the differences in the distributions was not possible. It is likely, however, that the differences are affected more by the variation within the compartment rather than the differences in the scale of the input data, as the values in both simulations were calculated from the same field data set. This is supported by Palahí et.al. (2008) and Kangas & Maltamo (2003), whose studies imply that there is no significant difference between the simulations based on treewise inventory data compared and data derived by a distribution model from stand-level figures, if the stand-level data is correctly derived.

The traditional and mosaic simulation setups produced quite distinctive forestry plans. The growth rate of stands in the mosaic simulations was 0.1 to 2.0 m³ha⁻¹a⁻¹ less than stand growth in the traditional compartmentwise simulation. The difference was considerably greater, although to the same direction, than the corresponding figures in previous studies, where the growth differences were only decimals (Sundström 2001, Pukkala 1990). The most prominent reason behind this seems to be the within-stand variation of site fertility, which was not studied in the reference studies (Pukkala 1990, Sundström 2001, Pukkala & Miina 2005). Aptly enough, in the compartments of this study where there was no variation in the site class, differences of the growth rates were exactly the same as in the study of Pukkala (1990). Opposite to Sundström (2001), where there was no single factor in the initial differences in the simulation data or the within-stand variation that would have explained the differences in the growth rates, the site class variation seems to be an important factor in this study. As the sample was only 14 compartments, it is not possible to derive wider conclusions based on this study alone. Therefore, in the following studies in this field the variation in soil should be included as a variable of within-stand variation, and considered in more detail as a factor affecting the growth estimations in simulations.

On compartments that had clearly reached the operation limits, the operations were naturally carried out in the first year of simulation regardless of the unit used for simulation calculations. On other compartments the difference in operation timings...
varied from one to three years, but there was no tendency of mosaic simulation operating before traditional nor vice versa. Instead, the differences in final cut timings were explained by the variation in site class and tree species distribution within the compartment being different on every compartment. They altered the final cut limits of age and median diameter in the mosaic simulations from the ones used in traditional sim(I). Timing differences in thinning seem to be caused by the initial differences in the characteristics of the data, as the compartments met the thinning limits in different levels. In addition, the thinning limits were altered by the site class variation, complicating the interpretation of average figures on the compartments. As there was no clear trend detected in the timing differences, the initial assumption of greater growth rate advancing the harvest propositions remains unanswered in this study.

The income estimates were greater in the mosaic simulations as expected. In final cuts mosaic simulations estimated considerably more of wood of others than the main species. In both final cuts and thinnings the logwood estimations were clearly greater than in the mosaic simulation, whereas differences in pulpwood estimations were clearly smaller. The results corresponded to the initial expectations based on Pukkala (1990), as the removal and income estimate in total appeared to be somewhat greater in the mosaic simulations. Also the remaining basal area was usually greater in the mosaic simulations.

The data used in this study was very limited, as only 14 compartments were examined in the end. Hence the findings of the study need to be interpreted cautiously. As real field data was used, the compartments cannot be interpreted as typical examples, but instead the study should be considered more as a case study. If the results were to be applied for forest planning in more general, the amount of compartments should have been larger for reliable statistical tests. Alternatively, a set of theoretical stands representing certain compositions of within-stand variation could have been used. Here, however, one of the advantages is that the complexity of the practical situation along with true variation is applied. As such, the study reaches its goal in evaluating the possible differences between the simulation setups in a practical situation.
In this study, in the mosaic simulations the data includes information of the within-stand variation, which is lost in the aggregate variables of the traditional simulation. Hence the mosaic simulations may be argued to represent the forest growth more realistically. In this viewpoint, sim(II) could be seen to give more accurate estimates of growth and yield from the operations in sim(I), whereas sim(III) would give more correct timing for the management operations. This would be beneficial in practical forest planning, as the outcome from the operations would be more accurately estimated.

This approach may, however, be misleading. The simulation results are highly dependent on growth models used, which in turn are based on field sample plots. The size of the sample plot affects the response of the growth model to competition: especially in dense stands a growth model based on small sample plots results in higher growth estimation than a model based on larger plots, which takes the competition into account from a larger area (Hynynen & Ojansuu 2003). In this study, the growth models applied were those used in the MELA system (Hynynen et al. 2002). The models are based on field data from INKA and TINKA inventories (Gustavsen et al. 1988). These sample plots varied in size according to the number of trees and there were also different sample plot groups used in the calculations, but even the average area of separate sample tree plots, the smallest unit of data, was 116 m$^2$. In the study on hand the basic data unit in mosaic simulations was 30 m x 30 m or smaller. When the growth models based on larger sample plots are applied to this data, the tree competition will be estimated from a larger area for each subcompartment, resulting in an overestimate of the competition in the compartment level. This leads to an underestimate in growth for the mosaic simulations, wherefore the growth estimate of sim(I) would actually be closer to the “correct” growth, that of the sample plots the growth models are based on. In other words, although small simulation units include more information in stand variation, their growth estimate may be biased and too small if their area is less than that in the data used for growth models.

Although many questions remain unanswered, the results of this study suggest that the extent of the data used in the planning calculations does have an effect on the final outcome of a forest plan. This is an important aspect in the moment, as much
more accurate information about forest structure will soon be feasible for forest planning in a competitive price. For example with air-borne laser scanning, the measured unit can become, instead of a stand, a small set of trees or even one single tree and the spatial distribution of the data will be readily available.

Based on this study, it is not possible to assess whether small units should be adopted in practical forest planning using traditional operation units. Instead, this study showed that if they are applied, a careful study of the models used in simulations as well as the data they are based on is needed beforehand.
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