Utilization of tree species stratum data in forest planning simulations

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Abstract

The objective here was to investigate the theoretical benefit of using tree species stratum forest inventory data instead of stand-level mean data in forest-planning simulations. This comparison was based on timing differences in thinning and clear-cuttings during a 20-year simulation period. The development of stand characteristics (age, basalarea, volume, dominant height, mean height, mean diameter) in those stands not harvested during the simulation period was also scrutinized. The calculations were performed with SIMO simulation and optimization software. In all 245 treewise measured circular plots established in 2007 in the vicinity of the Evo Forest Station, Finland, were used as study material. The results show that the use of tree species stratum data in forest-planning simulations is highly relevant from the viewpoint of both the development of stand characteristics and the timing of logging operations. The relative standard errors stemming from the level of input data varied from 2.1% to 20.6% and from 58% to 84% in stand characteristics and timing of logging operations, respectively. The significance of the stratumwise input data culminated in the functioning of the specieswise growth models at different stages of stand development. The results can be utilized in assessing the suitability of airborne laser scanning-based estimation methodologies in integrating detailed forest inventory with forest planning and operational logging planning.

Keywords:Airborne laser scanning (ALS), forest management planning, simulation , tree species detection, tree species stratum

1. Introduction

Laser scanning can be used in two spatil levels to estimate the volume of tree stock: (i) at the stand or plot level, using height and density distribution features derived from laser pulses (e.g. Holmgren 2003; Lim *et al*. 2003; Næsset 1997a, 1997b, 2002, 2004, Suvanto et al. 2005) or (ii) at the single-tree level, using tree height and crown width measurements (Hyyppä and Inkinen 1999, Persson *et al*. 2002, Popescu *et al*. 2003, Leckie *et al*. 2003, Maltamo *et al*. 2004). Stand-level laser scanning is more cost-efficient, due to its sparser pulse density (Holopainen & Talvitie 2006). On the other hand, single-tree interpretation makes it possible to understand on the stand's diameter/height joint distribution which facilitates forest-planning simulation and optimization, logging site planning, bucking control and wood procurement logistics.

However, the accuracy of estimating tree species stratum-level data has so far been rarely studied, although the significance of tree species in forest-planning simulation and optimization calculations is considerable. Packalén and Maltamo (2007) investigated the accuracy of estimating tree species stratum-level data with feature-based laser scanning, digital ortophotos and the nonparametric k-most similar neighbour (k-MSN) method in eastern Finland. The accuracy levels derived were considerably poorer than those of stand mean volume (V). On the stand level, the relative root-mean-square-error (rmse) of the estimated stratumwise mean V varied from 28% (pine, *Pinus* L.) to 62% (decidious), while the relative rmse of stand mean V was 10%. On the plot level, the respective stratumwise statistics waried from 51% to 102%, while the relative rmse of plot mean V was 20.5% (Packalén and Maltamo 2007).

Tree species stratum-level data are also error-prone in cases of traditional visual estimation and relascope plot-based estimation. Haara and Korhonen (2004) investigated the accuracy of visual estimation in eastern Finland. Their study showed that on the stand level the relative rmse of stratumwise mean V varied from 29.3% (pine) to 65% (deciduous), while the relative rmse of stand mean V was 24.8%. In other words, the estimation accuracy of the tree species stratum data presented in Packalén and Maltamo (2007) is similar to that of traditional visual estimation.

Another method for obtaining tree species stratum data is single-tree detection and interpretation. Airborne laser scanning (ALS) tree species detection was studied by Holmgren and Persson (2004), Korpela (2004), Korpela *et al*. (2007) and Kaartinen and Hyyppä (2008). These studies showed that tree species can be determined to about 50-95% accuracy, depending on laser pulse density, availability of aerial photographs and automation state. The automation of tree species interpretation is one of the major challenges remaining in individual tree interpretation.

In Finland, a new feature-based k-MSN laser-scanning method for estimating stock characteristics is currently being adopted in private forest management planning. Currently, the focus is on how to integrate the inventory data in the respective simulation and optimization calculations. It is then crucial to be aware of how inventory data of varying accuracy and scale affects the simulation results, e.g. the timing of loggings, which is of the significant economic importance to the forest owner.

The effect of inventory data accuracy on forest-planning simulation results was investigated e.g. with the cost-plus-loss method and by analysing the timing of loggings and respective net yield (Barth and Ståhl 2007, Eid 2000, Eid *et al*. 2004, Duvemo and Lämås 2006, Duvemo *et al*. 2007, Holopainen and Talvitie 2006, Holopainen *et al*. 2008). However, the effect of the scale of the inventory data, e.g. stratum data versus mean data, has not previously been investigated in this context.

1.1 The objective

The objective here was to clarify the significance of tree species stratum data in forest-planning simulations and was accomplished by comparing the simulation results of mean data with those of stratum data.

The comparisons were performed by stand characteristics (age (a), basal area (BA), V, dominant height (H_{dom}), mean height (H_{gm}), mean diameter-at-breast height (D_{gm})) 20-year future simulation for stands not affected by loggings and by the timing of the first logging operation (thinning or clear-cutting) encountered during the simulation period for stands affected by loggings. Stratumwise characteristics calculated on the basis of the single-tree measurements were used as reference data.

2. Material and Methods

2.1 Study area

The research material comprised 245 treewise fixed-radius (9.77 m) field plots measured in summer 2007 in an app. 2000-ha managed forested area located in the vicinity of Evo Forest

Station, Finland (61.19°N, 25.11°E). The sampling of the field plots was based on prestratification of existing stand inventory data. The plots were located with Trimble's GeoXM 2005 Global Positioning System (GPS) devise (Trimble Navigation Ltd., Sunnyvale, CA. USA), and the locations were postprocessed with local base station data, resulting in an error of 0.6 m. The following variables were measured in trees having a breast height diameter (DBH) of over 5 cm: location, tree species, crown class, DBH, height (h), lower limit of living crown and crown width.

2.2 Stand classes

The three (four) currently dominant tree species in forests in Finland are Scots pine *Pinus sylvestris* L., Norway spruce *Picea Abies* H. Karst., and silver birch *Betula pendula* Roth and downy birch *Betula pubescens* Ehrh. hereafter collectively referred to as birch. The most common alternatives with respect to a tree species mix are therefore 1) a single-species stand, 2) a two-species stand and 3) a three-species stand. The significance of tree species stratum data was analysed by these three stand classes. Appropriate sample plots for each class were selected by the criteria presented in Table 1.

Table 1. Stand classes used in the study.

Stand class	Description	Criteria
1	Single-species stand	Basal Area (BA) of the main tree species is greater than 90% of the total BA
2	Two-species stand	Combined BA of the two main tree species is greater than 90% of the total BA. Neither BA is greater then 70% of the total BA.
3	Three-species stand	BA of each of the three main tree species is greater than 20% of the total BA.

The stock statistics concerning the initial state of the field sample plots are presented in Table 2.

Table 2. Initial stock statistics.

Stand class		Age, a	BA, m^2	V, m^3	DgM, cm	(H_{gM}), m
	avg	73	18.8	184.1	23.8	19.1
1	min	26	0.4	1.2	5.5	3.8
	max	124	68.6	764.0	51.3	33.8
	avg	71	19.9	177.6	21.6	17.2
2	min	42	1.5	7.6	9.4	6.7
	max	193	42.1	487.5	48.9	29.8
	avg	59	22.5	180.6	19.4	16.5
3	min	37	7.0	27.4	9.0	7.2
	max	73	38.1	347.2	39.8	27.0
	avg	70	19.7	181.3	22.4	18.0
Total	min	26	0.4	1.2	5.5	3.8
	max	193	68.6	764.0	51.3	33.8

The sample plot sites varied from grove to dry heath and the development classes from advanced seedling stands to regeneration stands. Most of the sample plots were situated in advanced thinning stands (47%), regeneration stands (25%) or young thinning stands (24%). The remaining plots were situated in advanced seedling stands (2), shelter tree stands (1), seed tree stands (2) and seedling tree stands with an upper storey (1).

In the single-species stand class, 60% (41) of the sample plots were located in pine stands, 31% (21) in spruce stands and 9% (6) in birch stands. In the two-species stand class, 23 (46%) of the sample plots were situated in spruce-dominant stands, 14 (28%) in pine-dominant stands and 13 (26%) in birch-dominant stands. In the three-species stand class, the dominant tree species was spruce in 13 (65%) cases, birch in 4 (20%) cases and pine in 3 (15%) cases.

2.3 Simulations

The calculations were carried out using SIMO simulation and optimization software (SIMO simulation framework, Tokola *et al.* 2006, Mäkinen *et al.* 2008), which enables performance of both tree- and stand-level simulations; here, the tree-level simulator was utilized. The nonspatial tree-level growth models found in SIMO are, for the most part, similar to those found in the MELA2002 and MOTTI simulators (Hynynen *et al*. 2002, Salminen *et al*. 2005). They include growth models for all sites and tree species in Finland, including separate models for peat lands. The tree-level simulator can be used to simulate the growth of either sample trees measured in the field or descriptive trees generated on the basis of a theoretical diameter/height distribution.

In our study, the simulation was performed at the single-tree level. The statistics for the strata and compartments were derived as sums and means of the simulated tree properties.The procedure was based on the following two simulations carried out with SIMO software: i) the single stratum simulation and ii) the reference simulation.

In the single-stratum simulation a single tree species stratum was formed from the treewise plot data. The species having the greatest number of stems of plot trees with aDBH greater than 5 cm was selected as the stratum's main tree species.

In the reference simulation, multiple strata were formed from the treewise plot data representing the true initial and simulated final states. The result of the reference simulation was assumed to depict the final state of the stock. Reference simulation results regarding the timing of operations and development of stand characteristics were used as reference data with which the results of the single-stratum simulation were compared. The length of the simulation period was set at 20 years. Two types of simulation were then performed: those in which operations were not allowed, making it possible to compare stand characteristics at the end of the simulation period and those in which operations were allowed, making it possible to compare the timing of the next logging operation. Thinnings and clear-cuttings were studied separately; natural drainage was not allowed in either case. The comparisons were based on standard errors and biases.

3. Results

3.1 Final-state stand characteristics

Deviations of model outputs in final-state stand characteristics (a, BA, V, Dgm, Hgm, Hdom) were investigated by comparing the reference simulation results to single-stratum simulation results by stand classes presented in Table 1.

Table 3. Deviations of model outputs in final-state stand characteristics. Reference simulation versus single-stratum simulation. Relative deviation values calculated by reference stand values given in brackets.

Stand Class	Obs.		Age, a		BA, m2		V, m3		Dgm, cm		Hgm, m		H_{dom}, m	
1	68	bias	0.7	(0.8)	0.6	(1.7)	1.7	(0.5)	-0.1	(-0.3)	-0.2	(-1.1)	0.3	(1.2)
		se	1.5	(1.6)	1.8	(5.1)	11.4	(3.2)	0.6	(2.1)	0.5	(2.2)	0.5	(2.3)
2	50	bias	-0.4	(-0.5)	1.8	(4.7)	12.2	(3.4)	0.3	(0.9)	-0.3	(-1.5)	-0.6	(-2.8)
		se	17.1	(19.7)	5.6	(14.5)	75.9	(20.9)	1.9	(6.9)	1.3	(6.4)	2.6	(12.0)
3	20	bias	-2.2	(-2.9)	2.8	(6.0)	19.6	(4.7)	0.3	(1.1)	0.0	(0.2)	-0.2	(-1.1)
		se	8.5	(10.9)	8.4	(18.0)	85.9	(20.6)	1.7	(6.6)	0.9	(4.7)	2.0	(9.4)
Total	138	bias	-0.1	(-0.1)	1.4	(3.6)	8.1	(2.2)	0.1	(0.3)	-0.2	(-1.0)	-0.1	(-0.5)
		se	10.8	(12.4)	4.7	(12.5)	56.1	(15.2)	1.4	(4.9)	0.9	(4.4)	1.8	(7.9)

The error statistics (model outputs) derived for the final-state stand characteristics presented in Table 3 indicate that the use of stratumwise stock data is significant in each of the three stand classes studied. The greatest influence can be seen in the two-species and three-species stand classes. In the one-species stands, where the proportion of other species is less than 10%, the single-stratum simulation results approach the reference simulation results and the respective deviations are clearly smaller than those in the other two stand classes. The differences between the error statistics of the two-species and three-species stand classes were not very large.

The most significant standard errors were related to stand V (3.2-20.6%) and BA (5.2-18.0%). On the other hand, the mean characteristics such as H_{gm} (2.2-6.4%) and D_{gm} (2.1-6.9%) were not as sensitive to the use of single-stratum simulation. A minor bias (3.4- 6.1%) can be observed in the simulation results of stand V and BA. However, single-stratum simulation of H_{gm} and D_{gm} did not result in significant bias.

The standard errors increased rapidly as the simulation period lengthened in both multispecies stand classes (Figure 1). In stand class 1, secondary tree species (max. 10%) did not cause significant deviations. An especially strong increase in standard errors was found in stand V. When single-stratum simulation was used, the simulation period length did not have large affect the simulation error of the mean stand characteristics. In these cases the final state standard errors were only about 5%.

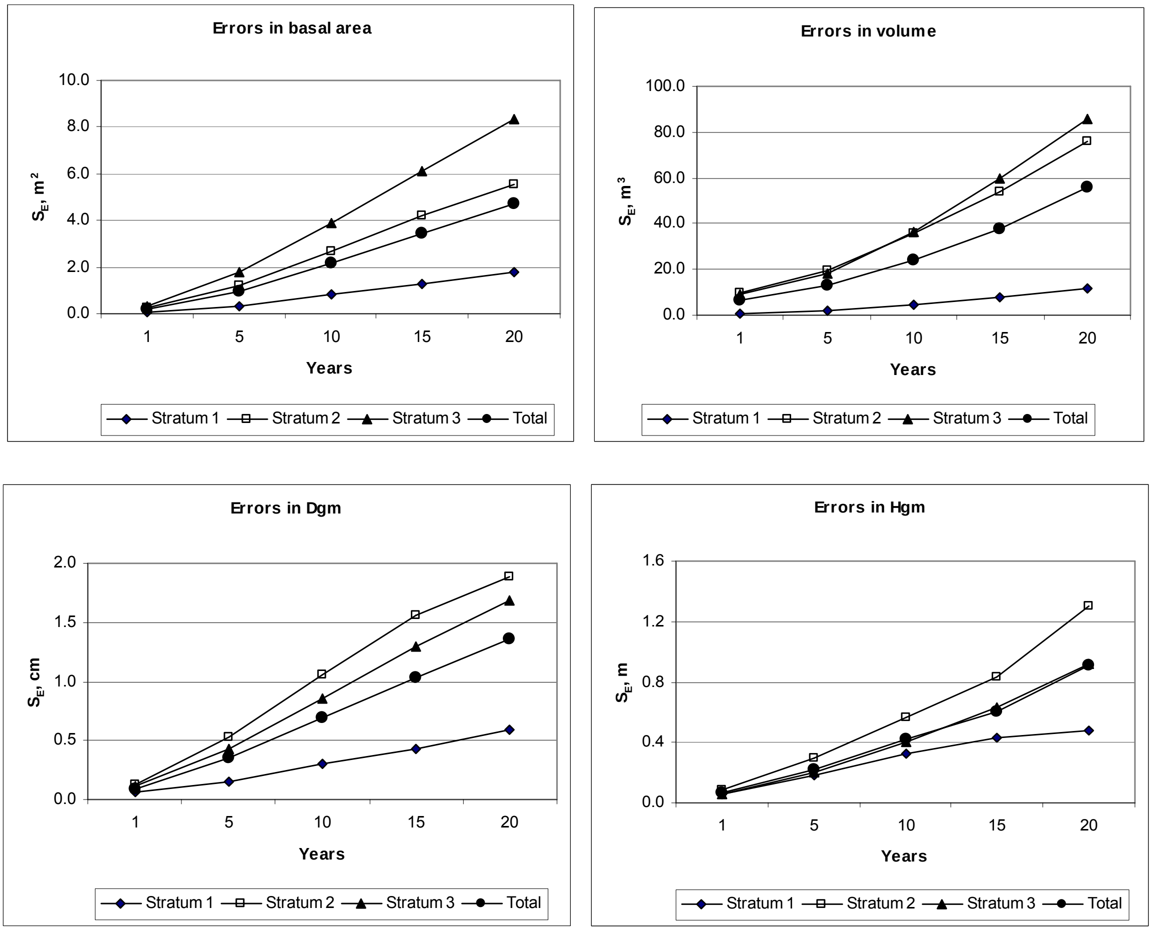

Figure 1. Error standard errors by simulation year (1-20) and stand class.

3.2 Timing of operations

Differences in the timing of simulated thinnings and clear-cuttings were then investigated (Table 4).

Table 4. Error in timing of the next logging operation. Reference simulation versus single-stratum simulation. The proportion of correctly defined operations (logging type identical) is given in brackets.

Timing error, next operation, a				
Stand class	Operation	Obs.	Bias	s_e
1		47	-0.3	1.0
	Thinning (100)	21	-0.7	1.5
	Clear-cutting (100)	26	0.0	0.5
2		38	0.9	4.3
	Thinning (66.7)	21	1.6	4.5
	Clear-cutting (73.7)	17	0.2	4.0
3		19	0.8	3.3
	Thinning (73.3)	14	0.5	3.1
	Clear-cutting (80.0)	5	1.8	4.3
Total		104	0.4	3.0
	Thinning (80.7)	56	0.4	3.3
	Clear-cutting (36.0)	48	0.3	2.7

The standard errors in timing varied from 0.5 to 1.5 years and from 3.1 to 4.5 years in single-species and multispecies stands, respectively; i.e. stratumwise simulation also had significantly influences the level of these errors. The errors found in multispecies stands are especially significant in this respect, since the average time to the next logging operation was only 5.3 years, resulting in 58-84% relative standard errors. No significant differences were found in the timing errors of thinnings and clear-cuttings. A slight timing bias (0.2-1.8 years) was also registered.

The definition of the next operation was fully correct only in the single-species stand class. Furthermore, the operation was defined correctly on an average of 66.7-73.7% and 73.3-80% of the cases in the two-species and three-species stand classes, respectively.

4. Discussion

The objective here was to investigate the significance of tree species stratum data in forest-planning simulations by comparing the simulation results obtained using mean stand characteristics with those obtained by stratumwise data. The simulations were carried out using actual treewise measured field material and the SIMO simulation software. Comparisons were performed on the development of stand characteristics during the simulation period (20 years) and the timing of the first logging operation occurring during the simulation period.

The simulation period commonly used in forest planning in Finland is 20 years, the same as the period length used in this study. In addition, a simulation period of this length ensures that the number of simulated operations is sufficient and that the functioning of the growth models is revealed. Since the development of stand characteristics without logging operations was also investigated, it was not deemed necessary to further extend the simulation period.

In light of the present results, the use of tree species stratum data in forest-planning simulations is highly relevant from the viewpoint of both the development of stand characteristics and the timing of logging operations. The relative standard errors stemming from the level of input data varied from 2.1% to 20.6% and from 58% to 84% in stand characteristics and timing of logging operations, respectively. The largest standard error in the stand characteristics was found for stand V (3.2-20.6%) and BA (5.2-18.0%), probably because the V increment simulation was based on the increment functions of D_{gm} and H_{gm}, which naturally vary by tree species. The stratumwise data were not as relevant for simulating mean characteristic development (H_{gm} and D_{gm}) as it was for simulating BA and V development, probably because the mean characteristics are BA-weighted and the dominant species thus always has the greatest influence in the calculations.

A slight bias was registered in the simulation results of stand V and BA (3.4-6.1%). However, no bias was found in the simulation results of the mean characteristics. If the intraspecies variation in a stand was not addressed, the simulations could have slightly underestimated the development of BA and V due to differences in the specieswise growth models. Simulation of the mean characteristics is not as sensitive to this type of variation. In general, the significance of the stratumwise input data culminates in the functioning of the specieswise and sitewise growth models at different stages of stand development. Future investigations should further address these factors.

Our study highlights the importance of tree species stratum data in forest-planning simulations. It is therefore essential to acquire stratumwise data for forest-planning input data. The results of our study could be utilized for assessing the suitability of ALS methods for feature-based or single-tree estimation when detailed forest inventory data are integrated with forest planning and operational logging planning.

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