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# Empirical Errors of Small Area Estimates from the Multisource National Forest Inventory in Eastern Finland

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The precision of multisource national forest inventory (MS-NFI) estimators and simple synthetic estimators based on NFI field data only was assessed employing an independent inventory data set of several small areas in Eastern Finland. There were seven test units of size 100 km$^2$ and three test units of size 1 km$^2$ for which a systematic field sampling was carried out. The 'improved' MS-NFI method yielded the most precise estimates for mean volume and mean volume of pine and spruce: relative root mean square errors (RMSE$^*$) were 5%, 12% and 15% for 100 km$^2$ test units and 13%, 27% and 40% for 1 km$^2$ test units respectively. The stratified MS-NFI method was best for broad-leaved volume estimation. Synthetic estimation based on the NFI9 field plots post-stratified with coarse scale forest variable maps from NFI8 resulted in RMSE$^*$s comparable to those of the ordinary MS-NFI in areas of 100 km$^2$ for mean volume and mean volume of pine and spruce. The amount of variation between the field inventory estimates for the test units explained by the MS-NFI estimators remained the same or increased when the size of the area increased from of 1 km$^2$ to 100 km$^2$ and up to 2000 km$^2$. The validation of the largest areas was made against the NFI9 field inventory estimates for groups of municipalities in the study area.

**Keywords** *k*-nearest neighbours estimation, Landsat ETM+, multisource forest inventory, synthetic estimation
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# 1 Introduction

Since the 1980's, multisource inventory methods employing optical wavelength satellite images and digital maps, in addition to field plot data, have been used to estimate forest variables for small areas (Tomppo 1996, Tokola and Heikkilä 1997, Nilsson 1997, Franco-Lopez et al. 2001, Lappi 2001). The variables of interest have been volumes by tree species, basal area, mean age, and mean breast height diameter of the stand. The Finnish multisource national forest inventory (MS-NFI) produces geo-referenced information, thematic maps and small area statistics. A non-parametric *k*-nearest neighbour method (*k*-NN) is used in the estimation. Field data from surrounding calculation units (municipalities), in addition to the unit itself, are utilised when estimating results for one unit (Tomppo 2006).

Analytical methods to estimate the error at the pixel level and to derive the error estimates for small areas are still under research in the Finnish MS-NFI. Average estimates of error at the pixel level can be determined and significant errors at subregion level (groups of municipalities) can be detected in the MS-NFI (Katila et al. 2000, Katila and Tomppo 2001). The uncertainty of the precision of small area estimates of MS-NFI is a clear drawback for their use as a data source in further analysis, e.g. as a basis for long term forest simulation (Tokola and Pesonen 1996) or for forest management planning purposes (Uuttera et al. 2002).

The precision of the multisource inventory estimates for small areas has been assessed empirically using independent test data. Often these data have been collected from secondary sources, e.g. forest management planning data based on interpretation of aerial photographs and subjectively selected field measurements (Päivinen et al. 1993, Tokola and Heikkilä 1997, Tomppo et al. 1998, Hyyppä et al. 2000). A field check based on sampling can be used to evaluate the precision of the estimates based on forest management planning data and possibly to correct for the average systematic errors (Laasasenaho and Päivinen 1986). However, uncertainty remains concerning the precision of this kind of test data. The error components (sampling, measurement and model errors) of the independent test data increase the total mean square error (MSE) used as a standard error estimate for multisource estimates. The published results have lead to a discussion of the contribution of MS-NFI data to small area estimation and even to a radical claim that the large region means based on NFI plots would be more precise than MS-NFI estimates for areas larger than 1000 ha (Päivinen and Anttila 2001).

Systematic field plot samples were measured on several areas of approximately 100 km$^2$ and 1 km$^2$ in Eastern Finland during Autumn 2000 to obtain an independent test data. The test units were located over a large geographical area, within an area of a Landsat ETM+ image (Katila and Tomppo 2006). The aim of this paper is 1) to give baseline figures of the precision of MS-NFI estimates from the operative inventory for the most important forest variables; 2) to verify the efficiency of some methodological advancements in the Finnish MS-NFI (Katila et al. 2000, Katila and Tomppo 2001, Katila and Tomppo 2002, Tomppo and Halme 2004); and 3) to study the improvement in the precision of small area estimates based on combination of satellite image data (MS-NFI) and NFI field data compared to those based on NFI field data only. The variables of interest are area of forestry land (FRYL, consisting of forest land, other wooded land, and waste land), mean volume of growing stock (m$^3$/ha) and total volume of growing stock (m$^3$) as well as mean and total volumes by tree species.

# 2 Materials

The study area is located between longitudes 27°40'E and 31°36'E and latitudes 61°21'N and 63°50'N (Fig. 1). The study area consists largely of medium fertile mineral soils. The forests are characterised by Scots pine (*Pinus sylvestris* L.) or Norway spruce (*Picea abies* (L.) Karst.), mixed with birch (*Betula* spp.) and other deciduous species.

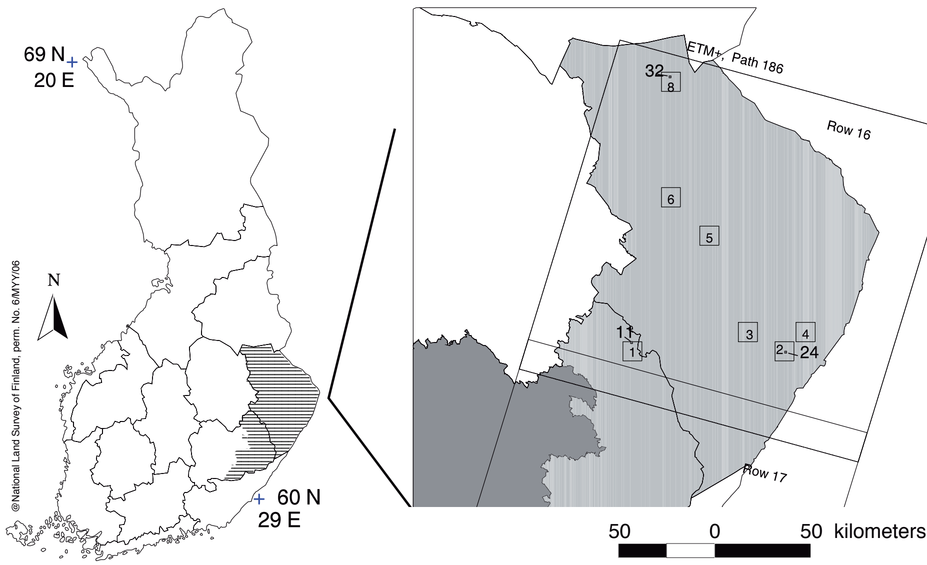


**Fig. 1.** Location of the study area, borders of Forest Centres (large regions), the large and small test units, the area covered by the two main Landsat 7 ETM+ images and the NFI9 field data from year 1999 (dark grey) and 2000 (light grey).

## 2.1 National Forest Inventory Field Data

The field sample of the 9th national forest inventory (NFI9) was measured from systematically located clusters of sample plots. There were 10–18 sample plots per cluster located along a rectangular or L-shape tract at 250 or 300 m intervals, depending on the area. The distance between clusters was 6 km × 6 km or 7 km × 7 km. Trees were measured from field plots belonging to forest and other wooded land (FOWL) stands. The tally trees were selected using the sampling with probability proportional to size by applying a basal area factor two. The probability of a tree's inclusion was proportional to its cross-sectional area at a height of 1.3 m; a maximum radius of 12.52 m was used (Tomppo et al. 2001, Korhonen et al. 2001).

## 2.2 Satellite Images and Map Data

Ninety-five percent of the area of test units was covered by a single Landsat 7 ETM+ satellite image from the same year (2000) as the measured test data. (Fig. 1, Table 1). The NFI9 field data from 1999 and 2000 were used in the MS-NFI estimation.

**Table 1.** Landsat 7 ETM+ Satellite images.

| Path/row | Date |
|---|---|
| 186/16 | 10.6.2000 |
| 186/17 | 10.6.2000 |
| 187/16 | 2.8.1999 |
| 185/16 | 4.8.1999 |

The satellite images were rectified to the national coordinate system using regression models of first or second order polynomials fitted to 30–70 control points that were identified from base maps. The nearest neighbour method was applied for the re-sampling of the images to 25 m × 25 m pixel size (Tomppo, 2006). All eight channels of Landsat 7 ETM+, including the thermal and panchromatic channels, were used in the *k*-NN estimation. The digital map data obtained from the National Land Survey was used to delineate the FRYL area and to stratify the FRYL for the *k*-NN estimation (Katila and Tomppo 2002). The digital elevation model was used to correct spectral values for the effect of the varying angle between sun elevation and surface normal (Tomppo 2006).

### 2.3 The Independent Field Data

Systematic field plot samples were measured on seven large test units using plot distances of 400 m × 300 m (north-south and east-west directions) (Table 2). The sample considered 25 lines (east-west direction) of 33 plots corresponding total area of 99 km$^2$. Three small test units were measured using 80 m × 75 m (unit 11) and 100 m × 75 m (units 24 and 32) plot distances in north-south and east-west directions respectively. The samples consisted of 13 lines (east-west direction) of 14 plots (unit 11) and 10 lines (east-west direction) of 14 plots covering total areas of 1.176 km$^2$ and 1.47 km$^2$, respectively (Fig. 1). There were in total 5775 field plots on the large test units and 462 field plots on the three small test units (Katila and Tomppo 2006).

**Table 2.** The measured field samples on large and small test units, number of field plots, total and on Forestry land.

| Unit | No. of field plots Total | FRYL | Total area ha |
|---|---|---|---|
| 1 | 825 | 680 | 9900 |
| 2 | 808 | 724 | 9696 |
| 3 | 712 | 607 | 8544 |
| 4 | 825 | 686 | 9900 |
| 5 | 825 | 746 | 9900 |
| 6 | 825 | 710 | 9900 |
| 8 | 825 | 722 | 9900 |
| 11 (a) | 182 | 178 | 117.6 |
| 24 (b) | 140 | 137 | 147 |
| 32 (b) | 140 | 138 | 147 |

(a) 80 m × 75 m plot distances.
(b) 100 m × 75 m plot distances.

# 3 Methods

### 3.1 MS-NFI Method

The FRYL is separated from other land use on the basis of the digital map data. The satellite images and other supplementary data are used to find, for each pixel $p$ belonging to the FRYL, $k$ most similar field plots in the training data set using the $k$-NN method. Forest variable estimates are weighted sums or averages of field measurements in plots $i$ belonging to the training data set $J$. The field plots are sorted according to Euclidean distance $d_{pi,p}$ between field plot pixels $p_i$ and pixel $p$ in the image feature space, and the $k$ nearest plots are chosen. The weight $w_{i,p}$ of the field plot $i$ to the pixel $p$ is defined as

$$w_{i,p} = \frac{1}{d^t_{p_i,p}} \Big/ \sum_{j\in\{i_1(p),\ldots,i_k(p)\}} \frac{1}{d^t_{p_j,p}}, \quad \text{if and only if } i \in \{i_1(p),\ldots,i_k(p)\} \tag{1}$$
$$= 0, \quad \text{otherwise,}$$

where $\{i_1(p), \ldots, i_k(p)\}$ is the set of the field plots whose corresponding pixels are the $k$ nearest ones to the pixel $p$. In this study, the value $t = 2$ was applied for the weighting parameter. MS-NFI results can be obtained from single pixel level to small areas (Tomppo 2006). Two sets of MS-NFI estimates were produced applying $k = 1$ and $k = 8$.

In the improved $k$-NN estimation (iMS-NFI) by Tomppo and Halme (2004), new features are introduced to the distance vector $d_{pi,p}$: i.e. all possible ratios of spectral bands and coarse scale forest variable predictions of key variables. 1 km×1 km size coarse maps are produced filling the pixels with the NFI cluster level averages of mean volumes (m$^3$/ha) of field plots, followed by low pass filtering of the maps. All the feature space variables are weighted prior to the calculation of the distance metric. The weighting is defined by means of genetic optimization algorithm. The parameter selection of the genetic algorithm is based on a pixel-level leave-one-out validation of the improved $k$-NN predictions. The objective function to be minimized is a linear combination of standard errors and biases for forest variables.

The digital map data used to delineate the FRYL includes errors and the area of FRYL is often overestimated (Katila and Tomppo 2002). Two methods have been introduced to reduce the effect of the errors in map data on MS-NFI small-area estimates: calibrated MS-NFI (cMS-NFI) and stratified MS-NFI (sMS-NFI). The calibration method is based on the confusion matrix estimated between land use classes of the field sample plots and the corresponding map information, for a large region. If the map strata can be expected to be reasonably homogeneous with respect to the map errors and land use class distribution, the proportions estimated for large region can be used to calibrate for MS-NFI land use class area estimates (based on map data) for small areas. Further, the field plot weights from $k$-NN estimation for computation unit $U$ (small area) are calibrated in such a way that the sum of the calibrated weights over all training data plots is equal to the calibrated FRYL area estimates from above (Katila et al. 2000). In the sMS-NFI, the $k$-NN estimation is applied within strata. All the field plots within each map stratum, regardless of the field measurement based land use class, are used for estimating the areas of land use classes and forest variables of the particular stratum simultaneously. The target area was stratified to FRYL mineral soil, FRYL peatland, arable land, built-up land and water (Katila and Tomppo 2002). These two methods can be applied both with ordinary and improved MS-NFI.

### 3.2 Simple Synthetic Estimators for Small Areas

The NFI field inventory estimates for a large region were used as a simple global estimator (SYN_glb). The NFI estimators based on pure field data are ratio estimators $\hat{M} = \sum_i y_i / \sum_i x_i$ where, for example, $x_i$ is the number of sample plots in cluster $i$ on stratum of interest, e.g. FRYL, and $y_i$ is the number of plots on subclass $l$ (proportions) or sum of the mean volumes of plots in stratum of interest (mean volume) (Heikkinen 2006). NFI field inventory estimates of mean volume and land use class proportions for a forestry centre were used as estimates for each of the test units belonging to the specific forestry centre (Tomppo et al. 2001, Korhonen et al. 2001). The total area estimates were derived from the resulting proportion of subclasses $l$ by multiplying them with the land area obtained from map data for each test unit.

The global estimator was modified to obtain another synthetic ratio of means estimator (SYN_rad) by setting the maximum allowed geographical horizontal distance from the centre point of the test unit to the field plots used in the estimation to be less than or equal to 30 km. In this way, the effect of the gradual changes in the average structure of the growing stock was minimised in the synthetic estimator, cf. (Katila and Tomppo 2001). The selected radius yields approximately a minimum number of field plots for which NFI9 field estimates can be calculated. The estimates of mean volume and land use class proportions were calculated from the NFI plots within the defined circle.

A third synthetic-ratio estimator (SYNG/R) for mean values of a small area $U$ employed post-stratification sample means $\hat{M}_h$ of the large region:

$$\hat{y}_U = \sum_{h=1}^{H} W_{U_h} \hat{M}_h , \tag{2}$$

where $h$ is a stratum in a large area $R$ (a forestry centre in this study) and $W_{U_h}$ is the proportion of $h$ in the cross-classification of strata and small area $U$ (Särndal and Hidiroglou 1989, Schreuder et al. 1993). The stratification was based on coarse scale maps from the NFI8 produced as for iMS-NFI (section 3.1). The mean volume and mean volume by tree species maps were stratified to 10 $m^3$/ha classes. The NFI8 data was used for bases of coarse scale maps because it was independent of the NFI9 data.

### 3.3 Forest Variable Estimation for the Test Units

The ratio estimators were applied to calculate the forest variable estimates for the test units. The standard errors (SE) were estimated using local quadratic forms as presented by Matérn (1960) and applied in the Finnish NFI (Heikkinen 2006). Plot-wise residuals were used in the error estimations. A post-stratification was applied when it yielded smaller SEs (not used in the volume estimation of small units). The post-stratification was based on digital map data (land use class estimation) and the MS-NFI9 thematic map of mean volume (volume estimation). In the former, the strata were as for the sMS-NFI (section 3.1) and in the latter, the FRYL was in addition stratified to four equal area strata.

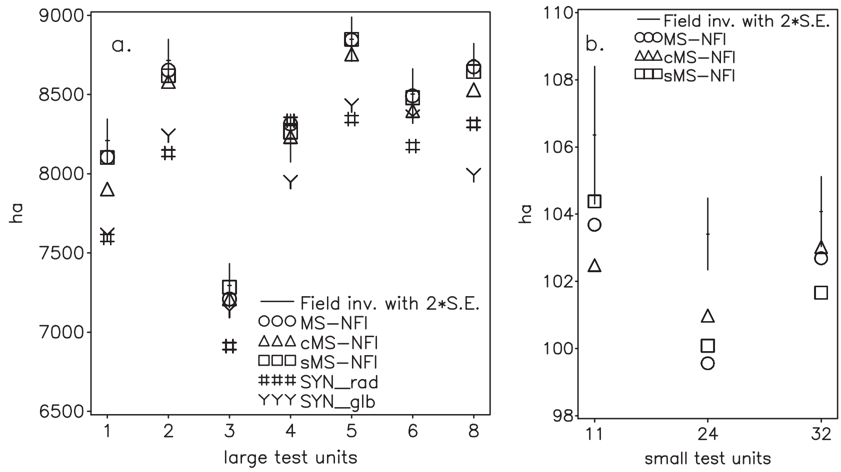


**Fig. 2.** FRYL (ha), large (a) and small (b) test units: pure field data estimates +/– two standard errors, MS-NFI, calibrated and stratified MS-NFI and synthetic estimators.

### 3.4 Results Validation

The field inventory estimates of variables and their standard errors for the test units, hereafter referred to as the reference values, were used for validation of the MS-NFI and synthetic estimators. The root mean square error RMSE$^*$ was used as a measure of prediction error of the estimates of continuous variables for small areas,

$$\mathrm{RMSE}^* = \sqrt{\frac{\sum_{U=1}^{n}(\hat{y}_U - y_U^*)^2}{n}} \, . \tag{3}$$

The reference value $y_U^*$ is the field inventory based estimate and $\hat{y}_U$ is the estimated value for small area $U$. The resulting RMSE$^*$ can be considered a conservative measure of precision because it contains the sampling error of the field data estimate. The relative RMSE$^*$ is obtained by dividing the RMSE$^*$ by the average of reference values $y_U^*$. The bias is $\bar{e}^* = \sum_{U=1}^{n}(\hat{y}_U - y_U^*)/n$. The RMSE$^*$s of the MS-NFI and synthetic estimates were compared with the standard deviation $s(y_U^*)$ of the field plot data estimates. An $R^{*\,2}$ coefficient was computed to evaluate the amount of variation reduced by the different estimators:

$$R^{*2} = 1 - \frac{MSE^*}{s(y_U^*)^2} \tag{4}$$

constrained by $R^{*2} \geq 0$ (cf. Tokola et al. 1996).

# 4 Results

### 4.1 The Precision of the MS-NFI and Synthetic Estimates of Forestry Land Area

The FRYL area estimates from the MS-NFI methods and the synthetic estimators were mostly underestimates (Fig. 2). This is contrary to the usual overestimation of FRYL in municipality level results based on map data (Tomppo et al. 1998). However, the test units were originally chosen by restricting the proportion of water to be less than 20% (Katila and Tomppo 2006). Therefore, the FRYL area proportion is higher than for the overall study area. The MS-NFI FRYL area estimates for the large test units did not deviate significantly (were within two SEs) from the reference values except for the cMS-NFI (Fig. 2). Only the map calibration increased the error in the MS-NFI estimates, which can be seen in the RMSEs calculated for the set of test units (Table 3) and in the significant deviations of the estimates from reference values in Fig. 2a. It should be noted that the MS-NFI and iMS-NFI estimates of FRYL are equal because the map data used to delineate the FRYL and the calibration matrix are the same in both methods. The synthetic estimates based on NFI9 field data only (and to the total land area of the test units obtained from map data) deviated significantly, as expected, from the

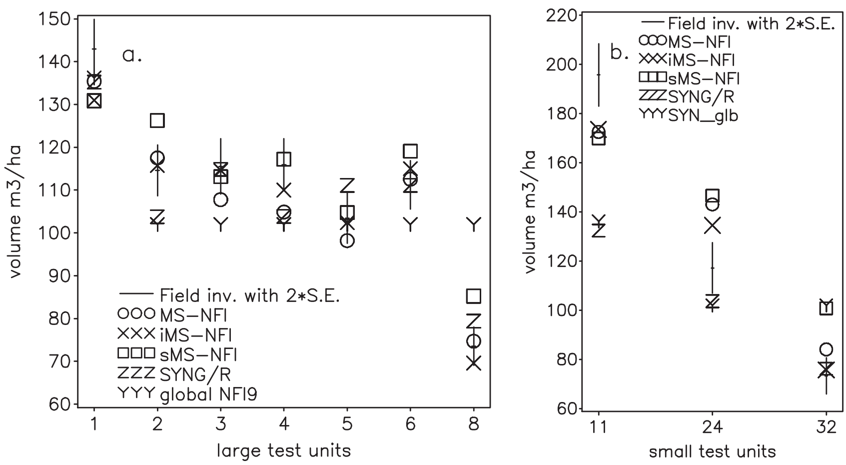


**Fig. 3.** Mean volume ($m^3$/ha), large (a) and small (b) test units: pure field data estimates +/– two standard errors, MS-NFI, improved MS-NFI and stratified MS-NFI and synthetic estimators.

**Table 3.** The mean ($\bar{y}_U^*$) and standard deviation ($s(y_U^*)$) of the field sample based FRYL estimates and the absolute and relative RMSE$^*$, bias ($\bar{e}^*$) and $R^{*2}$ coefficient for the MS-NFI and synthetic estimates of FRYL for the test units.

| Method | $\bar{y}_U^*$ (ha) | $s(y_U^*)$ (ha) | RMSE$^*$ (ha) | RMSE$^*$ (%) | $\bar{e}^*$ (ha) | $R^{*2}$ |
|---|---|---|---|---|---|---|
| LARGE UNITS, $n$=7 | | | | | | |
| Field sample | 8359 | 531 | | | | |
| MS-NFI(a) | | | 67 | 0.8 | –31 | 0.98 |
| cMS-NFI(a) | | | 158 | 1.9 | –129 | 0.91 |
| sMS-NFI | | | 63 | 0.8 | –39 | 0.99 |
| Stratified iMS-NFI | | | 81 | 1.0 | –62 | 0.98 |
| SYN_glb | | | 448 | 5.4 | –387 | 0.29 |
| SYN_rad | | | 448 | 5.4 | –399 | 0.29 |
| SMALL UNITS, $n$=3 | | | | | | |
| Field sample | 104.6 | 1.5 | | | | |
| MS-NFI(a) | | | 2.8 | 2.7 | –2.6 | 0 |
| cMS-NFI(a) | | | 2.7 | 2.6 | –2.4 | 0 |
| sMS-NFI | | | 2.6 | 2.5 | –2.6 | 0 |
| Stratified iMS-NFI | | | 2.8 | 2.6 | –2.7 | 0 |

(a) same results for iMS-NFI

reference values (Fig. 2a). In the small test units, the estimates deviated significantly for most of the predictions and there were no clear differences between the different versions of MS-NFI method (Table 3, Fig. 3b). A possible explanation is that the digital raster map data was not precise enough for areas this small. There is also uncertainty in the measures of prediction error on average for the small test units because there were only three small test units available.

## 4.2 The Precision of the MS-NFI and Synthetic Estimates of Volumes

The mean volumes from the MS-NFI methods were mostly within the two SEs of the reference values for the large test units (Fig. 3a). Only the stratified MS-NFI resulted in poorer estimates. The global synthetic estimates based on NFI9 field data (SYN_glb) deviated significantly from the reference values in many cases,

**Table 4.** The relative RMSE* of mean volume and mean volume by tree species estimates on FOWL from the MS-NFI and synthetic estimators and the mean of the field sample based estimates.

| Variable | Field sample volume estim. (m$^3$/ha) | Relative RMSE* (%) MS-NFI $k$=8 | $k$=1 | Calibr. | Impr. | Impr. & calibrated | Stratified | Impr. & stratified | Synthetic estimators SYNG/R | SYN _rad | SYN _glb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LARGE UNITS, $n$=7 | | | | | | | | | | | |
| Pine | 45.4 | 20.8 | 17.6 | 22.8 | 12.4 | 13.0 | 27.6 | 14.2 | 22.2 | 17.6 | 25.1 |
| Spruce | 46.3 | 26.0 | 24.8 | 24.7 | 14.6 | 13.1 | 25.8 | 13.3 | 27.5 | 33.5 | 41.6 |
| Birch | 16.1 | 17.7 | 17.5 | 17.4 | 16.1 | 16.0 | 8.6 | 15.4 | 24.9 | 17.6 | 21.4 |
| Other dec. | 3.3 | 26.1 | 22.6 | 26.2 | 28.9 | 28.0 | 22.5 | 26.4 | 62.7 | 67.8 | 56.6 |
| Total | 111.0 | 5.7 | 6.2 | 4.9 | 4.9 | 4.2 | 7.5 | 4.2 | 6.9 | 11.0 | 13.1 |
| SMALL UNITS, $n$=3 | | | | | | | | | | | |
| Pine | 37.9 | 62.3 | 59.5 | 62.8 | 36.5 | 36.6 | 64.8 | 38.3 | 50.1 | 43.8 | 56.6 |
| Spruce | 73.9 | 43.6 | 43.5 | 42.7 | 26.6 | 25.1 | 44.0 | 26.4 | 70.2 | 75.8 | 80.9 |
| Birch | 15.0 | 19.0 | 17.4 | 19.4 | 39.6 | 40.3 | 25.2 | 38.2 | 30.4 | 32.1 | 27.7 |
| Other dec. | 2.0 | 55.9 | 53.3 | 52.4 | 67.2 | 62.5 | 77.0 | 71.9 | 79.3 | 128.7 | 140.4 |
| Total | 128.7 | 16.3 | 15.5 | 16.0 | 12.7 | 12.1 | 21.5 | 12.7 | 29.0 | 34.2 | 30.4 |

whereas the SYNG/R estimator gave reasonable estimates compared to the MS-NFI. For the small test units, the errors were significant even for the MS-NFI methods in two out of three cases (Fig. 3b). It should be noted that the three units were purposively chosen to represent lowest and highest mean volumes of the growing stock variation inside the large units. The correction of map errors in the MS-NFI using stratification or calibration did not improve the volume estimates.

The RMSE*s of the estimates were larger for the volumes by tree species. The iMS-NFI gave the smallest relative RMSE* for pine and spruce mean volume, 12% and 15%, respectively, for large units and 37% and 27%, respectively, for small units (Table 4). The smallest relative RMSE* for birch volume was obtained with stratified MS-NFI and ordinary MS-NFI (9% and 17%) for large and small units, correspondingly. The RMSE*of the MS-NFI estimates applying the value $k$ = 1 were as small (and by tree species even smaller) as in the case of the ordinary MS-NFI ($k$ = 8). The RMSE*s of the synthetic estimators SYN_rad and SYNG/R were of the same magnitude as the ordinary MS-NFI for pine, spruce and birch volume of large units and for pine volume of small units.

In Fig. 4, the RMSE*s of mean volume and mean volumes by tree species estimates obtained for the ordinary MS-NFI, iMS-NFI, SYNG/R and SYN_glb are presented against the average area of FOWL for the small and large test units. In addition, the RMSE*s are calculated for groups of municipalities (1700–2900 km$^2$ of FOWL) from the MS-NFI9 estimations covering the NFI9 field work area in the year 2000. These results are extracted from Tomppo and Halme (2004). The RMSE*s of all the variables decrease when the size of the units increases. However, the decrease is slower between 100 km$^2$ and 2300 km$^2$. The SYNG/R estimates were not calculated for groups of municipalities because they were considered to be too dependent on the 'true values' of groups of municipalities. It should also be noted that the validation data for groups of municipalities (based on NFI9 field data) was not independent of the MS-NFI estimations.

The ordinary MS-NFI estimator decreases (explains) the variation between the test units by more than half measured with the $R^{*2}$coefficient, for mean volume and mean volume of spruce both for large and small test units, as well as for the volume of birch for small units (Table 5). The $R^{*2}$ coefficients were clearly higher when applying the iMS-NFI for mean volume of pine and spruce for large units and for mean volume of spruce for small units, whereas the predictions for birch and other broad-leaved volumes were poorer. The explanatory power of the post-stratification based synthetic estimator SYNG/R was comparable to the ordinary MS-NFI for the mean volume and mean volume of spruce for large units. It should be noted that the variation of the

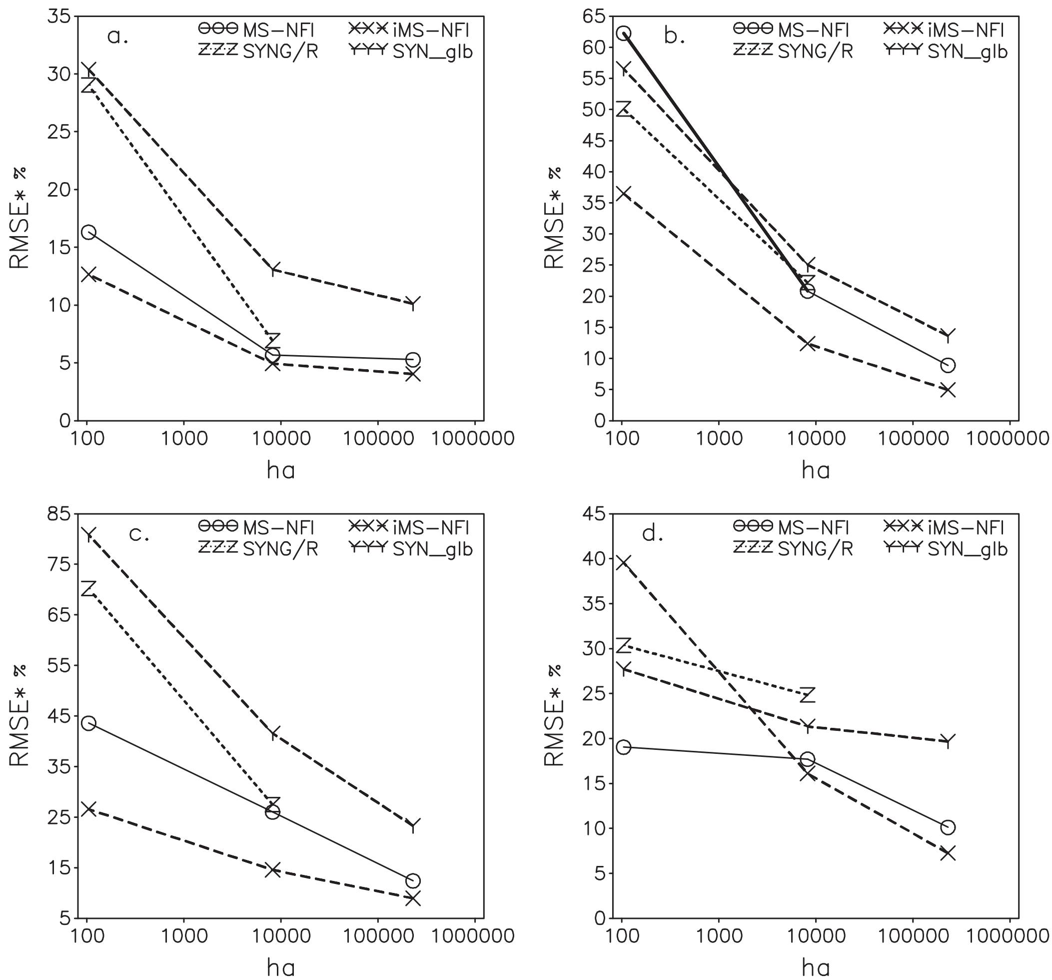


**Fig. 4.** The relative RMSE* (%) of mean volume (a), mean volume of pine (b), mean volume of spruce (c), and mean volume of birch (d) of MS-NFI, improved MS-NFI and two synthetic estimators against the average area (logarithmic scale) of forest and other wooded land of large and small test units and groups of municipalities from the year 2000 NFI field work area.

pine mean volumes for the test units was smaller than those for spruce and the $R^{*2}$ coefficients were poorer even though the relative RMSE* were of the same magnitude.

In Fig. 5a and 5b, the $R^{*2}$ coefficients obtained for ordinary MS-NFI and iMS-NFI method are presented against the average area of FOWL for the small and large test units and groups of municipalities (cf. Fig. 4). The two MS-NFI estimators show an increasing explanatory power for most of the variables as the size of the inventory area increases. For birch volume, however, the coefficients are inconsistent.

The results for the total volume estimates on FOWL from the MS-NFI followed the trends of the mean volume estimates: the estimates were mostly within two SEs of the reference values for the large test units and only the stratified MS-NFI resulted in poorer estimates (Table 6). The similarity between the mean and total volume results is understandable because the ordinary MS-NFI and iMS-NFI use the same FRYL area delineated from the numerical map data. The calibration of map errors was also done in same way in both

**Table 5.** The $R^{*2}$ coefficient of mean volume and mean volume by tree species estimates on FOWL from the MS-NFI and synthetic estimators and the standard deviation $s(y_U^*)$ of the field sample based estimates.

| Variable | $s(y_U^*)$ (m³/ha) | $R^{*2}$ MS-NFI k=8 | k=1 | Calibr. | Impr. | Impr. & calibrated | Stratified | Impr. & stratified | Synthetic estimators SYNG/R | SYN _rad | SYN _glb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LARGE UNITS, $n$=7 | | | | | | | | | | | |
| Pine | 8.5 | 0.00 | 0.11 | 0.00 | 0.56 | 0.52 | 0.00 | 0.43 | 0.00 | 0.12 | 0.00 |
| Spruce | 19.8 | 0.63 | 0.66 | 0.67 | 0.88 | 0.91 | 0.63 | 0.90 | 0.58 | 0.38 | 0.05 |
| Birch | 2.9 | 0.04 | 0.06 | 0.08 | 0.21 | 0.21 | 0.77 | 0.28 | 0.00 | 0.05 | 0.00 |
| Other dec. | 1.2 | 0.49 | 0.62 | 0.49 | 0.37 | 0.42 | 0.62 | 0.48 | 0.00 | 0.00 | 0.00 |
| Total | 20.6 | 0.91 | 0.89 | 0.93 | 0.93 | 0.95 | 0.83 | 0.95 | 0.86 | 0.65 | 0.50 |
| SMALL UNITS, $n$=3 | | | | | | | | | | | |
| Pine | 14.0 | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Spruce | 65.9 | 0.76 | 0.76 | 0.77 | 0.91 | 0.92 | 0.76 | 0.91 | 0.38 | 0.28 | 0.18 |
| Birch | 7.4 | 0.85 | 0.88 | 0.85 | 0.37 | 0.34 | 0.74 | 0.41 | 0.63 | 0.58 | 0.69 |
| Other dec. | 1.4 | 0.33 | 0.40 | 0.42 | 0.04 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 62.0 | 0.89 | 0.90 | 0.89 | 0.93 | 0.94 | 0.80 | 0.93 | 0.64 | 0.50 | 0.60 |

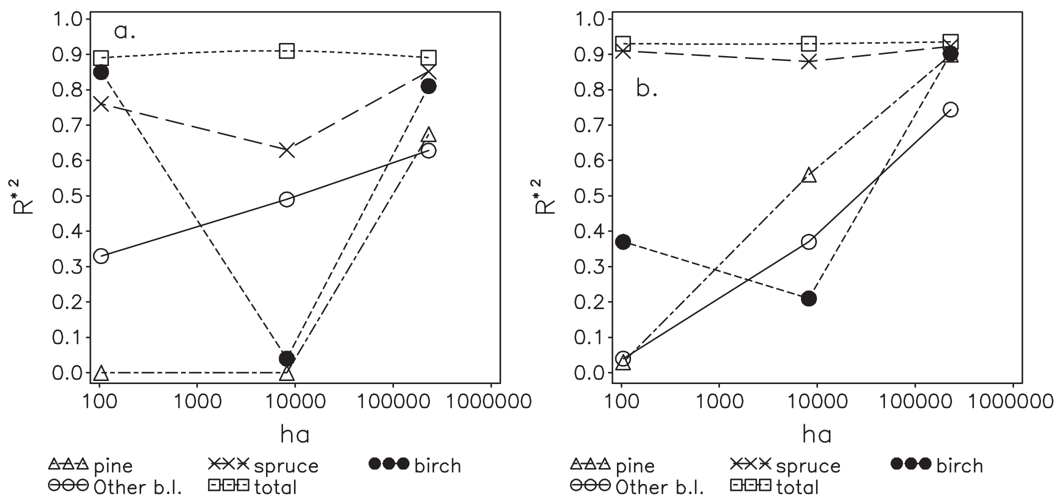


**Fig. 5.** The $R^{*2}$ coefficient of mean volume and volume by tree species estimates from the MS-NFI (a) and iMS-NFI (b) against the average area (logarithmic scale) of forest and other wooded land of large and small test units and groups of municipalities from the year 2000 NFI field work area.

methods. Only in the stratified MS-NFI was the bases for the FRYL area estimation different. The error in the total volume estimate was therefore a combination of FOWL area estimation error and the mean volume estimation error. The error estimates for the total volumes by tree species also agreed with the patterns of the mean volume estimates. The iMS-NFI estimates were more precise than the ones from ordinary MS-NFI for the total volumes of pine and spruce while the stratified MS-NFI estimates were most precise for the total volume of birch in large units and the ordinary MS-NFI in small units. Due to the similarities explained above, the relative RMSE*s calculated for the total volumes and total volumes by tree species were quite similar to those in Table 4, only the RMSE*s were roughly 0.5–1 percentage units higher in Table 6.

**Table 6.** The relative RMSE* of total volume and total volume by tree species estimates from the MS-NFI estimators and the mean of the field sample based estimates.

| Variable | Field sample volume estimate (1000 m$^3$) | Relative RMSE* of MS-NFI (%) $k$=8 | $k$=1 | Calibr. | Impr. | Improved & calibrated | Strat. | Improved & stratified |
|---|---|---|---|---|---|---|---|---|
| LARGE UNITS, $n$=7 | | | | | | | | |
| Pine | 371.3 | 20.8 | 17.6 | 21.5 | 12.8 | 12.7 | 28.1 | 14.0 |
| Spruce | 380.4 | 26.2 | 25.0 | 25.9 | 15.0 | 14.7 | 26.1 | 14.2 |
| Birch | 132.6 | 17.7 | 17.7 | 18.2 | 15.6 | 16.6 | 8.4 | 14.6 |
| Other dec. | 26.6 | 25.5 | 22.1 | 24.8 | 28.2 | 26.9 | 23.0 | 25.8 |
| Total | 910.8 | 5.8 | 6.3 | 5.6 | 5.4 | 5.6 | 8.1 | 4.7 |
| SMALL UNITS, $n$=3 | | | | | | | | |
| Pine | 3.9 | 59.3 | 57.1 | 59.4 | 34.9 | 34.6 | 61.8 | 37.6 |
| Spruce | 7.7 | 46.2 | 45.9 | 46.1 | 29.3 | 28.7 | 46.2 | 28.3 |
| Birch | 1.6 | 19.8 | 18.3 | 21.3 | 41.1 | 42.7 | 24.3 | 39.1 |
| Other dec. | 0.2 | 52.0 | 49.6 | 48.4 | 62.5 | 57.0 | 72.2 | 68.7 |
| Total | 13.5 | 16.6 | 16.0 | 17.4 | 13.9 | 14.4 | 21.0 | 13.0 |

# 5 Discussion

In this study, the numerical map data applied in the 9th MS-NFI seem to be sufficiently precise for estimating the FRYL area on units of 100 km$^2$, yielding a relative RMSE* of less than 1%. For areas of size 1 km$^2$ there was more variation in the precision of the results. The calibration of map errors for small areas relies on the assumption that the errors in the map strata are equally distributed over the inventory (calibration) area (Katila et al. 2000). In this study, the calibration increased the error in the FRYL area estimates compared to the ordinary MS-NFI, and it seems that the method is sensitive to the deviation of the properties of the small area's map data from that of inventory area. The test data should also include areas dominated by non-FRYL in order to provide a more reliable validation of map correction methods.

Relative RMSE*s of 5%, 12%, 15% and 16% for mean volume and mean volumes of pine, spruce and birch, respectively, were obtained in the large test units when results were calculated using the iMS-NFI. The corresponding relative RMSE*s for small units were 13%, 37%, 27% and 40%. The RMSE*s of the small units can be considered to be 'conservative' because the three units were purposively chosen to represent the lowest and highest mean volumes of the growing stock variation inside the large units. The error estimates for the mean volume were clearly smaller than those presented in Tomppo et al. (1998), which were approximately 13% and 22% for areas of size 100 km$^2$ and 1 km$^2$, respectively. Tokola and Heikkilä (1997) obtained relative RMSE*s of 14%, 48%, 27% and 37% for mean volume and mean volumes of pine, spruce and deciduous species, respectively, for 1 km$^2$ areas using a multisource NFI method in Eastern Finland. In central Sweden, multisource NFI estimates of relative RMSE*s of 36%, 42%, 49% were obtained for mean volumes of pine, spruce and deciduous species, respectively (Rosengren et al. 1999). The results for areas of 1 km$^2$ seem to be of same magnitude in these studies. However, it should be noted that the test areas and the errors in these data, as well as the parameters applied in MS-NFI methods are different in each study. By reducing the sampling error in the test data, the random error component decreases in the results. In fact, if the test data is considered to be independent of the MS-NFI estimates, the MSE* consists of two variance components: the variance of the MS-NFI estimates and the variance of the test units, $E(MSE^*) = 1/n \sum_{U=1}^{n} \mathrm{var}(\hat{y}_U) + 1/n \sum_{U=1}^{n} \mathrm{var}(y_U^*)$. If we apply the sampling variances obtained for the test units to the latter and subtract them from the MSE* we obtain for large units (100 km$^2$) relative RMSE*s of 4%, 11%, 14% and 15% for mean volume and mean volumes of pine, spruce and birch, respectively.

Usually, $k$ values of 5–10 have been applied in the operative MS-NFI to obtain a smaller variance for *k*-NN predictions at the pixel level. The larger variance at pixel level cancels out when *k*-NN predictions using $k = 1$ are used to estimate small areas equivalent to the test units employed here, cf. (Katila and Tomppo 2002). In fact, the estimates of volumes by tree species are slightly more precise using $k = 1$. It is assumed that the nearest neighbour correlates most strongly with the target pixel and yields the best estimates for larger areas.

The MS-NFI and iMS-NFI underestimated the mean volume on average by 1–4 $m^3$/ha for the large test units, even after calibration. The training data contains the field plots totally belonging to the FRYL in the MS-NFI (and calibrated MS-NFI), but the stratified MS-NFI includes all field plots within each stratum (Katila and Tomppo 2002). It has been noticed that if the mean volume estimates are calculated from MS-NFI training data and from the original NFI field plot data for, e.g., FRYL, the MS-NFI training data yields growing stock estimates that are 2–3% lower. Despite this, in this study the stratified ordinary MS-NFI did not result in significantly more precise estimates; it overestimated the mean volumes of the 100 $km^2$ test units.

The global synthetic estimates (SYN_glb) of mean volumes deviated significantly in many cases from the reference values, as can be expected, cf. Schreuder et al. (1993). For this reason SYN_glb can not be recommended for small area estimation of the size of units tested. Measured by $RMSE^*$, average errors comparable to ordinary MS-NFI were obtained for the mean volume and the volume of pine and spruce for areas of size 100 $km^2$ using the NFI9 field plots and large scale forest variable maps from NFI8 (synthetic estimator SYNG/R) (Table 4). The results for the synthetic estimator using maximum geographical distance (SYN_rad) were slightly poorer. It seems that the information content of Landsat 7 ETM+ images combined with NFI field data is not greatly superior to the pure NFI data combined with coarse scale forest variable maps in the mean volume estimation at the 100 $km^2$ or municipality scale. However, the mean volume estimates obtained from the synthetic estimators were more vulnerable to significant deviations (gross errors) from the reference values of the test units (Fig. 3).

Päivinen and Anttila (2001) argued that the decrease of the RMSE of the MS-NFI estimates as the size of the inventory areas increase is due to the decreasing variation of the true values of variables, e.g. the mean volume, for these areas. While the $RMSE^*$s of mean and total volume estimates display a decreasing trend when the size of the test unit increases, the proportion of the variation between the test units explained by the MS-NFI methods ($R^{*2}$ coefficient) remains more or less constant for the mean volume and mean volume of spruce. For the other variables, the $R^{*2}$ coefficient increases when the size of the unit increases. These results confirm that the MS-NFI estimates of mean volume and mean volumes by tree species maintain explanatory power in the small area estimation between the scales of 1 $km^2$ to 2000 $km^2$ (Fig. 5, Table 5). However, we can conclude that the MS-NFI estimates of the pine and other broad-leaved volume were poor for areas of scale 1 $km^2$. The separation of pine was difficult in the MS-NFI suggesting that it can be considered as a ‘general’ tree species in the study area, cf. (Katila and Tomppo 2001).

There are some limitations to the generalisation of the above results. For example, there were only three small test units in this study and the test area represents specific Eastern Finland conditions. Nevertheless, the results obtained are consistent with the earlier findings and can be considered to represent the baseline of the average precision of the small area estimates from the present Finnish MS-NFI. This can be concluded from the consistency of the obtained estimation parameters in the operative MS-NFI using Landsat TM images and NFI field plot data in different geographical regions in Finland (Katila and Tomppo 2001).

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