MULTI-SOURCE NATIONAL FOREST INVENTORY OF FINLAND

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ABSTRACT

The National Forest Inventory of Finland has produced large-area forest resource information during 70 years. The Finnish Forest Research Institute started to develop a new inventory system 1989, during the eight rotation, in order to get geographicly localized, up-to-date information and for smaller areas than earlier. The method exploits satellite image data and digital map data in addition to the ground measurements. Image analysis method has been chosen in such a way that estimates of all variables of inventory could have been computed for each pixel. The system is now operative and the inventory has been made in an area of about 8 million hectares producing theme maps and statistics for large and small areas (even single stands). The results has been compared with the estimates of standwise forest inventory and in large areas with those based on field sample plots of the National forest inventory only. These results match quite well indicating the applicability of small area estimates.

KEY WORDS: National Forest Inventory, Satellite images, Digital map data, k nearest neighbor classification

1. INPUT DATA

The possible satellite image data are at this moment Landsat TM, Spot and MOS-1 images. Of these, TM has been used in the first phase. Later, also Spot images and possible spaceborn radar data will be used.

Digital map data consisting of agricultural areas, roads, and built areas are utilized in order to separate forest and non-forest areas from each other. Digital peatland information has been used in order to improve the accuracy of estimates within forestry land. The spectral response of peatlands differs from that of the mineral soils with the same growing stock according to our earlier studies. Further, some peatlands can not be separated from mineral soils.

Some administrative information such as community boundaries and, in the future, boundaries of forest holdings are used in the digital form in order to differentiate computation units, cf. Tomppo (1991).

The recent NFI data can serve as ground truth data. In the new sampling design, the needs of satellite image interpretation and change detection will be taken into account more thoroughly. A part of sample plots will be changed permanent from the year which increases the efficiency of change detection.

2. IMAGE INTERPRETATION

The image analysis consists of preprocessing of the image (image rectification, removal of noise, striping, etc.), choice of features, classification, and postprocessing (generalization). The method has chosen in such a way that all inventory variables can be estimated for each pixel. A *k nearest neighbor classification* has been applied so far. The Euclidean distance, $d_{i,p}$, is computed in the feature space from the pixel p to be classified to each pixel i whose ground truth is known (sample plots). Take $d_{(1),p}, ..., d_{(n),p}, (d_{(1),p} \leq .... \leq d_{(n),p})$, $n \sim 5-10$ and define $w_{(i),p} = \frac{1}{d^2_{(i),p}} \sum_{i=1}^{n} \frac{1}{d^2_{(i),p}}$. Define the estimate $\hat{m}_p$ of the variable M for the pixel p

$$\hat{m}_p = \sum_{j=1}^{n} w_{(j),p} \cdot m_{(j),p} \; , \qquad (1)$$

where $m_{(j),p}$, $j = 1, ..., n$, are the values of the variable M in the n closest pixels in the spectral space to the pixel p, see Tomppo (1991). Both areal statistics of computation units and theme maps (site fertility, timber assortments and growth by tree species, etc.) with land use information have been produced in the classification phase.

The spatial information of the image can be taken into account in the feature choice and/or in the postprocessing. Segmentation techniques or Gibbsian random field modelling, for example, are possible postprocessing methods, see Tomppo (1989).

3. DATA MANAGEMENT

Special attention must be paid to data management; total single date coverage of the country with TM imagery involves about five Gbytes and the output 20 Gbytes of data. The output of the image analysis is compatible with the forest management planning system (MELA) developed by the Finnish Forest Research Institute. This system allows simulation of the development of the forest between two ground measurement (and image analysis) timepoints.

Combining the inventory data from different time points and sources can be carried out using, for instance, Kalman Filter technique to produce minimum variance unbiased estimator for the recent state, see Czaplewski et al (1987).

4. EXAMPLES OF LARGE AREA RESULTS

The above methodology and input data have been applied operationally in estimating NFI -variables in areas of six forestry board districts in South and Central Finland, the total area amounting to 7.95 million hectares. One possibility to judge the goodness of estimates is to compare them in large areas with those based on field measurements only because the standard error of those estimates can be estimated and are fairly small, e.g. the standard error of the mean growing stock of field inventory in an area of one million hectares is of the size 1 - 2 %.

The level of large (or small) area statistics can be controlled by means of crossvalidation. The estimates of variables are computed for each ground truth sample plot excluding the plot itself. The ratio of the means of ground measurements and the means of image analysis estimates can be used as a calibration coefficient for large area statistics. Examples of the level of calibration coefficient are given in the table 1.

Table 1. Means of ground measurements (MG), means of image analysis estimates (ME) and their ratios (R) applied in calibration.

Variable	MG	ME	R
Pine saw wood	17.8818	16.6637	1.07310
Pine pulp wood	23.3407	23.4210	0.99657
Pine waste wood	2.6504	2.6944	0.98367
Spruce saw wood	24.8424	22.2868	1.11467
Spruce pulp wood	19.3566	17.9536	1.07814
Spruce waste wood	1.8874	1.8385	1.02662
Birch saw wood	1.9776	1.7531	1.12809
Birch pulp wood	9.1155	8.4983	1.07263
Birch waste wood	2.2059	2.3110	0.95452
Other saw wood	0.1086	0.1009	1.07664
Other pulp wood	1.5754	1.4169	1.11186
Other waste wood	0.9780	0.9193	1.06383
Pine growth	22.1145	22.1270	0.99943
Spruce growth	17.4325	16.1378	1.08023
Birch growth	6.9278	6.7973	1.01920
Other growth	2.2096	2.0973	1.05356

Tables 2 - 4 show the multisource inventory based estimates (MSI) and the estimates of field inventory (FI) for some mean characteristics in forestry board district of Central Finland, with the total area of 1 296 700 hectares.

Table 2. The FI and MSI estimates of mean tree volume by tree species on forest and scrub land, Central Finland, area 1 296 700 hectares.

	FI		MSI	
	m^3	%	m^3	%
Pine	42.8	39.6	43.4	40.4
Spruce	48.0	44.4	47.1	43.9
Birch	14.2	13.2	13.9	12.9
Other	3.0	2.8	3.0	2.8
All	108.1	100.0	107.4	100.0

Table 3. The FI and MSI estimates of proportions of timber assortments (%) by tree species on forest and scrub land, Central Finland, area 1 296 700 hectares.

	Saw wood	Pulp wood	Waste wood
Pine, FI	41.8	52.3	5.8
Pine, MSI	41.6	52.3	6.1
Spruce, FI	55.2	40.9	3.9
Spruce, MSI	55.0	41.2	3.8
Birch, FI	16.1	68.0	15.9
Birch, MSI	15.8	68.2	16.0
Other, FI	5.6	58.7	35.7
Other, MSI	4.5	56.6	38.9
All, FI	43.4	49.5	7.1
All, MSI	43.1	49.5	7.4

Table 4. The FI and MSI estimates of mean tree stem volume increment on forest and scrub land with field inventory (FI), and multi-source inventory (MSI), Central Finland, area 1 296 700 hectares

	FI		MSI	
	m^3	%	m^3	%
Pine	2.1	43.8	2.2	44.0
Spruce	1.8	37.5	1.8	36.0
Birch	0.7	13.5	0.7	14.0
Other	0.2	4.2	0.3	6.0
All	4.8	100.0	5.0	100.0

These comparisons show that large area estimates match quite well. The estimates of the mean tree stem volume as well as timber assortments by tree species are very close to each other with both methods. The small differences in mean tree stem volume is caused by the fact that a part of non-forest land (roads, urban areas) is classified into forests because the digital map data involve some faults.

Another possibility for judging the goodness of estimates is to compare them with characteristics of standwise data, measured for forest management planning purposes. These inventories are carried out in Finland separately for private, governement and company owned forests and are based on visual ground estimation and information from false colour aerial photographs and involve thus some subjective errors causing problems in comparisons. Also these results confirm the applicability of the method at communal level, see Tomppo and Katila (1991).

5. CONCLUSIONS

The first large area results and tests show that the satellite image-aided inventory method works fairly well at the communal level. The reasons for small differences in some variables compared with estimates obtained with traditional methods will be traced. If systematic errors occur in new inventory method, the applicability of new features and new classification techniques will be tested. The results are promising at this phase and the satellite image-aided NFI method has made or is expected to make it possible to:

1) estimate all the variables of the national forest inventory for each point of the country; The variables include the properties of site type, soil, growing stock, growth, mortality, cutting, and damages and diseases. It is anticipated that some improvement in estimates of all variables can be expected compared with the current situation. The estimates of variables concerning a single pixel may be unreliable. However, the communal level estimates, and in the case of some variables possibly also the forest holding and stand estimates, are expected to be applicable.

2) Cost/benefit -ratio of the inventory can be improved, and the rotation can be shortened in the future. The information given by the inventory can be improved fairly much with a small additional charge.

Remote sensing helps in updating of inventory data. Clouds prevent obtaining imagery which covers the whole country each year. This is possible however every third or fifth year. The field data can be updated with a slight change detection (removed trees) in permanent sample plots and tree and stand models, and simulation between two image acquisition dates. Other remote sensing data such as radar data or different kinds of airborne data can be utilized later.

3) keep the geographically localized information in a digital form and to transfer it easily into the databases of the users for further processing.

4) estimate changes, e.g. growth and mortality, more accurately than before. The new ground sampling design, which includes permanent sample plots, will support this task.

5) monitor forest health and diseases more effective than before.

6) serve as a sampling frame for other studies. Forest health researchers can, for instance, direct their studies to such forests where something alarming has been detected.

7) effective inventory of multi-use resources. Examples are reindeer rangeland inventory in North Finland; and

8) serve as a GIS, combining of multi-source information and map production are possible.

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