New Strategies for European Remote Sensing, Olujić (ed.)

Operational use of remote sensing for regional level assessment of forest estate values

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Keywords: forest tax values, forest resource assessment, satellite remote sensing, National Forest Inventory

ABSTRACT: A new assessment of real estate values of forest land for tax purposes will be carried out in Sweden during 2005. This is part of the general tax assessment of farm holdings, made every 6th year. In the tax assessment, the forest owners themselves assess the amount of standing volume of wood for coniferous and deciduous trees. This is done either as a straightforward estimate or as a determination related to the average estimates for so-called value districts. Each value district contains from 2 000 ha up to 400 000 ha of forestland. Most of these value districts are too small for allowing an estimate by use of only the field sample based National Forest Inventory (NFI). In the 2005 tax assessment, mean standing volume for coniferous and deciduous trees have instead been estimated by combining Landsat ETM+ satellite data and field plot data from the Swedish NFI. A nation-wide raster data base with forest variables estimated by the k Nearest Neighbours (kNN) method was used. It can be anticipated that the kNN estimates of average stem volume for value districts will have a much lower RMSE than estimates based on only NFI plots. Previous results from northern Sweden show that the RMSE for stem volume per ha was 10% for a 75 000 ha large area using NFI plots only. For kNN estimates, a 10% RMSE was obtained for such a small area as 500 ha. For obtaining estimates that were comparable with the estimates based on NFI sample plots only, the kNN based estimates were calibrated against NFI estimates on the level of full satellite scenes, as well as on the level of counties, two entities that are much larger than the value districts and contain a sufficient number of NFI plots for obtaining an estimate.
In conclusion, sound use of satellite data in combination with a set of objectively sampled field plots have provided operationally used forestry statistics that would have been difficult to obtain by other means. The prerequisite is also that we have used satellite data with a resolution that makes it possible to match them with small field plots (10m radius), and that the satellite scenes are large enough to cover a sufficient number of sample plots from the NFI.

1 INTRODUCTION

A new assessment of real estate values of forest land for tax purposes will take place in Sweden during 2005. This is a part of the general assessment for farm holdings. The tax values should correspond to 75 % of the market values year 2003. The assessment procedure is briefly that each owner of farm holdings checks and makes necessary changes of data provided in the real estate tax

form provided by the Swedish Tax Agency. The following factors are included in the forest part and they are estimated based on best available information on a holding level:
- forest land area;
- site productivity;
- cost class (comprises the sub-factors: logging costs, regeneration conditions, ground property variables, timber quality and outcome, and distance of off-road extraction);
- standing volume of conifers;
- standing volume of non-conifers.

If the forest owner does not accept the data proposed by the Swedish Tax Agency, he could respond with either a straightforward estimate of the factor/sub-factor, or an assessment related to the average data given for the value district in which his holding is situated. The value district size is in the range 2 000 – 400 000 hectares of forest land. In case the tax board makes another decision than proposed by the forest owner, there are procedures for how the forest owner can appeal. However, the tax system is constructed in a way that from the landowner's point of view, there are both advantages and disadvantages with having a high tax value for the forest. The forest part is therefore not the most critical part of the real-estate taxation, neither for the landowners nor for the tax authorities.

The only comprehensive, up-to-date and nation-wide data source for large area forest estimates in Sweden is the field sample plot based National Forest Inventory (NFI). However, the NFI is designed for providing reliable estimates on the level of 21 counties and can not alone be used for providing statistics for most of the 315 value districts. One key problem is thus how to get reliable forest statistics for the value districts without launching new and expensive field inventories. In previous assessments, data from the NFI were adjusted by the use of data from a stand-wise, almost nation wide, general forest inventory, complemented with local data where available. However, the general forest inventory was carried out almost 20 years ago and it will not be remade.

Thus, the possibility to use satellite remote sensing to derive estimates of standing volumes for value districts was considered instead. There are a number of remote sensing techniques that can be used to estimate standing volume for different tree species. In Sweden, a nation-wide dataset with satellite based raster estimates of forest variables such as standing volume per tree species was available through a recent project called kNN-Sweden (Reese, 2003). This dataset has been derived by SLU by combining satellite data and field data from the NFI. The method used was the the ”k Nearest Neighbour” (kNN) method, which also is operationally used in the Finnish National Forest Inventory (Tomppo, 1993).

The tax assessment project is carried out in cooperation between the Department of Forest Resource Management and Geomatics at the Swedish University of Agricultural Sciences in Umeå, the Swedish National Board of Forestry, the Swedish National Land Survey, and the Swedish Tax Agency with co-funding from the Swedish National Space Board.

The objective of this paper is to describe how a remote sensing based method, in combination with National Forest Inventory field plots, were used to operationally derive value area statistics for all of Sweden. A comparison between volume estimates based on kNN data, NFI plots, and post-stratification of the NFI plots by means of satellite data is also provided.

2 MATERIAL AND METHODS

2.1 National Forest Inventory data

In the kNN-Sweden project, field data from the Swedish NFI were used in combination with satellite data to estimate a spatially continuous raster with standing volume of different tree species. The NFI is carried out as an annual field sample across the entire nation. It is based on a systematic grid of square clusters with 8 – 12 circular sample plots in each cluster (Ranneby et al., 1987). The sampling density and the cluster size vary for different regions of Sweden (Hägglund, 1983; Anon., 2002). Since 1996, the actual position of the NFI plots has been recorded using the Global Positioning System (GPS), resulting in a positional accuracy between 5 and 6.5 meters RMSE.

Normally, plot data from a six-year time period is used for the estimation of forest variables within a satellite scene. It is therefore necessary to fore-cast (or back-cast) plot data to the year of the image acquisition. Thus, the volume growth between the inventory and the date of the image acquisition was calculated based on growth functions for individual tree species. Using sample plots for a 6 year period, there are about 2000 plots available per Landsat scene.

2.2 Satellite data

In the kNN-Sweden project, mostly Landsat 7 ETM+, bands 3, 4, 5 and 7 were used for the estimations. The satellite data were geometrically precision-corrected to the Swedish National Grid (RT90) by the Swedish National Land Survey. All images had been re-sampled to 25m x 25m pixels. Most of the images were from the European-wide Image 2000 dataset, created primarily for the CORINE Land Cover 2000 project.

2.3 The kNN method

The satellite image estimations had been done in an in-house developed production line called MUNIN. The NFI field plot data was used, both for the estimation of a raster of forest parameters and for a number of pre-processing steps. All scenes were illumination corrected, using the C-correction developed by Teillet et al. (1982). Also within-scene haze differences were reduced by aid of the field plots. This was done by relating a haze-index based on satellite digital numbers over forests to NFI plots with known forest properties (Hagner and Olsson, 2004).

A countrywide database with pixel wise-estimates of total standing volume, standing volume per tree species, stand age, and tree height had been derived in the kNN-Sweden project. In the kNN-method, the forest variables (v) are calculated as weighted (w) averages of the k nearest field plots (e.g., Tomppo 1993; and Equation 1 below). The feature space distance (d) between a field plot and a pixel defines how close they are to each other. The feature space is defined by the ETM+ bands and number of nearest field plots (neighbours) were set to 15 (k=15).

$$\boldsymbol{v}_p = \sum_{j=1}^{k} w_{j,p} \cdot \boldsymbol{v}_{j,p}, \qquad \text{Equation 1}$$

where:

$$w_{j,p} = \frac{1}{d_{j,p}^2} \bigg/ \sum_{i=1}^{k} \frac{1}{d_{i,p}^2}$$

$$d_{1,p} \le d_{2,p} \le \ldots \le d_{k,p}$$

$d_{j,p}$ = feature space distance from pixel p to plot j, and
$v_{j,p}$ = variables for the plot with distance $d_{j,p}$.

In total, 31 Landsat scenes were used to derive the nationwide raster database with estimates of forest variables. The kNN database covers 96% of the forestland area in Sweden according to the 1:100,000 scale topographic map of Sweden.

2.4 *kNN estimates for value districts*

Mean values of standing volume for coniferous and deciduous trees were derived for a total of 314 value districts with a size between 2 000 and 400 000 ha. In order to avoid any systematic errors and to have estimates representing the state of the forests as close to year 2005 as possible, the kNN-estimates of standing volume for conifers and deciduous trees were calibrated to the same mean value as obtained for NFI plot based estimates for large areas. This was done in two steps. First, the volume estimates for all pixels within a scene were calibrated to the year of the image acquisition based on NFI data from 1996-2002. This was done by multiplying the pixel-wise kNN-estimates of standing volume for conifers and deciduous trees with constants that generate the same scene averages as obtained using only the NFI plots within the scene. The calibrated scene-wise estimates were then merged into a country-wide mosaic. In the last step, the volume estimates in this raster database were calibrated on a county level using the latest available NFI data for a five year period, which was plot data from 1998-2002. This calibration was made in the same way as the scene-wise calibration with the exception that the averages for the kNN estimates were adjusted to match the NFI estimates on a county level.

One of the reasons for calibrating the estimates is that problems related to image geometry, mixed pixels, etc might lead to biased estimates. Furthermore, the kNN estimates represents the state of the forest at different years, depending on the acquisition date of the image. The kNN-Sweden dataset also uses a slightly different forest land definition than the one used for the tax assessment. In the tax assessment, as well as in the NFI, forest land is defined as all land that has the potential to produce more than 1 $m^3ha^{-1}year^{-1}$, and that are not used for any other purposes than forestry. In kNN-Sweden, forest land is defined by the areas mapped as forest in the 1:100 000 scale topographic map produced by the Swedish National Land Survey.

2.5 *The post-stratification method*

The average kNN estimates within one satellite scene has been compared with estimates where the satellite image information were used for post-stratification of the NFI-plots instead (Nilsson et al. 2003). The stratifications were made by first dividing the Landsat images into spectrally similar segments. In the next step, each segment was assigned a class (stratum) based on the kNN estimates of either total standing volume or standing volume of deciduous trees. The stratification based on total standing volume was used to estimate total standing volume of conifers and the stratification based on deciduous trees was used to estimate standing volume for deciduous trees. All post-stratification estimates were derived using five strata.

3 RESULTS

Mean values of standing volume per hectare for coniferous and deciduous trees have been derived for all 314 value districts in Sweden (Figure 1).

A comparison of estimated volume for conifers and deciduous trees derived using *i*) kNN (before the calibration), *ii*) only NFI data, and *iii*) NFI data that were post-stratified using kNN data for one county, is presented in Table 1.

Table 1. Estimates of total standing volume and standard error derived using different estimation methods for one Landsat ETM+ scene in the county of Västerbotten

	Standing volume (million m^3)		Standard error (%)	
	Conifers	Deciduous trees	Conifers	Deciduous trees
kNN	129.8	24.2	-	-
Post-stratification	127.1	22.4	2.6	5.2
NFI	126.8	22.4	3.9	6.0

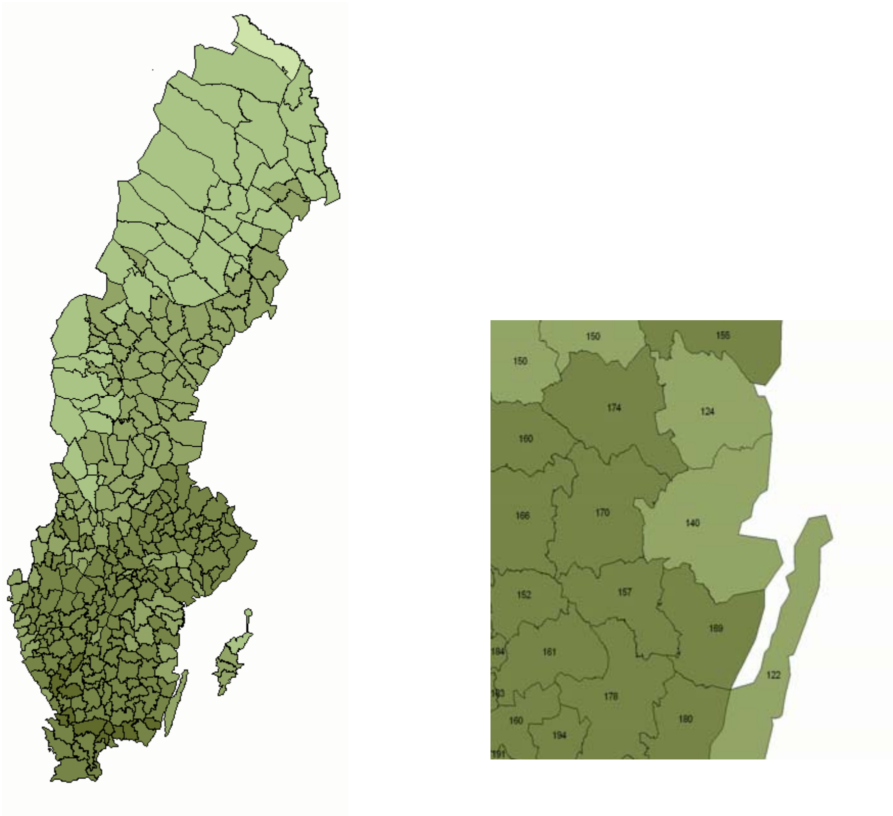

Figure 1. Map showing mean standing volume (in m^3 stem wood per ha) of coniferous plus deciduous trees, to the left all value districts in Sweden, to the right, an enlargement over part of SE Sweden, with the mean standing volume also shown with numbers.

4 DISCUSSION

The use of the kNN dataset has provided an efficient and cost-effective method for deriving statistics for value districts. The estimation accuracy obtained using the kNN dataset, or any other spatially explicit dataset with satellite based estimates, can however not easily be calculated without an extensive field dataset. Table 1 exemplifies for the area covered by a Landsat TM scene, that the total standing volume for the kNN estimates were similar to the NFI estimates even before the calibration, but the post stratification were even more similar. This indicates that post stratification would be a better method for large value areas. Post stratification produces unbiased estimates without any calibration. A further advantage with using post-stratification is that the estimation accuracy easily can be calculated. A disadvantage is however that estimates can only be derived for large areas that include a large number of NFI plots. Thus, post-stratification can probably not be used for the smallest value districts.

The estimation accuracy for total standing volume has also been evaluated on a stand level using field data from a test area in southern-western Sweden named Remningstorp. Using 89 stands, the results show that the overall stand-level RMSE for the kNN estimates of standing volume is 85 m^3ha^{-1}, or a 33% overall RMSE (Reese et al., 2003).

Earlier studies have also shown that that the estimation accuracy increases fast when areas larger than stands are aggregated. Fazakas et al. (1999) made a study in the county of Västerbotten using a systematic sample of field plots for a 5000 ha area. For kNN, trained by NFI plots, a 10% RMSE for the mean stem volume was obtained for such a small area as 500 ha, whereas averaging of a 75000 ha large area would have been be needed for obtaining the same accuracy using NFI plots only. Thus, it can be assumed that fairly high estimation accuracy is obtained for value districts, at least for coniferous trees.

In summary, nationwide remote sensing estimates have proven to be a valuable complement to National Forest Inventory sample plots for estimating mean stem volume within value districts. For the future, there are several possibilities to improve the methods, such as for example to use post stratification for the larger value districts. Also the use of time series of remote sensing data would have the potential to improve the estimates. A prerequisite for the method currently implemented, is however the availability of large "Landsat type" satellite images, which cover a large number of National Forest Inventory plots.

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