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Arbetsrapport 53 1999
Working Paper 53 1999

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ISSN 1401-1204
ISRN SLU-SRG-AR--53--SE

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Abstract

As part of the ”Monitoring of forest ecosystems” project, within the MISTRA program Remote Sensing for the Environment (RESE), and also with funding from the County Administration Board of Dalarna, a demonstration project was undertaken to estimate forest stand parameters in Dalarna with the use of satellite data. Using two full scenes of Landsat Thematic Mapper data and sample plot data from the Swedish National Forest Inventory, estimations of above ground tree biomass, age, total wood volume, and separate tree species' volumes were made using the ”*k* Nearest Neighbor” method. Accuracy assessment results at the single pixel level for total wood volume are consistent with results from previous *k*NN estimations, with an overall relative RMSE of 75% for the western scene, and 58% overall relative RMSE for the eastern scene. Validation data show a bias of the estimate toward the mean value of the estimation data. The pixel level estimates of above ground tree biomass and age had similar validation results to those for total wood volume. Biomass estimates had a 77% relative RMSE for the western scene, and 69% for the eastern scene. Age estimates had a relative RMSE of 60% in the western scene and 57% in the eastern scene. The results may suggest the need to incorporate a geographic limitation on the plots used in the estimation, and to further investigate the co-registration between the satellite and plot data. While pixel level errors are high, an aggregation of the estimates to larger (compartment-sized) areas could decrease the error significantly. Previous similar studies have shown that an RMSE of 10% for total wood volume can be obtained for as small areas as 100 to 450 hectares. The estimates from this study will be evaluated for use by the County Administration Board of Dalarna to find areas of ecological interest and to assist in planning.

Introduction

This project was undertaken at the request of the County Administration Board of Dalarna and also became a pilot project within the MISTRA program's (Swedish Foundation for Strategic Environmental Research) Remote Sensing for the Environment (RESE) project, "Monitoring of forest ecosystems". The aim was to demonstrate the ability of using Landsat Thematic Mapper (TM) satellite data combined with field data from the Swedish National Forest Inventory (NFI) to estimate multiple forest parameters over a large area. The Dalarna County Administration Board needed more detailed information about their forests. Using their Q-Vadis[1] system, they will use the detailed forest information in combination with other data such as digital elevation models (DEMs), geological maps, watershed maps, and other geographic information.

The method employed in this study to estimate forest variables, *k* Nearest Neighbor (*k*NN), has been described in previous studies (Kilkki and Päivinen 1987; Muinonen and Tokola 1990; Tomppo 1990; Tokola et al. 1996). Nilsson (1997), Fazakas et al. (1997), Holmgren et al. (1999), and Nilsson and Sandström (1999) have followed up these studies by applying the method in Sweden using the Swedish NFI data. Nilsson found that integrating remote sensing data with the Swedish NFI could help in estimating forest variables on both local and regional levels. He also reported that *k* equal to a number between 5 to 10 was sufficient for estimating volume within acceptable accuracy limits. Fazakas et al. found that pixel level accuracy of *k*NN volume estimations was poor, but when aggregated to larger areas such as 100 ha, the results were exponentially more accurate. Holmgren et al. (1999) incorporated ancillary data such as mean tree height or site index into a *k*NN estimation, which improved the estimation from 36% RMSE (Root Mean Square Error) to 17% for wood volumes on a compartment level.

Objectives

The objective of this project was to test and demonstrate the utility of Landsat TM satellite data, NFI field data, and the *k*NN method for the creation of a landscape scale estimation of wood volume, above ground tree biomass, and age for the forested land of Dalarna County.

Study Area

The county of Dalarna is located in central Sweden at the latitude range of 59°50' N to 62°15' N and longitude 12°00' E to 16°45' E. It covers a land area of approximately 2.8 million hectares. The dominant species are Scots pine (*Pinus sylvestris*), Norway Spruce (*Picea abies*), Birch (*Betula spp.*), and to a minor extent, other Broad-leaved deciduous species. Figure 1 shows the study area and the TM data coverage.

[1] Q-Vadis is an Arc/Info application based on Grid and Tin. It was developed by the environmental agency at the County Administration Board and the GIS research section at the National Land Survey in Sweden.

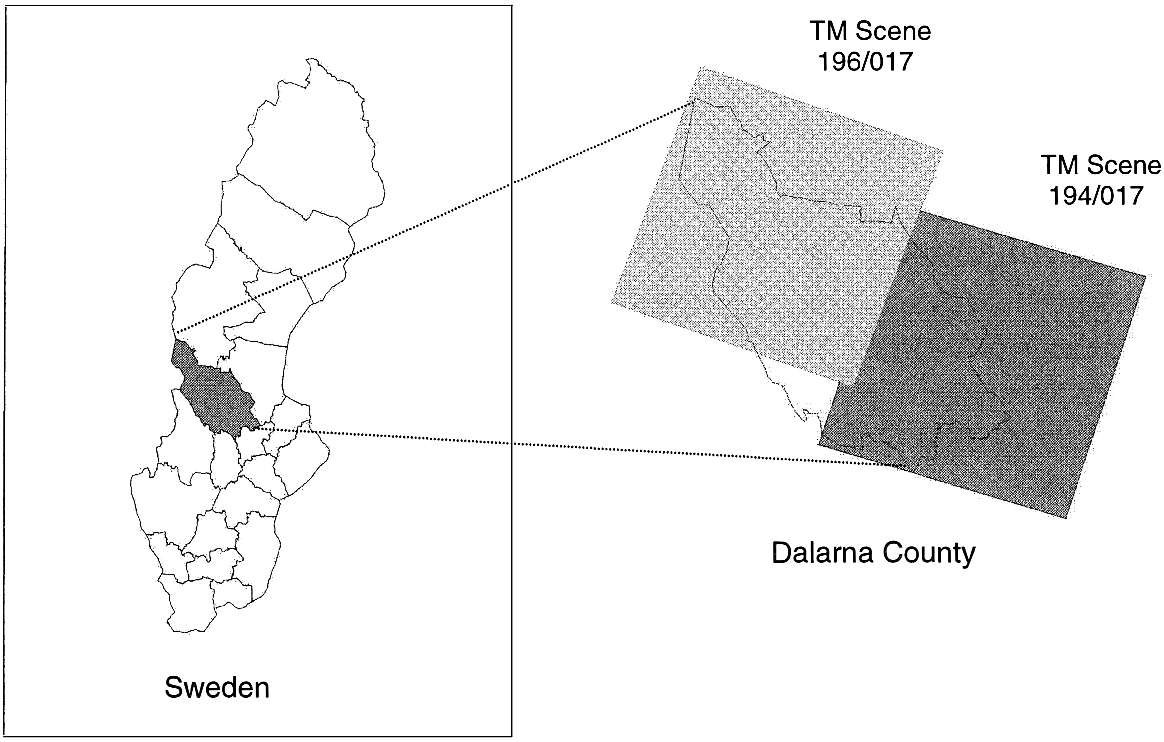

Figure 1. *Study area and TM data coverage.*

Materials and Methods

Satellite Data

The satellite data used for this project were two full scenes of Landsat TM data which were geometrically precision-corrected to the Swedish National Grid (RT90), and resampled to 25 m by 25 m pixels using cubic convolution (processing done by SSC-Satellitbild in Kiruna). The acquisition date of the western scene (path 196, row 17) was June 27, 1995 and the eastern scene (path 194, row 17, shifted south) was August 21, 1997. Six of the seven wavelength bands were used in the analysis, leaving out the more spatially coarse 120 m thermal band (TM band 6). Throughout this paper, the satellite data are referred to as “the western TM scene” and “the eastern TM scene”.

Map mask

Only areas considered as “productive forestland” were used in the estimation. Non-forestland areas were removed from the analysis via a forestland mask created from 1:50,000 scale topographic maps, where “forestland” was defined as the categories “forest” and “clearcuts”.

Forest Variable Dataset Extracted from NFI

The Swedish NFI is an annual national field sample of multiple forest parameters. It is based on a systematic grid across the country, which consists of “tracts”, or squares on which the plots to be sampled are located (Ranneby et al 1987). The tracts vary in size according to the defined region of Sweden to which they belong (Anon. 1998). There are both permanent and temporary plots, the difference being in size of both tract and plot, and that the permanent plots are surveyed repeatedly. Permanent plots are 10 meters in radius, and located on tracts that in this study area had a side length of 1200 meters in the mountainous areas and 1000 meters in the other areas, both with 8 plots to the tract. Temporary plots are seven meters in radius, and in Dalarna are located on tracts that have a side length of 1500 meters, with 12 plots to the tract (Hägglund 1983).

The plot coordinates in the NFI database are primarily from digitized locations which were recorded *in situ* by NFI field crews on 1:10,000 scale topographic maps. The use of Global Positioning System (GPS) to record plot coordinates was introduced to the NFI in 1996.

Two separate datasets to be used in the estimation were extracted from the NFI database: one covering the area of the western TM scene and one covering the area of the eastern TM scene. These datasets consisted of a subset of variables from the NFI database, such as volume, biomass, and age. Only plot data sampled from a four year period (1992-1995) were considered for this estimation.

A linear growth function projecting 5-year growth (Söderberg 1986) was applied to the volume measurements in attempt to reconcile the difference between the TM image acquisition date and the date of the NFI survey. These modified figures were then used in the estimation.

Each of these datasets also included the TM spectral values for each plot location. This was accomplished by geographic overlay of the dataset plot coordinates on the TM data and extraction of each of the six TM band's spectral values for that location using cubic convolution.

Outlier reduction

Because NFI data from years previous to the image data acquisition were used in the estimation, there was a chance that changes in the vegetation had occurred (exclusive to normal growth), and those data points should not be used in the estimation. There may also be errors in the NFI coordinate-to-image pixel registration. In an effort to eliminate potentially erroneous data from being used in the estimation, an outlier test was performed using a regression function. A regression model, in which pixel-wise digital numbers for each band was explained by several variables from the NFI database, was used (Equation 1).

$$DN_i = \alpha + \beta_1 ln(v_p) + \beta_2 ln(v_s) + \beta_3 ln(v_b) + \beta_4 ln(a) + \beta_5 (ln(v_t) * ln(a)) + \beta_6 q + \beta_7 r + \beta_8 s \quad (1)$$

i = TM bands 1-5, and 7

β_k = regression parameter

v_p = volume of pine

v_s = volume of spruce
v_b = volume of broad-leaved trees (birch and other broad-leaved combined)
v_t = total volume
a = age
q = ground moisture
r = ground vegetation type
s = site index for pine

Approximately 20% of the plots from each dataset with the highest residuals were then removed in order to eliminate potential outliers. After outlier removal, the datasets to be used in the estimations totalled 773 plots for the eastern TM scene and 680 plots for the western TM scene.

The kNN Method
Using the resulting dataset with outliers removed, total wood volume, the different tree species' volume, above ground tree biomass and age can subsequently be calculated for every pixel within the forest mask. The value for each pixel was calculated as a weighted mean value of the forest parameters of the *k* (in this case *k* = 5) nearest samples in spectral space (Equation 2). The Euclidean distance in spectral space was used to find the 5 nearest spectral neighbors. Weights assigned to each of the *k* samples were proportional to the inverse squared distance measured in spectral space from the pixel to be estimated (Equation 3).

$$v_p = \sum_{j=1}^{k} w_{j,p} * v_{j,p} \tag{2}$$

where,

$$w_{j,p} = \frac{1}{d_{j,p}^2} \Big/ \sum_{i=1}^{k} \frac{1}{d_{i,p}^2} \tag{3}$$

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

$d_{j,p}$ = Euclidean distance from pixel p to plot j, and
$v_{j,p}$ = biomass, age or wood volume for the plot with distance $d_{j,p}$

The result after processing a single TM scene was several raster files consisting of separate estimates for biomass, age, total wood volume, and the four species' volumes (Scots Pine, Norway Spruce, Birch and Other Broad-leaved) in cubic meters per hectare.

Accuracy Assessment

The validation data were from the 1996 NFI field survey, which used GPS to assign plot coordinates. These plots had not been used in the estimation. There were 179 plots used for accuracy assessment in the eastern TM scene, and 193 used for the western TM scene. Outlier elimination was not done with the validation data. The accuracy is based on a whole TM scene and not restricted to the borders of Dalarna county. A calculation of RMSE (Equation 4) and bias (Equation 5) between the validation data and the estimations were made for total wood volume, biomass and age at the single pixel level.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\hat{y}_i - y_i)^2} \tag{4}$$

$$Bias = \hat{y}_i - \overline{y}_i \tag{5}$$

where,

$\hat{y}$ = estimated variable, and

y = field measured variable.

Results and Discussion

A summary of the overall RMSE and bias for total wood volume, age and biomass at the original single pixel level is presented in Table 1. The findings of the accuracy assessment are comparable to those found in previous *k*NN studies (Nilsson 1997; Fazakas et al. 1997), that the overall RMSE, as a percentage relative to the mean wood volume, at the single pixel level is around 65 to 75%.

Table 1. *Summary of overall RMSE and bias for total wood volume, age and biomass*

	Estimation made for Eastern TM Scene			**Estimation made for Western TM scene**		
	Total Wood Volume	**Age**	**Biomass**	**Total Wood Volume**	**Age**	**Biomass**
Overall RMSE *	108	34	66	75	47	49
Overall Bias *	12	8	-11	6	-1	-36
Mean value in NFI data *	187	60	95	100	78	64
% Overall Relative RMSE	58%	57%	69%	75%	60%	77%
n	179	179	179	193	193	193

* RMSE, bias and mean value in NFI data are in units of m^3/ha for total wood volume, years for age, and tons/ha for biomass.

The eastern scene had a higher overall RMSE at the single pixel level (108 m^3/ha) than the RMSE for the western scene (75 m^3/ha). An explanation for this may be that the mean total wood volume of the NFI plots used for estimation in the eastern scene (187 m^3/ha) was higher than the mean volume of the NFI plots used in the western scene (100 m^3/ha). It has been shown that in using the *k*NN method there is a tendency of bias towards the mean, and that it may therefore underestimate the more extreme volumes of over 300 m^3/ha and overestimate the lower volumes of under 100 m^3/ha (Holmgren et al. 1999). The bias calculated for this project demonstrates this finding as well, with unbiased estimates approximately at the NFI plot data's mean volume in both scenes. There was also a wider range of volume measurements in the NFI data for the eastern scene (0-700 m^3/ha) than there was in the western scene (0-520 m^3/ha), allowing for higher variation in the estimates. If one looks at the estimate's overall RMSE relative to the NFI-determined mean volume as a percentage, the western scene had an overall 75% RMSE relative to the NFI mean, and the eastern scene had an overall 58% RMSE relative to the NFI mean. In order to look at the estimation errors more closely, Table 2 gives the RMSE and bias broken down into three different volume groups.

Table 2. *RMSE and bias for total wood volume estimations, broken down into three volume groups.*

	Eastern TM Scene Volume from NFI validation data			Western TM scene Volume from NFI Validation data		
	0-99 m3/ha	**100-299 m3/ha**	**300+ m3/ha**	**0-99 m3/ha**	**100-299 m3/ha**	**300+ m3/ha**
RMSE (m3/ha)	79	91	199	43	67	244
Bias (m3/ha)	54	26	-158	32	-34	-228
n	65	90	24	134	53	6

The errors in the previous tables require some explanation. Why might these errors exist, and how does it affect the quality of the data?

It has been found in previous studies that estimates of forest parameters from *k*NN on a pixel level are quite poor, and improve in accuracy when aggregated to larger areas (Nilsson and Ranneby 1997; Fazakas et al. 1997). Figure 2 shows the effect on the RMSE for wood volume when aggregating the estimates into different sized areas. In this light, the high RMSE at the single pixel level is not too surprising. Fazakas et al. (1997) had a study area of one-quarter Landsat TM scene, with 658 NFI plots used in the estimation. Their results for total wood volume showed a single pixel level overall RMSE of 67% (using cross-validation of NFI data) which decreased to 10% when estimates were aggregated to 100 hectares. Results from a study in Västerbotten (Nilsson and Sandström 1999) gave slightly higher errors when aggregating wood volume estimates into different sized areas. In their study, a 10% RMSE was obtained for 450 ha areas. Holmgren et al. (1999) also had a study area of one-quarter Landsat TM scene, using 1703 plots for estimation. Single pixel level estimates were not evaluated for this study; however, wood volume estimates were aggregated to an average size of 19 ha compartments, and obtained an overall RMSE of 36%. Such an area aggregation was not done in this project, as stand data to use for validation of the results were not available. However, if stand data become available, this aggregation could be tried in the future, and the accuracy further assessed.

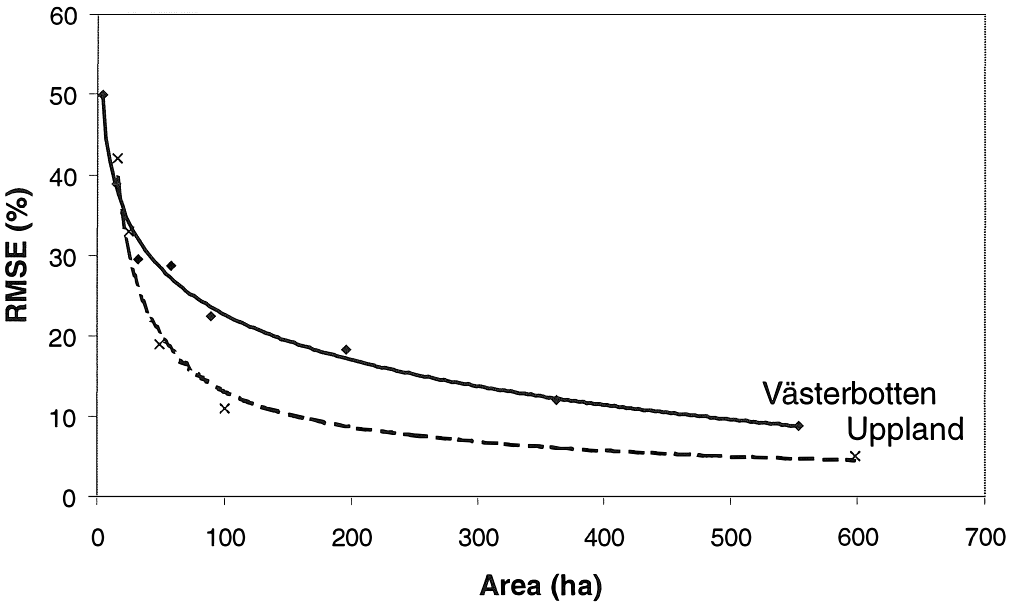

Figure 2. *RMSE between estimated and field-measured mean wood volume in Västerbotten (from Nilsson and Sandström 1999) and Uppland (from Fazakas et al. 1997) when calculated for different sized areas.*

Nevertheless, some factors which may account for errors as found at the single pixel level in this study, include the integrity of the geometry of the satellite data, the registration, and the precision of the geographic coordinates of the NFI data. Because the *k*NN method involves matching a 7 or 10 m plot with a single 25 m image pixel, both sources of data must be precisely located. In a landscape where the stands of forest are as fractured as in Dalarna, this can be important. Although the outlier reduction done with the estimation data does eliminate some errors, it is possible that it may not eliminate all of them. Such errors within the database can result in both poor estimations and poor accuracy assessment plot registration. It may be necessary to devise a way to assure that the plots and imagery are more correctly co-registered, and that outlier removal is optimized.

It was found that a few plots in both the estimation dataset and the validation data were located precisely on the edges between different volume stands. In some cases the estimation can be influenced by the pixels around it, or be located on the incorrect side of the edge, producing an “error” in the estimation. In the future, information about the distance of a plot from an edge could be incorporated in attempt to improve the estimation.

The errors tend to be much higher in the higher volumes. In addition to a tendency of estimating toward the mean, this could also be due to the fact that within the NFI data, especially for the western Dalarna scene, there were very few data points available for the volumes exceeding 300 m^3/ha. In addition, the higher volumes can have higher errors because the relationship between spectral values and wood volume is weak in a closed canopy and becomes more difficult to distinguish as the volume becomes greater (e.g., Franklin 1986).

Error could also be introduced when using a full TM scene which covers a large area with different physiographic regions. The area within the western scene consists of both the mountainous areas ("fjäll") of western Dalarna as well as the relatively flatter and more densely forested areas east of the mountains. Currently, our *k*NN algorithm uses all the plots within the scene. It may be necessary to limit the nearest neighbors used to those within a certain geographic distance.

Given the validation results, the user should consider their needs before using the data. As previously reported, and shown in this study, results on a pixel level produce a high relative RMSE. If one needs high accuracy at the pixel level of wood volume, this method may not be well enough refined at this time to produce those results. However, if one is willing to aggregate the data, as also shown in previous studies, these data will be adequate for that use. The aggregated stem volume estimates produced by Holmgren et al. (1999) were found to be accurate to the same level as aerial photo interpretation combined with field control. He also calculated the cost (inclusive of processing, NFI data and one-quarter TM scene) of producing stem volume and basal area estimates from satellite remote sensing to be the equivalent of 0.80 SEK/ha, showing data derived from remote sensing to be economically feasible.

It should be mentioned that the pixel level errors tend to be consistent and relative, so that the landscape patterns are still readily visible in maps of the estimation data. A closer look at the data is given in Figure 3 to show the typical quality of the single pixel level data.

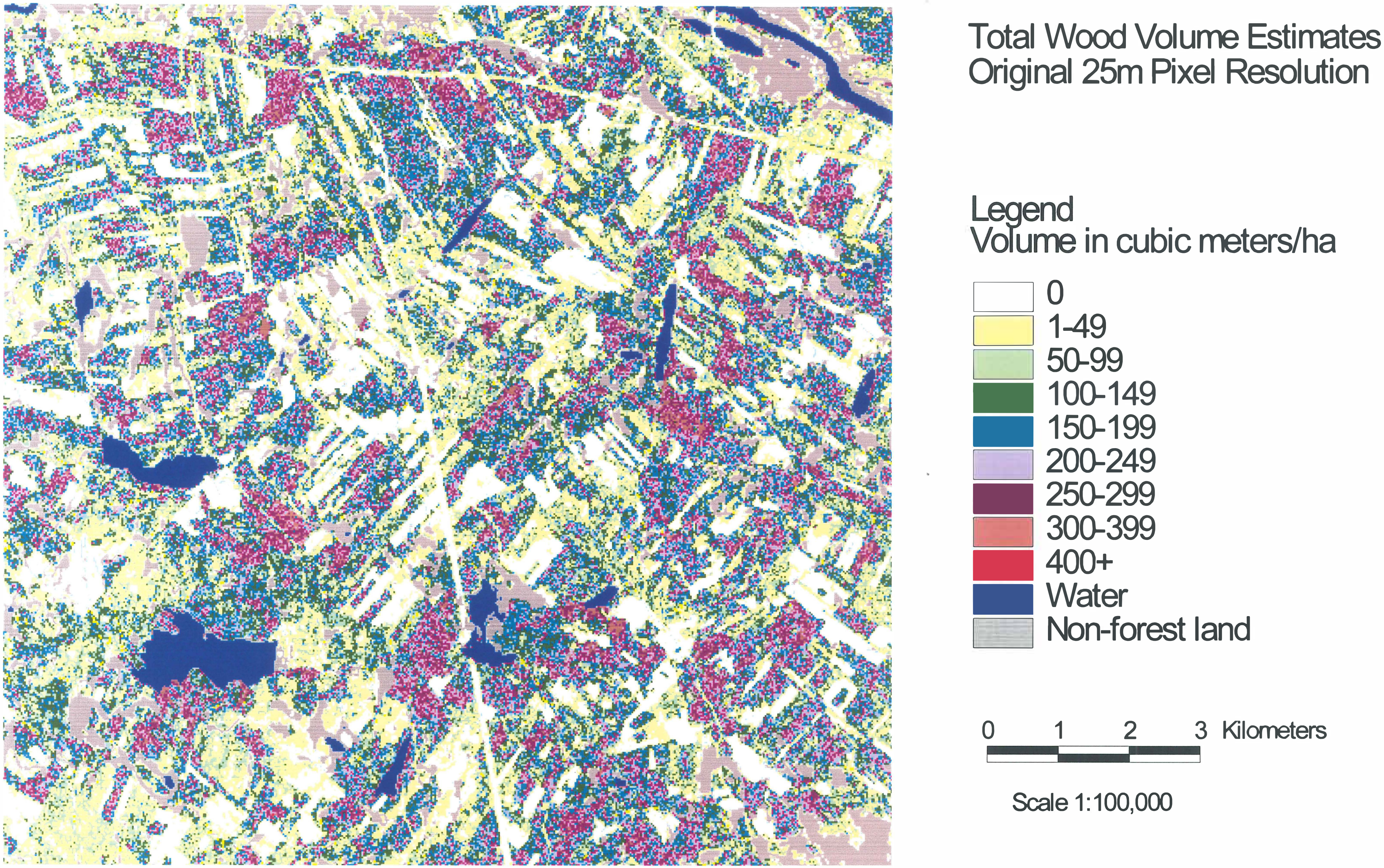

Figure 3. 1:100,000 scale map of total wood volume estimates from Eastern Dalarna

Other estimated parameters
Above ground tree biomass was estimated, and the overall RMSE was 49 tons/ha for the western scene (relative error of 77%), and 66 tons/ha for the eastern scene (relative error of 69%) (Table 1). The estimate dataset for biomass was not adjusted for growth, as a growth function for biomass does not exist. Fazakas et al. (1997) also estimated biomass, and found a 67% RMSE at the single pixel level which, when aggregated to 100 ha areas, decreased to approximately 17%.

A breakdown of RMSE for three different levels is given in Table 3. One can see similar accuracy results to the total wood volume estimations, as the two parameters are closely related. The biomass estimates are given in Appendix A (Table A.5).

Table 3. *RMSE and bias for biomass*

	Estimate for Eastern TM scene Validation data in tons/ha			**Estimates for Western TM scene Validation data in tons/ha**		
	0-99	**100-199**	**200+**	**0-99**	**100-199**	**200+**
Estimate RMSE (tons/ha)	47	63	159	39	47	172
Estimate Bias (tons/ha)	26	-40	-151	19	-39	-159
n	99	58	12	150	38	5

Estimation of stand age was also investigated in this project, with results being an overall RMSE of 34 years in the eastern scene (relative error of 57%) and 49 for the western scene (relative error of 60%) (Table 1). A breakdown by 25 year levels is given in Table 4. Neither Fazakas et al., Nilsson nor Holmgren et al. have estimated age, so a comparison to these studies cannot be made. The validation results for age were similar at the single pixel level to the RMSE for volume and biomass. The age estimates are given in Appendix A (Table A.6).

Table 4. *RMSE and bias for age*

	Estimates for Eastern TM scene Validation data in years						Estimates for Western TM scene Validation data in years					
	0-24	25-49	50-74	75-99	100-124	125-+	0-24	25-49	50-74	75-99	100-124	125+
Estimate RMSE (years)	38	38	24	22	45	39	51	46	44	30	33	66
Estimate Bias (years)	27	27	7	3	-25	-37	39	27	27	8	-21	-51
n	19	59	33	69	30	5	10	35	22	31	23	35

Separate estimates were also created for each of the individual species' wood volume (Scots Pine, Norway Spruce, Birch, and Other Broad-Leaved). However, their accuracy assessment is not addressed in this paper. Appendix A contains tables (Tables A.3 and A.4) of estimates for each of these parameters.

Summary

The objective of this project was to create landscape level estimates of wood volume, above ground tree biomass, and age for Dalarna. The results from this project were evaluated at the single pixel level, with RMSE results consistent with those from previous *k*NN estimations of wood volume and biomass. At the single pixel level for total wood volume, they were 58% for one TM scene, and 75% for the other. RMSE results for biomass and age were similar. The error may be decreased significantly by aggregation of the estimates to larger (compartment-sized) areas; however, this aggregation was not evaluated in this study as compartment data were not yet available. In future *k*NN estimations a geographic distance limitation may be incorporated.

The estimations have been preliminarily reviewed by members of the Dalarna County Administration Board, who, in conjunction with MDC, will use the data to carry out future projects that require landscape level data. The data were delivered in Arc/Info GRID format. In addition, maps have been made of the total wood volume estimates. Figure 4 is a map of the total wood volume estimates created by merging the two grids from each TM scene together.

Wood Volume Estimations from Landsat TM and NFI data

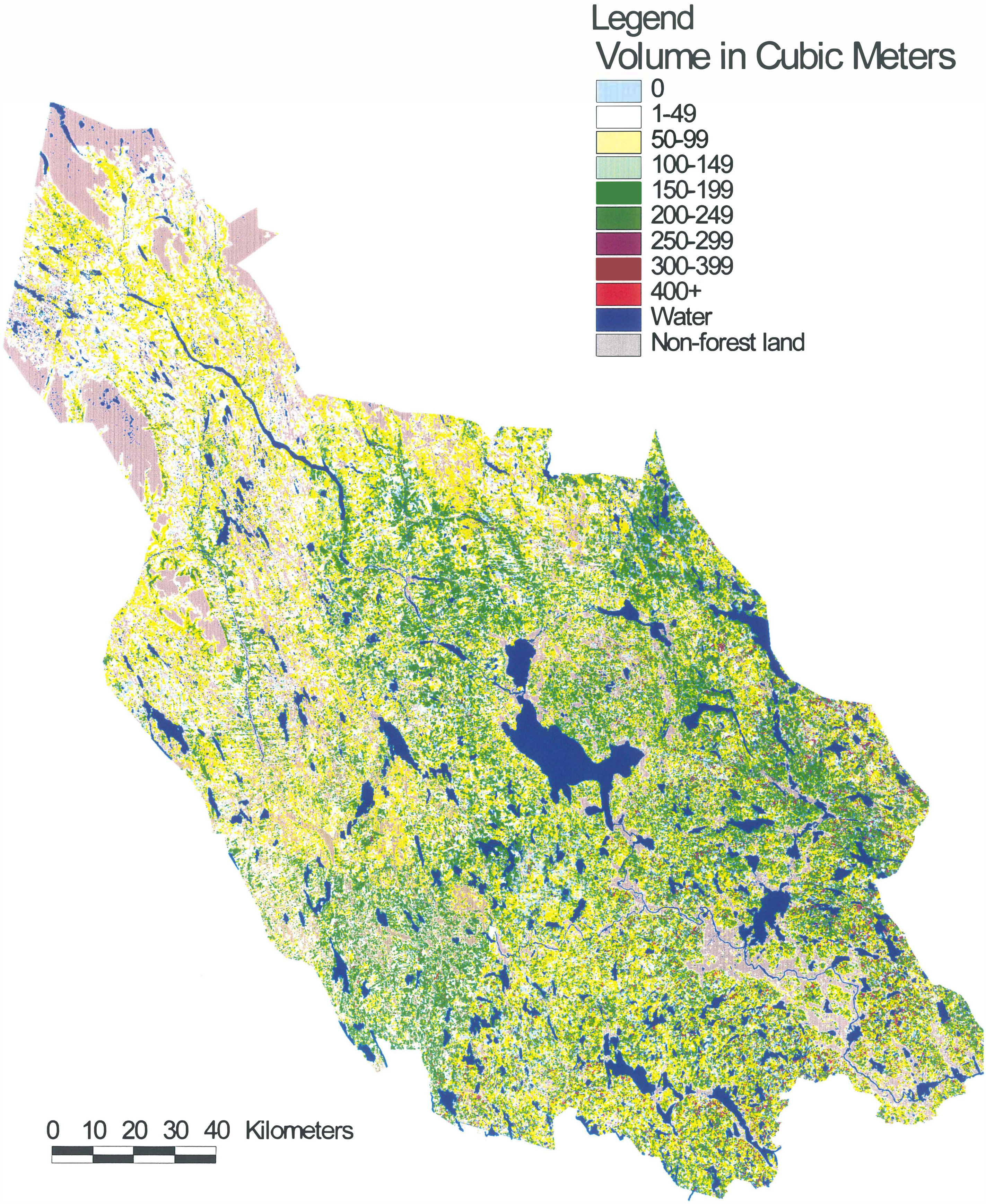

Figure 4. Total Wood Volume Estimates for Dalarna

Acknowledgements

This work was a demonstration project within the Swedish research program Remote Sensing for the Environment, RESE (http://www.mdc.kiruna.se/rese), financed by the Swedish Foundation for Strategic Environmental Research. The project was also financed and assisted by the County Administration Board of Dalarna.

References

Anonymous. 1998. Instruktion för Fältarbetet vid Risksskogstaxeringen. Swedish University of Agricultural Sciences, Department of forest resource management and geomatics, Umeå, Sweden.

Fazakas, Z., Nilsson, M., Olsson, H. 1997. Evaluation of the kNN method for combining NFI sample plot data and satellite data. Expert Meeting on Data Fusion Techniques, ISPRS Commission 7 working group report, Dec. 8-9, 1997, Freiburg, Germany.

Franklin, J. 1986. Thematic mapper analysis of coniferous forest structure and composition. International Journal of Remote Sensing 7:1287-1301.

Holmgren, J., Joyce, S., Nilsson, M., and Olsson, H. 1999. Estimating stem volume and basal area in forest compartments by combining satellite image data with field data. Scandinavian Journal of Forest Research (in press).

Hägglund. B. 1983. En ny svensk riksskogtaxering. Swedish University of Agricultural Sciences, Department of Forest Survey. 74pp.

Killki, P. and Päivinen, R. 1987. Reference sample plots to combine field measurements and satellite data in forest inventory. *In:* Remote Sensing-Aided Forest Inventory. Seminars organised by SNS and Taksaattoriklubi, Hyytiälä, Finland, pp. 209-212.

Muinonen, E. and Tokola, T. 1990. An application of remote sensing for communal forest inventory. *In*: The Usability of Remote Sensing for Forest Inventory and Planning. SNS/IUFRO workshop, Department of forest resource management and geomatics, Swedish University of Agricultural Sciences, Umeå, Sweden, pp. 35-42.

Nilsson, M. 1997. Estimation of forest variables using satellite image data and airborne Lidar. Acta Universitatis Agriculturae Suecia. Silvestria 17. Swedish University of Agricultural Sciences. Department of forest resource management and geomatics, Umeå, Sweden.

Nilsson, M. and Sandström, P. 1999. Evaluation of a non-parametric method for estimation of wood volume and biomass in boreal forests by combining remote sensing and field data. Submitted.

Nilsson, M. and Ranneby, B. 1997. Estimation of wood volume using satellite spectral data. A simulation study. Paper III in: Estimation of forest variables using satellite image data and airborne Lidar. Acta Universitatis Agriculturae Suecia. Silvestria 17. Swedish University of Agricultural Sciences. Department of forest resource management and geomatics, Umeå, Sweden.

Ranneby, B., Cruse, T., Hägglund, B., Jonasson, H. and Swärd, J. 1987. Designing a new national forest survey for Sweden. Studia Forestalia Suecica, No. 177. Swedish University of Agricultural Sciences, Faculty of Forestry, Uppsala, Sweden.

Söderberg, U. 1986. Functions for forecasting of timber yields – Increment and form height for individual trees of native species in Sweden. Report No. 14. Swedish University of Agricultural Sciences. Department of Forest Mensuration and Management.

Tokola, T., Pitkänen, J., Partinen, S., and Muinonen, E. 1996. Point accuracy of a non-parametric method in estimation of forest characteristics with different satellite materials. International Journal of Remote Sensing, 17:2333-2351.

Tomppo, E. 1990. Designing a satellite image-aided national forest survey in Finland. *In*: The Usability of Remote Sensing for Forest Inventory and Planning. SNS/IUFRO workshop, Department of forest resource management and geomatics, Swedish University of Agricultural Sciences, Umeå, Sweden, pp. 43-47.

Appendix A

Table A.1. *Distribution of plots used for estimation in the western TM scene*

NFI estimation data in volume (25m³/ha)														
	0	**1- 24**	**25-49**	**50-74**	**75-99**	**100-124**	**125-149**	**150-174**	**175-199**	**200-224**	**225-249**	**250-274**	**275-299**	**300-+**
n	50	132	82	54	70	50	60	60	34	23	17	17	13	18

Table A.2. *Distribution of plots used for estimation in the eastern TM scene*

NFI estimation data in volume (25m³/ha)																		
	0	**1- 24**	**25-49**	**50-74**	**75-99**	**100-124**	**125-149**	**150-174**	**175-199**	**200-224**	**225-249**	**250-274**	**275-299**	**300-324**	**325-349**	**350-374**	**375-399**	**400+**
n	29	51	54	56	53	43	41	75	44	54	52	38	39	25	25	28	19	52

Table A.3. *Volume estimates, as percent of forest land area classified within each separate file (separate files are created for total volume, pine, spruce and deciduous), for the western Dalarna TM scene*

M³/ha	**Total volume**	**Pine**	**Spruce**	**Deciduous**
0	8%	10%	43%	64%
1-24	25%	46%	33%	34%
25-49	11%	12%	10%	1%
50-74	9%	9%	5%	<1%
75-99	10%	8%	4%	<1%
100-124	11%	6%	2%	<1%
125-149	9%	5%	2%	<1%
150-174	6%	2%	1%	---
175-199	4%	1%	<1%	---
200-224	3%	<1%	<1%	---
225-249	2%	<1%	<1%	---
250-274	1%	<1%	<1%	---
274-299	1%	<1%	<1%	---
300-530	<1%	<1%	<1%	---
Total	**100%**	**100%**	**100%**	**100%**

Table A.4. *Volume estimates, as percent of forest land area classified within each separate file (separate files are created for total volume, pine, spruce, and deciduous), for the eastern Dalarna TM scene*

M^3/ha	**Total volume**	**Pine**	**Spruce**	**Deciduous**
0	10%	17%	20%	39%
1-24	8%	36%	25%	56%
25-49	12%	14%	14%	3%
50-74	9%	11%	11%	..1%
75-99	7%	9%	9%	<1%
100-124	7%	5%	6%	<1%
125-149	9%	4%	4%	<1%
150-174	9%	2%	4%	<1%
175-199	7%	1%	2%	<1%
200-224	6%	<1%	2%	<1%
225-249	5%	<1%	1%	<1%
250-274	4%	<1%	1%	<1%
274-299	3%	<1%	1%	<1%
300-400	3%	<1%	<1%	<1%
400-500	<1%	<1%	<1%	<1%
500-600	<1%	<1%	<1%	---
600-700	<1%	<1%	---	---
Total	**100%**	**100%**	**100%**	**100%**

Table A.5. *Biomass estimates as percent of area estimated*

Biomass (tons/ha)	**Eastern scene % of forest land area**	**Western scene % of forest land area**
0	9%	1%
1-49	27%	13%
50-99	30%	27%
100-149	24%	35%
150-199	9%	24%
200-350	<1%	<1%

Table A.6. *Age estimates as percent of area estimated*

Age (years)	**Eastern scene %of forest land area**	**Western scene %of forest land area**
0	8%	4%
1-24	11%	17%
25-49	21%	18%
50-74	21%	13%
75-99	21%	17%
100-124	14%	24%
125-149	4%	6%
150-174	<1%	<1%
175-320	<1%	<1%

Serien Arbetsrapporter utges i första hand för institutionens eget behov av viss dokumentation. Rapporterna är indelade i följande grupper: Riksskogstaxeringen, Planering och inventering, Biometri, Fjärranalys, Kompendier och undervisningsmaterial, Examensarbeten samt Internationellt. Författarna svarar själva för rapporternas vetenskapliga innehåll.

Riksskogstaxeringen:

1995 1 Kempe, G. Hjälpmedel för bestämning av slutenhet i plant- och ungskog. ISRN SLU-SRG-AR--1--SE

2 Riksskogstaxeringen och Ståndortskarteringen vid regional miljöövervakning. - metoder för att förbättra upplösningen vid inventering i skogliga avrinningsområden. ISRN SLU-SRG-AR--2--SE.

1997 23 Lundström, A., Nilsson, P. & Ståhl, G. Certifieringens konsekvenser för möjliga uttag av industri- och energived. - En pilotstudie. ISRN SLU-SRG-AR--23--SE.

24 Fridman, J. & Walheim, M. Död ved i Sverige. - Statistik från Riksskogstaxeringen. ISRN SLU-SRG-AR--24--SE.

1998 30 Fridman, J., Kihlblom, D. & Söderberg, U. Förslag till miljöindexsystem för naturtypen skog. ISRN SLU-SRG-AR--30--SE.

34 Löfgren, P. Skogsmark, samt träd- och buskmark inom fjällområdet. En skattning av arealer enligt internationella ägoslagsdefinitioner. ISRN SLU-SRG-AR--34--SE.

37 Odell, G. & Ståhl, G. Vegetationsförändringar i svensk skogsmark mellan 1980- och 90-talet. -En studie grundad på Ståndortskarteringen. ISRN SLU-SRG-AR--37--SE.

38 Lind, T. Quantifying the area of edge zones in Swedish forest to assess the impact of nature conservation on timber yields. ISRN SLU-SRG-AR--38--SE.

1999 50 Ståhl, G., Walheim, M. & Löfgren, P. Fjällinventering. - En utredning av innehåll och design. ISRN SLU-SRG--AR--50--SE.

52 Riksstogstaxeringen inför 2000-talet.- Utredningar avseende innehålll och omfattning i en framtida Riksskogstaxering. Redaktörer: Jonas Fridman & Göran Ståhl. ISRN SLU-SRG--AR--52--SE

Planering och inventering:

1995 3 Holmgren, P. & Thuresson, T. Skoglig planering på amerikanska västkusten - intryck från en studieresa till Oregon, Washington och British Columbia 1-14 augusti 1995. ISRN SLU-SRG-AR--3--SE.

4 Ståhl, G. The Transect Relascope - An Instrument for the Quantification of Coarse Woody Debris. ISRN SLU-SRG-AR--4--SE.

1996 15 van Kerkvoorde, M. A sequential approach in mathematical programming to include spatial aspects of biodiversity in long range forest management planning. ISRN SLU-SRG-AR--15--SE.

1997 18 Christoffersson, P & Jonsson, P. Avdelningsfri inventering - tillvägagångssätt och tidsåtgång. ISRN SLU-SRG-AR--18--SE.

19 Ståhl, G., Ringvall, A. & Lämås, T. Guided transect sampling - An outline of the principle. ISRN SLU-SRG-AR--19--SE.

25 Lämås, T. & Ståhl, G. Skattning av tillstånd och förändringar genom inventerings simulering - En handledning till programpaketet "NVSIM". ISRN SLU-SRG-AR--25--SE

26 Lämås, T. & Ståhl, G. Om dektektering av förändringar av populationer i begränsade områden. ISRN SLU-SRG-AR--26--SE

Biometri:

1997 22 Ali, Abdul Aziz. Describing Tree Size Diversity. ISRN SLU-SRG-AR--22--SE.

Fjärranalys:

1997 28. Hagner, O. Satellitfjärranalys för skogsföretag. ISRN SLU-SRG-AR--28--SE.

29. Hagner, O. Textur i flygbilder för skattning av beståndsegenskaper. ISRN SLU-SRG-AR--29--SE.

1998 32. Dahlberg, U., Bergstedt, J. & Pettersson, A. Fältinstruktion för och erfarenheter från vegetationsinventering i Abisko, sommaren 1997. ISRN SLU-SRG-AR--32--SE.

43 Wallerman, J. Brattåkerinventeringen. ISRN SLU-SRG-AR--43--SE.

1999 51 Holmgren, J., Wallerman, J. & Olsson, H. Plot - Level Stem Volume Estimation and Tree Species Discrimination with CASI Remote Sensing. ISRN SLU-SRG-AR--51--SE.

53 Reese, H & Nilsson, M. Using Landsat TM and NFI data to estimate wood volume, tree biomass and stand age in Dalarna. ISRN SLU-SRG-AR--53--SE.

Kompendier och undervisningsmaterial:

1996 14 Holm, S. & Thuresson, T. samt jägm.studenter kurs 92/96. En analys av skogstillståndet samt några alternativa avverkningsberäkningar för en del av Östads säteri. ISRN SLU-SRG-AR--14--SE.

21 Holm, S. & Thuresson, T. samt jägm.studenter kurs 93/97. En analys av skogstillståndet samt några alternativa avverkningsberäkningar för en stor del av Östads säteri. ISRN SLU-SRG-AR--21--SE.

1998 42 Holm, S. & Lämås, T. samt jägm.studenter kurs 93/97. An analysis of the state of the forest and of some management alternatives for the Östad estate. ISRN SLU-SRG-AR--42--SE.

Examensarbeten:

1995 5 Törnquist, K. Ekologisk landskapsplanering i svenskt skogsbruk - hur började det?. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--5--SE.

1996 6 Persson, S. & Segner, U. Aspekter kring datakvalitén s betydelse för den kortsiktiga planeringen. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--6--SE.

7 Henriksson, L. The thinning quotient - a relevant description of a thinning? Gallringskvot - en tillförlitlig beskrivning av en gallring? Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--7--SE.

8 Ranvald, C. Sortimentsinriktad avverkning. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--8--SE.

9 Olofsson, C. Mångbruk i ett landskapsperspektiv - En fallstudie på MoDo Skog AB, Örnsköldsviks förvaltning. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--9--SE.

10 Andersson, H. Taper curve functions and quality estimation for Common Oak (Quercus Robur L.) in Sweden. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--10--SE.

11 Djurberg, H. Den skogliga informationens roll i ett kundanpassat virkesflöde. - En bakgrundsstudie samt simulering av inventeringsmetoders inverkan på noggrannhet i leveransprognoser till sågverk. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--11--SE.

12 Bredberg, J. Skattning av ålder och andra beståndsvariabler - en fallstudie baserad på MoDo:s indelningsrutiner. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--12--SE.

13 Gunnarsson, F. On the potential of Kriging for forest management planning. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--13--SE.

16 Tormalm, K. Implementering av FSC-certifiering av mindre enskilda markägares skogsbruk. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--16--SE.

1997 17 Engberg, M. Naturvärden i skog lämnad vid slutavverkning. - En inventering av upp till 35 år gamla föryngringsytor på Sundsvalls arbetsomsåde, SCA. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN-SRG-AR--17--SE.

20 Cedervind, J. GPS under krontak i skog. Examensarbete i ämnet skogsuppskattning och skogsindelning. ISRN SLU-SRG-AR--20--SE.

27 Karlsson, A. En studie av tre inventeringsmetoder i slutavverkningsbestånd. Examensarbete. ISRN SLU-SRG-AR--27--SE.

1998 31 Bendz, J. SÖDRAs gröna skogsbruksplaner. En uppföljning relaterad till SÖDRAs miljömål, FSC's kriterier och svensk skogspolitik. Examensarbete. ISRN SLU-SRG-AR--31--SE.

33 Jonsson, Ö. Trädskikt och ståndortsförhållanden i strandskog. - En studie av tre bäckar i Västerbotten. Examensarbete. ISRN SLU-SRG-AR--33--SE.

35 Claesson, S. Thinning response functions for single trees of Common oak (Quercus Robur L.) Examensarbete. ISRN SLU-SRG-AR--35--SE.

36 Lindskog, M. New legal minimum ages for final felling. Consequences and forest owner attitudes in the county of Västerbotten. Examensarbete. ISRN SLU-SRG-AR--36--SE.

1998 40 Persson, M. Skogsmarksindelningen i gröna och blå kartan - en utvärdering med hjälp av riksskogstaxeringens provytor. Examensarbete. ISRN SLU-SRG-AR--40--SE.

41 Eriksson, F. Markbaserade sensorer för insamling av skogliga data - en förstudie. Examensarbete. ISRN SLU-SRG-AR--41--SE.

45 Gessler, C. Impedimentens potentiella betydelse för biologisk mångfald. -En studie av myr- och bergimpediment i ett skogslandskap i Västerbotten. Examensarbete ISRN SLU-SRG-AR--45--SE.

46 Gustafsson, K. Långsiktsplanering med geografiska hänsyn - en studie på Bräcke arbetsområde, SCA Forest and Timber. Examensarbete. ISRN SLU-SRG-AR--46--SE.

47 Holmgren, J. Estimating Wood Volume and Basal Area in Forest Compartments by Combining Satellite Image Data with Field Data. Examensarbete i ämnet fjärranalys. ISRN SLU-SRG-AR--47--SE.

49 Härdelin, S. Framtida förekomst och rumslig fördelning av gammal skog. - En fall-studie på ett landskap i Bräcke arbetsområde. Examensarbete SCA. ISRN SLU-SRG-AR--49--SE.

Internationellt

1998 39 Sandewall, M ., Ohlsson, B & Sandewall, R.K. People´s options on forest land use. - a research study of land use dynamics and socio-economic conditions in a historical perspective in the Upper Nam Nan Water Catchment Area, Lao PDR. ISRN SLU-SRG-AR--39--SE.

44 Sandewall, M., Ohlsson, B., Sandewall, R.K., Vo Chi Chung, Tran Thi Binh & Pham Quoc Hung. People´s options on forest land use. Government plans and farmers intentions - a strategic dilemma. ISRN SLU-SRG-AR--44--SE.

48 Sengthong, B. Estimating Growing Stock and Allowable Cut in Lao PDR using Data from Land Use Maps and the National Forest Inventory(NFI). Master thesis. ISRN SLU-SRG-AR--48--SE.