# Wood volume estimations for Älvsbyn Kommun using SPOT satellite data and NFI plots

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# *Wood volume estimations for Älvsbyn Kommun using SPOT satellite data and NFI plots*

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## *Summary*

Estimations of wood volume and age were made for Älvsbyn Kommun using SPOT satellite data and National Forest Inventory data. Two scenes of satellite data from 1996 were used, and NFI data from 1990-1998 were used for the estimation. The method used to make the estimates was *k* Nearest Neighbor. Problems were encountered with estimates of clearcuts in one of the scenes, most likely due to a late acquisition date (September 18) at a high latitude, and a sun angle of $25^{o}$. An illumination correction was performed with a 50m resolution DEM, and extra low volume plots were added; results were improved. The total wood volume RMSE was 69% for the eastern SPOT scene and 80% for the western scene. RMSE for age was assessed for the eastern scene at 53%.

### *Introduction*

This project was begun at the request of Norrbotten's Forestry Board (Skogsvårdstyrelsen) and the Norrbotten County Administrative Board (Länstyrelsen). Work was undertaken at the Remote Sensing Lab at Sveriges Lantbruks Universitet (SLU), beginning January 1999 and finishing December 1999. The objective was to estimate forest parameters such as wood volume for the area of Älvsbyn kommun, using SPOT (Satellite Probatoire d'Observation de la Terre) satellite data and National Forest Inventory (NFI) data. The estimates will be used both by Skogsvårdstyrelsen and Länstyrelsen.

The method which was used 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) and is also known by the name of the Reference Sample Plot (RSP) method. Forest parameter estimates from satellite data are currently used operationally in Finland's forestry program. Several studies have also applied this method in Sweden using Swedish NFI data (Nilsson 1997; Reese and Nilsson 1999; Fazakas et al. 1999; Holmgren et al. 2000; Nilsson and Sandström 2001). 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. (1999) and Nilsson and Sandström (2001) found that pixel level accuracy of *k*NN volume estimations was poor, but when aggregated to larger areas, the results were exponentially more accurate. Holmgren et al. (2000) 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.

A project similar to the Älvsbyn project was recently done for Dalarna Länstyrelsen using two Landsat TM scenes to estimate volume, biomass and age. One difference between the Älvsbyn and Dalarna projects was that the Älvsbyn estimates were made using SPOT-3 data, rather than Landsat TM. As for estimates previously made for Sweden using SPOT data, estimates were made using *k*NN in southern Sweden (as part of the "Life" project), and for an EU project on Non-Timber Resources (Vencatasawmy et al. 2001). The results from these projects were not yet assessed for accuracy.

### *Characteristics of SPOT and Landsat TM data*

Because both SPOT and Landsat have different generations of satellites in operation, there are currently a couple of options for their data. The characteristics of these are discussed here and detailed in Appendix A.

The SPOT satellite is referred to as SPOT-HRV (High Resolution Visible) with generations SPOT-1,-2 or -3 whose data consists of three multispectral bands (XS1, XS2, XS3) and one panchromatic band with spatial resolution of 20m and 10m respectively. SPOT also employs a pointable mirror (27° to each side), which allows imaging anywhere in an area of 475 km width, and has a swath width of 60km. SPOT-2 is still in limited operation, SPOT-1 very limited, and SPOT-3 went out of operation in November 1996.

In March 1998 the SPOT-4 HRVIR (High Resolution Visible and Infrared) satellite was launched, with enhanced performance of its sensor through addition of a new shortwave infrared spectral band (SWIR) also at 20m spatial resolution, and an extended nominal lifetime of five years (up from three). The addition of the SWIR should be of value in forestry studies, and is roughly equivalent to the Landsat TM band 5. SPOT-4 will have the same geometric imaging characteristics as the previous SPOT satellites, as well as retaining the same three multispectral bands, but has replaced the previous panchromatic band with a 10m sampling of the red band (band 2). A SPOT-5 satellite is planned for launch in 2001 or 2002, which will have increased spatial resolution in the panchromatic band (2.5m and 5m) and will return to using the band width which was used in SPOT-1 through 3 (rather than the red band). It will also have an increased spatial resolution in the visible and near-IR bands (10m), but will maintain 20m resolution in the SWIR band.

By comparison, Landsat 4 and 5 TM have six multispectral bands with spatial resolution of 30m, and a thermal band with spatial resolution of 120m. Landsat 7 ETM+ was launched April 1999 with new features being a panchromatic band with 15m spatial resolution and a thermal IR channel with 60m spatial resolution. In addition, the price of Landsat 7 data (~US$650/scene) is lower than previous Landsat missions (~US $4000/scene) and is currently lower than the cost of SPOT data. Swath width will remain the same for Landsat 7 as it was for previous sensors (185 km). Specifications for a Landsat 8 are proposed to be the same as for Landsat 7, with a projected launch date in 2003.

### *A brief literature review on using SPOT and/or Landsat data to estimate forest parameters*

It can be reasoned that there could be advantages or disadvantages of using either SPOT or Landsat TM data for forestry purposes. It is interesting to compare the properties of the two data sources. Increased spatial resolution of SPOT may seem to be an advantage over Landsat TM, however, the fewer spectral bands of SPOT as compared to Landsat TM can be a drawback. The best way to consider these two data sources may be to look at some results in the literature. It should be noted that results in the literature vary considerably (Cohen and Spies 1992; Trotter et al. 1997); this may depend on methods used, vegetation of the study area, the image data quality, the variable estimated, and desired accuracy levels. In general however, a majority of the studies show that optical remote sensing can be an economical way to do forest inventory over large areas for lower wood volumes. It should be kept in mind that most of the following studies are done with data previous to SPOT-4 or Landsat 7 data. One can expect that different results will come from these data.

Many studies show that both SPOT and Landsat data have a negative correlation with wood volume (Trotter et al. 1997), except for the near-infrared band, which can vary in its correlation from positive (Spanner et al. 1990), to negative (Ripple et al. 1991; Danson and Curran 1993) or flat (Franklin 1986; Peterson et al. 1987). The correlation between the spectral data and wood volume tends to be stronger for younger stands than for older stands (Franklin 1986; Horler and Ahern 1986; Peterson and Nilson 1993).

Just which bands are most important is also widely discussed in the literature, with varying results. It is generally agreed that the near-infrared band of both SPOT and Landsat is quite important for forestry purposes (Ripple et al. 1991). Ripple et al. (1991) speculated that shadow influenced the high correlation of the near-IR bands to wood volume, while Ardö (1992) found all the Landsat TM bands to be influenced by shadow, and both Horler and Ahern (1986) and Cohen and Spies (1992) found this especially true for the mid-infrared TM bands 5 and 7. However, it has been noted that shadow can be different for plantation forests than it is for natural boreal forest, and therefore may have different influence in the spectral bands for these two types of forests (Trotter et al. 1997). As well as possibly being influenced by shadow, the mid-infrared bands are also correlated to moisture and forest density, and other studies have shown their importance for determining wood volume, age class and basal area in plantation forests (Brockhaus and Khorram 1992). Horler and Ahern found TM bands 5 and 7 to be important in distinguishing clearcut regeneration and TM band 1 was significant in the discrimination of softwoods.

Often, many studies show a weak relationship (low $r^2$ values) between wood volume and spectral reflectance, yet having a high significance (Trotter et al. 1997). This can result in wood volume estimates that can have low accuracy at the pixel level (Iverson et al. 1989; Tomppo 1993; Tokola et al. 1996; Nilsson 1997) yet be accurate for larger areas such as stands or landscape level (Franklin 1986; Poso et al. 1987; Muinonen and Tokola 1990; Hagner 1990; Ahern et al. 1991). It is also important to note that once wood volumes increase and the canopy closes, the relationship between spectral reflectance and wood volume is asymptotic (Franklin 1986; Spanner et al. 1990; Danson and Curran 1993; Ekstrand 1994), and relationships for these higher volumes become more difficult to make and therefore less accurate. The following are brief summaries of often-cited articles which draw conclusions about the utility of both SPOT and Landsat TM for use in forestry remote sensing.

Brockhaus and Khorram (1992) compared SPOT (acquisition date March 14, 1987) and Landsat TM data (acquisition date September 24, 1982) and their correlation to basal area, age class and forest type in a pine and hardwoods dominated experimental forest in the southern U.S. They found that TM bands 2, 3, 4, 5 & 7 resulted in a classification accuracy that was 14% higher for forest type classification than that from using SPOT bands XS1, 2 & 3. The category with the lowest accuracy in both SPOT and TM was "recently harvested" areas, but they give no possible explanation for this. They also found that Landsat TM bands 2, 3, 4, 5 & 7 were significantly correlated to age class, while none of the SPOT bands were. The same TM bands were significantly correlated to basal area, while only SPOT XS3 was significantly correlated. They did not examine volume relationships. One might consider the potential influence of the March/September dates in their comparison.

Trotter et al. (1997) used Forest Inventory and Landsat TM data (acquisition date December 25, 1990) to determine wood volume in New Zealand for *Pinus radiata* plantation stands, comparing parametric regression, non-parametric line-fitting methods, and *k*NN. Using the *k*NN method (with k=15), they found very similar results to studies from SLU, and determined that aggregation of the estimates to 40 ha areas provided acceptable results. Results of determining wood volume from TM bands 3 and 4 were only slightly less accurate than that of using TM bands 1-5 & 7. However they determined that the small dynamic range of the spectral data presented a limiting factor for its use in inventory at more detailed scales.

Looking to future studies, Trotter et al. (1997) felt that their wood volume estimates could be improved if they used a combination of the panchromatic band and multispectral bands of SPOT (and are currently testing this), based on findings by DeWulf et al. (1990). De Wulf et al. demonstrated an improvement in estimating basal area when incorporating the SPOT panchromatic band with multispectral data. One could assume this might also be possible when using the Landsat ETM+ data, with its new 15m panchromatic band. DeWulf et al. (1990) used a February 1, 1987 SPOT panchromatic and a June 27, 1986 SPOT multispectral scene for a plantation forest in Belgium (*Pinus sylvestris* being 35.3% of the cover), and found that XS1 (green) and XS2 (red) bands of SPOT were "useless" (showing no relationship, perhaps due to the small dynamic range) for estimation of parameters such as stand density, stand age, average tree diameter, stand basal area, average canopy height and stand volume. Stand density and age were best related to the panchromatic band, as well as the XS3 (near-IR) band which also showed consistent relationships.

Cohen and Spies (1992) compared the utility of SPOT-HRV panchromatic (acquisition date June 24, 1989) to Tassled Cap indices created from multispectral Landsat TM data (acquisition date July 30, 1988) for analysis of forest stand structural attributes in several different ways. Regression models were used to estimate values for stand attributes, with results that both the SPOT and TM data were found to be equally good at estimating forest age class and stand structure. They also investigated the effect of topography on the ability to accurately estimate stand attributes and found it to be an important influence which affected the results. Their solution to this was to use the

Tassled Cap indice of ”wetness” which was insensitive to the large topographic differences found in their study area. As they looked to the future, they anticipated that the introduction of a panchromatic band for Landsat would perhaps make it a preferred data source for use in estimating forest stand attributes in the Pacific Northwest, due to the importance of the mid-infrared bands in calculating ”wetness.”

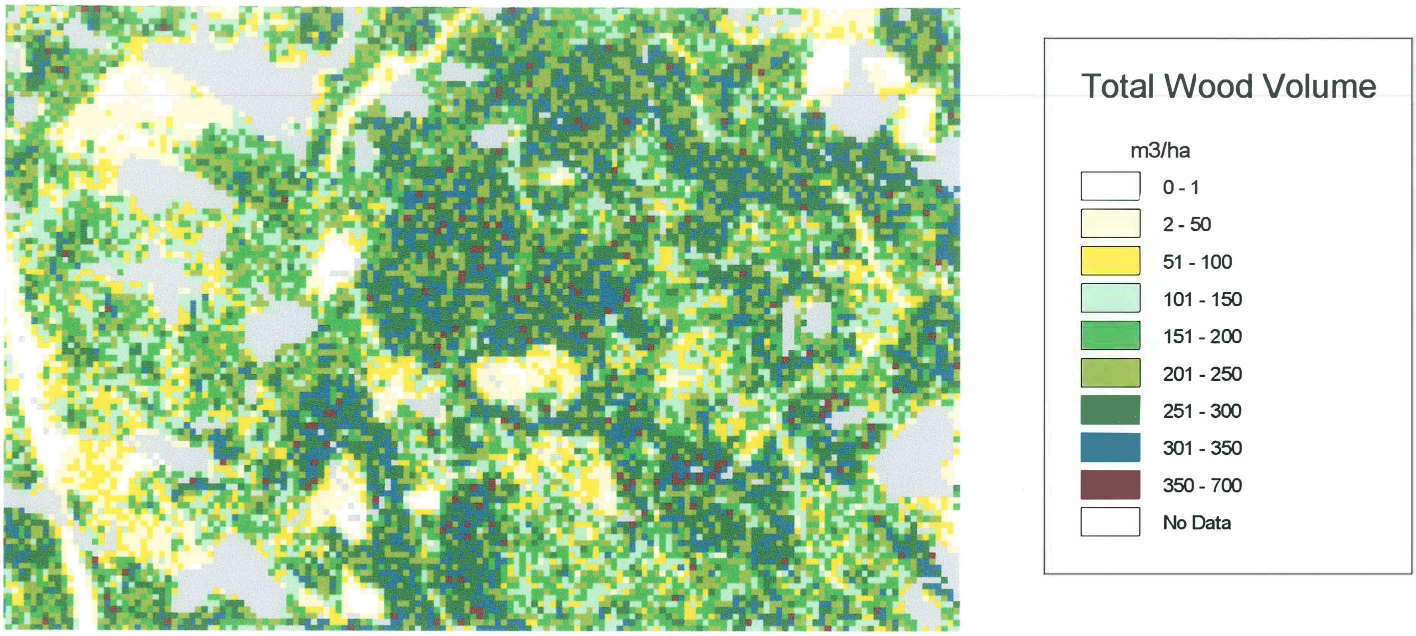
Some noteworthy differences to consider between SPOT and Landsat TM, especially where the present estimation method is considered, are the swath width, and spectral and spatial resolution. The swath width for SPOT is 60 km, and 185 km for Landsat. A single scene of SPOT data cover a smaller area (3,600km$^2$), and therefore contain fewer NFI plots than the larger TM scene (34,225 km$^2$). However, as shown in this study, the addition of the extra 164 plots from 1997 and 1998 did not appear to improve the classification greatly. Also of possible consequence is that the pixel size of SPOT is smaller and is closer in sample size to the NFI plot, and may therefore also have the effect of producing a ”more correct” signature.

Perhaps another useful comparison between *k*NN estimates of wood volume made by SPOT and Landsat data, is presented here for an area in which we have done *k*NN estimations using both Landsat-5 TM and SPOT-3 data (Figure 1). The Landsat data come from the Dalarna project (Reese and Nilsson 1999), and have been assessed for accuracy. The SPOT data are from an EU Non-timber Forest Resources project (Vencatasawmy et al., 2001) but have not been assessed for accuracy. A visual comparison is presented here, just for comparison’s sake. Further investigation should perhaps be pursued with comparison of results from the new SPOT-4 and Landsat 7 ETM+ data.

***Review of results from kNN estimations made at SLU Remote Sensing Lab***

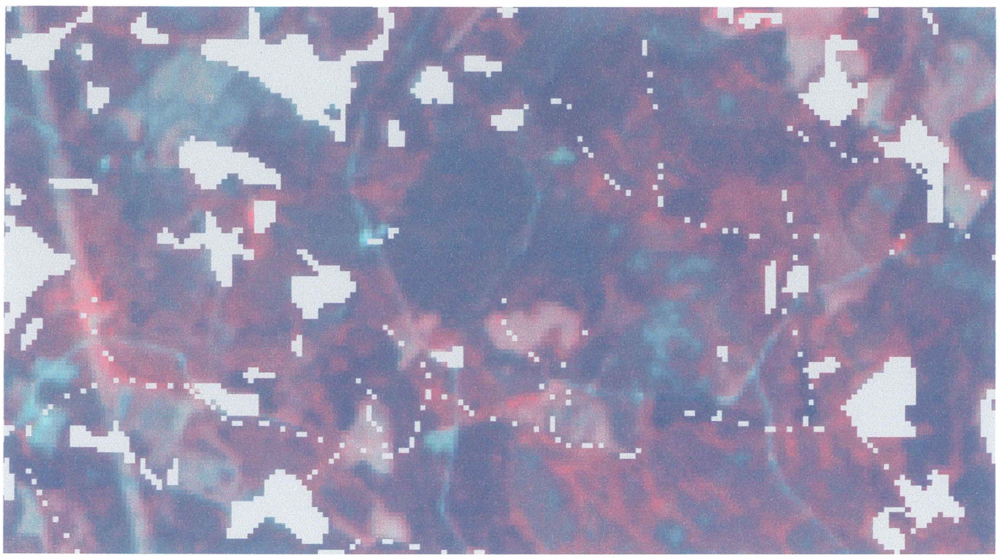
As mentioned previously, several projects have been done at the Remote Sensing Lab at SLU using *k*NN with different satellite data, although most have used Landsat TM data. Estimations of wood volume, age and biomass were made for Dalarna Län using two adjacent scenes of Landsat TM, with overall RMSE at the pixel level (listed by Eastern and Western scene, respectively) of 58% and 75% for wood volume, 57% and 60% for age, and 69% and 77% for biomass (Reese and Nilsson 1999). These were consistent with previous findings, which have high errors at the pixel level, but can be decreased when aggregated to larger areas. A geographic limitation was also tried, in which the values used in the estimation are limited by a set geographic distance. This improved the results slightly.

A *k*NN estimation of wood volume and biomass was also made for the coastal part of Västerbotten Län using one Landsat TM scene (Nilsson and Sandström 2001). They found that on a single pixel level, accuracies were higher if they used k=10 rather than 5, although accuracies were equal at an aggregated level for either k=10 or k=5. The results for this with k=10 at the single pixel level were 59% overall RMSE for total volume and 53% RMSE for biomass. They also used a geographic distance limitation and found the results were slightly better when using plots closer to the area of estimation. When the estimates for total volume were aggregated to a 350 ha level, overall RMSE improved to 14%.




(a) Estimates from Landsat TM data acquired August 21, 1997


(b) Estimates from SPOT-3 data acquired July 7, 1994



c) Raw SPOT data (XS bands 3,2,1). Non-forest mask in gray.

Figure 1. Comparing estimations of total wood volume made with (a) Landsat TM data and (b) SPOT data.

In these studies, and others (Nilsson 1997; Fazakas et al. 1999; Holmgren et al. 2000), it was found that high volumes (around 250 $m^3$/ha and more) are underestimated while lower volumes (less than 100 $m^3$/ha) are overestimated. There tends to be a bias of the estimate towards the mean wood volume value. It has also been true that in studies using Landsat TM data, the classification of Spruce and Pine sometimes get confused. However, classification can be good for distinguishing the deciduous trees from the coniferous. The figure below is an illustration of the effect of aggregating the estimates to a larger area (Fig. 2).

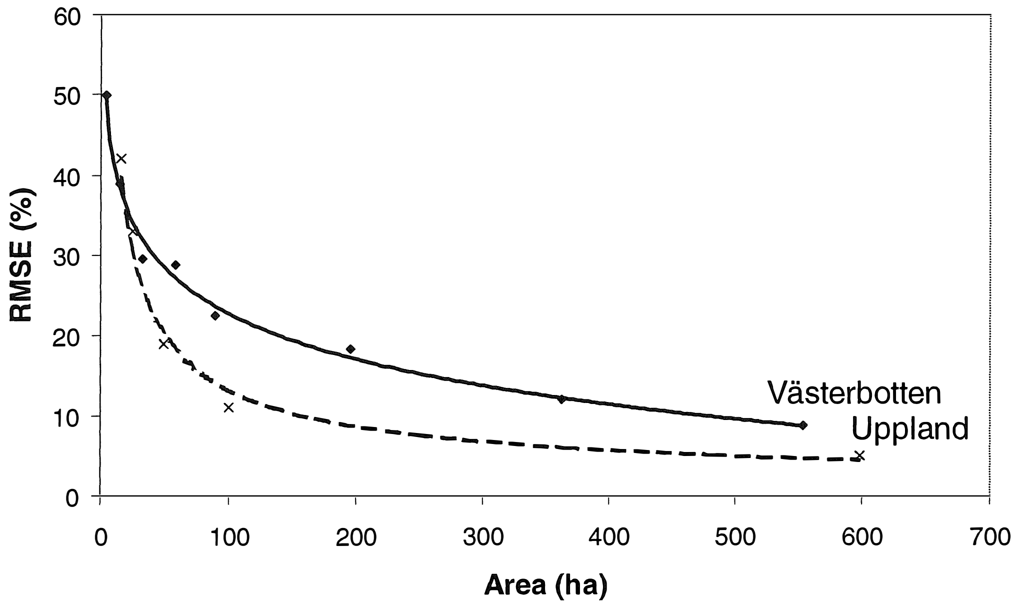



*Figure 2. The effect of aggregation to larger areas on the accuracy of the estimates (Uppland from Fazakas et al 1999; Västerbotten from Nilsson and Sandström 2001).*

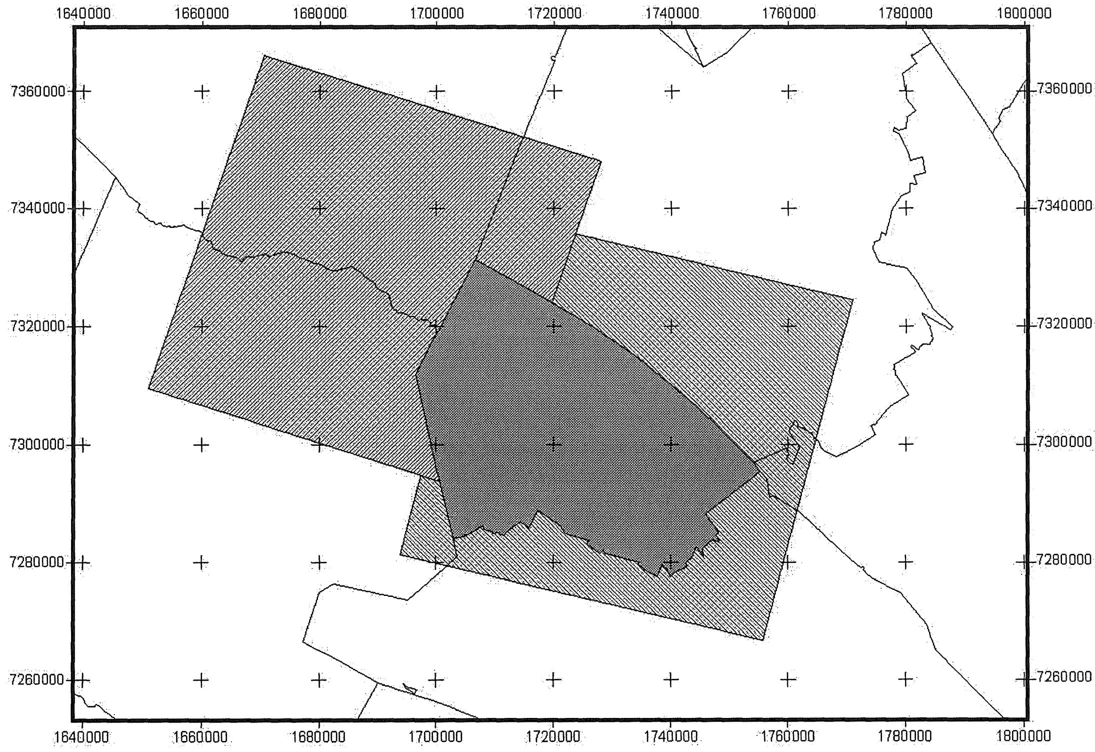
### *Objectives of the Älvsbyn project*

The objective of this project was to create estimations of age, total wood volume, and also wood volume for the different tree species. The project was to use two adjacent scenes of SPOT-3 image data from 1996, NFI data, and a forest mask, in a *k*NN estimation.

### *Study Area*

The study area was Älvsbyn Kommun which is approximately 200,000 ha in size, with the city of Älvsbyn located at approximately 65° 38' N, 21° 00' E. The vegetation there is typically Scots Pine (*Pinus sylvestris)*, Norway spruce (*Picea abies)*, and species of Birch (*Betula spp.*) The elevation ranges from approximately 0 to 571m. The study area, and the location of the satellite data are shown in Figure 3.

Figure 3. Älvsbyn and location of SPOT data




### *Digital data*

Two SPOT-3 satellite scenes were used for this estimation. The data were geometrically precision-corrected to the Swedish National Grid (RT90). The acquisition date of the eastern scene (path 054/row 214) was September 17, 1996 and the western scene (path 053/row 213) was August 22, 1996. Only the three multispectral wavelength bands were used in the analysis (XS1, 2 & 3), leaving out the 10m panchromatic band. Throughout this paper, the satellite data are referred to as "the eastern scene" and "the western scene".

The western scene had a viewing angle of $-1.04^{o}$ off nadir, with sun angle at $35^{o}$ and sun azimuth at $175^{o}$. The eastern scene had a viewing angle of $-12.16^{o}$ off nadir, with sun angle of $25^{o}$ and sun azimuth at $173^{o}$. Both scenes had "smearing" in band 2, and were corrected using a 7x7 filter (Hagner, unpublished). The eastern scene had a few small clouds and cloud shadows which were removed from the data.

### *Map mask*

A comparison of the Blue Map and the Vegetation Map was made to see which map best overlayed and respresented the forest area. After visual inspection, the Vegetation Map was chosen to be used as the map mask, because it seemed to fit the forest boundaries better. Only areas considered as "productive forestland" (all classes of Barrskog and Lövskog from the Vegetation map) were used in the estimation and non-forestland areas were removed from the analysis.

*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, with 8 plots to the tract. Temporary plots are seven meters in radius, and in Älvsbyn 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 SPOT scene and one covering the area of the eastern SPOT scene. These datasets consisted of a subset of variables from the NFI database, such as volume, biomass, and age. Plot data were sampled from a nine year period (1990-1998) for the eastern scene, and a seven year period (1990-1996) for the western scene.

A growth function projecting 5-year growth (Söderberg 1986) was applied to the volume measurements in attempt to reconcile the difference between the SPOT 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 SPOT spectral values for each plot location. This was accomplished by geographic overlay of the dataset plot coordinates on the SPOT data and extraction of each of the three SPOT band's spectral values for that location using nearest neighbor interpolation.

*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).

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

where
$i$ = SPOT bands 1-3
$\beta_k$ = 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. For the final classification, the datasets to be used in the estimations (after outlier removal) totalled 508 plots for the eastern scene and 283 plots for the western scene. Table 1 shows the distribution of number of plots and volumes from the NFI data used for the final estimation (which involved addition of extra plots and an illumination correction for the eastern scene as discussed in the "Corrections" section).

Table 1. Summary of number of NFI plots used in the estimation

| **Volume groups in $m^3$/ha** | **0-25** | **25-100** | **100-200** | **200-300** | **300+** | **total plots** | **overall mean** |
|---|---|---|---|---|---|---|---|
| **Eastern scene** | 50* | 101 | 138 | 52 | 21 | 508 | 115*$m^3$/ha |
| **Western scene** | 90 | 99 | 80 | 12 | 3 | 283 | 77 $m^3$/ha |

* exclusive of 140 extra low volume plots

### *The kNN Method*

Using the resulting dataset with outliers removed, total wood volume and the different tree species' volume 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

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

$d_{j,p}$ = Euclidean distance from pixel $p$ to plot $j$, and
$v_{j,p}$ = forest parameter estimated for the plot with distance $d_{j,p}$

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

***Results***

On June 10, 1999, a field check on the estimates of wood volume (total and by species) was performed on 20 out of 40 plots which were selected based on their accessibility and for their range of estimated volumes. It was found that results were accurate in the Western scene, while some results for the Eastern scene seemed to underestimate higher volumes and overestimate low volumes. This is somewhat typical of the results from the *k*NN estimations, in that the estimations have a tendency toward the mean value. However, at one particular overlap between the East and West scenes, there were differing estimates for what appeared in the imagery to be a clear-cut. Upon visiting the site, it was shown that the Western estimates were right (see Figure 4), while the Eastern scene had wrongly estimated the obvious clearcut to be of high volume (see Figure 5). This field check led us to look at the Eastern estimates more closely, and to figure out why these problems had occurred, and why such a difference should occur between the Eastern and Western scenes. In this initial estimation, 283 plots had been used for the Western scene, and 323 for the Eastern scene. Using the 20 ground truth plots collected in June (although this number is too few to be a meaningful assessment), the RMSE for total volume in the Eastern scene was found to be 71 $m^3$/ha (62% relative to the mean).

***Corrections***

*Potential solution 1: Creating more low volume plots*

When we compared the spectral signatures of the pre-outlier-removal plots to the post-outlier-removal plots for the Eastern scene, we found that the spectral variation (which can occur in very low volume [e.g., 0-10$m^3$/ha] areas) had been reduced more than in other volume classes. It was decided that we should visually inspect (on the image data) the NFI plots with 0 – 10 $m^3$/ha volume before outlier removal, and ascertain that they were indeed within clearcuts, and then exclude these plots from the outlier removal process. In addition, because there was such spectral variability within 0-10 $m^3$/ha volume areas, we also created additional plots. This was done by taking the NFI plots that were 0 to 10 $m^3$/ha volume and were determined to be at least one pixel away from a stand edge, and sampling not only at the pixel for that plot, but also ”creating plots” from the 8 pixels surrounding it. This created 140 extra plots with low volume, which were added to the original data set, resulting in 468 plots to use in this estimation.

*Results from Potential solution 1:*

By visual assessment, it appeared that adding more plots of low volume improved the estimation of these areas. Also, in using the 20 ground truth plots as a check, it had improved the accuracy to an RMSE of 61 $m^3$/ha for total volume (53% relative to the mean). However, while it did improve the estimation, the addition of these low volume plots did not completely render the clearcut in question to appear as the low volume that it should have been.

*Potential solution 2: Adding more plots from other years*

It was also considered that perhaps too low a number of plots, due to the relatively smaller area coverage of a SPOT scene, may have contributed to the inaccurate estimations of the eastern scene. At the time of first assembling the NFI data to be used in the estimation, the 1997 and 1998 coordinates were not available for use. However, by July 1999 these data were then available for use in the estimation. Adding plots from 1997 and 1998 gave us 164 additional plots, with 421 used in this estimation after outlier removal. Because the image date was from 1996, growth was subtracted from the 97/98 NFI data to fit the date of the imagery.

*Results from Potential solution 2:*

The results from this did not improve the estimation of the clearcut in question, and in fact, made a worse classification in a nearby clearcut which had previously classified correctly. The RMSE from the 20 ground truth plots was 70 $m^3$/ha (61%), not a significant improvement from the original.

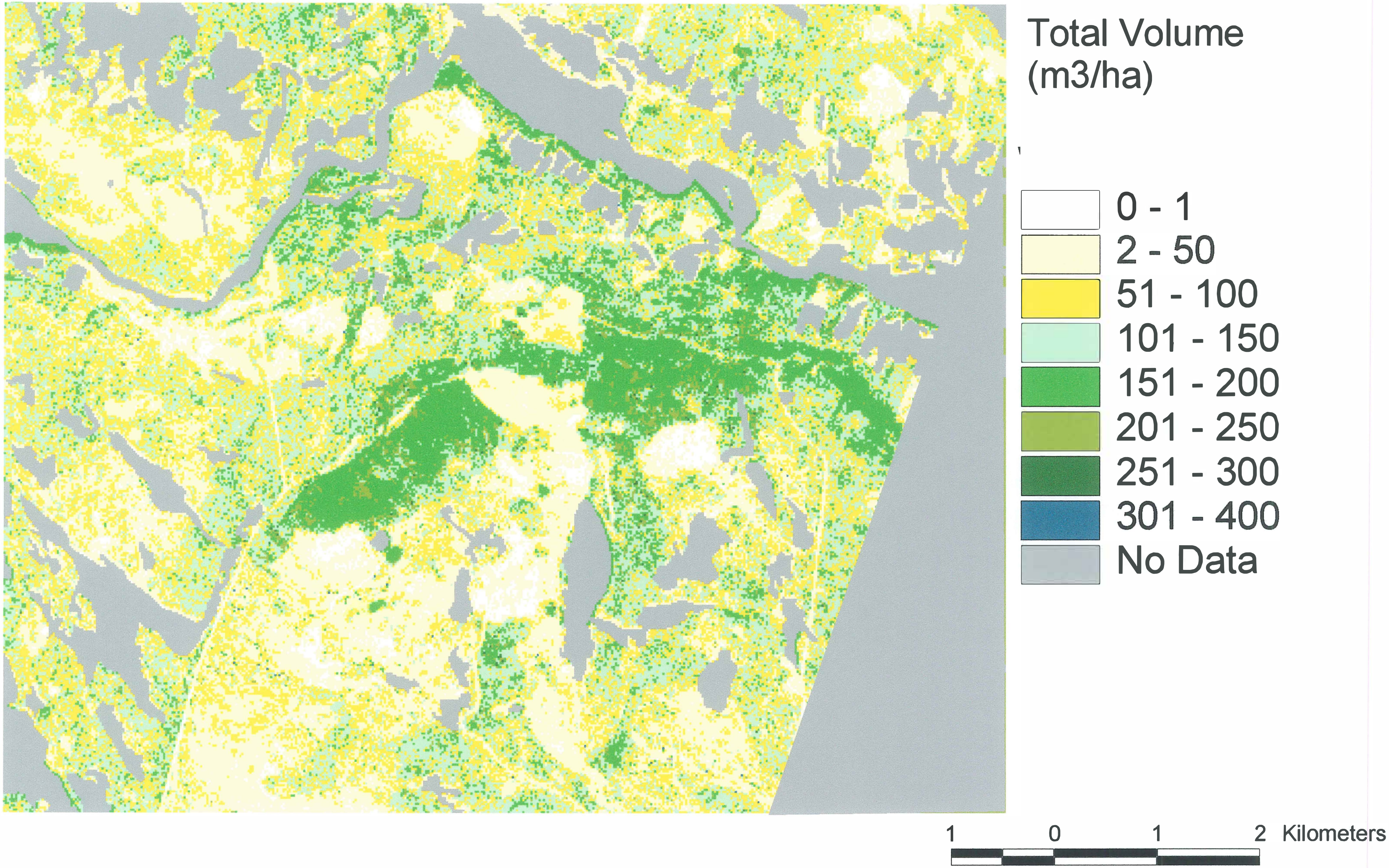



Figure 4. Subset of total volume estimates using the western SPOT scene. The clearcut we investigated is at the center of this figure.

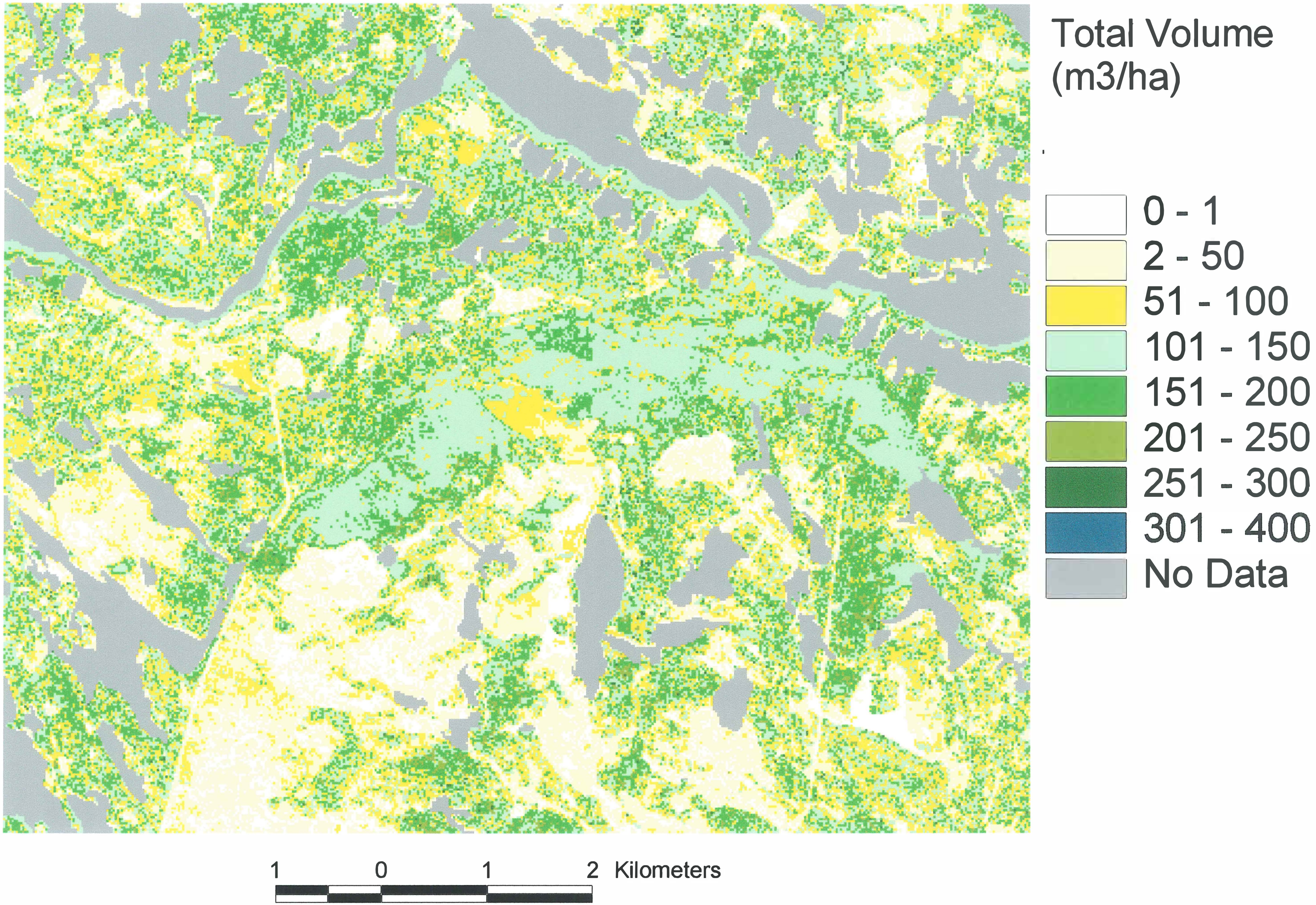



Figure 5. Subset of total volume estimates, the first results.

*Results from combining plots from both Potential solutions 1 and 2:*
An estimation which used a combination of the two previously mentioned extra data sets (low volume and 97/98 data) was tried. This estimation used 508 plots total. The visual assessment showed that the estimation of the clearcut was still not wholly correct, and was improved only slightly from the original. The result was not as good as using just the additional low volume plots, as plots from 1997 and 1998 may have added some error. However, it looked a little better than the result from using just the additional 97/98 data. The error from the 20 ground truth plots was calculated as 67 $m^3$/ha (58%).

*Potential solution 3: Correction for low sun angle*
The sun angle of the Eastern scene is 25°, as it was taken on September 18th, which is late in the year for such an area as Älvsbyn Kommun, which is at a high latitude. The clearcut in question, as well as other clearcuts in the area, lie in an area with some topographic differences. It appeared that shadow, cast from nearby slopes, especially at a low sun angle, may have been influencing the spectral signatures, and therefore made this particular clearcut appear more like high volume than low volume.

An illumination correction was applied to each band within the Eastern SPOT image. A 50m Digital Elevation Model (DEM) over the area was resampled to 20m using bilinear interpolation, and slope and aspect were derived. These were used to correct the SPOT data using a model described by Teillet et al. (1982). First, linear regression functions were derived for each spectral band using NFI data plot (Eq. 4), such that

$$DN_j = m \times \cos(i) + b \tag{4}$$

where,
$DN_j$ = Digital Number of SPOT band j,
m and b are constants, and
i = sun slope normal angle.

The cosine (cos(i)) of the solar incidence angle with respect to surface normal was calculated as shown in Eq. 5:

$$\cos(i) = \cos(e)\cos(z) + \sin(e)\sin(z)\cos(\Phi_s - \Phi_n) \tag{5}$$

where
i = solar incidence angle on slope
e = terrain slope
z = solar zenith angle
$\Phi_s$ = solar azimuth angle, and
$\Phi_n$ = surface aspect of the slope angle.

Parameter ”c” models the diffuse sky radiation and is computed in Eq. 6 as

$$c = b / m \tag{6}$$

and is added to the cosine correction (Eq. 7),

$$DNh = DNt\ [(\cos(z)+c/(\cos(i)+c)] \tag{7}$$

where
DNh = Digital Number observed for a horizontal surface.

Plot data from both 1997, 1998 and low volume plots were added to the original dataset, and outliers were re-run. After outlier reduction of 20% this resulted in 508 plots. Although the previously mentioned assessments found that adding only the low volume plots resulted in a lower error than adding 1997, 1998 and low volume plots, it was decided to still use the dataset with all these plots. This is because outlier reduction would be re-run on all of these plots, and with the illumination correction, there may have been very different results.

*Results from the Illumination Correction*
With visual assessment, the illumination correction seemed to give the better classification result of the clearcut (see Figure 6) than all the other methods previously tried. The clearcut area in question had low volumes of 0-50 $m^3$/ha, except for a small patch of 100-125 $m^3$/ha which appeared to be a problem in all of the estimations. The rest of the resulting estimation appeared much more like the results from the western estimation than any of the other attempts. Using the 20 ground truth plots, the RMSE was assessed at 62 $m^3$/ha (54%). Another ground truth point that was visited, which showed up in the original estimations to be 150 $m^3$/ha, but was actually a cliff with very low volume, was not improved with the illumination correction, nor any of the other attempts.

***Accuracy Assessment and summary***

As noted, a field check of 20 plots was done on June 10, 1999, of the original estimates. Those doing the field checking included Tina Nilsson, Peter Söderberg, Johan Ericsson, Heather Reese and Mats Nilsson. Wood volume was assessed subjectively, which may have a standard error of 13.5% at the stand level (Ståhl, 1992). The results of the accuracy for these plots was discussed earlier, in the Corrections section and ranged from 62% to 53% overall RMSE. However, 20 plots is not a large enough number of plots to constitute a proper accuracy assessment.

The other data available were some SCA data in three different parts of the scene, but this was not full coverage. In checking the field plots above to the SCA data, it was found that the estimates were as accurate or more than the SCA estimates to the actual measured wood volume.

A cross validation, or boot strapping technique was done to assess the accuracy for each. The results of this were a 69% and 80% overall RMSE for total volume, for the eastern and western scenes, respectively. The bias was 2 $m^3$/ha (eastern) and 0.6 $m^3$/ha (western). In the eastern scene, the overall RMSE for age was 53%, with a bias of 0.7 years.

As mentioned previously, these are results which were assessed at the pixel level, and the RMSE can be quite high. When the data are aggregated to larger areas, such as a stand level aggregation or larger, the accuracy of the estimates increases. It can be expected that the accuracy will be greater towards the mean values, which were approximately 115 $m^3$/ha in the eastern scene, and 77 $m^3$/ha in the western scene, as was listed in Table 1. It appeared that the illumination correction made to the eastern scene, in combination with the addition of extra low volume plots, aided in making a better classification, especially in a particular clearcut area which was located on a northern slope. Figure 7 is a map of the estimation of total wood volume for all of Älvsbyn Kommun, using the illumination correction for the eastern scene, and the original results for the western scene.

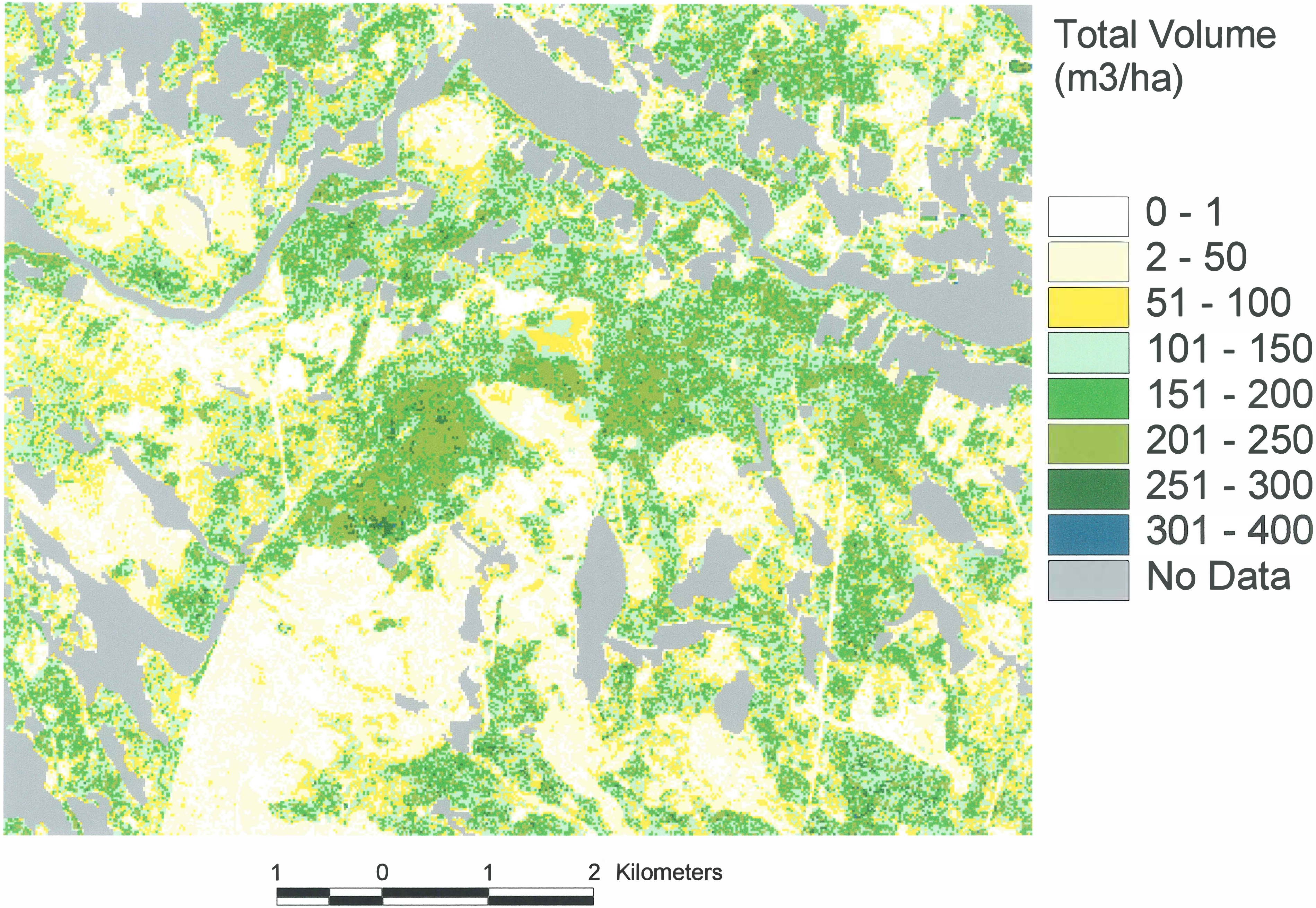



Figure 6. Subset of total volume estimates, using illumination corrected SPOT data

# Total wood volume estimation for Älvsbyn
# From SPOT data and NFI data

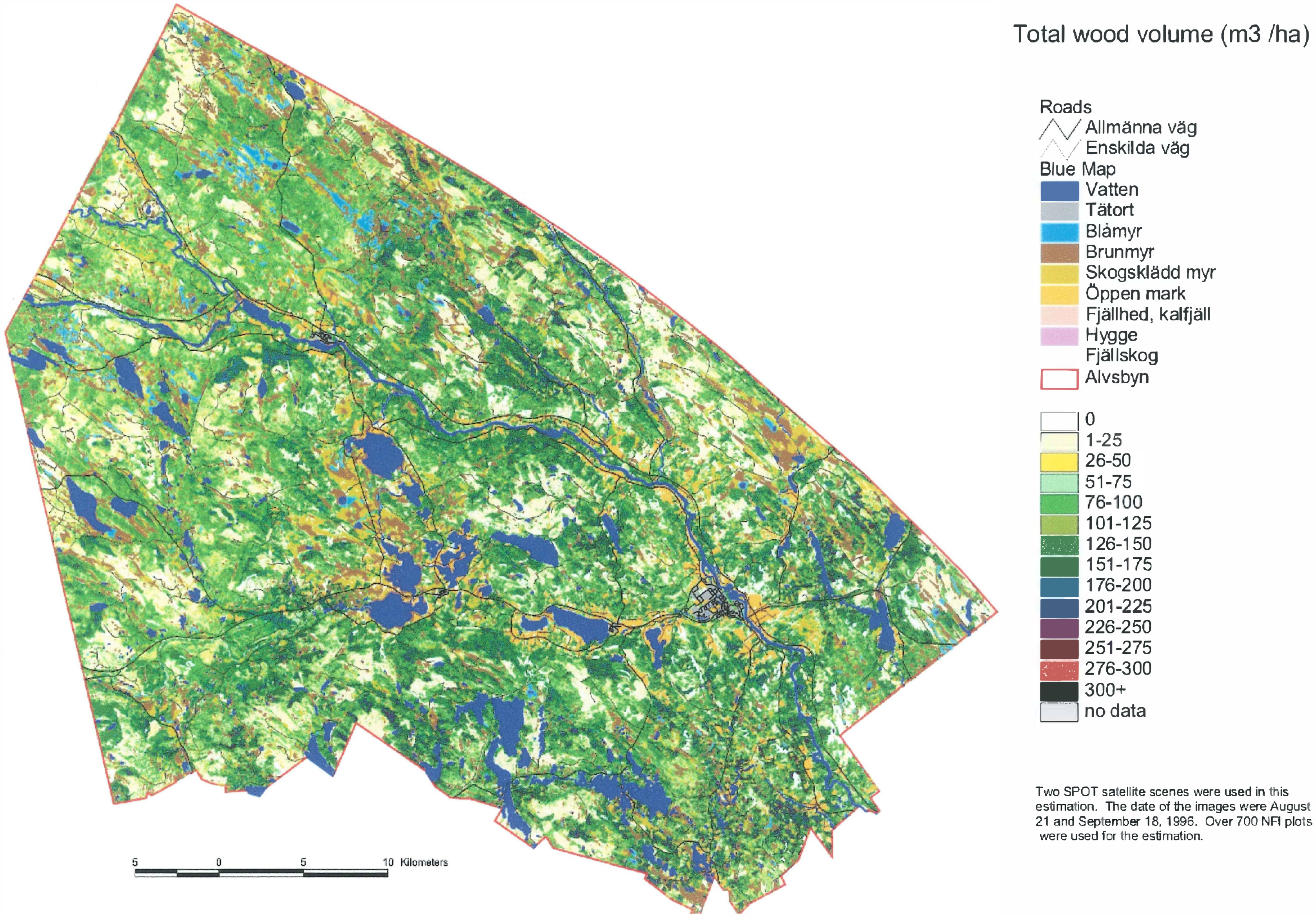



Figure 7. Final total wood volume estimates for Älvsbyn Kommun

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Appendix A: Characteristics of SPOT 1-4 and Landsat 4-7

**Landsat 4 and 5**

| **Band** | **Spectral width($\mu m$)** | **Spatial res.** |
|---|---|---|
| 1 (blue-green) | 0.45 – 0.52 | 28.5m |
| 2 (green) | 0.52 – 0.60 | 28.5m |
| 3 (red) | 0.62 - 0.69 | 28.5m |
| 4 (near-IR) | 0.76 – 0.90 | 28.5m |
| 5 (mid-IR) | 1.55 – 1.75 | 28.5m |
| 6 (thermal-IR) | 10.40 – 12.50 | 120m |
| 7 (mid-IR) | 2.08 – 2.35 | 28.5m |

**SPOT-1, -2 and -3 HRV**

| **Band** | **Spectral width ($\mu m$)** | **Spatial res.** |
|---|---|---|
| 1 (green) | 0.50 - 0.59 | 20m |
| 2 (red) | 0.61 – 0.68 | 20m |
| 3 (near-IR) | 0.79 – 0.89 | 20m |
| P (panchromatic) | 0.51 – 0.73 | 10m |

**Landsat 7 ETM+**

| **Band** | **Spectral width($\mu m$)** | **Spatial res.** |
|---|---|---|
| 1 (blue-green) | 0.45 – 0.52 | 30m |
| 2 (green) | 0.52 – 0.60 | 30m |
| 3 (red) | 0.62 - 0.69 | 30m |
| 4 (near-IR) | 0.76 – 0.90 | 30m |
| 5 (mid-IR) | 1.55 – 1.75 | 30m |
| 7 (mid-IR) | 2.08 – 2.35 | 30m |
| *P (panchromatic) | 0.5 – 0.9 | 15m |
| *thermal | 3.53 – 3.93 | 120m |
| *thermal | 8.2 - 8.75 | 60m |
| *thermal | 8.75 - 9.3 | 60m |
| *thermal | 10.2 - 11.0 | 60m |
| *thermal | 11.0 - 11.8 | 60m |

**SPOT-4 HRVIR**

| **Band** | **Spectral width ($\mu m$)** | **Spatial res.** |
|---|---|---|
| 1 (green) | 0.50 - 0.59 | 20m |
| 2 (red) | 0.61 – 0.68 | 10/20m |
| 3 (near-IR) | 0.79 – 0.89 | 20m |
| *4 (mid-IR) | 1.58 – 1.75 | 20m |

* denotes changes from previous generation

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.

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