# Forest change detection by satellite remote sensing in Eastern Finland

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## ABSTRACT

New methods for updating forest information are needed because of the high costs of periodically repeated total field inventories. Continuous updating of forest information is one way of reducing costs. However, quality of the continuously updated information has to be controlled and limited field control resources have to be targeted optimally. A non-parametric discrimination method based on the detection of changed forest stands by combining multitemporal Landsat TM data with old stand delineation and attribute data has been developed. The method was tested for the Finnish Forest and Park Service in Eastern Finland on a 1668.2 ha test area. If the reason for change is not specified, the correct classification percentage was 96.7 on peat land stands and 96.8 on mineral soil stands. When the field check is aimed only at stands with possible updating errors, according to the presented method, the amount of field work required is about 10-30 % of that needed with periodically repeated field inventory.

## 1. INTRODUCTION

Many forest owners and organisations in Finland have shifted to continuous updating of the information needed in forest management planning. Instead of repetitive total inventories, treatments are updated just after implementation, and untreated stands are updated according to growth models. The main reason for replacing the old repetitive inventory system has been an effort to decrease the costs of collecting and updating forest information. However, it is obvious that the quality of the information should be controlled, at least during the implementation of the new continuous updating systems (Varjo and Päivinen 1992). This phase can be over ten years long in large organisations like the Finnish Forest and Park Service. During this implementation phase, gaps in updating routines seem to exist, and they must be controlled and the errors corrected. After the implementation of the new system, possible forest damage has to be monitored.

Satellite remote sensing has been used for forest inventories and land use inventories, mainly at a regional level. So far, satellite information has not been accurate enough for operational purposes in Finland (Tomppo 1988, Tokola 1990, Häme 1991). The recent advance in radiometric calibration of satellite images has made production of a stable and accurate series of multitemporal images possible (Olsson 1991, 1993). Similarly, the satellite image based inventory and change detection methods have advanced (Tomppo and Siitonen 1991, Hagner 1989, Hagner 1990, Olsson 1990). By combining satellite images with accurate but old field information, it seems possible to create control systems for continuous updating of forest information. The idea is to combine the advantages of both satellite image interpretation and field inventory.

Satellite images provide a low cost repetitive source of information, and old field inventory data provide accurate though not always up to date information. By combining this information with continuous updating, it is possible to minimise the need for new field inventories without risking the quality of the information. The aim of this study is to find out if multitemporal TM images can be used for controlling the quality of continuously updated forest information. A difference image is formed, based on radiometric calibration by robust regression, and changes between images are detected by non-parametric (in the sense of Silverman 1986) discriminant analysis. The changes detected from TM images are compared to the manmade changes recorded. Only the stands where there is discrepancy between TM image interpretation and treatments recorded are recommended for field inspection. The decrease in field work compared to the old inventory system where all the stands were reinventoried every ten years is estimated.

## 2. MATERIAL AND METHODS

Two Landsat TM acquisitions were available. The acquisition dates and path/row indexes were 8th of June 1988 and 187/15 for the first image, 23rd of June 1990 and 185/15 for the second. The centre of the study area is located 63° 45' N and 29° 30' E and the study area was totally cloud free on both images. The images were registered together and rectified to the Finnish Uniform coordinate system. In registration and rectification the nearest neighbour method and second order polynomial were used. The stand delineation, based on aerial photographs and field work of the latest standwise forest inventory, was available and it was combined with the multitemporal image. Images were radiometrically calibrated by using an application of the band to band simple robust regression method (*e.g.* Rousseeuw & Leroy 1987, Olsson 1991). The stand DN means were regressed and the model was weighted by the inverse of standwise standard deviation. The standwise model was selected to avoid disturbing noise on the pixel level. Only forest stands were used for modelling (Olsson 1993). Outliers were detected and excluded before estimation of the final regression coefficients used to bring the earlier image radiometrically comparable with the latter one. The difference image was formed by subtracting the regression calibrated 1988 TM image from the 1990 TM image.

The study area is managed by the National Board of Forestry and old stand attribute data as well as stand delineation were based on the last total inventory in 1988. Independent data for radiometric calibration and training data for the change detection were collected from the forest district of Nurmes. The method was tested at the sub area totalling 1668.2 ha. The mean size of a stand was 5.1 ha. The area is dominated by Norway spruce and Scots pine. They both form pure and mixed stands but broad leaf species exist usually as a mixture with coniferous species.

Training data included clear cuts, hold over (HO) removals and thinnings between the TM acquisitions. When there were no more change classes available, the class "clear cut" was considered to represent drastic changes such as clear cuttings, regeneration cuttings and soil preparation, when estimating the decrease of field work with the system proposed. The assumption was based on the similarity of spectral change between these kind of reasons for change (*e.g.* Häme 1991). In a similar manner, thinnings were considered to represent moderate spectral changes, like thinnings, drainings, clearings and possible forest damage (*e.g.* Häme 1991). Peat lands and mineral soils were analysed separately because of the differences in spectral response (Saukkola 1982).

Linear standwise non-parametric discrimination was used for change detection. Independent variables for discrimination were selected from among the first three central moments of stand DNs (mean, standard deviation and skewness) for every channel of the regression calibrated difference image. Multicollinearity problems were resolved by utilising stepwise discrimination in selection. Only the central moments which, according to the stepwise discrimination had statistically significant influence in separating changes, were used in non-parametric change discrimination. In addition to previous spectral information, basal area and stand age were used in input vector for non-parametric change discrimination. In the discrimination, the treatment classes in training data – unchanged, clear cuts, HO removals and thinnings – were described by normal Kernel distribution (Silverman 1986).

The Kernel-method was selected because the change classes could not be properly described by any parametric distribution **(Figure 1)**. The measure of proximity used in

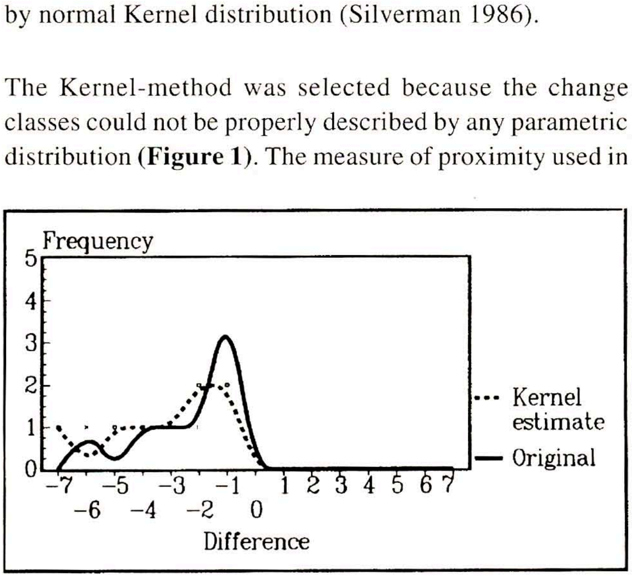


*Figure 1 - The channel 4 spectral difference between the images described by Kernel distribution on a thinned stand*

the discrimination was Mahanalobis distance based on the pooled covariance matrix. In the discrimination, a probability for each stand in the test area to belong to each class in the training data was formed based on density estimate (Formula 1). The window parameter was used to determine how accurately the Kernel distribution follows the original data and it was determined by the Silverman's (1986) approximation based in this case on the red channel standard deviation.

The bayesian decision rule was used for classifying changes. The a priori probabilities were set equal for all classes to make it possible to detect possible forest damages. As a result, a stand was classified according to the greatest a-posteriori probability.

The method is described in more details in (Varjo 1995).

$$f_t(x) = \frac{1}{n_t} \sum_{i=1}^{n_t} K_t(x - y_i) \qquad (1)$$

$f_t(x)$ = the density estimate of class t at stand x

$n_t$ = number of observations on training data set at class t

$y_i$ = class on training data including i observations

$$K_t(z) = \frac{1}{(2\pi)^{\frac{p}{2}} h^p |s|^{\frac{1}{2}}} e^{-\frac{1}{2}\frac{z' s^{-1} z}{h^2}}$$

p = dimension

h = window parameter

S = pooled variance-covariance matrix

## 3. RESULTS

The utility of the method was tested by classifying the test area into the following four groups: no change, clear cut, HO removal and moderate change. The most important Landsat TM channels in classification were 3, 4 and 7 and for mineral soils, channel 6. In addition, on peat land channel 5 was important. All the possible change stands were ocularly inventoried on the field. Because of the limited field work resources the stands which were classified into the class "unchanged" could not all be field inspected. The classification results in this class were controlled by selecting a fraction of stands to be field inspected by sequence sampling (**Tables 1 and 2**). According to the sequential sampling scheme used, the stands detected as "unchanged" in field inspection are unchanged with 95 % confidence level. A stand was defined to be correctly classified when a changed stand was classified into any of the change classes present. In this situation, the percentage of correctly classified stands was 96.8 for mineral soil and 96.7 for peat land (**Tables 1 and 2**).

**Table 1 - Results of the standwise change detection on mineral soils, moderate changes include thinnings, clearings and drainings. Percentage of correctly classified stands – ie change is classified into any of the change classes – is presented at the lower right corner**

| | Landsat TM change classification | | | | | |
|---|---|---|---|---|---|---|
| **Field control** | **Clear cut** | **Hold removal** | **Moderate change** | **No change** | **Total** | **%** |
| Clear cut | 9 | 1 | | | 10 | 6.4 |
| Hold over removal | | | | | | |
| Moderate change | | | 4 | | 4 | 2.6 |
| No change | | | 5 | 137 | 142 | 91.0 |
| Total | 9 | 1 | 9 | 137 | 156 | 100.0 |
| % | 5.8 | 0.6 | 5.8 | 87.8 | 100.0 | 96.8 |

The total area of the stands classified into change classes was 209.5 ha. From those 192.6 ha, 91.9 %, were classified according to the correct reason for the change, when the clear cuts classified into HO removals are not considered to be a mistake (**Tables 1 and 2**). The errors which occurred in change classification were caused by unchanged stands which were classified as "moderately changed". However, this is not very dangerous because these stands will be recommended to be field inspected. The errors in the other direction (i.e. where changed stands would have been classified into the class "unchanged") did not exist (**Tables 1 and 2).** Errors in the class HO removal do not cause problems because HO removals can be separated from moderate changes by the age of the stand when it is available, as in this case. All together, the classification results were very good, especially concerning clear cuts.

The field check can also be concentrated on the stands which were classified as moderately changed, and where there was no recorded information about possible change during the control period. The total area of these stands is 100.0 ha (6 %).

**Table 2 - Results of the standwise change detection on peat land, moderate changes include thinnings, clearings and drainings. Percentage of correctly classified stands – ie change is classified into any of the change classes – is presented at the lower right corner**

| | Landsat TM change classification | | | | | |
|---|---|---|---|---|---|---|
| **Field control** | **Clear cut** | **Hold removal** | **Moderate change** | **No change** | **Total** | **%** |
| Clear cut | 4 | | | | 4 | 3.3 |
| Hold over removal | | 1 | | | 1 | 0.8 |
| Moderate change | | 1 | | | 1 | 0.8 |
| No change | 1 | | 3 | 111 | 115 | 95.1 |
| Total | 5 | 2 | 3 | 111 | 121 | 100.0 |
| % | 4.1 | 1.7 | 2.5 | 91.7 | 100.0 | 96.7 |

The need for field checks can be decreased even more if treatments like draining and clearing can be recorded, at least to some extent. If information about all clearings and drainings had been available the area of field check needed would have been only 14.2 ha, 0,9 % of the total area.

The decrease in the amount of field work with this system is evaluated for the traditional ten years repetitive inventory period by assuming that similar changes occur for every two year period. If no previous information on treatments in the moderate change class is available, about 30 % of the area has to be visited. In an ideal case, where all the treatments are recorded, the need for a field check is about 5 % of the area. This need for field inspection is caused by the errors of the change detection method proposed.

## 4. DISCUSSION

As expected, all the clear cuts were correctly classified except one stand which had not changed, and one classified for HO removal. Obviously the first error was due to the size of the stand which was only 0,4 hectares. In this kind of situation, DN intensity means recorded from a stand can be very much affected by mixed pixels. However, border pixels can not be excluded because if they were, the stand mean intensities might be based on too few pixels. As a conclusion, classification results can be trusted in this case, and there is no need for field checking in the stands classified into the class "clear cut". (Häme 1991, Olsson & Ericsson 1992). The results of HO-removals can be trusted as well, if mixing HO-removal with clear cut, and vice versa, are not considered to be errors. This is possible because the resulting stage of a stand is the same after both treatments. However, it has to be remembered that the situation with these two change classes can be different if the mean size of the stand is much smaller than in this study.

With the training data where the moderate changes were represented only by thinnings, the results were better than expected when classifying moderate changes in the test data. One reason for this can be the better suitability of non-parametric discrimination, compared to traditional parametric methods. In previous studies, non-parametric methods have been successfully used in production of high accuracy thematic forest maps in the area of satellite remote sensing (Skidmore and Turner. 1988).

Some problems were caused by the tree species composition in the test area. Almost all the stands were a mixture of Norway spruce and Scots pine. The number of deciduous species was small and single species stands were rare. In this situation, the effect of the different tree species in change detection could not be studied. In addition, when only two satellite images are available, the results are valid only when the time span between the images is two years. It is obvious that the results will be better if a shorter control period is used and worse if a longer period is used. However, the two years time span between the images seems reasonable for change detection in this case.

## 5. CONCLUSIONS

Despite the problems mentioned above, the results show the possibilities of the presented approach for decreasing the need for field work. It is obvious that by using the proposed control method, updating of the treatments can be controlled by checking just a few uncertain cases, instead of making a total inventory. Even though the treatment information was not recorded within the "moderate change" class, the maximum amount of field work needed to maintain the quality of the information could be estimated for the test area. The amount of stands recommended for field checking was in this case only one third of the whole area, including all the manmade and possible natural changes within the ten year period. Normally it can be expected that at least some information about the treatments in the moderate change class is available. This means that the real need for a field check within a ten year period, under the conditions of the Finnish Forest and

Park Service in Eastern Finland, can be assumed to be 10-30 % of the area.

Apart from Finland, there seems to be a general need for the development of low cost forest inventory and updating methods. More and more accurate information about forests and land use is needed, but this information has to be gathered and updated with decreasing funds. The collection of tools presented can also provide an interesting alternative to solving these control and updating problems in different conditions from the ones prevailing in Finland.

In future, testing and further development of the method will continue. For developing the proposed method for operative use, the "moderate change" group will be divided according to the reason for the change. Larger test areas will be used and the effects of the length of the time span between the images will be studied. If more accurate change classes can be used, this gives more possibilities of targeting the field work according to different interests and requirements for accurate information. The problem can be solved in at least two ways. The more obvious one is to obtain more training data containing more specific change classes, and the other is to make decision rules based on old attribute data available. An effort will be made to estimate the relineation possibilities of the changes by also using satellite material. It should be possible to visually relineate big changes like clear cuts should be able to be relineated visually and, according to previous results, even some moderate changes can be visually relineated (Olsson & Ericsson 1992).

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