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ERKKI TOMPPO

SATELLITE IMAGE AIDED FOREST SITE FERTILITY ESTIMATION FOR FOREST INCOME TAXATION

SATELLIITTIKUVA-AVUSTEINEN METSIEN KASVUPAIKKALUOKITUS METSÄVEROTUSTA VARTEN

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ACTA FORESTALIA FENNICA 229

SATELLITE IMAGE AIDED FOREST SITE FERTILITY ESTIMATION FOR FOREST INCOME TAXATION

Satelliittikuva-avusteinen metsien kasvupaikkaluokitus metsäverotusta varten

Erkki Tomppo

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Two operative forest site class estimation methods utilizing satellite images have been developed for forest income taxation purposes. For this, two pixelwise classification methods and two post-processing methods for estimating forest site fertility are compared using different input data. The pixelwise methods are discriminant analysis, based on generalized squared distances, and logistic regression analysis. The results of pixelwise classifications are improved either with mode filtering within forest stands or assuming a Markov random field type dependence between pixels. The stand delineation is obtained by using ordinary segmentation techniques. Optionally, known stand boundaries given by the interpreter can be applied. The spectral values of images are corrected using a digital elevation model of the terrain. Some textural features are preliminarily tested in classification. All methods are justified by using independent test data. A test of the practical methods were carried out and a cost-benefit analysis computed. The estimated cost saving in site quality classification varies from 14 % to 35 % depending on the distribution of the site classes of the area. This means a saving of about 2.0—4.5 million Finnish marks per year in site fertility classification for income taxation purposes. The cost savings would rise even to 60 % if that version of the method were chosen where field checkings are totally omitted. The classification accuracy at the forest holding level would still be similar to that of the traditional method.

Tutkimuksessa kehitettiin kaksi operatiivista, satelliittikuviin perustuvaa metsien kasvupaikkojen luokitusmenetelmää metsien veroluokitusta varten. Tähän tarkoitukseen kehitettiin aluksi kaksi kuvanalkioittaista luokitusmenetelmää sekä vertailtiin niiden ominaisuuksia erilaisilla maastotukialue- ja kuva-aineistoilla. Kuvanalkioittaiset menetelmät ovat yleistettyihin neliöetäisyyksiin perustuva erotteluanalyysi ja logistinen regressioanalyysi. Kuvanalkioittaisten menetelmien tuloksia parantamaan kehitettiin kaksi luokitustuloksien jälkikäsittelymenetelmää, metsikkökuviointiin perustuva moodisuodatus kuvioiden sisällä sekä Markovin kenttä -tyyppiseen kuvanalkioiden riippuvuuteen perustuva menetelmä. Metsikkökuviointi saatiin joko käyttäen satelliittikuvien segmentointimenetelmiä tai tunnettuja kuvioiden rajoja ja digitointia. Maaston korkeusvaihtelun aiheuttaman kuvan intensiteettien vaihtelun poistamiseksi testattiin maaston digitaalisesta korkeusmallista johdettuja muuttujia. Luokitusalgoritmin piirteinä käytettiin intensiteettien kanonisia muuttujia. Lisäksi testattiin tekstuurimuuttujista johdettuja piirteitä. Kaikki menetelmät testattiin käyttäen riippumattomia vertailuaineistoja. Operatiivisten menetelmien tuoman hyödyn arvioimiseksi tehtiin menetelmien kenttätestit kustannus-hyöty -analyyseineen. Arvioidut kustannussäästöt kasvupaikkojen veroluokituksessa vaihtelivat 14 %:sta 35 %:iin riippuen luokitettavan alueen kasvupaikkajakaumasta. Menetelmillä saavutettaisiin siis noin 2,0—4,5 miljoonan markan vuotuinen säästö metsien veroluokituksessa. Jos maastotarkistus jätettäisiin kokonaan tekemättä, luokitustarkkuus olisi tilatasolla perinteisten menetelmien luokkaa, mutta kenttätöiden kustannussäästöt noin 60 %.

Keywords: site quality, satellite images, discriminant analysis, logistic regression analysis, Markov random field, segmentation
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Preface

This study began as a research project at Technical Research Centre of Finland and was completed at The Finnish Forest Research Institute. The initiative and financing came from the National Board of Taxation. Discussions with Mr. Lasse Loven, M.Sc.(For.) had a strong influence on both the goal setting and practical solutions. Acknowledgements are also gratefully extended to Mr. Esa Härkönen who worked at the Technical Research Centre as a research assistant in the project, to Professor Simo Poso who offered constructive criticism on the manuscript, to Ms. Anja Leskinen who helped in the word-processing and to Dr. Ashley Selby who edited the English language.

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Erkki Tomppo

1 Introduction

The taxation of forests in Finland is based on the average productivity of sites. The sites are divided into taxation classes on the basis of lesser vegetation according to Cajander's method (Cajander 1909). The average annual increment of stem wood has been estimated for each tax class by The Finnish Forest Research Institute in National Forest Inventories. One purpose even of the First National Forest Inventory, carried out during the years 1921—1924, was to provide information for taxing forest income.

The first law concerning the forest taxation was enacted in 1922. The average productivity of sites, measured by the First National Forest Inventory, was required as a basis for taxation in 1927.

Taxation presumes the mapping and the assessment of areas of different site types on each forest holding. Initially, the classes were mapped by land surveyings and during the division of estates. A problem of the taxation system is still the need to estimate the areas of quality classes. The National Board of Taxation is nowadays responsible for this work. The forests are delineated into (site quality class) stands for practical taxation. Aerial photographs have been applied since the end of the 1940's, in addition to ground measurements. This method has turned out to be rather expensive. The National Board of Taxation developed a new method in the mid-1980's aimed reducing the taxation cost. This method utilizes colour infra aerial photographs. The preliminary stand delineation and site type assessment, as well as a thorough field route planning are carried out as desktop work. The method reduces the costs of field work by about 50 % compared with the former one. In spite of that, the method is rather laborious. Each stand has to be visited. About 30 million Finnish marks is spent each year for the estimation of site quality for the forest taxation. In spite of that, a part of this data is always out of date and the taxation work should be speeded up.

The first attempt to utilize satellite images for site type estimation in the forest taxation of Finland was carried out by the Technical Research Centre of Finland at the beginning of 1980 (Häme & Jaakkola 1982). The test site was located in North Finland, and Landsat MSS images were applied.

Two new methods, KAUKO and KAUKO2, utilizing satellite images have been developed in this study. The methods exploit ground measurements, Landsat TM images and, optionally, a digital terrain model. In addition, KAUKO2 utilizes ground checks.

In the image interpretation, the pixelwise classification is first carried out using discriminant or optionally logistic regression analysis. This preliminary classification can be improved with two optional post-processing methods.

The first group of post classification methods is based on the interpretation of homogenous areas of forest, called stands. The pixelwise classification is improved by using within stands mode filtering. Stand delineation can be carried out by means of segmentation techniques.

Another group of methods is based on the locally dependent Markov random field as introduced by Besag (1986). The original method uses a classification image. It is modified to utilize the posterior class probabilities obtained in the pixelwise classification.

The classification result can further be improved by introducing a digital elevation model of the terrain. The angle α between the solar illumination angle and ground normal is first computed. The intensities of the satellite images are corrected by a function of $\cos(\alpha)$. The absolute elevation of the terrain also slightly improves the classification result. If the ground truth data only consists of the site fertility information of a forest, i.e. not of information concerning the growing stock, the proportion of correctly classified pixels is about 75 per cent in a test site of 200 hectares.

2 Research material

2.1 Study area

The area under investigation of the study is located in the commune of Orivesi in South Finland, about 60 kilometres north-east of the City of Tampere. The area consists of the four subareas established to examine purposes for forest income taxation, see Figure 1. The sample plots of the National Forest Inventory (NFI) restricted by the coordinates 300900—387100 east and 6831900—6890100 north were also included in the data, which were completed by forest stand data of the National Board of Forestry and a private forest holding included in the above mentioned rectangle.

2.2 Satellite image data

Two Landsat Thematic mapper images were employed in the study, the dates of the images being 21.06.1985 and 13.05.1985. The broad leaf trees were leafless at the time of the May image. The purpose of this image was to give information concerning the applicability of the spring time image in the site type estimation. The images were rectified on the ordinary map with the pixel size of 20 m $\times$ 20 m. The root mean square errors of the rectification models were 7.8 m in an easterly direction and 8.1 m in a northerly direction for the June image and 7.6 m and 6.7 m respectively for the May image.

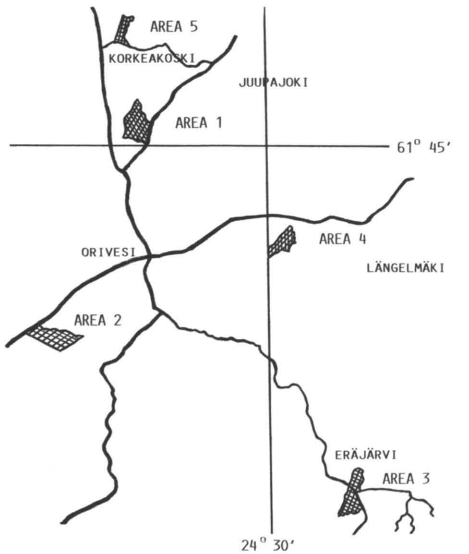

Figure 1. The geographic locations of the research areas.

2.3 Ground data

The classification models for mineral sites were estimated using two different ground data sets: the sample plot data of the National Forest Inventory and the forest taxation data, both completed with data from a private forest holding. The classification models for peatlands were estimated with the aid of stand data of the National Board of Forestry. The test data were independent forest taxation data and NFI data.

2.3.1 Forest taxation data

Forest taxation data consisted of four taxation test areas. Each area was divided into model estimation (M) and model testing parts (T), see Appendix 1. The ordinary forest taxation assessment had been carried out in these areas by four different persons. This involved the delineation of the areas into taxation stands, the assessment of site quality and its precision, which is a possible factor affecting site productivity e.g. stony or paludified mineral site, and the forest tax class of each stand.

In this study, only those parts of stands were accepted where the estimates of site quality, and their precision, agreed for at least two different individuals. (A small number of areas were accepted where only the taxation class agreed.) The boundaries of accepted areas were digitized (with Summagraphics digitizer of VEN-LA system of the National Board of Surveying) and transferred into the transfer file format of the FINGIS system. These files were further converted into a raster format of the DISIMP standard using a DISIMP standard program. Examples of these boundaries are shown in Appendix 2.

Homogeneous ground truth areas were extracted applying the spectral information of the original TM image, the digitized boundaries displayed on the image, and false colour aerial photographs of the study area. The homogeneity criteria were, in addition to the site quality and its precision, the dominant tree species and development class of trees, both estimated visually from false colour aerial photographs. The forests were classified into four subclasses: 1) open areas and young seedling stands, 2) old seedling stands, sapling stands and young thinning stands, 3) old thinning stands and mature stands 4) seed tree and shelterwood stands. Class four also included sparse and very clustered forests with open areas. The 3016 pixels of ground truth areas corresponded to about 120 hectares.

All these pixels were tested in the estimation of the discriminant functions in the first experiment. Later, only pixels free of boundary restrictions were applied in the modelling. The weighted means m(i,j) of the original spectral values were computed for each pixel using the spectral values of the four nearest neighbours and the plot itself, i.e.

$$m(i,j) = \sum_{k=i-1}^{i+1} \sum_{l=j-1}^{j+1} w(k,l)\, f(k,l), \qquad (1)$$

where f(k,l) is the original intensity, w(k,l) is the weight and m(i,j) the transformed intensity of the pixel (i,j).

The taxation stands of parts tested were also divided into homogeneous areas according to dominant tree species and the development class of trees (using an editing program of the Technical Research Centre (VTT)). All pixels of homogeneous areas were applied during the testing, the total number amounting to 4661 pixels which corresponded to 186 hectares.

2.3.2 Sample plots of the National Forest Inventory

The sampling unit of the NFI is a cluster of sample plots. The plots are located on a line which is also called a tract in the inventory. The distance between two neighbouring tracts in this data is 8 kilometres, in both north-south and east-west directions. One tract includes 21 main relascope sample plots (factor 2) with a radius varying from 0 about to 20 metres. Two subsidiary sample plots are located in the neighbourhood of the main plot at a distance of 20 metres. The distance between two neighbouring main plots is 200 metres. The geographical coordinates of both main and subsidiary plots are known.

The plots applied in the model estimation were measured in the test inventory of the 8th NFI in 1984 and were located within the coordinates (340000, 6840000) and (384000, 6884000). Only plots with a distance to the nearest stand boundary equal to or greater than 40 metres were accepted. The total number of acceptable plots in the model estimation amounted to 380. The weighted means of the original spectral values were computed for each plot using the spectral values of the four nearest neighbours and the plot itself. After a method of trial and error, the weights

$$W = \begin{pmatrix} 010 \\ 111 \\ 010 \end{pmatrix} \qquad (2)$$

were applied in Formula 1.

In the course of the study, the NFI plots were also used for model testing. The plots of the 8th NFI within the coordinates (3009000, 6831900) and (387100, 6890100) were employed in this purpose. This inventory was carried out in 1986.

2.3.3 The stand data of the National Board of Forestry

Both the number of peatland stands in the taxation data and the peatland sample plots in the NFI data were too small for estimating the discriminant functions for peatlands. The stand data of National Board of Forestry were therefore used for this purpose. The field work was carried out during the summers 1984 and 1985. Both stand characteristics data and boundary data were available in a digital form. DISIMP raster images were constructed from the vector form boundary data. Independent stand data of the National Board of Forestry were used for model testing.

The pixel intensity values were computed as in the case of forest taxation data, i.e. as the means within a 3 x 3 window, see Formulas 1 and 2. The purpose was to take into account the within stand variation and the noise. Only pixels free of boundary restrictions were accepted.

2.3.4 The stand data of the Forest management plans

Neither the taxation data nor the NFI data included enough poor site types, e.g. Calluna type. Both data were therefore completed by stand data of a private forest holding, Area 5 in Appendix 1. Data were collected by forestry students of the University of Helsinki in 1986 for forest management planning purposes. Both modelling and testing areas were gathered. The number of pixels amounted to 290 and 310 respectively.

2.4 The digital terrain model

A digital terrain model of the study area was used to correct the intensity values of the images. The elevation information was interpolated at the points of a 20 × 20 metres grid from the elevation contours of the base map. The unit of DTM was 0.1 metres. The original vector form model was transformed into raster form. The slope and aspect were estimated from this data for each pixel (i,j) using the elevations of the neighbouring pixels in westerly ($e_{i-1,j}$), easterly ($e_{i+1,j}$), southerly ($e_{i,j-1}$) and northerly ($e_{i,j+1}$) directions. The formulas (3) and (4) were applied:

$$\mathrm{slope}(i,j) = 100 \times \frac{\sqrt{(e_{i-1,j} - e_{i+1,j})^2 + (e_{i,j-1} - e_{i,j+1})^2}}{2d} \quad (3)$$

$$\mathrm{aspect}\,(i,j) = \pi/2 - \arctan\left(\frac{e_{i,j-1} - e_{i,j+1}}{e_{i-1,j} - e_{i+1,j}}\right),$$

$$\text{if } e_{i-1,j} - e_{i+1,j} > 0, \quad (4a)$$

$$\mathrm{aspect}\,(i,j) = 3\pi/2 - \arctan\left(\frac{e_{i,j-1} - e_{i,j+1}}{e_{i-1,j} - e_{i+1,j}}\right),$$

$$\text{if } e_{i-1,j} - e_{i+1,j} < 0. \quad (4b)$$

Here, d is the length of the side of the rectangular pixel; cf. Ritter (1987).

The angle α between the normal to the land surface and the sun illumination angle at the time of the satellite overpass was used in correcting the observed spectral values. The dependence of the normalized spectral value I_n on the angle α and the original spectral value I was assumed to be of the form

$$I_n = I/\cos^n(\alpha), \quad (5)$$

where $0 < n \leq 1$. The value of n was found by a system of trial and error using the residuals of discriminant functions as criteria. Let us denote the sun azimuth by ø, running from south to east and the sun elevation angle by Θ, running from vertical to horizontal. The unit vector towards the sun is thus $(x_s, y_s, z_s) = (\sin(\Theta)\cos(ø), \sin(\Theta)\sin(ø), \cos(-\Theta))$ and the surface normal unit vector $(x_n, y_n, z_n) = (i_x/s, -i_y/s, 2d/s)$, where $i_x = e_{i-1,j} - e_{i+1,j}$, $i_y = e_{i,j-1} - e_{i,j+1}$ and

$s = \sqrt{i_x^2 + i_y^2 + 4d^2}$. According to a well-known fact $\cos(\alpha) = x_n x_s + y_n y_s + z_n z_s$.

2.5 Other digital map data

The boundaries of peatlands in forest taxation areas were digitized. The total area of peatland was, however, small for which reason, the peatland data of the National Board of Forestry were applied in the model estimation.

2.6 Aerial photographs

False colour aerial photographs from the year 1983 were used as an aid in restricting the taxation ground truth areas. Dominant tree species and the development class of trees were also estimated from photographs. This was optional information in the model estimation.

3 Methods

The next step in the image analysis, following the image rectification and possible pre-processing, is classification. This involves the choice of features, possibly filtering, preliminary classification and post-processing. The experiments and solutions will be described in the following sections. Our own modifications are used in the choice of spatial features and in the post-processing phase.

3.1 Classification

The image analysis classes of mineral sites were the forest site fertility classes 1) OMT (rich sites), 2) OMT stony (stony rich sites), 3) MT (damp sites), 4) MT stony (stony damp sites), 5) VT (sub-dry sites), 6) VT stony (stony sub-dry sites), 7) CT (dry sites), 8) VT very stony (very stony sub-dry sites). The site fertility classes 1), 2) and 3) belong to the tax class I, site fertility classes 4) and 5) to the tax class II, site fertility classes 6) and 7) to the class III and site fertility class 8) to the class IV. The NFI data did not include class 8.

The classes for wetlands were 1) transformed Eutrophic hardwood-spruce forest mires, 2) transformed mesotrophic hardwood-spruce mires, 3) transforming Eutrophic or Mesotrophic spruce forest mires, 4) transformed paludified spruce forest mires, 5) Eutrophic, Mesotrophic or Oligo-mesotrophic hardwood-spruce forest mires (drained or natural), 6) transforming pine mires, 7) natural or drained pine mires, and 8) Ombrotrophic pine bog.

3.2 Features

The basic feature set, denoted here by FO, was the spectral features of original spectral bands c_i, $i = 1,...,7$, $i \neq 6$ and the ratios c_i/c_j, $i,j = 1,...,7$, $i,j \neq 6$. The thermal band c_6 was not used because of its poor spatial resolution. The ratios of the spectral bands reveal site properties which are independent of the growing stock. The variables of the set FO are highly correlated and their number is rather high. Therefore, the canonical variables of FO, denoted by FT, were applied. The variables of FT were computed with respect to the set of class indicator functions $I_{\mu_i}(x)$, $i = 1,...,8$, where $I_{\mu_i}(x) = 1$, if site class x is μ_i and 0 otherwise.

The textural features derived from the co-occurrence matrix were preliminarily tested. The features were:

inverse difference moment

$$f_1 = \sum_i \sum_j \frac{1}{1 + (i - j)^2}\, p(i, j), \quad (6)$$

entropy

$$f_2 = -\sum_i \sum_j p(i,j) \log(p(i,j)), \quad (7)$$

and difference entropy

$$f_3 = -\sum_{i=0}^{N_g - 1} p_{x-y}(i) \log(p_{x-y}(i)) \quad (8)$$

computed from spectral bands 3, 4 and 5, see Haralick et al. (1973). Here N_g is the number of distinct gray levels in a spectral band, p(i,j) is (i,j):th entry in a normalized spectral dependence matrix (= P(i,j)/R, where R is the number of neighbouring resolution cell pairs) and

$$p_x(i) = \sum_{j=1}^{N_g} p(i, j).$$

The co-occurrence matrix was computed by assuming the textural features to be constant within stands. In applications, an image segmentation, for instance, can first be carried out in order to obtain a stand delineation. After that, only one co-occurrence matrix for each segment will have to be computed. In this way, the computation time for textural features can be substantially reduced compared with the case in which it is computed for every pixel using a n x n window. The method can also be applied using known digitized stand boundaries.

3.3 Filtering

The filtering of intensities was applied both in estimating discriminant functions and in the classification phase. In the estimating phase, the spectral values were smoothed within a 3 x 3 window according to Formula 1. In the classification phase, an edge preserving mean filter was tested on the original spectral values. The shape of window varied in this method, as well as the size (from 2 to 4 pixels). The shape and size were chosen corresponding to the minimum variance of the intensities. This edge preserving smoothing was preferred to the usual mean filter because the distance to the nearest stand boundary was not known in each pixel.

3.4 Preliminary classification

The pixelwise class probabilities, the probabilities of an arbitrary observation y_i belonging to group k were computed using discriminant functions which are based on the generalized quadratic distances

$$D_k^2(y_i)=(y_i-m_k)' S_k^{-1} (y_i-m_k)+\ln|S_k|-2\ln(q_k), \quad (9)$$

where S_k is the estimate of the covariance matrix, m_k the estimate of the mean vector and q_k the prior probability of group k. The posterior probability of observation y_i belonging to group k is, under the multinormality assumption, obtained from (9) by

$$p(k|y_i) = \frac{\exp(-0.5D_k^2(y_i))}{\sum_{u=1}^{n} \exp(-0.5D_u^2(y_i))}. \quad (10)$$

Multivariate logistic regression analysis was applied as an optional pixelwise classification method. The class probabilities $p(k|y_i) = P(L_i = k|y_i)$, under constraints $\sum_{k=1}^{n} p(k|y_i) = 1$ and $p(k|y_i) > 0$, are obtained from the formula

$$p(k|y_i) = \frac{e^{\eta_k(yi)}}{\sum_{u=1}^{n} e^{\eta_u(yi)}}, \quad k = 1,...,n, \quad (11)$$

where η is the number of the classes and η_k a function of the feature vector y_i, whose parameters have to be estimated.

3.5 Postprocessing

The preliminary classification result was improved by using two optional post-processing methods. The first method was based on mode filtering within the forest stands. The stand boundaries were obtained either by segmentation methods or known a priori (e.g. digitized from aerial photographs). Another post-processing method was based on Markov random field modelling.

3.5.1 Segmentation

Segmentation can be regarded both as a method which produces a preliminary stand delineation for forest taxation purposes and a method for improving the accuracy of classification.

Segmentation techniques are very widely used methods in image analysis. The goal is to divide the image into disjoint but spatially connected subregions which are homogeneous, in a given sense, with respect to spectral features. Let X denote the grid of points of the picture, i.e. the set of pairs (i,j), i = 1,...,N, j = 1,...,M, where N and M are the number of pixels in x and y direction respectively. The purpose of a segmentation is to find a partition $\cup X_k$ such that

1) $\cup X_k = X$,
2) the set X_k is connected,
3) $X_i \cap X_j = 0, \ i \neq j$,
4) the pixels in the set X_i are similar in some sense.

The earliest segmentation methods were commonly divided into three subgroups: 1) edge detection 2) region extraction and 3) characteristic feature thresholding or clustering methods. Each of these groups can further be divided into subgroups. Comprehensive surveys have been presented by Fu & Mui (1981) and Haralick & Shapiro (1985). In addition, Geman & Geman (1984) and Derin & Cole (1986) have presented methods which are based on Markov random fields.

The directed trees method introduced originally by Narendra & Goldberg (1980) was modified and applied in this study.

This method does not belong to any of the previous groups, although it has features of each of them. It avoids, to some extent, the weaknesses of the previous methods. In this method, centrepoints of segments (stands), called root pixels are sought not, for instance, edges. Other pixels are connected to root pixels. Define a neighbourhood n (i,j) of pixel (i,j). (The eight closest pixels were applied in this study.) Define an edge image e(i,j) and an inverted edge image $\bar{e}(i,j)$ using a difference and complementation operation, for instance the sum of total variations of spectral bands, see Haralick et al. (1973).

The image to be segmented is first divided in the plateau points and nonplateau points by means of an edge gradient G(i,j) at the point (i,j)

$$G(i,j) = \max_{i',j'} (\bar{e}(i',j') - \bar{e}(i,j)), (i',j') \in n(i,j) \quad (12)$$

Let $\in > 0$ be a sensitive parameter. It distinguishes between the edge gradient on plateau regions from that at the valley regions. The point (i,j) is called a plateau point if

$$|G(i,j)| < \epsilon \quad (13)$$

The image is processed in the following steps:

1. For each nonplateau point (i,j),
   a) if G(i,j) < 0, (i,j) is an evident root pixel, no linking to other pixels
   b) if G(i,j) > 0, link (i,j) to (k,l) with $\bar{e}(k,l) = G(i,j) - \bar{e}(i,j)$.

2. For each plateau point (i,j),
   a) remove (k,l) from n(i,j), if $|\bar{e}(k,l) - \bar{e}(i,j)| > \epsilon$, i.e. retain only the neighbours that are on the same plateau as (i,j),
   b) remove from n(i,j) any (k,l) such that (k,l) is linked to (i,j) (possibly through other pixels) (otherwise cycles would result.),
   c) link (i,j) to an arbitrarily chosen remaining element of n(i,j).
3. Trace the resulting 'trees' of pixels and assign labels to the segments.

In words, in pass 1, linking of all the nonplateau points are done, and toward a higher inverted edge value. In pass 2, linking of plateau points are done, while avoiding to produce cycles. The resulting trees are traced and assigned with labels of segments, see also Tomppo (1987a) and Parmes et al. (1988).

The actual placement of a root is not unique, it depends on the order in which points are considered. However, the membership of the resultant trees is independent of the order in which the points are considered. The number of root pixels and the number of segments (not necessarily the same) are controlled by the value of the sensitivity parameter.

If the used edge operator is symmetric, the method implies that

1) The resultant boundaries will run through the centres of valleys of the inverted edge image, which in turn correspond to the true boundaries.
2) The boundaries in the original image may be wide, in spite the resultant boundaries run through the highest points of the edge image (the lowest points of the inverted edge image). Further, a possible edge-preserving smoothing before segmentation does not affect the placements of boundaries.
3) The height of the edge can vary around each segment. Further, different segments can be surrounded by edges of different heights, because the valley seeking operator does not rely on the absolute depth of the valley.
4) Edges which do not correspond to closed boundaries are absorbed by the surrounding segments.

Due to the reflection, absorption and emission properties of plants (Gates 1970), the best results can be expected from the TM channels 3) (the wavelength 0.63—0.69 μm), 4) (0.76—0.90 μm) and 5) (1.55—1.75 μm). The general features of stands are detected from the channels 3 and 5, whilst channel 4 reveals the amount of deciduous trees and site quality. These properties can also be seen from a visual inspection of images or in comparison with false-colour aerial photographs.

The original spectral values were scaled to the interval 0—254. An edge-preserving smoothing was applied after the transformation in order to reduce the within stand variation and the amount of noise; cf. Tomppo (1987a and 1987b). In order to obtain a satisfactory stand delineation, an appropriate stretching had to be applied to the smoothed image. This is especially true at the lower end of the histogram, which corresponds to high values of stem volume, where the spectral resolution must be increased, and correspondingly, at the upper end of the histogram (seedling stands and open areas) where the spectral resolution must be decreased. Different stretching functions for each input channel were applied. The stretching functions seem to be nearly independent of the image.

The mean stand size in different applications varied from 1.0 to 1.8 ha. It is very easy to change the mean stand size by the sensitivity parameter.

The test sites were divided into sub-areas, called segments, using the algorithm. The mode class was computed within each segment. Each pixel within a certain segment was labelled by the mode class.

3.5.2 The Markov random field method

Another post-processing method utilizes the spatial dependence of pixels. A locally dependent pairwise interaction Markov random field was assumed to be the model of dependence. Let us for a moment denote the pixels by i, i = 1,..,n and suppose that a symmetric neighbourhood relation is defined (denote by $j \in \partial i$ that j is a neighbour of i). The process can be defined by setting the probability p(x) of an arbitrary collection x of classes to be

$$p(x) \propto \exp(\sum_{1\le i\le n} G_i(x_i) + \sum\sum_{1\le i\le j\le n} G_{ij}(x_i, x_j)), \quad (14)$$

where $G_{ij} \equiv 0$ unless $j \in \partial i$ but otherwise arbitrary; cf. Besag (1984 and 1986).

A simple interaction function was tested in this project: Take $G_i = G_j$, j = 1,..,n and $G_{ij} = \beta$, if $j \in \partial i$ and 0 otherwise. The set ∂i, was assumed to be the 8 closest pixels of i with obvious boundary modifications. In this case, the conditional probability that the pixel i belongs to the class k given the classes of all other pixels is $P(L_i = k|$ other classes$) \propto e^{\beta u_i(k)}$ where $u_i(k) = \#(j \in \partial i | L_j = k)$. The parameter β can be estimated by a maximum pseudo-likelihood method; cf. Besag (1986). Bounds for β can be derived by using simple geometrical ideas, see Ripley (1986). Trial and error methodology was used in this work.

The reconstruction of the classification result was based on the iterated conditional mode (ICM) method described by Besag, see Besag (1986). Let us denote by $\hat{x}$ an original estimate of the true scene. The class $\hat{x}_i$ of the pixel i is changed in such a way that the conditional probability $P(x_i|y, \hat{x}_{S\setminus i})$ will be maximized with respect to x_i, where y is the vector of observed records, e.g. spectral values of satellite images. If conditional independence is assumed, as well as a local dependence of pixel classes (instead of global), it follows from Bayes' theorem that

$$P(x_i | y, \hat{x}_{S\setminus i}) \propto f(y_i | x_i)\, p_i(x_i | \hat{x}_{\delta i}). \qquad (15)$$

Here $\hat{x}_{S\setminus i}$ is the image, the pixel i excluded, and $f(y_i | x_i)$ the conditional density function of the observed signal at i given the class x_i. If applied for every pixel in turn, one iteration of the image is obtained. The algorithm is applied to a fixed number of cycles or until convergence. In practice, 5—10 cycles is enough.

The method was modified in such a way that $u_i(k) = \sum_{j \epsilon \partial i} P(L_j = k|y_j)$, i.e. the sum of probabilities of the class k of the neighbouring pixels obtained by a pixelwise classification on a previous reconstruction. Figure 4, page 24 shows an example of the effect of the reconstruction.

3.6 The choice of classification model

The objective is to find the most reliable method from among the alternatives mentioned above. The method should be easily repeatable from one image to another.

The problem is to find a suitable pre-processing method, features, including input data combination (ground truth data, May image, June image, DTM), classification method and post-processing method. We proceeded in such a way that other factors remained constant when changing anyone factor. The criteria were residuals from discriminant analysis and the likelihood ratio in logistic analysis. Further, independent test data were applied.

The modelling was started with the sample plots of the National Forest Inventory. The experiences were utilized in estimating the models with forest taxation data and vice versa.

DISIMP standard programs DAN and LAN were made for classifiation purposes. These optionally computed some linear transformations, for instance canonical transformations and DTM based corrections if these data were provided, see Formula 5. In practice, the application of the program is very easy.

4 Results

4.1 The discriminant power of spectral features

The significance of individual spectral bands in separating different fertility classes can be tested by means of F-statistics obtained from canonical discriminant analyses. Table 1 shows these values for single bands and band ratios using the June image computed both from NFI data and forest taxation data. All the values differ statistically significantly from zero at the level <0.0001 (<0.0002 for c_2 without DTM-correction). The statistics are given with, F_{dtm}, and without, F, DTM -correction.

The ratios worked better than the original bands, and the order of priority was c_3/c_4, c_4/c_7, c_2/c_4, c_4/c_5. The best single band proved to be band 4 followed by bands 7 and 1. The differences between these and bands 2, 3 and 5 were small. The order also depended on whether the DTM-correction was made or not. The order also depended slightly on the image data.

The preliminary tests with the thermal band demonstrated its good separation power. Tests could be carried out only with a limited data because of the poor spatial resolution of the thermal band.

4.2 Model and test data combinations

Mineral sites were classified and the classifications tested with three different model and test data combinations: 1) models from NFI data, tests with taxation data, 2) models and tests with taxation data and 3) models and tests with NFI data. Models for the peatland classification were estimated and tests carried out with data of the National Board of Forestry.

For testing purposes, study areas were classified using different models. In addition to the usual cross-validation, the areas of different tax classes and 'tax cubic metres' of areas, i.e. $\Sigma_i a_i b_i$, were computed and compared with corresponding characteristics estimated in the field. Here a_i is the area (ha) and b_i the productivity (m^3/ha) of class i. Proportions of correctly classified, over estimated and under estimated pixels were counted. A DISIMP standard program was made for this purpose. The program also counts the numbers of gross error pixels, i.e. pixels with errors of at least two classes.

4.2.1 Models from NFI data, testing with tax data

The test area was classified using different models, methods and input data. The proportion of correctly tax classified pixels was counted, as well as the proportion of pixels with gross errors.

The test characteristics are given in Appendix 4 for the most interesting cases with models estimated from NFI data and tests carried out with taxation data.

Table 2 shows the proportions of correctly classified and the proportions of gross error pixels for the pixelwise classification (Pix), for mode filtering with given stand boundaries (T), for mode filtering with segmentation-based stand delineation (S) and for Markov random field modelling (M). The discriminant functions are estimated from NFI data. In the input data, JI means the image of

Table 1. The values of F-statistics for spectral bands and band ratios.

var	c_1	c_2	c_3	c_4	c_5	c_7	$\frac{c_1}{c_2}$	$\frac{c_1}{c_3}$	$\frac{c_1}{c_4}$	$\frac{c_1}{c_5}$	$\frac{c_1}{c_7}$	$\frac{c_2}{c_3}$	$\frac{c_2}{c_4}$	$\frac{c_2}{c_5}$	$\frac{c_2}{c_7}$	$\frac{c_3}{c_4}$	$\frac{c_3}{c_5}$	$\frac{c_3}{c_7}$	$\frac{c_4}{c_5}$	$\frac{c_4}{c_7}$	$\frac{c_5}{c_7}$
F	17.8	4.5	11.1	22.6	10.9	16.5	6.4	15.2	57.4	19.7	30.9	33.9	68.8	24.3	37.6	78.2	15.8	31.1	68.6	73.1	39.2
F_{dtm}	14.3	7.5	11.4	24.1	11.4	16.7	6.4	15.1	57.4	19.7	30.9	33.9	68.8	24.3	37.6	78.2	15.8	31.1	68.6	73.1	39.2

Table 2. The proportions, %, of correctly classified pixels (COR) and the proportions of pixels with gross errors (GRE) in the test data using NFI data.

INPUT data	(T) COR/GRE	(S) COR/GRE	M COR/GRE	Pix COR/GRE
Discriminant analysis				
JI	63.1/6.1	60.3/6.8	59.9/7.4	54.5/9.5
JI, smoothed	66.9/6.2	58.4/7.6		
JI+DTM	66.2/5.2	61.7/6.4	61.4/6.7	57.9/7.4
JI+MI	65.5/4.5	60.3/9.4		54.1/10.5
JI+MI+DTM	67.2/4.7	61.5/6.0	62.6/6.6	57.2/6.9
JI+MI+DTM+DCL	67.3/7.5	62.5/6.9		59.2/7.6
Logistic analysis				
JI	52.6/4.9	54.3/8.7		51.0/11.4
JI+MI	57.0/5.6	54.6/9.0		50.8/10.7

21.06., MI that of 13.05., DTM the digital terrain model and DCL the development class of stand.

The smoothed image in Table 2 means an image whose intensities are within stands intensity means. The values 0.1—5.0 were tested as the value of parameter β of the Markov random field. In every case, the best result was given by the value 0.5, even though almost as good a value was obtained with the value 1.0. (With the June image, COR/GRE were respectively 59.3/7.7 for $\beta = 1.0$, 58.8/8.0 for 2.5 and 58.2/8.2 for 5.0. The spectral value correction due to DTM is of the form $1/\cos^{0.25}(\alpha)$. Other tested values of α gave slightly poorer results.

It can be seen from Table 2 that: 1) Discriminant analysis gives more reliable models than logistic regression analysis. The proportion of correctly classified pixels was 3 to 8 %-units higher. Therefore the logistic model was not tested further. 2) Mode filtering increases the proportion of correctly classified pixels by 3 to 10 %-units and decreases the proportion of gross errors by 1 to 3 %-units, generally more for a given stand delineation than for one which is segmentation-based. 3) The improving power of the Markov random field based post-processing is of the same magnitude as that of the segmentation-based mode filtering. 4) The digital terrain model improves the result by only 1.5 to 3.5 %-units. This is much lower than the figure achieved with the taxation data, as will be seen later. One reason for this may be that in the model estimation with the NFI data, the slope and aspect were measured manually from ordinary maps. (A digital model was used in the classification phase.) 5) The May image improves very little, or not at all, with DTM about 3 %-units. 6) The information given by the development class of trees improves the result by 1 to 2 %-units.

The reason for the overall low proportion of correctly classified pixels is the subjective nature of the site fertility assessment. The site fertility estimates of two persons often differ in a single stand. The differences at the forest holding level are, however, fairly small, usually only a few percent. One should note that also the class probabilities obtained in discriminant analysis give relevant information for the operational application of the methods.

4.2.2 Models and tests with forest tax data

Appendix 5 gives the estimated and measured areas of tax classes, the amount of under and over estimated pixels, as well as the amount of gross error pixels for the most interesting cases when modelling and testing with taxation data. Table 3 shows the corresponding proportions of correctly classified pixels (COR) and the proportions of pixels with gross errors (GRE). With this data, textural features were also tested, because the ground truth data consisted of homogeneous areas, not of plots as in the case of NFI data, see section 4.2. The spectral value correction derived from DTM is here of the form $1/\cos(\alpha)$. It can be seen from Table 3 that: 1) Textural features improve the results by about 4 to 6 %-units. 2) Mode filtering with segmentation boundaries improves the result by 4 to 9 %-units and

Table 3. The proportions, %, of correctly classified pixels (COR) and the proportions of pixels with gross errors (GRE) in the test data using taxation data when estimating the discriminant function.

INPUT data	(T) COR/GRE	(S) COR/GRE	M COR/GRE	Pix COR/GRE
JI	55.8/17.8	52.5/11.3	52.4/12.9	48.2/16.7
JI,DCL-wise	57.4/13.4	54.3/14.3		53.1/16.6
JI+DCL	55.6/9.6	57.4/10.6		50.6/14.1
JI+its texture	59.1/9.6	58.3/11.7		52.8/13.8
JI+DTM	60.2/10.0	63.3/12.5	63.1/9.1	59.5/13.3
JI+MI	68.9/10.2	59.0/10.1		50.1/14.7
JI+MI+DTM	73.8/6.8	67.6/7.1	67.4/7.6	63.1/9.9

with given stand boundaries by 1 to 18 %-units. 3) The improving power of Markov random field post-processing (with $\beta = 0.5$) is of the same magnitude as that of segmentation-based mode filtering. 4) DTM improves the pixelwise results and the result with segmentation-based mode filtering by about 10-% units, and with given stand boundaries based filtering by about 5 %-units. This is more than with the NFI data. One reason for this may be the errors which occurred in the manual measuring of slope and aspect of the NFI data. 5) The May image improves the result by 2 to 13 %-units.

4.2.3 Comparisons of NFI based and taxation data based models

The discriminant functions based on the NFI data gave more accurate classifications than those based on the forest taxation data when only using the June image data. DTM improves the result with the taxation data more (5—15 %-units) than with the NFI data (1.5—3.5 %-units). The May image does not practically improve the result with the NFI data while with the taxation data it improves by 2—13 %-units.

The residuals of the NFI models are fairly small, despite which their test results are not much better, cf. Appendices 3—5. The reasons for this may be: 1) the NFI data and taxation data are not compatible. 2) DTM data for the NFI sample plots are not accurate enough (most of it was manually measured from maps because numerically produced DTM was available only for a part of the area of the NFI plots, but for the whole area of the taxation test areas). 3) The NFI data are fairly small, only 371 plots in the case of the June image. Further, the plots are located in clusters of three. 4) The modelling areas of the taxation data were also used in testing NFI models. Some of the stands of the area were fairly small with a large number of boundary pixels. Stand boundary pixels were omitted at the modelling phase.

The classification results were also judged by counting the proportion of correctly classified pixels by forest site fertility classes. Table 4 shows the proportions for some NFI and taxation models. Site fertility classes are not separated with precision at this juncture.

The filtered June image here means an image whose intensities are within segmentation means of the original intensities. The value of the Markov model parameter was 1. The best classified sites were CT and OMT with both data and the worst was VT. This is caused by the recognition of stoniness. The classification of VT sites are even poorer with the NFI based models than with the taxation based ones. The separation of stoniness also causes the misclassification of MT sites.

4.2.4 NFI models NFI tests

The tests given above showed that the residuals of the NFI models were small compared with the taxation based ones. In spite of that, the test results with the taxation data were only slightly better, if at all, than with the NFI data. Therefore, NFI plots were also used in testing.

Appendix 6 presents the estimated and measured areas of tax classes, the numbers of under and over estimated pixels, as well as

Table 4. The proportions, %, of correctly classified pixels in the test data by means of segmentation based mode filtering, stand boundaries based mode filtering and Markov random field based post-processing.

INPUT	NFI OMT	NFI MT	NFI VT	NFI CT	Taxation OMT	Taxation MT	Taxation VT	Taxation CT
June, tax	0.97	0.55	0.30	0.94	0.83	0.44	0.38	1.00
June, seg	0.87	0.55	0.25	0.96	0.73	0.48	0.34	1.00
June, Markov	0.80	0.54	0.32	1.00				
Filtered June	0.93	0.63	0.28	0.99				
June+DTM, tax	0.93	0.64	0.21	0.93	0.94	0.49	0.49	1.00
June+DTM, seg	0.87	0.58	0.22	0.96	0.88	0.53	0.42	1.00
June+May, tax	0.98	0.55	0.48	0.97	0.91	0.61	0.48	1.00
June+May, seg	0.96	0.51	0.32	0.96	0.84	0.52	0.39	1.00
June+May+DTM,tax	0.94	0.62	0.15	1.00	0.99	0.70	0.48	1.00
June+May+DTM,seg	0.87	0.58	0.21	0.99	0.97	0.59	0.42	1.00
June+May+DCL+DTM,seg	1.00	0.64	0.21	1.00	0.99	0.64	0.53	1.00

Table 5. The proportions, %, of correctly classified pixels (COR) and the proportions of pixels with gross errors (GRE) using NFI data in modelling and testing.

INPUT image	Pix COR/GRE
June image	59.5/8.0
June image + May image	62.0/7.8

Table 6. The proportions, %, of correctly classified pixels (COR) and the proportions of pixels with gross errors (GRE) with pixelwise classification (Pix) and within stand mode filtering (T) for peatlands.

Input	T Cor/Gre	Pix Cor/Gre
JI	34.5/25.6	32.1/31.1
JI, filtered	34.3/26.3	32.3/31.4
without boundary pixels	34.7/27.1	32.7/30.7
JI+MI, filtered	41.6/23.3	
JI+MI	45.3/20.2	39.4/23.4

the amount of gross error pixels for the most interesting cases when modelling and testing with tax data. Table 5 shows the corresponding proportions of correctly classified pixels (COR) and the proportions of pixels with gross errors (GRE). Discriminant functions are based on generalized squared distances and canonical variables.

It can be seen from Tables 2 and 5 that: 1) The compatibility of NFI models with the NFI test data is better than with the taxation test data; with the June image about 5 %-units and with the June + May images about 8 %-units. 2) The proportion of gross error pixels also decreases compared with tests with taxation data. 3) The May image improves the classification more with the NFI data than with the taxation data.

4.2.5 Peatland models

Neither the NFI data nor the taxation data involved sufficient peatland plots or stands for modelling and testing purposes. The data of the National Board of Forestry were applied in order to test the applicability of satellite image interpretation in the estimation of peatland site fertility classes.

Appendix 7 presents the estimated and measured areas of tax classes, the number of under and over estimated pixels as well as the number of cross error pixels for some cases when modelling and testing with the peatland data of the National Board of Forestry. Pixelwise classification and mode filtering within stands were used. The treatment stands of the National Board of Forestry were employed. Table 6 shows the corresponding proportions of correctly classified pixels (COR) and the proportions of pixels with gross errors (GRE). Discriminant functions were based on generalized squared distances and canonical variables.

The satellite image based classification of peatlands seems to be less reliable than that for mineral soils. One reason for this may be variations in the wetness of both soil and needless which strongly affect the intensities but do not necessarily reveal the fertility of the soil. Another source of error is the fact that the stands of the National Board of Forestry are treatment stands rather than site quality class stands and include some variation in site quality. The May image noticeably improves the results for peatlands.

Table 7. Taxation cubic metres and sizes of classified test areas with pixelwise classification, with taxation stand mode filtering and with segmentation based mode filtering, using either the taxation or NFI data in modelling.

Input data	Area ha	TAX m^3	TAX m^3/ha	NFI m^3	NFI m^3/ha
Pixelwise classification:					
JI	865.56	3851.02	4.45	4404.55	5.09
JI+DTM					
exp. 1.0	865.56	3989.86	4.61		
exp. 0.25	865.56			4545.23	5.25
JI+MI	808.64	3727.47	4.61	4057.21	5.02
JI+MI+DTM					
exp. 1.0	808.64	3925.88	4.85	4291.74	5.31
exp. 0.25	808.64			4245.66	5.25
JI+MI+DCL+DTM					
exp. 1.0	276.96	1421.17	5.13		
exp. 0.25	276.96			1505.54	5.43
Taxation stand filtering:					
JI	196.80	933.62	4.74		
JI	294.96			1642.82	5.57
JI+DTM					
exp. 1.0	294.96	1483.43	5.03		
exp. 0.25	294.96			1674.68	5.68
JI+MI	196.80	999.96	5.09		
JI+MI	277.00			1504.18	5.43
JI+MI+DTM					
exp. 1.0	280.84	1486.47	5.29	1602.26	5.71
exp. 0.25	280.84			1620.26	5.77
JI+MI+DCL+DTM					
exp. 1.0	280.84	1506.30	5.36		
exp. 0.25	280.84			1632.00	5.81
Segmentation filtering:					
JI	865.56	3919.62	4.53	4659.23	5.38
JI+DTM					
exp. 1.0	865.56	3986.24	4.61		
exp. 0.25	865.56			4784.54	5.53
JI+MI	818.28	3924.76	4.80		
JI+MI	808.64			4267.12	5.28
JI+MI+DTM					
exp. 1.0	818.28	4088.49	5.00	4591.01	5.61
exp. 0.25	818.28			4500.88	5.50
JI+MI+DCL+DTM					
exp. 1.0	664.44	3409.32	5.18		
exp. 0.25	664.44			3712.09	5.59

4.3 District characteristics

The goodness of the site fertility estimation was also judged by computing the total productivity of test areas in terms of taxation cubic metres. These statistics were compared with the corresponding ones based on ground measurements. The fact that each tax class corresponds to a certain average productivity was utilized. Appendix 8 presents the areas of different site fertility classes, tax classes, as well as the amount of tax cubic metres for some models by test areas. The total amount of tax cubic metres of all four areas are summarized in Table 7.

The areal variations in different classifications are caused by the facts that the May image did not cover the whole area and that the taxation stands only partly cover the test areas. (The one on which the estimates of two different individuals agreed.) It can be seen from Table 7 that the NFI based models gave 8 %—10 % higher estimates of the taxation cubic metres than the taxation data based ones. The reason for this may be the general caution principle in forest taxation: the tie cases will be rounded downwards. This hypothesis is supported by the explanations of the Finnish Forest Research Institute and the National Board of Taxation. Preliminary results state that site fertility classes of the NFI are generally higher than the these for taxation. The mean difference in taxation cubic metres is about 10 %.

5 The factors of gross errors

The sources of gross errors (i.e. errors of at least two taxation classes) were explained by factors such as the proximity of a boundary of 1) a stand (obtained by segmentation), 2) a field or 3) a river (from an aerial photograph), and 4) a nonhomogeneous area, and 5) other (the reason not clear). Two subareas from the southern part of two test areas were chosen for the testing. The number of pixels was in the subarea (1) 492 and in the subarea (2) 599. The numbers of gross error pixels were respectively 75 and 52 (i.e. they were higher than on average). Table 8 shows the proportions of gross error pixels in the classes mentioned above.

The greater part (60—70 %) of the gross error pixels is explained by the proximity of a stand boundary. The boundary of field and forest explains 10 to 16 %. The intensities of misclassified pixels differed from those of neighbouring pixels.

The effect of development class of stand on the classification errors was also studied. (One should remember that the discriminant functions used in the classification did not involve information of development class.) The proportions of correctly classified pixels, as well as pixels with errors of one or two classes were counted. These are given by development class in Table 9. The June image and given stand delineation (based on forest taxation) were applied in all these cases. The numbers of pixels are also given in Table 9. See Section 2.3.1 for the definition of the development classes used here.

Table 9 shows that there is no clear relationship between the development classes of stand and the classification errors. Further, results seem to depend slightly on the ground truth data. However, old forests may be classified slightly better than young ones except in class 7 of the NFI data (which has a small number of observations and errors mainly of one class).

Table 8. Proportions, %, of gross error pixels by some factors in two subareas.

	Stand bound.	Field	River	Nonhom. area	Other
Subarea (1)	60.0	16.0	4.0	4.0	16.0
Subarea (2)	73.1	9.6	0.0	7.7	9.6

Table 9. The effect of development class of stand on classification errors.

Image	Ground data	Correct %	Error of 1 class %	Error of 2 class %
DCL 0—7 (7166)	NFI	63	32	5
DCL 0 (1107)	NFI	59	40	1
DCL 2 (1255)	NFI	56	35	9
DCL 5 (4389)	NFI	68	26	6
DCL 7 (415)	NFI	39	58	3
DCL 0—7 (4661)	Tax	56	26	18
DCL 0 (577)	Tax	60	20	20
DCL 2 (859)	Tax	48	22	30
DCL 5 (2895)	Tax	59	26	15
DCL 7 (280)	Tax	66	32	2

6 Line tests

The tests showed that in most cases the NFI data gave somewhat better results than the taxation data. Further, it is more applicable operationally because it is available for the whole country. Therefore, the NFI based models were chosen for further investigations. Six models based on this data were chosen for further tests. The test data above were used as comparison material. The criteria employed were the proportions of correctly classified pixels and gross error pixels.

Chosen models, which were based on the June image and discriminant analysis, were 1) pixelwise classification, 2) pixelwise classification improved with segmentation based post-processing, and 3) pixelwise classification improved with Markov random field based post-processing. An optional DTM gives three additional models. The May image did not sufficiently improve the result and its availability may be riskfull because of its short acquisition period and clouds.

A line test applied by the National Board of Taxation was carried out for these six models. Site fertility assessments on a part of the test sites has been carried out very thoroughly by means of line sampling. Eight to ten lines of 10 metres width and with an interval of 280 to 230 metres had been measured in each test site. Lengths and numbers of lines are given in Table 10.

Table 10. Length of test lines by test sites.

Line	Site 1	Site 2	Site 3	Site 4
1	350	150	140	500
2	740	1490	760	940
3	1190	1280	1010	1100
4	1390	1380	1080	1090
5	1540	970	930	1030
6	1310	960	690	760
7	1580	720	860	640
8	1150	560	1050	480
9	700		1260	
10			500	
11			250	
Total	9950	7150	8530	6540

Forest site type and its precision were measured at ten metres intervals (changes were recorded). The following characteristics were computed for each four subareas: 1) the level of classification $L_{\hat{B}} = 100 \cdot \hat{B}/B$ where $\hat{B}$ is the satellite image based estimate of productivity in cubic metres and B the one based on field measurements, 2) the within stands variation of classification, 3) the proportion of correct classification, and 4) the proportion of gross errors. The within stands variation of the classification, v_k, in the stand k (of classifiers) means here the variation coefficient of site fertility x along the control lines intersecting this stand, i.e.

$$v_k = \sqrt{\sum_{i=1}^{n_k} (x_i - \bar{x}_k)^2 / \bar{x}_k (n_k - 1)},$$

where x_i is the site quality of the line segment i (with a length of 10 metres) and n_k the number of the line segments in the stand k. The within stands variation of the set of stands (a forest area) is the weighted mean of variation coefficients with the size of the stand as the weight,

$$\sum_{k=1}^{N} a_k v_k,$$

where N is the number of stands and a_k the area of the stand k. Table 11 shows the results for each four test sites and six models to be tested. Only June imagery is used in each model.

Let us look first at the improvement power of the DTM. It can be seen from Table 11 that DTM

1) slightly increases the proportion of correct classification, moderately in test Area 1, where the elevation variation is highest
2) decreases the proportion of gross errors in Area 1
3) does not affect the within stands variation
4) increases the classification level.

Thus, the height of hills should be obviously at least 80 metres and the slopes at least 15—20 %, as in Area 1. Therefore, it was decided to use DTM in the operative test only for the

Table 11. The results of a line test for six models (Se = segmentation, Ma = Markov and Pi = pixelwise).

Model	Level				Variation				Correct				Gross errors			
Site	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Se	102	122	104	129	19	35	17	26	54	40	64	43	15	21	11	22
Ma	102	120	105	126	18	34	12	26	51	41	68	40	16	20	12	25
Pi	95	119	100	121	14	28	15	19	44	36	58	42	18	24	15	24
DTM Se	108	123	107	129	21	36	16	26	59	42	61	41	10	19	16	23
DTM Ma	107	122	108	129	20	35	14	29	55	39	66	40	12	19	15	24
DTM Pi	100	120	104	124	14	27	11	19	51	39	62	40	13	23	12	24

Area 1 and only the June imagery in the other areas.

The necessity of post-processing (generalization) and the order of priority of the two methods was studied next. The pixelwise classification was, in almost all cases, poorer than the generalized results. Differences between the Markov random field and segmentation based post-processing were small. However, Markov random field post-processing gave better results in Areas 2 and 3 with respect to almost all characteristics, while segmentation based post-processing gave better results in Areas 1 and 4 with respect to proportions of correctly classified and gross error pixels. Thus, MRF based post-processing seemed to give slightly better results and was chosen as the method for the operative test. The June image and DTM were used in Area 1 and only the June image in the other areas.

7 Operative taxation method

The applied operative taxation method uses false colour aerial photographs, standard base maps and classification maps based on satellite image analysis. Figure 2 shows the phases of the operative taxation method. In the following, the method is called the KAUKO2 method.

The following phases are necessary to produce the classification map (interpreted result):

1) the acquisition and rectification of the image,
2) optionally, the acquiring of digital map data, (DTM, etc.)
3) the acquisition of ground truth data,
4) combining the intensities and ground truth data,
5) estimation of the parameters of the classification models,
6) classification of the image,
7) post-processing, Markov random field generalization or segmentation,
8) printing of the classification result.

The first phase in the operative classification, after the acquisition of the material, is the separation of waste land such as rocks and very stony mineral soils. Peatland taxation is carried out using the information of maps and aerial photos only because satellite images do not give reliable site fertility estimates for peatlands. The second step is the preliminary taxation of mineral soils by means of satellite image based site fertility map, aerial photos and base map. The third step is the planning of the field route which goes through areas with unreliable or uncertain taxation results. The drawing of the final site fertility map follows the field checking. Field checking (and the route planning) can also be omitted, relying only on the image analysis and aerial photos. This approach is here called KAUKO. The preliminary taxation and the final map drawing will be computerized in the future. Workstations and personal computers are very suitable for this purpose.

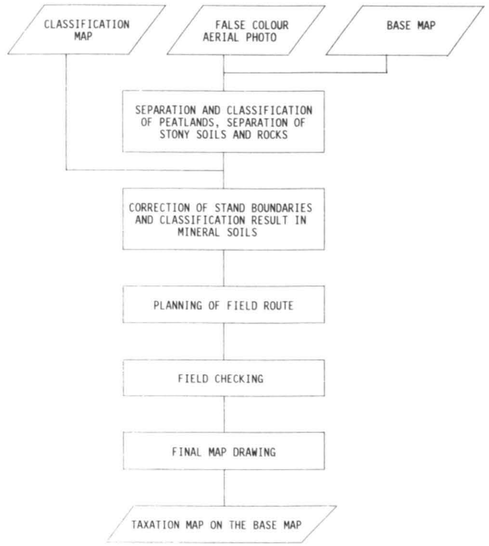

Figure 2. The phases of the KAUKO2 method.

8 Test of the operative taxation method

8.1 Test design

Tests with KAUKO and KAUKO2 were carried out in order to asses their efficiency as operative methods. The aim was to compare them with ordinary methods using characteristics mentioned in Chapter 7, as well as some other characteristics given later in this Chapter. The ordinary taxation methods were those known as BASE and VILMA. Both use aerial false colour photos and base maps. A preliminary taxation and a thorough field route plan is carried out in the VILMA method before field checking, while all stands are visited in the BASE method, cf. Myllyniemi (1985).

Because of measurements of efficiency, an upper limit for the available taxation time was given and the real time used in different parts of the taxation was recorded. Test areas were the four areas used in developing image analysis methods, cf. Chapter 2.

Two different test groups taxed the areas with the KAUKO and KAUKO2 methods. The first group consisted of 5 forest taxators and the second of 11 forest taxation controllers. The taxators taxed all four areas and the controllers either Area 1 or Area 4 with both methods. A group of 9 persons had earlier taxed areas with the BASE and VILMA methods. As mentioned before, the image analysis was based on sample plots of the National Forest Inventory as ground truth data, discriminant analysis classification and Markov random field post-processing. DTM was used in test Area 1. Table 12 shows the design of the test of the operative method, i.e. persons, areas and methods.

Table 12. Persons, areas and methods of the test of the operative method.

Test group taxators	Abbreviation	Site/Method	
Teijo Heinänen	TH	1,2,3,4/KAUKO,	1,2,3,4/KAUKO2
Harri Kiesilä	HK	1,2,3,4/KAUKO,	1,2,3,4/KAUKO2
Reijo Parkkila	RP	1,2,3,4/KAUKO,	1,2,3,4/KAUKO2
Kai Sjöberg	KS	1,2,3,4/KAUKO,	1,2,3,4/KAUKO2
Jukka Vähätaimi	JV	1,2,3,4/KAUKO,	1,2,3,4/KAUKO2
Test group controllers	**Abbreviation**	**Site/Method**	
Jyrki Ahvonen	JA	4/KAUKO,	4/KAUKO2
Markku Helkiö	MH	4/KAUKO,	4/KAUKO2
Heikki Korpelainen	HEKO	1/KAUKO,	1/KAUKO2
Risto Kujala	RK	4/KAUKO,	4/KAUKO2
Juho Lahti	JL	1/KAUKO,	1/KAUKO2
Eero Melanatie	EM	4/KAUKO,	4/KAUKO2
Matti Myllyniemi	MM	4/KAUKO2	
Juha Mäkitalo	JM	1/KAUKO,	1/KAUKO2
Kari Pilhjerta	KP	1/KAUKO,	1/KAUKO2
Pentti Pylkkö	PP	1/KAUKO,	1/KAUKO2
Jarmo Renvall	JR	4/KAUKO,	4/KAUKO2
Reference group	**Abbreviation**	**Site/Method**	
Markku Helkiö	HE	3,2/PERUS,	1,4/VILMA
Kari Kukkonen	KU	3,4/PERUS,	1,2/VILMA
Kalevi Kodisto	KO	3,2/PERUS,	1,4/VILMA
Lasse Lovén	LO	1,4/PERUS,	2,3/VILMA
Matti Myllyniemi	MY	1,2/PERUS,	3,4/VILMA
Pekka Riekko	RI	2,1/PERUS,	3,4/VILMA
Mauno Toivola	TO	2,3/PERUS,	4,1/VILMA
Tapio Vuori	VU	4,3/PERUS,	1,2/VILMA
Kaj Yrjönen	YR	4,1/PERUS,	2,3/VILMA

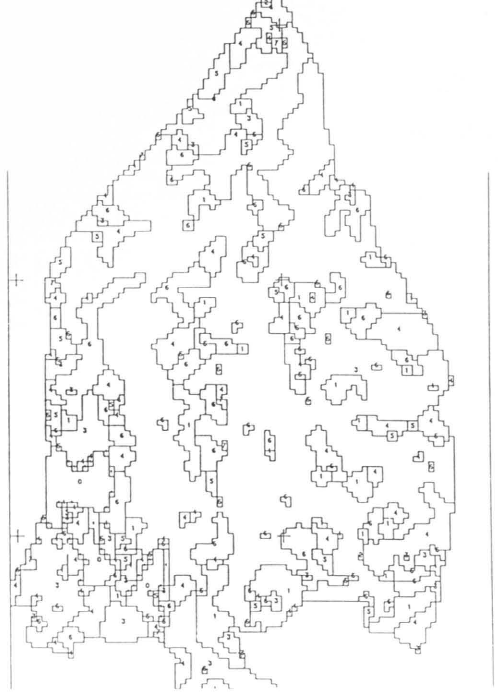

Figure 3. An example of a stand boundary map. The codes are: 1 = OMT, 2 = OMT stony, 3 = MT, 4 = MT stony, 5 = VT, 6 = VT stony, 7 = CT, and 0 = arable land.

Stand boundary maps of scale 1:10000 were produced with a CALCOMP plotter for the operative test. The forest site types and their precision are given by figures, see Figure 3. Plastic sheets were copied for operative use. Colour hard copies at a scale of 1:23000 were printed in map form, see Figure 4.

The tests were carried out in July 3—7, 1989. The first day was used to familiarize the test groups with the special features of the test areas, such as the general type of vegetation and so on. Taxation were carried out on the following four days. The controllers taxed one area on July 4th.

A plastic map element was produced as an output of the taxation from both KAUKO and KAUKO2. Corresponding elements from the BASE and VILMA methods were obtained from the National Board of Taxation.

A line sampling and the VELI program of the National Board of Taxation were used to analyze and judge the results, see Chapter 6. An example of the output of the VELI program is given in Appendix 9. The test variables were: 1) the level of classification (compared with a thorough ground measurements), 2) the level of classification in mineral soils $L_{\hat{B}} = 100 \cdot \hat{B}/B$, cf. Chapter 6, 3) the absolute deviance from the measured level, dev = $|L_{\hat{B}} - L_B|$, 4) the proportion of length of lines were the tax class is correct (compared with the thorough field measurement), 5) the proportion of line length with at most one tax class error, 6) the proportion of line length with an error of at least two tax classes (gross errors), 7) the within stands variation on mineral soils, and 8) the within stands variation on forest land.

8.2 Results of operative tests

8.2.1 Results by areas

A) Let us look the results in the case where the computation unit is a test area and all the test persons are included. Tables 13.1—13.8

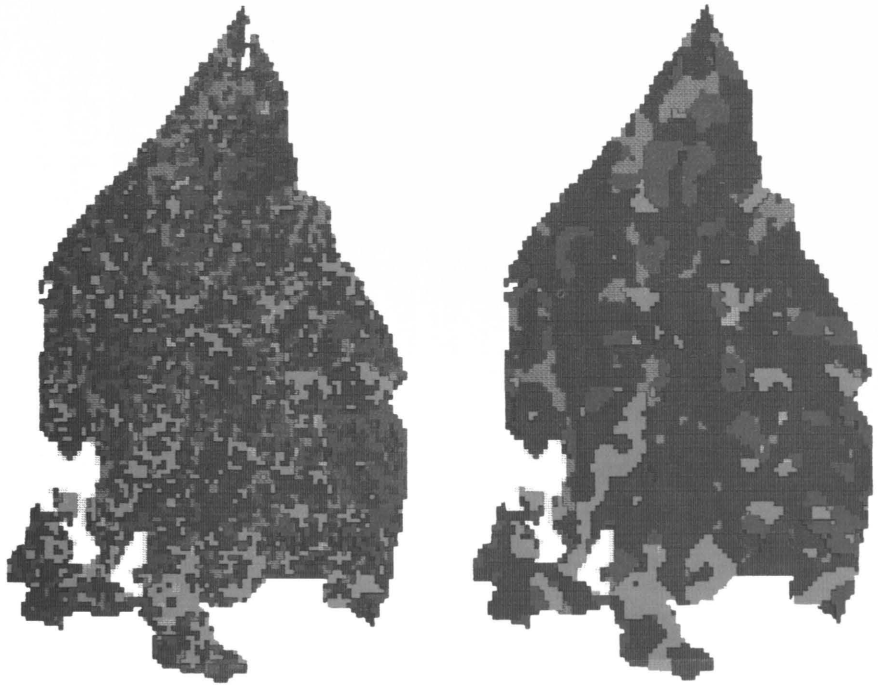

Figure 4. An example of the result of the Markov random field post-processing and a colour hardcopy. The pixelwise classification is on the left and the same after the post-processing on the right. The colours are: red = OMT, orange = OMT stony, dark green = MT, light green = MT stony, blue = VT, light blue = VT stony, violet = CT, and yellow = arable land.

show the means, standard deviations and the numbers of observations of the eight test variables mentioned above by test areas and by test groups for each four methods. Note that the BASE and VILMA methods were regarded as reference groups and KAUKO and KAUKO2 as test groups.

We are mainly interested in the differences of methods. The four test areas are, however, rather different in character: Area 1 has a relatively high amount peatlands; Area 2 consists of small stands with a high amount of cuttings; Area 3 has lot of agricultural areas; and Area 4 is forested having fairly large stands.

Thus, the area effect (α_i) has to be included in the models in addition to the method effect (β_j) when testing the differences of methods in Tables 13.1—13.8. Further, the between methods differences depend on the area. Consequently, the interaction of the method and area (γ_{ij}) has to be included in the model. Taxation results also depend on the taxator. The taxator effect ($\delta_{k(j)}$) is a nested effect within the methods because different groups and persons used different methods. The taxator effect is a random effect because taxators were chosen randomly and each taxator has personal characteristics which affects the result.

Thus, a suitable model for testing between methods differences is a mixed linear model of fixed and random effects

$$y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \delta_{k(j)} + \epsilon_{ijk},$$

where

y is the variable to be tested,

μ a general mean,

α_i a fixed area effect,

β_j a fixed method effect,

γ_{ij} a fixed interaction effect of area and method,

$\delta_{k(j)}$ a nested random effect of taxator and

ϵ_{ijk} an independently $N(0, \sigma^2)$ distributed error term. Here i, j and k refer to the area, method and taxator respectively.

The results of tests are given in Tables 13.1—13.8. Model estimations were carried out using the BMDP software package and the REML method. Pairwise tests are given in Appendices 10.1—10.8. The classification level, proportion of correct classifications and proportion of gross errors are shown in Figures 6.1—6.12 in Appendix 13.

The level of taxation, forest land, Table 13.1, Appendix 10.1: KAUKO2 gives a strict taxation level and KAUKO a slight overtaxation in Areas 2 and 4, as does VILMA in Area 2. As a whole, KAUKO is strictest, KAUKO2 and VILMA fairly similar and the BASE method most moderate. Between methods differences are statistically significant. Significant pairwise differences are (Appendix 10.1) in Area 2 (KAUKO > KAUKO2) and in Area 4 (KAUKO > BASE, VILMA, KAUKO2). KAUKO2 does not differ from BASE or VILMA in any area. Between areas differences are significant. This holds with respect all variables.

Level of taxation, mineral soils, Table 13.2, Appendix 10.2: All methods give a strict or over taxation in Areas 2 and 4. KAUKO gives a significantly higher level than VILMA and KAUKO2 in Area 4.

Table 13.1. Mean and standard deviation of taxation level and the number of observations by areas, groups and methods on forest land and tests of fixed effects based on asymptotic variance-covariance matrix.

		Method											
		Base			Vilma			Kauko2			Kauko		
Group	Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref.	1	99.5	6.5	4	97.6	5.6	5	96.4	4.5	5	97.2	2.8	5
and	2	99.0	8.0	5	106.0	14.4	4	106.6	5.4	5	110.6	6.7	5
test	3	97.4	2.9	5	101.3	1.7	4	98.8	5.4	5	100.4	4.0	5
	4	102.5	10.2	4	99.6	2.7	5	105.6	8.2	5	111.6	7.3	5
Con-	1	·	·	·	·	·	·	96.6	6.2	5	94.6	7.4	5
trollers	4	·	·	·	·	·	·	106.0	7.7	6	116.2	6.8	5
All		99.4	6.8	18	100.8	7.5	18	101.8	7.4	31	105.1	9.9	30

Source	F-statistic	Degrees of freedom		Probability
Constant	20252.34	1	80	0.00000
Area	9.02	3	80	0.00003
Method	2.90	3	80	0.03981
Interaction	2.08	9	80	0.04090

Table 13.2 Mean and standard deviation of taxation level and the number of observations by areas, groups and methods on mineral soils and tests of fixed effects based on asymptotic variance-covariance matrix.

		Method											
		Base			Vilma			Kauko2			Kauko		
Group	Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref.	1	101.5	6.2	4	99.4	6.5	5	96.2	4.4	5	97.0	3.4	5
and	2	111.1	5.4	5	113.8	16.0	4	110.0	6.6	5	111.2	6.3	5
test	3	101.4	3.9	5	104.0	1.4	4	97.6	5.9	5	99.2	3.8	5
	4	107.5	11.1	4	103.6	2.6	5	106.0	7.7	5	111.4	7.8	5
Con-	1	·	·	·	·	·	·	96.8	6.5	5	94.0	8.0	5
trollers	4	·	·	·	·	·	·	106.7	7.5	6	116.0	7.2	5
All		105.3	7.6	18	104.8	9.2	18	102.4	8.2	31	104.8	10.3	30

Source	F-statistic	Degrees of freedom		Probability
Constant	19822.75	1	80	0.00000
Area	17.21	3	80	0.00000
Method	0.80	3	80	0.49477
Interaction	1.39	9	80	0.20851

The deviance from the level of ground measurements, Table 13.3, Appendix 10.3: KAUKO2 gives the best result and KAUKO the worst. Differences are, however, small and varies only between areas.

Proportion of correct taxation, Table 13.4, Appendix 10.4: Between areas effects are also significant here. Differences of methods are also significant. Pairwise differences exist in Areas 1 (KAUKO < BASE) and 4 (KAUKO < KAUKO2).

Table 13.3 Mean deviance of taxation level from the level of ground measurements, standard deviation of the deviance and number of observations by areas, groups and methods on mineral soils and tests fixed effects based on asymptotic variance-covariance matrix.

		Method											
		Base			Vilma			Kauko2			Kauko		
Group	Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref.	1	5.0	2.8	4	5.0	3.3	5	4.2	4.0	5	3.8	2.2	5
and	2	11.0	5.4	5	17.3	10.6	4	10.0	6.6	5	11.2	6.3	5
test	3	3.0	2.5	5	4.0	1.4	4	4.4	4.3	5	2.8	2.4	5
	4	10.5	6.5	4	3.6	2.6	5	7.6	5.7	5	11.4	7.8	5
Con-	1	.	.	.	.	.	.	6.0	3.2	5	8.0	5.4	5
trollers	4	.	.	.	.	.	.	7.7	6.2	6	16.0	7.2	5
All		7.3	5.5	18	7.1	7.5	18	6.7	5.2	31	8.9	6.9	30

Source	F-statistic	Degrees of freedom		Probability
Constant	171.74	1	80	0.00000
Area	10.83	3	80	0.00000
Method	0.40	3	80	0.75112
Interaction	1.80	9	80	0.08053

Table 13.4. Mean proportion of correct classes, standard deviation and number of observations by areas, groups and methods on mineral soils and tests of fixed effects based on asymptotic variance-covariance matrix.

		Method											
		Base			Vilma			Kauko2			Kauko		
Group	Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref.	1	54.3	5.0	4	50.4	5.7	5	49.0	6.6	5	47.4	4.7	5
and	2	45.6	2.7	5	43.5	3.0	4	45.4	5.0	5	43.6	2.9	5
test	3	70.0	5.5	5	72.3	1.7	4	67.8	9.3	5	65.8	9.9	5
	4	51.5	8.3	4	52.8	3.1	5	53.2	4.3	5	49.4	4.3	5
Con-	1	.	.	.	.	.	.	47.8	4.8	5	45.4	6.7	5
trollers	4	.	.	.	.	.	.	53.5	2.4	6	46.4	3.4	5
All		55.6	11.0	18	54.4	11.0	18	52.8	9.0	31	49.7	9.2	30

Source	F-statistic	Degrees of freedom		Probability
Constant	7955.64	1	80	0.00000
Area	77.22	3	80	0.00000
Method	2.93	3	80	0.03870
Interaction	0.66	9	80	0.74282

Proportion of at most one class error, Table 13.5, Appendix 10.5: Different methods give, on the average, similar proportions. The figures vary by areas only.

Proportion of gross errors, Table 13.6, Appendix 10.6: Between methods differences are small. KAUKO2 gives the best and KAUKO the worst results. Only between areas differences are statistically significant.

Table 13.5. Mean proportion of taxation with at most one class error, standard deviation of the proportion and number of observations by areas, groups and methods and tests of fixed effects based on asymptotic variance-covariance matrix.

		Method											
		Base			Vilma			Kauko2			Kauko		
Group	Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref.	1	90.3	1.5	4	89.4	1.5	5	89.6	2.1	5	89.2	2.6	5
and	2	84.6	2.3	5	86.0	2.4	4	85.6	3.4	5	85.2	3.4	5
test	3	90.0	1.9	5	91.5	0.6	4	91.0	2.9	5	89.8	0.8	5
	4	88.3	4.1	4	89.0	2.6	5	90.2	2.4	5	87.8	2.3	5
Con-	1	.	.	.	.	.	.	88.4	4.0	5	88.8	3.3	5
trollers	4	.	.	.	.	.	.	90.0	0.6	6	86.2	2.3	5
All		88.2	3.3	18	89.0	2.6	18	89.2	3.1	31	87.8	2.9	30

Source	F-statistic	Degrees of freedom		Probability
Constant	86579.29	1	80	0.00000
Area	17.27	3	80	0.00000
Method	1.09	3	80	0.35619
Interaction	0.63	9	80	0.75056

Table 13.6. Mean proportion of gross errors, standard deviation of proportion and number of observations by areas, groups and methods on mineral soils and tests of fixed effects based on asymptotic variance-covariance matrix.

		Method											
		Base			Vilma			Kauko2			Kauko		
Group	Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref.	1	10.0	1.2	4	10.2	1.6	5	10.2	2.0	5	10.4	2.7	5
and	2	15.2	2.3	5	14.5	2.5	4	14.6	3.2	5	14.8	3.3	5
test	3	10.2	2.3	5	8.3	0.5	4	9.0	2.9	5	10.0	1.2	5
	4	11.8	4.1	4	11.0	2.5	5	9.6	2.3	5	12.2	2.3	5
Con-	1	.	.	.	.	.	.	11.6	3.8	5	11.0	3.4	5
trollers	4	.	.	.	.	.	.	10.0	0.6	6	13.6	2.3	5
All		11.9	3.3	18	10.9	2.9	18	10.8	3.0	31	12.0	3.0	30

Source	F-statistic	Degrees of freedom		Probability
Constant	1487.12	1	80	0.00000
Area	19.45	3	80	0.00000
Method	0.92	3	80	0.43681
Interaction	0.68	9	80	0.72653

Within stands variation on mineral soils, Table 13.7, Appendix 10.7: Between methods differences are highest with respect to this variable. Between areas differences are even higher. KAUKO gives the worst result in Area 2, which has a lot of small stands. Differences with all other methods are statistically significant. This is the case also in Area 3, where KAUKO2 also gives a poorer result than BASE and VILMA. In Area 4, only the difference between KAUKO and BASE is statistically significant.

Within stands variation in forest land, Table 13.8, Appendix 10.8: Differences between satellite image based and other methods decrease if peatlands are included in the taxation. KAUKO gives a still poorer result than others in Areas 2 and 3.

Table 13.7. Mean within stands variation of mineral soils, standard deviation of variation and number of observations by areas, groups and methods on mineral soils tests of fixed effects based on asymptotic variance-covariance matrix.

		Method											
		Base			Vilma			Kauko2			Kauko		
Group	Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref.	1	18.5	1.3	4	18.4	0.9	5	19.8	1.6	5	19.8	1.3	4
and	2	29.3	3.6	4	30.8	1.7	4	31.8	1.3	5	35.3	5.9	3
test	3	13.4	2.8	5	14.8	3.4	4	16.8	3.8	5	19.6	6.5	5
	4	22.8	1.7	4	23.5	2.5	4	25.2	1.8	5	25.8	2.0	5
Con-	1	•	•	•	•	•	•	21.6	1.1	5	21.5	0.6	4
trollers	4	•	•	•	•	•	•	24.3	1.5	6	26.5	1.0	4
All		20.5	6.5	17	21.6	6.4	17	23.3	5.1	31	24.2	6.1	25

Source	F-statistic	Degrees of freedom		Probability
Constant	5672.70	1	73	0.00000
Area	108.94	3	73	0.00000
Method	10.06	3	73	0.00001
Interaction	0.58	9	73	0.80909

Table 13.8. Mean within stands variation on forest land, standard deviation of variation and number of observations by areas, groups and methods on mineral soils and tests of fixed effects based on asymptotic variance-covariance matrix.

		Method											
		Base			Vilma			Kauko2			Kauko		
Group	Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref.	1	18.3	2.1	3	18.4	1.1	5	19.8	1.1	5	19.5	1.0	4
and	2	28.0	•	1	30.8	1.3	4	32.0	1.4	4	36.0	5.7	2
test	3	13.4	2.8	5	15.0	2.6	4	16.8	3.8	5	19.6	6.5	5
	4	25.3	2.1	4	26.8	1.9	4	25.6	1.3	5	25.8	2.0	5
Con-	1	•	•	•	•	•	•	21.4	0.9	5	21.0	0.0	4
trollers	4	•	•	•	•	•	•	24.5	1.4	6	26.5	1.0	4
All		19.3	6.1	13	22.5	6.6	17	23.1	5.0	30	23.6	5.8	24

Source	F-statistic	Degrees of freedom		Probability
Constant	4915.44	1	67	0.00000
Area	102.50	3	67	0.00000
Method	6.32	3	67	0.00077
Interaction	1.67	9	67	0.11421

A part of test persons removed

All the test and comparison persons were included in the previous considerations. Some persons were such, however, that their taxation results may distort the comparisons of methods. Another set of tests were therefore carried out in such a way that some persons were excluded. Reasons for the removal were, for instance, a lack of experience in taxation in South Finland, no experience in taxation at all, no experience with false colour images or colour-blindness. Three taxators and eight controllers remained after rejection. These were combined into a single group. Some results of the BASE method were also rejected on the same basis as earlier in the VILMA research, see Myllyniemi (1985). A visual inspection shows that the rejected observations are often at the lower or upper end of distributions, see Appendices 12.1—12.12.

Results

Tables 14.1—14.8 show the means and standard deviations of above mentioned eight variables by areas, groups and methods, as well as the numbers of observations. Results of the tests based on model (4) are given below the tables. Results of pairwise tests are given in Appendices 11.1—11.8.

Level of taxation, forest land, reduced data, Table 14.1, Appendix 11.1: KAUKO still gives higher level than other methods, especially in Areas 2 and 4. Differences are not statistically significant.

Level of taxation, mineral soils, reduced data, Table 14.2, Appendix 11.2: All methods overestimate the site fertility in Areas 2 and 4. Between methods differences are not statistically significant.

Table 14.1. Mean and standard deviation of the taxation level and the number of observations in the reduced data and tests of fixed effects based on asymptotic variance-covariance matrix.

	Method											
	Base			Vilma			Kauko2			Kauko		
Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	102.0	5.0	3	97.6	5.6	5	97.4	5.3	7	95.4	6.5	7
2	101.5	6.6	4	106.0	14.4	4	105.0	6.2	3	109.3	3.2	3
3	97.4	2.9	5	101.3	1.7	4	100.0	2.0	3	102.0	2.6	3
4	104.0	4.2	2	99.6	2.7	5	103.3	6.8	6	110.3	6.5	6
All	100.5	4.9	14	100.8	7.5	18	100.9	6.1	19	103.4	8.6	19

Source	F-statistic	Degrees of freedom		Probability
Constant	17339.58	1	54	0.00000
Area	5.25	3	54	0.00299
Method	1.00	3	54	0.40078
Interaction	1.40	9	54	0.21065

Table 14.2. Mean and standard deviation of the taxation level and the number of observations on mineral soils in the reduced data tests of fixed effects based on asymptotic variance-covariance matrix.

	Method											
	Base			Vilma			Kauko2			Kauko		
Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	104.3	3.1	3	99.4	6.5	5	97.6	5.6	7	95.0	7.2	7
2	112.3	5.3	4	113.8	16.0	4	109.0	7.9	3	111.3	4.0	3
3	101.4	3.9	5	104.0	1.4	4	99.0	2.6	3	100.7	2.3	3
4	107.5	2.1	2	103.6	2.6	5	104.2	6.7	6	109.8	6.8	6
All	106.0	5.8	14	104.8	9.2	18	101.7	7.0	19	103.2	9.3	19

Source	F-statistic	Degrees of freedom		Probability
Constant	16046.28	1	54	0.00000
Area	11.46	3	54	0.00001
Method	0.97	3	54	0.41184
Interaction	0.84	9	54	0.58306

The deviance from the level of ground measurements, reduced data, Table 14.3, Appendix 11.3: KAUKO2 still gives the best result and KAUKO the worst. Differences are, however, small and vary only between areas.

Proportion of correct taxation, reduced data, Table 14.4, Appendix 11.4: Between areas differences are high also here. Differences of methods are 'almost' significant. Pairwise differences exist in Areas 1 (KAUKO < BASE) and 4 (KAUKO < BASE).

Table 14.3 Mean deviance from the level of ground measurements, standard deviation of the deviance and number of observations by areas, groups and methods on mineral soils in the reduced data and tests of fixed effects based on asymptotic variance-covariance matrix.

	Method											
	Base			Vilma			Kauko2			Kauko		
Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	4.3	3.1	3	5.0	3.3	5	4.7	3.5	7	7.0	4.9	7
2	12.3	5.3	4	17.3	10.6	4	9.0	7.9	3	11.3	4.0	3
3	3.0	2.5	5	4.0	1.4	4	2.3	0.6	3	2.0	0.0	3
4	7.5	2.1	2	3.6	2.6	5	5.5	5.4	6	9.8	6.8	6
All	6.6	5.1	14	7.1	7.5	18	5.3	4.8	19	7.8	5.7	19

Source	F-statistic	Degrees of freedom		Probability
Constant	118.47	1	54	0.00000
Area	9.81	3	54	0.00003
Method	0.69	3	54	0.56472
Interaction	1.00	9	54	0.44889

Table 14.4. Mean proportion of correct taxation, standard deviation of proportion and number of observations by areas, groups and methods on mineral soils in the reduced data and tests of foxed effects based on asymptotic variance-covariance matrix.

	Method											
	Base			Vilma			Kauko2			Kauko		
Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	55.3	5.5	3	50.4	5.7	5	49.7	5.1	7	46.0	6.1	7
2	45.5	3.1	4	43.5	3.0	4	46.3	5.5	3	45.3	2.1	3
3	70.0	5.5	5	72.3	1.7	4	72.0	4.0	3	71.3	5.0	3
4	58.5	2.1	2	52.8	3.1	5	54.2	3.2	6	49.5	3.5	6
All	58.2	11.0	14	54.4	11.0	18	54.1	9.4	19	51.0	10.2	19

Source	F-statistic	Degrees of freedom		Probability
Constant	9527.83	1	54	0.00000
Area	94.77	3	54	0.00000
Method	2.31	3	54	0.08670
Interaction	1.15	9	54	0.34491

Proportion of at most one class error, reduced data, Table 14.5, Appendix 11.5: Different methods give, on the average, similar proportions. The figures vary by areas only. Data reduction does not affect the results.

Proportion of gross errors, reduced data, Table 14.6, Appendix 11.6: Between methods differences are small. KAUKO2 still gives the best result (10.3 %) VILMA and KAUKO give the same mean proportion (11.1 %). Only between areas differences are statistically significant.

Table 14.5. Mean proportion of the taxation with at most one class error, standard deviation of the proportion and number of observations by areas, groups and methods in the reduced data and tests of fixed effects based on asymptotic variance-covariance matrix.

	Method											
	Base			Vilma			Kauko2			Kauko		
Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	90.0	1.7	3	89.4	1.5	5	89.3	3.7	7	89.4	3.2	7
2	85.5	1.3	4	86.0	2.4	4	87.3	2.9	3	86.7	2.5	3
3	90.0	1.9	5	91.5	0.6	4	91.0	3.6	3	89.7	1.2	3
4	91.5	0.7	2	89.0	2.6	5	90.7	1.6	6	88.3	1.4	6
All	88.9	2.7	14	89.0	2.6	18	89.7	3.1	19	88.7	2.4	19

Source	F-statistic	Degrees of freedom		Probability
Constant	63836.93	1	54	0.00000
Area	11.72	3	54	0.00001
Method	0.44	3	54	0.72239
Interaction	0.66	9	54	0.74389

Table 14.6. Mean proportion of gross errors, standard deviation of proportion and number of observations by areas, groups and methods on mineral soils in the reduced data and tests of fixed effects based on asymptotic variance-covariance matrix.

	Method											
	Base			Vilma			Kauko2			Kauko		
Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	10.3	1.2	3	10.2	1.6	5	10.7	3.5	7	10.1	3.3	7
2	14.3	1.0	4	14.5	2.5	4	13.0	2.6	3	13.7	2.1	3
3	10.2	2.3	5	8.3	0.5	4	9.0	3.6	3	10.0	1.7	3
4	8.5	0.7	2	11.0	2.5	5	9.2	1.5	6	11.5	1.5	6
All	11.1	2.6	14	10.9	2.9	18	10.3	3.0	19	11.1	2.6	19

Source	F-statistic	Degrees of freedom		Probability
Constant	1027.19	1	54	0.00000
Area	13.69	3	54	0.00000
Method	0.30	3	54	0.82553
Interaction	0.80	9	54	0.61932

Within stands variation on mineral soils, reduced data, Table 14.7, Appendix 11.7: Between methods differences are still significant. Between areas differences are again even higher. KAUKO, and partly KAUKO2 also, gives poorer results than BASE and VILMA. Pairwise differences occur in Areas 2 and 3 (KAUKO > BASE, VILMA). Also KAUKO2 gives a better result than KAUKO in these areas.

Within stands variation on forest land, reduced data, Table 14.8, Appendix 11.8: Differences between satellite image based and other methods decrease again if peatlands are included in the taxation data. KAUKO still gives a poorer result than others in Areas 2 and 3.

Table 14.7. Mean within stands variation of mineral soils, standard deviation of variation and number of observations by areas, groups and methods on mineral soils in the reduced data and tests of fixed effects based on asymptotic variance-covariance matrix.

	Method											
	Base			Vilma			Kauko2			Kauko		
Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	19.0	1.0	3	18.4	0.9	5	21.4	1.0	7	21.0	0.9	6
2	31.0	1.0	3	30.8	1.7	4	31.7	1.5	3	36.5	7.8	2
3	13.4	2.8	5	14.8	3.4	4	17.0	5.3	3	21.3	8.5	3
4	22.0	1.4	2	23.5	2.5	4	24.8	1.8	6	25.6	1.1	5
All	20.1	7.2	13	21.6	6.4	17	23.4	5.0	19	24.4	6.4	16

Source	F-statistic	Degrees of freedom		Probability
Constant	3771.86	1	49	0.00000
Area	72.36	3	49	0.00000
Method	7.67	3	49	0.00027
Interaction	0.85	9	49	0.57418

Table 14.8. Mean within stands variation on forest land, standard deviation of variation and number of observations by areas, groups and methods in mineral soils in reduced data and tests of fixed effects based on asymptotic variance-covariance matrix.

	Method											
	Base			Vilma			Kauko2			Kauko		
Area	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	18.3	2.1	3	18.4	1.1	5	21.1	0.9	7	20.7	0.5	6
2	28.0	·	1	30.8	1.3	4	31.7	1.5	3	40.0	·	1
3	13.4	2.8	5	15.0	2.6	4	17.0	5.3	3	21.3	8.5	3
4	24.0	1.4	2	26.8	1.9	4	25.2	1.6	6	25.6	1.1	5
All	18.0	5.7	11	22.5	6.6	17	23.4	5.1	19	23.7	6.0	15

Source	F-statistic	Degrees of freedom		Probability
Constant	3648.28	1	46	0.00000
Area	68.27	3	46	0.00000
Method	8.30	3	46	0.00016
Interaction	2.09	9	46	0.05046

Conclusions about areawise tests

Satellite image based methods seem to give quite applicable result according to the tests. Between methods differences occurred only in four test variables if all the test persons and reference persons are included. The taxation level given by KAUKO was rather high, but decreased after ground measurements (KAUKO2). It may be possible to decrease the level with experience. Statistically significant differences did not exist after the data reduction.

The proportion of correct taxation was somewhat lower with KAUKO than with the other method. The within stand variation was somewhat higher with satellite image based methods than with other methods. Some differences also remained after data reduction. KAUKO2 and VILMA give similar within stand variation if peatlands were included in the taxation.

Thus, differences between methods were fairly small and the satellite image based methods gave satisfactory results; in some sense even better results than the traditional ones for areas of a few hundred hectares. A typical Finnish forest holding is approximately 40 hectares. The next question is how the image based methods work for areas of that size.

8.2.2 Testline results

Digital forest holding boundary information was not available for this investigation, and so artificial holdings were composed from test lines in order to check the reliability of KAUKO and KAUKO2 at the forest holding level. The variables 1) level of classification, 2) proportion of correct classification, and 3) proportion of gross errors were considered. It is enough to consider the between lines variation (standard deviation) by areas because the means and standard deviations of areas have been computed above and the differences seem to be acceptably small. A large standard deviation indicates a considerable between forest holding variation and vice versa. A weighted mean and standard deviation were used in the computations, with the line length as a weight.

Tables 15.1—15.3 show the means and standard deviations of line characteristics for the three variables by areas, groups and methods. Tables 16.1—16.3 show the corresponding results after a part of the test and reference persons had been removed according to the above criteria. The total means may differ to some extent from those of Tables 13—14 because some of the lines had to be rejected in the VELI program.

It can be seen from the tables that differences of between lines variances are fairly small with all variables and do not differ statistically significantly from zero. KAUKO2 gives the best result with all variables in the whole area both in the complete and reduced data.

We can deduce that satellite image based methods give reliable results also at the forest holding level because one line can represent a small forest holding.

Time comparisons

KAUKO and KAUKO2 work quite well according to previous tests. The next question is what is the possible time saving compared with the traditional methods BASE and VILMA. The possible time saving of satellite image based methods is achieved in three possible ways: 1) time saving in preliminary stand delineation, 2) time saving in preliminary taxation, and 3) time saving in field work. On the other hand, satellite image based classification brings additional elements into the preliminary phase which also require time.

Table 17 indicates the mean performance times of different methods by areas and groups. The field work time and other time have been given separately for BASE and VILMA methods. The field work time has been given only for KAUKO2 because KAUKO indicates the other times needed. The standard deviations have been given for these methods because they could have been computed, but only the mean times by areas were available for others.

The performance speed (ha/h) were computed from the figures of Table 17 and are given in Table 18. The sizes of the areas were: 1: 305 ha, 2: 233 ha, 3: 282 ha, and 4: 195 ha, that is 1015 ha altogether. The reference group and the group taxators were in the calculations, but not the group controllers because of their limited practice in taxation. The total time in the case of KAUKO consists of the preliminary tax-

Table 15.1 Weighted means and standard deviations of the taxation level of lines, the line length as a weight.

Group	Area	Method Base			Vilma			Kauko2			Kauko		
		Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref. and test	1	98.6	11.3	36	97.5	10.0	45	96.7	8.8	45	97.4	9.4	45
	2	99.1	11.6	32	106.9	16.8	25	107.5	10.9	40	112.2	13.6	40
	3	99.3	12.0	54	105.4	15.7	44	101.9	13.7	55	104.1	14.1	55
	4	102.6	13.1	31	99.6	9.2	40	105.4	11.1	40	111.8	11.1	40
Con-trol-lers	1	.	.	.	.	.	.	97.4	10.6	52	94.9	12.3	45
	4	.	.	.	.	.	.	106.6	10.5	40	116.3	11.6	40
All		99.7	12.0	153	101.6	13.4	154	101.8	11.8	272	104.8	14.5	265

Table 15.2. Weighted means and standard deviations of the taxation level of lines, the line length as a weight.

Group	Area	Method Base			Vilma			Kauko2			Kauko		
		Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref. and test	1	54.2	13.7	36	51.7	14.8	45	51.1	15.7	45	50.1	15.7	45
	2	45.4	11.6	32	43.3	10.1	25	45.3	11.8	40	43.8	9.6	40
	3	68.3	18.2	54	70.9	15.9	44	67.0	18.0	55	65.5	17.8	55
	4	51.3	13.3	31	52.9	10.8	40	53.4	12.7	40	49.4	11.9	40
Con-trol-lers	1	.	.	.	.	.	.	50.3	14.8	52	47.0	17.2	45
	4	.	.	.	.	.	.	53.3	13.7	40	46.5	13.5	40
All		55.8	17.1	153	55.0	16.5	154	53.3	16.2	272	50.6	16.5	265

Table 15.3. Weighted means and standard deviations of proportions of gross errors of lines, the line length as a weight.

Group	Area	Method Base			Vilma			Kauko2			Kauko		
		Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
Ref. and test	1	10.2	8.6	36	9.9	5.5	45	9.7	5.2	45	9.9	5.9	45
	2	15.2	6.6	32	14.4	5.1	25	14.6	5.9	40	14.8	6.5	40
	3	10.5	8.4	54	9.6	8.1	44	10.1	7.4	55	11.1	10.2	55
	4	11.6	7.2	31	10.8	7.3	40	9.5	5.8	40	12.2	6.3	40
Con-trol-lers	1	.	.	.	.	.	.	10.7	7.4	52	10.5	7.7	45
	4	.	.	.	.	.	.	9.9	5.5	40	13.6	6.3	40
All		11.7	8.1	153	10.9	6.8	154	10.7	6.6	272	11.8	7.6	265

ation, stand delineation and the final drawing. The total time of KAUKO2 is the field work time of KAUKO2 plus KAUKO's time.

The BASE method is the most time consuming. KAUKO2 is somewhat and KAUKO considerably faster than VILMA. Assuming that the test areas are a representative sample from forest lands we can deduce that a transfer from VILMA to KAUKO2 saves about 10 % of the field work time and costs and for KAUKO about 60 %. The saving from VILMA to KAUKO2 is 15 % in Area 1 and 16 % in Areas 3 and 4, while KAUKO2 is a bit slower than VILMA in Area 2.

According to test results, the possible operative taxation method might be KAUKO2 with a somewhat reduced field work. The total time-saving in field work could be from 20 % to 30 %. The methods can also be judged by inspecting the changes of some test variables as a function of the performance time. Figure 5 shows the standard deviation of taxation level, the proportion of correct taxation, the proportion of gross errors and the within stands variation computed from reduced data as a function of the taxation speed.

Table 16.1 Weighted means and standard deviations of the taxation level of lines, the line length as a weight in the reduced data.

Area	Method Base			Vilma			Kauko2			Kauko		
	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	101.2	11.0	27	97.5	10.0	45	97.7	10.2	72	95.7	11.8	63
2	101.8	14.2	32	107.1	16.9	32	105.7	10.3	24	110.5	11.4	24
3	99.3	12.0	55	105.4	15.7	44	103.3	14.2	33	105.4	14.3	33
4	104.0	6.8	16	99.6	9.2	40	103.4	9.7	48	110.3	11.3	48
All	101.0	12.0	130	101.8	13.6	161	101.0	11.3	177	103.1	13.9	168

Table 16.2. Weighted means and standard deviations of the proportions of the correct taxation of lines, the line length as a weight in the reduced data.

Area	Method Base			Vilma			Kauko2			Kauko		
	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	56.0	12.6	27	51.7	14.8	45	51.8	14.9	70	47.9	16.9	63
2	45.3	11.6	26	43.3	10.1	25	46.2	12.8	24	45.7	9.4	24
3	68.3	18.2	54	70.9	15.9	44	70.8	17.7	33	70.4	17.3	33
4	58.3	9.8	15	52.9	10.8	40	54.3	13.0	48	49.5	12.3	48
All	58.3	17.0	122	55.0	16.5	154	54.6	16.4	175	51.7	17.2	168

Table 16.3. Weighted means and standard deviations of the proportions of gross errors of lines, the line length as a weight in the reduced data.

Area	Method Base			Vilma			Kauko2			Kauko		
	Mean	STD	n	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	10.8	9.7	27	9.9	5.5	45	10.0	7.1	70	9.7	7.4	63
2	14.4	5.4	26	14.4	5.1	25	13.1	6.2	24	13.2	5.1	24
3	10.5	8.4	54	9.6	8.1	44	9.8	7.1	33	11.0	11.0	33
4	8.5	5.2	15	10.8	7.3	40	9.1	5.6	48	11.5	6.1	48
All	11.3	8.1	122	10.9	6.8	154	10.2	6.8	175	10.9	7.7	168

Table 17. The mean performance times (minutes) of taxation methods by areas.

Group	Area	Method Base			Vilma			Kauko2			Kauko		
		Field	Tot	n	Field	Tot	n	Field	Tot	n	Field	Tot	n
Ref. and test	1	880	965	4	168	402	5	194	344	5	0	150	5
	2	986	1064	5	173	331	4	189	372	5	0	183	5
	3	776	844	5	233	398	4	190	334	5	0	144	5
	4	720	800	4	216	372	5	177	312	5	0	135	5
Con-trollers	1	.	.	.	.	.	.	215	374	5	0	159	5
	4	.	.	.	.	.	.	216	332	5	0	116	5

Table 18. The performance speed (ha/h) of different phases by methods and areas.

Area	Method Base Field work	Drawing	Total	Vilma Preliminary classification	Field work	Drawing	Total	Kauko2 Field work	Total	Kauko Total
1	21	215	19.1	107	109	290	45.5	94.3	53.2	122.1
2	14	179	13.0	133	81	265	42.3	74.0	37.6	76.4
3	22	250	20.2	161	73	282	42.6	89.1	50.7	117.5
4	16	147	14.4	111	54	229	31.4	66.1	37.5	86.7
All	18	196	16.5	125	77.1	269	40.5	81.2	44.7	99.5

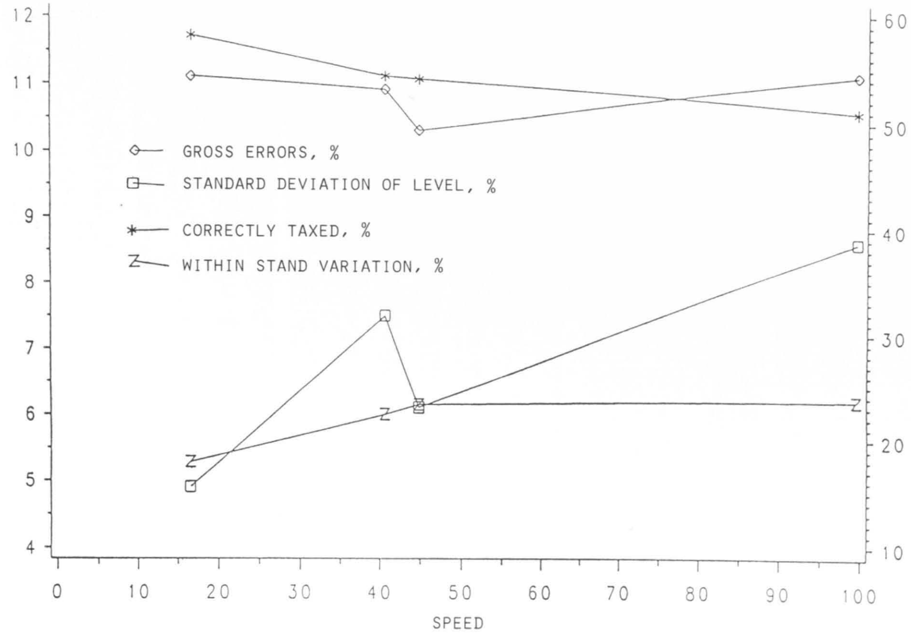

Figure 5. The standard deviation of taxation level, the proportion of correct taxation, the proportion of gross errors and the within stands variation as a function of the taxation speed.

9 Cost-benefit analysis

The test results have shown that satellite image based forest taxation method decreases field work compared with traditional ones. Both the digital terrain model and a Spring time image improves the reliability of image classification. The utility of the operative method can be judged comparing its cost and benefits.

The total benefit of KAUKO2 depends on the size of the area to be classified, the actual distribution of forest site types and the proportion of peatlands. The test areas of this study were small and the total area of stands with the extreme values of forest site fertility classes (OMT and CT) was small thereby creating difficulties for the image based methods.

Let us suppose that 70 % of the 90 km x 90 km area of a satellite image is forest land. We calculate the cost savings assuming first that the savings in field work are 15 % and compare the costs of field work with those of VILMA.

VILMA		
Field work 567 000 ha à 15 mk/ha		8 505 000
KAUKO2		
Image analysis		
Ground truth data and its processing	5 000	
Satellite image + pre-processing	12 500	
Image classification	10 000	
Printing ATK	20 000	
Image analysis, total		47 500
Field checks		
0.85 x 567 000 ha á 15 mk/ha		7 229 250
Total costs		7 276 750
Saving		1 228 250

The cost saving is about 1.2 million Finnish marks, i.e. 14.4 %. If the time saving would be 35 %, the cost of field work would be 5.5 million marks and the saving about 3 million marks. The taxation cost with KAUKO in an area of one TM image quarter would be 3.5 million marks and the cost saving 5 million marks.

A digital terrain model or another satellite image increases the cost very little compared with the total taxation costs. The benefit of a digital terrain model depends on the degree of elevation variation and the slopes. A Spring time image improves the classification result slightly but not essentially. The use of Spring image is limited by its short acquisition time. In cost-benefit analysis, one should note that satellite image aided methods can transfer a part of taxation work into Winter time thereby making them more effective.

10 Conclusions and suggestions for operative taxation

The four areas applied in the study were fairly different with respect to their general features. KAUKO and KAUKO2 made errors in different places in different areas. Thus the possible feedback effect did not fully work in tests and the full benefits of the image aided methods could not be assessed. Feedback means here that the first field checks indicate where the errors will be made and next field checks can be directed to similar areas. It can be expected that feedback further reduces the amount of field work if the area to be classified is large and relatively homogenous.

Thus the results suggest for further operative experiments.

10.1 Suggestions for operative taxation

1) Ground truth data

NFI data can be recommended as ground truth data. The image analysis based on the NFI data gave more reliable models than that based on forest taxation data. The NFI data do not involve a possible caution principle evident in the taxation data; a principle which may decrease the level of site fertility classification. Further, the NFI data is more homogeneous than the taxation data because the group of field workers is smaller in the NFI. The use of NFI data for taxation may unify the taxation result in different parts of the country, it is technically easy and can be done automatically.

NFI data consist of fairly small sample plots, making the accuracy of the localization of plots and the image rectification very important. On the other hand, in this case the forest site type is known exactly on the plots, while small micro variation occurs within the taxation stands.

2) Imagery and ancillary data

A summer image gives a satisfactory result. The use of a digital terrain model is technically simple and is justified if the elevation variation of the area is high enough (≥ 80 m). A spring time image increases the costs only very little if the area is large enough. Its use is limited by its availability.

3) Features and methods of image analysis

Canonical variables of the original TM spectral bands and their ratios computed with respect to the class indicator functions were settled as basic features of image analysis. Discriminant analysis, based on generalized quadratic distances, worked better than logistic regression analysis. A classification program which computes the required transformations including DTM based corrections, if requested, was prepared. In practice, the image classification is simple. The parameter estimation from one image to another is straightforward.

Textural features improved the results to some extent, see Table 3. Additional tests are needed for final conclusions. The computation of textural features required some extra work before classification.

Image filtering before image classification improved the result slightly, and post-processing after classification considerably. Comparisons with independent data showed that Markov random field and segmentation based post-processing have about same improving power. More detailed calculations (VELI tests) showed that MRF based post-processing worked slightly better in some areas. The differences of the methods are, however, small and the choice may depend in practice on the availability of the software and resources.

A stand delineation can be done either automatically with a computer or manually on the basis of an analogue site fertility map. Different stand delineations and their effect on the classification result could be easily tested in the workstation based method. Pixelwise and/or standwise probabilities of different site fertility classes can be produced by both methods.

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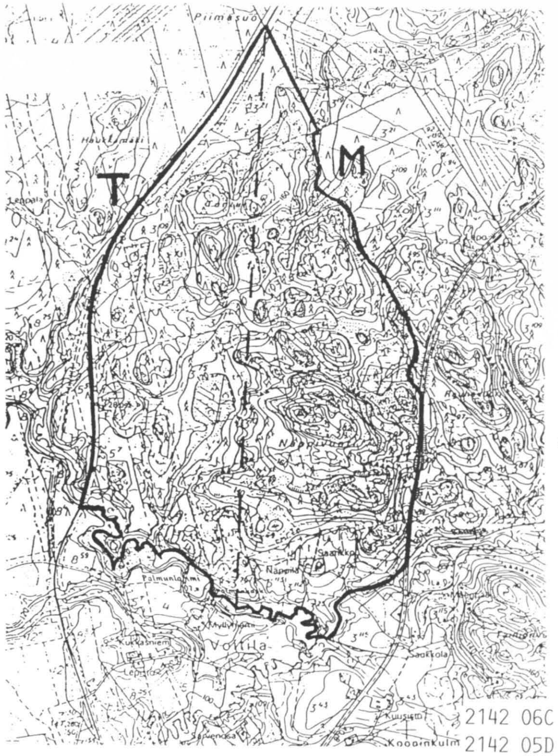
Total of 16 references

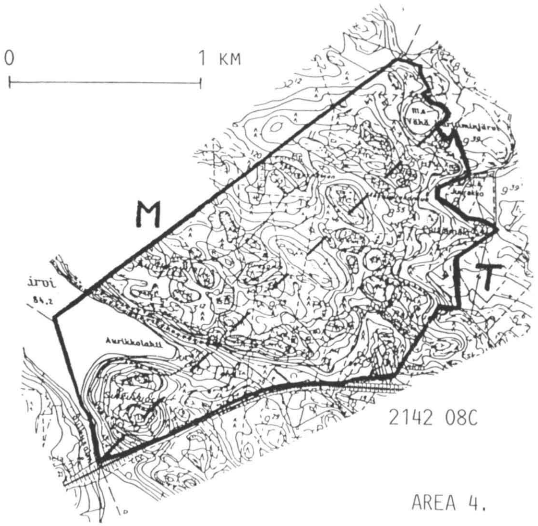
Appendix 1. The study areas.



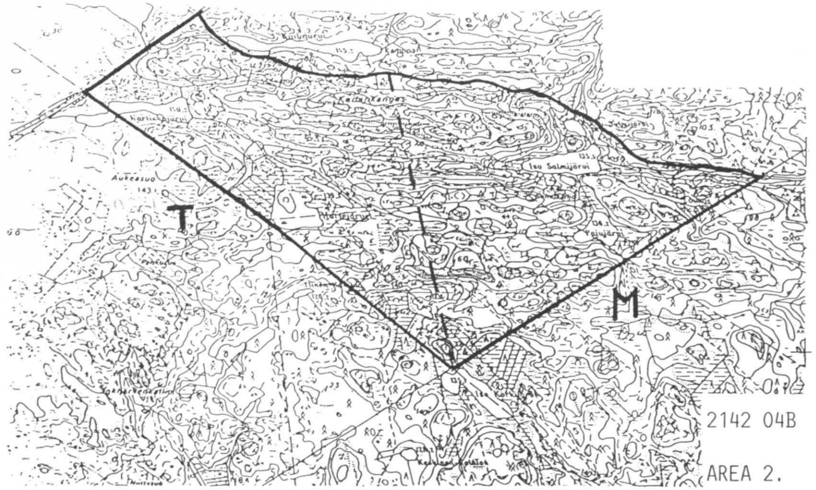
2142 06C
2142 05D
AREA 1.

0 1 KM

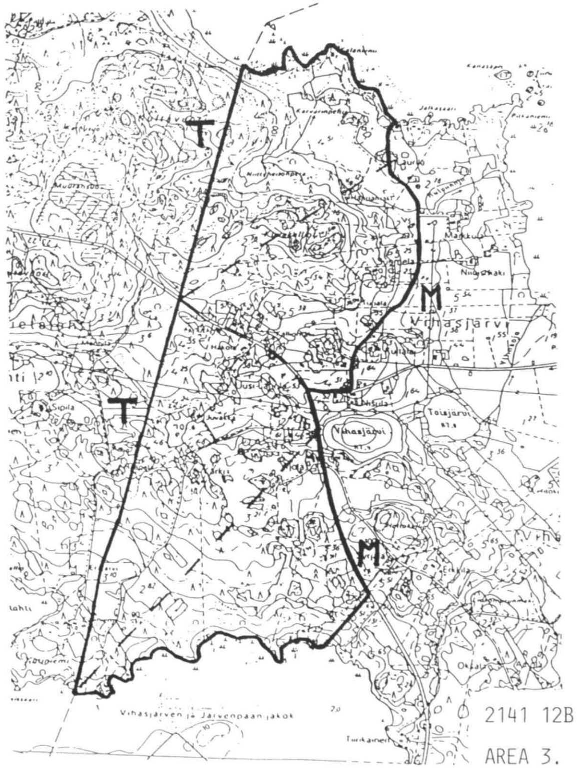
2142 06D
AREA 5.



2142 08C
AREA 4.



2142 04B
AREA 2.



2141 12B
AREA 3.

Appendix 2. Those parts of site quality stands which were used in the study.

Appendix 3.1. Models from the NFI data, June image. Number of observations and percent classified into BON:

From BON	OMT	OMT, stony	MT	MT, stony	VT	VT, stony	CT	Total
1	37	0	2	0	2	1	0	42
	88.10	0.00	4.76	0.00	4.76	2.38	0.00	100.00
2	1	8	0	0	0	0	0	9
	11.11	88.89	0.00	0.00	0.00	0.00	0.00	100.00
3	25	0	64	15	12	14	0	130
	19.23	0.00	49.23	11.54	9.23	10.77	0.00	100.00
4	7	0	6	16	6	4	3	42
	16.67	0.00	14.29	38.10	14.29	9.52	7.14	100.00
5	0	0	1	1	33	0	1	36
	0.00	0.00	2.78	2.78	91.67	0.00	2.78	100.00
6	1	0	1	1	5	15	1	24
	4.17	0.00	4.17	4.17	20.83	62.50	4.17	100.00
7	0	1	0	1	0	4	91	97
	0.00	1.03	0.00	1.03	0.00	4.12	93.81	100.00
Total	71	9	74	34	58	38	96	380
Percent	18.68	2.37	19.47	8.95	15.26	10.00	25.26	100.00
Priors	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	

Appendix 3.2. Models from the NFI data, June + May Images + DTM. Number of observations and percent classified into BON:

From BON	OMT	OMT, stony	MT	MT, stony	VT	VT, stony	CT	Total
1	34	0	2	0	0	0	0	36
	94.44	0.00	5.56	0.00	0.00	0.00	0.00	100.00
2	0	9	0	0	0	0	0	9
	0.00	100.00	0.00	0.00	0.00	0.00	0.00	100.00
3	15	0	94	8	7	6	0	130
	11.54	0.00	72.31	6.15	5.38	4.62	0.00	100.00
4	0	0	4	36	1	1	0	42
	0.00	0.00	9.52	85.71	2.38	2.38	0.00	100.00
5	0	0	1	1	30	0	1	33
	0.00	0.00	3.03	3.03	90.91	0.00	3.03	100.00
6	0	0	1	0	0	23	0	24
	0.00	0.00	4.17	0.00	0.00	95.83	0.00	100.00
7	0	0	0	0	1	3	93	97
	0.00	0.00	0.00	0.00	1.03	3.09	95.88	100.00
Total	49	9	102	45	39	33	94	371
Percent	13.21	2.43	27.49	12.13	10.51	8.89	25.34	100.00
Priors	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	

Appendix 3.3. Models from the Tax data, June image. Number of observations and percent classified into BON:

From BON	OMT	OMT, stony	MT	MT, stony	VT	VT, stony	CT	VT,v. stony	Total
1	122	43	31	25	28	6	0	4	259
	47.10	16.60	11.97	9.65	10.81	2.32	0.00	1.54	100.00
2	1	52	2	2	1	2	0	0	60
	1.67	86.67	3.33	3.33	1.67	2.32	0.00	1.54	100.00
3	38	129	141	93	41	20	0	34	496
	7.66	26.01	28.43	18.75	8.27	4.03	0.00	6.85	100.00
4	8	62	25	100	17	15	0	54	281
	2.85	22.06	8.90	35.59	6.05	5.34	0.00	19.22	100.00
5	3	7	8	19	43	6	0	16	102
	2.94	6.86	7.84	18.63	42.16	5.88	0.00	15.69	100.00
6	6	19	17	33	10	45	4	47	181
	3.31	10.50	9.39	18.23	5.52	24.86	2.21	25.97	100.00
7	0	0	0	0	0	1	96	0	97
	0.00	0.00	0.00	0.00	0.00	1.03	98.97	0.00	100.00
8	0	0	0	2	2	2	0	37	43
	0.00	0.00	0.00	4.65	4.65	4.65	0.00	86.05	100.00
Total	178	312	224	274	142	97	100	192	1519
Percent	11.72	20.54	14.75	18.04	9.35	6.39	6.58	12.64	100.00

Appendix 4.1. Models from the NFI data, tests from the Tax data, June image, Pixelwise classification.

Class	Estimated class OMT	OMT, stony	MT	MT, stony	VT	VT, stony	CT	Total
1	336	13	723	238	54	89	5	1458
2	41	2	69	17	2	8	0	139
3	466	2	1062	384	118	301	4	2337
4	229	6	785	331	141	228	1	1721
5	45	1	80	76	75	22	2	301
6	89	0	169	150	152	142	23	725
7	0	11	2	46	14	16	375	464
Total	1206	35	2890	1242	556	806	410	7145

Class	Proportions from correct site fertility classes							
1	0.230	0.009	0.496	0.163	0.037	0.061	0.003	1.0
2	0.295	0.014	0.496	0.122	0.014	0.058	0.000	1.0
3	0.199	0.001	0.454	0.164	0.050	0.129	0.002	1.0
4	0.133	0.003	0.456	0.192	0.082	0.132	0.001	1.0
5	0.150	0.003	0.266	0.252	0.249	0.073	0.007	1.0
6	0.123	0.000	0.233	0.207	0.210	0.196	0.032	1.0
7	0.000	0.024	0.004	0.099	0.030	0.034	0.808	1.0

Correct site fertility class 32.5122 %
Correct tax class 54.4857 %
Gross errors 9.4892 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class
Measured	285.80	157.36	80.88	47.56
Estimated	285.80	165.24	71.92	48.64

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class
Measured	1440.85	959.90	347.78	133.17
Estimated	1453.41	1007.96	309.26	136.19

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	II ⇒ III
Areas	58.92	32.52	16.28	10.12
Tax m^3	127.44	58.54	53.72	15.18

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	III ⇒ II
Areas	71.16	45.84	10.84	14.48
Tax m^3	140.00	82.51	35.77	21.72

Appendix 4.2. Models from the NFI data, tests from the Tax data, June image, Segmentation mode filtering.

Class	Estimated class OMT	OMT, stony	MT	MT, stony	VT	VT, stony	CT	Total
1	334	0	934	144	18	27	1	1458
2	28	0	91	11	0	9	0	139
3	371	0	1498	284	31	150	3	2337
4	106	0	1161	257	88	109	0	1721
5	55	0	95	55	83	13	0	301
6	104	0	194	139	165	96	27	725
7	0	0	0	0	19	0	445	464
Total	998	0	3973	890	404	404	476	7145

Class	Proportions from correct site fertility classes							
1	0.229	0.000	0.641	0.099	0.012	0.019	0.001	1.0
2	0.201	0.000	0.655	0.079	0.000	0.065	0.000	1.0
3	0.159	0.000	0.641	0.122	0.013	0.064	0.001	1.0
4	0.062	0.000	0.675	0.149	0.051	0.063	0.000	1.0
5	0.183	0.000	0.316	0.183	0.276	0.043	0.000	1.0
6	0.143	0.000	0.268	0.192	0.228	0.132	0.037	1.0
7	0.000	0.000	0.000	0.000	0.041	0.000	0.959	1.0

Correct site fertility class 37.9706 %
Correct tax class 60.2799 %
Gross errors 6.8300 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class
Measured	285.80	157.36	80.88	47.56
Estimated	285.80	198.84	51.76	35.20

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class
Measured	1440.85	959.90	347.78	133.17
Estimated	1534.05	1212.92	222.57	98.56

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	II ⇒ III
Areas	32.00	19.52	7.60	4.88
Tax m^3	67.54	35.14	25.08	7.32

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	III ⇒ II
Areas	81.52	56.68	11.92	12.92
Tax m^3	160.74	102.02	39.34	19.38

Appendix 4.3. Models from the NFI data, tests from the Tax data, June image, Markov random field post-processing.

Class	OMT	OMT, stony	MT	Estimated class MT, stony	VT	VT, stony	CT	Total
1	245	2	906	205	55	40	5	1458
2	21	0	100	8	2	8	0	139
3	306	0	1476	235	94	225	1	2337
4	82	0	1059	307	111	162	0	1721
5	23	1	96	90	82	9	0	301
6	82	0	190	159	142	131	21	725
7	0	1	0	10	11	3	439	464
Total	759	4	3827	1014	497	578	466	7145

Class	Proportions from correct site fertility classes							
1	0.168	0.001	0.621	0.141	0.038	0.027	0.003	1.0
2	0.151	0.000	0.719	0.058	0.014	0.058	0.000	1.0
3	0.131	0.000	0.632	0.101	0.040	0.096	0.000	1.0
4	0.048	0.000	0.615	0.178	0.064	0.094	0.000	1.0
5	0.076	0.003	0.319	0.299	0.272	0.030	0.000	1.0
6	0.113	0.000	0.262	0.219	0.196	0.181	0.029	1.0
7	0.000	0.002	0.000	0.022	0.024	0.006	0.946	1.0

Correct site fertility class 37.5087 %
Correct tax class 59.3422 %
Gross errors 7.7257 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class
Measured	285.80	157.36	80.88	47.56
Estimated	285.80	183.60	60.44	41.76

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class
Measured	1440.85	959.90	347.78	133.17
Estimated	1496.78	1119.96	259.89	116.93

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	II ⇒ III
Areas	41.96	23.96	11.16	6.84
Tax m^3	90.22	43.13	36.83	10.26

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	III ⇒ II
Areas	74.24	50.44	10.92	12.88
Tax m^3	146.15	90.79	36.04	19.32

Appendix 4.4. Models from the NFI data, tests from the Tax data, June image + DTM, Pixelwise classification.

Class	OMT	OMT, stony	MT	Estimated class MT, stony	VT	VT, stony	CT	Total
1	437	47	652	215	65	39	3	1458
2	47	1	65	18	2	6	0	139
3	610	25	1081	338	130	149	4	2337
4	256	19	787	362	160	137	0	1721
5	35	2	86	79	83	15	1	301
6	90	5	216	140	161	95	18	725
7	0	11	3	48	30	28	344	464
Total	1475	110	2890	1200	631	469	370	7145

Class	Proportions from correct site fertility classes							
1	0.300	0.032	0.447	0.147	0.045	0.027	0.002	1.0
2	0.338	0.007	0.468	0.129	0.014	0.043	0.000	1.0
3	0.261	0.011	0.463	0.145	0.056	0.064	0.002	1.0
4	0.149	0.011	0.457	0.210	0.093	0.080	0.000	1.0
5	0.116	0.007	0.286	0.262	0.276	0.050	0.003	1.0
6	0.124	0.007	0.298	0.193	0.222	0.131	0.025	1.0
7	0.000	0.024	0.006	0.103	0.065	0.060	0.741	1.0

Correct site fertility class 33.6319 %
Correct tax class 57.8586 %
Gross errors 7.3618 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class
Measured	285.80	157.36	80.88	47.56
Estimated	285.80	179.00	73.24	33.56

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class
Measured	1440.85	959.90	347.78	133.17
Estimated	1500.80	1091.90	314.93	93.97

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	II ⇒ III
Areas	44.88	30.72	8.04	6.12
Tax m^3	91.01	55.30	26.53	9.18

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	III ⇒ II
Areas	75.56	47.40	13.00	15.16
Tax m^3	150.96	85.32	42.90	22.74

Appendix 4.5. Models from the NFI data, tests from the Tax data, June image + DTM, Segmentation mode filtering.

Class	OMT	OMT, stony	MT	Estimated class MT, stony	VT	VT, stony	CT	Total
1	492	43	725	174	23	0	1	1458
2	26	0	102	10	1	0	0	139
3	549	24	1376	307	33	45	3	2337
4	184	0	1113	224	180	20	0	1721
5	23	0	106	85	86	1	0	301
6	87	0	318	96	174	23	27	725
7	0	3	0	0	17	2	442	464
Total	1361	70	3740	896	514	91	473	7145

Class	Proportions from correct site fertility classes							
1	0.337	0.029	0.497	0.119	0.016	0.000	0.001	1.0
2	0.187	0.000	0.734	0.072	0.007	0.000	0.000	1.0
3	0.235	0.010	0.589	0.131	0.014	0.019	0.001	1.0
4	0.107	0.000	0.647	0.130	0.105	0.012	0.000	1.0
5	0.076	0.000	0.352	0.282	0.286	0.003	0.000	1.0
6	0.120	0.000	0.439	0.132	0.240	0.032	0.037	1.0
7	0.000	0.006	0.000	0.000	0.037	0.004	0.953	1.0

Correct site fertility class 36.9909 %
Correct tax class 61.6655 %
Gross errors 6.3961 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class
Measured	285.80	157.36	80.88	47.56
Estimated	285.80	206.84	56.40	22.56

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class
Measured	1440.85	959.90	347.78	133.17
Estimated	1567.41	1261.72	242.52	63.17

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	II ⇒ III
Areas	24.72	21.92	1.96	0.84
Tax m^3	47.18	39.46	6.47	1.26

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	III ⇒ II
Areas	84.84	57.04	16.32	11.48
Tax m^3	173.75	102.67	53.86	17.22

Appendix 4.6. Models from the NFI data, tests from the Tax data, June image + DTM, Markov random field post-processing.

Class	OMT	OMT, stony	MT	Estimated class MT, stony	VT	VT, stony	CT	Total
1	549	25	690	134	56	0	4	1458
2	34	0	98	6	0	1	0	139
3	528	6	1458	183	85	76	1	2337
4	146	6	1157	226	126	60	0	1721
5	29	2	99	78	89	3	1	301
6	73	0	322	116	161	43	10	725
7	0	3	2	9	22	4	424	464
Total	1359	42	3826	752	539	187	440	7145

Class	Proportions from correct site fertility classes							
1	0.377	0.017	0.473	0.092	0.038	0.000	0.003	1.0
2	0.245	0.000	0.705	0.043	0.000	0.007	0.000	1.0
3	0.226	0.003	0.624	0.078	0.036	0.033	0.000	1.0
4	0.085	0.003	0.672	0.131	0.073	0.035	0.000	1.0
5	0.096	0.007	0.329	0.259	0.296	0.010	0.003	1.0
6	0.101	0.000	0.444	0.160	0.222	0.059	0.014	1.0
7	0.000	0.006	0.004	0.019	0.047	0.009	0.914	1.0

Correct site fertility class 39.0343 %
Correct tax class 61.4136 %
Gross errors 6.7460 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class
Measured	285.80	157.36	80.88	47.56
Estimated	285.80	209.08	51.64	25.08

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class
Measured	1440.85	959.90	347.78	133.17
Estimated	1567.66	1275.39	222.05	70.22

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	II ⇒ III
Areas	24.40	18.56	3.28	2.56
Tax m^3	48.07	33.41	10.82	3.84

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	III ⇒ II
Areas	85.88	57.56	16.00	12.32
Tax m^3	174.89	103.61	52.80	18.48

Appendix 5.1. Models from the tax data, tests with the tax data, June image, Pixelwise classification.

	Estimated class								
Class	OMT	OMT, stony	MT	MT, stony	VT	VT, stony	CT	VT v.stony	Total
1	418	84	170	103	176	78	9	34	1072
2	0	0	0	0	0	0	0	0	0
3	339	177	233	194	183	266	13	66	1471
4	135	161	134	175	144	274	8	138	1169
5	21	6	20	14	27	19	2	55	164
6	37	34	49	98	22	132	28	75	475
7	0	0	0	1	0	11	296	2	310
8	0	0	0	0	0	0	0	0	0
Total	950	462	606	585	552	780	356	370	4661

Class	Proportions from correct site fertility classes								
1	0.390	0.078	0.159	0.096	0.164	0.073	0.008	0.032	1.0
3	0.230	0.120	0.158	0.132	0.124	0.181	0.009	0.045	1.0
4	0.115	0.138	0.115	0.150	0.123	0.234	0.007	0.118	1.0
5	0.128	0.037	0.122	0.085	0.165	0.116	0.012	0.335	1.0
6	0.078	0.072	0.103	0.206	0.046	0.278	0.059	0.158	1.0
7	0.000	0.000	0.000	0.003	0.000	0.035	0.955	0.006	1.0

Correct site fertility class 27.4834 %
Correct tax class 48.2300 %
Gross errors 16.7132 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class	IV-class
Measured	186.44	101.72	53.32	31.40	0.00
Estimated	186.44	80.72	45.48	45.44	14.80

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class	IV-class
Measured	937.69	620.49	229.28	87.92	0.00
Estimated	837.39	492.39	195.56	127.23	22.20

Under classifications based on the image analysis (ha) and (m³):

	Total	I ⇒ II	I ⇒ III	I ⇒ IV	II ⇒ III	II ⇒ IV	III ⇒ IV
Areas	67.80	26.24	14.64	4.00	12.12	7.72	3.08
Tax m³	157.74	47.23	48.31	18.40	18.18	21.62	4.00

Over classifications based on the image analysis (ha) and (m³):

	Total	II ⇒ I	III ⇒ I	IV ⇒ I	III ⇒ II	IV ⇒ II	IV ⇒ III
Areas	28.72	19.08	4.80	0.00	4.84	0.00	0.00
Tax m³	57.44	34.34	15.84	0.00	7.26	0.00	0.00

Appendix 5.2. Models from the tax data, tests with the tax data, June image, Segmentation filtering.

	Estimated class								
Class	OMT	OMT, stony	MT	MT, stony	VT	VT, stony	CT	VT v.stony	Total
1	548	16	186	93	170	43	1	15	1072
2	0	0	0	0	0	0	0	0	0
3	477	197	159	246	185	182	3	22	1471
4	157	159	116	195	142	266	7	127	1169
5	30	0	18	16	7	39	0	54	164
6	26	22	31	78	63	160	35	60	475
7	0	0	0	0	0	8	302	0	310
8	0	0	0	0	0	0	0	0	0
Total	1238	394	510	628	567	698	348	278	4661

Class	Proportions from correct site fertility classes								
1	0.511	0.015	0.174	0.087	0.159	0.040	0.001	0.014	1.0
3	0.324	0.134	0.108	0.167	0.126	0.124	0.002	0.015	1.0
4	0.134	0.136	0.099	0.167	0.121	0.228	0.006	0.109	1.0
5	0.183	0.000	0.110	0.098	0.043	0.238	0.000	0.329	1.0
6	0.055	0.046	0.065	0.164	0.133	0.337	0.074	0.126	1.0
7	0.000	0.000	0.000	0.000	0.000	0.026	0.974	0.000	1.0

Correct site fertility class 29.4143 %
Correct tax class 52.5209 %
Gross errors 11.2851 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class	IV-class
Measured	186.44	101.72	53.32	31.40	0.00
Estimated	186.44	85.68	47.80	41.84	11.12

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class	IV-class
Measured	937.69	620.49	229.28	87.92	0.00
Estimated	862.02	522.65	205.54	117.15	16.68

Under classifications based on the image analysis (ha) and (m³):

	Total	I ⇒ II	I ⇒ III	I ⇒ IV	II ⇒ III	II ⇒ IV	III ⇒ IV
Areas	60.52	27.76	9.16	1.48	12.48	7.24	2.40
Tax m³	129.12	49.97	30.23	6.81	18.72	20.27	3.12

Over classifications based on the image analysis (ha) and (m³):

	Total	II ⇒ I	III ⇒ I	IV ⇒ I	III ⇒ II	IV ⇒ II	IV ⇒ III
Areas	28.00	19.20	3.16	0.00	5.64	0.00	0.00
Tax m³	53.45	34.56	10.43	0.00	8.46	0.00	0.00

Appendix 5.3. Models from the tax data, tests with the tax data, June image + DTM, Segmentation filtering.

Class	Estimated class OMT	OMT, stony	MT	MT, stony	VT	VT, stony	CT	VT v.stony	Total
1	754	32	233	13	0	40	0	0	1072
2	0	0	0	0	0	0	0	0	0
3	602	64	291	157	72	258	3	24	1471
4	187	96	185	163	239	219	3	77	1169
5	13	0	17	18	41	27	0	48	164
6	35	1	98	70	28	176	27	40	475
7	0	0	0	0	0	10	300	0	310
8	0	0	0	0	0	0	0	0	0
Total	1591	193	824	421	380	730	333	189	4661

Class	Proportions from correct site fertility classes								
1	0.703	0.030	0.217	0.012	0.000	0.037	0.000	0.000	1.0
3	0.409	0.044	0.198	0.107	0.049	0.175	0.002	0.016	1.0
4	0.160	0.082	0.158	0.139	0.204	0.187	0.003	0.066	1.0
5	0.079	0.000	0.104	0.110	0.250	0.165	0.000	0.293	1.0
6	0.074	0.002	0.206	0.147	0.059	0.371	0.057	0.084	1.0
7	0.000	0.000	0.000	0.000	0.000	0.032	0.968	0.000	1.0

Correct site fertility class 37.0092 %
Correct tax class 63.2911 %
Gross errors 12.5295 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class	IV-class
Measured	186.44	101.72	53.32	31.40	0.00
Estimated	186.44	104.32	32.04	42.52	7.56

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class	IV-class
Measured	937.69	620.49	229.28	87.92	0.00
Estimated	904.52	636.35	137.77	119.06	11.34

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	I ⇒ IV	II ⇒ III	II ⇒ IV	III ⇒ IV
Areas	39.24	9.68	12.04	0.96	9.96	5.00	1.60
Tax m^3	92.59	17.42	39.73	4.42	14.94	14.00	2.08

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	IV ⇒ I	III ⇒ II	IV ⇒ II	IV ⇒ III
Areas	29.20	19.92	5.36	0.00	3.92	0.00	0.00
Tax m^3	59.42	35.86	17.69	0.00	5.88	0.00	0.00

Appendix 6.1. Models from the NFI data, tests with the NFI data, June image, Pixelwise classification.

Class	Estimated class OMT	OMT, stony	MT	MT, stony	VT	VT, stony	CT	Total
1	37	4	67	13	4	6	0	131
2	7	0	14	3	0	2	0	26
3	37	6	80	32	18	25	3	201
4	7	1	21	16	10	21	2	78
5	2	0	6	17	22	19	3	69
6	3	0	7	14	17	15	2	58
7	0	0	0	0	2	2	3	7
Total	93	11	195	95	73	90	13	570

Class	Proportions from correct site fertility classes							
1	0.282	0.031	0.511	0.099	0.031	0.046	0.000	1.0
2	0.269	0.000	0.538	0.115	0.000	0.077	0.000	1.0
3	0.184	0.030	0.398	0.159	0.090	0.124	0.015	1.0
4	0.090	0.013	0.269	0.205	0.128	0.269	0.026	1.0
5	0.029	0.000	0.087	0.246	0.319	0.275	0.043	1.0
6	0.052	0.000	0.121	0.241	0.293	0.259	0.034	1.0
7	0.000	0.000	0.000	0.000	0.286	0.286	0.429	1.0

Correct site fertility class 30.3509 %
Correct tax class 59.4737 %
Gross errors 8.0702 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class
Measured	22.80	14.32	5.88	2.60
Estimated	22.80	11.96	6.72	4.12

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class
Measured	119.92	87.35	25.28	7.28
Estimated	113.39	72.96	28.90	11.54

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	II ⇒ III
Areas	6.04	2.80	1.44	1.80
Tax m^3	12.49	5.04	4.75	2.70

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	III ⇒ II
Areas	3.20	1.48	0.40	1.32
Tax m^3	5.96	2.66	1.32	1.98

Appendix 6.2. Models from the NFI data, tests with the NFI data, June image + May image, Pixelwise classification.

Class	OMT	OMT, stony	MT	Estimated class MT, stony	VT	VT, stony	CT	Total
1	22	6	60	6	2	5	0	101
2	7	0	8	1	1	1	0	18
3	26	2	99	25	14	16	2	184
4	5	1	26	14	9	8	1	64
5	1	0	17	9	21	15	2	65
6	0	1	13	6	16	13	1	50
7	0	0	0	0	1	4	2	7
Total	61	10	223	61	64	62	8	489

Class	Proportions from correct site fertility classes							
1	0.218	0.059	0.594	0.059	0.020	0.050	0.000	1.0
2	0.389	0.000	0.444	0.056	0.056	0.056	0.000	1.0
3	0.141	0.011	0.538	0.136	0.076	0.087	0.011	1.0
4	0.078	0.016	0.406	0.219	0.141	0.125	0.016	1.0
5	0.015	0.000	0.262	0.138	0.323	0.231	0.031	1.0
6	0.000	0.020	0.260	0.120	0.320	0.260	0.020	1.0
7	0.000	0.000	0.000	0.000	0.143	0.571	0.286	1.0

Correct site fertility class 34.9693 %
Correct tax class 61.9632 %
Gross errors 7.7710 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class
Measured	19.56	12.12	5.16	2.28
Estimated	19.56	11.76	5.00	2.80

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class
Measured	102.50	73.93	22.19	6.38
Estimated	101.08	71.74	21.50	7.84

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	II ⇒ III
Areas	3.96	1.96	0.96	1.04
Tax m^3	8.26	3.53	3.17	1.56

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	III ⇒ II
Areas	3.48	2.00	0.56	0.92
Tax m^3	6.83	3.60	1.85	1.38

Appendix 7.1. Peatland models and tests with the stand data of the national board of forestry, June image, Pixelwise classification.

Class	OMT	OMT, stony	MT	Estimated class MT, stony	VT	VT, stony	CT	VT v.stony	Total
1	37	56	47	14	136	7	9	16	322
2	243	282	315	106	668	102	9	151	1876
3	159	181	116	131	447	68	58	82	1242
4	44	144	51	159	336	118	10	17	879
5	100	71	51	18	324	31	1	46	642
6	99	199	103	578	666	407	178	334	2564
7	42	98	70	182	334	127	139	98	1090
8	3	19	29	270	124	100	137	502	1184
Total	727	1050	782	1458	3035	960	541	1246	9799

Class	Proportions from correct site fertility classes								
1	0.115	0.174	0.146	0.043	0.422	0.022	0.028	0.050	1.0
2	0.130	0.150	0.168	0.057	0.356	0.054	0.005	0.080	1.0
3	0.128	0.146	0.093	0.105	0.360	0.055	0.047	0.066	1.0
4	0.050	0.164	0.058	0.181	0.382	0.134	0.011	0.019	1.0
5	0.156	0.111	0.079	0.028	0.505	0.048	0.002	0.072	1.0
6	0.039	0.078	0.040	0.225	0.260	0.159	0.069	0.130	1.0
7	0.039	0.090	0.064	0.167	0.306	0.117	0.128	0.090	1.0
8	0.003	0.016	0.024	0.228	0.105	0.084	0.116	0.424	1.0

Correct site fertility class 20.0633 %
Correct tax class 32.0849 %
Gross errors 31.1358 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class	IV-class	0-class
Measured	391.96	87.92	84.84	128.24	43.60	47.36
Estimated	391.96	71.08	89.60	159.80	21.64	49.84

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class	IV-class
Measured	1325.60	536.31	364.81	359.07	65.40
Estimated	1298.77	433.59	385.28	447.44	32.46

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	I ⇒ IV	I ⇒ 0	II ⇒ III	II ⇒ IV	II ⇒ 0	III ⇒ IV	III ⇒ 0	IV ⇒ 0
Areas	134.92	19.28	36.52	0.72	6.68	38.76	2.72	3.96	7.16	15.20	3.92
Tax m^3	339.81	34.70	120.52	3.31	40.75	58.14	7.62	17.03	9.31	42.56	5.88

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	IV ⇒ I	0 ⇒ I	III ⇒ II	IV ⇒ II	0 ⇒ II	IV ⇒ III	0 ⇒ III	0 ⇒ IV
Areas	131.28	21.12	18.76	5.60	0.88	30.00	10.08	11.96	18.44	8.96	5.48
Tax m^3	312.98	38.02	61.91	25.76	5.37	45.00	28.22	51.43	23.97	25.09	8.22

Appendix 7.2. Peatland models and tests with the stand data of the national board of forestry, June image, mode filtering within stands.

Class	OMT	OMT, stony	MT	Estimated class MT, stony	VT	VT, stony	CT	VT v.stony	Total
1	0	0	0	232	263	36	0	0	322
2	182	93	191	180	965	33	0	232	1876
3	62	93	49	308	650	0	48	27	1242
4	0	0	18	166	579	116	0	0	879
5	70	0	9	0	475	8	50	30	642
6	35	11	0	1064	1056	336	0	62	2564
7	12	0	0	209	712	65	52	40	1090
8	0	0	15	348	112	0	70	639	1184
Total	361	202	282	2298	4812	594	220	1030	9799

Class	Proportions from correct site fertility classes								
1	0.000	0.000	0.000	0.071	0.817	0.112	0.000	0.000	1.0
2	0.097	0.050	0.102	0.096	0.514	0.018	0.000	0.124	1.0
3	0.050	0.079	0.039	0.248	0.523	0.000	0.039	0.022	1.0
4	0.000	0.000	0.020	0.189	0.659	0.132	0.000	0.000	1.0
5	0.109	0.000	0.014	0.000	0.740	0.012	0.078	0.047	1.0
6	0.014	0.004	0.000	0.415	0.412	0.131	0.000	0.024	1.0
7	0.011	0.000	0.000	0.192	0.653	0.060	0.048	0.037	1.0
8	0.000	0.000	0.013	0.294	0.095	0.000	0.059	0.540	1.0

Correct site fertility class	18.4713 %
Correct tax class	34.5137 %
Gross errors	25.5944 %

The areas of measured and estimated tax classes (ha):

	Total	I-class	II-class	III-class	IV-class	0-class
Measured	391.96	87.92	84.84	128.24	43.60	47.36
Estimated	391.96	22.52	103.20	216.24	8.80	41.20

The measured and estimated tax cubic metres:

	Total	I-class	II-class	III-class	IV-class
Measured	1325.60	536.31	364.81	359.07	65.40
Estimated	1199.80	137.37	443.76	605.47	13.20

Under classifications based on the image analysis (ha) and (m^3):

	Total	I ⇒ II	I ⇒ III	I ⇒ IV	I ⇒ 0	II ⇒ III	II ⇒ IV	II ⇒ 0	III ⇒ IV	III ⇒ 0	IV ⇒ 0
Areas	141.00	15.76	51.88	0.00	9.28	53.80	1.92	1.08	2.00	3.68	1.60
Tax m^3	362.20	28.37	171.20	0.00	56.61	80.70	5.38	4.64	2.60	10.30	2.40

Over classifications based on the image analysis (ha) and (m^3):

	Total	II ⇒ I	III ⇒ I	IV ⇒ I	0 ⇒ I	III ⇒ II	IV ⇒ II	0 ⇒ II	IV ⇒ III	0 ⇒ III	0 ⇒ IV
Areas	115.68	6.40	4.64	0.48	0.00	42.92	8.36	14.52	31.08	4.48	2.80
Tax m^3	236.41	11.52	15.31	2.21	0.00	64.38	23.41	62.44	40.40	12.54	4.20

Appendix 8.1. Models from the NFI data, June image + DTM, Pixelwise classification. The estimated numbers of pixels in site fertility classes.

Area	OMT	OMT, stony	MT	Class MT, stony	VT	VT, stony	CT	Total
1	1080	92	3143	1476	504	812	33	7140
2	614	67	1886	1237	1526	566	24	5920
3	1286	99	1473	514	337	184	13	3906
4	1196	42	2027	752	404	251	1	4673
Total	4176	300	8529	3979	2771	1813	71	21639

The estimated areas of tax classes (ha):

Area	Total	I-class	II-class	III-class
1	285.60	172.60	79.20	33.80
2	236.80	102.68	110.52	23.60
3	156.24	114.32	34.04	7.88
4	186.92	130.60	46.24	10.08
Total	865.56	520.20	270.00	75.36

The estimated amounts of tax cubic metres (m^3):

Area	Total	I-class	II-class	III-class
1	1488.06	1052.86	340.56	94.64
2	1167.66	626.35	475.24	66.08
3	865.79	697.35	146.37	22.06
4	1023.72	796.66	198.83	28.22
Total	4545.23	3173.22	1161.00	211.01

Appendix 8.2. Models from the NFI data, June image + DTM, Segmentation filtering. The estimated numbers of pixels in site fertility classes.

Area	OMT	OMT, stony	MT	Class MT, stony	VT	VT, stony	CT	Total
1	744	116	4462	1225	334	248	11	7140
2	302	0	2476	1138	1836	164	4	5920
3	1583	45	1664	376	167	37	34	3906
4	994	17	2815	480	314	53	0	4673
Total	3623	178	11417	3219	2651	502	49	21639

The estimated areas of tax classes (ha):

Area	Total	I-class	II-class	III-class
1	285.60	212.88	62.36	10.36
2	236.80	111.12	118.96	6.72
3	156.24	131.68	21.72	2.84
4	186.92	153.04	31.76	2.12
Total	865.56	608.72	234.80	22.04

The estimated amounts of tax cubic metres (m^3):

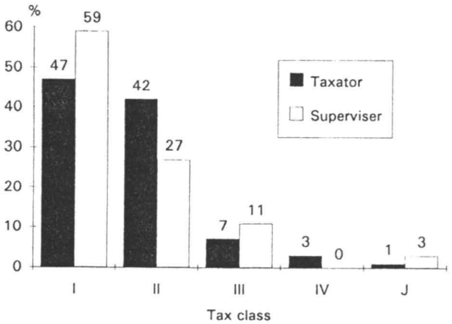
Area	Total	I-class	II-class	III-class
1	1595.72	1298.57	268.15	29.01
2	1208.18	677.83	511.53	18.82
3	904.60	803.25	93.40	7.95
4	1076.05	933.54	136.57	5.94
Total	4784.54	3713.19	1009.64	61.71

Appendix 9. An example of the output of the VELI program.
Results of the check of the field work Area 1 4.7.1989
Taxator: Harri Kiesilä Superviser: Lasse Lovén
Tax cubic metres: Orivesi I = 6.1 II = 4.3 III = 2.8 IV = 1.5

I. The lengths of lines

Line	Length	Forest land	Swamp (m)
1	350	350	270
2	740	740	120
3	1190	1190	70
4	1390	1390	40
5	1530	1530	40
6	1310	1310	110
7	1570	1471	0
8	1140	1120	69
9	700	180	20

II. The distribution of tax classes in the area



III. The means of tax cubic metres

Line	Taxator	Superviser	Index (%)
1	2.1	3.1	69
2	4.5	4.9	93
3	5.0	5.0	101
4	4.8	5.5	88
5	5.2	5.4	98
6	4.5	5.0	90
7	5.2	5.0	103
8	5.9	5.0	118
9	6.1	5.9	103
All	5.0	5.1	98
Swamps	3.3	4.0	82
Mineral soils	5.0	5.2	98

IV. Within stands variation (the variation coefficient %)

Line	II	III	All together
1	0	13	29
2	21	106	31
3	25	67	26
4	20	0	19
5	11	23	15
6	11	40	13
7	24	21	20
8	16	0	29
9	0	0	10
All	8	0	20
Swamps	19	51	21
Area	18	48	21

V. Differencies on the line segments (%)

Line	Diff = 0 CL	Diff = 1 CL	Diff > 1 CL
1	14	86	0
2	43	43	14
3	54	36	10
4	42	53	4
5	57	40	3
6	53	37	9
7	62	34	4
8	68	20	12
9	88	12	0
Area	54	39	7

VI. The list of gross errors

Line	Start	End	Superviser	Taxator
2	20	24	J JK	III VTK
3	47	53	III K	I MT
6	24	30	I OMT	III MTK
8	0	4	J TIE	I MT
9	61	65	III MTK	I MT

Appendix 10.1. Pairwise tests for predicted cell means, taxation level.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	—0.4279	0.0000						
2 3	—0.1126	0.3344	0.0000					
2 4	1.3888	1.8918	1.5765	0.0000				
3 3	—0.4729	—0.0478	—0.3822	—1.9368	0.0000			
3 4	0.3739	0.8220	0.5067	—1.0149	0.8671	0.0000		
4 3	0.6410	1.1035	0.7882	—0.7478	1.1486	0.2671	0.0000	
4 4	0.0225	0.4777	0.1433	—1.4414	0.5255	—0.3716	—0.6531	0.0000
1 1	—0.9193	—0.4689	—0.8551	—2.5792	—0.4137	—1.3662	—1.6854	—1.0206
2 1	2.4999	3.1054	2.7709	1.0360	3.1531	2.1057	1.8242	2.6276
3 1	0.2027	0.6688	0.3344	—1.2612	0.7166	—0.1914	—0.4729	0.1911
4 1	3.6773	4.4960	4.1098	2.0174	4.5512	3.2304	2.9112	3.9443
1 2	—0.7661	—0.3034	—0.6896	—2.4260	—0.2482	—1.2130	—1.5322	—0.8551
2 2	1.5990	2.1499	1.8154	0.1351	2.1976	1.2049	0.9234	1.6721
3 2	—0.1576	0.2866	—0.0478	—1.6215	0.3344	—0.5518	—0.8333	—0.1911
4 2	1.6599	2.3170	1.9308	0.0000	2.3721	1.2130	0.8938	1.7653

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	4.0547	0.0000						
3 1	1.2412	—2.4365	0.0000					
4 1	6.0807	0.9102	3.7237	0.0000				
1 2	0.2027	—3.8892	—1.0757	—5.8780	0.0000			
2 2	2.9514	—0.9555	1.4810	—2.0135	2.7859	0.0000		
3 2	0.7999	—2.8187	—0.3822	—4.1650	0.6344	—1.8632	0.0000	
4 2	3.4120	—1.2688	1.5446	—2.6688	3.2093	—0.1655	1.9860	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1 = Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 10.2. Pairwise tests for predicted cell means, taxation level on mineral soils.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	—0.4567	0.0000						
2 3	2.0658	2.6755	0.0000					
2 4	2.5271	3.1205	0.5980	0.0000				
3 3	—0.0217	0.4613	—2.2142	—2.6855	0.0000			
3 4	0.5157	1.0003	—1.5222	—2.0114	0.5654	0.0000		
4 3	1.1346	1.6526	—0.8698	—1.3925	1.2177	0.6189	0.0000	
4 4	0.4567	0.9687	—1.7068	—2.2071	0.5074	—0.0870	—0.7393	0.0000
1 1	—1.4794	—1.0387	—4.1280	—4.4999	—1.5713	—2.0958	—2.8355	—2.1572
2 1	2.1093	2.7216	0.0461	—0.5545	2.2603	1.5657	0.9133	1.7529
3 1	—0.5001	—0.0461	—2.7216	—3.1639	—0.5074	—1.0438	—1.6961	—1.0148
4 1	3.0081	3.8084	0.7191	—0.0123	3.2758	2.3917	1.6520	2.6899
1 2	—1.2328	—0.7723	—3.8617	—4.2533	—1.3050	—1.8493	—2.5890	—1.8909
2 2	1.8483	2.4448	—0.2306	—0.8154	1.9835	1.3047	0.6524	1.4761
3 2	—0.8481	—0.4152	—3.0906	—3.5119	—0.8764	—1.3917	—2.0441	—1.3839
4 2	1.2082	1.8643	—1.2251	—1.8123	1.3316	0.5918	—0.1479	0.7457

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	4.1813	0.0000						
3 1	0.9854	—2.7677	0.0000					
4 1	5.9365	0.6658	3.8617	0.0000				
1 2	0.3262	—3.9150	—0.7191	—5.6103	0.0000			
2 2	3.8617	—0.2768	2.4909	—0.9854	3.5954	0.0000		
3 2	0.5593	—3.1368	—0.3690	—4.2878	0.2930	—2.8600	0.0000	
4 2	3.5554	—1.2784	1.9175	—2.3811	3.2292	—0.9588	2.3436	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1 = Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 10.3. Pairwise tests for predicted cell means, mean deviance on mineral soils.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	0.0000	0.0000						
2 3	1.6883	1.7907	0.0000					
2 4	3.2701	3.4470	1.7587	0.0000				
3 3	−0.5628	−0.5969	−2.3877	−4.0098	0.0000			
3 4	−0.2669	−0.2814	−1.9697	−3.5371	0.2814	0.0000		
4 3	1.4682	1.5476	−0.1407	−1.8019	2.1104	1.7352	0.0000	
4 4	−0.3939	−0.4178	−2.2086	−3.8410	0.1791	−0.1126	−1.9416	0.0000
1 1	0.2872	0.3102	−1.7576	−3.6214	0.9994	0.6062	−1.4677	0.7926
2 1	1.7446	1.8504	0.0597	−1.7024	2.4474	2.0260	0.1970	2.2683
3 1	−0.6191	−0.6566	−2.4474	−4.0661	−0.0597	−0.3377	−2.1667	−0.2388
4 1	2.7759	2.9983	0.9305	−1.1327	3.6875	3.0949	1.0210	3.4808
1 2	0.0319	0.0345	−2.0333	−3.8766	0.7237	0.3510	−1.7229	0.5169
2 2	1.4069	1.4923	−0.2985	−2.0401	2.0892	1.6883	−0.1407	1.9101
3 2	−0.1688	−0.1791	−1.9698	−3.6158	0.4178	0.1126	−1.7165	0.2388
4 2	0.8934	0.9650	−1.1028	−3.0152	1.6542	1.2124	−0.8615	1.4474

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	1.8265	0.0000						
3 1	−1.0684	−2.5070	0.0000					
4 1	3.2922	0.8616	3.7565	0.0000				
1 2	−0.3377	−2.1022	0.7926	−3.6299	0.0000			
2 2	1.4130	−0.3581	2.1489	−1.2751	1.6887	0.0000		
3 2	−0.5169	−2.0295	0.4775	−3.2051	−0.2412	−1.6714	0.0000	
4 2	0.8020	−1.1717	1.7231	−2.4903	1.1396	−0.7582	1.1717	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1 = Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 10.4. Pairwise tests for predicted cell means, proportion of correctly taxed.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	−1.0777	0.0000						
2 3	−2.4218	−1.3950	0.0000					
2 4	−2.8527	−1.9522	−0.6137	0.0000				
3 3	4.3533	5.7569	7.2684	7.3572	0.0000			
3 4	4.7206	6.0576	7.3687	7.6758	0.6253	0.0000		
4 3	−0.7950	0.2510	1.5674	2.0683	−5.2393	−5.5051	0.0000	
4 4	−0.4264	0.7021	2.0858	2.5822	−5.0660	−5.4669	0.4004	0.0000
1 1	−2.5115	−1.3927	0.2180	0.8977	−8.0396	−8.1531	−1.5741	−2.1904
2 1	−3.0206	−2.0602	−0.6647	−0.0128	−7.8193	−7.9979	−2.1935	−2.7513
3 1	3.1615	4.4965	5.8921	6.1693	−1.2625	−1.8159	3.9885	3.8054
4 1	−2.0338	−0.8767	0.7339	1.3754	−7.5236	−7.6754	−1.0964	−1.6744
1 2	−1.8678	−0.6975	0.9132	1.5414	−7.3444	−7.5094	−0.9304	−1.4951
2 2	−2.4920	−1.4996	−0.1041	0.5158	−7.2587	−7.4694	−1.6650	−2.1907
3 2	3.7457	5.1162	6.5117	6.7535	−0.6428	−1.2316	4.5728	4.4251
4 2	−0.3579	0.9332	2.5438	3.0513	−5.7137	−5.9995	0.5795	0.1355

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	−1.0031	0.0000						
3 1	6.7023	6.7310	0.0000					
4 1	0.6404	1.5284	−6.1769	0.0000				
1 2	0.8513	1.6812	−5.8902	0.2195	0.0000			
2 2	−0.3383	0.5608	−5.9984	−0.8545	−1.0522	0.0000		
3 2	7.3013	7.1791	0.6199	6.7851	6.7226	6.7916	0.0000	
4 2	2.8481	3.3127	−4.2587	2.2163	2.0238	2.7125	−5.0623	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1 = Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 10.5. Pairwise tests for predixted cell means, at most one class error.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	−0.3759	0.0000						
2 3	−3.3776	−3.0523	0.0000					
2 4	−2.3515	−2.1800	0.7785	0.0000				
3 3	−0.0507	0.3450	3.5712	2.4269	0.0000			
3 4	0.6683	1.0865	3.9598	3.1473	0.7544	0.0000		
4 3	−1.1804	−0.8173	2.0753	1.2189	−1.1856	−1.8009	0.0000	
4 4	−0.6834	−0.3426	2.7263	1.8049	−0.6709	−1.4393	0.5098	0.0000
1 1	−0.8218	−0.4271	3.0946	1.9858	−0.8251	−1.6197	0.5305	−0.0510
2 1	−3.0412	−2.8248	0.2368	−0.5573	−3.1708	−3.7472	−1.8449	−2.4979
3 1	−0.3002	0.0813	3.1429	2.1838	−0.2647	−1.0061	0.8962	0.4082
4 1	−2.1345	−1.8433	1.6784	0.6732	−2.2414	−2.9324	−0.7822	−1.4673
1 2	−0.7829	−0.3851	3.1366	2.0247	−0.7831	−1.5808	0.5694	−0.0090
2 2	−2.7769	−2.5445	0.5171	−0.2929	−2.8905	−3.4828	−1.5805	−2.2176
3 2	0.4409	0.8670	3.9286	2.9249	0.5210	−0.2650	1.6373	1.1939
4 2	−0.0707	0.3834	3.9051	2.7370	−0.0147	−0.8686	1.2816	0.7594

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	−2.9849	0.0000						
3 1	0.5506	3.1384	0.0000					
4 1	−1.8051	1.4870	−2.0485	0.0000				
1 2	0.0513	2.8759	−0.4806	1.7832	0.0000			
2 2	−2.5100	0.2812	−2.6339	−1.0880	−2.6883	0.0000		
3 2	1.4302	3.7031	0.7881	2.8522	1.4621	3.6842	0.0000	
4 2	0.9910	3.6474	0.2910	2.7229	0.9794	3.5011	−0.6494	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1 = Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 10.6. Pairwise tests for predicted cell means, gross errors.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	0.0331	0.0000						
2 3	3.1373	3.1656	0.0000					
2 4	2.5585	2.7653	−0.3250	0.0000				
3 3	0.0352	0.0019	−3.3318	−2.6602	0.0000			
3 4	−0.9929	−1.0862	−4.0660	−3.7068	−1.0808	0.0000		
4 3	1.0504	1.0270	−1.9729	−1.5521	1.0650	1.9993	0.0000	
4 4	0.5142	0.5369	−2.6557	−2.1953	0.5079	1.6207	−0.5459	0.0000
1 1	0.4592	0.4549	−3.1973	−2.5953	0.4527	1.6446	−0.7423	−0.1333
2 1	2.9262	3.0670	−0.1088	0.2233	3.0651	3.9751	1.8630	2.5555
3 1	0.0429	0.0103	−3.1656	−2.6600	0.0084	1.0919	−1.0203	−0.5012
4 1	1.9286	2.0402	−1.6120	−1.1259	2.0380	3.1140	0.7271	1.4520
1 2	0.5654	0.5695	−3.0827	−2.4890	0.5673	1.7508	−0.6360	−0.0187
2 2	2.7970	2.9301	−0.2458	0.0941	2.9282	3.8459	1.7338	2.4186
3 2	−0.5668	−0.6361	−3.8120	−3.2697	−0.6380	0.4822	−1.6300	−1.1476
4 2	−0.1513	−0.2037	−3.8559	−3.2057	−0.2059	1.0341	−1.3527	−0.7919

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	3.2559	0.0000						
3 1	−0.4696	−3.3097	0.0000					
4 1	2.0233	−1.5758	2.1497	0.0000				
1 2	0.1401	−2.9703	0.5601	−1.7982	0.0000			
2 2	2.9273	−0.1374	2.9294	1.3352	2.9676	0.0000		
3 2	−1.1916	−3.7152	−0.6485	−2.7837	−1.3789	−3.8613	0.0000	
4 2	−0.8053	−3.7469	−0.2165	−2.7436	−0.9869	−3.7871	0.5594	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1 = Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 10.7. Pairwise tests for predicted cell means, within stands variation.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	—0.0553	0.0000						
2 3	5.6388	5.9991	0.0000					
2 4	6.4256	6.8285	0.7868	0.0000				
3 3	—2.8199	—2.9323	—8.7637	—9.5931	0.0000			
3 4	—1.9670	—2.0181	—7.6059	—8.3927	0.7464	0.0000		
4 3	2.2293	2.4052	—3.4095	—4.1963	5.1698	4.1963	0.0000	
4 4	2.6227	2.8199	—3.0161	—3.8029	5.5844	4.5897	0.3934	0.0000
1 1	1.2871	1.4476	—5.2241	—6.1326	4.7007	3.5584	—1.2871	—1.7414
2 1	8.1748	8.6002	2.9543	2.2258	11.1396	9.9959	6.1109	5.7466
3 1	0.6082	0.7037	—5.3356	—6.1650	3.6360	2.6816	—1.7417	—2.1564
4 1	4.6978	5.1277	—1.9374	—2.8632	8.4526	7.0124	2.0746	1.6116
1 2	1.3793	1.5575	—5.3604	—6.3008	4.9434	3.7303	—1.2852	—1.7555
2 2	7.3538	7.8585	1.4099	0.5806	10.7908	9.4272	5.0039	4.5892
3 2	—0.9400	—0.9383	—6.8838	—7.7132	1.9940	1.1335	—3.2898	—3.7045
4 2	4.0125	4.4017	—2.7272	—3.6676	7.7876	6.3635	1.3479	0.8777

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	8.0582	0.0000						
3 1	—0.6669	—7.9907	0.0000					
4 1	4.1877	—5.1309	4.3297	0.0000				
1 2	0.0586	—8.2451	0.7449	—4.3681	0.0000			
2 2	7.2706	—1.7945	7.1548	3.7830	7.5167	0.0000		
3 2	—2.4886	—9.4128	—1.6421	—6.1917	—2.6410	—8.7968	0.0000	
4 2	3.3428	—5.8786	3.5891	—0.9777	3.4834	—4.6725	5.4852	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1 = Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 10.8. Pairwise tests for predicted cell means, within stands variation on mineral soils.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	0.0171	0.0000						
2 3	3.3882	3.5602	0.0000					
2 4	6.5209	7.4839	0.9567	0.0000				
3 3	—2.7094	—3.1473	—5.4203	—10.3733	0.0000			
3 4	—1.7305	—1.9897	—4.6821	—9.0188	0.9787	0.0000		
4 3	3.6610	4.0941	—1.0312	—3.1420	7.1355	5.7711	0.0000	
4 4	4.4084	5.0801	—0.4869	—2.2830	7.9679	6.6702	0.8601	0.0000
1 1	1.1190	1.3070	—2.9746	—6.8963	4.7985	3.3956	—3.2681	—4.2613
3 1	0.7142	0.8051	—3.0956	—6.6487	3.9532	2.7484	—3.3359	—4.2428
4 1	4.6749	5.5652	—0.7537	—3.1010	9.1331	7.3861	0.5959	—0.4161
2 1	7.7788	8.4742	2.6010	2.4436	10.8561	9.7288	5.0117	4.3087
1 2	1.3670	1.6202	—2.8721	—6.8975	5.2540	3.7553	—3.1420	—4.1700
2 2	7.1508	8.1241	1.3855	0.6779	11.0926	9.5949	3.8212	2.9607
3 2	—0.8363	—0.9855	—4.1297	—8.3375	2.1630	1.0604	—5.0245	—5.9314
4 2	4.1216	4.9308	—1.1424	—3.8320	8.5643	6.8206	—0.0767	—1.1047

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
3 1	—0.4201	0.0000						
4 1	4.9089	4.7320	0.0000					
2 1	8.0992	7.9685	5.1372	0.0000				
1 2	0.3001	0.6911	—4.8241	—8.0076	0.0000			
2 2	7.6830	7.3665	3.9005	—1.8903	7.8142	0.0000		
3 2	—2.4009	—1.7911	—6.6851	—9.2217	—2.8018	—9.2406	0.0000	
4 2	4.1229	4.0028	—0.8780	—5.6632	4.1023	—4.7062	6.1653	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1 = Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 11.1. Pairwise tests for predicted cell means, taxation level.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	—0.9885	0.0000						
2 3	—0.1074	0.9538	0.0000					
2 4	0.8593	2.0544	1.0441	0.0000				
3 3	—1.0334	—0.0519	—1.0028	—2.1034	0.0000			
3 4	—0.1611	0.8927	—0.0580	—1.1021	0.9416	0.0000		
4 3	0.3595	1.2550	0.4736	—0.3789	1.2942	0.5210	0.0000	
4 4	—0.5392	0.5188	—0.4647	—1.5653	0.5707	—0.4036	—0.8628	0.0000
1 1	—1.5624	—0.6084	—1.5893	—2.7672	—0.5524	—1.5238	—1.7539	—1.1688
2 1	1.4736	2.6360	1.6827	0.7160	2.6809	1.7364	0.9585	2.1867
3 1	0.0000	0.9885	0.1074	—0.8593	1.0334	0.1611	—0.3595	0.5392
4 1	1.9335	3.4501	2.2452	1.1014	3.5042	2.3087	1.2726	2.9082
1 2	—1.0869	—0.0480	—1.0657	—2.2437	0.0080	—1.0003	—1.3447	—0.6084
2 2	0.6028	1.6625	0.7518	—0.2148	1.7074	0.8055	0.1797	1.2131
3 2	—0.4019	0.5392	—0.3222	—1.2889	0.5841	—0.2685	—0.7189	0.0899
4 2	0.3094	1.5534	0.4660	—0.6778	1.6076	0.5295	—0.1340	1.0115

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	3.3059	0.0000						
3 1	1.5624	—1.4736	0.0000					
4 1	4.3954	0.2320	1.9335	0.0000				
1 2	0.6139	—2.8304	—1.0869	—3.8056	0.0000			
2 2	2.2757	—0.8707	0.6028	—1.2375	1.8001	0.0000		
3 2	1.0869	—1.8754	—0.4019	—2.3976	0.6114	—1.0047	0.0000	
4 2	2.3311	—1.3922	0.3094	—1.9892	1.7413	—0.3867	0.7734	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1=Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 11.2. Pairwise tests for predicted cell means, taxation level on mineral soils.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	—1.0403	0.0000						
2 3	1.5963	2.9499	0.0000					
2 4	1.8987	3.2943	0.3267	0.0000				
3 3	—0.6186	0.4870	—2.4908	—2.8352	0.0000			
3 4	—0.0672	1.0560	—1.7967	—2.1234	0.5969	0.0000		
4 3	0.5342	1.4909	—0.8447	—1.1114	1.1228	0.6224	0.0000	
4 4	—0.1546	1.0227	—1.9858	—2.3301	0.5357	—0.0918	—0.7178	0.0000
1 1	—2.0829	—1.1572	—4.2383	—4.6068	—1.6832	—2.2113	—2.4009	—2.2618
2 1	1.3203	2.5164	—0.1848	—0.4873	2.0947	1.4786	0.6467	1.6307
3 1	—0.6916	0.2671	—2.3356	—2.6380	—0.1546	—0.6721	—1.1528	—0.6186
4 1	1.1978	2.6534	—0.5766	—0.9344	2.1448	1.3917	0.4401	1.5853
1 2	—1.5090	—0.4809	—3.6065	—3.9750	—1.0069	—1.5795	—1.9070	—1.5855
2 2	0.8802	2.0244	—0.6553	—0.9578	1.6026	1.0082	0.2530	1.1387
3 2	—1.0059	—0.0843	—2.6716	—2.9741	—0.5061	—1.0082	—1.4339	—0.9700
4 2	—0.0363	1.2123	—1.9285	—2.2863	0.7036	0.0398	—0.6287	0.1441

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	3.6450	0.0000						
3 1	1.2646	—2.0118	0.0000					
4 1	4.1059	—0.3267	1.9964	0.0000				
1 2	0.7408	—3.0712	—0.6907	—3.3941	0.0000			
2 2	3.1243	—0.4401	1.5717	—0.1815	2.5505	0.0000		
3 2	0.8927	—2.3262	—0.3143	—2.3594	0.3188	—1.8861	0.0000	
4 2	2.5374	—1.5608	0.7623	—1.5115	1.8256	—1.0526	1.1252	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1=Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 11.3. Pairwise tests for predicted cell means, mean deviance on mineral soils.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	0.1860	0.0000						
2 3	2.1118	2.2019	0.0000					
2 4	3.4455	3.7204	1.4406	0.0000				
3 3	−0.3720	−0.6443	−2.8093	−4.3279	0.0000			
3 4	−0.0889	−0.3037	−2.3770	−3.8176	0.3037	0.0000		
4 3	0.7067	0.6088	−1.1174	−2.2937	1.0958	0.8234	0.0000	
4 4	−0.2046	−0.4510	−2.6271	−4.1456	0.1933	−0.1215	−0.9497	0.0000
1 1	0.7873	0.6959	−1.7065	−3.3317	1.3918	0.9751	−0.1271	1.1830
2 1	1.7467	1.7668	−0.2445	−1.5783	2.3248	1.9562	0.8555	2.1574
3 1	−0.5822	−0.8369	−2.7342	−4.0680	−0.2790	−0.5335	−1.2275	−0.4464
4 1	1.5847	1.6262	−0.7628	−2.3409	2.2991	1.8411	0.5822	2.0972
1 2	0.1125	−0.0994	−2.4495	−4.0747	0.5965	0.2322	−0.7079	0.3877
2 2	1.1644	1.1159	−0.8669	−2.2007	1.6738	1.3338	0.3348	1.5065
3 2	−0.4990	−0.7439	−2.6453	−3.9790	−0.1860	−0.4446	−1.1531	−0.3534
4 2	0.3361	0.1682	−2.1305	−3.7086	0.8411	0.4734	−0.4990	0.6393

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	1.2794	0.0000						
3 1	−1.4762	−2.3289	0.0000					
4 1	1.0376	−0.4322	2.2570	0.0000				
1 2	−0.8712	−1.9542	0.8014	−1.8746	0.0000			
2 2	0.5905	−0.5822	1.7467	−0.2401	1.2653	0.0000		
3 2	−1.3778	−2.2457	0.0832	−2.1609	−0.7030	−1.6635	0.0000	
4 2	−0.5493	−1.6807	1.0084	−1.5291	0.2877	−1.0084	0.9124	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1=Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 11.4. Pairwise tests for predicted cell means, proportion of correctly taxed.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	−1.5192	0.0000						
2 3	−2.8955	−1.6427	0.0000					
2 4	−3.4844	−2.3132	−0.6361	0.0000				
3 3	4.5166	6.9695	8.2137	8.8842	0.0000			
3 4	4.9812	7.3252	8.5078	9.1439	0.7543	0.0000		
4 3	0.7801	2.1773	3.3759	3.8953	−3.0912	−3.5707	0.0000	
4 4	−0.7801	0.8534	2.4473	3.1178	−6.1161	−6.5206	−1.5322	0.0000
1 1	−3.0417	−1.6899	0.1794	0.8970	−9.2179	−9.4186	−3.5061	−2.6117
2 1	−2.7544	−1.5603	−0.0491	0.5398	−7.5960	−7.9257	−3.2437	−2.2993
3 1	4.4070	6.4464	7.6067	8.1957	0.4106	−0.2699	3.1616	5.7073
4 1	−1.8553	−0.3343	1.3936	2.0904	−7.6137	−7.9262	−2.4789	−1.2256
1 2	−1.8313	−0.2634	1.5121	2.2297	−7.7913	−8.0859	−2.4643	−1.1852
2 2	−2.4789	−1.2523	0.2454	0.8343	−7.2881	−7.6313	−2.9974	−1.9914
3 2	4.5906	6.6517	7.8030	8.3920	0.6159	−0.0736	3.3258	5.9126
4 2	−0.3711	1.3989	3.0195	3.7163	−5.8805	−6.3003	−1.1936	0.5076

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	−0.2173	0.0000						
3 1	8.2562	7.1614	0.0000					
4 1	1.4148	1.3252	−6.9440	0.0000				
1 2	1.5627	1.4278	−7.0457	0.0866	0.0000			
2 2	0.1086	0.2754	−6.8859	−1.0071	−1.1019	0.0000		
3 2	8.4734	7.3450	0.1836	7.1561	7.2629	7.0695	0.0000	
4 2	3.3012	2.8094	−5.4598	1.8178	1.7998	2.4914	−5.6718	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1=Kauko, 2=Kauko2, 3=Base and 4=Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 11.5. Pairwise tests for predicted cell means, at most one class error.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	−0.1623	0.0000						
2 3	−2.6176	−2.6476	0.0000					
2 4	−2.2335	−2.5812	0.2715	0.0000				
3 3	−0.0064	0.1795	3.0578	2.5301	0.0000			
3 4	0.6881	0.9903	3.4324	3.4874	0.7885	0.0000		
4 3	0.8701	1.0262	3.1116	2.8459	0.9355	0.2402	0.0000	
4 4	−0.5403	−0.4906	2.2355	2.0135	−0.6145	−1.4984	−1.3604	0.0000
1 1	−0.3173	−0.1720	2.6641	2.3663	−0.3643	−1.1877	−1.1974	0.2979
2 1	−2.0128	−2.0930	0.3573	0.1035	−2.2449	−2.8601	−2.6309	−1.7090
3 1	−0.4194	−0.3056	2.0657	1.8152	−0.4627	−1.1485	−1.1937	0.0784
4 1	−1.0774	−1.0620	1.7421	1.4507	−1.2442	−1.9959	−1.8489	−0.6081
1 2	−0.4376	−0.3136	2.5315	2.2334	−0.5053	−1.3206	−1.3024	0.1563
2 2	−1.7092	−1.7524	0.6829	0.4297	−1.9053	−2.5340	−2.3571	−1.3684
3 2	0.2384	0.4322	2.7708	2.5217	0.2730	−0.4420	−0.6005	0.8162
4 2	0.2968	0.5411	3.2485	2.9611	0.3524	−0.4855	−0.6419	0.9949

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	−2.2127	0.0000						
3 1	−0.1870	1.8793	0.0000					
4 1	−1.0307	1.3799	−0.6849	0.0000				
1 2	−0.1543	1.9421	0.0522	0.8221	0.0000			
2 2	−1.7044	0.3075	−1.3064	−0.8796	−1.6956	0.0000		
3 2	0.6056	2.2801	0.6662	1.3707	0.7802	2.2969	0.0000	
4 2	0.7659	2.6276	0.7863	1.6717	0.9710	2.5533	0.0295	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1=Kauko, 2=Kauko2, 3=Base and 4=Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 11.6. Pairwise tests for predicted cell means, gross errors.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	−0.0960	0.0000						
2 3	2.3744	2.6893	0.0000					
2 4	2.4661	3.1326	0.2096	0.0000				
3 3	0.0276	0.1421	−2.7369	−2.7733	0.0000			
3 4	−1.0375	−1.1008	−3.5797	−4.1138	−1.2091	0.0000		
4 3	−0.9114	−0.8506	−2.9538	−3.0974	−1.0021	0.0183	0.0000	
4 4	0.3759	0.6009	−2.1751	−2.4518	0.4013	1.7115	1.2664	0.0000
1 1	−0.0803	0.0248	−2.8488	−3.0906	−0.1283	1.1742	0.9054	−0.5623
2 1	2.0758	2.4240	−0.0699	−0.2659	2.2941	3.2761	2.7304	1.9465
3 1	0.1369	0.2506	−2.1472	−2.3462	0.1255	1.1958	0.9855	−0.2268
4 1	0.8839	1.1469	−1.7088	−1.9410	0.9955	2.1957	1.7303	0.5797
1 2	0.3128	0.4880	−2.4156	−2.6565	0.3333	1.6083	1.2474	−0.0992
2 2	1.7662	2.0768	−0.4017	−0.5982	1.9478	2.9438	2.4517	1.5994
3 2	−0.3490	−0.2941	−2.6678	−2.8676	−0.4180	0.6744	0.5482	−0.7715
4 2	−0.5289	−0.5019	−3.2574	−3.4926	−0.6482	0.6440	0.4939	−1.0690

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	2.6959	0.0000						
3 1	0.2585	−2.2334	0.0000					
4 1	1.2806	−1.6572	0.8123	0.0000				
1 2	0.5055	−2.1442	0.1546	−0.7326	0.0000			
2 2	2.1754	−0.3127	1.6450	1.1455	1.8842	0.0000		
3 2	−0.3324	−2.4484	−0.4907	−1.2984	−0.7748	−2.4365	0.0000	
4 2	−0.5703	−2.9341	−0.6939	−1.7218	−1.1100	−2.8400	−0.1460	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1=Kauko, 2=Kauko2, 3=Base and 4=Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 11.7. Pairwise tests for predicted cell means, within stands variation.

	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	—0.2874	0.0000						
2 3	5.1408	6.0350	0.0000					
2 4	5.3813	6.4397	—0.1145	0.0000				
3 3	—2.6822	—2.7653	—8.4299	—9.0469	0.0000			
3 4	—1.9464	—1.9032	—7.4422	—7.9148	0.7039	0.0000		
4 3	1.1495	1.5051	—3.4486	—3.5341	3.5955	2.9283	0.0000	
4 4	2.0609	2.6593	—3.4349	—3.5864	5.2665	4.3284	0.6059	0.0000
1 1	0.9894	1.5019	—4.9468	—5.2834	4.3902	3.3868	—0.4284	—1.3547
2 1	6.7056	7.5672	2.1075	2.3224	9.6576	8.7849	5.0720	5.2507
3 1	0.9996	1.4050	—4.1412	—4.3127	3.7998	3.0151	—0.2555	—0.9923
4 1	3.1612	3.9821	—2.5864	—2.6854	6.7474	5.6576	1.5051	1.0950
1 2	1.2310	1.8092	—4.8517	—5.2020	4.7961	3.7271	—0.2493	—1.1560
2 2	5.4264	6.3543	0.2856	0.4198	8.7492	7.7475	3.7040	3.7402
3 2	—0.8568	—0.6706	—5.9976	—6.2973	1.7243	1.0305	—1.9159	—2.9769
4 2	2.8856	3.7163	—3.0505	—3.2062	6.6046	5.4641	1.2138	0.7225

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
2 1	6.6403	0.0000						
3 1	0.1649	—5.8115	0.0000					
4 1	2.6572	—4.5571	2.0436	0.0000				
1 2	0.2695	—6.5751	0.0483	—2.4919	0.0000			
2 2	5.2766	—1.8520	4.4268	2.9057	5.1896	0.0000		
3 2	—1.9787	—7.4719	—1.8564	—4.1191	—2.2448	—6.2832	0.0000	
4 2	2.3224	—4.9980	1.7314	—0.4429	2.1407	—3.3803	3.8750	0.0000

The first figure both in the line and column indicates the area and the second figure the method
1=Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

Appendix 11.8. Pairwise tests for predicted cell means, within stands variation on mineral soils.

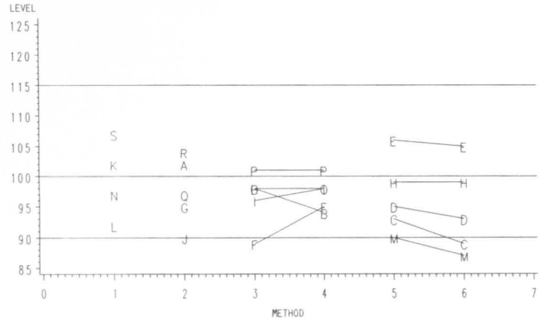
	1 3	1 4	2 3	2 4	3 3	3 4	4 3	4 4
1 3	0.0000							
1 4	0.0324	0.0000						
2 3	3.2295	3.3826	0.0000					
2 4	6.2506	7.1077	0.9348	0.0000				
3 3	—2.5890	—3.0268	—5.1445	—9.9352	0.0000			
3 4	—1.6662	—1.9324	—4.4737	—8.5869	0.9215	0.0000		
4 3	2.4067	2.5891	—1.2569	—2.9842	4.8888	3.9981	0.0000	
4 4	4.2343	4.8124	—0.4427	—2.1780	7.6395	6.3866	1.2059	0.0000
1 1	1.2624	1.4351	—2.6260	—6.0130	4.5965	3.3544	—1.5886	—3.6272
3 1	1.4190	1.5542	—2.2261	—4.7339	4.1756	3.1833	—1.1296	—2.7175
4 1	3.8257	4.3802	—0.8536	—2.9517	7.4070	6.0620	0.7222	—0.6560
2 1	7.2268	7.5964	3.2633	3.1931	9.3443	8.6024	5.0253	4.5708
1 2	1.5620	1.8005	—2.4800	—5.8971	5.0698	3.7501	—1.3868	—3.4401
2 2	6.2722	6.9803	1.2057	0.4545	9.6017	8.3717	3.2114	2.4709
3 2	—0.6249	—0.7310	—3.6714	—6.9190	1.8905	0.9982	—2.9578	—4.9026
4 2	3.7153	4.2996	—1.0201	—3.3258	7.4609	6.0415	0.5358	—0.9401

	1 1	2 1	3 1	4 1	1 2	2 2	3 2	4 2
1 1	0.0000							
3 1	0.3775	0.0000						
4 1	3.1493	2.2533	0.0000					
2 1	6.9155	6.2488	5.0807	0.0000				
1 2	0.3329	—0.1170	—2.9307	—6.7977	0.0000			
2 2	5.9802	4.8534	3.1867	—2.7911	5.8789	0.0000		
3 2	—1.9840	—2.0440	—4.5246	—7.6689	—2.3091	—6.9543	0.0000	
4 2	3.0043	2.0770	—0.2754	—5.2932	2.7919	—3.5465	4.4617	0.0000

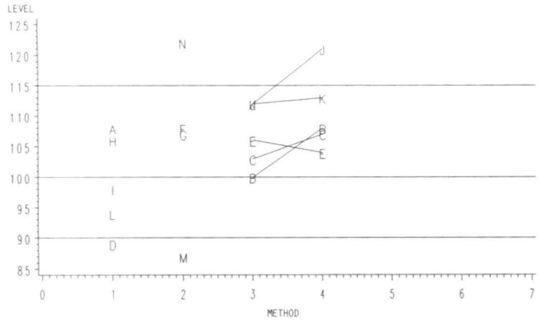
The first figure both in the line and column indicates the area and the second figure the method
1=Kauko, 2 = Kauko2, 3 = Base and 4 = Vilma

Figures whose absolute values are greater than 2 differ statistically significantly from 0

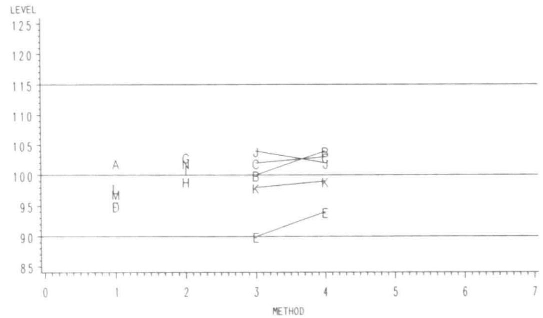
Appendix 12.1. The taxation level by methods, Area 1, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



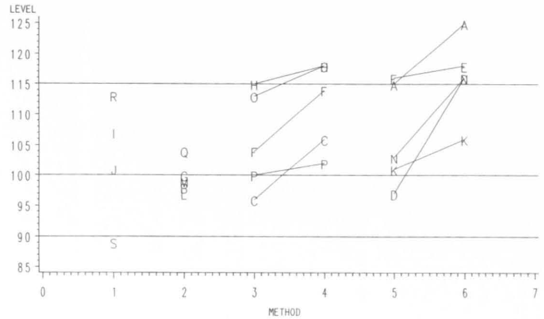
Appendix 12.2. The taxation level by methods, Area 2, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



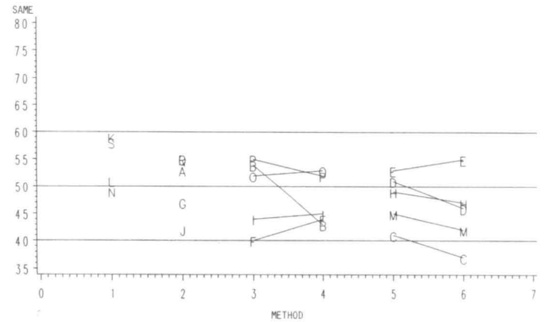
Appendix 12.3. The taxation level by methods, Area 3, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



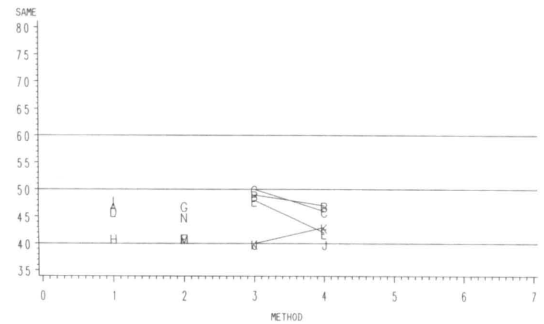
Appendix 12.4. The taxation level by methods, Area 4, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



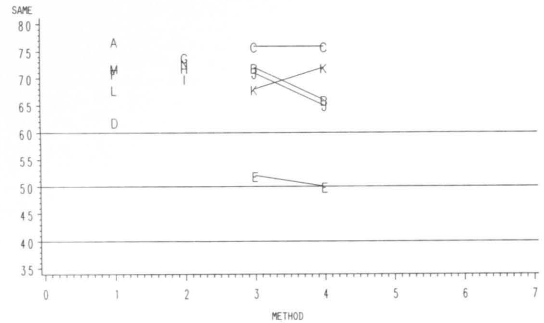
Appendix 12.5. The proportion of correctly classified by methods, Area 1, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



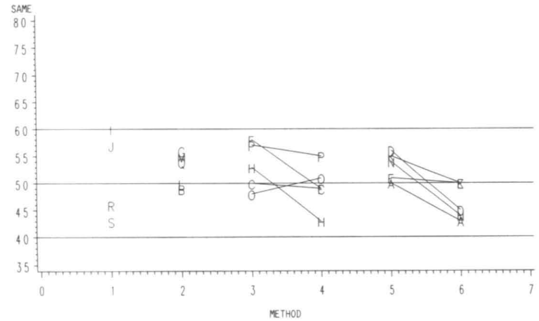
Appendix 12.6. The proportion of correctly classified by methods, Area 2, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



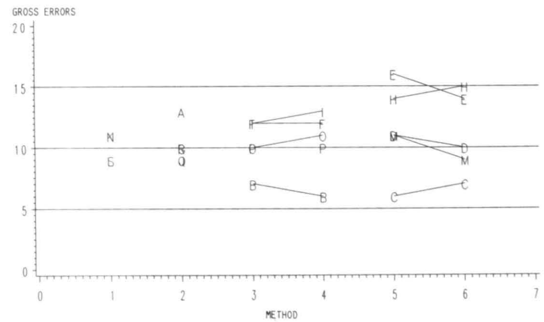
Appendix 12.7. The proportion of correctly classified by methods, Area 3, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



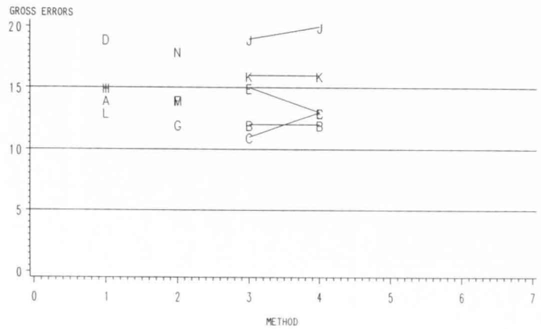
Appendix 12.8. The proportion of correctly classified by methods, Area 4, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



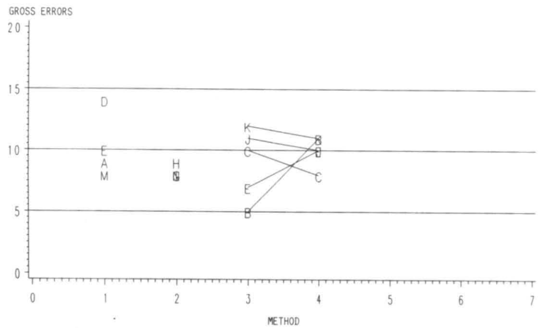
Appendix 12.9. The proportion of gross errors by methods, Area 1, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



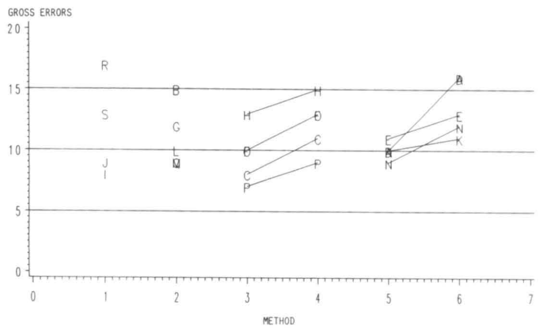
Appendix 12.10. The proportion of gross errors by methods, Area 2, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



Appendix 12.11. The proportion of gross errors by methods, Area 3, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



Appendix 12.12. The proportion of gross errors by methods, Area 4, 1 = BASE, 2 = VILMA, 3 = KAUKO2 controllers, 4 = KAUKO controllers, 5 = KAUKO2 taxators, 6 = KAUKO taxators. The letters refer to different persons.



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