S.A.P.I.EN.S
2.2 (2009)
Vol.2 / n°2 Special issue

Gintautas Mozgeris

The continuous field view of representing forest geographically: from cartographic representation towards improved management planning

Electronic reference
Gintautas Mozgeris, « The continuous field view of representing forest geographically: from cartographic representation towards improved management planning », *S.A.P.I.EN.S* [Online], 2.2 | 2009, Online since 11 February 2009, Connection on 15 October 2012. URL : http://sapiens.revues.org/734

Publisher: Institut Veolia Environnement
http://sapiens.revues.org
http://www.revues.org

Document available online on: http://sapiens.revues.org/734
This document is a facsimile of the print edition.

INSTITUT
Veolia Environnement

S·A·P·I·EN·S
VOLUME 1 ISSUE 2 2008

Methods

The continuous field view of representing forest geographically: from cartographic representation towards improved management planning

Gintautas Mozgeris

GIS Education and Research Centre, Institute of Environment, Lithuanian University of Agriculture, Studentu 11, LT-53361, Akademija, Kaunas r., Lithuania

Correspondence to: G. Mozgeris (gintautas.mozgeris@gmail.com)

Abstract

Enhanced vizualization leads to better forest management solutions. This paper discusses the application of numerical remote sensing and geographic information systems to forest inventory. Natural phenomena usually exhibit both continuous and discrete behaviour. Discrete models have been used since the inception of aerial photography, long before the introduction of mathematical statistics, computers or remote sensing but today, forest attributes can also be described as continuous surfaces. This paper briefly presents the uses and limitations of a popular non-parametric estimator (the k*-nearest neighbour).: it improves visual representation, and provides a better input for GIS based modelling, thus facilitating natural resource inventory and management planning. However, in many countries, the operational forest management planning approaches still require some discretisation of continuous surfaces into areal units, corresponding to virtual—or dynamic—forest compartments.*

TABLE OF CONTENTS

Received: 08 July 2008 – Revised: 08 January 2008 – Accepted: 23 January 2008 – Published: 10 February 2009.
Edited by: Sébastien Gadal – Reviewed by two anonymous referees.

1. INTRODUCTION

Enhanced visualization is usually the step towards better forest management solutions. Maps can easily summarize and communicate results of forest inventories, and are used as decision supporting tools. Conventional forest maps present an abstract view of parts of the world with an emphasis on selected forest compartments, infrastructure objects, locations of monuments, etc. They are usually addressed to numerous identified (e.g. forest managers) and unidentified (e.g. the public) users. Aerial photographs and later satellite images have been used for forest management for more than a century (Hildebrandt, 1993). The invention of Geographic Information Systems (GIS) has fundamentally changed the way visualization of geographic phenomena is created and used, whether they are forest, coastal, urban, agricultural, etc. GIS-based representations can portray the dynamics through animations, 3-D visualisation, and support sophisticated spatial analyses and modelling.

This paper discusses a way to describe forest geographically storing an array of continuous surfaces of forest attributes. It is based on the combination of modern GIS and numerical remote sensing techniques and is applicable to many other areas of interest.

2. REPRESENTING FOREST GEOGRAPHICALLY

2.1. DISCRETE OBJECTS OR CONTINUOUS FIELDS?

What is "a forest"? Is it different from other phenomena represented in geographical databases? Russian forestry scientist G.Morozov defines forest as an aggregate of trees, which grow near-by, affect each other and the surrounding space and,

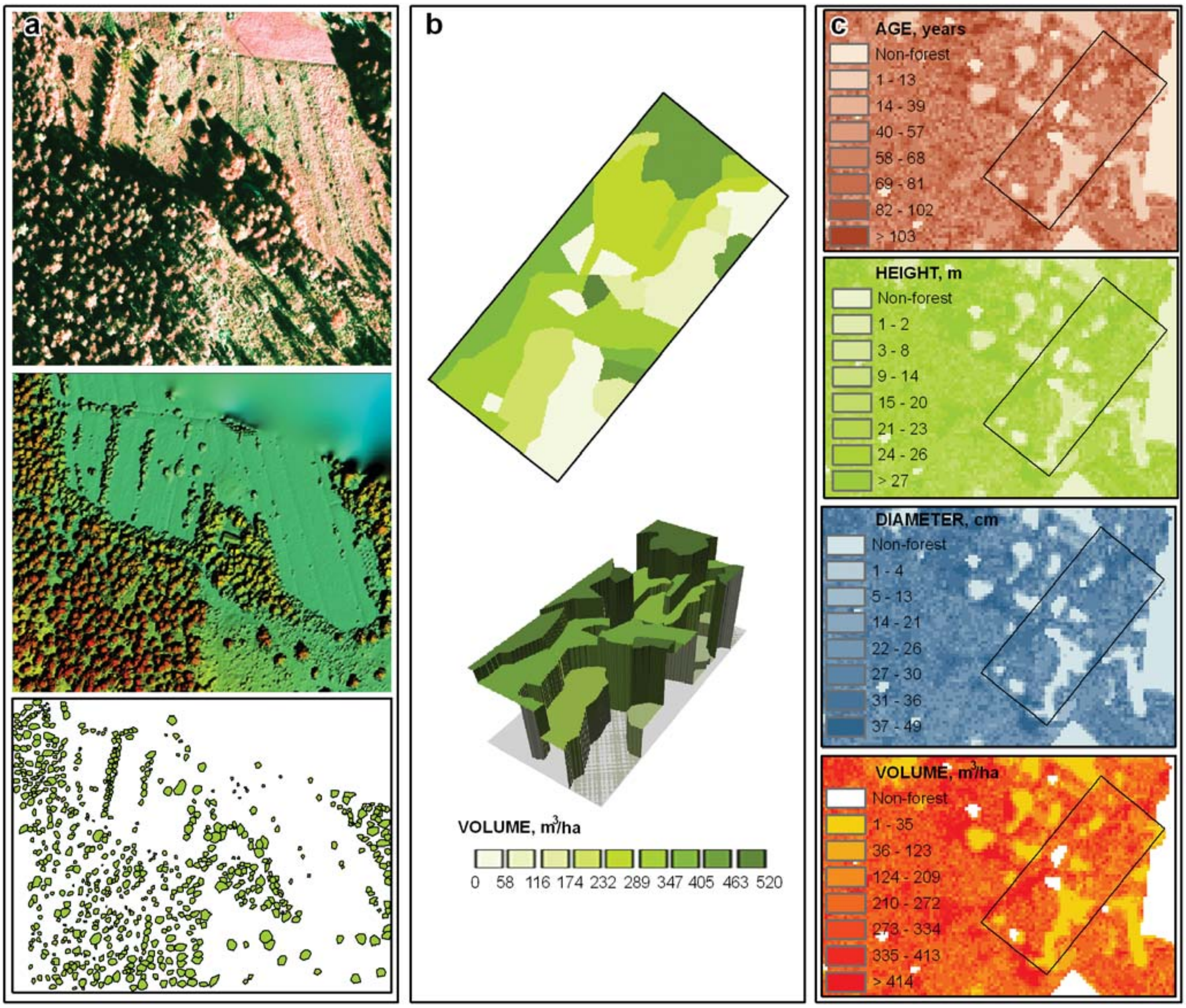

Figure 1. Two ways of representing forest in digital computer environments: discrete objects (a) and continuous fields (b and c). (a) single tree crowns are delineated (bottom) from aerial image (top) and image, generated from laser scanned point clouds (middle) and stored in a database (reproduced with permission of Blom Kartta Oy). (b) volume in m³/ha represented using discrete model of spatial variation; (c) stand age, height, diameter and volume per ha are represented as separate layers using continuous model of spatial variation.

therefore, are changing their outside and inner structure (1930). This is a purely naturalistic approach. Legally, a forest can also be defined as "at least 0.1 ha area grown-up with trees the height of which reaches 5 m or more under natural conditions, as well as thinned out or even having lost the vegetation naturally or because of human activities" (Forest act of Republic of Lithuania). These examples show that definitions directly influence the data model which will be used to describe the forest in a digital data base.

There are two fundamental ways of representing geography in digital computer environments, discrete objects and continuous fields (Longley *et al.*, 2005).

Spatial variation in continuous fields can be itself treated as discrete or continuous (and sometimes as a mix of the two) (e.g. Burrough, 1996; Heuvelink, 1996). Discrete models of spatial variation are usually implemented using vector polygons while continuous models are based on a raster approach.

2.1.1. DISCRETE OBJECTS:

Discrete object view assumes the world to be empty, except where it is occupied by objects having well defined boundaries, linear or point-wise locations. Locations may overlap and can be counted. Biological organisms or man-made objects are typical features that fit well in this model, e.g. trees, roads, buildings, etc. Modern science and technology would theoretically allow for a description of a forest using the model of discrete objects. Every single tree, its location and its descriptive characteristics could be measured and stored in a digital database. Single tree crowns may be easily identified on aerial images or in point clouds derived using laser scanning (Figure 1.a). However, in practice, forests have been described as "continuous fields" divided into compartments for centuries.

2.1.2. CONTINUOUS FIELDS:

The continuous field view assumes that the real world is a series of continuous maps or layers, each of them representing the variability of a certain attribute over the Earth's surface. There are no gaps in such layer: each location has one or another value of an attribute, e.g. "forest" or "non-forest"; "young forest", "middle aged forest" or "mature forest". Stand-wise forest inventories define discrete spatial objects with crisp boundaries—forest compartments—and assign uniform characteristics within a given polygon. Forest compartments do not overlap, the values of forest attributes are dependant on many factors, especially human activities (Figure 1b), and change abruptly on the boundary of a compartment. The main concepts of forest compartment and stand-wise forest inventories were developed centuries ago, long before the introduction of mathematical statistics, computers and remote sensing. This historical way of representing spatial variation with discrete model is thus widely used in operational forest inventories and management planning.

However, the description of forest attributes as continuous surfaces is getting more popular today. All attributes vary continuously and smoothly over space and their values are available at any location or point and stored in digital databases (Fig. 1c). In this paper we focus on the method that describes forest attributes as continuous surfaces, an approach that can be applied to any other natural phenomena which present smooth variation in space.

2.2. HOW TO GET CONTINUOUS SURFACES OF FOREST ATTRIBUTES?

For each given attribute, a unique value should be recorded at every location or point inside the forest (and this value will be equal to zero outside). Many countries have been using this approach for decades to get information for strategic forestry planning from their National forest inventories (by combining sampling methods with remotely sensed data).(e.g. Tomppo, 1993; Nilsson, 1997; Tomppo *et al.*, 1999; Gjersten *et al.*, 2000, Franco-Lopez *et al.*, 2001 and many other authors). It is used to aggregate detailed stand-wise forest information to be represented at a coarser scale (e.g. Kurlavicius *et al.*, 2004) or when more detailed information is not available (Paivinen *et al.*, 2001).

Forest information is organized using a grid of systematically distributed virtual samples or points corresponding to pixels in a raster data model. Such points may be distributed rather sparsely[1] or may form very dense networks (e.g. 25x25 m, 1x1 m and so on). Each point represents an array of several forest attributes of interest at that location. Pixels of rasters and images may also be considered as virtual points and digital numbers of e.g. satellite images replaced by estimated forest characteristics. Such point-wise or pixel-wise information may be used for forest inventories that support tactical and operational forest management planning.

A surface of forest characteristic or virtual samples of forest characteristics can be obtained by:

(i) measuring all of them in the field (Gunnarsson *et al.*, 1999), however this is rather expensive since a separate measurement is required for each point. In the case of Landsat TM for instance, someone would have to estimate forest stand volume or age for a 30x30m grid systematically.

(ii) measuring a subset in the field and extrapolate the results for the other locations using geostatistical methods (such as the kriging interpolation, Gunnarsson *et al.*, 1999). In this case spatial autocorrelation should be present in the studied phenomenon and with large sample volume, we may be back to the previous case.

(iii) measuring them on images using stereo photogrammetric equipment, however this is labour consuming and expensive too

(iv) modelling the surfaces of forest attributes using available auxiliary information (usually in digital format) that correlates with forest characteristics—satellite and

1 e.g. 250x250 m, as in the case of forest area in Lithuanian National forest inventory by sampling methods (Kasperavičius *et al.*, 1999)

aerial images, historical forest inventory information, GIS databases, etc. This approach is the cheapest, and is detailed below.

In the case of raster surfaces, layers of auxiliary information (e.g. satellite images, digital elevation models, soil type maps, etc.) are available for the whole area of interest. Forest attributes are measured in the field for a limited number of locations; they may even be already available from other types of inventories[2]. Next, all pixels are divided into two groups: A-observations and B-observations. Both input (auxiliary) and output (forest attributes) data are known for the B-observations but only input (auxiliary) data are known for the A-observations. The task is to get the forest characteristics on the basis of auxiliary information for all A-observations utilizing the knowledge on relationships between auxiliary and field information, developed using B-observations. Numerous parametric and nonparametric methods of estimations have been used for that purpose[3] and they give similar estimation accuracies (Mozgeris, 2000). However the k-nearest neighbor estimation is favored in most forest inventory oriented applications and it is expected to be of great potential to model other geographic phenomena: It is well documented in the literature, easy to understand and implement (free software available), and it can accommodate a wide range of auxiliary information.

The *k*-nearest neighbor method (Tomppo, 1993) or multi-dimensional version of inverse distance weighted technique familiar to the majority of GIS users, can be briefly described as follows: Euclidean distance $d_{i,p}$ is calculated between each A-observation sampling unit p in n dimensional feature space of auxiliary information and B-observation unit i with field measured forest characteristics. n here refers to the total number of layers of auxiliary information—channels of satellite image, parameters from stand-wise inventories, etc. k (1-10 and more) distances $d_{i,p}$ - $d_{(1),p}$ ... $d_{(k),p}$, ($d_{(1),p} \leq \ldots \leq d_{(k),p}$) are found and the weight is calculated:

$$w_{(i),p} = \frac{1}{d^t_{(i),p}} \sum_{i=1}^{k} \frac{1}{d^t_{(i),p}}$$

Value $\hat{m}_p$ of forest parameter M on sample unit p of A-observation equals:

$$\hat{m}_p = \sum_{j=1}^{k} w_{(j),p} \bullet m_{(j),p}$$

Where $m_{(j),p}$, $j=1,\ldots k$ – values of forest parameter M in k nearest B-observation plots to p in n dimentional space.

The influence of different settings on the accuracy of estimations has been widely studied: for instance, the Mahalanobis distance has been used instead of the Euclidean one without significant success indeed (Mozgeris, 1996; Franco-Lopez *et al.*, 2001). The number of *k* minimal amount of B-observations has been discussed in-depth a decade ago (Tomppo, 1996; Tokola *et al.*, 1996; Mozgeris, 1996; Nilsson, 1997) to develop general methodological framework for the use of *k*-nearest neighbor estimation in remote sensing assisted forest inventories.

Digital satellite images have been the major source of auxiliary information to get continuous surfaces of forest characteristics. Principal component transformations and pre-stratification are used to facilitate the integration of satellite images with other types of auxiliary information[4]. Geographical distance between A-observations and B-observations is also taken into account (Katila *et al.*, 2001). An expert system (Wang, 2006), different techniques to weight alternative estimates (Mozgeris, 2000), and, finally, optimization techniques called genetic algorithm (Tomppo *et al.*, 2004; Tomppo *et al.*, 2006), have been used to improve the accuracies of point-wise estimates taking into account diverse sources of auxiliary information and parameters of estimators. However, despite the intensive research on the optimization of estimation techniques, it is generally concluded that no universal solution can satisfy the needs of all users. Several approaches should be tested using modern computation tools to find the best one, fitting certain conditions.

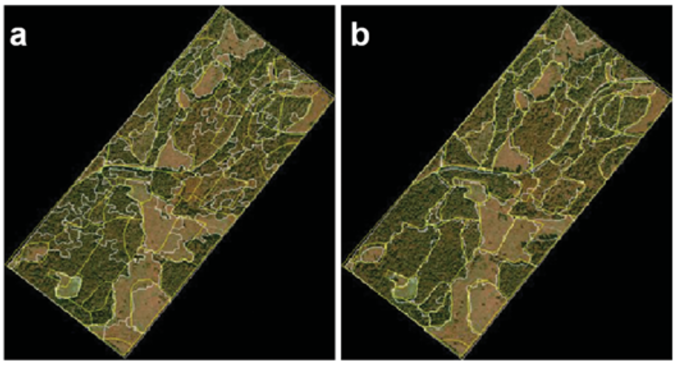

Figure 2. Automatic segmentation of digital colour infrared image (white lines) and boundaries of compartments, defined more than a decade before the acquisition of aerial image within the frames of conventional stand-wise inventories using visual interpretation (yellow lines). Visual appearance of the segment borders can be easily improved using GIS tools; (a) uncontrolled segmentation using just aerial images, (b) segmentation, supported with the data from stand-wise inventory.

3. THE USE OF CONTINUOUS SURFACES OF FOREST CHARACTERISTICS

Natural phenomena usually exhibit both continuous and discrete behaviour (Burrough, 1996). Such spatial continuity (even when disrupted by abrupt changes) is rather difficult to visualize using discrete model or choropleth presentations. Any natural characteristic sampled and measured in the field can be represented for a certain location using the model of point-wise characteristics. The array of such characteristics depends on the objectives of the representation (improved visual representation, input for GIS based modelling, enhanced opportunities for natural resource inventory and management planning, etc.).

2 For instance almost all European countries carry-out National forest inventories, which include systematic measurements in the forest following some statistical schemes

3 regression (e.g. Hagner, 1990; Nilsson, 1997; Mozgeris and Augustaitis, 1999), static and dynamic stratification (e.g. Poso *et al.*, 1987; Mozgeris, 1996), k-nearest neighbor estimation (e.g. Tomppo, 1993; Gjersten *et al.*, 2000; Tokola *et al.*, 1996), most similar neighbour estimation (Moeur and Stage, 1995), GIS-driven pseudo-raster transformations (Kurlavicius *et al.*, 2004), etc.

4 such as historical forest inventory information, which may be outdated and rather inaccurate for direct use but can still correlate with the actual forest characteristics, general use GIS data, soil maps, digital elevation models and their derivatives, etc. (e.g. Tokola *et al.*, 1997; Katila *et al.*, 2001; Mozgeris, 2006).

The operational forest management planning approaches in many countries require some discretisation of continuous surfaces into areal units, corresponding to forest compartments. The A-observations (points, pixels, etc.) are easily grouped based on the values of certain characteristics (e.g. all set of characteristics that are used to single-out forest compartments) to form discrete units (conventional compartments, polygons where certain assortment is available for logging, etc.). Since such units can change in size, shape and role, they are called virtual or dynamic compartments. The concept of dynamic forestry unit, developed following the principles described above, has been discussed previously (Holmgren and Thuresson, 1997; Gunnarsson *et al.*, 1999), but it has not yet received much attention in the forest inventory literature.

Here we present two possible uses of the estimated surfaces of forest characteristics to solve conventional stand-wise forest inventory tasks, which may be successfully adopted for other applications. The first one allows improved automatic delineation of discrete units, corresponding to forest compartments. The other facilitates change detection by combining single acquisition time satellite images and information from stand-wise inventories (which may be adopted to detect the changes in other spatially distributed resources too).

3.1. IMPROVED AUTOMATIC STAND DELINEATION

Forest compartments are usually singled-out in stand-wise inventories using methods of visual interpretation of high resolution aerial or satellite images[5]. Automatic stand delineation has always been a very challenging task both for researchers and for forest inventory practitioners. Traditional image classification algorithms, which are successful for many other applications, (such as maximum likelihood, parallelepiped or minimum distance), usually do not work for forest management planning. This is mainly due to the fact that foresters need to have stand-wise information on numerous stand parameters rather than discrete pixel by pixel classes and large approximations are needed to express continuous forest characteristics with few discrete classes. How to use segmentation to divide the image into spatially contiguous regions that are homogeneous regarding to their radiometric characteristics has been abundantly documented in the last two decades (Tomppo, 1987, 1988; Hagner, 1990; Hame, 1991; Parmes, 1993; Olsson, 1994; Haapanen & Pekkarinen, 2000). Similar research has been carried out in Lithuania a decade ago as well, even though the results have not been used operationally (Mozgeris *et al.*, 2000; Mozgeris, 2001). However, new approach in segmentation tactics—estimation of forest characteristics for every pixel of satellite or aerial image and using them instead of original image values—improves the efficiency of segmentation and seems to bear great potential for future studies. Even rather out-dated borders of forest compartments from previous forest inventories can improve the segmentation outputs (see Figure. 2).

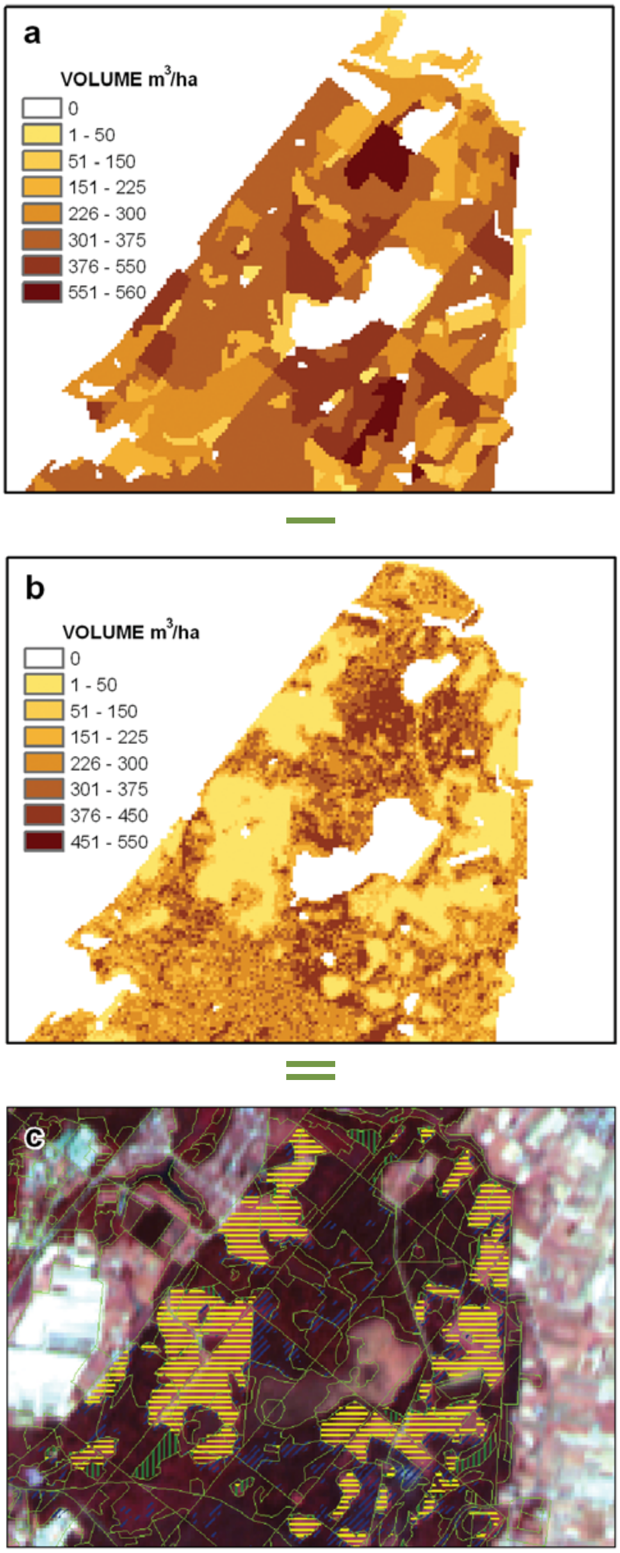

Figure 3. Forest change detection subtracting grids of volume in m^3/ha represented using discrete model of spatial variation (a) and continuous model of spatial variation (b). (a) forest inventory data from 1988; (b) derived surface using SPOT 4 HRVIR satellite image, ~600 field plots data from 1999 and *k*-nearest neighbor estimation. (c) SPOT HRVIR image and boundaries of compartments defined by stand-wise inventory 3 years after the satellite image acquisition (green lines) together with the identified changes: clear-cuts (yellow striped pattern, detected), non-clear felling (blue striped pattern), clear-cut after satellite image acquisition (green striped pattern, not detected).

5 such as Ikonos, QuickBird, sometimes SPOT, Landsat or similar, depending on the targeted level of details.

3.2. CHANGE DETECTION USING SINGLE ACQUISITION TIME SATELLITE IMAGES

Several techniques are used to detect changes between images[6]. All of them combine multiple satellite images with different acquisition dates. Conventional stand-wise forest inventories are repeated regularly (e.g. every ten years) and differences are identified by comparing successive compartment boundaries. When forest managers update their forest inventory data regularly, the attributes of forest compartments are updated using growth models, accounting for silvicultural treatments and natural hazards. Most changes can be easily detected in a 10 years period. However, being able to monitor changes within a shorter period of time is of considerable interest for forest management. Surfaces of key forest characteristics can be used to detect changes (or inaccuracies) in stand-wise inventory data (Figure 3):

1. Stand-wise forest inventory defines the boundaries of compartments and their descriptions. Information may age up to 10-15 years, even if it is updated by forest managers and stand growth models. Volume per 1 ha (age, etc.) from the stand-wise inventory data is converted to raster.

2. Continuous surfaces or grids of the same forest characteristic can be easily achieved using single acquisition time satellite images utilizing limited field measurements (e.g. from National Forest Inventories by sampling methods, which are carried-out practically in all European countries).

3. Grid of estimated forest characteristic (e.g. volume per 1 ha) is subtracted from the grid, generated using the stand-wise forest inventory vector polygons. Differences larger than some marginal value indicate forest changes and, up to some extent, inaccuracies of stand-wise inventory.

This gives a brief and general description of the idea. To have practical value for operational forest management, other aspects need to be taken into account, such as the rules to classify the differences according to the types of change, the principles of ground-truthing[7], accuracy issues of stand-wise information, etc.

4. OPPORTUNITIES FOR OTHER FIELDS

This paper focuses on the opportunities to use geomatics for forest inventory. The approaches discussed here are well known to forest inventory professionals and could be of great interest for other disciplines. As mentioned above, most natural phenomena usually exhibit both continuous and discrete behaviour (Burrough, 1996), and natural characteristic that can sampled and measured in the field can be represented using the model of point-wise characteristics. Different outputs can be generated using different array of auxiliary information, based on similar processing mechanisms. We use here the non-parametric *k*-nearest neighbour estimator to get the dependant variable from various independent variables—the non-parametric methods are recommended as an alternative to the traditional approaches based on regression models. The main advantage of non-parametric methods is that they retain the full range of variation of the data as well as the covariance structure of the population (Moeur and Stage, 1995). And finally, they are more easy to use and accessible to everyone, even to the amateur in statistics.

Single acquisition time satellite images, transformed into continuous surfaces of major forest characteristics, have been successively used together with the data from stand-wise forest inventories to detect clear-cut areas in the forest. The comparison of several independently produced classified images is of course the most obvious method to detect changes in the state of a geographic phenomenon (Singh, 1998). But when images are not available at a given time, they can be inferred from a model of evolution.

In conclusion, powerful tools for image segmentation are available nowadays. In particular, the fuzzy logic based software by Definiens emulates the human cognitive processes to perform automated image analysis[8]. The technology is context-based and identifies objects rather than simply examining individual pixels. This approach can be used to monitor a vast range of natural and social phenomena such as natural resource management or infrastructure planning.

References

Burrough P.A. (1996). Natural objects with indeterminate boundaries. In: Geographic Objects with Indeterminate Boundaries, Burrough, P.A. and Frank, A.U. (eds.), Taylor & Francis, pp. 3-28

Eastman J.R. & J.E. Mckendry (1991). Explorations in Geographic Information Systems Technology. Volume 1. Change and Time Series Analysis, UNITAR European Office, Geneva, 86.

Franco-Lopez H., A. Ek & M.E. Bauer (2001). Estimation and Mapping of Forest Stand Density, Volume, and Cover Type Using the k-Nearest Neighbors Method, Remote Sensing of Environment, Vol.77, pp.251–274.

Gjertsen A. K., S. Tomter & E. Tomppo (2000). Combined Use of NFI Sample Plots and Landsat TM Data to Provide Forest Information on Municipality Level. In: T. Zawil-Niedzwinski, & M. Brach (Eds.). Remote sensing and forest monitoring: Proceedings of IUFRO conference, 1 – 3 Jun. 1999, Rogow, Poland. Luxembourg: Office for Official Publications of the European Communities, pp.167 – 174.

Gunnarsson F. *et al.* (1999). On the potential of kriging for forest management planning, Scandinavian journal of forest research, Vol. 13, pp.237 – 245.

6 image differencing, image regression, image ratio, principal components analysis, comparison of independent classification results, classification of integrated information from different dates of acquisition (Singh, 1998; Eastman and McKendry, 1991).

7 Ground truthing is the act of physically going to a field to determine the cause of variability detected in an image.

8 www.definiens.com

Haapanen R. & A.Pekkarinen (2000). Utilising satellite imagery and digital detection of clear cuttings for timber supply management / Manuscript of paper submitted to ISPRS, Vol. XXXIII, Amsterdam. 8..

Hagner O. (1990). Computer Aided Forest Stand Delineation and Inventory Based on Satellite Remote Sensing. In: The usability of remote sensing for forest inventory and planning: proc. from SNS/IUFRO workshop, Umea, 26-28 February. Umea, pp.94-105.

Hame T. (1991). Spectral interpretation of changes in forest using satellite scanner images // Acta Forestalia Fennica. Vol. 222. 112 p.

Heuvelink G.B.M. (1996). Identification of Field Attribute Error under Different Models of Spatial Variation, International Journal of Geographic Information Systems, Vol.10, No.8, pp. 921-935.

Hildebrandt G. (1993). Central European contribution to remote sensing and photogammetry in forestry, In: Forest resource inventory and monitoring and remote sensing technology: Proceedings of the IUFRO centennial meeting in Berlin, Japan Society for Forest Planning Press, Tokyo, Japan, pp. 196-212.

Holmgren P. & T.Thuresson (1997). Applying objectively estimated and spatially continuous forest parameters in tactical planning to obtain dynamic treatment units, Forest Science, Vol. 43, pp.317 – 326.

Kasperavi ius A., A. Kuliešis & Mozgeris G. (2000). Satellite imagery based forest resource information and its application for designing the National forest inventory in Lithuania, In: T. Zawil-Niedzwinski, & M. Brach (Eds.). Remote sensing and forest monitoring: Proceedings of IUFRO conference, 1 – 3 Jun. 1999, Rogow, Poland. Luxembourg: Office for Official Publications of the European Communities, pp.50-58.

Kuliesis A. & A. Kasperavicius (1999). National Forest Inventory Guide, Kaunas, 133 p. (in Lithuanian)

Kurlavicius, P. *et al.* (2004). Identifying high conservation value forests in the Baltic States from forest databases, Ecological Bulletins 51, pp.351-366.

Lilesand T.M. & R.W. Kiefer (1994). Remote sensing and image interpretation, John Wiley & Sons Inc., 750 p.

Longley P.A. *et al.* (2005). Geographic Information Systems and Science, 2nd Edition, John Wiley & Sons, Inc., 517 p.

Moeur M. & A.R. Stage (1995). Most Similar Neighbor: an Improved Sampling Inference Procedure for Natural Resource Planning, Forest Science 41 (2), 337 – 359.

Morozov G.F. (1931). Study on the forest, Moskva-Leningrad, Goslesbumizdat, 440 p. (in Russian).

Mozgeris G. (1996).Dynamic Stratification for Estimating Pointwise Forest Charakteristics. Silva Fennica, Vol. 30(1), 61-72.

Mozgeris G. & A. Augustaitis (1999). Using GIS techniques to obtain a continouos surface of tree crown defoliation, Baltic forestry, Vol. 5, No.1, pp.69-74.

Mozgeris G., A.Kuliešis & A.A. Kuliešis (2000). Looking for new solutions in delineating forest stands: segmentation of multi-source data, In: Proc. of III International Symposium "Application of Remote Sensing in Forestry", Faculty of Forestry, Technical University in Zvolen, Zvolen, September 12-14, 2000, ISBN 80-968494-0-9, p. 123-132

Mozgeris G. (2000). Estimation of point-wise forest characteristics using two-phase sampling, Vagos, Transactions of Lithuanian University of Agriculture. Vol. 48(1), 28-38 (In Lithuanian).

Mozgeris G. (2001). Research on application of satellite image segmentation for stand-wise forest inventory. Vagos, Transactions of Lithuanian University of Agriculture 52 (5), 15-23 (In Lithuanian).

Nilsso M. (1997). Estimation of Forest Variables Using Satellite Image Data and Airborne Lidar. PhD thesis, Swedish University of Agricultural Sciences, The Department of Forest Resource Management and Geomatics. Acta Universitatis Agriculturae Sueciae. Silvestrias, 17.

Olsson H. (1994). Monitoring of local reflectance changes in boreal forests using satellite data / Report 7, Dept. of biometry and forest management, Swedish university of agricultural sciences. Umea.

Paivinen R. *et al.* (2001). Combining Earth Observation Data and Forest Statistics, EFI Research Reports 14, European Forest Research Institute and Joint Research Centre – European Commission, 101.

Parmes E. (1993). Segmentation of Landsat and Spot satellite imagery, Photogrammetric Journal of Finland. Vol. 13. 52-58.

Poso S., R. Paananen & M. Simila (1987). Forest inventory by compartments using satellite imagery, Silva Fennica, Vol. 21 (1), 69-94.

Singh A. (1989). Digital change detection techniques using remotely-sensed data. Review Article, International Journal of Remote Sensing, Vol. 10, No. 6, 989-1003.

Tokola T. *et al.* (1996). Point Accuracy of a Non-parametric Method in Estimation of Forest Characteristics with Different Satellite Materials. International journal of remote sensing, Vol. 17, No. 12, 2333-2351.

Tomppo E., C. Goulding, C. & M. Katila (1999). Adapting Finnish multisource forest inventory techniques to the New Zealand preharvest inventory, Scandinavian Journal of Forest Research, Vol.14, 182 – 192.

Tomppo E. (1996). Multi-source National Forest Inventory of Finland, In: R.Vanclay, J. Vanclay, & S. Miina (Eds.), New thrusts in forest inventory: Proceedings of the subject group 4.02-00 'Forest Resource Inventory and Monitoring' and subject group 4.12-00 'Remote Sensing Technology', vol. 1, IUFRO XX World Congress, 6 - 12 Aug. 1995 Tampere, Finland, European Forest Institute, Joensuu, Finland, 27- 41.

Tomppo E. (1993). Multi-source national forest inventory of Finland, Proc. Of Ilvessalo symposium on national forest inventories. IUFRO S4.02, Finnish forest research institute, University of Helsinki. Helsinki, 52-60.

Tomppo E. (1987). Stand delineation and estimation of stand variates by means of satellite images, Remote sensing-aided forest inventory: proc. from seminars organized by SNS and Taksstoriklubi, Hyytiala, Finland, December 10-12, 1986: research notes No. 19. University of Helsinki. Dept. of forest mensuration and management. Helsinki, 60-76.

Tomppo E.(1988). Standwise forest variate estimation by means of satellite images, Satellite imageries for forest inventory and monitoring: experiences, methods, perspectives: proc. from the IUFRO Subject Group 4.02.05 meeting in Finland, Aug. 29 – Sept. 2, 1988: research notes No. 21. University of Helsinki, Dept. of forest mensuration and management. Helsinki, 103-111.

Wang G (1996). An expert system for forest resource inventory and monitoring in the frame of multi-source data, University of Helsinki. Department of forest resource management. Publications 10. Helsinki, 173.