The posibiliry of applying aerial photographs from cyclical aerial survery in the Republic of Croatia to forest management

Pernar, Renata; Klobučar, Damir; Kušan, Vladimir

Source / Izvornik: **Glasnik za šumske pokuse: Annales Experimentis Silvarum Culturae Provehendis, 2003, 40, 113 - 167**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

UDK: 630*587

Original scientific paper
Izvorni znanstveni članak

THE POSIBILITY OF APPLYING AERIAL PHOTOGRAPHS FROM CYCLICAL AERIAL SURVEY IN THE REPUBLIC OF CROATIA TO FOREST MANAGEMENT

MOGUĆNOSTI PRIMJENE AEROFOTOSNIMAKA IZ CIKLIČKOG SNIMANJA REPUBLIKE HRVATSKE U UREĐIVANJU ŠUMA

RENATA PERNAR[1], DAMIR KLOBUČAR[2], VLADIMIR KUŠAN[3]

[1]Faculty of Forestry, University of Zagreb, P. O. Box 422, HR – 10002 Zagreb
[2]Hrvatske šume Ltd., Lj. F. Vukotinovića 2, HR – 10000 Zagreb
[3]Oikon Ltd., V. Prekrata 20, HR – 10000 Zagreb

Received – *Prispjelo*: 12. 3. 2003. Accepted – *Prihvaćeno*: 25. 9. 2003.

As the application of remote sensing methods to forestry is not satisfactory, this paper will discuss the possibilities of using aerial photographs from cyclic aerial survey in the Republic of Croatia in forest management.

Photographs from cyclic aerial survey were selected for reasons of their availability on the market at a very reasonable price, unlike the commissioned recordings which considerably increased the cost of using remote sensing methods in the past.

The images are black-and-white aerial photographs at an approximate scale M ≈ 1:20,000 m and an overlap accuracy of 60%.

The paper was based on the following guidelines: work rationalisation, the possibility of applying new technologies and lowered costs of data collection.

The introductory part gives an overview of the development of the science of forest management and its links with forest mapping, remote sensing and the construction of the GIS model. A review of past research is also given entailing stand volume estimation and the importance and use of digital terrain models in modern forestry.

The set goals are achieved through a qualitative and quantitative analysis of a model that consists of a stereomodel, a digital orthophotograph and a digital terrain model.

Qualitative analysis involves the detection of all differentiating contents that may purposefully substitute taxation (management) field activities related to internal forest division by using remote sensing methods. A brief survey is given on the possibility of using models in other fields on pragmatic bases.

The construction of a digital orthophoto and the possibilities of its application are also given. Orthophotographs are recommended for every management plan (regular revisions), preferably with larger-scale images.

Quantitative analysis is based on the following five methods of stand volume estimation per hectare:

I with Špiranec's growth-yield tables
II with normal models according to ecological-management types
III with classifying compartments according to management and age class and site quality using a referent compartment
IV with classifying compartments according to management and age class without a referent compartment
V with terrestrially measured maximal, minimal and average growing stock per hectare.

Based on the obtained results and suitability for operational application, the 1st method with Špiranec's growth-yield tables was found to be the most acceptable. This method can also be used in forestry operative, especially in forest management. Other methods of volume estimation (based on investigation and results) are also worth considering and have their place in remote sensing of growing stock. This refers primarily to the 2nd estimation method with normal models according to ecological-management types.

Key words: remote sensing, aerial photographs, cyclic aerial survey, geographical information system (GIS), orthophotograph, digital terrain model (DTM), forest management

INTRODUCTION
UVOD

This work is aimed at applying remote sensing methods to forestry in the Republic of Croatia with special emphasis on forest management. Since its beginnings, forest management as a scientific and professional activity has been based on the postulate of sustainability.

In view of growing demands and pressures on forest resources, forest management can successfully fulfil its tasks only in continuo. This involves continuous monitoring of forest growth, long-term planning and permanent application and control of all procedures.

An increase in the population was accompanied with growing needs for timber and arable land, which led to extensive felling of forests. However, as people became seriously concerned that timber resources would become exhausted, they began to manage forests (Nenadić, 1929).

This forest discipline, whose expansion dates from the end of the 19th and the beginning of the 20th century, has been defined by a number of authors.

Forest management is a system of activities that regulate overall forest economics in time and space so that management goals are achieved (Judeich, 1904).

Forest management includes planned organisation of forest economics (Wagner, 1928).

According to Anučin (1940), forest management is a complex of measures aimed at producing management plans.

The task of forest management is to regulate forests in time and space and prescribe management methods that will achieve management goals. Managing a forest in time and space means determining in advance where, when and how much to cut. This process entails permanent use of forest land and stands with simultaneous preservation and achievement of productive soil force (Loger, 1946).

Parallel to achievements and scientific successes in the countries with developed forestry, methods and techniques of forest management were also introduced in Croatia by renowned forest managers (Hlava, Partaš, Nenadić, Plavšić, Klepac and others). These outstanding foresters have ardently passed their knowledge of simulation techniques for stand growth monitoring, remote sensing methods (aerial, satellite) and GIS model establishment on generations of forest managers until the present day.

According to Croatian authors (Meštrović et al., 1992), forest management is a highly complex scientific activity which synthesises numerous polyvalent tasks in management plans.

The preservation of forest resources in forest management is based on the principle of sustainable yield.

Over time, the principle of sustainability has developed into the principle of progressive sustainability and finally into the principle of overall use in accordance with modern concepts of polyfunctional use of forests and continuous reproduction of its resources (Meštrović et al., 1992).

The present sustainable management with forest resources is based on a much broader concept than that of a continuous production of equal timber yields. In this context, the preservation of forests for their non-commercial functions and genetic potential is much more important than a continuous production of timber (Čavlović, 1996).

In multi-purpose and sustainable forest management (ensuring ecosystem sustainability, the preservation and improvement of general forest functions, economic aspects and others), where goals are polyvalent and united in time, the achievement of a normal condition is of fundamental importance. This is logical, because only a normal (optimal) forest can satisfy our requirements and needs.

The normal forest is the forest whose wood mass is capable of producing the best annual yield under the existing site conditions, tree species, management form and social needs. This wood mass is called a normal growing stock (Klepac, 1965).

Creative forest management involves skilful adaptation of goals and measures to natural processes in a forest, contrary to conservationism marked by stereotypes and lack of criticism (Gašperšić, 1985).

Successful management with all commercial, stand and silvicultural forms, the achievement of a stable and productive forest ecosystem, the application of multipurpose and sustainable management and realisation of a normal growing stock as one of the primary goals can only be achieved with timely problem detection, suitable goals, proper analysis and realisation of forest management plans, as well as proper implementation of integral politics in view of the set goal (Klobučar, 2002).

A reliably constructed map is of vital importance in forestry and should be in the interest of all forestry segments.

A reliable map has diverse applications and value indicators which can be successfully determined qualitatively and quantitatively.

A list of its applications may start with the simplest ones, such as a general spatial representation of a forest administration, a nature park or a management unit, for example.

A correctly (location - in terms of space and size) mapped area of a compartment and its subcompartments, for example, plays a crucial role in the sphere of using different thematic units (maps) and possibilities of accurate calculations of wood volumes, increment, allowable yields and silvicultural practices and the related material-financial calculations.

Any information on a forest should be accompanied with a point (area) on Earth to which this information refers. The position of points on the Earth's surface is determined with surveying measurements. For this reason, the application of surveying methods dates from the very beginnings of forestry. Up-to-date geodetic plans and maps are invaluable in rational forest management (Kalafadžić, 1994).

As has been pointed out, the development of planned management with forest resources is closely connected with forest mapping.

Forest management maps are made primarily for the needs of forest management. They are easy-to-read special maps of forest management areas at 1:300,000 scale or larger, or a basic map at 1:5,000 or 1:10,000 scale, thematic maps at 1:25,000 scale and larger, and an easy-to-read map at 1:50,000 scale or larger for the need of management plans.

These maps are set down and prescribed by the Forest Management Act (NN 11/97).

Basic maps show a forest area with boundaries of compartments, subcompartments, cadaster districts and ownerships.

A topographic map contains boundaries of counties, municipalities, compartments, the existing and planned communications, ditches and other facilities intended for forestry production. When such a map is used for producing a forest management plan of an area, it is complemented with torrential, erosive and flood areas, watercourses and water-covered areas, as well as with geological-lithological compositions.

Thematic or special maps represent a surface pattern of age classes, management classes, management methods, prescribed yields, silvicultural activities, ecological-management types (EMT), fire hazards, phytocoenology, pedology and typology.

Their purpose is to give a cartographic presentation of forest data from forest inventories. Apart from giving general topographic information, these maps also provide other spatial forest data relevant for forest management (Meštrović et al; 1992).

Forest maps are usually constructed to meet the needs of forest management, or better said, the needs of management inventories. Their application is polyvalent in almost all forest disciplines.

The groundwork for the compilation of such a large number of maps is made up of different cartographic presentations which are systematically made by competent state bodies for the whole country. These are cartographic plans (1:2,880; 1:2,500), the Croatian Basic Map (CBM, 1:5,000) and military topographic maps (1:25,000, 1:50,000, 1:100.000).

High quality thematic maps are one of the principal bearers of rational management with forest resources. Digital cartography raises the overall process of map construction and content (theme) application at a higher level.

Naturally, in order for digital models (e.g. digital maps) to show the true state in the field through geometric shapes, which in fact represent thematic contents of our interest (pedology, phytocoenology, number of trees per ha - N/ha, volume per ha - V/ha, basal area per ha-G/ha and others), they require accurate and precise measurements regardless of whether they entail terrestrial or remote data collection.

There will be an increasing demand for digital maps and specialisation in this cartographic field in forestry from its own needs, but also from the (im)possibility of interacting with other scientific, specialist fields concerned with successful natural resource management.

Digital mapping makes it possible to manipulate cartographic bases in a rational and economic manner, as well as complement and harmonise maps with the existing terrain conditions. New technologies of geodetic and photogrammetric measurements provide data in the form in which they can be directly fed in digital databases. Increased productivity based on automated and computer-supported graphics has led to general abandonment of classical drawings. A particularly useful cost-cutting feature relates to the fact that data can be rapidly stored, changed and complemented within the created databases, which allows daily updating of the existing graphic presentations (maps). A digitalised database provides ways of usage that no drawn map can match. In other words, the use of direct application programmes enables research and conclusions in the manner which far exceeds the possibilities of conventional cartographic material (Kalafadžić and Kušan, 1991).

Data on forest conditions are collected in a variety of ways. In forestry practice (operative) the largest amount of information is provided by forest mensuration (forest inventory). Since forest mensuration, depending on the scale of stock-taking (detailed or operative, management, national, special) provides fundamental data on the true condition of trees, stands or larger forest areas, this discipline has a primary role in forestry practice. Therefore, depending on inventory goals and size, forestry experts obtain a large number of information of importance for all forestry disciplines.

Forest inventory provides information that serves as a basis for further decision making (mid-term, long-term).

Forest inventories are aimed at collecting comprehensive relevant data on forest condition, thus ensuring all the necessary information needed in all segments of forest management. In the light of continuously changing conditions of forest production caused particularly by man's activity, a forest inventory should not be rigid: on the contrary, it should be a flexible procedure which will apply all modern scientific achievements so as to obtain the necessary information quickly, reliably and at low cost (Kalafadžić and Kušan, 1991).

The use of diverse thematic contents obtained with interpretation of aerial photographs (satellite recordings) significantly increases the quantity of forest information, which ultimately enables reliable and valid decision making. Aerial photographs are the primary source of information for a number of inventories and planning in modern forest management (Reutebuch, 1987).

Forest mapping based on aerial photographs saw its wide application both in developed and in developing countries in the eighties of the 20th century (Jano, 1986, Stellingwerf, 1986).

Forest mapping is usually accompanied with forest inventory. Since aerial photographs enable collecting stand data in such a way that they are spatially determined, the application of aerial photographs to forest inventories and mapping has become a regular procedure in forest inventory manuals (Loetsch and Haller, 1973, Kramer and Akça, 1987).

The oldest use of photogrammetry, which achieved relatively successful results in forestry, relates to the domain of forest management. Forest photogrammetry has become a routine procedure in the past decades. According to Tomašegović (1987), it is an information system that provides foundations and methods for rapid, inexpensive and reliable synoptic identification of environmental elements relevant for forestry (relief, vegetation, water regime, communication network, etc.).

The three fundamental components related to forestry activity are: space, time and matter. These three components are indivisible; in other words, maximal production is achieved only through their synergistic action.

The leading technologies of the 21st century will be remote sensing, GIS and GPS. The advantage of these technologies, especially when used jointly, is that they make it possible to undertake the most demanding tasks, such as collecting, selecting and analysing geographical data, as well as controlling and managing certain processes based on geographical data. They can register and change a large number of spatial data relatively swiftly, reliably and economically and analyse and interpret them in a multidisciplinary way according to the needs of a user (Oluić, 2001).

As the majority of information in forestry is determined by their spatial position, the geographical information system (GIS) has proved to be the best information technology to be used in forestry (Kušan et al., 1993).

The establishment of a GIS model is not the end of the process, but the beginning of constructing only one element of a comprehensive planning system, that is, timely and valid decision making, the so called decision support system (Pernar, 1996).

PAST RESEARCH OF STAND VOLUME ESTIMATION IN AERIAL PHOTOGRAPHS

DOSADAŠNJA ISTRAŽIVANJA ODREĐIVANJA VOLUMENA SASTOJINE NA AEROSNIMKAMA

Stand volume estimation in aerial photographs has been studied by a number of authors.

According to Kušan (1996), research aimed at estimating stand parameters in aerial photographs can be divided into two groups:

- investigating the reliability of estimating stand parameters
- investigating the relationships between stand parameters and parameters measurable in aerial photographs.

Tomašegović (1986) states that the most suitable estimation method, using the criteria of relative accuracy, should be the one that leads towards the goal with as few assumptions (correlations) as possible. These assumptions should be based on the reliably collected and valid material.

The same author (1986) also states that:

- Zieger (1929) calculates stand wood volume with the mean error of individual recordings of ±7%,
- Neumann (1933) calculates stand wood volume with the mean error of ±7.4%,
- Spuur (1947) calculates stand wood volume for the whole measured area with an accuracy of + 8.6%, while error for individual stands is -3.8 to 6.7%,
- Wodera (1948) calculates total wood volume with an accuracy of - 6.1%,
- Zobiery (1972) calculates wood volume with a standard error of ± 4.8%,
- in estimating the total wood volume for beech stands on Zagrebačka Gora, an error of - 8.8% was found, while the average percentage error of wood volume in relation to concrete volumes of individual stands was ± 15.2%.

Lukić (1981) uses photogrammetric measurements to estimate wood volume with an error of 14.08% by area unit.

Multiple regression analysis was used to achieve regression equations that express the relationship between photogrammetrically determined parameters and terrestrially measured stand volumes with an acceptable mean error of ± 9-10% relatively independently of the site, type of recording and interpreter (Akca and Zindel, 1987).

Kušan (1991) calculated stand volumes using growth-yield tables with parameters measured in aerial photographs. The mean photogrammetric volume per hectare determined with Hausser's growth-yield tables had an error of - 3.2%, while the same volume error per hectare determined with Swiss growth-yield tables was - 5.7% in relation to the mean volume measured in the field.

Kušan and Krejči (1993) estimate the stand volume of pedunculate oak in EMT II - G - 10 using a regression model with deviations from observed data of - 4.5%, except in young stands with higher deviations.

Jakšić (1996) uses regression equations to estimate the stand volume of pedunculate oak, achieving the best deviation of - 9.60% in relation to terrestrially measured volume.

DIGITAL TERRAIN MODEL
DIGITALNI MODEL TERENA

Modern methods of planning and managing space require the establishment of an effective GIS. The quality of a GIS is significantly improved with the introduction of the DTM into the database, whereby data are geometrically positioned in space in terms of position and altitude. In order to create a DTM with relevant characteristics, it is necessary to collect data containing positional and altitudinal terrain information (Gajski et al., 1994).

Digital terrain models are applied to many fields dealing with spatial management. In forestry, DTMs are commonly used in many segments, such as forest exploitation, forest management, ecology and others (Kušan, 1995).

The use of DTM has become customary in both technical and biological forestry disciplines (Gosshard, 1978). With regard to technical disciplines, DTMs can be used for:

- mapping with aerial photographs (Schneider and Bartl, 1994)
- producing orthophotographs, orthophotoplans and/or orthophotomaps (Ecker, 1992, Miller et al, 1994).

In biological disciplines, DTMs can be used for calculating individual site characteristics (terrain inclination, exposition, insolation, etc.).

The results of interpreting photographs of hilly terrains or spatially heterogeneous areas should be complemented with additional information in raster form - thematic maps (pedological, vegetational and others) and maps describing relief features (inclination, exposition, DTM). In this way, the results of interpretation can be significantly improved (Skidmore, 1988, Lillesand and Kieffer, 1994).

The advantage of DTMs is reflected in the possibility of three-dimensional projections of interesting terrain configurations. Using simple visualisation it is possible to plan and determine forest accessibility and thus contribute to the preservation of the currently highly endangered sensitive natural balance (Pernar, 1996).

RESEARCH GOAL
CILJ ISTRAŽIVANJA

Since the use of remote sensing methods in forestry is not satisfactory, the purpose of this work is to show the possibilities of applying aerial photographs from cyclic aerial survey in the Republic of Croatia to forest management.

Photographs from cyclic survey have been chosen for reasons of their very reasonable price on the market, contrary to commissioned recordings used until now, which made remote sensing very expensive.

The basic guidelines of this work, set down in the Introduction, are concerned with work humanisation, use of new technologies and reduction of data collecting costs.

In order to achieve the set goals, the following procedures should be accomplished:

- vector contour lines and carry out management division
- construct a digital terrain model (DTM)
- produce a digital orthophoto.

The application of individual procedures and the overall model to forest management should be defined on the basis of obtained cyclic aerial photographs, digital terrain model and digital orthophoto, with brief overviews of other segments. In other words, in order to achieve the goal, a model should be analysed qualitatively and quantitatively.

Qualitative analysis involves detection of all differentiating elements of interest to forest management. These elements primarily refer to substituting a manager's (appraiser's) field work on internal forest division with remote sensing methods.

Quantitative analysis is based on five methods of stand volume estimation. To construct these estimations, our own knowledge and insights in forest management was used, as well as past studies of measurement and estimation of growing stock with remote sensing methods.

All qualitative and quantitative data obtained with remote sensing methods will be compared with the data from recent terrestrial measurement in order to:

- use the results of stand volume estimation to define (among five proposed methods) the most suitable estimation to be used in operative forest management,
- identify applicative possibilities of the most suitable estimation, as well as indicate positive and negative aspects of other stand volume estimations (including the most suitable one).

FIELD OF RESEARCH
PODRUČJE ISTRAŽIVANJA

GEOGRAPHICAL POSITION
ZEMLJOPISNI POLOŽAJ

Research was conducted in the management unit "Jamaričko Brdo", part of the Forest Administration Lipovljani.

The forests of this management unit are located in Western Posavina, or more accurately in Moslavina, 5 – 6 km north of Novska and 6 – 7 km east of Lipovljani. In geographical coordinates, this area is located between 16° 40' and 17° 30' east longitude, and 45° 20' and 45° 30' north latitude. This hilly area encompasses the slopes of Blatuško and Novsko Brdo, which are the last sequels of Mount Psunj. The altitude ranges between 120 and 225 m.

PEDOLOGICAL FEATURES
PEDOLOŠKE ZNAČAJKE

Pedological research, followed by soil type mapping in the area of this management unit was done within typological mapping (Jureša et al., 1991).

Based on this research and on geomorphological, physical and chemical properties of investigated soils, forest soils in the management unit "Jamaričko Brdo" were classified and the following soil types: pseudogley, luvisol, dystric cambisol, eugley and colluvium.

CLIMATE
PODNEBLJE

According to Köppen's classification, which is commonly used to represent climate, the area of the management unit "Jamaričko Brdo" belongs to the Cfwbx" climate type.

PLANT COMMUNITIES
BILJNE ZAJEDNICE

The indented relief of this management unit has resulted in diverse site conditions. This is reflected in the composition and distribution of forest communities (Jureša et al., 1991).

Based on previous research, four forest communities have been identified:

- forest of sessile oak and common hornbeam *(Querco petraeae-Carpinetum illyricum* Horvat),
- forest of sessile oak and common hornbeam var. with beech *(Querco petraeae-Carpinetum illyricum* Horvat var. *Fagus sylvatica)*,
- forest of pedunculate oak and common hornbeam (*Carpino betuli-Quercetum roboris* /Anić/ Rauš),
- forest of black alder with quaking sedge (*Carici brizoides-Alnetum* Horvat).

ECOLOGICAL - MANAGEMENT TYPES (EMT)
EKOLOŠKO - GOSPODARSKI TIPOVI (EGT)

Based on the analysis of essential components for determining EMTs, that is, geological - lithological, phytocoenological and pedological components, as well as silvicultural characteristics, productive abilities and economic indicators, four ecological - management types were identified in the management unit "Jamaričko Brdo": II-E-10, II-E-11, II-E-30 and II-G-10.

WORKING METHOD AND RESULTS
NAČIN RADA I REZULTATI

PRODUCING A DIGITAL ORTHOPHOTO MAP
IZRADA DIGITALNE ORTOFOTOKARTE

To produce a digital orthophoto map, suitable technical equipment (hardware and software) and trained staff are needed.

The process of producing a digital orthophoto map can be divided into:

- geometric photo correction
- radiometric (tonal) correction.

It is assumed that the first step of this process is photograph digitalisation; in other words, transforming a photograph from the original graphic (analogue) format to a digital format.

In the process of geometric correction, mathematical models (or a transformation set) are selected which transform one coordinate system into another. Geocoding is the most important process in geometric correction.

Geocoding involves the transfer of individual pixels into the coordinate system of a given cartographic projection. In order to determine the projection coordinates of any pixel, all the data must be geo-referenced (Frančula, 1999).

The procedure consists of identifying and connecting control points (distinct points which are relatively easy to recognise both in recordings and on maps; crossroads, watercourses and river mouths, larger infrastructural objects, road and railway crossings, airports and similar) (Figure 1), so that image coordinates can be transferred into the map coordinate system and vice versa (Oluić, 2001).

To do this, the following transformations can be used: Helmert's, affine, project, polynomial or some other transformation.

Producing an orthophoto on the basis of a photograph involves the use of camera elements, the so-called elements of internal and external orientation, so that a more accurate geometric correction is obtained in the corresponding software.

A digital orthophotographic map is a geometrically corrected photograph in a digital format resulting from a mathematical transfer of digital recordings from the central into the orthogonal projection.

Figure 1. Overlapping of details in the CBM and in the aerial photograph
Slika1. Spajanje (preklapanje) detalja na ODK i aerosnimci

The applicability and suitability of both a photoplan and an orthophotoplan largely depend on photographic quality. Photographic quality regulates not only the accuracy derived from such a plan, but also readability and richness of details and nuances that can be easily observed and clearly established (Braum, 1982).

Since cyclic photographs are taken with standardised methodology and means, the quality of photographic material is predetermined, making it impossible to affect its original recording quality.

However, it is possible to influence the quality subsequently (by regulating contrasts, thickening and thinning, filtering, etc.) after scanning photographic images, that is, after their transformation into a digital format. This is called digital image processing.

Thus, radiometric correction relates to mechanographic image processing aimed at transforming data about (in) an image into the most suitable form for analysis.

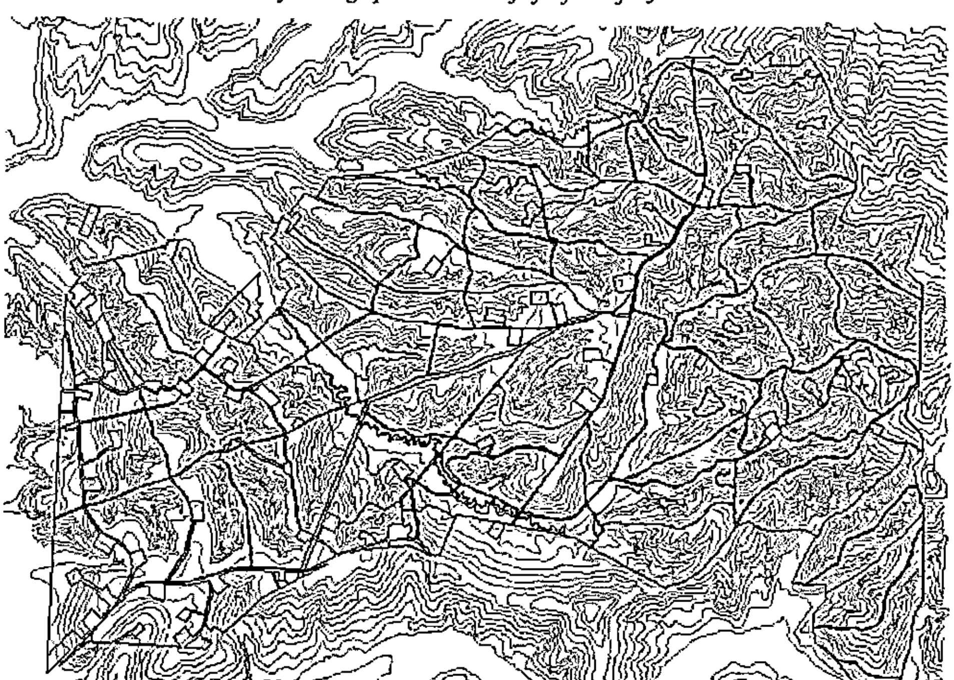
Producing an orthophoto map is a faster and more economical procedure than producing a classical or a digital map. In this case, the user takes over the role of a decoder or interpreter and interprets the shown image from his or her own experience. Such maps are exceptionally suitable for various kinds of spatial planning in urbanism, road building, forestry and water management. The production of an orthophotographic map is based on the oriented digital photogrammetric recording and digital terrain model. Once a digital terrain model has been made, there is no need for new models; thus, the process of producing maps with new recordings is accelerated. This provides for continuous monitoring of spatial events and occurrences. The user receives an analogue orthophoto map (paper) and a digital, geocoded raster image which he can use in his GIS or CAD applications. A digital orthophoto is made in black-and-white (greyscale) or in colour (RGB).

The procedure itself of producing a good-quality digital orthophoto, or the steps preceding a successful realisation of the set goals, is contained in several software packages (R2V, Arc VieW 3.1., ER Mapper 6.1).

Black-and-white aerial photographs (M ≈ 1: 20,000) were used to produce a digital orthophoto, obtained during a cyclic aerial survey of the Republic of Croatia. Recordings no. 061, 063, 065 from the 6/2 series and recordings no. 676 and 677 from the 8/1 series were used for this purpose.

Figure 2. Vectored contour lines and management division of the Management unit "Jamaričko Brdo"

Slika 2. Vektorizirane slojnice i gospodarsko razdjeljenje G. j. "Jamaričko brdo"



Contour lines were vectorised in R2V software to produce DTM and orthophotographs.

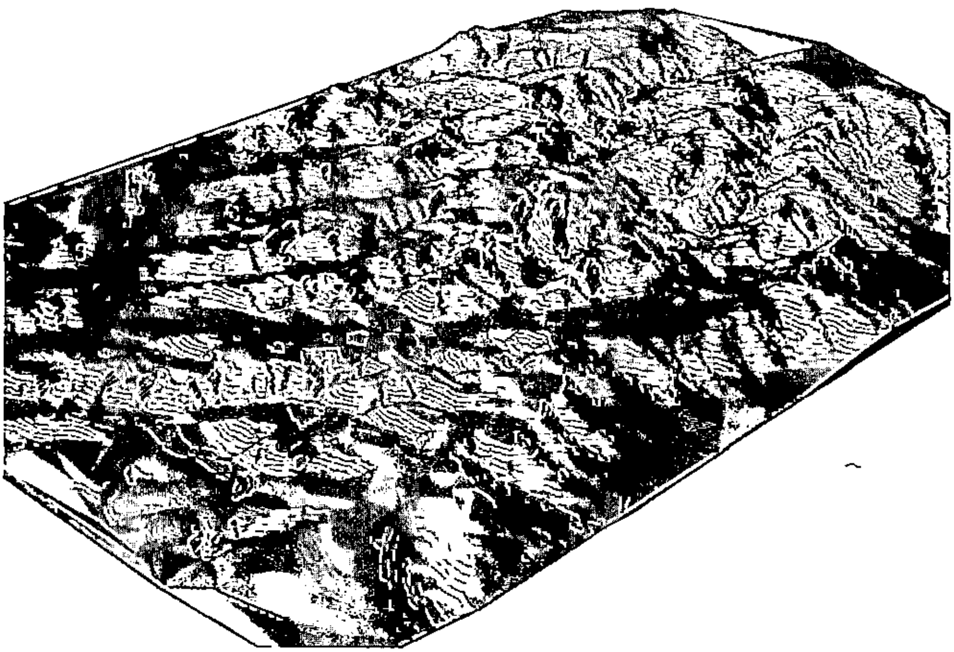
Apart from vectoring contours and external boundaries of the management unit, compartments, subcompartments, roads, trails, gas pipes, facilities, drills and streams were also vectored (Figure 2). After the contours were vectored, they were assigned numerical altitudinal signs (ID).

A digital orthophoto was made with modules of the ER Mapper programme package, version 6.1. The basic parameters required by this software were:

- information about the camera type and calibration parameters, so called Camera file,
- control points with X, Y and Z values are then joined to the recordings. X and Y are coordinate values previously read from geocoded CBM lists, while Z is altitude for the given control points.
- the DEM file is complemented with the produced DTM (Figure 3).

Figure 3. Three-dimensional presentation of a wider area of the M. U. "Jamaričko Brdo" constructed with the z contours and shading

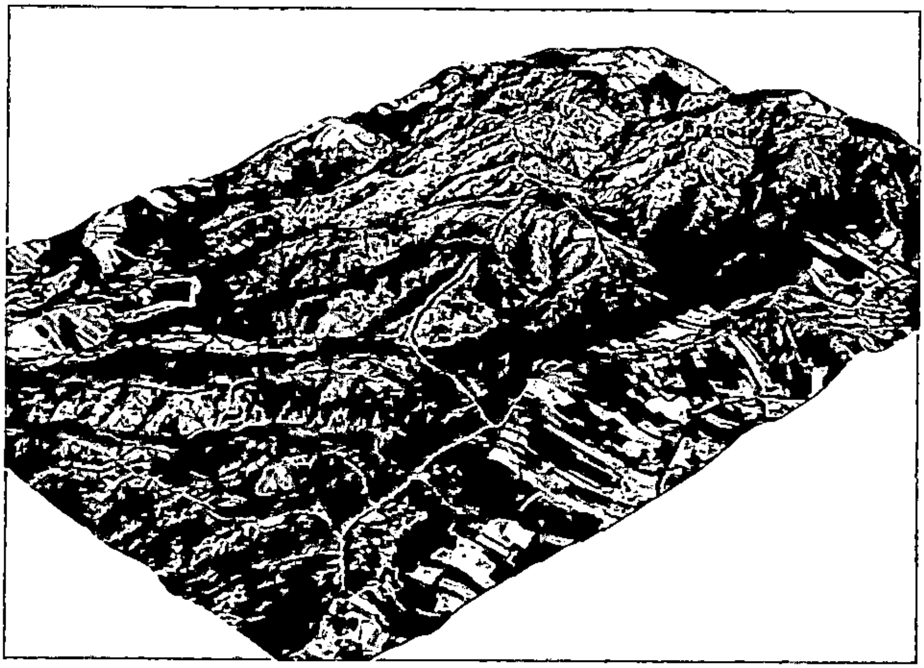
Slika 3. Trodimenzionalni prikaz šireg područja G. j. "Jamaričko brdo", izrađen pomoću z linija (slojnica) i sjenčanjem



After a digital orthophoto was produced (Figure 4), its accuracy, or the accuracy of CBM geocoding, was assessed, because the coordinate values of control points used in the digital orthophoto were read from geocoded CBM lists.

Figure 4. Perspective view of a constructed orthophoto of the M. U. "Jamaričko Brdo", laid over the DTM (a view from the south-west direction)

Slika 4. Perspektivni prikaz izrađenog ortofota G. j. "Jamaričko brdo", prevučen preko DMR-a (pogled iz jugozapadnog smjera)



The accuracy of digital orthophotograph geocoding was assessed on a sample of 43 check points. It was found that the differentiating values along the X and Y coordinates were acceptable, that is, they were below 5.0 m in a positive or a negative sense and fell within the limits of average deviations along the X coordinate of - 2.21 m, or along the Y coordinate of - 4.34 m. For application in forestry operative, where the most suitable and the most widely used map has a 1:10,000 scale, deviation represents the value below 0.5 mm, which is more than acceptable for this profession. More significant deviations were calculated in 6 control points at a maximal value of -25.58 m along the X coordinate and -38.45 m along the Y coordinate.

The results of the CBM geocoding analysis are satisfactory because the deviations of control points (1040) do not exceed 5.00 m, with maximal deviation of 3.68 m along the X coordinate and 3.46 m along the Y coordinate.

From the aspect of forestry operative, it should be stressed again that on the whole these are minimal deviations which relate to a point, that is, a dimensionless object, while all other object have an almost total overlap with their projections on a geocoded CBM either in terms of lines or surfaces.

From this aspect, as well as from the aspect of a broad range of orthophoto applications (presented in this paper), it is recommended that an orthophoto is produced for every management plan (regular review), preferably with larger-scale images. The whole photograph should be covered with control points so as to minimise errors (Klobučar, 2003).

ANALYSIS OF PHOTOGRAPHS
ANALIZA SNIMAKA

In order to present the possibilities of applying cyclic aerial photographs to forest management and make the necessary analyses, we should first know the characteristics of the material (quality, type of photographic layer, scale and others) at our disposal.

Cyclic aerial survey are supervised by the State Geodetics Administration. Understandably, they are oriented towards surveying requirements of space management and have limited application in forestry and forest management.

This does not mean that forestry cannot participate in the work of the State Geodetics Administration. On the contrary, there are open possibilities for adapting a part of this project to the needs of forestry (especially when recording larger forest areas).

If forestry invests in new aerial survey, it will be given an opportunity to actively participate in the planning of aerial coverage and decide on important issues, such as the vegetation period at which to do the survey, the type of camera, the format of aerial photographs, the emulsion, the scale, etc. (Tomašegović, 1986).

The above does not mean that cyclic aerial survey of the Republic of Croatia, that is, aerial photographs as their derivatives in the existing form, should be excluded from applications in forestry.

As the title of this paper says, the basic goal is to present qualitative and quantitative possibilities of using these photographs in Croatian forestry, and in forest management in particular.

This is directly linked to photointerpretation, or to the part used in forestry - aerial photo appraisal.

Aerial photo appraisal is a set of methods used to identify tree species or types of forest vegetation, number and dimension of trees, stand cover, site quality, age and volumes per stand area from aerial photographs (Donassy et al., 1983).

As has been pointed out, aerial photo appraisal is a segment of remote sensing based on aerial photographs. Its results are qualitative and quantitative data.

Qualitative data are subjective by nature. They are determined by a photograph interpreter on the basis of his own observation of photographic features (hue, texture, shape, appearance, structure and others).

Quantitative data are obtained from measuring selected measurable elements in a photograph, both of individual tree elements and of the whole stand.

As this analysis is primarily aimed at obtaining true stand elements in the most economic way in terms of finances and time, it was concluded that this could successfully be achieved with aerial photographs taken in the course of cyclic survey in the Republic of Croatia.

Based on past research, Croatian scientists recommend infrared colour photographs as the most useful, preferably with larger scales (at least 1:10,000) and an overlap of 60% to 70% in all terrain types.

Forestry constantly seeks a new influx of information. Information can be obtained from remote sensing methods. Remote sensing reduces the scope of field data collection and provides advantages in terms of time and economy. Today, photographs have become an indispensable means of studying and monitoring the environmental condition and its changes. The latter refers particularly to colour infrared (CIR) aerial photographs. Photographic interpretation can provide reliable statistical data about various phenomena and objects (Pernar, 1996).

As for the measurement itself, methods of aerial photointerpretation can be divided into those aimed at measuring the size of individual trees and those aimed at measuring stand elements.

Qualitative photograph analysis
Kvalitativna analiza snimaka

It is not possible to achieve the set goal and explain the possibilities of applying remote sensing research, in this case aerial research (aerial photographs from cyclic survey), only with photogrammetry and photo interpretation.

These two only illustrate one side of the issue. To give a comprehensive overview of the application of remote sensing, it is necessary to have theoretical and practical knowledge of the forestry profession, and particularly of forest management as one of the main forestry components.

In describing and analysing qualitative and quantitative applications of cyclic survey in Croatia to forest management, we will primarily focus on the products of these recordings: orthophotographs and stereomodels. The digital terrain model (DTM), since it has been constructed, will serve as a support to the former two products.

This is understandable and acceptable, because they are parts of a model or a whole which share many mutual points. Therefore, the contents of both orthophotos and stereomodels and the DTM partially coincide. Analysis depends to a larger or smaller degree on the observed model features.

If the text does not state explicitly that one or two components of the observed model are being discussed, it will be assumed that the model is regarded as a whole.

SPATIAL FOREST MANAGEMENT
PROSTORNO UREĐIVANJE ŠUMA

Internal forest segmentation consists of dividing a management unit into smaller parts: gravitational areas, watersheds, compartments, subcompartments, cutting sequences and coupes (Klepac, 1965).

This survey of the necessary management (preparatory) and field activities shows the need for comprehensive perception of the position of a management unit and its orographic, hydrographic (or site features in a wider sense) and infrastructural (roads, trains, paths, transmission lines, gas pipes, drills, buildings etc.) characteristics at a micro (internal division) and a macro level, that is, the segmentation of forests into management units.

Therefore, in order to create entry parameters for the purpose of achieving the set objective, it is ideal to have a bird's eye view of the management unit and the wider area.

A stereopair with its contents, supported by a digital terrain model (DTM) or by stereoscopic coverage (3D) satisfies the above mentioned objective.

The parameters enable partial or full analysis and preparation for field coverage of initial activities related to the establishment of a management unit (so called first management) or the reconstruction of management division (e.g. new compartment enumeration, regular review and similar). It also makes it possible to carry out a number of other activities in new or the existing management units, such as compartmentalisation, preliminary stand mapping (subsequently verified in the field), growing stock assessment, area calculation, accessibility, mapping and others.

The support is very useful and purposeful in hilly and mountainous areas (with distinct terrain configuration), but it also benefits lowland regions.

The model contains all the necessary parameters for clear identification of compartment boundaries.

Thus, the model will show identical gravitational areas, which will represent one group. The group will be further divided according to natural terrain features (in the narrow sense), that is, distinct landmarks (ridges, elevations, watersheds, fissures, crests, contours and others) and artificial objects mentioned before.

It is also possible to divide compartments into subcompartments on the basis of similar ecological conditions, as the model enables a view of various expositions, inclinations, sunny and shaded sides, etc.

The DTM support opens further possibilities of applying these and some other analyses (instead of altitude, some other factors are used as the z variable) and gives new quality to spatial division and analysis of a management unit.

It also makes it possible to determine better extracting directions of timber assortments, which would provide economic benefits to forest production and exploitation as an integral forestry discipline.

As for stand mapping, orthophotographs, stereomodels and DTMs can be successfully used.

A number of scientific and specialist articles have been written and published concerning the use of aerial photographs and stereomodels in stand mapping.

In our concrete example, with regard to stand mapping and to all other management (aerial photo appraisal) activities, the main disadvantage of aerial photographs obtained from cyclic survey is the already mentioned small scale and the resulting impossibility of identifying tree species. This is a limiting factor in dividing compartments into subcompartments or in initial stand grouping according to similar species compositions and management classes.

The impossibility of identifying tree species owing to small scales should not be taken in the absolute sense; similar may also happen with aerial photographs using larger scales, but they are much less frequent.

The first part of the text mentions the parameters (exposition, inclination, sunny and shaded sides, terrain indentation, etc.) that can be used in this management activity. In the second part of the text, we will refer to additional possibilities and differentiating factors.

These differentiating factors relate in the first place to the concrete model; however, some other fields (site conditions) considered useful for such a model will also be mentioned.

It is essentially important to realise that there are no established patterns, but only general considerations and accepted postulates. Original solutions and results would depend primarily on the perception of the interpreter and his intellectual abilities, while acquired experience and knowledge would permanently have to be widened and applied to new projects.

In order to use the mentioned site elements for stand mapping, which can be defined with a DTM, then with a stereomodel and to a lesser extent with an orthophoto (contour), it is necessary to know the ecological constitution and biological requirements of tree species in the area under study.

In our concrete example, the more important commercial tree species include sessile oak, common beech and hornbeam, and to a much lesser degree pedunculate oak and alder. Wild cherry is also commercially interesting in this management unit, but since this species has been individually infiltrated, it cannot be identified on the basis of stand features.

The biological-ecological characteristics of these species are well known. In our case, the generally known facts used in remote mapping (which were partially simplified) were confirmed with field observation: sessile oak favours more southern and sunnier sides, beech is more sciophytic and inhabits mainly the slopes, while hornbeam grows in lower parts (usually along the ditches).

The DTM makes it possible to classify the terrain in terms of inclinations, elevations, expositions, weather (insolation) and other factors which indicate stand conditions and quality, as well as various favourable and less favourable species compositions. The stands in compartments 23e, 24a,b, 69a,b were defined and mapped in this way, because steeper inclinations, a more indented terrain with numerous ditches and varying expositions affect site quality and species composition, or, in other words, the entire stand structure.

It should be pointed out that the above are newly mapped compartments. The number of compartments would be much higher if previously mapped stands (through earlier management plan reviews) (compartments 17a,b, 18a,b, 22a,b,c, 23a,b,c,d, 25a,b, 26a,b, 29a,b, 31a,b, 36a,b, 43a,b, 46a,b, 47a,b, 48a,b, 66a,b, 67a,b, 68a,b,) were incorporated. These stands are easily outlined and differentiated with the afore-mentioned parameters.

Preliminary defined inclinations, before field work itself, indicate stands of protective character. In our case there were no such stands or areas because the inclinations were significantly below this category.

It is interesting to do model analysis of areas covered with pedunculate oak, black alder and their accompaniments (hornbeam in the first place, followed by elm, field maple, spreading elm, fruit trees and others). Alder (pure) favours wetter sites immediately adjacent to smaller or bigger streams, while pedunculate oak follows or not, depending on the terrain configuration. Its species composition contains hornbeam and alder in dependence on micro-site conditions.

These sites can successfully be perceived in an orthophotograph and a stereomodel, while sites at low altitudes are detected in DTM.

In the first two means, the sites are clearly visible because their hues are in contrast (dark grey or black) with their surroundings (light grey).

All these site features can be clearly identified in remote sensing research in compartments 23e, 29b in the management class of pedunculate oak, while previous mapping has been verified in the management class of pedunculate oak (compartments 66b, 67b) and management class of black alder (compartments 17b, 18b, 22c, 23c, 25b, 36b, 42b, 46b, 47b, 48b).

There are also smaller areas in which identical or similar characteristics were observed, but they were not investigated due to their size (below 1.0 ha) (e.g. compartments 22b, 24b, 35a, 61a, 68a, b, 69a, b, 70a).

This should be pointed out for the following reason: the orthophotograph is geocoded and the programme provides rapid and accurate definition of area size (closed units - polygons), which makes it possible to analyse area size rapidly and decide whether or not it should be mapped.

This management unit contains only one coniferous stand (management class of spruce, compartment 22d), while in the eastern part (outside the management unit boundaries) there is a coniferous stand that belongs to the forest office of Lipik.

Both stands are clearly visible and recognisable both in the stereomodel and the orthophotograph and can be successfully and simply separated (mapped) from the other part of deciduous stands. In terms of hues, these stands are the darkest, that is, the closest to the black colour.

Density and number of trees
Obrast i broj stabala

One of the most important functions of a model, and especially of a stereomodel and partially of an orthophotograph, is their ability to estimate (appraise) the canopy.

This function was used for stand mapping and, as was later confirmed, for stand volume estimation.

The importance of canopy, that is, the degree of ground cover is primarily in correlation with density.

Stand density may be expressed with the number of trees, basal area and volume of a stand in absolute and relative units. The number of trees is the absolute measure of stand density expressed in the number of trees per hectare. Relative density represents the relationship between absolute stand parameters (number of trees, basal area, volume) and standard (normal, ideal) parameters (Pranjić and Lukić, 1997).

Past research (Neumann 1933, Klier 1974, Križanec 1987, Kušan 1991 and others) has shown firm correlation between these two parameters. Therefore, the use of canopy as a measure of density is justified.

As we know, density is one of the elements for stand mapping, that is, for establishing the difference among identical elements. According to Forest Management Regulations (NN 11/97), there are the following density categories:

- normal density, above 0.8;
- less than normal, from 0.50 to 0.80;
- poor to 0.50.

Based on these indicators, that is, on a firm correlation between density and cover, (the latter was assessed), preliminary remote stand mapping was conducted.

All remote sensing research and detection of varied contents and their mapping is followed by their verification in the field. The same was done in our case, too. Some of the compartments were not mapped for different reasons (homogeneity, small areas, omission, etc.).

Since during the past period some of the stands in this management unit were affected by a calamity in the form of snow and ice break, which resulted in lower density, these stands were identified and mapped with remote sensing means as separate units, that is, as new compartments.

Naturally, there was no mapping in stands whose structure (cover) visually indicated slightly reduced density (for any reason) but still within the limits of normal density (> 0.8), which is the case with the majority of (areas) stands in this management units. Alternatively, lesser damage (not easy to identify) caused a reduction in density by 0.1 - 0.2; therefore, no mapping was necessary, because the stands retained their heterogeneity, but with reduced (compartments: 44b, 53a, 55a, 63a) or slightly reduced density, such as compartments 24a, 32a, 37a, 39a, 40a, 49a, 50a, 52a, 59a.

Stands with moderately reduced density were mapped (by 0.3 – 0.4) in compartments 43a, 44a, 46a, 47a, 61b, 68a, 69a, as well as stands suffering very extensive damage which caused a considerable reduction of density (below 0.5), e.g. compartments 44c, 46c, 48c, 50b, c, 51b, 64c. This also includes stands containing parts in which total tree damage took place (trees were removed with sanitary felling). Presently, these areas are clearings not covered with forest trees: compartments 57b, 61c, 62b, 63b, 64d.

Compartments 14b and 27c (bare productive land for hunting) are also noticeable, whose pictorial texture is unique in the whole area of the observed management unit: this enabled its mapping, while compartment 27d was not mapped since it is partly covered with shrubs and individual trees (alder and poplar).

It can be concluded that stereomodels and orthophotographs made it possible to "recognise the terrain with remote sensing" and indicate stands with reduced density. These areas were mapped and verified with field rounds and adequate marking (permanently mapped).

The importance of "remote terrain recognisance" should be pointed out for the purpose of prescribing silvicultural treatments and necessary material-financial calculations.

Photographs give a very clear picture of large gaps, blanks and clearings resulting from the mentioned elementary catastrophe. The gaps will be restocked (linden and cherry trees) over non-forested stand areas and damaged trees will be removed in compartments 43a, 44a, 45b, 61b, 68a, or a combination of thinning of thicker and more coherent groups and restocking with the mentioned species will be done in compartments 48a, 51a, 69a. The clearings will be afforested.

The calamity will be analysed with regard to the area; in other words, the model will provide the answer to the question "at which expositions and inclinations did the calamity take place?"

In the concrete case, the calamity largely affected southern expositions regardless of their inclination. It is assumed that the trees growing in northern expositions have acquired better resistance and vitality due to more extreme conditions. Microclimatic conditions in these expositions are unfavourable, so these trees have adapted ("acclimatised") to such site conditions.

A stereomodel and an orthophotograph make it very easy to determine areas damaged by snow and ice in the course of several years.

The area and the management unit were cyclically recorded in March, when vegetation was dormant and the ground layer was not developed and did not cover the soil. In the recordings, the ground layer is reflected in white colours or in light grey hues approaching white.

This white "mosaic" in the orthophotograph and the stereomodel, that is, in the stand area (the area among the trees) also indicates stand density to the interpreter (manager). These are rarefied stands, but the total growing stock of the whole area and in terms of hectare is satisfactory (normal), since beeches and sessile oaks, with frequent additions of cherry trees and some individual lindens, have large dimensions and volumes.

A counterpart to these stands would be well canopied stands with no white "patterns". In the stereomodel and the orthophotographs such stands would be reflected in much darker colours (e.g. dark grey or some similar hues) covering the whole area of compartments or subcompartments; their density should be 1.0 or slightly less or more (here I mean the true measured density obtained by comparing concrete and table basal areas, as density assessment with basal areas is the best practice). Judging by density, such stands would have a suitable growing stock.

However, these stands have 10 to 15% less growing stock in relation to table values. Naturally, density was estimated with the same growth-yield table.

How is this possible?

After analysing the model in detail, studying the old management plan and making a field round it was found that these stands grow on sloped terrain, with their compartments or subcompartments climbing down to the ditches.

As was said in the introduction, hornbeam is the most frequent tree species inhabiting lower areas and ditches. It frequently climbs up to 1/3 of the slope (in other words, it has a considerable share in the species composition) and disturbs the desired species composition. In other words, a stand does not have the growing stock that would be expected with regard to normal density (compared to other tree species, hornbeam has smaller dimensions of breast diameters and heights, which results in a lower growing stock).

It would be interesting to study this problem fully by using the existing (constructed) model or some similar or completely different remote sensing methods.

It is a known fact (in even-aged stands) that the number of trees correlates with stand age and quality. Of several thousand trees (per surface unit) in the early developmental stage of a stand, only about a hundred or several hundred trees remain by the end of the rotation period, depending on the principal species and its rotation. It is also known that the number of trees is connected with stand site quality. The higher the quality, the lower the number of trees is, and vice versa. Trees in (with) better site qualities have larger dimensions and stands have larger growing stocks.

This fact was used to try and determine whether it was possible to map a stand on the basis of the measured (counted) number of trees in a stereomodel, in other words, whether it was possible to use this parameter to measure or estimate the growing stock.

The number of trees counted in the stereomodel did not correspond to terrestrially counted number of trees, or the age of a given stand.

There are justifiable reasons for this: in the first place, the small scale of the photographs (M ≈ 1:20,000), the season in which the cyclic coverage was done (March), in which vegetation was still dormant and tree crowns were not sufficiently distinct to be observed (counted).

In this sense, it can only be said that the number of trees counted in the stereomodel was 30 - 50% lower for the given stand (compartment) in relation to the number of trees recorded with partial terrestrial measurement. This parameter cannot be used for stand mapping or for measurement or estimation of the stand's growing stock.

Classifying stands into age classes and assistance with thinning

Svrstavanje sastojina u dobne razrede i pomoć pri prorjeđivanju

A stereomodel makes it possible to classify stands into age classes directly by age and stage of development (this possibility is considerably reduced in an orthophotograph). Age classes are grouped so that young, middle-aged and old stands are differentiated.

The observed management unit has a distinctly unfavourable age structure consisting mainly of middle-aged stands.

The boundary of a young stand, compartment 26b (I age class) in the management class of pedunculate oak was clearly outlined in the stereomodel and orthophoto, while a young stand (compartment 27b) in the management class of common beech was not identified as such. Stands at the end of the rotation can only be identified in a stereomodel. One stand (compartment 22e) in the management class of common beech and one stand (compartment 25b) in the management class of black alder were identified in this way. The two remaining stands (compartments 22a, 23a) in the management class of common beech were not detected. Therefore, possibilities of classifying stands into age classes on the basis of visible characteristics (primarily in the stereomodel) are reduced.

Although this is a relatively rough stand stratification based on age structure, it may provide new information to somebody with a good knowledge of productive forest (stand) abilities in the given area. Here, we primarily mean the prescribed yield.

For example, if we know that the forests in this or some other management unit have an average increment of 9 m^3/ha (for the period of 10 years; 90 m^3/ha) and that their average wood mass is 250 m^3/ha, it can easily be concluded (based on the model analysis) in which area thinning should be done, what its average intensities should be and what the thinning volume should be, which would have very positive effects in planned management.

An analogue procedure could be applied to stands intended for principal yields.

The above will be particularly useful in management units with irregular age structures in which stands are grouped in two or three age classes.

The produced model can also be applied to the prescribed yield of previous thinning, which would indicate to the manager the parts (areas) of stands in which this silvicultural procedure was not done in the previous period or was done with weaker or stronger intensity.

Photointerpretation should result in a map showing non-thinned, poorly thinned or intensively thinned parts of a compartment. These data, combined with table surveys, show areas where interventions are needed and give a plan of future thinning activities in general (Tomašegović, 1983).

Understandably, each remote mapping of this or any other content should be followed by ground verification in a positive or negative context.

In positive cases (assumed to be dominant), field activities will be made easier (for example, a part of the areas will already have been mapped), while all disadvantages of such mapping should be solved on the ground.

APPLYING MODELS TO OTHER FIELDS
MOGUĆNOST PRIMJENE MODELA NA DRUGIM PODRUČJIMA

A properly constructed model can purposefully be applied to some other segments of management or any other silvicultural activities.

Other possibilities will be described of using aerial photographs or constructed models in forestry. This refers to contents that are considered useful in forest resource management.

The previous chapter deals with the analysis of a model based on a concrete example so that damage from snow and ice can be assessed. This model may also be used in an identical or modified way to analyse other forms of calamities (stand dieback, fires, windthrows, etc.).

DTMs can be used to determine points (viewpoints) of observation posts (e.g. fire, hunting and others) with the aim of building as few observation posts as possible while at the same time covering the largest possible (fire-fighting) or desirable (hunting) visible areas.

Furthermore, these models give a true (non-subjective) presentation of spatial arrangement, that is, terrain configuration in altitudinal and horizontal sense, as well as contents in this terrain. Agricultural areas, forest complexes, roads, waterways (rivers, larger streams, lakes and others), various artificial objects (drills, quarries, buildings, houses and others) and infrastructural facilities (gas lines, transmission lines, light strips, etc.) are clearly outlines in the models.

This is useful as it was found that less forest area may be mapped in the CBM by forestry criteria than in aerial photographs.

Significant differences were found between forest surface area and CBM and forest surface area obtained from aerial photo interpretation. In the CBM there was 15.5% less mapped forest surface. The most frequently unmapped objects were forest stands in different degradation stages (Pilaš, 1993).

Similar situations were observed during management activities in the eu-Mediterranean and the sub-Mediterranean, since management division and other forms of division were based on CBM lists.

It can be concluded that the application of models is purposeful for the following reason: contents in the CBM are not updated regularly after every environmental change, whereas recent aerial photographs (orthophoto maps) give a true "new" state in the field.

Almost identical problems occur in management units where towers (oil-wells) for geological and mining research or exploitation are positioned. Such plants are situated in the management unit "Žutica" and the investigated management unit "Jamaričko Brdo" (both in the area of Forest Administration, Branch Office Zagreb). When forested areas are segmented and cleared (complete removal of vegetation) so that wells can be activated, these plants generally take up much larger areas than is necessary for their optimal function.

Aerial photographs or orthophotos give a highly accurate picture of the scope of unnecessary forest removal, since they clearly discriminate between the "working" (active) part of the well and the areas (also cleared) presently covered with pioneer species or shrubs.

Maps can be made of areas around the wells that may soon be restored to production, since no geological-mining operations are taking place there.

In other words, the model can be used for studying the dynamics of "surface mining", and for reducing unnecessary operations (cutting, digging etc.) in a forest complex.

The material can be used for making retention plans for protection against torrents and harmful deposits carried by these torrents.

The model can also be applied to landslide assessment. Areas where forests are managed in the vicinity of public roads (and elsewhere) can be inspected for risks of slides and danger to passengers.

It is a well known fact that most of the problems (stand degradation in the first place) in lowland forests are linked to water (river valleys and courses, elevations, depressions, dams, ditches, hydropower stations, dry periods during vegetation, floods, etc.), and that stands are under the strong influence of water (groundwater and floodwater). We believe that the model can be used in soil draining and irrigation (forest canals or any other facilities and operations aimed at regulating the water regime) in an efficient and materially acceptable manner.

When management plans are reviewed, new areas (cadaster plots) are almost always added which are more or less dispersed around the parent management unit. We are usually unsure (due to outdated cadaster data) what type of land is involved (agricultural, forest, and others) and where exactly it is located. By geocoding the cadaster plan and its "overlapping" with the orthophoto (in the corresponding programme), the exact spatial distribution (location) of new areas (cadaster plots) is obtained. Updated situation is also achieved together with the purpose and management with these areas in the past. Therefore, models, that is, orthophotos, are used to delineate ownership boundaries.

The accessibility of a management unit (km/1,000 ha), or the accessibility of compartments and subcompartments in the orthophoto (in the corresponding programme environment) can be quickly and simply identified both in individual sequences and along the whole length of communications. As for the communications themselves (usually asphalted), whether used for public or forestry purposes or only for forestry purposes (usually non-asphalted roads, skidding lines and similar), their identification in the model (stereomodel and orthophoto) is better if they are wider and if they pass through or divide young stands, while in older stands covered with tree crowns only contours can be outlined.

STAND VOLUME ESTIMATION
PROCJENA VOLUMENA SASTOJINE

Volume estimation and field measurement included in this work do not refer to all the stands, that is, to the total forested area (1,341.04 ha) in the management unit "Jamaričko Brdo".

The stands in the 1st age class (14.67 ha) and commercial and protection stands in the management class of black alder (31.19 ha), which are not suitable for this analysis, have been excluded.

The total analysed area of the management unit has been reduced by 45.86 ha, and amounts to 1,295.18 ha.

Field measurement and data processing
Terenska izmjera i obrada podataka

Field activities involving a regular management review for the management unit "Jamaričko Brdo" was done during autumn and winter of 2001 and to a lesser extent at the beginning of 2002. All the activities were done according to the Forest Management Act (NN 11/97).

Before estimating stand volumes, we had at our disposal recent data with newly recorded boundaries of compartments and subcompartments (recorded with the GPS), their areas based on geocoding the management map, and the proportion of individual management classes and their age structures.

Distributions of breast diameters by compartments by tree species were entered in UREL (a programme for constructing management plans in "Croatian Forests" Ltd). The stands were previously grouped (by purpose, management and age class and site quality). The corresponding local height curves were allocated within the groups, thus obtaining growing stocks based on height curve parameters and parameters of volume tables for a given species.

Partial stand inventory was done over a larger part of the treated management unit by placing circles with a 13m-radius (1,260 circles were measured), while the total (complete) measurement or the so-called callipering was done over only 34.84 ha.

Methods of volume estimation
Metode procjene volumena

Stand volumes were estimated with five methods:

I with Špiranec's growth-yield tables
II with normal models according to ecological-management types

III by putting compartments into classes according to management and age class and site quality using a referent compartment

IV by putting compartments into classes according to management and age class without a referent compartment

V on the basis of terrestrially measured maximal, minimal and average growing stock per hectare.

General pre-activities, common to all these estimations, relate to the construction of the model (orthophoto and stereomodel) described above and management classification vectoring.

No data on new growing stocks (V_m) were available in estimating the volume (V_p) of a stand; however, work was made easier by the fact that stand conditions of this management unit were very familiar.

In all methods of stand volume estimation, the appraised density (S) was used as the entry parameter, or reducer. This parameter was used directly in the first two methods and indirectly in the remaining three methods.

Density was estimated both in the stereomodel and the orthophoto. Management division was put over the orthophoto. This procedure considerably alleviated the work, because compartment and subcompartment boundaries can be identified with higher certainty in the stereomodel. The advantages of these two different pieces of "groundwork" successfully complemented each other.

The first and the second method of stand volume estimation were based on growth-yield tables (Špiranec, 1975, Bezak et al. 1989) and the age - growing stock relationships observed during estimation.

In the third method of stand volume estimation, the stands were first grouped according to defined criteria. Estimation itself was based on visual observation and perception of the features of every compartment in the stereomodel and the digital orthophoto in comparison with the referent compartment.

The fourth method of stand volume estimation was used by Pejnović (2000) in his specialist work. Since he based his interpretation on satellite recordings, it is understandable that this estimation method was partially adapted to the available material.

The fifth method of stand volume estimation was based on terrestrial measurement and statistical method of calculated growing stocks per hectare and of subsequently selected compartments (five), whose growing stocks and perceived images from the stereomodel and the orthophoto were used for comparison with volume estimation of other stands, which were also observed in a stereomodel and in a digital orthophoto.

Stand volume estimation based on Špiranec's growth-yield tables
Procjena volumena sastojine uz pomoć Špirančevih prirasno-prihodnih tablica

Stand age directly correlates with its growing stock. The analysis of trends in growing stocks with Špiranec's growth-yield tables revealed that for a given site quality (for Croatian principal commercial species: pedunculate oak, sessile oak and common beech), age multiplied with a certain number gives a growing stock that is approximately equal to the normal growing stock over a longer period of stand development (from 30 to 70 years).

This was confirmed with dendrometric processing of terrestrial measurement.

For example: in our concrete case (compartment 23b), a stand in the management class of pedunculate oak, aged 70 years, in the 1st site quality, has a growing stock of 333 m^3/ha and density of 0.85. According to the growth-yield table for the given age in the 1st site quality, the normal growing stock is 382 m^3/ha. When this growing stock is multiplied with concrete density (0.85), the result is 325 m^3/ha, which does not show any important difference in relation to terrestrial measurement (-2.4%).

In this example the mean annual increment of the principal stand is 5.46 and is obtained with dividing the normal growing stock (382 m^3/ha) with the stand age (70 years).

This number in fact represents the mean annual increment (i_p) of the principal stand, which also corresponds to the maximal average annual, or the maximal ten-year thinning volume per hectare, calculated on the basis of Matić's formula (1991).

This fact was used in stand volume estimation in the following way: density was assessed with the model, while site quality and age were taken from terrestrial measurement (Table 1).

Table 1. Simplified relations of site class values, ages and calculated factors according to Špiranec's growth-yield tables for pedunculate oak, sessile oak and common beech (* for older and younger stands the i_p is reduced by 1.0 from the calculated one).

Tablica 1. Pojednostavljeni odnosi bonitetnih vrijednosti, primjerenih starosti i izračunatih faktora prema Špirančevim prirasno-prihodnim tablicama za hrast lužnjak, hrast kitnjak i običnu bukvu (za starije i mlade sastojine uzima se za 1,0 umanjen i_p od izračunatog.)*

	Age Dob	Site quality I *Bonitet I*	Site quality II *Bonitet II*	Site quality III *Bonitet III*
		i_p*	i_p*	i_p*
Quercus robur	31 – 100	≈ 6	≈ 5	≈ 4
Quercus petraea	31 – 60	≈ 6	≈ 5	≈ 4
Fagus sylvatica	31 – 100	≈ 6	≈ 5	≈ 4

It can be concluded (for these three species and the corresponding normal models) that the value of mean annual increment diminished by one in young, middle-aged and old stands stems from the fact that the mean annual increment in young stands is on the upward trend, in middle-aged stands it culminates and retains approximately the same values over a longer time period, and then falls after 2/3 of the rotation (pedunculate oak), or 1/2 of the rotation (sessile oak), while in case of beech, it retains identical values from 1/3 to the end of the rotation.

This is verified with the culmination of volume increment of sessile oak, which culminates with 12.1 m^3/ha before the age of 25 in the 1st site quality, of pedunculate oak with 12.7 m^3/ha as late as the age of 75, and beech with 13.5 m^3/ha at the age of 55 (Špiranec, 1975).

Mean annual increment culminates later than current annual increment. In accordance with periods of the culmination of current annual increment, the value of mean annual increment of the principal stand is easily observed and explained over the mentioned periods.

This method makes it possible to estimate stand volumes quickly and efficiently and carry out terrestrial measurement without using growth-yield tables. The condition for this is the knowledge of mean annual increment and properly identified stand density and site quality. For our concrete example, this means:

70 (years) x 5.46 (ip) x 0.85 (density) = 325 m^3/ha or

382 m^3/ha (normal growing stock) x 0.85 (density) = 325 m^3/ha

Statistical processing of results of the 1st assessment (Figure 5, 6)

X

estimation		reliability	
$\bar{V}_p$	270.35	P 95%	253 < 270 < 287
std	79.05	P 99%	248 < 270 < 292
var	6248.91		
cv	29.24		

Y

measurement		reliability	
$\bar{V}_m$	272.18	P 95%	255 < 272 < 290
std	81.56	P 99%	249 < 272 < 295
var	6652.56		
cv	29.97		

r	0.90	$y = b_1x+b_0$
cov	5756.55	$b_1 = 0.93$
		$b_0 = 20.10$

F-test		U-test	
F-cal.	1.06	-cal.	0.16
F-test ($\alpha = 0.01$)	1.70	U-test ($\alpha = 0.01$)	2.56
F-test ($\alpha = 0.05$)	1.45	U-test ($\alpha = 0.05$)	1.96

At estimation probability of 95%, it can be concluded that 270 m^3/ha is within the interval between 253 m^3/ha and 287 m^3/ha. Analogously, starting from 99% probability, the number 270 m^3/ha falls within the interval [248, 292].

Figure 5. Graphic presentation of the estimated and measured volume value ratio (1st estimation)

Slika 5. Grafički prikaz odnosa procjenjenih i izmjerenih vrijednosti volumena (I procjena)

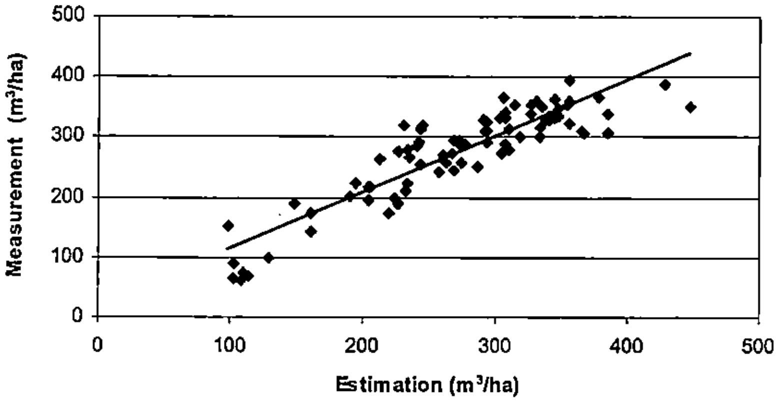
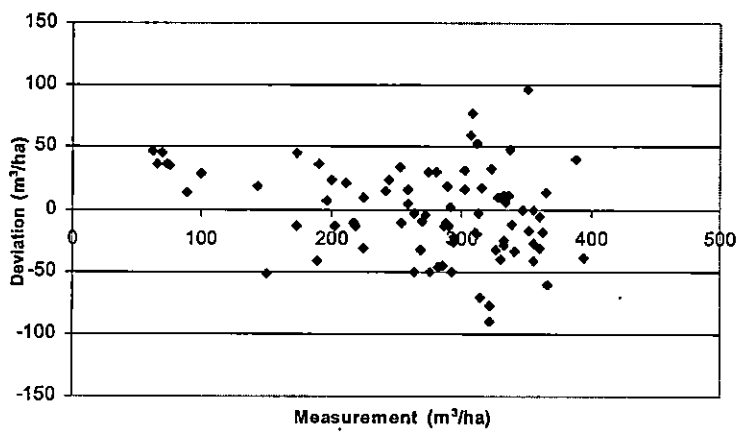


Figure 6. Graphic presentation of the deviation of estimated volume values from measured volume values (1st estimation)

Slika 6. Grafički prikaz odstupanja procjenjenih od izmjerenih vrijednosti volumena (I procjena)



Estimation of stand volume with normal model according to ecological-management types

Procjena volumena sastojine uz pomoć normala prema ekološko-gospodarskim tipovima

This method of stand volume estimation is almost analogous to the method of volume estimation described above, the only difference being the use of different growth-yield tables.

This model uses growth-yield tables calculated on the basis of ecological-management stand types. These tables do not contain site quality because the tables themselves reflect site qualities (Table 2).

Since the stands in this management unit are mostly mixed, the applied growth-yield tables were for mixed stands of sessile oak, beech and hornbeam EMT II-E-10, growth-yield tables for mixed stands of sessile oak and beech EMT II-E-11 and growth-yield tables for mixed stands of pedunculate oak and hornbeam EMT II-G-10.

Table 2. Average increment values of the main stand for the following EMT: II-E-10, II-E-11, II-G-10

Tablica 2. Vrijednosti prosječnog prirasta glavne sastojine za EGT: II-E-10, II-E-11, II-G-10

Age *Dob*	II-E-10		II-E-11		II-G-10	
	Growing stock *Drvna zaliha*	i_p	Growing stock *Drvna zaliha*	i_p	Growing stock *Drvna zaliha*	i_p
20	57.9	2.90	58.7	2.94	63.2	3.16
30	104.3	3.48	102.2	3.41	115.0	3.83
40	151.9	3.80	158.4	3.96	169.7	4.24
50	198.0	3.96	211.2	4.22	237.4	4.75
60	241.5	4.03	261.0	4.35	310.9	5.18
70	279.7	4.00	307.1	4.39	407.4	5.82
80	309.1	3.86	342.9	4.29	433.2	5.42
90	343.9	3.82	378.1	4.20	455.3	5.06
100	387.6	3.88	411.3	4.11	496.9	4.97
110	411.8	3.74	432.0	3.93	535.1	4.86
120	452.4	3.77	449.6	3.75	562.4	4.69
130					588.9	4.53
140					595.0	4.25

The EMTs by compartments were taken from earlier management plans (valid from 1 Jan 1992 - 31 Dec 2001).

Statistical processing of results of the 2nd assessment (Figure 7, 8)

X

estimation		reliability	
$\bar{V}_p$	240.59	P 95%	225 < 241 < 256
std	73.61	P 99%	220 < 241 < 261
var	5418.03		
cv	30.59		

Y

measurement		reliability	
$\bar{V}_m$	272.18	P 95%	255 < 272 < 290
std	81.56	P 99%	249 < 272 < 295
var	6652.56		
cv	29.97		

r	0.81	$y = b_1x+b_0$
cov	4826.81	$b_1 = 0.90$
		$b_0 = 55.23$

F-test		U-test	
F-cal.	1.23	U-cal.	2.57
F-test ($\alpha = 0.01$)	1.70	U-test ($\alpha = 0.01$)	2.56
F-test ($\alpha = 0.05$)	1.45	U-test ($\alpha = 0.05$)	1.96

Figure 7. Graphic presentation of the estimated and measured volume value ratio (2nd estimation)

Slika 7. Grafički prikaz odnosa procjenjenih i izmjerenih vrijednosti volumena (II procjena)

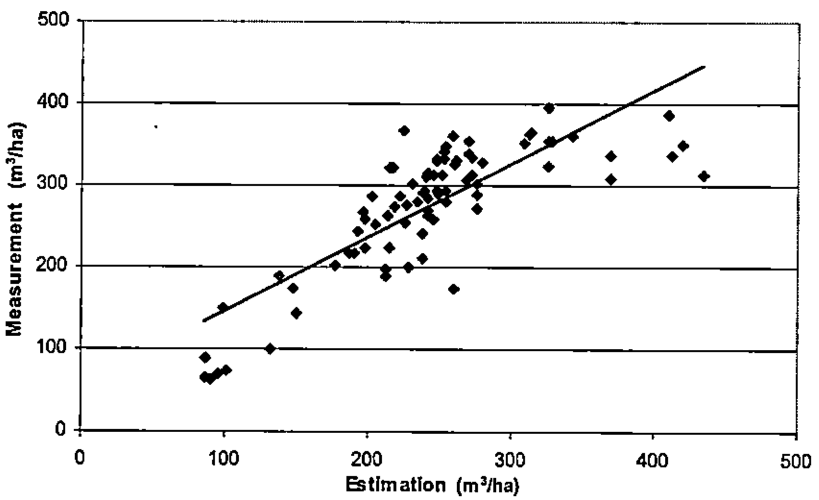
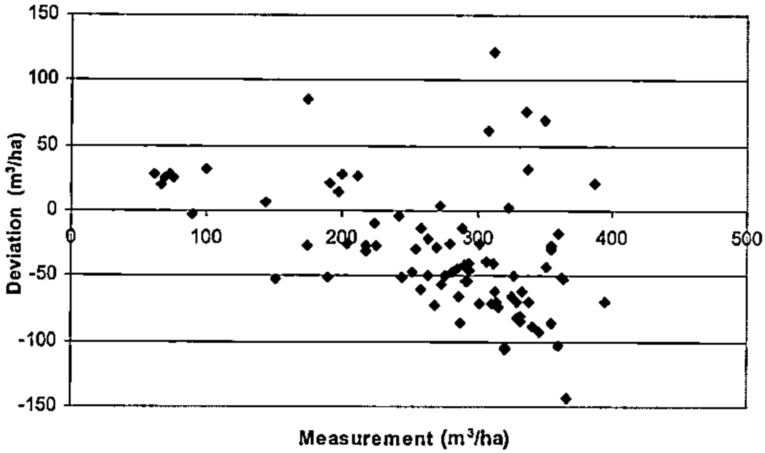


Figure 8. Graphic presentation of the deviation of estimated volume values from measured volume values (2nd estimation)

Slika 8. Grafički prikaz odstupanja procjenjenih od izmjerenih vrijednosti volumena (II procjena)



At estimation probability of 95%, we conclude that 241 m^3/ha are in the interval from 225 m^3/ha to 256 m^3/ha. Analogously, starting from 99% probability, the number 241 m^3/ha falls within the interval [220, 261].

Stand volume estimation by grouping compartments into classes according to management and age class and site quality using a referent compartment
Procjena volumena sastojine svrstavanjem odsjeka u klase prema uređajnom i dobnom razredu i bonitetu uz korištenje referentnog odsjeka

Since the majority of the stands in this management unit are in the 4th age class of sessile oak management class (rotation 120 years), the compartments within this and other management classes (pedunculate oak and common beech) have been classified according to age class and site quality.

The age class range of the principal Croatian commercial tree species is 20 years. In our concrete case, it is between 61 and 80 years for the most common 4th age class.

An arithmetic mean of the growing stock per hectare was calculated within every class. One compartment was selected in every class, whose growing stock was identical or similar to the previously calculated one. The selected compartments were considered the best class representatives and defined as referent compartments.

The referent compartment represents the growing stock of an average model stand in a certain class and is used to correct estimation of growing stocks in the other compartments.

No referent compartment was selected for the classes with fewer than five compartments. Instead, a referent compartment from the class most similar to the no-referent class compartment was used.

The constructed orthophoto was used to estimate the growing stock of every compartment, i.e. its digital record on the monitor screen, as well as stereoscopic observation of the given compartment.

Statistical processing of the results from the 3rd assessment (Figure 9, 10)

X			
estimation		reliability	
$\bar{V}_p$	264.49	P 95%	247 < 265 < 282
std	78.51	P 99%	242 < 265 < 287
var	6164.02		
cv	29.68		

Y			
measurement		reliability	
$\bar{V}_m$	272.45	P 95%	254 < 273 < 291
std	83.40	P 99%	248 < 273 < 297
var	6955.47		
cv	30.61		

r	0.94	$y = b_1x + b_0$
cov	6080.42	$b_1 = 1.00$
		$b_0 = 8.16$

F-test		U-test	
F-cal.	1.13	U-cal.	0.61
F-test ($\alpha = 0.01$)	1.70	U-test ($\alpha = 0.01$)	2.56
F-test ($\alpha = 0.05$)	1.45	U-test ($\alpha = 0.05$)	1.96

At estimation probability of 95%, it can be concluded that 265 m^3/ha is in the interval from 247 m^3/ha to 282 m^3/ha. Analogously, starting from 99% probability, the number 265 m^3/ha falls within the interval [242, 287].

Figure 9. Graphic presentation of the estimated and measured volume value ratio (3rd estimation)

Slika 9. Grafički prikaz odnosa procjenjenih i izmjerenih vrijednosti volumena (III procjena)

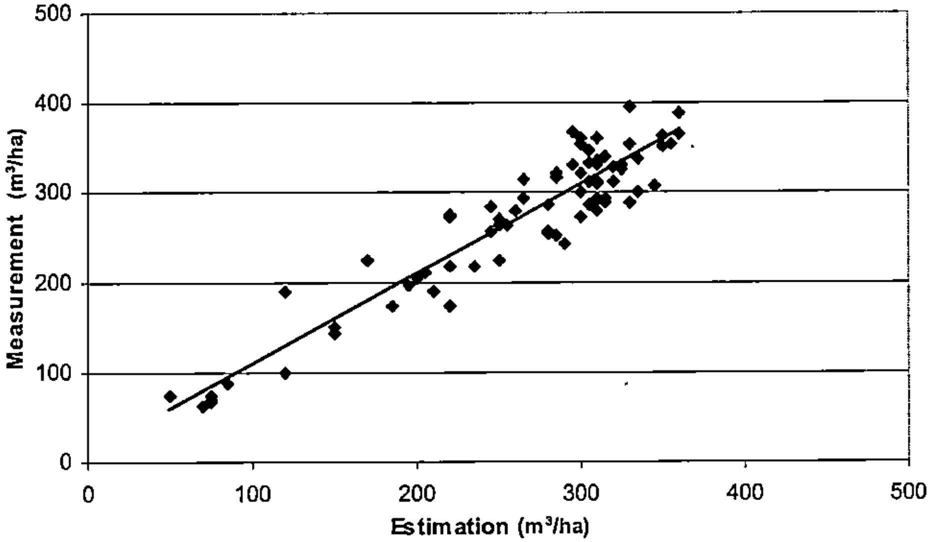
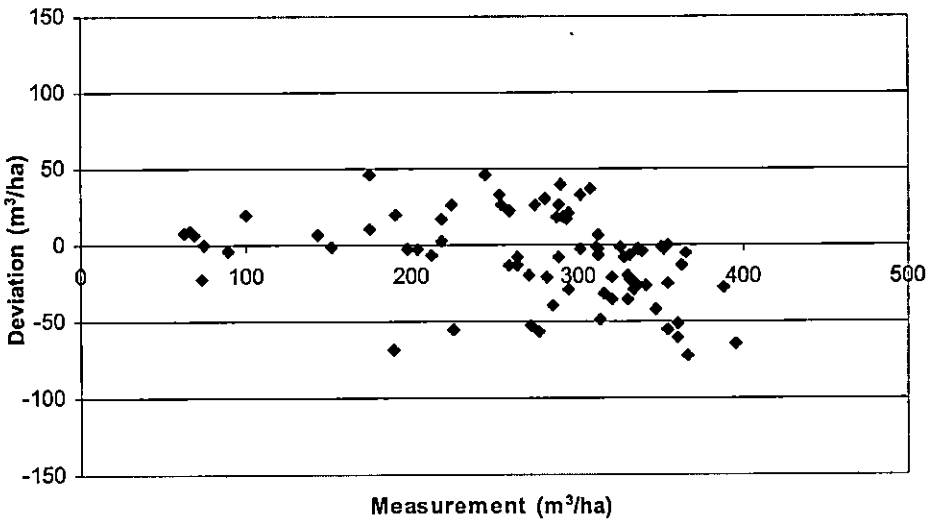


Figure 10. Graphic presentation of the deviation of estimated volume values from measured volume values (3rd estimation)

Slika 10. Grafički prikaz odstupanja procjenjenih od izmjerenih vrijednosti volumena (III procjena)



Estimating stand volumes by grouping compartments into classes according to management and age class without a referent compartment

Procjena volumena sastojine svrstavanjem odsjeka u klase prema uređajnom i dobnom razredu bez referentnog odsjeka

Before estimating stand volumes with the above method, compartments were grouped by management and age class.

As was the case with the earlier estimation method, a digital orthophoto was combined with stereoscopic observation of a given compartment. Visual perception of the compartment was compared with other compartments in a given group.

Naturally, to accomplish the work, concepts perceived during taxation (field) activities were used, as well as theoretical concepts and relevant facts concerning maximal and minimal limits of growing stocks of individual management classes at a given age (age class).

Statistical processing of results of the 4th assessment (Figure 11, 12)

X

estimation		reliability	
$\bar{V}_p$	293.55	P 95%	276 < 294 < 312
std	82.00	P 99%	271 < 294 < 317
var	6724.71		
cv	27.93		

Y

measurement		reliability	
$\bar{V}_m$	272.18	P 95%	255 < 272 < 290
std	81.56	P 99%	249 < 272 < 295
var	6652.56		
cv	29.97		

r	0.87	$y = b_1x + b_0$
cov	5763.82	$b_1 = 0.87$
		$b_0 = 17.50$

F-test		U-test	
F-cal.	1.01	U-cal.	1.76
F-test ($\alpha = 0.01$)	1.70	U-test ($\alpha = 0.01$)	2.56
F-test ($\alpha = 0.05$)	1.45	U-test ($\alpha = 0.05$)	1.96

At estimation probability of 95% it can be concluded that 294 m³/ha is in the interval from 276 m³/ha to 312 m³/ha. Analogously, starting from 99% probability, the number 294 m³/ha falls in the interval [271, 317].

Figure 11. Graphic presentation of the estimated and measured volume value ratio (4th estimation)

Slika 11. Grafički prikaz odnosa procjenjenih i izmjerenih vrijednosti volumena (IV procjena)

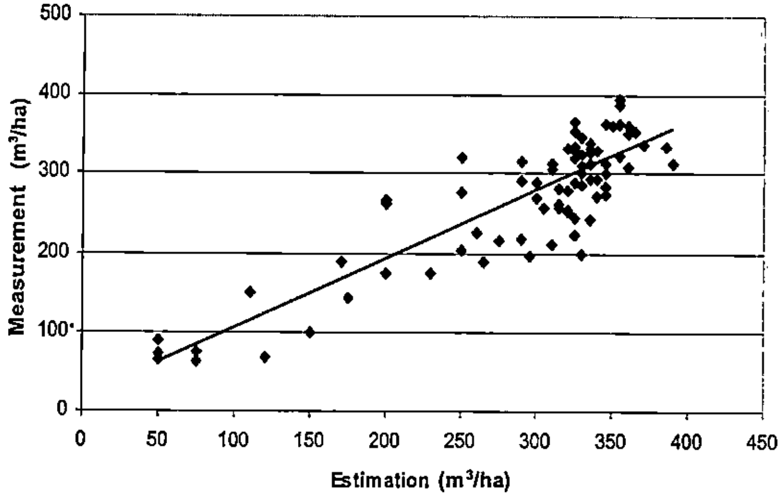
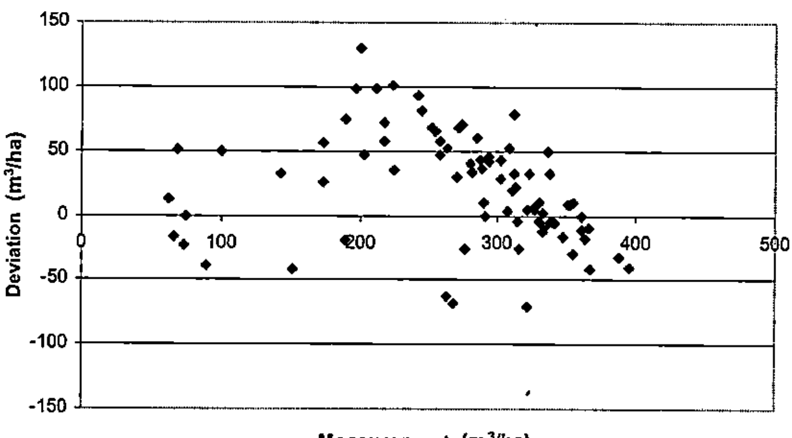


Figure 12. Graphic presentation of the deviation of estimated volume values from measured volume values (4th estimation)

Slika 12. Grafički prikaz odstupanja procjenjenih od izmjerenih vrijednosti volumena (IV procjena)



Stand volume estimation based on terrestrially measured maximal, minimal and average growing stock per hectare

Procjena volumena sastojine na osnovi terestički izmjerene maksimalne, minimalne i prosječne drvne zalihe po hektaru

In the method of stand volume estimation, maximal, minimal and average growing stock per hectare was measured terrestrially for all compartments, regardless of the management and age class.

Based on the average growing stock, those compartments were selected whose growing stocks were the closest to the previously calculated stock. Two arithmetic means were determined between the maximal and the average, that is, the minimal and the average growing stock per hectare. Two stands were found whose measured growing stocks per hectare were the closest to these arithmetic means.

In this way three compartments with maximal (15a), minimal (48c) and average (36a) growing stocks per hectare were obtained and two compartments (33a, 43a) whose terrestrially measured growing stocks per hectare were between these two poles (in this case, extremes) and the average growing stock.

The function of five compartments was analogous to that of a referent compartment in the third method of stand volume estimation. In this method, these compartments were first observed in the stereoscope and digital orthophoto. Based on their terrestrially measured growing stock per hectare and the previously perceived picture, the growing stock of each compartment was estimated by means of the stereoscope and orthophoto. Taking into consideration overall insights into the compartment and the management unit, they were compared with previous compartments.

Statistical processing of the results of the 5th assessment (Figure 13,14)

X

estimation		reliability	
$\bar{V}_p$	276.67	P 95%	259 < 277 < 294
std	78.22	P 99%	254 < 277 < 299
var	6118.61		
cv	28.27		

Y

measurement		reliability	
$\bar{V}_m$	273.77	P 95%	256 < 274 < 291
std	78.34	P 99%	251 < 274 < 297
var	6137.56		
cv	28.62		

r	0.94		$y = b_1x + b_0$	
cov	5695.83		$b_1 = 0.94$	
			$b_0 = 12.87$	
F-test			U-test	
F-cal.		1.00	U-cal.	0.24
F-test (α=0.01)		1.70	U-test (α = 0.01)	2.56
F-test (α=0.05)		1.45	U-test (α = 0.05)	1.96

Figure 13. Graphic presentation of the estimated and measured volume value ratio (5th estimation)

Slika 13. Grafički prikaz odnosa procjenjenih i izmjerenih vrijednosti volumena (V procjena)

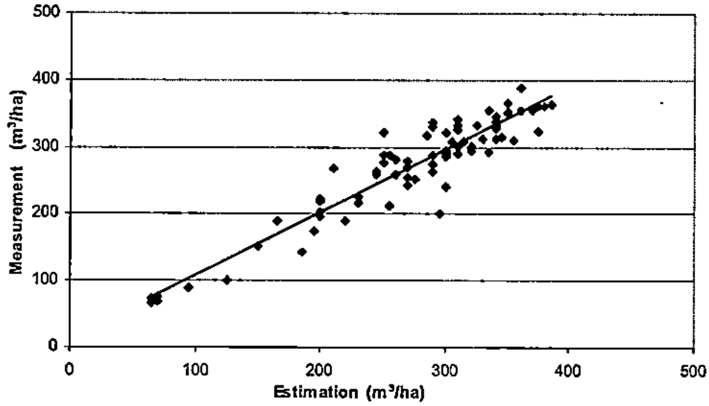
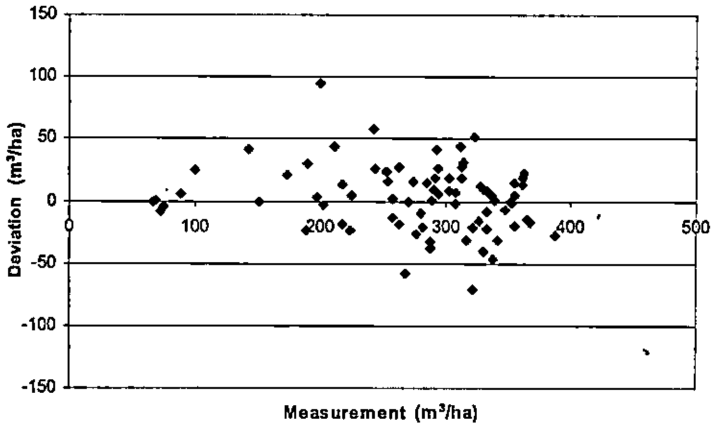


Figure 14. Graphic presentation of the deviation of estimated volume values from measured volume values (5th estimation)

Slika 14. Grafički prikaz odstupanja procjenjenih od izmjerenih vrijednosti volumena (V procjena)



At estimation probability of 95%, it can be concluded that 277 m³/ha is in the interval from 259 m³/ha to 294 m³/ha. Analogously, starting from 99% probability, the number 277 m³/ha falls in the interval [254, 299].

DISCUSSION
RASPRAVA

Before any statistical data analysis, it is necessary to explain some basic parameters in the management unit "Jamaričko Brdo". The obtained results will be compared and deviations explained (in other words, the strength of corelation between an individual estimation and the measured growing stock), (Table 3, 4).

These parameters are very important for constructing the estimation model, for example, by grouping stands according to similar features and selecting and forming samples that should represent the basic statistical set (management and age class, site quality, etc.).

The goal is to explain the reasons for statistical deviations, as well as advantages and disadvantages of individual estimations both in the sample and in other management units.

The table 3 shows the total forested area of the management unit "Jamaričko Brdo". As was said before, the analysis of stand volume estimation did not include stands in the 1st age class (since these are not measured due to a low taxation limit) and stands in the management class of black alder (these stands inhabit narrow depressions along the streams and are not suitable for analysis).

Even without the management class of black alder, the structure of the remaining analysed area of the management unit was unchanged. The total forested area is 1,295.18 ha (without the 1st age class and the management class of black alder), and the growing stock is 378,871 m³ or 293 m³/ha.

The table also shows that the stands in this management unit have a highly unfavourable age structure. The majority of the stands are in the 4th age class of the management class sessile oak, whereas other management classes are much less represented.

The forests in the sample management unit belong to very good to good site quality classes. The most represented is the EMT II-E-10 (Table 4).

It is also important here that the stands in this Management unit (their age structure and participation of a given management class, range of site classes) are well stratified in terms of estimations and analyses. The next section of the paper will deal with every estimation method separately.

Table 3. The structure of the M. U. "Jamaričko Brdo" by management and age classes
Tablica 3. Struktura G. j. "Jamaričko brdo" prema uređajnim i dobnim razredima

Management class *Uređajni razred*	Age classes - *Dobni razredi*											Total - *Ukupno*	
	I	II	III	IV		V		VI		VII			
	ha	ha	ha	ha	m³	ha	m³	ha	m³	ha	m³	ha	m³
Quercus robur	10.44			21.93	7459							32.37	7459
Quercus petraea				1100.36	315439	33.76	11926					1134.12	327365
Fagus sylvatica	3.49			122.86	38959			16.27	5088			142.62	44047
Alnus glutinosa								15.80	4203	15.39	4170	31.19	8373
Picea abies	0.74											0.74	
Total	14.67			1245.15	361857	33.76	11926	32.07	9291			1341.04	387244
Without the 1st age class and the management class of b. alder *Bez prvog dobnog razreda te uredivački razred c. johe*				1245.15	361857	33.76	11926	16.27	5088			1295.18	378871

Table 4. The represented site classes and EMT by management classes for the treated part of the M. U. "Jamaričko Brdo"
Tablica 4. Zastupljenost boniteta i EGT- a prema uređajnim razredima za tretirani dio G. j. "Jamaričko brdo"

Management class *Uređajni razred*	Site quality (ha) *Bonitet*						Total *Ukupno*	EMT (ha) EGT			Total *Ukupno*
	I	I/II	II	II/III	III	III/IV		II-E-10	II-E-11	II-G-10	
Quercus robur	21.93						21.93			21.93	21.93
Quercus petraea	249.22	355.36	440.34	89.20			1134.12	798.94	335.18		1134.12
Fagus sylvatica		79.31	43.55			16.27	139.13	14.27	124.86		139.13
Total - *Ukupno*	271.15	434.67	483.89	89.20		16.27	1295.18	813.21	460.04	21.93	1295.18

THE 1ST ESTIMATION METHOD
I. PROCJENA

If we compare the advantages and disadvantages of individual estimations, their results, the speed and simplicity of work, then the first method of stand volume estimation with Špiranec's growth-yield tables seems to be the most acceptable.

Statistical analysis found a very high correlation coefficient (0.90) with the results of terrestrial measurement. Moreover, reliability of 95% and 99% overlaps almost completely with reliability measured terrestrially.

The total estimated growing stock in the investigated stands of 370,984 m^3 (286 m^3/ha) differs by -7,887 m^3 or -2.08 m^3/ha from the total terrestrially measured growing stock of 378,871 m^3 (293 m^3/ha).

The speed and practicability of work for operative use is good, because the stand density is relatively easily estimated (appraised) from the stereopair and digital orthophoto. The use of growth-yield tables is also very simple.

However, it is vitally important that management classes (principal tree species), site qualities and stand ages, which are indispensable elements for growth-yield tables, are properly defined with terrestrial measurement. The obtained results of stand volume estimation show that all the above taxation parameters were properly measured and defined in the field and that density was well estimated.

Admittedly, stand density can also be assessed terrestrially, e.g. in the course of identifying management classes.

However, this procedure would be more complex and costly. Still, the most important fact is that all the gaps in the stand canopy (incomplete spaces) are better seen stereoscopically from aerial photographs. As has already been pointed out, cyclic recording were taken when the vegetation was dormant. Consequently, the lower degree of the cover is clearly seen in lighter (different variations of grey) colours reflected by the forest soil.

It can be concluded from the above that the first estimation method is very suitable for forest management operative. It can be applied to:

- constructing regular management plans
- successive alterations with terrestrial measurement every ten years
- checking growing stocks
- monitoring all stages of terrestrial measurements
- swift inventories of growing stocks (monitoring)
- estimating damage caused by elementary catastrophes (fire, snow, ice, wind, etc.)
- managing private forests
- constructing management plans for mined forest areas.

THE 2ND ESTIMATION METHOD
II. PROCJENA

The only difference between this estimation method and the method treated above lies in the application of different growth-yield tables. This estimation method uses growth-yield tables by ecological-management types which do not contain site qualities, because the constructed tables are a reflection of site qualities.

Significant differences in arithmetic means, as well as the lowest correlation coefficient (0.81) were only found by statistical data processing in this estimation method.

Compared to other estimations, the highest deviation (-52,824 m^3 or -13.94%) of the total assessed growing stock (326,047 m^3 or 252 m^3/ha) was calculated in relation to terrestrially measured growing stock (378,871 m^3 or 293 m^3/ha). This minus in the deviation is best seen in the reliability interval, where reliability estimation interval (95% and 99%) overlaps with measured reliability interval only in its extreme left part.

The cause of these deviations should primarily be sought in the structure (Table 3) and site qualities (Table 4) of the stands in the management unit "Jamaričko Brdo", that is, in the used table values of the normal growing stock of the EMT growth-yield tables.

In our opinion, this method of stand volume estimation can be used in all segments of forest management similarly to the first method. However, more caution should be applied, because normal models from the used EMTs do not cover the whole range of Špiranec's site qualities. Therefore, this estimation method would only be suitable for some individual management units.

THE 3RD ESTIMATION METHOD
III. PROCJENA

Originally, this method of stand volume estimation was analysed only as a theoretical possibility to be used as a control method to terrestrial growing stock measurement, since its application implies the use of referent compartments defined on the basis of recent terrestrial measurement.

A referent compartment, i.e. a stand model, is obtained from the arithmetic means of terrestrially measured growing stocks per hectare within a given class, which is the main disadvantage of this estimation method.

This disadvantage may be eliminated or mitigated if referent compartments from recent terrestrial measurement are replaced with referent compartments from the current management plan.

The next requirement concerns the experience of the appraiser and of a good photo-interpreter. Knowledge and experience synthesised in these two disciplines are reflected in visual perception of a referent compartment, that is, in the differences between the other stands in relation to the referent one.

In our example there were five referent compartments. Since the age structure of the management unit "Jamaričko Brdo" is exceptionally unfavourable (Table 3, 4), such a structure was favourable in relation to the estimation that would have been obtained had the age structure been more normal, since the number of classes and consequently of referent compartments would have increased considerably.

The positive side of this method is the high correlation coefficient (0.94) between the estimated and the terrestrially measured growing stock per hectare. Also, the deviation of the total estimated growing stock of 345,276 m^3 or 286 m^3/ha is slightly less (-9,542 m^3 or -2.69%) compared to the total terrestrially measured growing stock of 354,818 m^3 or 294 m^3/ha.

It can be concluded that the application of this method may be dual: if referent compartments are identified on the basis of recent terrestrial measurement, then the method can exclusively be used for controlling terrestrial measurements, but if it is identified on the basis of the current management plan, then it can be used to estimate the growing stock.

THE 4TH ESTIMATION METHOD
IV. PROCJENA

Unlike the method of stand volume estimation described above, in this method stands are grouped by management and age class. In this way, the number of groups (classes) has been reduced, but estimation has been made more difficult.

If we refer back to the third method, where we pointed out the importance of the appraiser experienced in taxation and photointerpretation, these qualities are even more important in the fourth method.

In the sample management unit, in which the majority of the stands are in very good to good site quality classes (I - II), there is deviation of 33,531 m^3 or 8.85 % from the total estimated growing stock (412,402 m^3 or 318 m^3/ha) in relation to the total terrestrially measured (378,871 m^3 or 293 m^3/ha) growing stock.

Therefore, the relatively higher deviation was recorded in the management unit in which stands were grouped in advance.

However, if we take the example (arbitrary) of sessile oak management class (the 4th age class only) with site quality ranging from I to IV, where the extent of normal growing stock (according to Špiranec's growth-yield tables) ranges from 155 m^3/ha at the age of 60 in site quality IV to 420 m^3/ha at the age of 80 in site quality

I, it is clear from this difference (265 m^3/ha) of growing stock per hectare how experienced an appraiser should be in forest management (theoretically and practically) and in photointerpretation.

This example shows that forest management is one of the key forestry disciplines, which deserves much more attention than it receives now, but also that forestry experts should be permanently trained in remote sensing, if such methods are to be applied to forestry in the Republic of Croatia.

It can be concluded that the 4th method of stand volume estimation is suitable for management units with a smaller number of management and age classes (like the one being studied), as well as fewer site qualities. In order to apply this method to more complex management units, the requirements mentioned above should be satisfied.

THE 5TH ESTIMATION METHOD
V. PROCJENA

Similarly to the third estimation method, this method was also originally intended as a theoretical one, in other words, as a control method of terrestrial measurement.

The basic problem of the fifth method is how to determine growing stock per hectare in five referent compartments. To define growing stocks in these compartments, it is necessary to have terrestrially measured growing stocks in all compartments whose volumes are to be estimated with this method. It is clear, therefore, that this method is more complex and more expensive that terrestrial measurements and other methods. In other words, it is closer to the third method.

Identically to the third estimation method, if referent compartments from recent measurements are replaced with compartments from present management plans, this estimation method becomes acceptable.

Taking in consideration statistical analysis and the deviation of the total estimated growing stock in relation to the total terrestrially measured growing stock, this estimation method gives the best results.

The correlation coefficient between the estimated and the terrestrially measured growing stock per hectare is high (0.94), while the deviation of the total estimated growing stock (365,207 m^3 or 295 m^3/ha) in relation to the total terrestrially measured growing stock (359,969 m^3 or 291 m^3/ha) is only +5,239 m^3 or 1.46%.

Based on the experience acquired in stand volume estimation, and comparing good and bad sides of this method, we believe that it is not the most suitable.

The unsuitability of this method for fast and inexpensive estimation of stand growing stocks would particularly be seen in management units with a large number

Table 5. Deviations of the estimated volume in relation to the terrestrially measured volume by hectare (for individual assessment, according to classes)

Tablica 5. Odstupanje procjenjenog u odnosu na terestički izmjereni volumen po hektaru (za pojedinu procjenu, prema postupnim razredima)

Estimation *Procjena*	Number of compartments per estimation *Broj odsjeka po procjeni*								Number of referent compartments *Broj referentnih odsjeka*	%	Total *Ukupno*	%
	<10	%	10-20	%	20-30	%	30>	%				
1	46	56	24	29	7	8	6	7	0	0	83	100
2	17	21	31	37	23	28	12	14	0	0	83	100
3	50	60	23	28	3	4	2	2	5	6	83	100
4	34	41	20	24	17	21	12	14	0	0	83	100
5	57	69	14	17	6	7	1	1	5	6	83	100

of site quality classes, management and age classes and similar, where the number of referent compartments would have to be increased as a certain number of groups would have to be formed (for example, management and age classes, etc.). Thus, the number of compartments per groups would approach the number of referent compartments.

CONCLUSIVE REMARKS
ZAVRŠNA RAZMATRANJA

For easier reference, data on the deviations of the estimated volume values per hectare (by individual estimation) in relation to terrestrially measured volumes were grouped into percentage classes (Table 5).

This table is simple, but its explanation should exclusively be linked to previous results and arguments in favour or against any given estimation method. As has been said before, of the five methods of stand volume estimation, the one using Špiranec's growth-yield tables has proved to be the most acceptable (the 1st estimation method), whereas this method would not have priority according to the table.

The advantage of the presented methods of growing stock estimations (inventories) rests first of all in the speed and possibility of multiple measurements at very low cost, yet yielding satisfactory results.

These methods open the possibility of monitoring growing stocks, which can successfully be applied to other management units as well. Data obtained in this or any other way, maybe with more suitable, faster and more accurate methods supported by mathematical-statistical procedures (regression, correlation, samples and similar) could be applied from the "small" to the "large" (e.g. forest administration) and vice versa.

The survey of the results of stand volume estimation in aerial photographs shows that our own estimation has yielded good results.

CONCLUSIONS
ZAKLJUČCI

Research into the possibility of using aerial photographs from cyclical survey of the Republic of Croatia to forest management was conducted in the management unit "Jamaričko Brdo" in the forest office of Lipovljani.

The following results can be drawn from the research and its results:

1.Aerial photographs from cyclic survey in the Republic of Croatia should be used for drawing up management plans (regular review) as they provide a large number of data.

2. The sample model can purposefully complement taxation (management) field activities on internal forest division with remote sensing methods.

3. The main drawback of aerial photographs from cyclic survey in the Republic of Croatia is their small scale (M ≈ 1:20,000). This scale obstructs the measurement of individual tree elements and considerably reduces the possibility of stand element identification.

4. Stand volume per hectare was estimated with five methods. Statistically significant deviation of arithmetic means was found only in the 2nd method. A high correlation coefficient was found in all estimation methods. The highest was in the 3rd and the 5th method (0.94), while a slightly lower one was found in the 1st method (0.90) and the 4th method (0.87). The smallest was in the 2nd method (0.81).

5. With regard to total estimated and total terrestrially measured growing stock, the best result was achieved with the 5th method (+1.46%), while deviations in other methods are as follows: the 1st (-2.08%), the 3rd (-2.69%), the 4th (+8.85%) and the 2nd (.13.94%).

6. Based on the obtained estimation results and suitability for operative application, among the five methods of stand volume estimation, the 1st estimation method using Špiranec's growth-yield tables proved to be the most acceptable. In our opinion, this method is worth considering for application to forestry operative and particularly to forest management.

Naturally, other methods of stand volume estimation (based on the research and its results) also deserve attention and have their place in remote estimation of growing stocks. Here, we primarily mean the 2nd estimation method based on normal models according to ecological-management types.

7. The paper stresses exceptionally broad possibilities of applying remote sensing methods to forest management in the Republic of Croatia. However, there are many other possibilities which should be permanently investigated. It is clear that these possibilities will rise in proportion with technological progress.

REFERENCES
LITERATURA

Anučin, N. P., 1940: Osnovi lesnoj taksaciji. Lenjingrad.

Akca, A., & Zindel, V., 1987: Zur Vorpatsschhätzung mit Hilfe vod digitalen Luftbilden und Regnessionsmodellen bei Baumart Fichte. Allg. Forst. J. Ztg. 158 (7-8): 109-115

Bezak, K., Cestar, D., Hren, V., Kovačević, Z., Martinović, J., & Pelcer, Z., 1989: Uputstvo za izradu karte ekološko - gospodarskih tipova brdskog i nizinskog područja (II) SR Hrvatske. Radovi 79, Zagreb, 119 pp.

Čavlović, J., 1996: Sustavna dinamika u planiranju gospodarenja regularnim šumama na području Uprave šuma Zagreb. Glas. šum. pokuse 33, Zagreb, 109-152.

Donassy, V., Oluić, M., & Tomašegović, Z; 1983: Daljinska istraživanja u geoznanostima. JAZU, Savjet za daljinska istraživanja i fotointerpretaciju, Zagreb, 333 pp.

Ecker, R., 1992: Digital ortophoto generation based on high - Quality DTM, ITC Journal 1: 59-64.

Frančula, N., 1999: Digitalna kartografija (2. prošireno izdanje). Geodetski fakultet, Zagreb, 195 pp.

Gajski, D., Fiedler, T., & Semak, L., 1994: Digitalni modeli terena u geografskim informacijskim sustavima. CAD FORUM, Zbornik radova, Zagreb, 20-26.

Gašperšić, F., 1985: Kreativnost u uređivanju šuma. Referat, Brioni, 5-18.

Gooshard, T W., 1978: Applications OF DTM in the forest service. Photogrammetric Engineering and Remote Sensing, 44(12):1577-1586.

Jano, A. P., 1986: A Critical survey of the operational use of spaceneron remote sensing in Canadian forestry. Procceedings Division 6, 18 th IUFRO World Cogress, Ljubljana, 154-165.

Jakšić, A., 1996: Određivanje volumena sastojina hrasta lužnjaka pomoću ICK aerosnimki: Diplomski rad, Šumarski fakultet, Zagreb, 32 pp.

Judeich, F., 1904: Die Forsteinrichtung. Leipzig.

Jureša, N., 1991: Ekološko - gospodarski tipovi šuma g. j. „Jamaričko brdo". Odjel za uređivanje šuma Zagreb, 29 pp.

Kalafadžić, Z., & Kušan, V., 1991: Visoka tehnologija u inventuri šuma. Šum. list 115(11-12):509-520.

Klepac, D., 1965: Uređivanje šuma. Nakladni zavod znanje, Zagreb, 341 pp.

Klier, G., 1974: Forstliche Photogrammetrie 1/2. Manuskript, Technischen Universität Dresden, 161 pp.

Klobučar, D., 2002: Mogućnosti primjene aerfotosnimaka iz cikličkog snimanja Republike Hrvatske u uređivanju šuma. Magistarski rad, Zagreb, 176 pp.

Klobučar, D., 2003: Ocjena točnosti geokodiranja Osnovne državne karte i digitalnog ortofota. Šum. list 9-10, Zagreb, 457-465.

Kramer, H., & Akca, A., 1987: Leitfaden Für Dendrometrie und Bestandesinventur, Frankfurt an Mein, 365.

Križanec, R., 1987: Distribucija i projekcija krošanja u korelaciji s prsnim promjerom stabala u jelovim šumama. Disertacija. 2. dio, Zagreb, 330 pp.

Kušan, V., 1991: Mogućnost određivanja taksacijskih elemenata šumskih sastojina metodom fotointerpretacije uz pomoć prirasno - prihodnih tablica. Magistarski rad, Zagreb, 77 pp.

Kušan, V., & Krejči, V., 1993: Regresijski model za procjenu volumena sastojina hrasta lužnjaka (Quercus robur L.) na aerosnimkama. Radovi, 28 (1-2): 69-77.

Kušan, V., Vondra, V., Kalafadžić, Z., Ananić, M., & Belušić, R., 1993: GIS - tehnologija koja dolazi. Glas. šum. pokuse, Posebno izd. 4: 265-270.

Kušan, V., & Kalafadžić, Z., 1994: Daljinska istraživanja i GIS kao dio jedinstvenog informacijskog sustava. Bilten za daljinska istraživanja i fotointerpretaciju 13: 83-91.

Kušan, V., 1995: Digitalni model reljefa i njegova primjena. Meh. šumar. Vol. 20. br. 2: 77-84.

Kušan, V., 1996: Pristup daljinskim istraživanjima i GIS-u u hrvatskome šumarstvu. Šum. list 120 (3-4), 171-177.

Kušan, V., 1996: Točnost digitalnog modela reljefa nizinskog, brdskog i gorskog područja. Zaštita šuma i pridobivanje drva (knjiga 2), Zagreb, 411- 422.

Lillesand, T. M., & Kiefer R. W., 1994: Remote sensing and image interpretation. Third edition, John Wiley & Sons, Inc., New York, 750.

Loetsch, F., & Haller, K. E., 1973, Forset inventory. Vol. 1, second edition, BLV München, 436.

Loger, L., 1946: Osnovi uređivanja šuma. Šumarski priručnik II, Zagreb.

Lukić, N., 1981: Ispitivanje pouzdanosti fotointerpretacijske inventure drvnih masa šuma jele u odnosu na listu podataka dobivenu mjernom fotointerpretacijom. Šum. list 105(3-4), 133-145.

Matić, S., 1991: Njega šuma proredom. Šumarski fakultet sveučilišta u Zagrebu i "Hrvatske šume", Uprava šuma Koprivnica, Zagreb, 45 pp.

Meštrović, Š., Pranjić, A., Kalafadžić, Z., Križanec, R., Bezak, K., & Kovačić, D., 1992: Uređivanje šuma. Monografija "Šume u Hrvatskoj", Zagreb, 131-151.

Miller, D. R., Finch P., & Fon, T. C., 1994: A model of DTM and ortophotograph quality using aerial photography. Tagungsband, Symposium Photogrammetrie und Forst, Freiburg, 227-237.

Nenadić, Đ., 1929: Uređivanje šuma. Zagreb, 302 pp.

Neumann, Ch., 1933: Beitrag zur Vorratsermittlung aus Luftmessbildren. Zeitschrift für Weltforstwirschaft, 147 - 158, 195 - 233.

Oluić, M., 2001: Snimanje i istraživanje Zemlje iz Svemira. HAZU i Geosat, Zagreb, 516 pp.

Pavlić, I., 1988: Statistička teorija i primjena. Tehnička knjiga, Zagreb, 343 pp.

Pejnović, T., 2000: Usporedba digitalne i vizualne interpretacije satelitskih snimaka za potrebe inventure šuma. Specijalistički rad, Zagreb, 77 pp.

Pernar, R., 1996: Primjena rezultata interpretacije aerosnimaka i geografskog informacijskog sustava za planiranje u šumarstvu. Disertacija, Zagreb, 141 pp.

Pilaš, I., 1993: Usporedba šumskih površina na osnovnoj državnoj karti (ODK) i aerosnimku. Meh. šumar., 18 (2): 73-75.

Pranjić, A. & Lukić. N., 1997: Izmjera šuma. Zagreb, 405 pp.

Reutebuch, S. E., 1987: PC-based analytical stereoploter for use in Forest Service field office. Proceedings, ASPRS – ACSM fall conv. Am. Soc. Photogramm & Remote Sensing, Falls Church, VA. 223-332.

Skidmore, A. K., 1989: An expert system classifes eucalypt forest types using TM data and digital terrain model. Photogrammetric Engineering and Remote Sensing, 55(10):1449-1464.

Schneider, W., & Bartl, R., 1994: Forstliche Kartierung und GIS – Daten – Erfassung aus Lufbildren nach dem Monoplotting – Verfahren. Tagungsband Symposium Photogrammetrie und Forst, Freiburg, 317-328.

Stellingwerf, D. A., 1986: remote Sensing in European forestry, Proceedings Division 6, 18 th IUFRO World Congress, Ljubljana, 166-177.

Špiranec, M., 1975: Prirasno-prihodne tablice. Pos. udru. šum. priv. org. Zagreb i šumarski Institut Jastrebarsko, Zagreb, 103 pp.

Tomašegović, Z., 1986: Fotogrametrija i fotointerpretacija. Zagreb, 157 pp.

Tomašegović, Z., 1987: Primjena fotogrametrije fotointerpretacije u planiranju. Glas. šum. pokuse, Posebno izd. 3: 85-94.

Wagner, C., 1928: Lehrbuch der theoretichen Forsteinrichtung. Berlin.

Wodera, H., 1948: Holzmassenermittlung nach Lufbildern. Forst-u. holzw. Zeitung Nr. Wien 13-14 i 15-16.

Zieger, E., 1972: Ermittlung von Bestandesmessen mit Hilfe des Hugershoff – Heydeschen Autokartographen, Mitteilungen aus der sächsischen forstlichen Versuchsanstalt zu Tharandt, Berlin

Zobiery, M., 1972: Mehrstufige Stichproben im aufgelockereten Gebirgswald, (Mitteilungen d. Schweizerischen Anstalt für das forstliche Versuchswesen) Birmensdorf.

* ER Mapper 6.0, User guide

* Narodne novine., 1997: Pravilnik o uređivanju šuma. Broj 11.

* Narodne novine., 2001: Pravilnik o načinu topografske izmjene i o izradbi državnih zemljovida. Broj 55.

* Osnova gospodarenja za g. j. „Jamaričko brdo", važnost 1. 1. 1992. - 31. 12. 2001.

* Osnova gospodarenja za g. j. „Jamaričko brdo", važnost 1. 1. 2002. - 31. 12. 2011.

MOGUĆNOSTI PRIMJENE AEROFOTOSNIMAKA IZ CIKLIČKOG SNIMANJA REPUBLIKE HRVATSKE U UREĐIVANJU ŠUMA

SAŽETAK

Mogućnosti primjene aerofotosnimaka iz cikličkog snimanja Republike Hrvatske u uređivanju šuma istražene su na području gospodarske jedinice „Jamaričko brdo", šumarije Lipovljani.

Snimke iz cikličkog snimanja su odabrane iz razloga jer se nalaze na tržištu uz vrlo pristupačnu cijenu, za razliku od dosadašnjih istraživanja koja su bazirana na naručenim snimkama, što je značajno poskupljivalo primjenu metoda daljinskih istraživanja.

Inače, to su crno-bijele aerofotosnimke približnog mjerila M≈ 1: 20 000, sa 60% preklopom.

Osnovne odrednice rada odnose se na racionalizaciju rada, mogućnost primjene novih tehnologija i smanjivanje troškova prikupljanja podataka.

U uvodnom dijelu opisan je razvoj znanosti o uređivanju šuma, njezina povezanost s šumarskom kartografijom, daljinskim istraživanjima i uspostavom GIS modela. Također, je dat prikaz dosadašnjih istraživanja određivanja volumena sastojine, kao i značenje i uporaba digitalnog modela terena u modernom šumarstvu.

Ostvarivanje postavljenih ciljeva provodi se kroz kvalitativnu i kvantitativnu analizu modela, koji se sastoji od stereomodela, digitalnog ortofota i digitalnog modela reljefa.

Kvalitativna analiza predstavlja uočavanje svih razlikovnih sadržaja koji svrsishodno mogu poslužiti u racionalizaciji taksacijskih (uređivačkih) terenskih radova na poslovima unutrašnje razdiobe šuma metodama daljinskih istraživanja. Nadalje se daje kratki osvrt na mogućnosti primjene modela na drugim područjima s općenitim pragmatičnim postavkama.

Također, opisana je izrada digitalnog ortofota, mogućnosti njegove aplikacije i preporučuje se izrada ortofota prilikom izrade svake gospodarske osnove (redovne revizije), ali po mogućnosti sa snimkama krupnijeg mjerila.

Kvantitativna analiza je bazirana na pet načina procjene volumena sastojine po hektaru:

I uz pomoć Špirančevih prirasno – prihodnih tablica

II uz pomoć normala prema ekološko – gospodarskim tipovima

III svrstavanjem odsjeka u klase prema uređajnom i dobnom razredu i bonitetu uz korištenje referentnog odsjeka

IV svrstavanjem odsjeka u klase prema uređajnom i dobnom razredu bez referentnog odsjeka

V na osnovi terestički izmjerene maksimalne, minimalne i prosječne drvne zalihe po hektaru

Rezultati procjene volumena sastojine su analizirani statistički i uspoređeni sa podacima recentne terestičke izmjere.

Na osnovi provedene statističke analize samo je kod II procjene utvrđeno signifikantno odstupanje aritmetičke sredine. Kod svih načina procjene utvrđen je visok koeficijent korelacije. Najveći je kod III i V procjene (0,94), dok je nešto manji kod I (0,90) i IV (0,87), a najmanji kod II (0,81) procjene.

U odnosu ukupno procjenjene i ukupno terestički izmjerene drvne zalihe najbolji rezultat je postignut V procjenom (+1,46%), dok su odstupanja ostalih procjena: I (-2,08%), III (-2,69%), IV (+8,85%) i II (-13,94%).

Na osnovi dobivenih rezultata procjenjivanja, kao i pogodnosti za operativnu primjenu, kao najprihvatljivija metoda pokazala se I procjena uz pomoć Špirančevih prirasno – prihodnih tablica. Također se smatra da je metoda vrijedna da se razmotri kao mogućnost za primjenu u šumarskoj operativi, poglavito u uređivanju šuma. Dakako, da i ostale metode procjene volumena (na bazi provedenog istraživanja i dobivenih rezultata) zavrjeđuju pažnju i imaju svoje mjesto u daljinskom određivanju drvnih zaliha, u prvom redu drugi (II) način procjene uz pomoć normala prema ekološko – gospodarskim tipovima.

Ova aplikacija bi se mogla implementirati:

- prilikom redovnih izrada osnova gospodarenja,
- u sukcesivnom izmjenjivanju svakih deset godina sa terestičkom izmjerom,
- prilikom kontrole drvne zalihe,
- u kontroli terestičke izmjere u svim njezinim fazama,
- u brzim inventarizacijama drvnih zaliha (monitoring),
- prilikom procjene šteta uslijed elementarnih nepogoda (požar, snijeg, led, vjetar i dr.),
- u uređivanju privatnih šuma,
- u izradama osnova gospodarenja za minirane šumske površine.

Glavni nedostatak aerofotosnimaka iz cikličkog snimanja Republike Hrvatske je sitno mjerilo (M ≈ 1: 20 000). Ovo mjerilo onemogućava izmjeru elemenata pojedinačnih stabala, dok u znatnoj mjeri reducira određivanje elemenata sastojine.

Rad ukazuje na činjenicu da su mogućnosti primjene metoda daljinskih istraživanja u uređivanju šuma Republike Hrvatske izrazito velike, ali i da postoji čitav niz drugih mogućnosti i nepoznanica koje treba permanentno istraživati. Također, jasno je da će ove mogućnosti rasti razmjerno tehnološkom napretku.

Ključne riječi: daljinska istraživanja, aerosnimke, cikličko snimanje, geografski informacijski sustav (GIS), ortofoto, digitalni model reljefa (DMR), uređivanje šuma