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ZA ŠUMSKE POKUSE

ANNALES
EXPERIMENTIS SILVARUM CULTURAE PROVEHENDIS

40

SVEUČILIŠTE U ZAGREBU
ŠUMARSKI FAKULTET
UNIVERSITAS STUDIORUM ZAGRABIENSIS
FACULTAS FORESTALIS

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Original scientific paper
Izvorni znanstveni članak

SOME QUALITY CHARACTERISTICS OF FIR TREES (*Abies alba* Mill.) IN THE EDUCATIONAL-EXPERIMENTAL FOREST SITE ZALESINA, MANAGEMENT UNIT "BELEVINE"

NEKE ZNAČAJKE KAKVOĆE STABALA OBIČNE JELE (*Abies alba* Mill.) U GOSPODARSKOJ JEDINICI "BELEVINE" NASTAVNO-POKUSNOG ŠUMSKOG OBJEKTA ZALESINA

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This paper presents research results of some quality characteristics of fir trees (*Abies alba* Mill.) in selection forests in "Belevine" management unit, EEFS Zalesina.

Research encompassed 1,404 fir trees with dbh from 20 cm to 85 cm and heights from 12 m to 40 m. After felling and debranching, the timber volume of trees up to 7 cm diameter under and over bark was determined with the sectioning method. Timber assortments were processed and measured according to the Croatian standards for roundwood.

Timber volume of trees to 7 cm diameter under and over bark, as well as the processed timber volume is shown in two-entry and one-entry tables.

Bark volume ranges from 12.45 % to 10.67 %. The proportion of bark decreases from 21.8 % at 20 cm diameter to 7.4 % at 84 cm diameter according to the diameter of roundwood.

The yield has values from 81.7 % to 83.0 %; it decreases with an increase in dbh and rises with an increase in tree height.

In the regressed assortment structure, sawlogs in quality class I have the highest values in the 42.5 cm diameter class (18.4 %), but sawlogs in quality class II have the highest value with the thinnest trees in the sample (36.2 %). The proportions of quality class III increase from 29.7 % to 42.4 % with a rise in dbh. The maximal proportion of mining timber is in the diameter class 22.5

cm (59.96 %), but it decreases to 0.51 % in the diameter class 77.5 cm. The proportions of pulpwood are under 8%.

The maximal value of wood is found in the 52.5 cm diameter class.

Key words: fir tree, quality characteristics, timber volume, timber assortment, quality class

INTRODUCTION
UVOD

Forests continuously produce wood - a living organic matter - by using natural factors of site and climate. The role of a forest is reflected in its direct (forest products) and indirect values (ecological, protective, social forest functions). Forest products, as direct forest values, are divided into main and secondary products. Main forest products are timber assortments, whereas secondary forest products include resin, edible forest fruit, medicinal herbs, mushrooms, leaf litter, forest grazing, forest litter, browse, duff, and products of forest soil (rocks, peat, clay).

Forest harvesting is a human activity dealing with the collection and purposeful utilisation of all existing renewable and non-renewable natural resources (products) of a forest.

Timber exploitation is a working process that entails a set of activities related to wood extraction. It includes felling trees, their conversion into forest products and removing trees or parts of trees from the forest to the user, sawmill processor or forest product market. Thus, timber exploitation relates only to felling and processing trees and their transport.

From the aspect of timber exploitation, stems are the most valuable parts of trees. Stem is a part of large timber used to estimate the value of a standing tree. When a tree is felled and processed, its branches are removed to obtain the stem, which is then cross cut into timber assortments.

Timber assortments depend on the properties of a given tree. Trees do not have uniform qualities. Knowing the structure and quality of trees allows us to determine which trees provide the most economical yields and helps in planning felling activities, rate and organisation of harvesting operations, costs, economic gain and marketing activities.

MAIN ISSUES
PROBLEMATIKA

The basic question that forestry specialists are faced with is how to decipher natural rules and understand the biological production of a forest in given site and climatic conditions, as well as how to identify the type of factors and the extent to which they affect a forest. Extensive past research has revealed certain differences in the characteristics of trees of the same species and identified some of these characteristics. Determining tree characteristics and their dependence on certain conditions, apart from broadening forestry knowledge, has also substantially influenced the forestry practice in the sense of planning and organising work, intensifying forest operations and increasing timber volume yield.

Timber volume tables have been drawn up for individual tree species, in which timber volume is expressed as a function of easily measurable tree functions - breast diameter and height. Timber volume tables are based on the fundamental truth that trees of the same species, of identical breast diameters and heights and grown under very similar ecological conditions, as a rule have identical volumes. The accuracy of tables increases with the number of sample trees. Timber volume in a table can be expressed as the total volume or the volume of limited diameters, over or under bark. In timber exploitation, tables of timber volume up to 7 cm in diameter are more important because they represent the volume of large timber used for timber assortments.

The number of independent variables in a regression table model determines table types: there are one-entry tables (tariffs), two-entry (volume) tables and multi-entry tables. One-entry tables express the volume of mean tree of a diameter class as a function of one parameter - usually breast diameter. In two-entry tables, volume is the function of breast diameter and tree height.

The first timber volume tables were made for birch by Cotta in 1804 (Pranjić & Lukić 1997).

In 1891, Schuberg constructed volume tables for main tree species using sample trees measured in even-aged forests. Timber volume tables were based on a large number of trees in the thinner diameter class. Since Schuberg's tables for trees with breast diameters exceeding 50 cm were obtained with extrapolation, their application yields too low volume values of thicker trees.

In his search for the most suitable form of a regression function in drawing up two-entry volume tables, Emrović (1960b) concludes that data regression will be achieved with the lowest possible standard deviation around the regression range using the highest possible number of parameters. However, since it is neither practical nor economical to have a large number of function parameters, he recommends the Schumacher-Hall function.

Špiranec (1976) made timber volume tables for fir and spruce by sectioning 3,844 fir trees and 750 spruces tree from 43 management units in the area of 6 forest-management classes. He used Schumacher-Hall's equation to regress tree volumes.

Schmid-Haas & Winzeler (1981) devised more accurate method of calculating timber volume with a three-parameter function (breast diameter, tree height and diameter at 7 m from the ground or 30% of the tree height) rather than with two-parameter functions. Kružić (1993) found the Schumacher-Hall's function for volume table regression unsuitable, especially for thin trees.

While studying the applicability of Algan's and Schaeffer's tariffs for the calculation of fir wood volume, Rebula (1996) found that these tariffs yielded 3- 7 % higher values of timber volume.

In fir forest management, tariffs by Šurić, Šurić - Pranjić and Špiranec have been used to calculate growing stocks since 1945. However, when growing stocks calculated with local tariffs and with the tariffs mentioned above were compared, deviations were detected in growing stocks (Božić 2000).

Although in felling and processing operations efforts are made to utilise as much timber volume as possible, losses are inevitable. The volume of timber assortments represents the processed volume. The non-processed product of felling and processing consists of bark, waste related to large timber which has not been used for a variety of reasons, and waste incurred by the prescribed method of assortment measuring. Volume losses at felling and processing occur in measuring processed assortments due to rounding down diameters and lengths, making undercuts, butt shaping, cross cutting, as well as to length allowance and errors in Huber's formula.

Since the bark of technical timber assortments represents waste, it is necessary to determine the proportion of bark in the total timber volume. The proportion of bark is usually expressed for the tree as a whole. However, bark thicknesses and percentages change along the stem at different heights from the ground or at different diameters. Accordingly, bark thickness and percentage is not the same for all timber assortments obtained from felling and processing one tree.

Klepac (1972) studied the bark of fir in different plant communities. According to Klepac, bark thickness and percentage share in the total timber volume depend on a range of factors, such as tree thickness, stand structure, stand density (basal area), management method, site class, phytocoenological community and others. The average volume of bark of 11% for all observed phytocoenological communities falls within the limits of fir bark percentage according to Flury (8.3 - 12.3 %). He finds the thinnest fir bark in the phytocoenosis of fir and hard fern (10.1 % of the total wood volume), and the thickest in the phytocoenosis of fir with small-reed (14.4 %). His research shows that bark is thicker in stands with a low basal area where trees are exposed to external influences and thinner in better-quality sites.

Bark thicknesses along the stem and its proportion in the volume of timber and sawlogs with regard to tree thickness, sawlog origin and thickness and tree heights was studied by Bojanin (1960, 1966a, 1966b). The share of bark volume in his research ranges from 10.7 % to 12.6 % (11.05 % on average).

Macek & Korinek (1972) and by Kirschner (1976) studied double bark thickness in dependence on the diameter of fir roundwood.

From an economic standpoint, timber assortments are the main forest products. As the demand for wood is constantly growing, forestry is faced with the challenge of providing increasing quantities and qualities of wood assortments. Adequate stem processing yields timber assortments with properties, qualities and dimensions that enable further conversion and utilisation and ensure the best use of timber volume at the lowest production costs and the highest value of processed timber assortments. Timber assortments on the market are classified into quality classes according to a given standard system. In order to determine annual harvesting volume, plan the operations and keep the records more easily, it is important to know the quantity and quality of timber assortments. These tasks can be done properly if sufficiently accurate data are available about the structure of timber assortments (assortment tables). Therefore, advance knowledge of the participation of timber assortments by quality classes in dependence on forest communities is very important forest-management, marketing and organisational information.

Bojanin (1960) studies the share of assortments and the amount of losses incurred by felling and processing fir trees in the phytocoenosis of fir with hard fern, while Plavišić & Golubović (1963) investigate the percentage ratio of fir assortments and identify the highest quantity of sawlogs in the III quality class (65 % of the total processed volume). According to research by Plavšić (1967) in the forest of fir with hard fern, the highest quantity of fir timber assortments in the highest quality class is found in the diameter class 62.5 cm in site class I and in the diameter class 57.5 cm in site class II.

The quality of fir timber assortments has been studied by a number of scientists who have endeavoured to find an answer as to what the quality of assortments depends on and which breast diameter of fir trees yields the economically highest values. Rebula (1998a) defines the highest value of fir stems at 50 cm dbh, while the value of trees with dbh less than 27 cm is lower than felling and processing costs. Knoke (1997) studies the economic value of logs and finds that the relative value of logs with large mean diameters compared to those with smaller mean diameters decreases with an increase in breast diameter.

There are numerous different tables worldwide showing the kind and quantity of timber assortments made from stems of different dimensions. Most of these tables are based on breast diameters, tree heights and stem forms (form factor). The quality of wood assortments is evaluated and sorted on the basis of assortment dimensions while the presence of defects is evaluated using the norms that prescribe product characteristics. With regard to past application of the Croatian system of norms, it was shown that wood defects play an important role in placing timber assortments into quality classes, while the dimension of assortments is decisive only as a minimal measure (Rebula 1994).

The following authors constructed assortment tables for main tree species: Hubač (1973) in the Chech Republic, Mikhov (1980) in Bulgaria, Schopfer & Dauber (1989) in the area of West Germany, Sterba et al. (1986) in Austria and Petraš & Nociar (1991) in Slovakia.

RESEARCH GOAL
CILJ ISTRAŽIVANJA

Research aimed at defining the quality characteristics of fir trees in "Belevine" management unit was intended to achieve applicable results in future management with fir stands in the studied area.

The following tasks have been set to achieve research goals:

- construct two-entry tables and one-entry tables of fir tree timber volume in "Belevine" management unit,
- construct two-entry tables of fir tree timber volume under bark in "Belevine" management unit and use the differences in the tables of fir tree timber volume over and under bark to determine the volume and percentage of bark with regard to breast diameter and tree height,
- construct two-entry tables of processed fir tree volume and use two-entry tables of fir tree volume to study yield and loss percentages of felling and processing with regard to breast diameter and tree height,
- construct one-entry tables of fir timber volume under bark and processed timber volume of trees,
- determine yield of felling and processing fir trees and the quantity of waste in absolute and relative values according to breast diameters,
- determine bark thickness and percentage according to varying diameters of roundwood,
- study the structure of timber assortments by quality classes in the processed fir tree volume, construct assortment tables by diameter classes,
- make value analysis of timber assortment structure by tables and determine a diameter class with the economically highest value of timber volume.

OBJECT OF THE RESEARCH
PREDMET ISTRAŽIVANJA

EUROPEAN SILVER FIR (*Abies alba* Mill.)
OBIČNA JELA (*Abies alba* Mill.)

Silver fir (*Abies alba* Mill.) is a tree attaining 40 m in height and 1.5 m in breast diameter. The stem is cylindrical and straight. The bark is light grey and relatively smooth, whereas at an older age it becomes broken and darker. In youth, the crown is conical, at an older age it is cylindrical, while when old, the crown tops assume plate-like forms. The branches are laid horizontally and are placed into whorls around the stem, forming more or less regularly arranged branch layers at right angles to the stem axis. The branch whorl is a point on the stem where several branches or nodules grow at approximately the same height. Fir trees are capable of self-cleaning. The shoots are grey-brown and slightly hairy. The needles are tufted, 1-5 - 3 cm long and 2 - 2.5 mm wide, notched at the tip or blunt, grooved on the upper side, dark green and glossy, while on the underside there are 2 white strips of stomata. At the tips of branches and on the main shoot the needles point at all sides and are spiky at the top. The root system of silver fir has a typical taproot that grows about 1 m deep on average. The roots of adjacent trees are frequently fused.

Silver fir is a sciophytic species. At a young age it grows very slowly and may tolerate shade for a long time. Šafar (1981) found that firs 1.5 - 2 m tall were aged between 20 to 120 years. When stunted firs gain space, they start growing faster and are normally fertilised and propagated with seeds.

Silver fir grows on limestone and on silicates. It favours fresh, cooler, humus-rich soils. In the summer it prefers warm weather and in the winter moderately colder climate with abundant air humidity. It is sensitive to early and late frosts and does not tolerate polluted air. It grows best in areas with mean annual air temperatures of 9°C and mean annual precipitation quantity of about 1,500 mm. It forms pure or mixed stands with beech and spruce, which ensures natural regeneration and sustainability.

Fir is naturally distributed in mountainous districts of central, southern and partly Western Europe. In the north, it starts from Poland to extend westwards up to northern Spain and eastwards to the east of Romania and Bulgaria, while southwards it reaches the northern boundaries of Greece. In Croatia, silver fir has a widespread distribution: from Gorski Kotar over Velebit it extends across the whole Dinaric mountain chain, and can also be found in mountainous areas between the rivers Sava and Drava (Vidaković 1993). The upper boundary of the altitudinal distribution of silver fir is in the Alps from 1,200 to 1,700 m above the sea, with optimal heights ranging between 400 and 1,500 m.

SELECTION FIR FORESTS
PREBORNE ŠUME JELE

Silver fir (*Abies alba* Mill.) is one of the most important and the most valuable tree species in Croatian forestry. It participates with 9.4 % or 30,374 million m^3 in the total growing stock of the Republic of Croatia. In state-owned forests managed by the company "Hrvatske šume" d.o.o., Zagreb, fir accounts for about 28.133 million m^3 or 10.1 % of the growing stock. In other state-owned forests fir participates with 20.2 % (1,594 million m^3), while in private forests its share is only 1.7 % of the growing stock (648,000 m^3).

The company "Hrvatske šume" d.o.o., Zagreb produces about 3 million m^3 timber assortments annually. Of this amount, roundwood accounts for about 50 %, while the rest relates to stacked wood (for fuelwood and industrial processing). The annual net prescribed yield of fir is about 350,000 m^3, or about 12 % of the total production of timber assortments (www.hrsume.hr).

Silver fir in Croatia constitutes selection forests of a high silvicultural form, which cover 29 % of the total forest area or 540,641 ha. The growing stock of these forests is about 102 million m^3, of which silver fir accounts for about 30 %. The remaining 70 % in the mixture proportion largely relates to common beech, and less to common spruce and other broadleaves (Matić et al. 1996).

A selection forest is any high forest with a permanently non-uniform structure. It constantly regenerates with selection management (Križanec 1987). This form of management, important for sciophytic tree species, relates primarily to fir because the selection structure and selection management suit the ecological requirements and biological properties of this tree species. Fir is capable of tolerating shade for a very long period. When it acquires living space, it grows into a tree of good quality both in pure stands and in mixed stands in combination with spruce or beech.

"Selection management can only be applied to forests in which silver fir is a structural element, because silver fir is the basic species of selection forests and selection management. Fir may be accompanied by beech and spruce (Matić et al. 1996)".

A selection forest consists of trees of differing heights, differing diameters and differing ages over a surface unit. The selection structure presupposes the classification of trees into diameter classes according to Liocourt's rule of gradual and regular decrease in the number of trees with a growing diameter class. Liocourt established a ratio between the number of trees in one diameter class and that in the immediately higher diameter class. This ratio is constant for a given site quality and ranges from 1.3 to 1.5 (Božić 1999). In a graph, Liocourt's curve or the curve of a normal tree series has the shape of a hyperbolic curve, which is determined with maturity dimension and geometric progression coefficient.

$k^n, k^{n-1}, k^{n-2}, \ldots k^3, k^2, k^1, k^0$, where:

k - geometric progression coefficient,

n - number of diameter classes from maturity dimension to taxation limit of 10 cm.

When trees distributed by diameter classes form Liocourt's curve in a graph, the forest is said to have an optimal structure in terms of tree number. An optimal structure may be achieved with a different arrangement of trees over an area.

In selection management, trees may be arranged over an area in two ways; for this reason, we speak about single tree management and group management. The spatial arrangement of trees in selection management is estimated in the following way:

- single tree management - trees of differing heights and different diameters are scattered over an area,
- group management - trees of similar diameters and heights, or similar tree species are distributed over an area larger than 10 ares and smaller than 1 ha.

The single tree management method is applied to stands on karst terrain with shallow soils, where soil should be permanently protected from unfavourable abiotic factors. The group management method is applied to stands on mildly sloping terrains with deep, nutritious and humid soils, since on good soils fir regenerates naturally in groups.

Until the Forest Management Act of 1994 came to force, selection forests were also managed with the cluster management method. The diameter of a cluster is larger than two heights of the tallest trees. The application of the cluster management method in the range of beech-fir forests disrupts the selection structure, which is out of line with the natural management method and is mistaken from an ecological and biological standpoint and consequently from an economic standpoint (Prpić & Seletković 1996). The Forest Management of 1996 banned the cluster management method.

Normal or optimal growing stock in a selection forest is that growing stock which gives the best yield and enables permanent natural regeneration of the forest. This means that normal growing stock in a selection forest should not be either too high or too low, but just sufficient for the best production and permanent natural regeneration.

The ideal selection forest structure is composed of trees of differing heights and diameters over a unit area. Such a forest contains normal growing stock, distributed in the selection structure, which ensures maximal increment, optimal natural regeneration and stability (Matić et al. 1996).

The goal of selection felling is to form and maintain the selection structure of a stand. Selection felling is characterised by a synchronous use of all stages of silvicultural treatments in the same area, ranging from tending seedlings and young forests to thinning and tree exploitation.

Felling intensity depends on the quality and structure of a stand, the total growing stock, increment, and management intensity. Management intensity depends on the length of the felling cycle, which is the period between two felling operations over the same area in a selection forest.

Selection single or group felling is performed in ten-year felling cycles. Trees above the defined diameter of felling maturity are marked and cut in regular cutting operations.

Klepac (1997) cites the conditions for successful selection management:

- selection felling should be performed frequently (in 5 to 10-year intervals) with the most favourable selection felling intensity of 15 to 25 % (based on 10 years),
- a selection forest should contain a dense network of communications and skid roads so that frequent felling operations are economically viable,
- a selection forest should permanently undergo natural regeneration.

In the last several decades, the selection of trees to be cut was influenced by physiological weakening and dieback of fir. In some years the entire annual harvesting volume from the forest of Gorski Kotar was derived from dead trees. Research by Krpan et al. (1995) showed that trees with damage degrees between zero and three did not suffer any change in physical-mechanical properties and neither did the usable value of fir. However, changes in dead trees, especially if they were left standing for longer periods, affected their quality and considerably lessened the exploitable and market value of fir roundwood.

RESEARCH SITE
MJESTO ISTRAŽIVANJA

FOREST MANAGEMENT UNIT "BELEVINE"
GOSPODARSKA JEDINICA "BELEVINE"

The management unit "Belevine", part of the educational-experimental forest site Zalesina, Faculty of Forestry in Zagreb, is located in the area of selection forests in Gorski Kotar.

The mildly undulating relief furrowing fan-like in the northeast - southwest direction extends from the east towards the northwest. The relief is marked by two hills (two knolls), three smaller plateaux, and one narrow valley stretched along the part in the northeast. The remaining part covers the more or less mild slopes interspersed with numerous beds of mountain streams.

The management unit "Belevine" lies at an altitude of 720-870 m. The altitudinal difference between the highest and the lowest point of the terrain is only 150 m, resulting in the entire management unit being in the same site class. Almost the whole management unit has a sunny exposition, except for 10 - 15 % of the area with a shaded exposition. The slopes are largely mild to moderately steep (inclination up to 20 °). The mild to moderate inclination has influenced the formation of deep soils.

The geological substrate in the management unit "Belevine" is made up of silicate rocks. The parent material has diverse composition. The prevalent parent substrate is made up of Permo-Carbonate (Palaeozoic) layers of black slates, orange-reddish schists, sandstones and conglomerates. The stands in the management unit "Belevine" are supported by podzols, acid brown soils and brown podzol soils. From the aspect of forest management, the soils on Palaeozoic sediments are considered better than the soils on Mesozoic limestones, because the diverse composition, soil depth, terrain form and hydrographic features provide favourable conditions for the development of vegetation. This is confirmed by the high site class (site class II for fir according to tariffs by Šurić-Pranjić).

In Köppen's classification of climatic regions in Croatia, "Belevine" management unit is located in the climatic zone of C-climate or warm-temperate rainy climate and belongs to the "Cfsbx" climate type. The features of this climate type are as follows: the mean monthly temperature of the coldest month ranges from -3 °C to + 18 °C; summers are fresh with the mean monthly temperature in the warmest month below 22 °C; precipitation is relatively uniformly distributed over the whole year, but the driest part of the year occurs in the warm season. The secondary precipitation maximum occurring at the beginning of the warm part of the year is followed by the principal maximum in the autumn, which is higher than the former.

The climate is characterised by low monthly mean air temperatures, which is reflected in the low annual mean air temperature of 6.7 °C. One of the climatic particularities is the occurrence of late spring frosts in April, May and even June. Relative air humidity is high over the whole year and varies from 76 % to 86 %. The distribution of the total annual precipitation quantity (1,982 mm) is characterised by two minimums: at the end of winter and in summer. During the vegetation period (which coincides with the length of the warm part of the year), there is about 1,000 mm precipitation or about 50 % of the total annual precipitation quantity. In this locality, the growth period lasts for 146 days on average (from 116 - 195 days) or about 5 months. The snow period lasts for 188 days and inevitably affects the length of the growth period.

With regard to the geographical position and altitude and to horizontal vegetation distribution, "Belevine" management unit belongs to the zone of deciduous and mixed forests of moderately humid, cold sites of the alliance *Fagion illyricum.*

In vertical sense, "Belevine" is located in the belt of beech (*Fagetum croaticum*) and sub-belt of beech and fir (*Abieti-Fagetum illyricum*), and extends at an altitude of 650 - 1,200 m.

This management unit is predominantly covered with the forest of fir with hard fern (*Blechno-Abietetum* Ht. 1950). Generally, the community of fir with hard fern occurs in the high-mountain belt over silicate rocks, 670 to 950 m above the sea. In Gorski Kotar, this community is developed at higher positions of the climatozonal area of beech and fir and inhabits mildly dry slopes or smaller valleys with deep, leached acid soils over silicates and sandstones (Vukelić & Rauš 1998).

In "Belevine", this plant community occurs in the following subassociations and facies:

- fir forest with hard fern and bedstraw (*Blechno-Abietetum galietosum rotundifoliae* Ht. 1950), with two facies: facies *Vaccinium myrtillus* and facies *Festuca sylvatica,*
- fir forest with hard fern and yellow moss (*Blechno-Abietetum hylocomietosum* Ht. 1950),
- fir forest with hard fern on red marls (*Blechno-Abietetum fagetosum* Rauš 1975).

In the management unit "Belevine" this community is located in the distribution range of beech on the boundary of the natural distribution range of fir. A beech-fir forest (*Abieti-Fagetum croaticum* Ht. 1950) is found in smaller marginal areas and is not considered characteristic for the management unit.

Table 1. Share of forest associations
Tablica 1. Prikaz zastupljenosti biljnih zajednica

Forest association *Biljna zajednica*	Area - *Površina* (ha)	%
Blechno-abietetum galietosum rotundifoliae Horv. 50	168.74	59.8
Blechno-abietetum galietosum rotundifoliae, facijes *Vaccinium myrtillus*	13.39	4.7
Blechno-abietetum galietosum rotundifoliae, facijes *Festuca silvatica*	33.45	11.8
Blechno-abietetum hylocomietosum Horv. 50	3.43	1.2
Blechno-abietetum fagetosum	34.28	12.2
Abieti-Fagetum croaticum Horv. 1938	29.15	10.3
Total - *Ukupno*	282.44	100.0

The stands in the management unit are divided into two ecological-management types. The ecological-management type I-C-40 consists of the forest of fir with hard fern (*Blechno-Abietetum* Ht.), whereas the ecological-management type I-C-10a is represented by the forest community *Abieti-Fagetum dinaricum* Horv.

Table 2. Share of ecological management types
Tablica 2. Prikaz zastupljenosti ekološko gospodarskih tipova

Ecological management type *Ekološko gospodarski tip*	Area - *Površina* (ha)	%
I-C-40	253.29	89.7
I-C-10 a	29.15	10.3
Total - *Ukupno*	282.44	100.0

The management unit covers a surface area of 293.94 ha, of which 283.20 ha is forested, 5.88 ha is a non-forested productive area and 4.86 ha is infertile soil. The management unit is internally divided into 18 compartments with an average size of 16.33 ha each.

The stands in the MU "Belevine" are seed forests of high silvicultural form managed selectively. In terms of mixture proportion by growing stock and by tree number, "Belevine" is a mixed forest of fir and beech. In the past 50 years, one of the management goals from the 1951 Management Plan relating to 20 % of beech in the mixture proportion has been achieved. Beech has increased its share in the growing stock from 3 to 24 %, and its number from 21 to 49 %. The mixture proportion per wood volume and tree number is given in Table 3.

Table 3. Mixture proportion per tree species
Tablica 3. Omjer smjese po vrstama drveća

Inventory *Inventura*	Tree species *Vrsta drveća*	Growing stock *Drvna zaliha*	Mixture proportion *Omjer smjese*	Number of trees *Broj stabala*	Mixture proportion *Omjer smjese*
		m^3	%		%
1951.	Fir - *Jela*	123 670	97	91 183	79
	Beech - *Bukva*	3 891	3	24 879	21
1999.	Fir - *Jela*	99 541	76	53 862	51
	Beech - *Bukva*	30 712	24	51 129	49

The forests of "Belevine" are at the stage of thick trees because in the last 30 years, trees with breast diameters over 51 cm have accounted for more than 50 % of the basal area.

The growing stock amounts to 131,274 m^3 or 464.79 m^3/ha. Fir and spruce account for 99,585 m^3 or 352.37 m^3/ha, while beech and other tree species account for 31,689 m^3 or 112.20 m^3/ha. The annual increment is 7.86 m^3/ha, of which 5.10 m^3/ha relates to fir (with spruce), and 2.76 m^3/ha relates to beech with other tree species. The average increment percentage is 1.69 % (for fir and spruce it is 1.32 %, and for beech and other tree species it is 3.32 %).

The management unit "Belevine" is managed with selection management using the group method, which will be accomplished with selection cutting. The single tree management method is only applied to parts of the compartment along the railway line and to steep beds of hilly streams so as to prevent landslides.

This management unit is managed with the "New system of selection forest management" by Professor Klepac, so that two basic management principles can be accomplished simultaneously: the establishment of a stable condition combined with permanent satisfaction of the sustainable forest management. An optimal growing stock calculated according to the II normal model for fir and the III normal model for beech is 480 m^3/ha.

The largest part of the forest is taken up by the management class "Uneven-aged seed fir forests II" in the distribution range of the forest community of fir with hard fern. The management class "Uneven-aged seed forests of beech III and fir II" accounts for a small part of the forest within the distribution range of beech and fir. A mixed normal model of fir and beech with an 80:20 mixture proportion per growing stock and maturity dimensions for fir of 70 cm and beech of 50 cm was constructed for the first management class. A transitional mixed normal beech and fir model with a mixture proportion of 80 % beech and 20 % fir by growing stock with maturity dimensions identical to the first normal model was drawn up for the management class of beech and fir, in which fir accounts for less than 10 %.

A ten-year prescribed harvesting volume for the management unit "Belevine", based on the relationship between the existing and the optimal growing stock, past harvesting volumes, maturity dimension, measured increment, regeneration stage, health status and purpose of the forest, is approximately 32,000 m^3, which corresponds to an average intensity of 22.5 %. With regard to a 10-year cutting cycle, the annual harvesting volume will be realised every year over approximately 10 % of the total area so as to satisfy the principle of sustainable management. The volume of sanitary felling is about 2 m^3/ha annually.

RESEARCH METHODS
METODE RADA

Research was based on the sample of fir trees felled in the regular cutting cycle. Trees from sanitary felling were not considered.

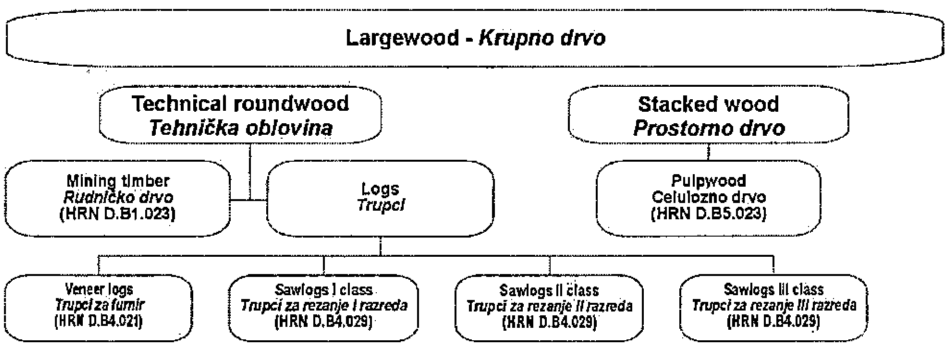
Before felling, two perpendicular breast diameters and height were measured on standing trees. The height of the trees was measured with an altimeter with an accuracy of 0.5 m, and breast diameters were rounded down to the nearest centimetre. Their arithmetic mean was also rounded down to the nearest centimetre. The trees were then measured after felling and debranching. The length (height) of the felled tree (from the root to the highest terminal bud) was measured with a measuring tape with an accuracy of one decimetre.

All sample trees were sectioned in order to obtain an accurate estimate of large timber volume (up to 7 cm) over and under bark. Trees with bark were sectioned after felling. Tree trunks were divided into sections of 2.0 m, with the end sections ranging from a minimum of 1.0 m to a maximum of 3.0 m in length. The section length was measured on each section (l) with decimetre accuracy and two mutually perpendicular diameters in the mid-section (d_1 and d_2) were measured with millimetre accuracy.

The trees were debarked up to the point on the stem where numerous knots appeared. In the process, the mid-sections of previous sectioning over bark were marked with forest chalk, which made it possible to measure mean diameters of the sections under bark in the same points. The mid-sections of the end parts were debarked so that diameters under bark could be measured. Bark thickness (k_1 and k_2) was measured during debarking on each mid-section in the two opposite samples. Bark was measured with millimetre accuracy and the sample included dead and living bark. After debarking, the trees without bark were sectioned. Diameters under bark (d_3 and d_4) were measured in the mid-sections with millimetre accuracy. The ordinal number of the section, section length, section diameters over and under bark and bark thicknesses k_1 and k_2 were entered into sectioning forms.

When tree sectioning was completed, timber assortments were bucked and crosscut. Timber assortments of fir are produced from stems, and assortment quality depends on their position on the stem. As a rule, the lower half of the stem length represents a better quality zone. As the distance from the stump increases, the mean diameter of the assortments decreases. The number and size of knots increases at the beginning of the crown, which considerably lessens the quality of assortments. In processing, special attention is paid to bucking the stem with the goal of obtaining the highest value of forest assortments from the available tree wood volume. Timber assortments were bucked, crosscut, measured, inspectioned and marked in accordance with the Croatian standards for roundwood. Timber assortments were measured according to the Croatian standard D.B0.022 "Sorting and measuring unprocessed and processed timber" Timber assortments were put into quality classes according to Croatian standards for conifer roundwood shown in Figure 1.

Figure 1. Distribution of coniferous roundwood
Slika 1. Raspodjela oblog drva četinjača



Timber inspection is a process of measuring, grading and recording saleable timber assortments. The mean diameter is an arithmetic mean of two mutually perpendicular measurements. Two mean diameters (rounded down to the nearest centimetre) and length were measured on debarked timber assortments. The timber assortments from the top part of the stem were subsequently debarked in the points of mean assortment diameters. The timber assortments from the top part of the stem were predominantly classified as pulpwood, which is also taken without bark. Log lengths were measured with a tape so that the number could be rounded down to the nearest decimetre, and length allowance was then subtracted (with conifers it is 2 cm by a current metre, on condition that one log may have a minimum of 5 cm and a maximum of 20 cm). Length allowance is not taken for veneer logs and pulpwood. Log length is measured at the shortest point. In order to accurately determine quality classes, timber defects on the logs that influence the classification into quality classes were inspected and measured. Timber defects were measured according to the Croatian standards D.AO. 101 and D.A1. 041. Information on the processed assortments (quality class, assortment length, mean assortment diameter) was entered into the felling register.

DATA PROCESSING
OBRADA PODATAKA

The measured data were transferred from field sectioning forms and felling registers into computer databases for easier availability. The first to be entered were data on the basic tree characteristics: breast diameters and tree heights.

Using the German system, the sample trees were put into diameter classes 5 cm wide with class means at 22.5 cm, 27.5 cm, 32.5 cm, etc. Classifying trees into diameter classes of 2 cm in width is not practical for research because it implies a much larger number of diameter classes. Moreover, the Croatian forestry acknowledges diameter classes of 5 cm.

Data from tree sectioning forms were entered for each tree showing mean section diameters over and under bark at a given distance from the stump and double bark thicknesses in the point of measurement. Based on the above, data were then calculated, with calculations including:

- mean diameter of each section over bark $d_{sob} = \frac{d_1 + d_2}{2}$
- mean diameter of each section under bark $d_{sub} = \frac{d_3 + d_4}{2}$
- double bark thickness in the point of mean diameter of each section $b = d_{sob} - d_{sub}$,
- volume of each section over bark (Huber's formula) $V_{sob} = \frac{d_{sob}^2 \cdot \pi \cdot l}{40000}$
- volume of each section under bark $V_{sub} = \frac{d_{sub}^2 \cdot \pi \cdot l}{40000}$
- total timber volume over and under bark of each tree obtained with summing the volume of all timber sections
- total bark volume of each tree as a difference of the total timber volume over and under bark
- proportion of bark in relation to the tree according to the equation

$$b_{\%} = \frac{\Sigma V_{sob} - \Sigma V_{sub}}{\Sigma V_{sob}}$$

d_1, d_2 - measured mean section diameters	V_{sob} - section volume over bark
d_{sob} - mean diameter of section over bark	V_{sub} - section volume under bark
d_{sub} - mean diameter of section under bark	$b_{\%}$ - proportion of bark
b - double bark thickness	

The calculated assortment timber volumes were summarized by quality classes for each tree. The processed tree volume was calculated by summing up all timber volumes of assortments. The ratio of the processed volume - the total volume shows the degree of timber yield at felling and processing, whereas the differences of these volumes show the quantity of waste at felling and processing.

All the trees possessing the above characteristics make up an elementary database. Double-entry tables and one-entry tables of timber volume, bark volume and percentage and assortment tables will be based on mathematical-statistical data processing in the elementary database.

Data relating to each section measurement were excluded from timber sectioning data entered into the computer. This database contains mean section diameters over bark, the distance of section diameter from the stump, double bark thickness in mid-section together with breast diameter and tree height at which a given section is found. The database is a foundation for the study of bark thickness in dependence on stem thickness.

Assortment timber volumes are distributed according to quality classes and diameter classes of trees. The total processed volume of diameter classes is given summarily. The summary values of assortment volumes by quality and diameter classes were divided with the number of trees in the respective diameter class. In this way, the mean tree assortment structure of diameter classes was determined and presented in absolute and relative values of quality classes.

The data were mathematically-statistically processed on a personal computer using the Microsoft EXCEL 97 programme package.

The data were subjected to descriptive statistical analyses. Various indicators of the central data dispersion trend were studied. The most favourable central trend indicators were found to be the arithmetic mean and standard deviation as a dispersion measure of this value.

In order to illustrate timber quality, research focused on establishing functional dependence of tree parameters. The data were subjected to regression analyses with one or more independent variables. Regression curves were selected on the basis of the following parameters: correlation coefficient (R), standard deviation of a dependent variable around the regression line (s_{y_x}), t-variable (*t Stat*) and the probability of error of the first kind (*P-value*) of regression coefficients (Serdar & Šošić 1981, Kachigan 1991).

The following equations were used for regression.

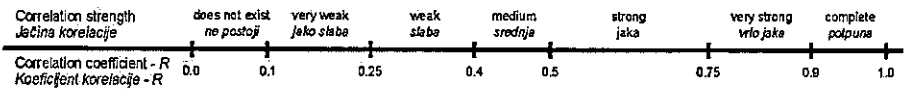
- Mihajlo's function for determining height curves of the studied tree sample $h = a_0\, e^{-a1/d} + 1.3$,
- Schummacher-Hall's equation for determining timber volume of a tree over and under bark and the volume of processed timber: $V = a_0\, d^{a1}\, h^{a2}$,
- equation of the second order to formulate one-entry tables of fir trees, assortment tables and dependence of bark thickness on tree diameter

$$y\,(V,\,b) = a_0 + a_1\, d + a_2\, d^2$$

a_0, a_1, a_2, - coefficients of regression equation	*b* - double bark thickness
d - breast diameter of tree	*V* - tree volume
h - tree height	

The Roemer-Orphal's scale was used to establish a firm link between the regressed independent and dependent variable (Kump et al. 1970).

Figure 2. Roemer-Orphal distribution
Slika 2. Roemer-Orphal-ova raspodjela



RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA

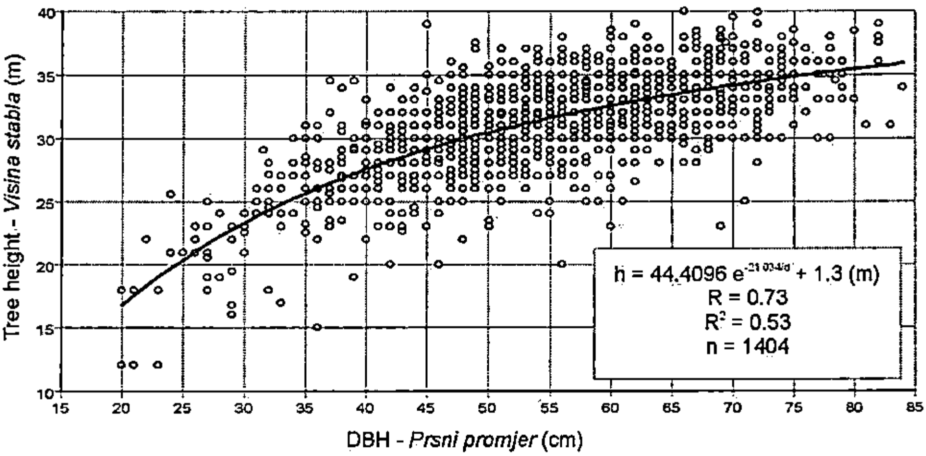
TREE SAMPLE
UZORAK STABALA

Research was conducted on a sample of 1,404 fir trees felled and processed in regular cutting operations. Breast diameters of the trees ranged between 20 cm and 85 cm, in other words, the trees were classified into 13 diameter classes from 22.5 cm to 82.5 cm. The number of trees per diameter class shows normal distribution trend with arithmetic mean in the diameter class of 52.5 cm. Tree heights ranged from 12 m to 40 m, and the trees were divided into height classes 5 m wide. Table 4 shows the number of sample trees per diameter and height classes.

Table 4. Number of trees per diameter and height classes
Tablica 4. Broj stabala uzorka po debljinskim i visinskim razredima

Tree height	Diameter class - *Debljinski razred*, cm													Total
Visina stabla, m	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	*Ukupno*
10-15	3													3
15-20	3	6	2	2										13
20-25	4	12	18	8	11	5	2	2						62
25-30		1	21	55	88	88	65	31	9	9	2			369
30-35			1	14	41	101	156	156	123	76	50	11	3	732
35-40						8	21	35	50	48	34	24	5	225
Total - *Ukupno*	10	19	42	79	140	202	244	224	182	133	86	35	8	1404

Figure 3. Height curve of sample trees
Slika 3. Visinska krivulja uzorka stabala



Based on the measured heights, a height curve of sampled trees was constructed with Mihajlo's function. Figure 3 shows the measured data with an inserted regressed height curve. The height curve of the sample trees was compared to the height curve taken from the Management Plan (* 1999) for the management unit "Belevine". It

Table 5. Comparison of height curves
Tablica 5. Usporedba visinskih krivulja

Diameter - class *Debljinski razred*	Tree height - *Visina stabala*		Difference *Razlika*
	Sample - *uzorak*	Management plan - *Osn. gosp.*	
cm	m		
22.5	18.7	18.4	0.3
27.5	22.0	21.7	0.3
32.5	24.5	24.4	0.2
37.5	26.6	26.6	0.1
42.5	28.4	28.4	0.0
47.5	29.8	29.9	-0.1
52.5	31.0	31.2	-0.1
57.5	32.1	32.3	-0.2
62.5	33.0	33.2	-0.2
67.5	33.8	34.1	-0.3
72.5	34.5	34.8	-0.3
77.5	35.2	35.5	-0.3
82.5	35.7	36.1	-0.4

can be concluded from Table 5 that the heights of diameter classes coincide almost completely (with only a few differences). The applied t-test confirmed the hypothesis that there were no differences between the quoted values ($t_{0.05} \doteq 0.115$), and that the choice of sample trees was proper.

TWO-ENTRY TABLES
DVOULAZNE TABLICE

In two-entry tables, two independent variables are in functional relation with a dependent variable. The constructed two-entry tables show the dependence of timber volume, bark volume and yield percentage on breast diameter and tree height.

TWO-ENTRY TABLES OF FIR TIMBER VOLUME
DVOULAZNE TABLICE DRVNOG OBUJMA STABALA JELE

Using the tree sectioning method, the timber volume of 1,404 sample trees up to 7 cm diameter over and under bark was determined. The processed timber volume was determined by adding up timber assortment volumes of each tree from the felling register. Figures 4, 6 and 8 show the calculated data of tree volumes over and under bark and the processed volume in dependence on breast diameters.

Figure 4. Data of tree volume over bark

Slika 4. Podaci o drvnom obujmu stabala s korom

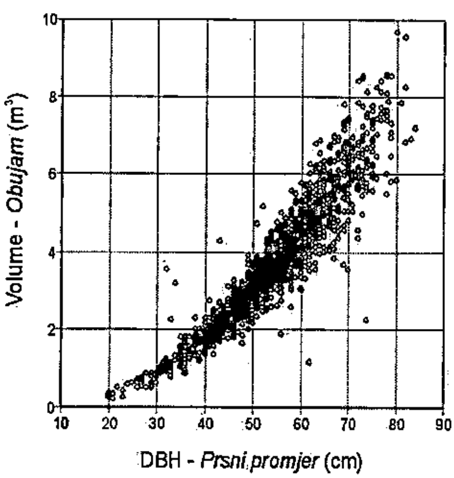


Figure 5. Tree volume over bark (Schumacher-Hall)

Slika 5. Drvni obujam stabala s korom (Schumacher-Hall)

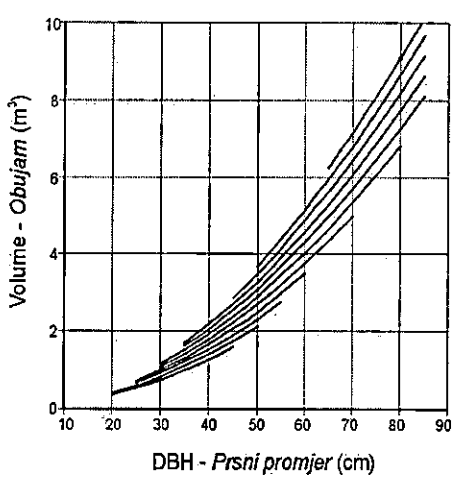


Figure 6. Data about tree volume under bark

Slika 6. Podaci o drvnom obujmu stabala bez kore

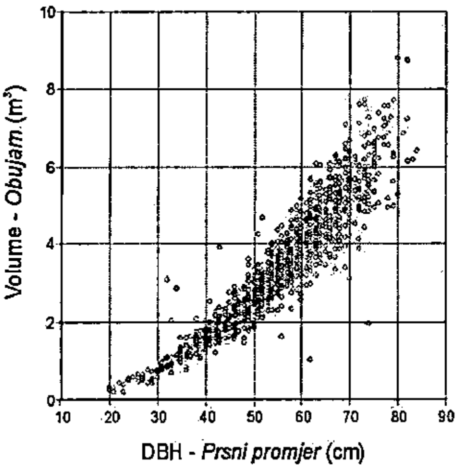


Figure 7. Tree volume under bark (Schumacher-Hall)

Slika 7. Drvni obujam stabala bez kore (Schumacher-Hall)

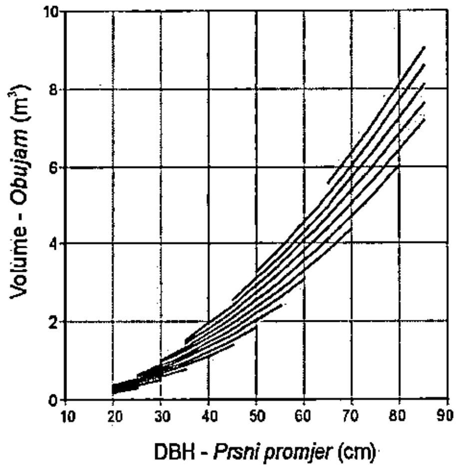


Figure 8. Data of processed tree volume

Slika 8. Podaci o iskorištenom drvnom obujmu stabala

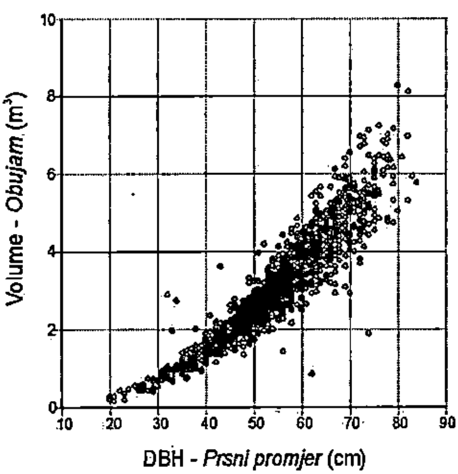


Figure 9. Processed tree volume (Schumacher-Hall)

Slika 9. Iskoristivi drvni obujam stabala (Schumacher-Hall)

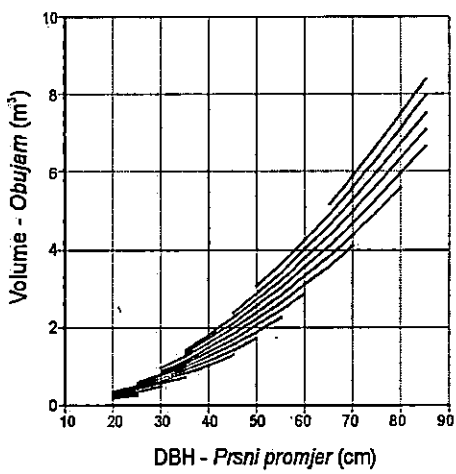


Table 6. Estimation of parameters of tree variables
Tablica 6. Procjena parametara varijabli stabala

Tree variables *Varijable stabla*	Number of trees *Broj stabala*	Arithmetic mean *Aritmetička sredina*	Standard deviation *Standardna devijacija*	Standard error *Standardna pogreška*	Range *Raspon* (min.- max.)	
DBH - *Prsni promjer*		54.3	11.53	0.31	20	85
Tree height - *Visina stabla*		31.0	3.89	0.10	10	40
Timber volume to 7 cm diameter over bark *Drvni obujam do 7 cm promjera s korom*	1404	3.73	1.69	0.04	0.22	9.66
Timber volume to 7 cm diameter under bark *Drvni obujam do 7 cm promjera bez kore*		3.31	1.50	0.04	0.19	8.81
Processed timber volume *Iskorišteni drvni obujam*		3.08	1.40	0.04	0.16	8.33

The smallest square method was used to insert regression lines into the presented data by applying the Schumacher-Hall equation for estimating timber volume in dependence on breast diameter and tree height. Total data correlation was accomplished with data regression according to Roemer-Orphal scale (correlation coefficient values of 0.97).

Table 7. Regression equations of dependence of timber volume on DBH and tree height
Tablica 7. Regresijke jednadžbe ovisnosti drvnog obujma o prsnom promjeru i visini stabala

Timber volume of trees *Drvni obujam stabala*	Regression equations *Regresijske jednadžbe*	Corellation coeficient *Koeficijent korelacije*
Tree volume to 7 cm diameter over bark *Obujam stabla do 7 cm promjera s korom*	$V = 0.000075 \cdot d^{1.81567} \cdot h^{1.01588}$	0.97
Tree volume to 7 cm diameter under bark *Obujam stabla do 7 cm promjera bez kore*	$V = 0.000064 \cdot d^{1.80674} \cdot h^{1.04000}$	0.97
Processed tree volume *Iskoristivi obujam stabala*	$V = 0.000060 \cdot d^{1.80486} \cdot h^{1.03712}$	0.97

Based on the parameters of regression lines, two-entry tables of fir tree timber volumes were constructed and presented in graph form (Figures 5, 7 and 9). Ranges of breast diameters and tree heights presented in two-entry tables were determined by recorded and measured values on sample trees. The values of tree volume in tables increase with an increase in breast diameters and tree heights. At identical breast diameter and tree height, timber volume of trees to 7 cm diameter over bark has the largest values, followed by timber volume of trees to 7 cm diameter under bark, while processed timber volume of trees has the lowest values. Within this range, timber volume to 7 cm over bark ranges from 0.216 m^3 for trees with breast diameters of 20 cm and heights of 12 m to 10.167 m^3 for trees with breast diameters of 85 cm and heights of 40 m. For these trees, the timber volume to 7 cm under bark ranges from 0.189 m^3 to 10.030 m^3, while the processed timber volume ranges from 0.177 m^3 to 9.301 m^3.

TWO-ENTRY TABLES OF FIR BARK VOLUME
DVOULAZNE TABLICE KORE STABALA JELE

The difference between the regressed timber volume values of fir trees to 7 cm diameter over and under bark represents the volume of fir tree bark shown in two-entry tables. The volume of tree bark increases with an increase in breast diameter and tree height and assumes values from 0.03 m^3 in trees with breast diameters of 20 cm and heights of 12 m to 1.12 m^3 in trees with breast diameters of 85 cm and heights of 40 m.

Apart from two-entry tables of bark volume, tables of bark percentages were also constructed using the formula:

$$b_{\%} = \frac{\Sigma V_{ob} - \Sigma V_{ub}}{\Sigma V_{ob}} \cdot 100$$

(V_{ob} - tree volume over bark; V_{ub} - tree volume under bark; $b_{\%}$ - proportion of tree bark)

where tree volumes over and under bark (V_{ob}, V_{ub}) represent the regressed values shown in the constructed two-entry tables. The percentage of bark proportion is within the limits from 12.45 % to 10.67 %. Within the same diameter class, the percentage of bark declines as tree height increases. The proportion of bark in trees of equal heights is directly proportionate to breast diameter. However, in analysing mean values of bark percentage of diameter classes, bark percentage decreases with an increase in tree breast diameter, which confirms former research stating that the percentage of bark decreases as breast diameter increases (Bojanin 1966b, Klepac 1972, Krpan 1986).

Figure 10. Bark volume
Slika 10. Obujam kore

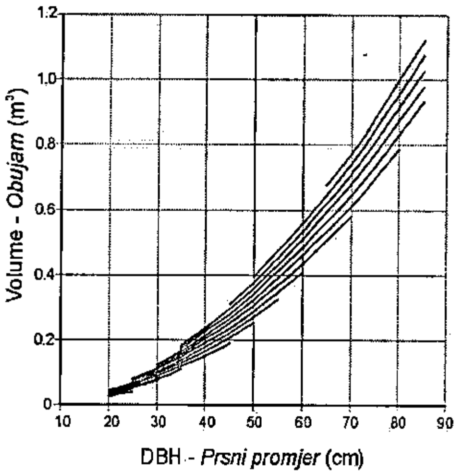
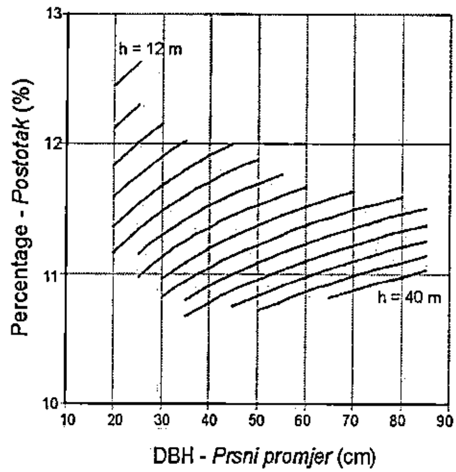


Figure 11. Bark volume percentage
Slika 11. Obujmeni postotak kore



TIMBER VOLUME YIELD AND WASTE ACCORDING TO TWO-ENTRY TABLES
ISKORIŠTENJE DRVNOG OBUJMA I OTPAD PREMA DVOULAZNIM TABLICAMA

The percentage of fir timber volume yield is determined as the ratio between the processed timber volume (the sum of volumes of timber assortments made from a tree) and the timber volume of tree to 7 cm diameter over bark. In the sample, the yield ranged from 70.18 % to 94.90 % with an arithmetic mean of 82.54 %. The calculated yield values of sample trees were not subjected to regression analysis due to a statistically unreliable correlation coefficient.

For this reason, yield tables were calculated from the regressed values of the processed timber volumes of trees and the total timber volume of trees to 7 cm diameter over bark.

For data on breast diameters and heights in the sample, yield values range from 81.7 % to 83.0 %. The yield rises with an increase in the height of trees at identical breast diameters (Figure 12).

Waste consists of bark and losses in timber volume resulting from felling and processing. Losses in timber volume from felling and processing relate to real waste, or to parts of large wood of trees which remain unused in a forest for a variety of reasons, as well as to losses incurred by the prescribed measuring methods (rounding down assortment diameters and lengths, the prescribed log length allowance and er-

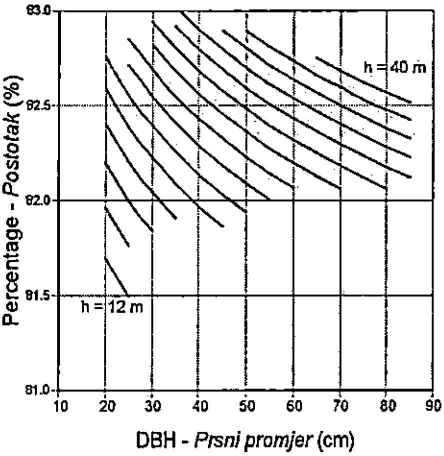


Figure 12. Timber volume yield according to tables

Slika 12. Iskorištenje drvnog obujma prema tablicama

rors in Huber's formula). It should be pointed out that, in case of debarking, bark on technical assortments and on conifer pulpwood is included in the waste structure.

Accordingly, if bark is excluded from waste structure, a part of losses from felling and processing may be expressed

Figure 13. Volume of timber losses from felling and processing

Slika 13. Obujam gubitaka pri sječi i izradi stabala

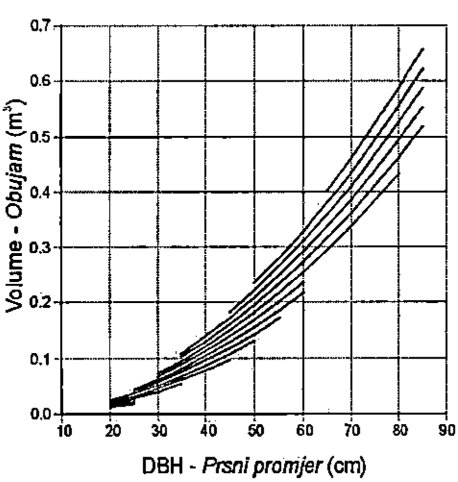
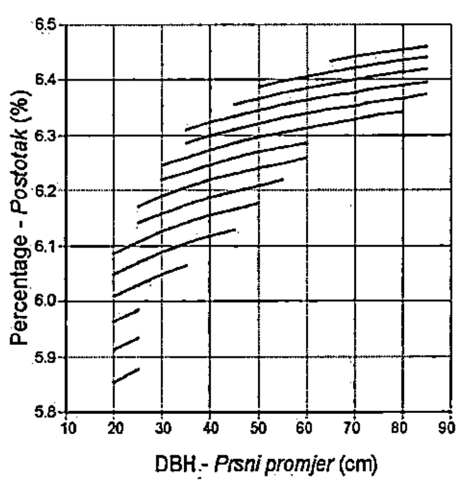


Figure 14. Percenatge of timber volume losses from felling and processing

Slika 14. Obujmeni postotak gubitaka pri sječi i izradi stabala



- in absolute values - by subtracting the processed timber volume of trees and bark volumes of trees from the total timber volume to 7 cm diameter over bark,
- in relative values - from the ratio of the quoted difference and the total timber volume of trees.

Absolute and relative values of losses from felling and processing increase from 0.01 m^3 to 0.66 m^3 or from 5.85 % to 6.46 % with an increase in either the breast diameter or the height of trees

ONE-ENTRY TABLES
JEDNOULAZNE TABLICE

One-entry tables represent a regression model in which the volume of a tree is the function of its breast diameter. One-entry tables of fir timber and bark volume were constructed mathematically and the structure of yield and waste from felling and processing was calculated in absolute and percentage values.

ONE-ENTRY TABLES OF FIR TIMBER VOLUME
JEDNOULAZNE TABLICE DRVNOG OBUJMA STABALA JELE

To construct one-entry tables, the same data for tree sectioning were used as in the construction of two-entry timber volume tables. The data were regressed with the curve of the second order (parabola), which is known as the model of Hohenadl-Kren (Kružić 1993a):

$$V = a_0 + a_1 d + a_2 d^2$$

(a_0, a_1, a_2 - coefficients of regression equation; *d*- tree breast diameter; *V* - tree volume)

The highest correlation coefficients were obtained with regression analysis by applying the mentioned regression line without a free member b_0. The analytical expression of dependence of volume on breast diameter shows that it is possible to estimate tree volumes if tree heights exceed the height of breast diameters at 1.3 m. Data on tree volumes to 7 cm diameter over and under bark and the processed volumes were regressed. Identical correlation coefficients of 0.94 were obtained in all regressions. The value of correlation coefficient points to full linkage according to the Roemer-Orphal scale.

Table 8. Regression eqations of dependence of timber and bark volume on DBH
Tablica 8. Regresijke jednadžbe ovisnosti obujma drva i kore o prsnom promjeru stabala

Timber volume of trees *Drvni obujam stabala*	Regression equations *Regresijske jednadžbe*	Corellation coeficient *Koeficijent korelacije*
Tree volume to 7 cm diameter over bark *Obujam stabla do 7 cm promjera s korom*	$V = -0.00638\ d + 0.00132\ d^2$	0.94
Tree volume to 7 cm diameter under bark *Obujam stabla do 7 cm promjera bez kore*	$V = -0.00601\ d + 0.00118\ d^2$	0.94
Processed tree volume *Iskoristivi obujam stabala*	$V = -0.00521\ d + 0.00109\ d^2$	0.94
Bark volume *Obujam kore*	$V = -0.00038\ d + 0.00014\ d^2$	0.87

According to the regressed values (Figures from 15 to 17), timber volume to 7 cm diameter over bark ranges from 0.401 m^3 for trees with breast diameters of 20 cm to 8.790 m^3 for trees with breast diameters of 84 cm. For the same breast diameters, timber volume to 7 cm diameter under bark ranges from 0.352 m^3 to 7.822 m^3, while the processed timber volume ranges from 0.332 m^3 to 7.252 m^3.

Figure 15. Dependence of tree volume over bark on DBH
Slika 15. Ovisnost drvnog obujma stabala s korom o prsnom promjeru

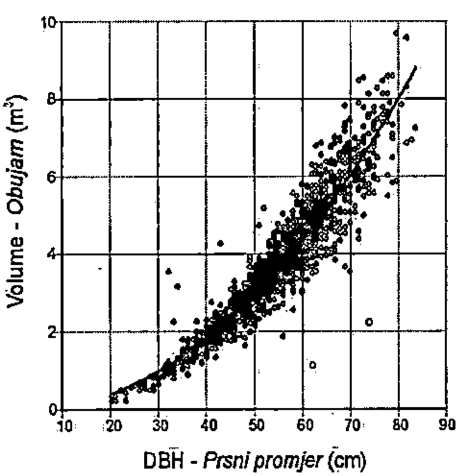


Figure 16. Dependence of tree volume under bark on DBH
Slika 16. Ovisnost drvnog obujma stabala bez kore o prsnom promjeru

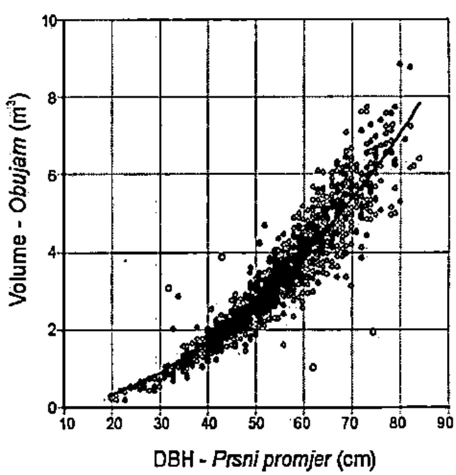


Figure 17. Dependence of processed tree volume on DBH

Slika 17. Ovisnost iskorištenog drvnog obujma o prsnom promjeru

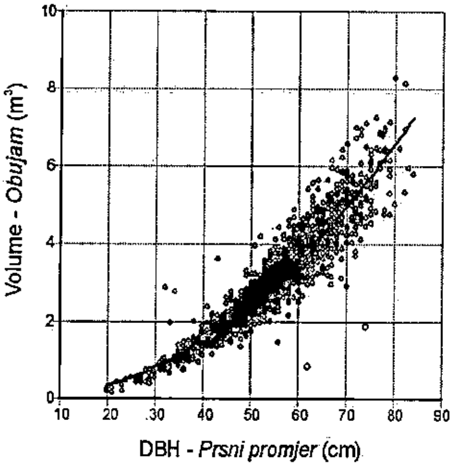
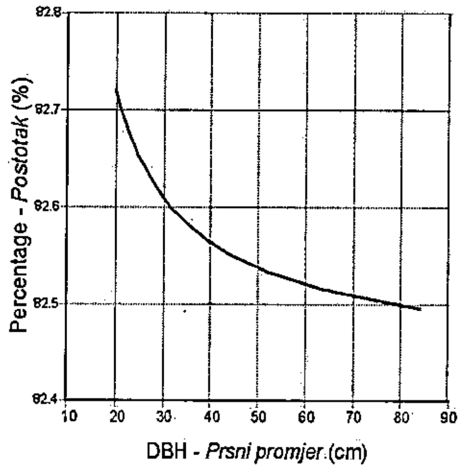


Figure 18. Dependence of timber volume yield on DBH

Slika 18. Ovisnost iskorištenja drvnog obujma prema prsnom promjeru



Tables of bark volumes were constructed from calculated values of bark volumes of individual trees. Bark volume of a tree represents the difference between tree volume over and under bark obtained by sectioning. The same analytical expression was used for data regression and the correlation coefficient of 0.87 was obtained. Bark volume increases with a rise in breast diameter and ranges from 0.049 m^3 for trees with breast diameters of 20 cm to 0.968 m^3 for trees with breast diameters of 84 cm. (Figure 19)

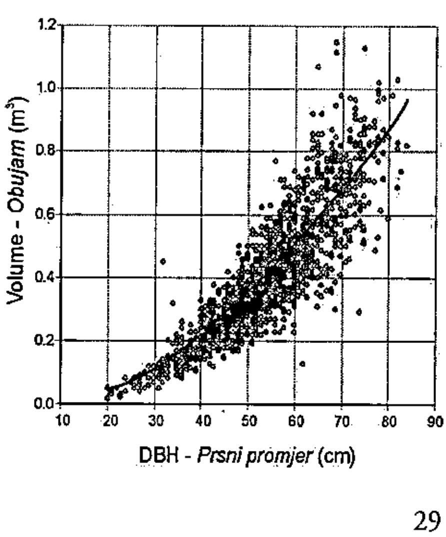


Figure 19. Dependence of bark volume on DBH

Slika 19. Ovisnost obujma kore o prsnom promjeru

TIMBER VOLUME YIELD AND WASTE ACCORDING TO ONE-ENTRY TABLES

ISKORIŠTENJE DRVNOG OBUJMA I OTPAD PREMA JEDNOULAZNIM TABLICAMA

Based on the constructed one-entry tables, the structure of yield and waste was established in dependence on breast diameter. Waste is the difference between regressed values of tree volumes to 7 cm diameter over bark and the processed volume. Losses at felling and processing represent the difference between waste and bark volume. In the preceding chapter it was stated that bark volume is completely included in the structure of waste, and losses at felling and processing contain real waste and losses due to standard-related measurement method.

Timber volume yield, waste and losses at felling and processing are presented in absolute and percentage values. Percentage values of yield at felling and processing decrease only slightly with an increase in breast diameter. For the volume of trees with breast diameters from 20 cm to 84 cm, yield decreases from 82.72 % to 82.50 %, making the difference of 0.22 %. Waste percentage at felling and processing has a reverse trend. With an increase in breast diameters, the percentage of tree bark also decreases from 12.26 % for the thinnest trees (breast diameter of 20 cm) to 11.02 % for the trees with breast diameters of 84 cm, while the percentage of real waste and other losses at felling and processing rises from 5.02 % to 6.49 % for the same marginal values of breast diameters.

Figure 20. Dependence of waste volume on DBH

Slika 20. Obujmeni udio otpada ovisno o prsnom promjeru

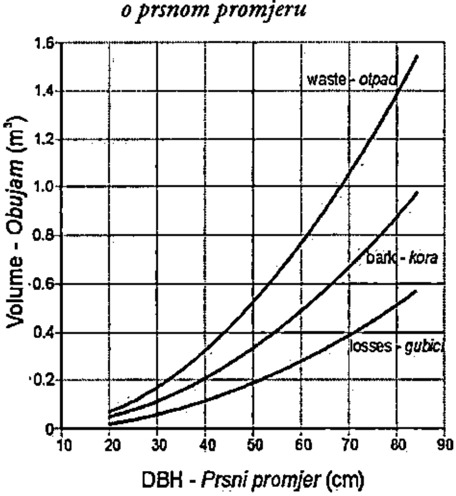
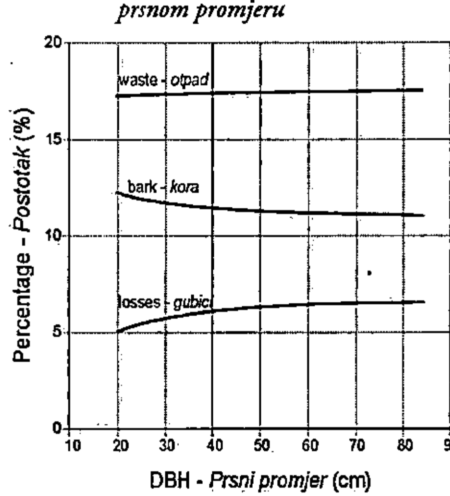


Figure 21. Dependence of waste percentage on DBH

Slika 21. Postotni udio otpada ovisno o prsnom promjeru



BARK THICKNESS
DEBLJINA KORE

The sectioning method was used to measure the diameter and double bark thickness at each mid-section. Based on measuring 14,614 sections, pairs of data of mean mid-section diameters and double bark thicknesses were established. Research was aimed at determining the dependence of double bark thickness on roundwood diameter. Bojanin (1966a, b) proved that the thickness of bark on assortments did not depend on the thickness of trees or the distance from the ground or the position; in other words, it did not depend on whether the bark was on the crown or on the pure part of the stem; it only depended on the diameter of roundwood. Past research on the dependence of bark thickness on roundwood diameter established a correlation in the form of a straight line (Bojanin 1966b, Klepac 1972) or parabola (Krpan 1986). In regression data analysis, a curve of the second order was chosen (parabola), achieving a correlation coefficient of 0.7, that is, higher than the one achieved with regressing data with a line.

Regression equation of double bark thickness is:

$$b = 0.73259 + 0.04439\,d - 0.00018\,d^2.$$

(d - breast diameter of tree; b - double bark thickness)

By subtracting double bark thickness from roundwood diameters over bark, roundwood diameters under bark were determined and basal areas for diameters over and under bark were calculated. Bark percentage was determined according to basal areas over and under bark on a given tree diameter.

According to Figure 22, an increase in diameter results in thicker bark and smaller percentage. Double bark thickness at roundwood diameter of 10 cm is 1.16 cm, and at roundwood diameter of 84 cm it is 3.16 cm. The percentage of bark is the highest with roundwood diameter of 20 cm (21.8 %). It drops distinctly with an increase in diameter and amounts to 7.4 % with roundwood diameter of 84 cm.

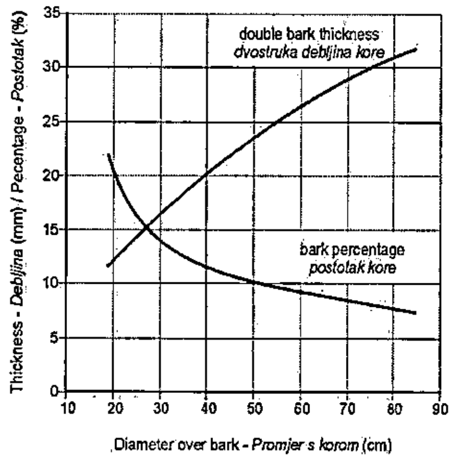


Figure 22. Bark thickness and percentage
Slika 22. Debljina i postotak kore

Research into bark thickness is particularly important from the standpoint of forestry practice, when timber assortments are measured over bark and double bark thickness has to be subtracted so that the mean diameter of assortments under bark can be determined according to the Croatian standards for roundwood.

With regard to roundwood diameters and minimal values of mean assortment diameters, a conclusion may be drawn on the volume of bark on individual assortments. For sawmill logs in quality classes I and II with mean diameters exceeding 25 cm (according to the standards), the percentage of bark ranges from 13.0 % for diameter of 25 cm under bark to 7.4 % for diameter of 81 cm under bark. Since the average mean diameter falls between these values, it can be concluded that these timber assortments will have the percentage of bark of about 10%. For sawmill logs in quality class III, a little higher bark percentage may be expected due to the allowed minimal mean diameter of 20 cm. Since mean diameters of mining timber under bark are between 9 cm and 25 cm, bark percentages are within the limits of 21.8% and 13 %. Bark percentage of pulpwood is within similar limits.

ASSORTMENT STRUCTURE
SORTIMENTNA STRUKTURA

Timber assortments were processed from felled fir trees and classified according to the Croatian standards for roundwood into the following quality classes: veneer logs, sawlogs (quality classes I, II and III), mining timber and pulpwood. Based on assortment measurements, their volume was established and assortment volumes summarised by quality classes and tree. A total of 4,319.31 m^3 of timber assortments were made. Table 10 shows the processed volume of timber assortments according to diameter classes and quality classes.

The sample contained only 12 veneer logs divided into 7 diameter classes. The total volume of veneer logs accounts for only 9.24 m^3or 0.23 % of the entire processed volume. Plavšić & Golubović (1963), in their study of percentage ratio of fir assortments in a sample of 1,607 trees, did not register one single veneer log. In constructing assortment tables for fir stemwood, Rebula (1996) does not mention the quality class of veneer logs either. Based on earlier research and on the studied sample, it may be concluded that veneer logs of fir trees in selection stands are very rare and are the result of a large number of favourable factors, from stand, site and climatic factors to genetic properties of individual trees. Although veneer logs are the most valuable assortments, their very low proportion excludes them from the study of assortment structure.

Table 10. Total timber volume of the sample according to diameter classes
Tablica 10. Ukupni drvni obujam uzorka po debljinskim razredima

Diameter classes *Debljinski razred*	Number of trees *Broj stabala*	Tree volume *Obujam stabala*	Timber assortments - *Drvni sortimenti*								
			Veneer logs *Furnirski trupci*	Sawlogs I. class *Pilanski trupci I.*	Sawlogs II. class *Pilanski trupci II.*	Sawlogs III. class *Pilanski trupci III.*	Logs total *Trupci ukupno*	Mining timber *Rudničko drvo*	Technical roundwood *Tehnika ukupno*	Pulpwood *Celulozno drvo*	Total *Ukupno*
cm		m^3									
22.5	10	4.01			0.65		0.65	2.48	3.13	0.19	3.32
27.5	19	12.18			2.37	2.13	4.50	4.96	9.46	0.63	10.09
32.5	42	50.72		6.20	15.21	11.42	32.82	8.18	41.00	1.06	42.06
37.5	79	120.62		19.27	30.77	34.67	84.71	10.76	95.47	4.02	99.49
42.5	140	290.77	0.43	41.09	86.49	83.75	211.76	16.34	228.09	11.13	239.22
47.5	202	535.82	1.41	78.63	168.47	159.62	408.14	17.33	425.47	17.71	443.18
52.5	244	815.93	2.04	114.22	233.22	273.41	622.90	18.31	641.21	30.14	671.35
57.5	224	902.00		113.21	268.27	313.90	695.38	12.14	707.52	39.87	747.39
62.5	182	881.94	1.87	122.36	235.62	310.32	670.17	7.95	678.13	50.24	728.37
67.5	133	753.09	1.09	117.80	184.43	268.98	572.29	3.99	576.28	43.83	620.11
72.5	86	547.61	1.41	67.86	168.10	176.57	413.94	1.96	415.90	33.98	449.88
77.5	35	253.23	0.99	41.28	65.67	86.53	194.47	1.14	195.61	14.12	209.73
82.5	8	65.87		3.97	26.01	20.23	50.20		50.20	4.92	55.12
Total *Ukupno*	1404	5233.80	9.24	725.89	1485.27	1741.52	3961.92	105.55	4067.46	251.84	4319.31

Table 11. Proportion of quality classes in total timber volume of the sample according to diameter classes
Tablica 11. Postotni udjeli razreda kakvoće u ukupnom drvnom obujmu uzorka po debljinskim razredima

Diameter classes *Debljinski razred*	Timber assortments - *Drvni sortimenti*								
	Veneer logs *Furnirski trupci*	Sawlogs I. class *Pilanski trupci I.*	Sawlogs II. class *Pilanski trupci II.*	Sawlogs III. class *Pilanski trupci III.*	Logs total *Trupci ukupno*	Mining timber *Rudničko drvo*	Technical roundwood *Tehnika ukupno*	Pulpwood *Celulozno drvo*	Total *Ukupno*
cm	%								
22.5	0.00	0.00	19.58	0.00	19.58	74.70	94.28	5.72	100.00
27.5	0.00	0.00	23.49	21.11	44.60	49.16	93.76	6.24	100.00
32.5	0.00	14.74	36.15	27.14	78.03	19.45	97.48	2.52	100.00
37.5	0.00	19.37	30.92	34.85	85.14	10.81	95.96	4.04	100.00
42.5	0.18	17.18	36.15	35.01	88.52	6.83	95.35	4.65	100.00
47.5	0.32	17.74	38.01	36.02	92.09	3.91	96.00	4.00	100.00
52.5	0.30	17.01	34.74	40.73	92.78	2.73	95.51	4.49	100.00
57.5	0.00	15.15	35.89	42.00	93.04	1.62	94.67	5.33	100.00
62.5	0.26	16.80	32.35	42.60	92.01	1.09	93.10	6.90	100.00
67.5	0.18	19.00	29.74	43.38	92.29	0.64	92.93	7.07	100.00
72.5	0.31	15.08	37.37	39.25	92.01	0.44	92.45	7.55	100.00
77.5	0.47	19.68	31.31	41.26	92.72	0.54	93.27	6.73	100.00
82.5	0.00	7.19	47.18	36.69	91.07	0.00	91.07	8.93	100.00
Total -	0.21	16.81	34.39	40.32	91.73	2.44	94.17	5.83	100.00
Ukupno					97.41	2.59	100.00		
	0.23	18.32	37.49	43.96	100.00				

Sawlogs in quality class I occur from the diameter class of 32.5 cm upwards with a proportion of 16.81 % in the total processed volume. In the total processed timber volume, sawlogs in quality classes II and III have the highest proportion participating with 34.39 %, or 40.32 % in the total processed volume.

The diameter class of 22.5 cm does not contain any sawlogs in quality class III, which can be explained by a regular form of higher stem parts of thinner trees and by small-dimension knots. The processed assortments were consequently classified into mining timber, which is represented with 74.7 % in this diameter class. The proportion of mining timber abruptly declines with an increase in tree breast diameters. The mining timber was not processed from the thickest trees in the sample, which is related to higher knottiness in the upper stem parts and a greater taper, which is an eliminating defect for this assortment. The proportion of pulpwood in the total processed volume is only 5.83 %.

The proportions of quality classes in absolute values were calculated on the basis of mean trees of diameter classes in the following way: the sum values of timber assortment volumes by quality classes and diameter classes (from Table 10) were divided by the number of trees in a respective diameter class.

Minimum assortment volumes were determined on the basis of the minimum permitted dimensions of assortments in an individual quality class according to roundwood standards (Table 12).

Table 12. Minimum dimensions of assortments according to quality classes
Tablica 12. Najmanje dimenzije sortimenata po razredima kakvoće

Dimension *Veličina*	Unit *Jedinica mjere*	Timber assortment - *Drvni sortiment*					
		Veneer F	Sawlog I.	Sawlog II.	Sawlog III.	Mining timber *Rud. dr.*	Pulpwood *Cel. dr.*
Minimum diameter *Najmanji promjer*	cm	35	25	20	20	9	7
Minimum length *Najmanja duljina*	m	2	4	4	3	1.5	1
Volume *Obujam*	m^3	0.19	0.19	0.13	0.09	0.01	0.004

The values of volumes of individual quality classes lower than the minimum assortment volumes were detected in the assortment structure of mean trees of diameter classes, which is unacceptable for data processing.

For these reasons, a regression analysis of quality class volumes was done in dependence on breast diameter based on the assortment structure of all trees.

The regressed values of a quality class are shown in diameter classes, where they appeared in the sample, and the regression line was chosen not only with statistical criteria, but attention was paid to the fact that the value of an individual quality class satisfies the minimal timber volume value of this class.

With regard to the requirement for minimal assortment volumes in a quality class, regression lines combined with reliable statistical parameters were chosen. The regression analysis was done with curves of the second order (parabolas) with or without a free member:

$$V = a_0 + a_1 d + a_2 d^2 \qquad \text{ili} \qquad V = a_1 d + a_2 d^2$$

(a_0, a_1, a_2 - coefficients of regression equation; d- breast diameter of tree; V- tree volume)

Coefficients of regression equation and correlation coefficients according to quality classes are shown in Table 13.

Table 13. Regression analysis data
Tablica 13. Podaci o regresijskoj analizi

Timber assortment *Drvni sortiment.*	Coeficients of regression equation *Koeficijenti regresijske jednadžbe*			Statistical parameters *Statistički parametri*		Number of trees *Broj stabala*	
	a_0	a_1	a_2	R	R^2	possible *moguć*	real *stvarni*
Sawlogs I. *Pilanski trupci I.*	-0.10288	0.00481	0.00013	0.27	0.08	1375	614
Sawlogs II. *Pilanski trupci II.*		-0.00046	0.00035	0.46	0.21	1404	1108
Sawlogs III. *Pilanski trupci III.*		-0.00662	0.00052	0.52	0.27	1394	1240
Mining timber *Rudničko drvo*	0.55113	-0.01439	0.00010	0.46	0.22	1396	761
Pulpwood *Celulozno drvo*	0.123827	-0.00847	0.00017	0.45	0.20	1404	1258

Correlation indexes indicate poor connection among parameters and higher data dispersion, but the possibility of error in the data on quality class volume in the regression analysis was removed. Figures 23 to 27 show data relating to volumes of quality classes in dependence on tree breast diameter, as well as data regression lines.

The basic problem in the study of assortment structure stems from the fact that a certain number of trees do not contain assortments in all quality classes. In his work, Vuletić (1999) claims that this phenomenon leads to grouping the measured data into two separate sets, of which one represents real values, and the other lies on the x-axis and contains all values equalling zero. The values on the x-axis do not indicate low tree quality; rather, they indicate its incomplete assortment structure, because a tree may contain only one or two assortments and still have very high quality. The author calls zero values on the x-axis false zeros, because although their volume values equal zero, a certain quality class may be expected from the trees in view of their breast diameters.

Sawlogs in quality class I with the lowest minimal diameter of 25 cm occur in trees in the diameter class of 32.5 cm, or more accurately, from breast diameters of 34 cm. It is assumed that trees with breast diameters over 34 cm yield sawlogs in quality class I, and so do all other trees in the diameter class 32.5 cm. In the regression analysis, it was assumed that sawlogs in quality class I may be expected from all trees in diameter class 32.5 cm and more. Timber assortment in the mentioned quality class occurs on only 614 trees, although this assortment could be obtained from 1,375 trees in view of their breast diameters.

Figure 23. Dependence of sawlog volume in I. quality class on DBH

Slika 23. Obujam pilanskih trupaca I. razreda kakvoće ovisno o prsnom promjeru

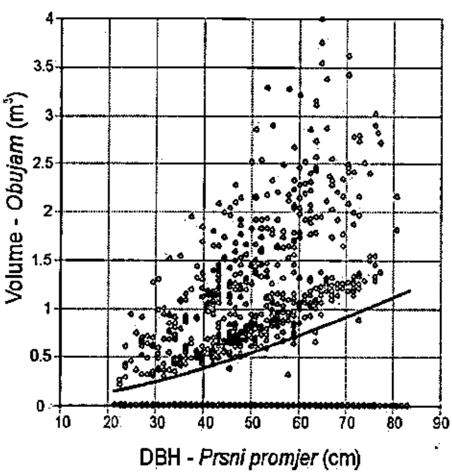


Figure 24. Dependence of sawlog volume in II. quality class on DBH

Slika 24. Obujam pilanskih trupaca II. razreda kakvoće ovisno o prsnom promjeru

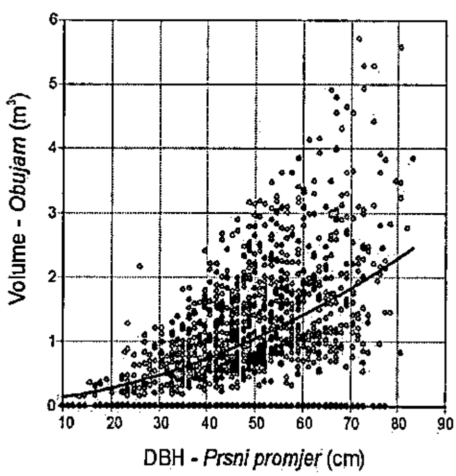


Figure 25. Dependence of sawlog volume in III. quality class on DBH

Slika 25. Obujam pilanskih trupaca III. razreda kakvoće ovisno o prsnom promjeru

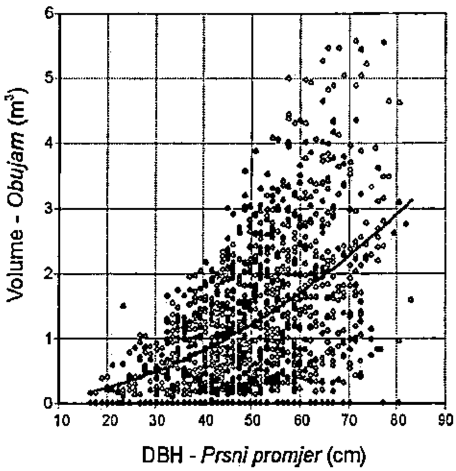


Figure 26. Dependence of mining timber volume on DBH

Slika 26. Obujam rudničkog drva ovisno o prsnom promjeru

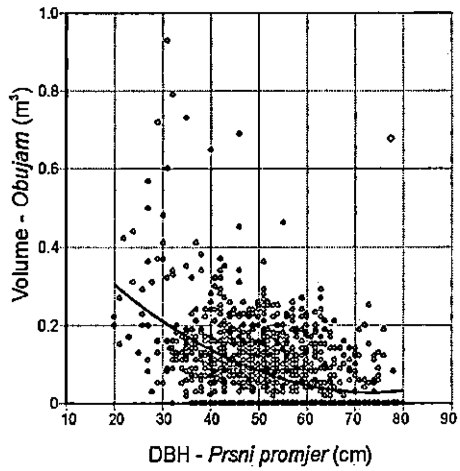
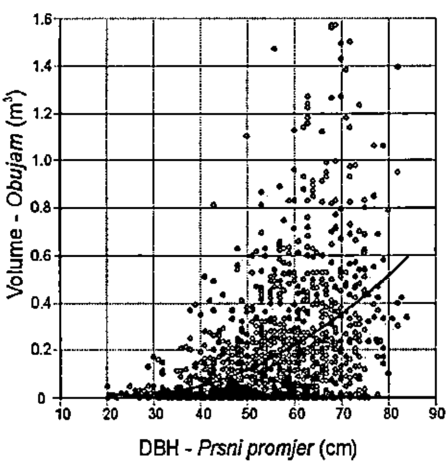


Figure 27. Dependence of pulpwood volume on DBH

Slika 27. Obujam celuloznog drva ovisno o prsnom promjeru



In terms of breast diameter, sawlogs in quality class II may be expected in all sample trees; however, they were measured only in 1,108 trees. Sawlogs in quality class III occur from breast diameter of 26 cm, or diameter class of 27.5 cm upward. A total of 1,240 trees with quality class III sawlog assortment were measured.

Mining timber in the sample was not measured in any tree in the last diameter class of 82.5 cm; therefore, these trees were not included in the regression analysis. Of 1,396 trees in all, mining timber was measured in 761 trees.

Pulpwood was registered in all diameter classes, but was measured on 1,258 trees. The values of pulpwood volumes in other trees are considered false zeros.

Table 14. Regressed assortment volume values of sample trees according to diameter and quality classes

Tablica 14. Izjednačene vrijednosti drvnog obujma sortimenata stabala uzorka po razredima kakvoće i debljinskim razredima

Diameter class *Debljinski razred*	Timber assortment - *Drvni sortimenti*						Processed volume (tables) *Iskoristivi obujam (tablice)*	Diference *Razlika*
	Sawlogs I. class *Pilanski trupci I*	Sawlogs II. class *Pilanski trupci II*	Sawlogs III. class *Pilanski trupci III*	Mining timber *Rudničko drvo*	Pulpwood *Celulozno drvo*	Total *Ukupno*		
cm	m^3						m^3	
22.5		0.17		0.28	0.02	0.46	0.43	-0.03
27.5		0.25	0.21	0.23	0.02	0.71	0.68	-0.03
32.5	0.19	0.36	0.33	0.19	0.03	1.09	0.98	-0.11
37.5	0.25	0.48	0.48	0.15	0.04	1.41	1.34	-0.07
42.5	0.33	0.61	0.66	0.12	0.07	1.79	1.75	-0.04
47.5	0.41	0.77	0.86	0.09	0.10	2.23	2.21	-0.02
52.5	0.49	0.94	1.09	0.07	0.14	2.73	2.73	0.00
57.5	0.59	1.13	1.34	0.05	0.19	3.30	3.30	0.00
62.5	0.69	1.34	1.62	0.04	0.25	3.93	3.93	0.00
67.5	0.79	1.57	1.92	0.03	0.31	4.63	4.61	-0.02
72.5	0.90	1.81	2.25	0.03	0.39	5.39	5.35	-0.04
77.5	1.02	2.07	2.61	0.03	0.47	6.21	6.14	-0.07
82.5	1.15	2.35	2.99		0.56	7.05	6.99	-0.07

Timber volume of sawlogs rises with an increase in tree breast diameter for all quality classes. The volume of sawlogs in quality class I ranges from 0.19 m^3 for diameter class 32.5 cm to 1.15 m^3 for diameter class 82.5 cm, while the volumes for quality class II range from 0.17 m^3 to 2.35 m^3 for all diameter classes of the sample. Sawlogs in quality class III occur from diameter class 27.5 cm and display the highest growth in volume values with an increase in breast diameter (from 0.21 m^3 to 2.99 m^3). The volume of this class has the highest values in the structure of volumes of mean trees from diameter class 42.5 cm to 82.5 cm (Table 14).

The volume of mining timber decreases from 0.28 m^3 to 0.03 m^3, and that of pulpwood increases from 0.02 m^3 to 0.56 m^3 for all diameter classes of the sample where recorded.

The sum of regressed quality class volumes of diameter classes was compared with processed timber volumes according to one-entry tables. The total processed volume in terms of assortment structure is slightly higher than the table volume, and the differences vary in values by 0.11 m^3. For diameter classes from 47.5 cm to 67.5 cm, there are no differences or they are very small (0.02 m^3), which indicates a sufficient number of trees of these diameter classes in the sample. In the distribution of breast diameters of sample trees, the curve ends are questionable due to an insufficient number of the thinnest and the thickest trees. However, with regard to cutting maturity of fir trees in the studied management unit (70 cm) and the principles of selective cutting, it is very hard to ensure a statistically sufficient number of trees with breast diameters less than 40 cm and more than 70 cm. If these criteria were satisfied, the comparison of assortment structure with one-entry tables of processed timber volume would probably be more accurate. Although the regression analysis of all values is not sufficiently reliable in terms of statistics due to data dispersion within diameter classes, the results are still applicable because of regular data sequences.

Based on volume values of quality and diameter classes, proportionate values were constructed (Table 15)

Sawlogs in quality class II assume the highest values in the first two diameter classes of the sample (36.18 % and 35.53 %). After that, the proportion varies slightly with an increase in breast diameters (32.69 % in diameter class 32.5 cm, 34.59 % in diameter class 47.5 cm and 33.35 % in diameter class 82.5 cm). The proportions in quality class III rise from 29.66 % to 42.43 % with an increase in tree breast diameters.

The proportion of mining timber is the highest in diameter class 22.5 cm (59.96 %). With an increase in breast diameters, it decreases to as much as 0.51 % in diameter class 77.5 cm. The proportions of pulpwood are below 8 % for all diameter classes of the sample. The lowest values were recorded in diameter class 32.5 (2.31 %), and the highest in diameter class 82.5 cm (7.98 %).

Table 15. Proportion of regressed values of sample tree assortment volumes according to diameter and quality classes

Tablica 15. Postotni udjeli izjednačenih vrijednosti drvnog obujma sortimenata stabala uzorka po razredima kakvoće i debljinskim razredima

Diameter class *Debljinski razred*	Timber assortment - *Drvni sortimenti*					
	Sawlogs I. class *Pilanski trupci I*	Sawlogs II. class *Pilanski trupci II*	Sawlogs III. class *Pilanski trupci III*	Mining timber *Rudničko drvo*	Pulpwood *Celulozno drvo*	Total *Ukupno*
cm	%					
22.5		36.18		59.96	3.86	100
27.5		35.53	29.66	32.37	2.43	100
32.5	17.04	32.69	30.67	17.29	2.31	100
37.5	18.04	33.91	34.36	10.75	2.94	100
42.5	18.36	34.45	36.85	6.66	3.69	100
47.5	18.32	34.59	38.55	4.11	4.43	100
52.5	18.10	34.53	39.72	2.53	5.12	100
57.5	17.80	34.36	40.53	1.57	5.74	100
62.5	17.46	34.14	41.11	1.00	6.29	100
67.5	17.12	33.89	41.52	0.69	6.78	100
72.5	16.78	33.64	41.82	0.55	7.21	100
77.5	16.46	33.40	42.04	0.51	7.59	100
82.5	16.25	33.35	42.43		7.98	100

VALUE ANALYSIS
VRIJEDNOSNA ANALIZA

The value of timber and timber assortments changes in accordance with changes in the society and in market and economic relationships, with the application of new technologies and with the effects of other factors. The resulting problem entails finding a unit that will represent the perpetual value of assortments. Monetary units are not suitable. The value of assortments is better expressed with a ratio which expresses relative value relationships of individual assortment classes (Rebula 1996).

Relative relationships used in research to date have been called *quality numbers* (Plavšić 1967), *value ratio* (Svetličić 1983), *value coefficient* (Svetličić 1983, Čop 1983), and others, among which the German *measuring numbers* (Messzahlen) are the best known.

Determining monetary value of trees is based on the structure of quality class volume and the tariffs for main forest products on the home market; A - 02.01, "Hrvatske šume" p.o. Zagreb. To calculate monetary tree value, the price of timber assortments on the stump was used. According to the tariffs, the monetary value of assortments was classified by mean diameters of sawlogs (mean diameter up to 39 cm, mean diameter from 40 to 49 cm, and mean diameter over 50 cm).

Therefore, in analysing monetary values, sample trees had to be divided according to the above classification so that the tariffs could be accurately applied. Trees with breast diameters up to 39 cm can only contain logs with the same mean diameter at most. Breast diameter of trees is taken 1.3 m from the ground. When a tree is felled, the stump height is assumed to be 30 cm at most. The first log with a minimal length of 2 m is found on the stem 0.3 to 2.3 m from the ground; in other words, the mean diameter of the first log is at the point of breast diameter. Logs with mean diameters exceeding the breast diameter cannot be made from these trees since the minimal log length is 2 m. For this reason, monetary values are taken from the tariff that relate to the above diameter assortment degree according to quality classes.

Trees with breast diameters from 40 to 49 cm can contain assortments with mean diameters to 49 cm. To analyse the monetary value of these trees, the arithmetic mean is taken from the tariff of the values of the first two diameter degrees of assortments. The same procedure is applied to the thickest trees.

Table 16. Average prices of timber assortments and value coefficients
Tablica 16. Prosječne cijene drvnih sortimenta i vrijednosni koeficijenti

DBH *Prsni promjer stabla*	Average prices of timber assortments *Prosječne cijene drvnih sortimenata*				
	Sawlogs I. class *Pilanski trupci I*	Sawlogs II. class *Pilanski trupci II*	Sawlogs III. class *Pilanski trupci III*	Mining timber *Rudničko drvo*	Pulpwood *Celulozno drvo*
cm	kn/m^3				
20-39	321.40	235.88	139.24	190.30	164.50
40-49	369.70	273.50	164.77	190.30	164.50
> 50	418.00	311.11	190.30	190.30	164.50
	Value coefficient - *Vrijednosni koeficijent*				
20-39	1.03	0.76	0.45	0.61	0.53
40-49	1.19	0.88	0.53	0.61	0.53
> 50	1.34	1.00	0.61	0.61	0.53

Value coefficients were calculated from the obtained monetary values of assortments for diameter classes in the tariff. The value coefficient of 1.00 was chosen for sawlog quality class II of trees with breast diameters exceeding 50 because the proportion of this quality class and tree diameter in the sample was the highest. For other diameter and quality classes, the value coefficient is a ratio of monetary class value and monetary values of sawlog quality class II of trees with breast diameters exceeding 50 cm.

Value coefficients were multiplied with values of quality class volumes. Value coefficients for trees to 39 cm breast diameter were applied to diameter classes reaching 37.5 cm. For diameter classes 42.5 cm and 47.5 cm, value coefficients of trees with breast diameters from 40 to 49 cm were used, and for the next diameter classes, value coefficients of trees with breast diameters exceeding 50 cm were used.

Value analysis was based on processed assortment structures of diameter classes. Based on the assortment volume by quality classes and value coefficients, stem values and values per timber volume unit were determined for each diameter class.

Stem value represents the sum of products of quality class volumes and the associated value coefficients. It shows the amount by which the value of stem timber volume (the sum values of all assortments) is higher than 1 m^3 sawlog assortment in class II of a given diameter class.

Value per timber volume unit is the value of 1 m^3 of all processed stem assortments, expressed with the quotient of stem value and total processed timber volume of the tree.

Stem value increases with an increase in tree breast diameter and ranges from 0.27 to 6.18 for breast diameters from 20 cm to 84 cm. A rise in breast diameters is accompanied by a rise in the height of trees and the length of stem. A longer stem provides larger processed volume, which leads to a higher value of the stem.

The value per unit of timber volume changes irregularly with tree thickness, which is the consequence of the absence of some quality classes in the thinnest tree class and of classifying monetary values according to assortment diameter.

The value per timber volume unit in diameter class 22.5 cm is 0.661 and is higher than the value in diameter class 27.5 cm (0.613). The assortment structure of diameter class 22.5 cm does not contain any sawlogs in quality class III, but it contains a large proportion of mining timber.

Judging from the average prices of timber assortments (Table 16), the price of mining timber of trees with breast diameters to 39 cm is higher than the price of sawlogs in class II. The difference in the assortment structure of diameter classes and the relations of prices of assortments in certain quality classes has led to the lowest value per unit of timber volume in diameter class 27.5 cm.

Trends in values per timber volume unit of diameter classes show value grouping in terms of division of assortments into diameter classes according to the tariff. Thus, in trees with breast diameters less than 39 cm, the value per timber volume unit changes distinctly with breast diameter, in trees with diameter classes 42.5 cm and 47.5 cm it is almost identical (0.775 and 0.776), while the value per timber volume unit in the thickest trees (diameter classes from 52.5 upwards) exceeds 0.85.

Table 17. Values of stem and timber according to diameter classes
Tablica 17. Vrijednost debla i drva po debljinskim razredima

Diameter class *Debljinski razred*	Timber assortment - *Drvni sortimenti*					Value - *Vrijednost*	
	Sawlogs I. class *Pilanski trupci I*	Sawlogs II. class *Pilanski trupci II*	Sawlogs III. class *Pilanski trupci III*	Mining timber *Rudničko drvo*	Pulpwood *Celulozno drvo*	stem *debla*	timber *drva*
cm	m^3						
22.5		0.17		0.28	0.02	0.31	0.661
27.5		0.25	0.21	0.23	0.02	0.44	0.613
32.5	0.19	0.36	0.33	0.19	0.03	0.74	0.679
37.5	0.25	0.48	0.48	0.15	0.04	0.95	0.679
42.5	0.33	0.61	0.66	0.12	0.07	1.39	0.776
47.5	0.41	0.77	0.86	0.09	0.10	1.73	0.775
52.5	0.49	0.94	1.09	0.07	0.14	2.39	0.874
57.5	0.59	1.13	1.34	0.05	0.19	2.88	0.871
62.5	0.69	1.34	1.62	0.04	0.25	3.41	0.867
67.5	0.79	1.57	1.92	0.03	0.31	4.00	0.863
72.5	0.90	1.81	2.25	0.03	0.39	4.63	0.859
77.5	1.02	2.07	2.61	0.03	0.47	5.31	0.856
82.5	1.15	2.35	2.99		0.56	6.02	0.853

In diameter classes from 52.5 upwards, the value per timber volume unit mildly drops with an increase in tree breast diameter. The highest value per unit of timber volume is shown in diameter class 52.5 cm and amounts to 0.874, and falls slightly to 0.853 in diameter class 82.5 cm. The effects of the above value trend per unit of timber volume is the result of a faster rise of the volume in sawlog quality class III with an increase in breast diameter compared to sawlogs of higher quality.

According to the value analysis based on the currently valid tariff of "Hrvatske šume" p.o. Zagreb, trees in diameter class 52.5 cm achieve the highest value per unit of timber volume.

Recent research into values of fir trees has shown identical or similar patterns, which are in contradiction with the earlier research into fir trees in Gorski Kotar. Plavšić (1967) finds the highest values of fir trees in diameter classes 72.5 cm, whereas Golubović (1967) finds that trees in diameter classes 62.5 cm and 67. 5 cm are the economically most profitable for sawmill processing. However, Rebula (1996) claims that the value per unit of timber volume increases rapidly with thickness, but reaches its maximum at breast diameter between 40 cm and 50 cm, to decrease after that. Knoke (1997) finds that the relative value of logs with large mean diameters in comparison with logs with smaller mean diameters decreases as breast diameter increases.

FELLING MATURITY OF FIR TREES
SJEČIVA ZRELOST STABALA JELE

To manage selection forests, it is very important to know and apply the most suitable felling maturity of trees. The felling maturity of trees in a selection stand is expressed with breast diameters. Selection felling involves marking and felling trees above the determined diameter of felling maturity.

Determining felling maturity is important in forest management because of its effects on the quantity of annual harvesting volume. Depending on the method of determining felling maturity, there is biological and economical maturity.

Biological maturity includes the bottom and the top boundary. The bottom boundary is described with the smallest breast diameter at which trees begin to bear seed. The top boundary of biological maturity is the boundary of physical death of trees and is therefore not used in intensive management.

The economic felling maturity of trees is the result of commercial needs expressed in management goals (Plavšić 1967). A tree is mature for felling when its dimensions, shape or other characteristics are capable of satisfying a given need (Miletić 1960). To determine the economic felling maturity, there are material or financial indicators.

Material indicators express the following:

- production maturity of maximum timber volume yield – defined by breast diameters of trees with the highest average annual current increment,
- technical maturity – defined by breast diameter of trees whose processing achieves the highest percentage share of main assortments

Financial indicators express the following maturities:

- the maturity of the highest quality of tree timber volume – defined by breast diameter at which the highest mean price per timber volume unit is achieved
- production maturity of the most valuable yield of timber volume – defined by breast diameter at which the highest average value of annual current increments is achieved

- maturity of maximal profitability – defined by breast diameter at which maximal profitability of invested means is achieved
- maturity of the maximal forest rent – defined by breast diameter at which the maximal forest rent value is achieved

Technical maturity and the maturity of the maximal quality of timber volume is determined in forest exploitation.

Technical maturity at a diameter class of 42.5 cm (18.32 % of I class sawlogs in the processed timber volume) is based on the assortment structure and percentage values of the most valuable quality class. However, due to a small share of this quality class in the assortment structure, it is better to regard the total quantity of sawlogs in quality classes I and II as the most valuable assortments. In percentage relations, the sum of the two most valuable assortments achieves the highest value at the diameter class 47.5 cm (52.9 %).

The maturity of the maximal quality of tree timber volume indicates the diameter class at which quality begins to decline. This maturity is an indication of the need to remove from the stand overly strong fir trees, unless they are indispensable out of silvicaltural and protection measures (Plavšić 1967). Based on the value analysis of the assortment structure of diameter classes, the highest value per unit of timber volume is achieved at diameter class 52.5 cm.

In the management unit "Belevine", the felling maturity of trees is at breast diameters of 70 cm. The current felling maturity does not yield the highest quality of tree timber volume, or the highest value per timber volume unit. From the aspect of forest exploitation, the determined maturity of the maximal timber volume quality at diameter class 52.5 cm points to the need to decrease the felling breast diameter and consequently to manage selection forests more intensively. A decrease in breast diameters of trees to be felled would lead to the introduction of high technologies into forestry practice. However, in view of the small differences between the value of trees of felling maturity and trees in the diameter class 52.5 cm, a change in felling maturity should be justified with complex investigations into tree increment, silvicultural, ecological and protective characteristics of fir trees in this area so that the selection structure may be preserved.

CONCLUSIONS
ZAKLJUČCI

Research was based on a sample of 1,404 fir trees felled in regular felling of cutting cycle. All sample trees were sectioned in order to make accurate estimation of the volume of large wood (to 7 cm) over and under bark. Timber assortments were bucked, crosscut, measured and inspected in accordance with Croatian standars for roundwood.

The volume of trees with diameters to 7 cm over and under bark, as well as the processed tree timber volume, was shown in two-entry and one-entry tables. The values of timber volume increase with an increase in tree breast diameter and height. The constructed two-entry tables of timber volume for fir are of a local character. The sample of 1,404 fir trees, which were felled and processed in the same management unit, vouches for the accuracy in using these tables to determine the timber volume in the mentioned area.

Bark volume of the trees ranges from 12.45% to 10.67%. In trees with equal breast diameters, bark percentage decreases with an increase in tree height. The percentage of bark in trees of equal heights rises with an increase in breast diameter. Mean values of bark percentage decrease with an increase in tree breast diameter. Double bark thickness rises with an increase in tree diameter, while the percentage decreases.

The yield percentage assumes values between 81.7% and 83.0%, and decreases slightly with an increase in breast diameter.

Based on past research and on the studied sample, it can be concluded that veneer logs of fir in selection stands are very rare and are the result of a number of favourable factors, ranging from site, stand and climatic factors to genetic traits of individual trees.

Timber volume of sawlogs increases with an increase in tree breast diameter for all quality classes. In a regressed assortment structure, sawlogs in quality class I attain the highest values in the diameter class of 42.5 cm (18.4%) and sawlogs in quality class II attain the highest values in the group of thinnest sample trees (36.2%). Sawlogs in quality class III have the highest values in the volume structure from diameter class 42.5 cm to 82.5 cm. The share of mining timber is the highest in diameter class 22.5 cm (59.96%) and decreases to 0.51 % in the diameter class of 77.5 cm. The percentage share of pulpwood in all diameter classes is below 8 %.

The highest value per timber volume unit, determined on the basis of value coefficients and the volume structure of quality classes, is achieved at diameter class 52.5 cm and decreases slightly until diameter class 82.5 cm.

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NEKE ZNAČAJKE KAKVOĆE STABALA OBIČNE JELE (*ABIES ALBA* MILL.) U GOSPODARSKOJ JEDINICI "BELEVINE" NASTAVNO-POKUSNOG ŠUMSKOG OBJEKTA ZALESINA

SAŽETAK

Rad prikazuje rezultate istraživanja značajki kakvoće stabala obične jele (*Abies alba* Mill.) provedenih na području prebornih šuma Gospodarske jedinice "Belevine" Nastavno-pokusnog šumskog objekta Zalesina Šumarskog fakulteta u Zagrebu. Gospodarsku jedinicu "Belevine" prekriva pretežito jelova šuma s rebračom (*Blechno-Abietetum* Ht. 1950).

Osnovu istraživanja predstavlja uzorak od 1 404 stabla jele koja su posječena u redovnoj sječi etata ophodnjice. Stabla iz sanitarne sječe nisu uzeta u uzorak. Prsni promjeri stabala uzorka su se kretali u rasponu od 20 cm do 85 cm tj. stabla su razvrstana u 13 debljinskih razreda od 22,5 cm do 82,5 cm. Visine stabala kretale su se u rasponu od 12 m do 40 m. Stabla jele su mjerena nakon obaranja i kresanja grana. Sekcioniranje je stabla u svrhu preciznog utvrđivanja obujma krupnog drva s korom i bez kore provedeno na svim stablima uzorka. Drvni sortimenti su prikrajani, trupljeni, mjereni i preuzimani u skladu s hrvatskim normama za oblo drvo.

Svi podaci mjerenja su uneseni u terenske obrasce, a potom u računalne datoteke radi lagane dostupnosti pri obradi podataka. Obrada podataka je izvršena na temelju mjerenih i izračunatih veličina značajki stabala uzorka. Za svako stablo unošeni su podaci iz obrazaca sekcioniranja stabla koji prikazuju srednje promjere sekcija s korom i bez kore na određenoj udaljenosti od panja i dvostruke debljine kore na mjestu izmjere. Na osnovu su podataka izračunati: srednji promjeri svake sekcije s korom i bez kore, dvostruke debljine kore na mjestu srednjih promjera svake sekcije, obujmi sekcija s krom i bez kore te sumiranjem obujama svih sekcija stabla ukupni obujmi stabala s korom i bez kore.

Izračunati drvni obujmi sortimenata sumirani su po razredima kakvoće za svako stablo. Sumiranjem svih drvnih obujama sortimenta stabla izračunava se iskorišteni obujam stabla. Odnos iskorištenog i ukupnog obujma stabla izražava iskorištenje stabla pri sječi i izradbi, a razlika navedenih obujama prikazuje količinu otpada pri sječi i izradi.

Iz podataka sekcioniranja stabala unošenih u računalo izdvojeni su podaci o mjerenju svake sekcije. Ova baza podataka sadrži srednje promjere sekcija s korom, visinu promjera sekcije od panja, dvostruku debljinu kore na sredini sekcije te prsni promjer i visinu stabla na kojem se određena sekcija nalazi. Izrađena baza podataka čini osnovu za istraživanje debljine kore u ovisnosti o debljini debla. Sva stabla opisana navedenim značajkama tvore osnovnu bazu podataka. Izrada dvoulaznih i jed-

noulaznih tablica obujma stabala, obujma i postotka kore stabala i sortimentnih tablica temeljila se na matematičko-statističkoj obradi osnovne baze podataka. Podaci su podvrgnuti regresijskim analizama s jednom ili više nezavisnih varijabli kako bi se utvrdila funkcionalna ovisnost između značajki stabala te prikazala kakvoća stabala.

Na osnovu izmjerenih visina izrađena je visinska krivulja stabala uzorka primjenom Mihajlove funkcije. Visinska je krivulja uzorka stabala uspoređena s visinskom krivuljom preuzetom iz Osnove gospodarenja (* 1999) za Gospodarsku jedinicu "Belevine" te su za sve debljinske razrede utvrđene vrlo male razlike vrijednosti visina stabala (Tablica 5). Provedenim t-testom održala se hipoteza da ne postoji razlika između navedenih vrijednosti ($t_{0,05} = 0,115$) te se potvrđuje ispravnost odabira stabala uzorka.

Izrađene dvoulazne tablice iskazuju ovisnost drvnog obujma, obujma i postotka kore i postotka iskorištenja o prsnom promjeru i visini stabala. Drvni obujam stabala prikazan je dvoulaznim tablicama na osnovu izjednačenja podataka obujma stabala Schumacher-Hallovom jednadžbom. Izjednačenjem se podataka obujma stabla s korom i bez kore te iskorištenog obujma u ovisnosti o prsnom promjeru stabala postigla potpuna korelacija podataka prema Roemer-Orphal-ovoj skali (vrijednosti koeficijenta korelacije 0,97). Obujam stabala je obujam krupnog drva s korom i bez kore te iskoristivi drvni obujam stabala. Prikazani je opseg prsnih promjera i visina stabala u dvoulaznim tablicama određen prema evidentiranim i izmjerenim vrijednostima na uzorku stabala te predstavlja granične vrijednosti tih parametara. Vrijednosti se drvnog obujma u tablicama povećavaju s povećanjem prsnog promjera i visine stabala (Slika 5, 7, 9). Pri istom prsnom promjeru i visini stabla najveće vrijednosti prikazuje drvni obujam stabla do 7 cm promjera s korom, zatim drvni obujam stabala do 7 cm promjera bez kore, a najmanje vrijednosti iskazuje iskoristivi drvni obujam stabla. U promatranom opsegu drvni obujam do 7 cm s korom se kreće od 0,216 m^3 za stabla 20 cm prsnog promjera i 12 metara visine do 10,167 m^3 za stabla 85 cm prsnog promjera i 40 m visine. Za navedena stabla drvni obujam do 7 cm bez kore kreće se od 0,189 m^3 do 10,030 m^3, a iskoristivi drvni obujam od 0,177 m^3 do 9,301 m^3.

Izrađene tablice drvnog obujma stabala jele su lokalnog karaktera. Uzorak od 1 404 stabla jele posječenih i izrađenih u istoj gospodarskoj jedinici jamče nam točnost pri korištenju tih tablica za određivanje obujma stabla na navedenom području.

Tablice su obujma i udjela kore stabala izračunate iz vrijednosti drvnog obujma sa i bez kore iz dvoulaznih tablica. Obujam kore stabla raste s povećanjem prsnog promjera i visine stabala te poprima vrijednosti od 0,03 m^3 kod stabala 20 cm prsnog promjera i visine 12 m do 1,12 m^3 kod stabala 85 cm i 40 m visine (Slika 10). Postotni se udio kore na temelju izjednačenih vrijednosti drvnog obujma stabala do 7 cm promjera s i bez kore kreće u granicama od 12,45 % do 10,67 % (Slika 11). Kod stabala istog prsnog promjera, postotak kore opada s porastom visine stabala.

Stabla jednake visine imaju veći postotak kore što im je veći prsni promjer. Srednje vrijednosti postotka kore opadaju s porastom prsnog promjera stabla.

Na osnovu vrijednosti tablica iskorištenog drvnog obujma stabla i ukupnog drvnog obujma stabala do 7 cm promjera s korom određeni su postoci iskorištenja pri sječi i izradi. Postotak iskorištenja poprima vrijednosti u rasponu od 81,7 % do 83,0 % za opseg prsnih promjera i visina iz dvoulaznih tablica drvnog obujma (Slika 12). Postotak iskorištenja se povećava s porastom visine kod stabla istih prsnih promjera. Stabla iste visine imaju manji postotak iskorištenja što im je veći prsni promjer.

Za izradu jednoulaznih tablica upotrebljeni su isti podaci sekcioniranja stabala kao kod izrade dvoulaznih tablica drvnog obujma. Izjednačenje podataka prikazanih na slikama od 15 do 17 je izvršeno krivuljom drugoga reda (parabola), koja se u literaraturi navodi kao Hohenadl-Krenov model (Kružić 1993a). Izjednačeni su podaci o obujmima stabala do 7 cm promjera s korom i bez kore te iskorištenog obujma. Pri svim su izjednačenjima dobiveni jednaki koeficijenti korelacije i to 0,94.

Prema jednoulaznim tablicama, drvni obujam do 7 cm promjera s korom se kreće od 0,401 m^3 za stabla 20 cm prsnog promjera do 8,790 m^3 za stabla 85 cm prsnog promjera. Za iste se prsne promjere stabala drvni obujam do 7 cm promjera bez kore kreće od 0,352 m^3 do 7,822 m^3, a iskoristivi drvni obujam od 0,332 m^3 do 7,252 m^3.

Tablice obujma kore su izrađene iz izračunatih vrijednosti obujma kore pojednih stabala. Obujam kore stabla predstavlja razliku između obujma stabla s i bez kore dobiven sekcioniranjem. Pri izjednačenju podataka korišten je isti analitički izraz te postignut koeficijent korelacije 0,87 (Slika 19). Obujam kore se povećava s rastom prsnog promjera te iznosi od 0,049 m^3 za stabla prsnog promjera 20 cm do 0,968 m^3 za stabla prsnog promjera 84 cm.

Iskorištenje pri sječi i izradi prema jednoulaznim tablicama se u postotnim vrijednostima neznatno smanjuje s povećanjem prsnog promjera. Za opseg stabala prsnog promjera od 20 cm do 84 cm postotak iskorištenja opada od 82,72 % do 82,50%.

Na osnovu izmjere 14 614 sekcija postavljeni su parovi podataka srednjih promjera sredina sekcija i dvostruke debljine kore. Istraživanje je provedeno s ciljem određivanja ovisnosti dvostruke debljine kore o promjeru drva. Pri regresijskoj analizi podataka odabrana je krivulja drugog reda (parabola) pri čemu je postignut koeficijent korelacije od 0,7 (Slika 22).

Odbijanjem dvostruke debljine kore od promjera drva s korom određeni su promjeri drva bez kore te izračunate temeljnice za promjere s korom i bez kore. Postotak kore je određen prema temeljnicama s korom i bez kore na određenom promjeru drva.

Dvostruka debljina kore raste s povećanjem promjera drva, a postotak opada. Kod 10 cm promjera drva iznosi 1,16 cm, a kod 84 cm promjera drva 3,16 mm. Postotak kore najveći je kod promjera drva od 20 cm (21,8 %), izrazito opada s povećanjem promjera te kod promjera drva 84 cm iznosi 7,4 %.

Kod pilanskih trupaca I. i II. razreda kakvoće, najmanjeg srednjeg promjera prema normama od 25 cm, postotak kore približno iznosi 10 %. Za pilanske trupce III. razreda kakvoće treba očekivati malo viši postotak kore zbog dopuštenog najmanjeg srednjeg promjera od 20 cm. Postoci se kore na rudničkom i celuloznom drvu nalaze u granicama od 21,8 % do 13 %.

Iz posječenih stabla jele izrađeni su drvni sortimenti te razvrstani prema hrvatskim normama za oblo drvo u slijedeće razrede kakvoće: furnirski trupci, pilanski trupci (I., II. i III. razred kakvoće), rudničko drvo i celulozno drvo. Na osnovu izmjere sortimenata utvrđen je njihov obujam te su sumirani obujmi sortimenta po razredima kakvoće i stablu (Tablica 10). Ukupno je izrađeno 4 319,31 m^3 drvnih sortimenata.

U uzorku se pojavljuje svega dvanaest furnirskih trupaca razvrstanih u sedam debljinskih razreda. Ukupni obujam furnirskih trupaca čini svega 9,24 m^3 ili 0,23 % od ukupno izrađenog obujma. Plavšić & Golubović (1963), pri istraživanju postotnog odnosa jelovih sortimenata u uzorku od 1607 stabala, nisu evidentirali niti jedan furnirski trupac. Rebula (1996) također pri izradi sortimentnih tablica deblovine jele ne spominje razred kakvoće furnirskih trupaca. Na osnovu prijašnjih istraživanja te istraživanog uzorka zaključuje se da su furnirski trupci kod jele u prebornim sastojinama vrlo rijetki te su rezultat velikog broja povoljnih čimbenika, od stanišnih, sastojinskih i klimatskih do genetskih svojstava pojedinih stabala. Iako su furnirski trupci najvrijedniji sortimenti zbog vrlo malih vrijednosti ne mogu se uvrstiti u istraživanje strukture sortimenata.

Pilanski trupci I. razreda pojavljuju se od debljinskog razreda 32,5 cm, točnije od prsnog promjera 34 cm. Pilanski trupci II. razreda kakvoće su izmjereni unutar svih debljinskih razreda uzorka. Debljinski razred 22,5 cm ne sadrži pilanske trupce III. razreda kakvoće već su izrađeni sortimenti razvrstavani u rudničko drvo, što možemo objasniti malim padom promjera tanjih stabala i prisustvom zdravih kvrga malih promjera. Rudničko drvo nije izmjereno niti na jednom stablu debljinskog razreda 82,5 cm, što se veže na činjenicu veće kvrgavosti ovršina te većeg pada promjera koji je eliminirajuća greška za taj razred kakvoće. Celulozno je drvo evidentirano u svim debljinskim razredima.

U strukturi su sortimenata srednjih stabala debljinskih razreda uočeni manji obujmi od obujama razreda kakvoće s obzirom na dopuštene najmanje dimenzije drvnog sortimenta prema normama za oblo drvo.

Iz navedenih je razloga izvršena regresijska analiza obujama razreda kakvoće u ovisnosti o prsnom promjeru na temelju sortimentne strukture svih stabala. Za regresijski su model odabrane krivulje drugog reda (parabole) s ili bez slobodnog člana ovisno o zahtjevu za postizanjem najmanjeg obujma razreda kakvoće izjednačenih vrijednosti. Izjednačene vrijednosti određenog razreda kakvoće su prikazane prema debljinskim razredima gdje su se pojavile u uzorku. Indeksi korelacije su ukazali na slabu povezanost parametara i veće rasipanje podataka, ali je otklonjena mogućnost greške podataka o obujmu razreda kakvoće u regresijskoj analizi (Tablica 13).

Osnovni problem koji se javlja pri istraživanju sortimentne stukture proizilazi iz činjenice da određeni broj stabala ne sadrži sortimente svih razreda kakvoće. Vuletić (1999) u svom radu tvrdi da je posljedica te pojave grupiranje izmjerenih podataka u dva odvojena oblaka od kojih jedan predstavlja prave vrijednosti, a drugi leži na x-osi i sadrži sve vrijednosti jednake nuli. Vrijednosti na x-osi nisu pokazatelj male kakvoće stabla već njegove nepotpune sortimentne strukture, jer stablo može sadržavati samo jedan ili dva sortimenta i biti visoke kakvoće. Nulte vrijednosti na x-osi autorica naziva nepravim nulama, jer se na stablima s obzirom na prsni promjer može očekivati izrada određenog razreda kakvoće.

Pilanski trupci I. razreda kakvoće s najmanjim srednjim promjerom od 25 cm pojavljuju se od debljinskog razreda 32,5 cm, točnije od prsnog promjera 34 cm. Pretpostavka je da se na stablima prsnog promjera većeg od 34 cm očekuje prisustvo pilanskih trupaca I. razreda kakvoće, kao i na ostalim stablima debljinskog razreda 32,5 cm. U regresijskoj analizi za pretpostavku je uzeto da se na svim stablima od debljinskog razreda 32,5 cm na više može očekivati izrada pilanskih trupaca I. razreda kakvoće. Navedeni je razred kakvoće izrađen na svega 614 stabala, iako se s obzirom na prsni promjer mogao izraditi na 1 375 stabala.

Pilanski trupci II. razreda kakvoće s obzirom na prsni promjer mogu se očekivati na svim stablima uzorka, ali su izmjereni na 1 108 stabala. Pilanski trupci III. razreda kakvoće se pojavljuju od prsnog promjera 26 cm u uzorku te broj stabala nižeg debljinskog razreda nismo uvrstili u broj stabala gdje se može pojaviti ovaj sortiment, već samo na svim stablima od debljinskog razreda 27,5 cm naviše. Ukupno je izmjereno 1 240 stabla sa sortimentom III. razreda kakvoće pilanskih trupaca.

Rudničko drvo u uzorku nije izmjereno niti na jednom stablu zadnjeg debljinskog razreda od 82,5 cm te navedena stabla nisu uključena u regresijsku analizu. Od ukupno 1 396 stabala rudničko je drvo izmjereno na 761 stablu.

Celulozno drvo je evidentirano u svim debljinskim razredima, ali je izmjereno na 1 258 stabala. Vrijednosti obujama celuloznog drva kod ostalih stabala smatramo nepravim nulama.

Drvni obujam pilanskih trupaca raste s povećanjem prsnog promjera stabla za sve razrede kakvoće. Obujam se pilanskih trupaca I. razreda kakvoće kreće u rasponu od 0,19 m^3 do 1,15 m^3, a za II. razred kakvoće pilanskih trupaca obujmi se kreću od 0,17 m^3 do 2,35 m^3 u rasponu svih debljinskih razreda uzorka. Pilanski trupci

III. razreda kakvoće iskazuju najveći rast vrijednosti obujma s povećanjem prsnog promjera (od 0,21 m^3 do 2,99 m^3). Obujam ovog razreda ima najveće vrijednosti u strukturi obujama srednjih stabala od debljinskog razreda 42,5 cm do 82,5 cm (tablica 14).

Obujam rudničkog drva opada od 0,28 m^3 do 0,03 m^3, a celuloznog drva raste od 0,02 m^3 do 0,56 m^3 u rasponu debljinskih razreda uzorka u kojima su zabilježeni.

Pilanski trupci II. razreda kakvoće najveće vrijednosti poprimaju u prva dva debljinska razreda uzoraka (36,18 % i 35,53 %). Postotni udio III. razreda kakvoće raste sa povećanjem prsnog promjera stabla od 29,66 % do 42,43 % (Tablica 15).

Udio rudničkog drva je najveći u debljinskom razredu 22,5 cm (59,96 %), a s povećanjem prsnog promjera se smanjuje sve do 0,51 % u debljinskom razredu 77,5 cm. Postotni udjeli celuloznog drva su ispod 8 % za debljinske razrede uzorka. Najmanje vrijednosti su zabilježene u debljinskom razredu 32,5 (2,31 %), a najveće u debljinskom razredu 82,5 cm (7,98 %).

Ukupno izrađeni obujam prema sortimentnoj strukturi je veći od obujma iskoristivog drva prema jednoulaznim tablicama, u vrijednostima do 0,11 m^3. Za debljinske razrede od 47,5 cm do 67,5 cm razlike ne postoje ili su vrlo male (0,02 m^3), što ukazuje na dovoljan broj stabala tih debljinskih razreda u uzorku. U distribuciji prsnih promjera stabala uzorka nedovoljan je broj najtanjih i najdebljih stabala. No, s obzirom na sječivu zrelost jelovih stabala u promatranoj gospodarskoj jedinici (70 cm) i principe preborne sječe vrlo je teško osigurati statistički dovoljan broj stabala prsnih promjera manjih od 40 cm i većih od 70 cm.

Novčana je vrijednost stabala određena na osnovu strukture obujma razreda kakvoće i cjenika glavnih šumskih proizvoda za domaće tržište; A - 02.01, "Hrvatske šume" d.o.o. Zagreb. Pri obračunu novčane vrijednosti stabala iz cjenika je korištena cijena šumskih sortimenata na panju. Prema cjeniku, novčana je vrijednost sortimenata razdijeljena s obzirom na srednji promjer pilanskih trupaca (do 39 cm srednjeg promjera, od 40 do 49 cm srednjeg promjera i srednjeg promjera većeg od 50 cm). Prema tome u analizi novčanih vrijednosti morali smo podjeliti stabla uzorka prema istoj podjeli kako bi mogli točno primjeniti cjenik. Stabla prsnog promjera do 39 cm mogu sadržavati jedino sortimente najviše istog srednjeg promjera. Stoga iz cjenika uzimamo novčane vrijednosti za navedeni debljinski stupanj sortimenta prema razredima kakvoće. Stabla prsnog promjera od 40 do 49 cm mogu sadržavati sortimente srednjeg promjera do 49 cm te za analizu novčane vrijednosti tih stabala uzimamo aritmetičku sredinu vrijednosti prva dva debljinska stupnja sortimenata iz navedenog cjenika. Isti postupak je primjenjen kod najdebljih stabala.

Vrijednosni koeficijent 1,00 određen je za II. razred kakvoće pilanskih trupaca kod stabla prsnog promjera većeg od 50 zbog toga što je u uzorku najveći udio navedenog razreda kakvoće i promjera stabla. Za druge debljinske razrede i razrede kakvoće vrijednosni koeficijent je omjer novčane vrijednosti razreda s novčanom vrijednosti II. razreda kakvoće pilanskih trupaca kod stabla prsnog promjera većeg od 50 cm.

Vrijednost debla i vrijednost po jedinici drvnog obujma je određena na osnovu vrijednosnih koeficijenata i strukture obujama razreda kakvoće.

Vrijednost debla predstavlja sumu umnožaka obujama razreda kakvoće i pripadajućih vrijednosnih koeficijenata. To nam govori za koliko je obujam drva u deblu (suma vrijednosti svih sortimenata) vrijedniji od 1 m^3 pilanskih trupaca II. klase srednjeg promjera većeg od 50 cm.

Vrijednost po jedinici drvnog obujma je vrijednost 1 m^3 svih izrađenih sortimenata iz debla, izražena kvocjentom vrijednosti debla i ukupno iskorištenog drvnog obujma stabla.

Vrijednost debla raste s povećanjem prsnog promjera stabala i kreće se od 0,27 do 6,18 za prsne promjere od 20 cm do 84 cm. Porastom prsnog promjera stabala raste visina stabla te time ujedno i duljina debla. Veća duljina debla omogućava veći izrađeni obujam stabla što uzrokuje veću vrijednost debla.

Najmanja je vrijednost po jedinici drvnog obujma u debljinskom razredu 27,5 cm (Tablica 17). Vrijednost po jedinici drvnog obujma je jednaka u debljinskim razredima 32,5 cm i 37,5 (0,679) te u debljinskim razredima od 42,5 cm i 47,5 cm (0,775 i 0,776). Najveća vrijednost po jedinici drvnog obujma se pokazuje kod debljinskog razreda od 52,5 cm i iznosi 0,874 te lagano opada do 0,853 kod debljinskog razreda 82,5 cm.

U Gospodarskoj jedinici „Belevine" se pri odabranoj sječivoj zrelosti za jelu od 70 cm prsnog promjera ne postiže najveća vrijednost po jedinici drvnog obujma. S obzirom na male razlike u vrijednosti drva stabla sječive zrelosti i stabla debljinskog razreda 52,5 cm, promjena sječive zrelosti se mora opravdati kompleksnim istraživanjima prirasta stabla, uzgojnih, ekoloških i zaštitnih osobitosti stabala jele na tom području s ciljem očuvanja preborne strukture.

Istraživanje je navednih značajki kakvoće stabla prilog intenzivnom gospodarenju šumama. Određivanje strukture značajki kakvoće stabala daje nam odgovore o uporabljivosti drvnog obujma te racionalnim i najisplativijim načinima pridobivanja drva.

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Original scientific paper
Izvorni znanstveni članak

COMPARISON BETWEEN SKID TRAIL SOIL PENETRATION CHARACTERISTICS AND TRACTIVE PERFORMANCE OF ADAPTED FARM TRACTORS

USPOREDBA PENETRACIJSKE ZNAČAJKE TLA TRAKTORSKE VLAKE I VUČNE ZNAČAJKE ADAPTIRANOGA POLJOPRIVREDNOG TRAKTORA

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This paper describes the analysis for determining the possibility to estimate the tractive performance of an adapted farm tractor (AFT) based on soil penetration characteristics measured by cone penetrometer. It has been established by research carried out to date at the Faculty of Forestry in Zagreb that such assessment is possible for friction-cohesive soils, but not for sand so that further target investigations should be conducted.

With that purpose, a simplified investigation of tractive performance of the adapted 4x2 farm tractor was carried out with the measurement of the horizontal tractive force and simultaneous wheel slip. Granulometric soil content was completely determined as well as skid trail inclination, its moisture and soil penetration characteristics. Gross tractive coefficient was calculated on the basis of the measured tractor dimensions and the dynamic model of its load during skidding.

The research was carried out on the skid trail of silty loam granulometric soil content with two moisture degrees. The analysis of the results obtained by exponential regression model showed that the difference between the penetration characteristics of dry and wet soil correspond to the changes of the tractor tractive performance. The difference was also observed in view of forwarder tractive performance determined by some previous investigations on the soil of the same granulometric content.

Key words: wood skidding, adapted farm tractor, tractive performance, cone penetrometer characteristics, exponential regression model

INTRODUCTION
UVOD

Mechanized extraction of the so-called small wood is very significant in Croatia especially for the part of industrial timber produced in forest thinning because the share of small wood ranges between 10 % and 60 % in the annual cut, depending on different forest administrations and forest offices (Tomičić, 1986, Štefančić, 1989). Significant use of mechanized transportation of wood started in early 1960s when the use of farm tractors started. At the beginning they were applied for extraction or transport of wood and in silvicultural operations mainly in establishing the plantations of Euro/American poplar. At that time they were not provided with special technical adaptations, which could have improved their characteristics and eleminate some deficiencies caused by their inadequate original purpose. Up to late 1980s, the existing driving machines were mostly large-series farm tractors, adapted to forest operations or not. Arisen and ever growing problems with malfunctions and spare parts especially when using imported machines and special devices, were caused by insufficient strength of machine components, low safety factor and inadequate distribution of front/rear load.

By the introduction of specialized machines, skidders and forwarders, in the Croatian forests in 1970s (Beđula & Slabak, 1974), work mechanization, as a simple replacement of human and animal work, entered into a period of creating and modelling up-to-date work technologies in forest silvicultural and harvesting operations. The ways of performing these operations depend primarily on natural features of the forest area and methods of growing the stands. As a result the technology was established of performing specific degrees of forest-production operations such as cutting, processing, skidding/forwarding and transport as well as the closely related choice or implementation of a specific technique.

In shelterwood felling of low-lying forests, where pedunculate oak prevails as the most valuable species, forwarders are used almost exclusively with the applied cut-to-length method wherever the load bearing capacity of soils is satisfying, since wood forwarding on wheels causes much less damage to young growth than skidding. Similarly, tractor assemblies – farm tractors with trailer and crane as well as those equipped with winch are used in thinning these forests.

On sloped terrain of mountainous areas, wood skidding is usually applied in shelterwood felling of even-aged forests and in selective felling along with the application of cut-to-length, semi and full-length methods. Medium-sized skidders and adapted farm tractors with winch are also used in thinning operations of these forests.

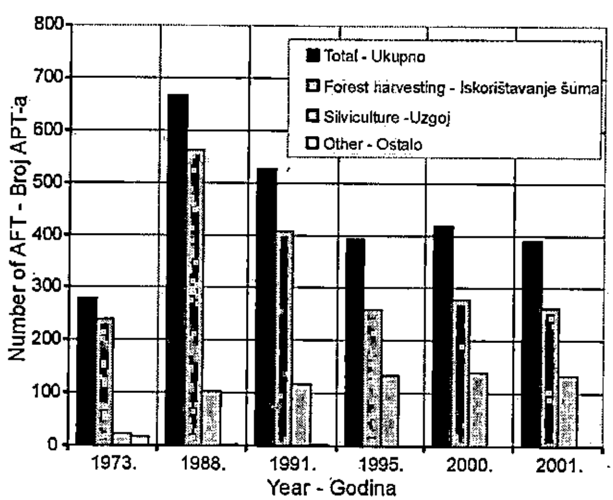
Consequently the tractors designed for the extraction of wood in mountainous conditions are equipped with forest winches for timber skidding, usually double-drum winches for winding the pulling rope and the tractors designed for the extraction of wood in low-lying areas are additionally equipped with the forest trail with crane - the so-called tractor assemblies. In this way, by assembling the farm tractor, the shock protective frame and the coupling device for forest equipment the adapted farm tractors (AFT) are made or in other words farm tractors adapted to forest operations.

As they were originally designed for a completely different purpose, regardless of the adaptations, they could not meet the basic requirements of the thinning vehicles:

- small dimensions, especially width;
- good manoeuvrability, especially low turning radius and
- good longitudinal/lateral stability and rear axle load capacity.

Among these requirements, due to the possibility of using separate left/right brakes, farm tractors only meet the requirement related to a relatively satisfying turning radius, Horvat (1983, 1996a). According to Horvat (1996b and 2001) and Sever & Horvat (1997) providing such tractors with forest equipment (winch, anchoring board, protection cabin, etc.) lowers the vehicle stability especially the longitudinal one and hence skidding up the slope very often causes lifting of the front part. During skidding in mountainous conditions energy characteristics as well as tractive efficiency and maximum winch force must not be too low.

Figure 1. Number of AFT in Croatian forestry
Slika 1. Broj APT-a u hrvatskome šumarstvu



In spite of all deficiencies, adapted farm tractors have had a historical role in up-grading the degree of mechanization of thinning wood extraction. Based on their current number it can be said that their role is still significant. The survey of the number of adapted farm tractors in use over a 40-year period in the Croatian forestry given by Horvat and Šušnjar (2001) has been completed with some data related to 2001 thanks to some new sources and monitoring methods and it is shown in Figure 1.

RESEARCH ISSUES
PROBLEMATIKA ISTRAŽIVANJA

Some machines, such as heavy skidders, forwarders, etc. are basically used in final felling but also in thinning operations causing often damage to soil and remaining trees due to inadequate technical characteristics, Sever & Knežević (1989). Soil compactness caused by vehicle passage is systematically measured by cone penetrometer at the Faculty of Forestry Zagreb. Bojanin et al. (1976) were the first to describe such measurements performed by use of a penetrometer with the so-called energy penetration and Sever (1980) gave the description of the first statistical analysis of the results of such investigations. Cone penetrometer produced in Croatia has been used since early 1980s and in view of its drive/method of data collecting it makes part of BUSCH penetrometer group. It was thoroughly described by Sever and Horvat (1985). Hitrec and Horvat (1987) developed a programme for exponential regression analysis aimed at processing the data related to soil penetration characteristics determined by cone penetrometer as well as for defining the vehicle tractive performance.

Right this programme for the exponential regression analysis provided the possibility for making a better interpretation of the measurement results and for comparing different penetration characteristics. Thus Horvat (1994a) set forth that the penetration characteristics can be well described by the exponential correlation model of the form:

$$CI = A_{CI}\left(B_{CI}^{Z} - 1\right)$$

which is shown for a measurement in Figure 2. The characteristic point in which the horizontal asymptote intersects the tangent from the 0 point ($\mathbf{T}_{CI}$) has then the following coordinates:

$$T_{CI}\left(\frac{-1}{\ln B_{CI}}; -A_{CI}\right)$$

The same author (1994b) showed that the change of soil compactness after multiple vehicle passage could be observed by measurement of the penetration char-

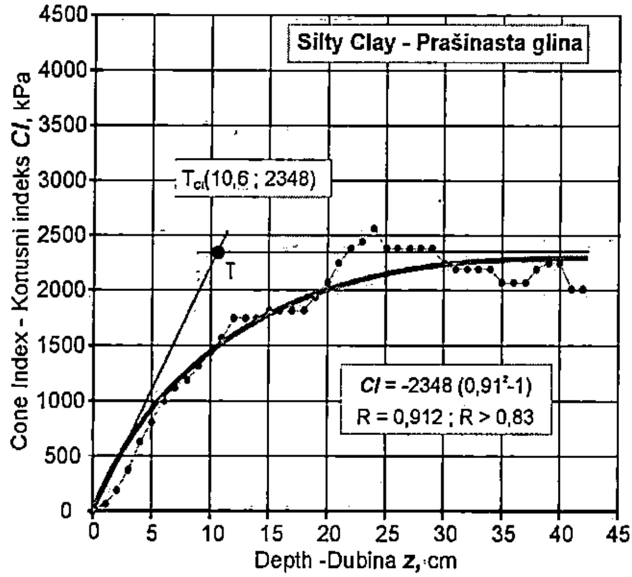


Figure 2. Penetration characteristics analysed by exponential regression analysis and the characteristic point (Horvat, 1994a)

Slika 2. Penetracijska značajka analizirana eksponencijalnim regresijskom modelom s ucrtanom karakterističnom točkom (Horvat, 1994a)

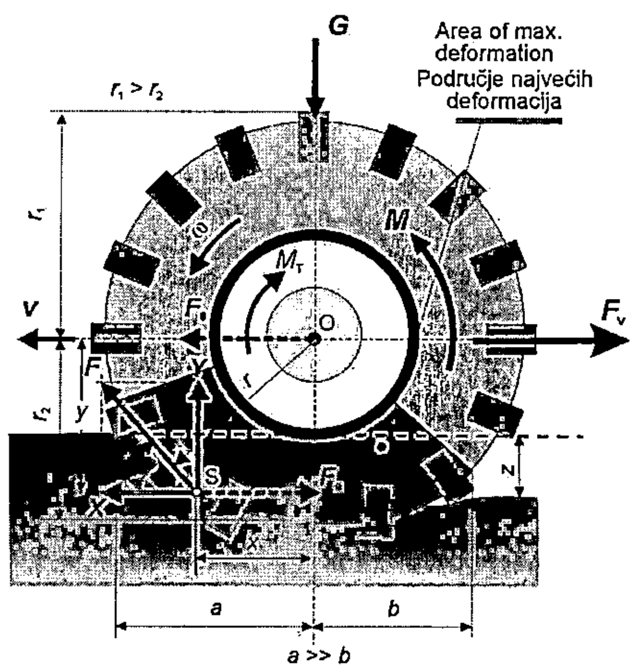


Figure 3. Model of driven wheel of AFT

Slika 3. Model vučnog kotača APT-a

acteristics, as well as the natural soil regeneration 10 years after compaction (Horvat, 1995).

The analysis of driven wheel model travelling on deformable ground, as shown in Figure 3, can be used for the analysis of the wheel load.

One of the analysis methods was applied with this model and namely the introduction of imagined forces acting in the centre of gravity of the surface of contact. Their values are equal to the product of multiplication of the surface and the relative stress (tangential or radial) at the point of contact between wheels and the ground. As the basic balance equation is defined as follows:

$$X = F_v; Y = G; M_k = F \cdot r,$$

The result of balance condition is the following:

$$F_v \cdot y + G \cdot x + M_t = F \cdot r.$$

Torque M_k can be replaced by the action of imagined coupling of forces $F_o y$ and then the following applies:

$$F_0 \cdot y = F \cdot r, \text{ and then as follows } F_0 = F\frac{r}{y}.$$

If the expression for the resultant force is introduced in the equation and the moment arm – r is substituted with the distance between the wheel centre and the line of action of the force F:

$$r = \frac{y + x \cdot tg\alpha}{\sqrt{1 + tg^2\alpha}} = \frac{y + x \cdot \frac{G}{F_v}}{\frac{1}{F_v}\sqrt{F_v^2 + G^2}}$$

The final expression for the circumferential force is obtained:

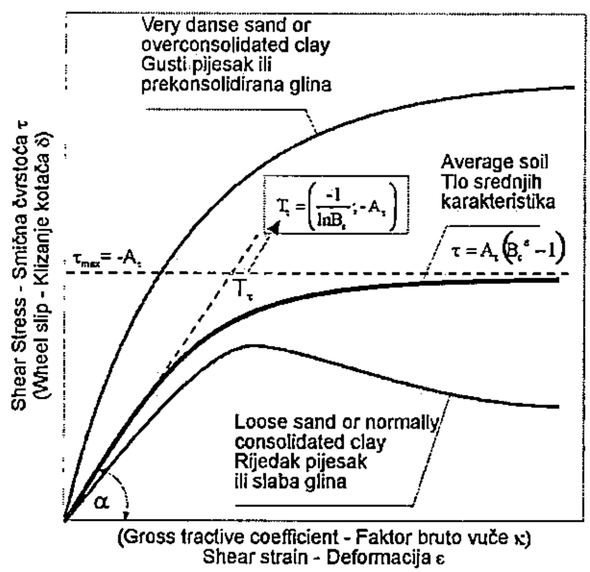
$$F_0 = \sqrt{F_v^2 + G^2}\,\frac{y + x \cdot \frac{G}{F_v}}{\frac{1}{F_v}\sqrt{F_v^2 + G^2}} = F_v + G\frac{x}{y} = F_v + F_r.$$

F_o is the circumferential force and y is the dynamic wheel radius often marked as r_d. If the latter is divided by vertical load, the known expression for the gross tractive factor is obtained:

$$\kappa = \mu + f$$

If the wheel of the vehicle moves on the soil, i.e. on a deformable base, the force will be transfered from the wheel to the soil causing stress and shear strain to the soil in tangential direction provided that there is friction between the tyre and the soil. As the tyres of forest vehicles must also have the ribs, tangential strain will surely be present. In that case, shear-strain ($\varepsilon - \tau$) is the most significant soil characteristic, as the forces are realized based on the soil shear strength. When measured by triaxial test or direct shear-strain device its trend is as shown in Figure 3. As early as 1960 Bekker suggested that the exponential form with horizontal asymptote should be used for this soil characteristic in order to investigate the off-road drive of the vehicle. The so-called wheel-slip curve (δ–κ) derives directly from shear-strain soil characteristics and it connects the gross tractive coefficient (κ) and wheel slip (δ) and it has, therefore, the same trend. Consequently gross tractive coefficient and wheel slip are also plotted on coordinates in Figure 4.

Figure 4. Strain-stress soil characteristics
Slika 4. Značajka tla deformacija-naprezanje



Considering similar trend of penetration soil characteristics and strain-stress (wheel slip curve) soil characteristics, Horvat (1996a and 1996b) started developing the correlation between these characteristics with regard to published investigations of forwarder tractive characteristics and penetration characteristics of soils on which the investigations were carried out. Based on these research and made analysis, the conclusions of the author are as follows:

- there are pretty good indications that the vehicle tractive performance on silty clay, silty clay loam and silty loam, i.e. on mostly cohesive soil, can be assessed as satisfying subject to the penetration test;
- the assessment related to friction soil, such as Dense Sand, is not satisfying;
- further target investigations are required, and
- good knowledge of forest vehicle dynamic model is required for making this assessment.

Further to previous research, soil penetration characteristics and tractive performance of the adapted farm tractor are correlated in this paper.

SCOPE AND METHOD OF INVESTIGATION
OBJEKT I METODE ISTRAŽIVANJA

According to Balady (1987) the approach to solving the complex issue of investigating the wheel – soil system, i.e. vehicle – soil, with the purpose of assessing the vehicle tractive performance, can be divided into three basic groups:

1. Empiric approach, which requires the basic soil data (granulometric content, moisture), terrain description (slope, vegetation), penetration test and tractive experiment. The results of such approach are based on measurements but they are restricted to the conditions under which the experiment was carried out.
2. Analytic approach, which involves simple, basic patterns obtained on the basis of the main soil indicators, cone penetration test, penetration-rotational plate test (bevameter test) and the device for direct strength measurement. Unlike the empiric approach, in this case no tractive experiment is carried out and tractive performance is estimated based on known loaded vehicle dynamic model and they apply only under optimum conditions.
3. Numerical approach is the most complex. It contains complex mathematical models developed by three-dimensional finite elements analysis based on data obtained by laboratory research of soil content and by triaxial test.

According to this division, the estimated content of the said research would be mostly related to the first, empiric group. The possibility of developing simple, basic patterns, i.e. an analytic-empiric approach by the application of the dynamic load model of the adapted tractor in skidding was provided by the increase of the research volume obtained by measuring a higher number of soil characteristics and vehicle-soil effects.

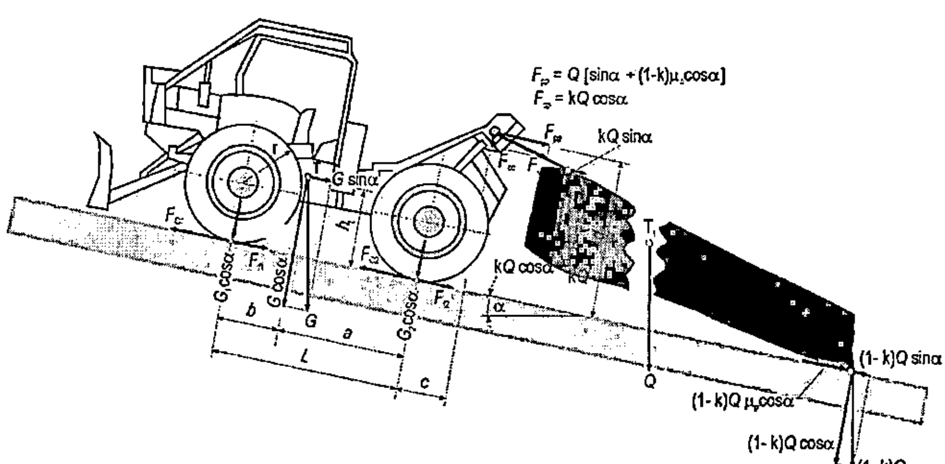
These target investigations were carried out through a simplified testing of tractive performance of the adapted farm tractor involving the measurement of horizontal components of the tractive force, terrain slope and wheel slip. The measurement of all values required for calculating the APT gross tractive coefficient were carried out and they were as follows:

- overall dimensions;
- distance between front and rear axle;
- track width;
- position of the lead point;
- mass;
- center of gravity.

The calculation was carried out based on dynamic load model of the adapted farm tractor during skidding as shown in Figure 5 in conjunction with the basic definition of the gross tractive coefficient as the quotient between peripheral force and adhesive mass:

$$\kappa = \frac{F_0}{G_{ad}} = \frac{F_H + F\sin\alpha}{F_B}$$

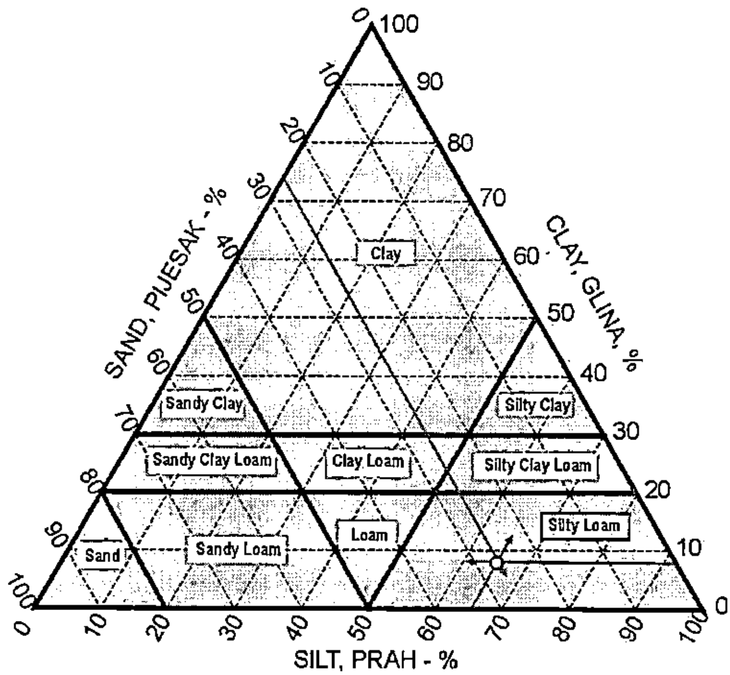
Figure 5. Dynamic weight distribution of AFT at wood skidding
Slika 5. Dinamička preraspodjela opterećenja APT-a tijekom privlačenja



Penetration characteristics were measured by the penetrometer of the Faculty of Forestry Zagreb, which can be classified as Busch penetrometer according to its drive/data processing. The resistance was measured by tensometric method – manual force and its shear strain – penetration depth by passing of the indented lever close to the spiral. The measurement results were then processed by a software programme developed for exponential regression analysis at the Faculty of Forestry Zagreb.

Skid trail inclination was measured by clinometer and moisture was determined as the weight share. Granulometric soil content was determined in the pedological laboratory of the Faculty of Forestry Zagreb and it is shown in Figure 6. It can be seen that the soil was silty loam.

Figure 6. Granulometric soil content
Slika 6. Granulometrijski sastav tla



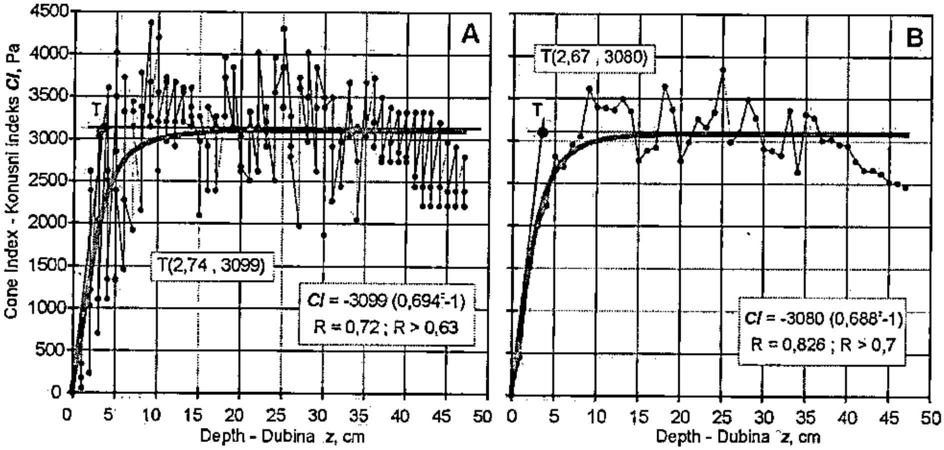
The investigated part of the skid trail was divided into three 20-m segments with a slope gradient of 1.6 %, 8.6 % and 18.1 %. Measurements of soil tractive characteristics and the penetration test were carried out at two soil moisture degrees and specifically 24 % - dry soil and 44 % - wet soil.

INVESTIGATION RESULTS
REZULTATI ISTRAŽIVANJA

The analysis of measurement results of penetration characteristics by the exponential regression model was performed by use of mean values of individual penetration tests, as suggested by Horvat (1994a) – Figure 7.

Figure 7. Method of regression analysis of repeated penetration tests (Horvat, 1994a)

Slika 7. Penetracijska značajka mokre traktorske vlake prije privlačenja



Due to the simplicity of the graphic report, in further presentation of research results, the penetration tests for individual skid trail segments are shown in diagrams only through the regression exponential curve.

The measurements of penetration characteristics were performed before and after skidding, on dry and wet skid trail with the aim of analysing soil compaction caused by timber skidding carried out by use of an adapted farm tractor. The results of these measurements are shown in the form of diagrams in Figure 8, 9, 10 and 11.

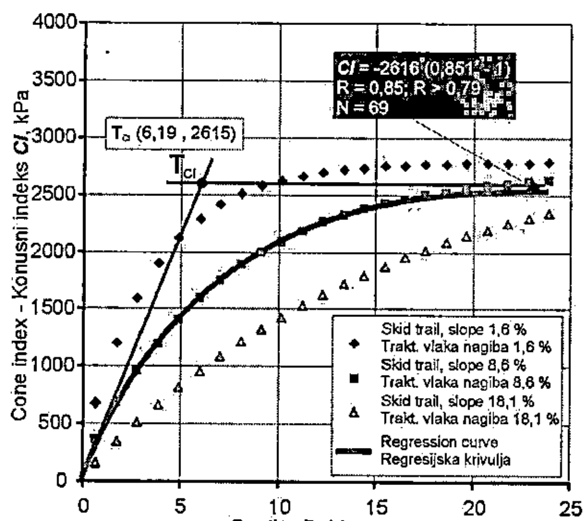


Figure 8. Penetration characteristics of wet skid trail before skidding

Slika 8. Penetracijska značajka mokre traktorske vlake prije privlačenja

Figure 9. Penetration characteristics of dry skid trail before skidding
Slika 9. Penetracijska značajka suhe traktorske vlake prije privlačenja

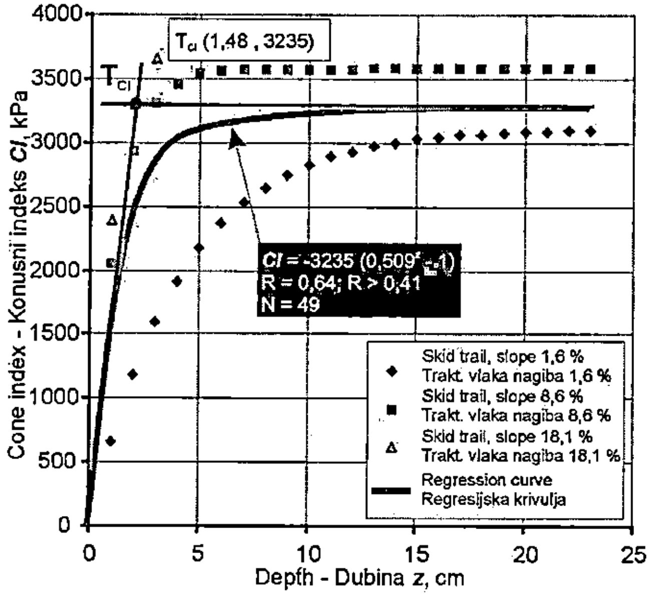
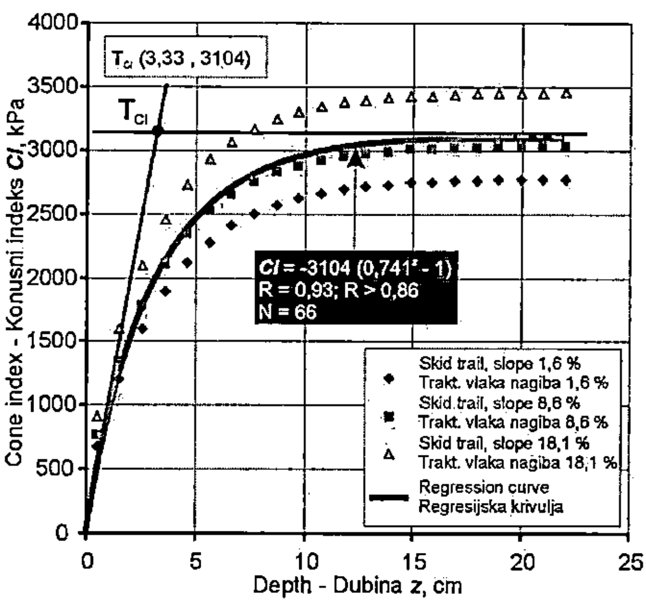


Figure 10. Penetration characteristics of wet skid trail after skidding
Slika 10. Penetracijska značajka mokre traktorske vlake poslije privlačenja



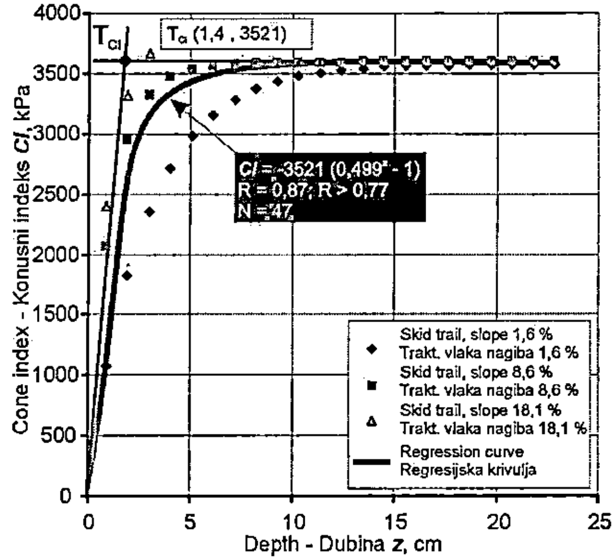


Figure 11. Penetration characteristics of dry skid trail after skidding

Slika 11. Penetracijska značajka suhe traktorske vlake poslije privlačenja

Tractive characteristics during timber skidding were determined by a simplified method of measurement of the horizontal component of tractive force and gross tractive coefficient was calculated on the basis of these measurements and measured tractor dimensions by use of the skidder dynamic load model during skidding as shown in Figure 5. Figure 12 and 13 show drive-wheel slip curves of the adapted farm tractor on dry and wet skid trail.

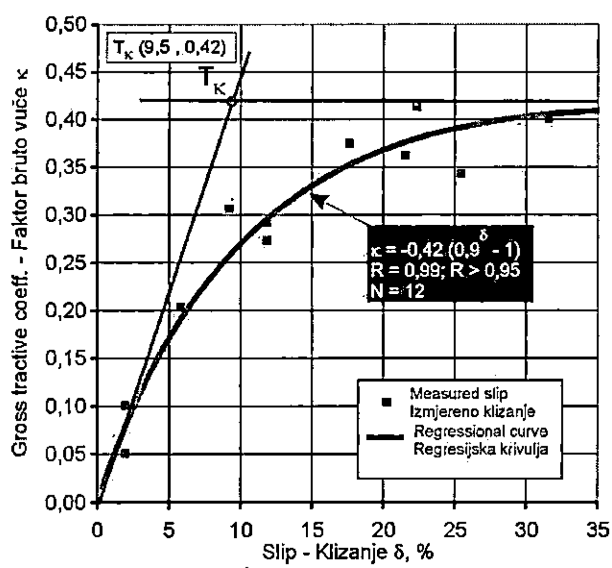
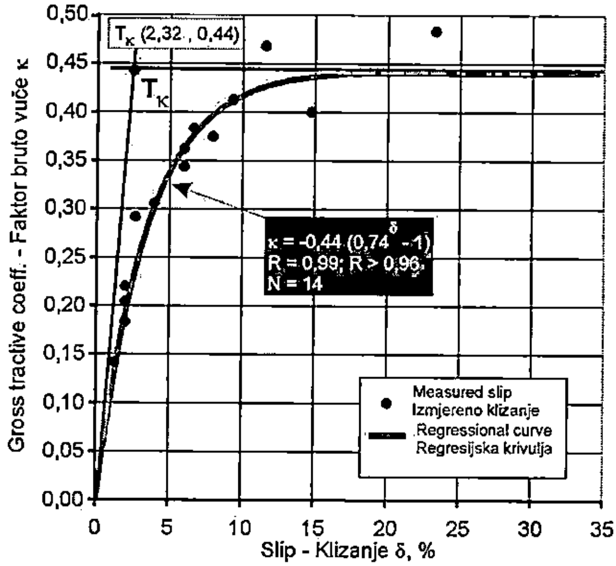


Figure 12. Tractive characterics of AFT on wet skid trail

Slika 12. Vučna značajka APT-a na mokroj traktorskoj vlaci

Figure 13. Tractive characterics of AFT on dry skid trail

Slika 13. Vučna značajka APT-a na suhoj traktorskoj vlaci



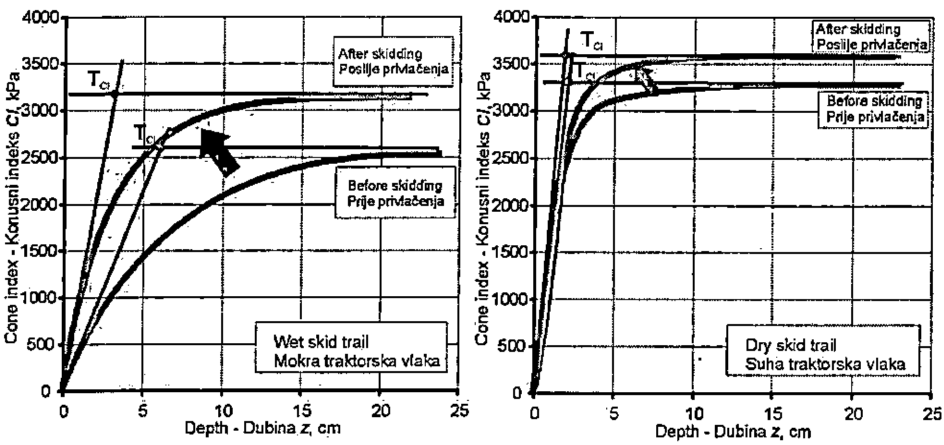
ESTIMATION OF SOIL COMPACTION BASED ON PENETRATION CHARACTERICS

PROCJENA ZBIJANJA TLA TEMELJEM PENETRACIJSKE ZNAČAJKE

This analysis requires the correlation between penetration characteristics shown in Figure 8 and 10 – wet skid trail before and after skidding and Figure 9 and 11 – dry skid trail before and after skidding. With that purpose the diagram was plotted as shown in Figure 14 from which it can be seen that the penetration characteristics changed, i.e. soil compaction occurred with both moisture contents after the passage of AFT with logs. Subject to these measurements, it can also be observed that the degree of increase of penetration soil/soil compactness is higher on wet soil. The characteristic point T (intersection of horizontal asymptote and tangent from the coordinate system 0 point) changes its position after soil compaction towards left and upward, i.e. in the area of lower depths and higher cone indexes.

It should also be noted that the penetration characteristics of the wet soil show that its load bearing capacity gets lower with the increase of moisture. This also implies that with some types of soil it is not enough to use the penetrometer to make the assessment of the soil load bearing capacity. Similarly if the basic penetration characteristics are known for a specific moisture degree, load-bearing capacity can also be assessed only by measuring its moisture.

Figure 14. Changes in penetration characteristics after wood skidding
Slika 14. Promjene penetracijske značajke nakon privlačenja

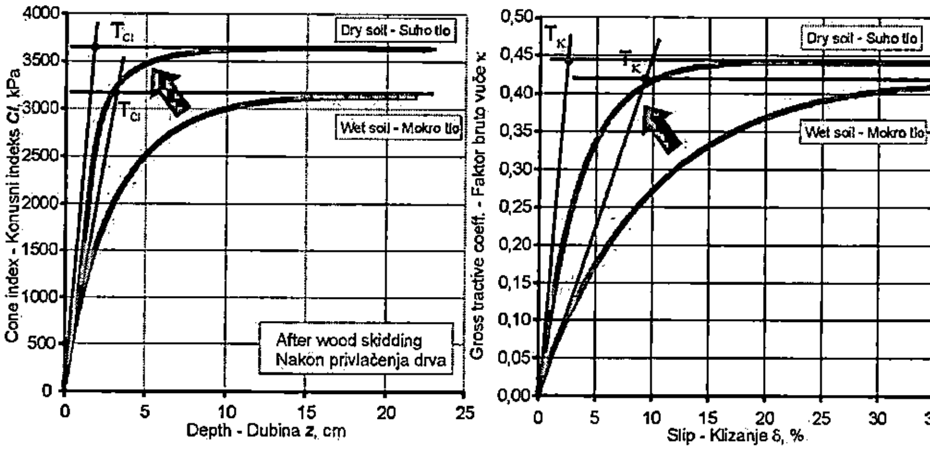


TRACTIVE PERFORMANCE OF AFT AND SOIL PENETRATION CHARACTERISTICS
VUČNA ZNAČAJKA APT-A I PENETRACIJSKA ZNAČAJKA TLA

For this analysis the data were used obtained by measurement of penetration resistance after skidding, as the tractive experiment was carried out by graded traction of different load repeatedly over the same skid trail. Many authors established in their studies, and so did Horvat (1994b), that the highest degree of compaction occurred at the very first vehicle passage. Figure 15 on the left shows the penetration characteristics of dry and wet skid trail and on the right the AFT tractive performance also on dry and wet soil.

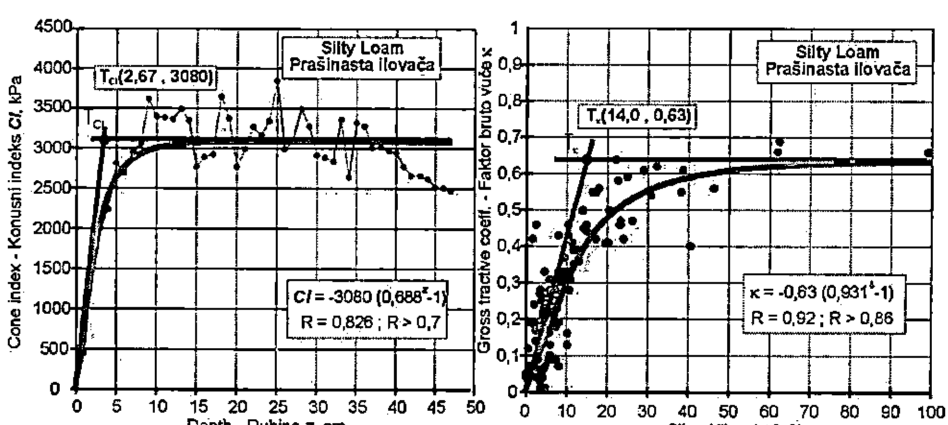
Correlation between these two diagrams shows that dry soil with better load bearing capacity (soil of higher penetration resistance) also has better tractive characteristics. Consequently the trend of the characteristic point is similar – left and upward i.e. towards lower depths and higher cone indexes i.e. towards lower slip and higher gross tractive coefficient. It can be, therefore, said that there are serious indications that silty loam tractive characteristics can be assessed based of soil penetration characteristics.

Figure 15. Penetration and tractive characteristics for two moisture contents of silty loam
Slika 15. Prodirne i vučne značajke za dva stanja vlažnosti prašinaste ilovače



In his past research, Horvat (1996a, 1996b) established the similarity between penetration characteristics and forwarder tractive performance by measuring these features on 4 types of soil. This research on silty loam is shown in Figure 16. It can be seen that the penetration characteristics of silty loam in dry condition are similar to characteristics measured in new experiments.

Figure 16. Comparison between soil penetration characteristics and forwarder tractive performance (Horvat 1996a, 1996b)
Slika 16. Usporedba penetracijske značajke tla i vučne značajke forvardera (Horvat 1996a, 1996b)



On the other hand, the forwarder tractive performance (Figure 16) differs considerably from the AFT tractive performance. The reason can lie in the fact that the tractive experiment for the forwarder was carried out by complete measurement, while the AFT tractive performance was determined by simplified measurement with the calculation by use of dynamic load model of AFT load.

CONCLUSIONS
ZAKLJUČCI

Based on the analysis of soil penetration resistance by cone penetrometer and the measured/calculated tractive performance of the adapted farm tractor it can be concluded as follows:

- Silty loam soil penetration characteristics show considerable difference depending on its moisture content - 24 % and 44 %;
- penetration characteristics can be used for the assessment of soil compaction after vehicle passage and it gets higher with higher moisture content;
- it has been confirmed that there are serious indications for making the assessment of the vehicle tractive performance based on soil penetration characteristics; the use of exponential regression model is highly suitable for determining both characteristics;
- in order to provide further verification of this thesis, it is necessary to carry out target investigations on different soils with different forest vehicles.

Certainty of this assessment can be increased by conducting the measurement of the highest gross tractive coefficient (maximum tractive force). Dependability of the assessment can also be increased by widening the volume of target investigations. Anyway, the correlation between the penetration and tractive characteristics must be thoroughly investigated so as to replace expensive, comprehensive and time-consuming tests of measuring the vehicle tractive performance by less demanding investigations of soil penetration characteristics in conjunction with a reduced research of the vehicle tractive performance as well as of some vehicle characteristics related to its size and mass. Dynamic weight distribution of the vehicle should, of course, be taken into consideration.

Efforts should also be focused on the development of new penetrometers whose use should not be more complicated than that of cone penetrometers and they should be better adapted to forest soil and their results should be more reliable. For example the round ribbed-plate penetrometer could meet such requirements.

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USPOREDBA PENETRACIJSKE ZNAČAJKE TLA TRAKTORSKE VLAKE I VUČNE ZNAČAJKE ADAPTIRANOG POLJOPRIVREDNOG TRAKTORA

SAŽETAK

U radu je opisana jedna metoda procjene vučne značajke adaptiranoga poljoprivrednog traktora temeljem prodirne značajke tla traktorske vlake. U dosadašnjim je takvim istraživanjima provedenim na Šumarskome fakultetu u Zagrebu utvrđeno da je ovakva procjena moguća za frikcijsko-kohezijska tla, ali ne i za pijesak, te da se i nadalje trebaju provoditi ciljana istraživanja.

U tu je svrhu obavljeno pojednostavljeno istraživanje vučne značajke adaptiranoga poljoprivrednog traktora pogona 4x2, s mjerenjem vodoravne vučne sile i istodobnoga klizanja kotača. Granulometrijski su sastav tla, nagib traktorske vlake, njena vlaga kao i penetracijska značajka tla određeni u potpunosti. Bruto faktor vuče je proračunat temeljem izmjerenih dimenzija traktora, vučnoga pokusa i dinamičkoga modela njegova opterećenja tijekom privlačenja.

Istraživanje je provedeno na traktorskoj vlaci koja je po granulometrijskome sastavu tla pjeskovita ilovača, s dva stupnja vlažnosti. Analiza je dobivenih rezultata eksponencijalnim regresijskim modelom pokazala da razlike penetracijske značajke suhoga i vlažnog tla odgovaraju i promjenama vučne značajke traktora. Uočena je i razlika prema vučnoj značajki forvardera dobivenoj ranijim istraživanjima na tlu istoga granulometrijskog sastava.

Na temelju provedene analize penetracijskog otpora tla konusnim penetrometrom i mjerene/proračunate vučne značajke adaptiranoga poljoprivrednog traktora može se zaključiti:

- penetracijska značajka tla, koje je po sastavu pjeskovita ilovača, razlikuje se bitno za njegovu vlažnost od 24 % i 44 %,
- penetracijskom se značajkom može dobro procijeniti zbijanje tla nakon prolaska vozila, koje je veće za vlažnije stanje,
- potvrđeno je da postoje dobre naznake za procjenu vučne značajke vozila temeljem prodirne značajke tla, pri čemu je posebno pogodno koristiti eksponencijalni regresijski model za obje značajke,
- u svrhu daljnje potvrde ove postavke nužna su ciljana istraživanja na različitim tlima, s raznim šumskim vozilima.

Pouzdanost ove procjene vučne značajke temeljem prodirne značajke povećat će se povećanjem opsega ciljanih istraživanja. U svakom slučaju, vezu između penetracijske i vučne značajke treba dobro istražiti da bi se skupi, opsežni i dugotrajni pokusi mjerenja vučnih svojstava vozila zamijenili kraćim i jeftinijim istraživanjem

penetracijske značajke tla, uz reducirano istraživanje vučne značajke, te nekih dimenzijskih i težinskih značajki vozila. Jasno da pri tome treba voditi računa o dinamičkom opterećenju vozila.

Također se treba raditi na razvoju novih penetrometara čija uporaba nije složenija od konusnih, da su pogodniji za šumska tla, a rezultati pouzdaniji, kakav je primjerice penetrometar s okruglom pločom i rebrima.

Ključne riječi: privlačenje drva, adaptirani poljoprivredni traktori, vučna značajka, konusni penetrometar, eksponencijalni regresijski model

UDK: 630*587

Preliminary contribution
Prethodno priopćenje

ESTIMATING STAND DENSITY AND CONDITION WITH THE USE OF PICTURE HISTOGRAMS AND VISUAL INTERPRETATION OF DIGITAL ORTHOPHOTOS

PROCJENA OBRASTA I STANJA SASTOJINE UPORABOM HISTOGRAMA SLIKE I VIZUALNOM INTERPRETACIJOM DIGITALNOG ORTOFOTA

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The paper presents the possibilities of using histograms of a stand scene and visual interpretation of a digital orthophoto to estimate stand density and condition. Black-and-white aerial photographs with an approximate scale M ≈ 1:20,000 and 60% overlap, obtained during cyclical survey of the Republic of Croatia, were used for this purpose.

According to research results, there are three basic forms of histograms which may be associated with the corresponding density categories. They may also purposefully be used to estimate the density and condition of a stand. Furthermore, the form of histograms of stand scenes corresponds to stand descriptions.

Stands with normal and poor density may be defined with digital value classes, while stands with density between 0.50 and 0.80 cannot be specified accurately.

Ocular assessment of density based on stand canopy was also made, and firm correlation with concrete density was established, i.e. it was found that canopy may be used as a measure of density.

Key words: cyclical survey, digital orthophoto, picture histogram, density, canopy, stand description

INTRODUCTION
UVOD

The highest benefit is achieved with the least costly data which nevertheless provide information of acceptable accuracy (Oluić, 2001).

Such information has been collected for a relatively long time with remote sensing methods, that is, with visual or computer analyses of aerial or satellite images.

Aerial photographs obtained in the cyclical survey of the Republic of Croatia are available on the Croatian market at a very reasonable price.

These are black-and-white aerial photographs at an approximate scale M ≈ 1:20,000 and a 60%-overlap. It is useful to determine the purposefulness of these photographs in assessing stand density and stand condition.

Density is the most frequently used parameter in quantitative descriptions of stands. Density is one of the most important and the most useful stand parameters which indicate the general condition of a stand. Density by tree species indicates past management but also future planning and implementation of management guidelines.

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

Canopy is the degree of ground cover and mutual spatial relations of tree crowns in a forest. This is the relation of the crown projection towards the total ground surface, and is expressed in percentages or tens of units. When crown projections cover, for example, 80% of the ground surface, the canopy is 80% or 0.8.

In terms of mutual spatial crown relations, the canopy is assessed ocularly and is subjective as such.

There may be extensive differences between canopy and density. Canopy shows the mutual spatial ratio of trees in a stand and the degree of ground cover. Density gives a reliable measure in terms of basal area - wood mass ratio in a stand. In normally developed stands, canopy and density are identical. In stands developed with a small number of trees from youth, abundant light has allowed the growth of very large crowns and the canopy may be complete or normal, while density may be low (Dekanić, 1983).

In even-aged high forests, complete canopy is almost identical to complete density. This does not mean that a decrease in density is parallel to an equal decrease in canopy. The differences are bigger or smaller according to biological properties of species (so, for example, a beech stand aged 120 years with highly developed crowns may have density of 0.8, whereas the canopy is almost complete). Age may also play a decisive role, together with a relatively significant role of the health status (dry-topped trees), as well as the composition mix of varying species (Klepac, 1983).

As experience shows, terrestrial canopy identification is predominantly related to negative errors, because an assessor is often misled by the space below the crowns and thus estimates a smaller canopy. Identifying canopy with aerial photo appraisal may be linked with positive errors, if small darker gaps among the crowns are interpreted wrongly (Tomašegović, 1986).

Research conducted in this respect (Neumann, 1933, Klier, 1974, Križanec, 1987, Kušan, 1991, Klobučar, 2002) has confirmed firm correlation between canopy and density; in other words, it has been confirmed that canopy may be used as a measure of density.

RESEARCH GOAL
CILJ ISTRAŽIVANJA

The paper is aimed at presenting the possibilities of using a digital orthophoto in the estimation of stand density and stand condition by applying image processing software and visual interpretation.

To achieve the set goal successfully, it is necessary to:

- Delineate subcompartments (stands) in an orthophoto,
- Construct a scene histogram for each subcompartment (stand),
- Define digital classes and complement them with relevant density categories,
- Describe (descriptive key) the basic histogram form for each density category,
- Correlate stand histograms with stand descriptions (O-2 form),
- Recommend the content, functionality and need to describe a stand,
- Establish correlation between the canopy and density,
- Establish correlation between the concrete and the estimated density.

METHOD OF WORK
METODA RADA

Research was conducted in the management unit "Jamaričko Brdo", which belongs to Lipovljani Forest Administration.

To do the research, it was necessary to first construct a digital orthophoto and to vectorize management division.

The procedure of making an orthophoto map is faster and therefore more economical compared to the production of a classical or digital map. In this case, a user assumes the role of a decipherer or interpreter and interprets the presented image from his or her experience. Such maps are exceptionally suitable for various kinds of spatial planning in urbanism, road construction, forestry and water management. An orthophoto is based on an oriented digital photogrammetric image and a digital terrain model. Once constructed, the digital terrain model need not be made again; therefore, the process of creating a map with new images is very fast, which enables continuous monitoring of spatial phenomena and events. The user receives an analogous orthophoto map (paper) and a digital, orthorectified picture which they may use in their GIS or CAD applications. A digital orthophoto is made in the black-and-white technique (greyscale) or in colour (RGB).

The applicability and suitability of both a photo plan and an orthophoto plan depends to a large extent on photographic quality. This quality is crucial not only for the accuracy derived from such a plan, but also for the readability and richness of detail and nuances that can be easily observed and defined with certainty (Braum, 1982).

Since cyclical surveys are conducted with standardised methodologies and means, the quality of photographic material is determined in advance; therefore, the original photograph quality cannot be influenced upon.

Cyclical surveys are done in the winter, when the ground is covered with the least quantity of ground vegetation and the trees are leafless, at the time of the day when the shadows are small and the weather calm.

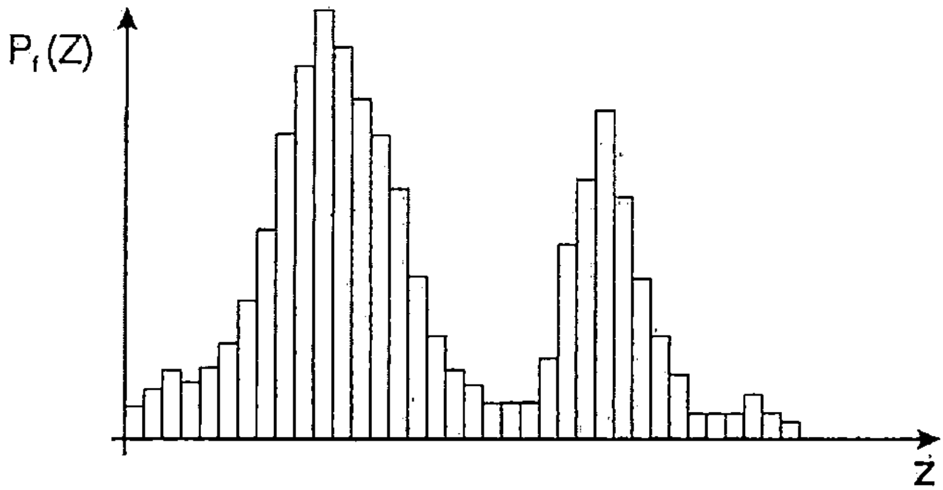
Forest areas not covered with ground vegetation, shrubs and forest trees are reflected in photographs in white or light grey colours, while areas covered with forest trees are reflected in darker tones of grey or in black. In a digital orthophoto, they are pixels in these same colours, or in the corresponding digital values.

A photograph from an individual spectral canal shows reflected electromagnetic energy from the area of the recorded terrain, as well as its distribution in two-dimensional space. Energy is shown with digital numbers that represent varying tones of grey (Oluić, 2001).

A photograph is scanned to be disseminated into a series of rectangular units, so called pixels. A digital datum that is described by a given pixel is the intensity of grey hues ranging from 0 to 255. The value 0 stands for colour black and 255 for colour white. This procedure refers to black-and-white photographs.

A histogram is a graphic representation of numerically expressed values of gray (colour) in the pixels of a scanned photo (Figure 1).

Figure 1. Example of picture histogram
Slika 1. Primjer histograma slike



On the horizontal axis of a histogram, gray values range from 0 to 225 and on the vertical axis there is the total number of pixels with these gray values. Relative relations by separate parts of a histogram are important. Histogram analysis provides reliable data on the quality of a photograph.

To analyse a histogram, attention should be paid to three important rules:

- A histogram should be filled in its entire width, that is, it should incorporate all values from 0 to 225. Gaps in the histogram, like a comb, mean that some tones are absent and that the quality of a photograph is consequently poorer.
- Account should be taken of undesirable accumulation of points with extreme values 0 and 225 (so called black and white point). This does not refer to cases in which the original contains both white and black background, which should be retained as such.
- A histogram should be as smooth as possible, with no sudden oscillations and distinct accumulations in all other values (Vlašić, 1995).

The three rules above are not so important for our research. What is important is to be able to discriminate covered areas (darker colours - lower pixel values) from bare areas (lighter colours - higher pixel values). In the next part of the text we will explain the basic forms of the most common histograms (already drawn), which will clarify the above statement.

a) In the first case (rule), if a histogram contains almost all values from 0 to 225, it means that the histogram has a shape of a longer or a shorter comb, and that stand density is not uniform over the whole area, but that it has a relatively broad valence. In other words, a stand consists of larger or smaller coherent and less coherent groups and clusters of trees interspersed with bare land and failed patches.

Therefore, gaps in the histogram indicate thinned stands of reduced density, which is numerically represented with the mean pixel value that belongs to the right side of the histogram (Figure 2).

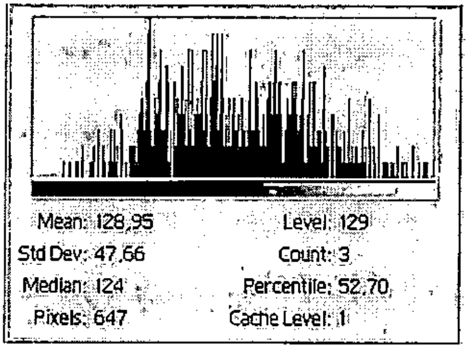


Figure 2. Histogram of 64c compartment
Slika 2. Histogram 64c odsjeka

In our concrete example in subcompartment 64c, the calculated stand density is 0.38 and the canopy is patched.

This histogram analysis, that is, its value distribution, corresponds to the descriptive part, the so-called stand description (O-2 form).

... the stand was damaged by snowbreak over a larger part of the area. The central part of the compartment is almost completely bare, while the edges are covered with thinned groups and clusters. The stand is slightly denser (hornbeam) in the southern part of the compartment, towards the oil well (O-2, 64c).

b) Undesirable accumulations of pixels in extreme values approaching the so-called black or white point in the given histograms are very rare or almost non-

Figure 3. Histogram of 22d compartment
Slika 3. Histogram 22d odsjeka

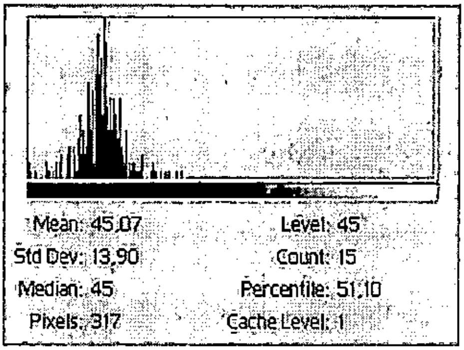
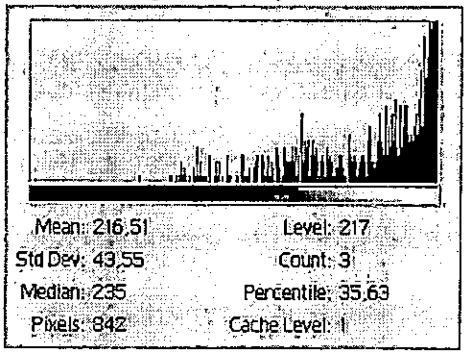


Figure 4. Histogram of 27c compartment
Slika 4. Histogram 27c odsjeka



existent. A histogram with more extreme values relates to the area covered with conifers (Figure 3), and to a bare area (Figure 4).

In cases in which pixel accumulation was closer to the white point, such a histogram would indicate reduced density (Figure 2) or an almost complete absence of forest trees (Figure 4), with which the stand description also corresponds.

A histogram represents a bare productive hunting area covered with grass vegetation and with individual alders on the edges (O-2, 27c).

c) The most frequently produced histograms are those contrasting the third rule. Extreme accumulations of points with a high participation of individual pixel values or levels of grey in the left part of the histogram indicate uniformity of density in a positive sense (Figures 5 - 14), while a histogram with a higher pixel participation in its right part relates to the previously described histograms that indicate reduced density.

Naturally, these histograms correspond to relevant stand descriptions. What is most important, the form of a histogram with the highest number of pixels in its left part, whose digital values are marked with darker colours, corresponds to closed stands with normal density.

This interaction between histograms and stands and normal density has also been confirmed with recent terrestrial measurement and with an equivalent dendrometric list.

These observations have also been confirmed by general histogram analyses.

A scene with a homogeneous area and low contrast will produce a histogram in the form of a simple maximum. A broad simple maximum indicates homogeneity, but with a wide range of contrasts. However, pictures containing several different types of surfaces will have histograms with several maximums (Oluić, 2001).

To carry out this work, a digital orthophoto was constructed. Stand descriptions (Klobučar, 2001) and terrestrial measurement data were used. These data relate to density values obtained from comparing the measured basal areas per hectare with tabular (normal) basal area from Špiranec's yield tables.

Stands in the 1st age class were precluded from this analysis, as well as stands in the management class of black alder, which are unsuitable for this analysis. A total of 83 compartments were analysed.

Since the human eye does not discriminate all 256 levels of the grey tone, or pixel values (0-225), but only some twenty (Oluić, 2001), pixels were grouped into 16 classes with 16 digital values (Table 1).

A histogram was produced for every subcompartment (stand) in the programme Photoshop 6.0, in which, apart from visual perception, it is possible to read mean pixel values (mean), standard deviation (Std Dev) and median (median).

After a histogram has been constructed, and on the basis of the read mean pixel value, arelevant class was associated to the subcompartment. Also, subcompartments were previously grouped according to density categories (NN 11/97):

Table 1. Digital values grouped in classes
Tablica 1. Digitalne vrijednosti grupirane u klase

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	16	32	48	64	80	96	112	128	144	160	176	192	208	224	240
1	17	33	49	65	81	97	113	129	145	161	177	193	209	225	241
2	18	34	50	66	82	98	114	130	146	162	178	194	210	226	242
3	19	35	51	67	83	99	115	131	147	163	179	195	211	227	243
4	20	36	52	68	84	100	116	132	148	164	180	196	212	228	244
5	21	37	53	69	85	101	117	133	149	165	181	197	213	229	245
6	22	38	54	70	86	102	118	134	150	166	182	198	214	230	246
7	23	39	55	71	87	103	119	135	151	167	183	199	215	231	247
8	24	40	56	72	88	104	120	136	152	168	184	200	216	232	248
9	25	41	57	73	89	105	121	137	153	169	185	201	217	233	249
10	26	42	58	74	90	106	122	138	154	170	186	202	218	234	250
11	27	43	59	75	91	107	123	139	155	171	187	203	219	235	251
12	28	44	60	76	92	108	124	140	156	172	188	204	220	236	252
13	29	45	61	77	93	109	125	141	157	173	189	205	221	237	253
14	30	46	62	78	94	110	126	142	158	174	190	206	222	238	254
15	31	47	63	79	95	111	127	143	159	175	191	207	223	239	255

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

RESEARCH RESULTS AND DISCUSSION
REZULTATI ISTRAŽIVANJA I RASPRAVA

Grouping subcompartments into categories yielded the following results (Tables 2-4):

- Stands with normal density above 0.80 (n=59), table 2.

From the analysis of the above table it ensures that:

1 subcompartment belongs to class 5 (66b)

11 subcompartments belong to class 6 (22a, 22b, 23a, 23e, 35a, 36a, 41a, 55a, 65a, 66a, 67b),

16 subcompartments belong to class 7 (13b, 17a, 21a, 23d, 26a, 27a, 31b, 33a, 34a, 42a, 49a, 54a, 64a, 67a, 68b, 69b),

Table 2. Normal density compartments with relevant classes and statistical values
Tablica 2. Odsjeci normalnog obrasta sa pripadajućim klasama i statističkim vrijednostima

Compartment *Odjel*	Subcomp. *Odsjek*	Density *Obrast*	Mean *Aritm. sred.*	Std. dev.	Median *Medijana*	Class *Klasa*
13	,b	0.94	108.85	27.16	107	7
14	a	0.87	113.91	35.12	111	8
15	a	1.02	114.06	36.94	111	8
16	a	0.86	111.61	31.82	111	8
17	a	0.96	108.74	31.47	106	7
18	a	1.00	130.61	42.44	131	9
19	a	1.11	112.93	35.49	113	8
20	a	1.08	112.01	31.09	110	8
21	a	1.01	111.43	31.46	110	7
22	a	0.89	87.47	17.27	85	6
22	b	0.94	86.96	23.26	88	6
23	a	0.93	93.86	21.90	91	6
23	b	0.85	112.08	25.33	110	8
23	d	0.94	100.36	28.50	99	7
23	e	0.91	95.27	23.15	94	6
24	a	0.94	117.70	34.10	113	8
24	b	0.81	130.09	35.91	128	9
25	a	1.00	117.15	36.84	114	8
26	a	0.85	100.44	22.64	98	7
27	a	0.83	102.38	30.89	98	7
28	a	0.97	119.68	28.01	117	8
29	a	0.89	125.85	41.60	123	8
29	b	0.86	118.84	32.08	121	8
30	a	0.90	134.33	35.69	133	9
31	a	1.01	118.12	30.45	116	8
31	b	0.98	102.53	38.89	101	7
32	a	0.85	124.46	44.11	124	8
33	a	0.89	108.25	33.04	106	7
34	a	0.96	103.87	37.99	100	7
35	a	1.02	84.73	25.12	83	6
36	a	1.03	88.25	18.28	87	6
37	a	0.86	119.99	31.56	118	8
38	a	1.04	137.24	37.38	136	9
39	a	0.97	147.47	38.74	147	10

Nastavak tablice 2.

40	a	0.95	118.84	49.69	118	8
41	a	1.01	83.32	26.66	82	6
42	a	1.02	95.66	26.99	93	7
45	a	0.94	116.81	47.76	113	8
45	c	0.88	175.68	35.46	176	12
49	a	0.83	111.09	34.17	109	7
50	a	0.95	119.75	38.81	117	8
54	a	0.91	110.79	31.70	110	7
55	a	0.91	92.26	29.42	89	6
56	a	0.86	113.37	38.67	110	8
58	a	0.84	129.34	41.45	130	9
59	a	0.95	120.88	33.38	119	8
60	a	0.94	120.51	25.58	119	8
61	a	0.88	111.46	39.39	105	8
62	a	0.85	129.85	28.51	128	9
64	a	0.83	107.64	35.51	103	7
64	b	0.84	125.33	39.61	122	8
65	a	0.96	91.79	28.58	89	6
66	a	0.84	82.90	20.86	82	6
66	b	0.99	76.60	16.19	77	5
67	a	1.01	102.19	25.46	100	7
67	b	0.82	85.85	19.99	85	6
68	b	0.83	98.62	30.25	95	7
69	b	0.94	98.54	33.22	93	7

23 subcompartments belong to class 8 (13a, 14a, 15a, 16a, 19a, 20a, 23b, 24a, 25a, 28a, 29a, 29b, 31a, 32a, 37a, 40a, 45a, 50a, 56a, 59a, 60a, 61a, 64b),
6 subcompartments belong to class 9 (18a, 24b, 30a, 38a, 58a, 62a).
1 subcompartment belongs to class 10 (39a)
1 subcompartment belongs to class 12 (45c).

Stands with normal density are predominant and the majority are found in class 8 or in lower classes (5, 6, 7). Therefore, stands with normal density are associated (defined) with these classes.

The arithmetic mean of mean pixel values is 110.75 and is on the border between class 7 and 8. The highest mean pixel value is 175.68 in subcompartment 45c, while the lowest value is 76.60 in subcompartment 66b.

The analysis of the descriptive part in Table 2 shows that 51 subcompartments or 87% belong to the above classes, whereas only 8 subcompartments or 13% belong to classes higher than 8.

Figure 5. Histogram of 15a compartment
Slika 5. Histogram 15a odsjeka

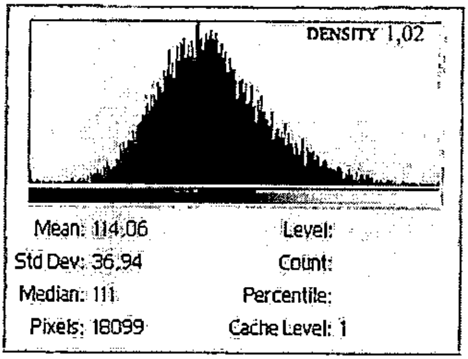


Figure 6. Histogram of 55a compartment
Slika 6. Histogram 55a odsjeka

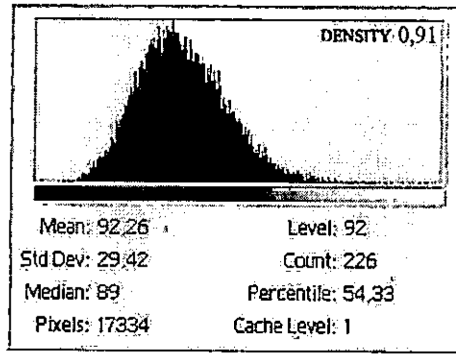


Figure 7. Histogram of 13a compartment
Slika 7. Histogram 13a odsjek

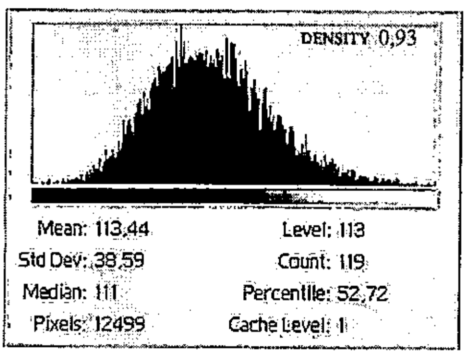


Figure 8. Histogram of 14a compartment
Slika 8. Histogram 14a odsjeka

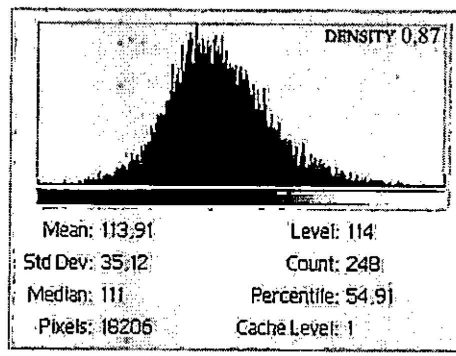


Figure 9. Histogram of 23e compartment
Slika 9. Histogram 23e odsjeka

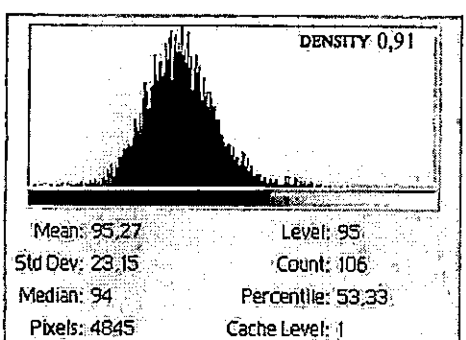


Figure 10. Histogram of 25a compartment
Slika 10. Histogram 25a odsjeka

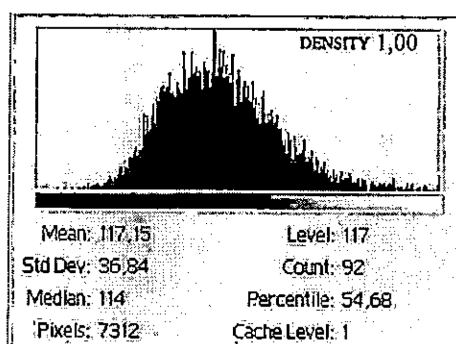


Figure 11. Histogram of 27a compartment
Slika 11. Histogram 27a odsjeka

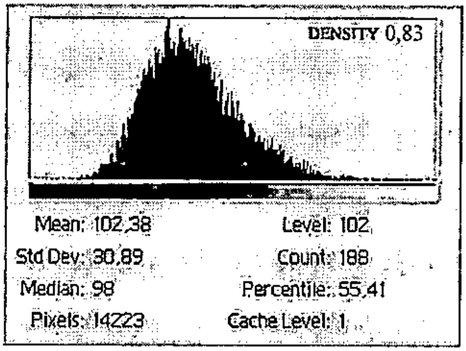


Figure 12. Histogram of 67a compartment
Slika 12. Histogram 67a odsjeka

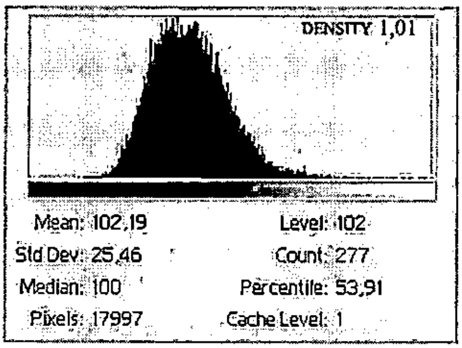


Figure 13. Histogram of 68b compartment
Slika 13. Histogram 68b odsjeka

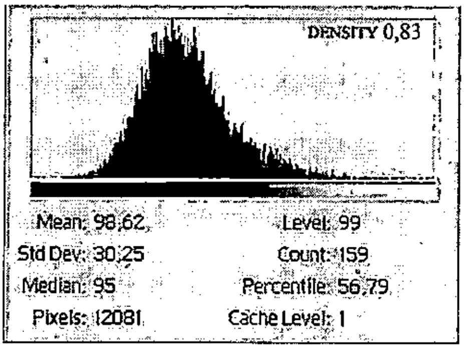
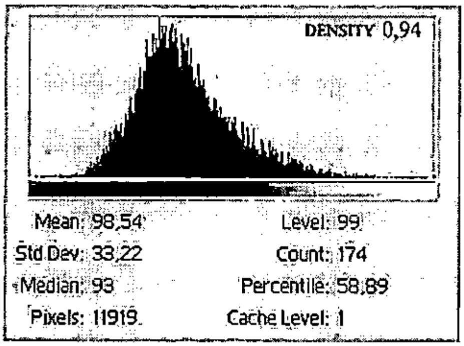


Figure 14. Histogram of 69b compartment
Slika 14. Histogram 69b odsjeka



However, it should be pointed out, (and this fact was already partly discussed (rule c)), that histograms showing scenes of stands with normal density are mostly uniform in appearance and that in form they resemble the normal distribution with a stronger or weaker slant and flatness.

These are simple histograms with one maximum, whose mean pixel values are mostly in the above classes (5, 6, 7, 8) and in which the largest number of pixels belongs to the left side of the histogram, but closer to the centre of the abscissa (Figures 5 - 14).

As seen in the preceding pictures, each histogram has a definite number of pixels which represent lighter values or bare areas. This fact is justified by the fact that density in the majority of Croatian regular commercial forests is lower than 1.0 (0.8 is the statistically average density in regular forests, and the same is valid for the sample management unit). This is considered to be the reason that histograms contain these pixels.

Naturally, there are several histograms with an atypical form (Figures 15-17) with mean values in the quoted classes, which define stands with normal density. Such a histogram form is not accidental; it can be explained with the structure, canopy and tree distribution in a stand, and will indicate to an informant the stand's specific feature and possible exclusions. Such histograms require specific interpretative knowledge, and the explanation of their forms may be read from stand descriptions:

... the stand canopy is complete, sporadically incomplete, less frequently bare (O-2, 32a)

... the stand canopy and density are disrupted by several failed patches and bare land (a slightly larger bare area of about 0.4 ha with a sporadic tree is located among oil-wells) resulting from snowbreak (O-2, 45a).

Since only 13% of the stands do not correspond to the defined classes for normal density, these compartments will be analysed in the next part.

Subcompartment 45c belongs to a high class 12 with regard to the density value of 0.88. This can be explained with the fact that the subcompartment borders with subcompartment 45b (density 0.51), whose structure is disturbed and which belongs to class 11. The border part between these two subcompartments is almost bare and the light pixels (which belong to subcompartment 45c) have affected the increased mean pixel value of subcompartment 45c. Also, the stand in subcompartment 45c has an in-

Figure 15. Histogram of 32a compartment
Slika 15. Histogram 32a odsjeka

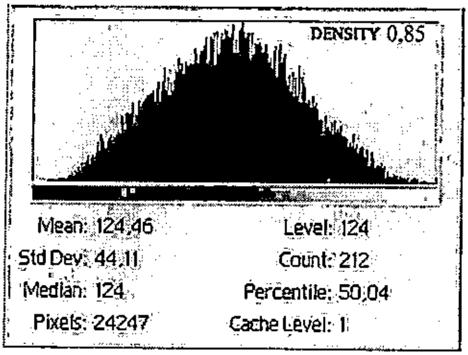


Figure 16. Histogram of 40a compartment
Slika 16. Histogram 40a odsjeka

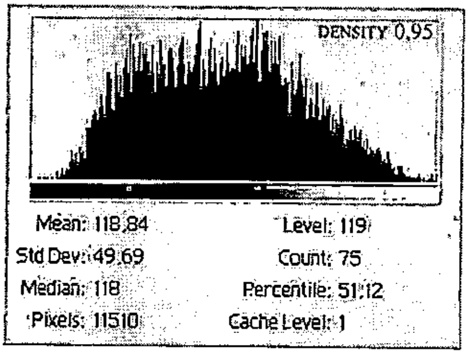
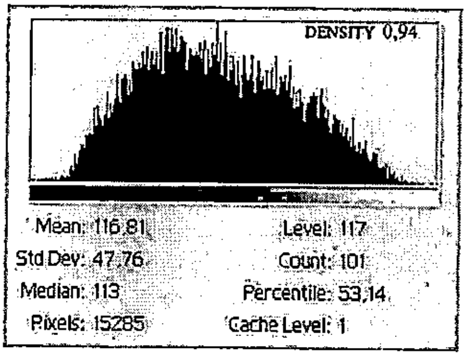


Figure 17. Histogram of 45a compartment
Slika 17. Histogram 45a odsjeka



complete canopy, of medium density and sporadic rare places, a well developed layer of ground vegetation and rare shrubs (O-2), which is an additional indicator of an increased mean pixel value.

Subcompartment 39a has normal density and is in the inappropriate class 10, which defines stands with poor density. One of the reasons for an increased mean pixel value in this subcompartment can be read in the O-2 form, which states that: "due to icebreak on the border with compartment 34, there are several smaller bare areas."

There are reasons why the three compartments of the remaining six are in class 9 (inappropriate), which defines stands of poorer density.

Thus, the stand canopy in subcompartment 18a ranges from incomplete to complete, medium thick and sporadically thin. In subcompartment 38a there are several smaller bare areas, identical to subcompartment 58a, which has affected the increase in mean pixel values. However, the mean pixel value for all three subcompartments is relatively close to the upper boundary of class 8.

There is no adequate explanation for the tree remaining subcompartments (24b, 30a, 62a). It can only be pointed out that the areas of these subcompartments in photographs, or in the digital orthophoto, are seen as a mosaic of lighter and darker variations of grey (Figure 18). Therefore, the lighter tones have affected the increased value of mean pixel.

Figure 18. Histogram of 30a compartment
Slika18. Histogram 30a odsjeka

- Stands with density from 0.50 to 0.80 (n=15)

From the analysis of Table 3, it is clear that:

5 subcompartments belong to class 7 (46a, 47a, 48a, 52a, 57a),

4 subcompartments belong to class 8 (51a, 68a, 69a, 70a),

2 subcompartments belong to class 9 (43a, 53a),

2 subcompartments belong to class 11 (45b, 61b).

Stands with density from 0.5 to 0.8 are found in classes ranging from 7 to 11. Therefore, these are classes that define stands with normal density (class 7 and 8) and classes (9, 10 and 11) that define stands with poor density.

The arithmetic mean of mean pixel values is 129.09 and belongs to class 9. The highest mean pixel value is 170.54 in subcompartment 45b, while the lowest pixel value is 96.44 in compartment 52a.

This is understandable, because stands with such densities, or their scenes, consist of light pixels that represent poorer density and of darker pixels that represent

Table 3. Compartments with density from 0.50 to 0.80 with relevant classes and statistical values

Tablica 3. Odsjeci obrasta od 0.50 do 0.80 sa pripadajućim klasama i statističkim

Compartment *Odjel*	Subcomp. *Odsjek*	Density *Obrast*	Mean *Aritm. sred.*	Std. dev.	Median *Medijana*	Class *Klasa*
44	b	0.70	144.84	43.15	146	10
45	b	0.51	170.54	43.41	176	11
46	a	0.77	110.55	37.62	107	7
47	a	0.71	102.79	44.77	97	7
48	a	0.72	107.38	42.34	102	7
51	a	0.76	117.90	35.36	112	8
52	a	0.77	96.44	28.23	93	7
53	a	0.73	142.87	39.11	142	9
57	a	0.75	107.25	44.06	104	7
61	b	0.64	168.34	43.60	172	11
63	a	0.75	155.07	37.35	156	10
68	a	0.66	124.32	37.18	119	8
69	a	0.75	127.26	35.41	124	8
70	a	0.78	120.30	27.49	118	8

normal density. Depending on the larger number of one or the other pixel group, the compartment is defined with a given class which denotes stands with normal or poorer density.

Thus, stands within this group cannot be specified with certain classes, but reduced density or unfavourable stand structure will be indicated in the form of the histogram.

Figure 19. Histogram of 44b compartment
Slika 19. Histogram 44b odsjeka

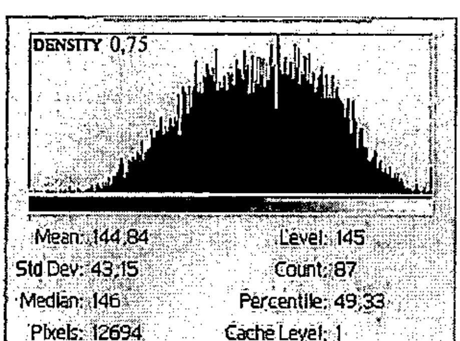
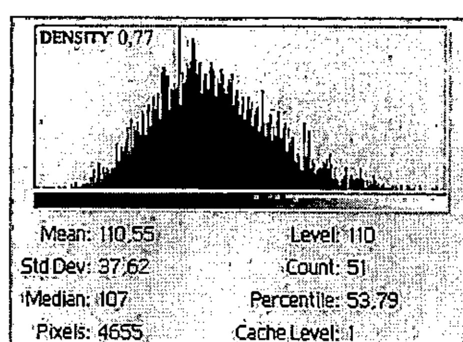


Figure 20. Histogram of 46a compartment
Slika 20. Histogram 46a odsjeka



Stands with density insignificantly lower than normal, whose histograms (Figures 19-29) resemble histograms of stands with normal density but with a higher pixel participation in the right part of the histogram, will belong to the first part of this group.

The second part of this group encompasses stands with significantly reduced density and a disturbed stand structure, which is seen in their histograms (Figures 30-33) of incomplete comb-like forms.

Figure 21. Histogram of 47a compartment
Slika 21. Histogram 47a odsjeka

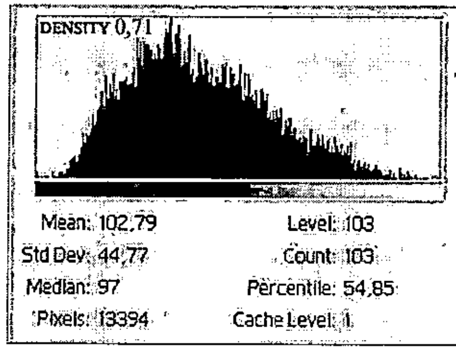


Figure 22. Histogram of 48a compartment
Slika 22. Histogram 48a odsjeka

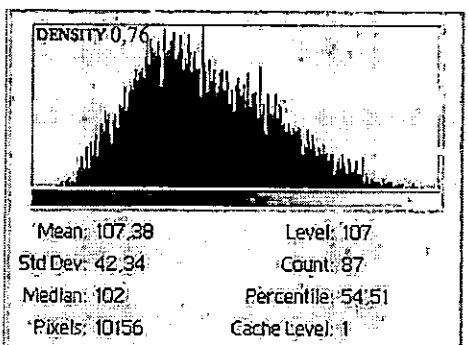


Figure 23. Histogram of 51a compartment
Slika 23. Histogram 51a odsjeka

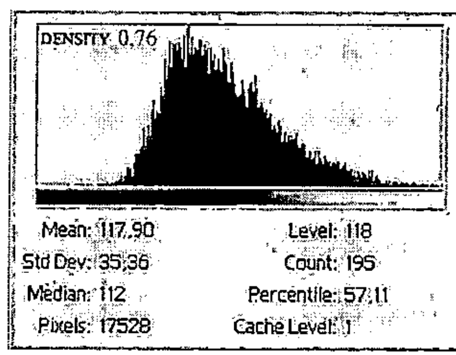


Figure 24. Histogram of 52a compartment
Slika 24. Histogram 52a odsjeka

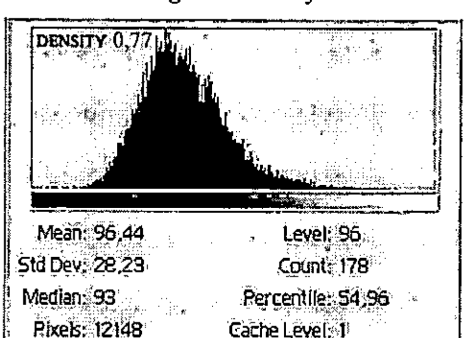


Figure 25. Histogram of 53a compartment
Slika 25. Histogram 53a odsjeka

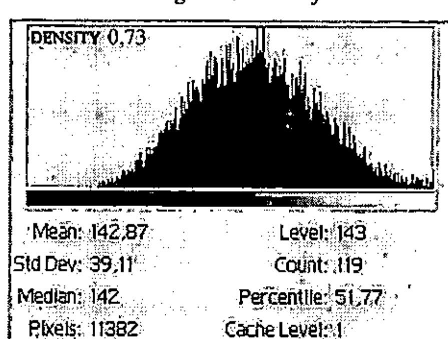


Figure 26. Histogram of 57a compartment
Slika 26. Histogram 57a odsjeka

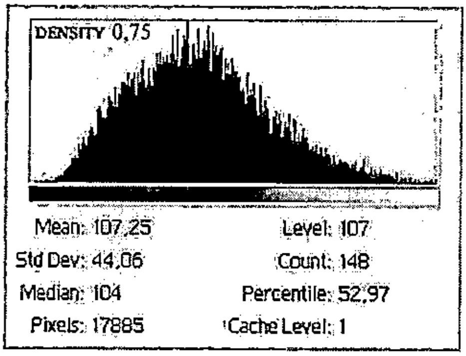


Figure 27. Histogram of 63a compartment
Slika 27. Histogram 63a odsjeka

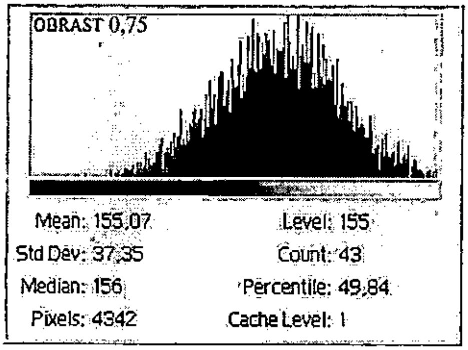


Figure 28. Histogram of 69a compartment
Slika 28. Histogram 69a odsjeka

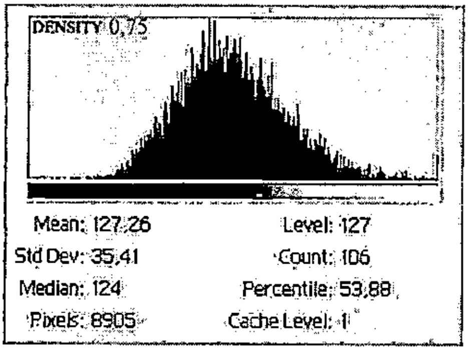


Figure 29. Histogram of 70a compartment
Slika 29. Histogram 70a odsjeka

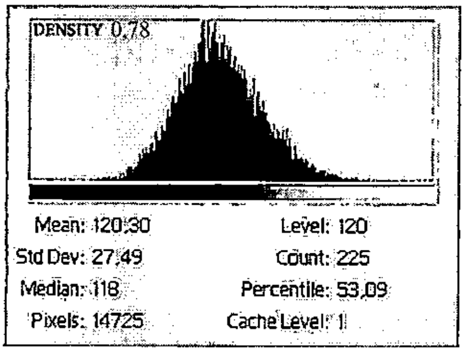


Figure 30. Histogram of 43a compartment
Slika 30. Histogram 43a odsjeka

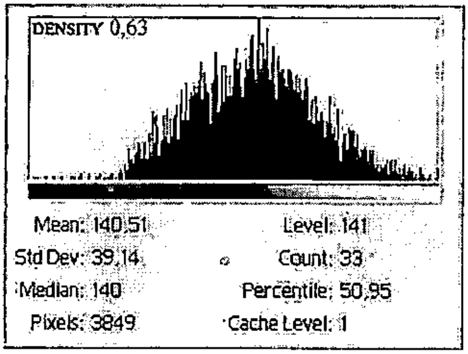


Figure 31. Histogram of 45b compartment
Slika 31. Histogram 45b odsjeka

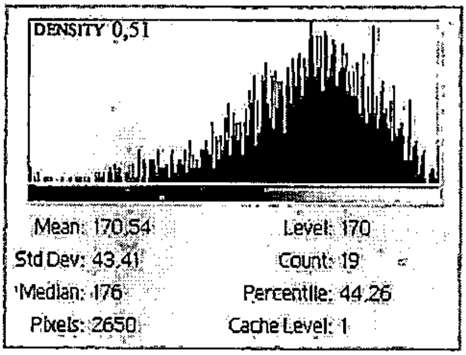


Figure 32. Histogram of 61b compartment
Slika 32. Histogram 61b odsjeka

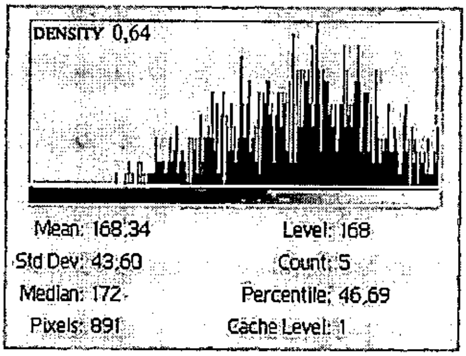
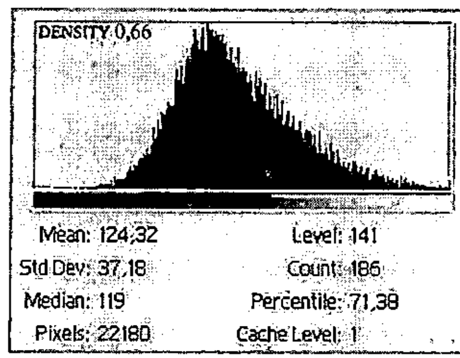


Figure 33. Histogram of 68a compartment
Slika 33. Histogram 68a odsjeka



Naturally, the presented histograms correspond to stand descriptions:

... the stand was damaged across the entire area during snowbreak. Considerable damage was inflicted to the eastern part of the compartment, where a sporadic stocked group or a smaller cluster occurs in several smaller clearings. In the western part of the compartment, there is a succession of bare areas and failed patches with infrequent groups and clusters (O-2, 43a).

... the stand has an incomplete canopy. Some consequences of snowbreak are visible over a smaller area (below "c"). In other words, the canopy is sporadically gapped and there are still some remaining damaged trees (O-2, 44b).

... during snowbreak (on several occasions), the stand structure was disturbed. Barea areas, failed patches and smaller clearings with stocked groups and clusters alternate over a larger part of the area. More coherent and slightly larger stocked areas are found along the openings as well as below the boundary of compartments 46 and 47, while a visually distinct, strip-like, unstocked area extends along the whole compartment. There are still some remaining damaged (bent, dry-topped, rotten, broken etc.) trees (O-2, 45b).

... the stand is medium thick over a larger part of the area. There are some sporadic less dense parts resulting from snowbreak. Damage caused by snowbreak can be seen on hornbeams (to some extent), and the trees are bent (O-2, 46a).

... stand coherence is partially disturbed in the upper part of the compartment (towards compartment 49), since there are several failed patches and smaller clearings resulting from snowbreak (O-2, 48a).

... the stand is medium thick and closed, with an incomplete canopy and with several failed patches occurring during snowbreak (O-2, 51a).

... on the whole, the stand is medium thick and closed; however, there are several failed patches and smaller bare areas brought about by snowbreak from several successive years (O-2, 52a).

... it should be pointed out that the stand is medium thick to thin over its larger part due to snowbreak, with incomplete canopy (O-2, 53a).

... the stand is medium thick, mainly closed (O-2, 57a).

... snowbreaks have led to a disturbed stand structure. Larger or smaller, thinly stocked groups alternate with bare areas in the form of gaps and patches over the whole compartment. The stocked groups are not fully vital, because some trees within these groups are damaged (O-2, 61b).

... the stand is uniform in the sense that the canopy oscillates over the whole compartment and is incomplete on average (O-2, 63a).

..., larger or smaller bare areas and failed patches, less frequently smaller clearings, with stocked (thin to medium thick) groups and clusters, alternate over a larger part of the area (O-2, 68a).

... larger or smaller bare areas and failed patches, and less frequently smaller clearings, with stocked (thin to medium thick) groups and clusters, alternate over a larger part of the area (O-2, 69a).

... there is a smaller clearing (about 0.3 ha) resulting from snowbreak on the boundary with subcompartment 69b (O-2, 70a).

Table 4. Poor density compartments with relevant classes and statistical values
Tablica 4. Odsjeci slabog obrasta sa pripadajućim klasama i statističkim vrijednostima

Compartment *Odjel*	Subcomp. *Odsjek*	Density *Obrast*	Mean *Aritm. sred.*	Std. dev.	Median *Medijana*	Class *Klasa*
44	a	0.49	144.42	49.43	145	10
44	c	0.25	171.18	46.79	169	11
46	c	0.26	108.84	49.87	103	7
48	c	0.22	80.80	38.54	77	6
50	b	0.24	138.28	33.17	135	9
50	c	0.31	132.30	43.10	120	9
51	b	0.26	181.13	33.82	183	12
64	c	0.38	128.95	47.66	124	9

- Stands with poor density up to 0.50 (n=9):

From the analysis of Table 4, it ensures that:

1 subcompartment belongs to class 6 (48c).

1 subcompartment belongs to class 7 (46c)

1 subcompartment belongs to class 8 (22c)

3 subcompartments belong to class 9 (50b, 50c, 64c),

1 subcompartment belongs to class 10 (44a),

1 subcompartment belongs to class 11 (44c),

1 subcompartment belongs to class 12 (51b).

Stands with poor density are defined by classes 9, 10, 11 and 12. It can be noted that not all subcompartments in this group belong to these classes, but that one subcompartment each belongs to class 6, 7 and 8, which define normal density.

The arithmetic mean of mean pixel values is 133.43 and belongs to class 9. The highest mean pixel value is 181.13 in subcompartment 51b, while the lowest mean pixel value is 80.80 in subcompartment 48c.

Subcompartments 48c and 46c belong to classes 6 and 7. These subcompartments have small areas (1.00 ha and 0.67 ha) which are not clearly visible in a digital orthophoto. The boundary of the compartments (which overlaps across the digital orthophoto) depends on the accuracy of mapping and on the accuracy of digital orthophoto geocoding (Klobučar, 2003). It can be concluded, therefore, that small area subcompartments are not suitable for such analyses. For the same reason, compartments in the management class of black alder that take up small narrow areas along streams were also excluded from the analyses.

With regard to the calculated density of 0.48, subcompartment 22e also belongs to a lower class, which does not correspond to the defined class scope of 9-12. This stand is a good example illustrating that there may be big differences between the canopy and density in cases in which stands have developed with a small number of trees, while crowns have developed under abundant quantities of light.

In the concrete example, it is an old, thin beech stand (aged 111 years) with an incomplete to broken canopy and large, branchy crowns. It is these large and branchy crowns that have caused the average pixel value to drop into a lower (8) class than expected. However, the histogram indicates a disturbed stand structure in this subcompartment, too.

The histograms of all these stands also indicate disturbed stand structures and considerable decrease in density. These histograms have the form of a longer or shorter comb (rule a), (Figures 2, 34-41).

Figure 34. Histogram of 22e compartment
Slika 34. Histogram 22e odsjeka

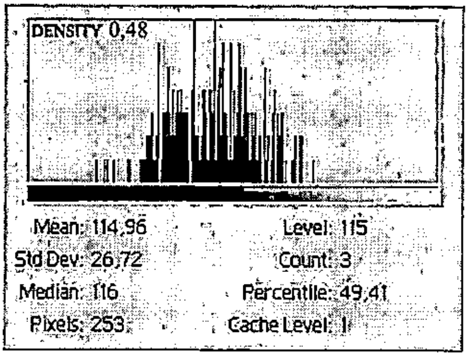


Figure 35. Histogram of 44a compartment
Slika 35. Histogram 44a odsjeka

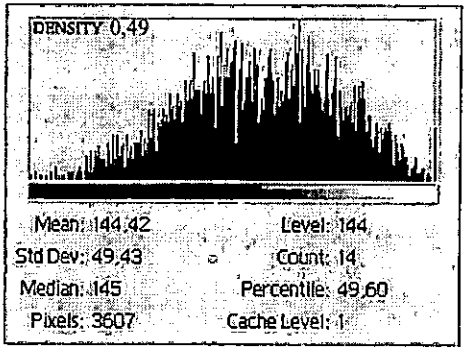


Figure 36. Histogram of 44c compartment
Slika 36. Histogram 44c odsjeka

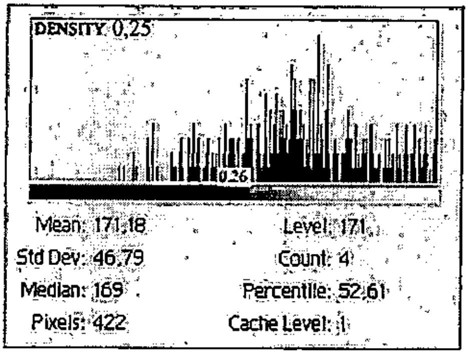


Figure 37. Histogram of 46c compartment
Slika 37. Histogram 46c odsjeka

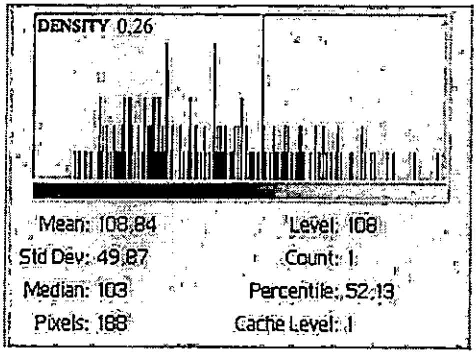


Figure 38. Histogram of 48c compartment
Slika 38. Histogram 48c odsjeka

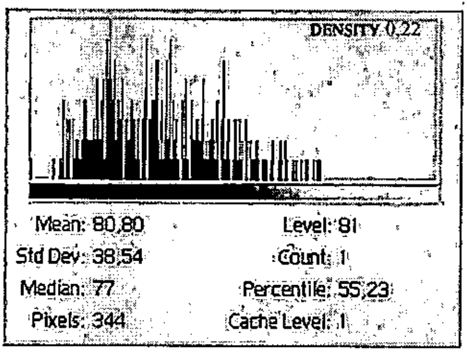


Figure 39. Histogram of 50b compartment
Slika 39. Histogram 50b odsjeka

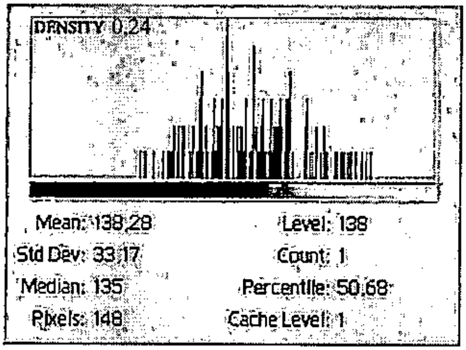


Figure 40. Histogram of 50c compartment
Slika 40. Histogram 50c odsjeka

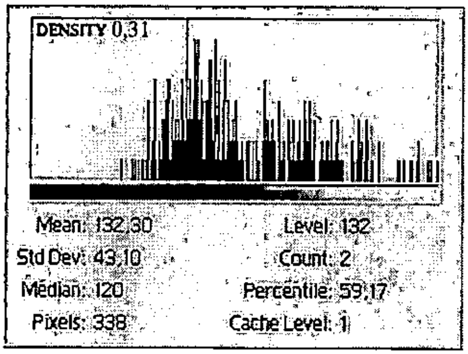
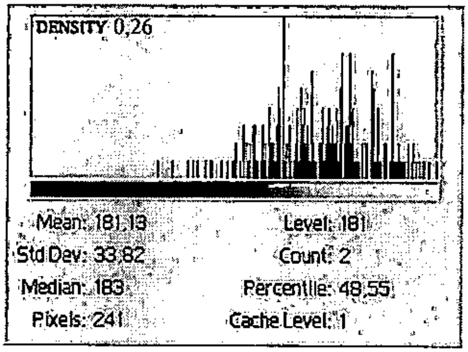


Figure 41. Histogram of 51b compartment
Slika 41. Histogram 51b odsjeka



As in the two preceding groups, the histograms of stands with poor density correspond with stand descriptions and dendrometric lists.

... in the past period, the stand suffered snowbreak on several occasions, which has led to a significant disturbance of its structure. In this sense, the least damage occurred along the very ridge (an opening towards compartment 46), where sessile oaks and beeches with some hornbeams form a more coherent (about 0.4 ha) structure. Snowbreak affected the central part of the compartment most. As a result, in this part of the compartment there is a bare area in the form of a wider or narrower strip containing a sporadic tree or groups of trees. The edge part towards the "b" compartment along the ditch, where hornbeams arranged in thinner or thicker groups have the largest participation, is in the middle between the two above situations (O-2, 44a).

... the stand has been considerably damaged by snowbreak, and is today a thin stand with individual trees or groups of trees (O-2, 44c).

... the stand structure is disturbed, and smaller and mostly sporadic groups dominated by hornbeam with some individual sessile oaks alternate in a mosaic-like pattern (O-2, 46c).

... today, this stand consists only of several smaller remaining groups of hornbeams or individual sessile oaks or beeches (O-2, 48c).

... today, this is a structurally destroyed stand with only two smaller remaining groups of beech and hornbeam trees (O-2, 50b).

... the stand structure is disturbed over the whole area. There are only some sporadic remaining trees towards the "a" compartment and a larger group along the opening with subcompartment 51a (O-2, 50c).

... the stand structure is disturbed over the whole area. There are only some smaller groups or the trees are dispersed individually over the whole area (O-2, 51b).

Dendrometric data themselves, if they are not accompanied with good stand descriptions, do not give a comprehensive insight into the stand condition and do not guarantee the establishment of a functional GIS model, the so called descriptive or attributive part

Apart from general stand features, a stand description should also contain:

- the composition mix and silvicultural form,
- spatial distribution of species in the horizontal and vertical sense,
- the quality and appearance of trees (stems and crowns), the condition of the canopy, density and health status,
- age and diameter structure by species,
- regeneration status,
- a description of the ground layer, etc.

It is clear from the above that a stand description should provide a descriptive interpretation of a dendrometrical list.

The recommended content of a stand description may be used by a forestry expert in prescribing and implementing management guidelines.

The above histograms and descriptive explanations of their forms show that darker pixels, or their digital values, represent tree crowns, and that lighter pixels and their digital values refer to bare areas.

Furthermore, the stands (compartments) grouped according to digital classes and density categories, based on average pixel values and concrete density, provide a very transparent illustration of correlation between digital classes and density categories.

Therefore, individual digital classes or digital pixel values in fact represent the reflected electromagnetic energy from the surface of tree crowns, which are defined by specified density.

These facts were used to do an ocular estimate of stand canopy from the stereomodel and digital orthophoto. As the reasons for possible correlation between density and canopy have been described above, the estimated degree of ground coverage with crowns or crown coverage in fact represents the ocularly estimated stand density.

Thus, all darker colours, in other words, dark grey and black pixels, denote (define) the areas stocked with forest trees; the density of a compartment or a subcompartment whose entire area is darker was 1.0. Of the total compartment or subcompartment area, darker areas representing density are assessed in percentages or hundreds of units; therefore, the compartment or subcompartment is proportionally decreased by the amount of lighter areas.

This estimation method has a drawback; it is not possible to assess density values above 1.00 because this value is held by a stand with a completely dark scene, which is the upper differentiation boundary.

In the concrete management unit, density was estimated according to the described methodology (Table 5, Figures 42, 43).

CONCRETE DENSITY
KONKRETNI OBRAST

$\bar{O}$	0.82	F – test		
Std	0.21	F – cal.		1.44
var	0.04	F – test	(α = 0.01)	1.70
Cv	25.36	F – test	(α = 0.05)	1.45

ESTIMATED DENSITY
PROCIJENJENI OBRAST

$\bar{S}$	0.81	U – test		
Std	0.17	U – cal.		0.32
var	0.03	U – test	($\alpha = 0.01$)	2.56
Cv	21.40	U – test	($\alpha = 0.05$)	1.96
R	0.91			
cov	0.03			

Table 5. The relationship between concrete and estimated density with determined differences
Tablica 5. Odnos konkretnog i procijenjenog obrasta sa utvrđenim razlikama

Compartment *Odjel*	Subcomp. *Odsjek*	Concrete density *Konkretni obrast (O)*	Estimated density *Procijenjeni obrast (S)*	Difference of density *Razlika obrasta*
13	a	0.93	0.85	-0.08
13	b	0.94	0.90	-0.04
14	a	0.87	0.95	0.08
15	a	1.02	0.95	-0.07
16	a	0.86	0.85	-0.01
17	a	0.96	0.85	-0.11
18	a	1.00	0.90	-0.10
19	a	1.11	0.95	-0.16
20	a	1.08	1.00	-0.08
21	a	1.01	0.95	-0.06
22	a	0.89	1.00	0.11
22	b	0.94	0.95	0.01
22	e	0.48	0.60	0.12
23	a	0.93	0.95	0.02
23	b	0.85	0.90	0.05
23	d	0.94	1.00	0.06
23	e	0.91	1.00	0.09
24	a	0.94	0.85	-0.09
24	b	0.81	0.90	0.09

Nastavak tablice 5

25	a	1.00	0.85	-0.15
26	a	0.85	0.90	0.05
27	a	0.83	0.90	0.07
28	a	0.97	0.90	-0.07
29	a	0.89	0.85	-0.04
29	b	0.86	0.90	0.04
30	a	0.90	0.90	0.00
31	a	1.01	0.95	-0.06
31	b	0.98	0.95	-0.03
32	a	0.85	0.80	-0.05
33	a	0.89	0.90	0.01
34	a	0.96	0.90	-0.06
35	a	1.02	1.00	-0.02
36	a	1.03	1.00	-0.03
37	a	0.86	0.85	-0.01
38	a	1.04	0.80	-0.24
39	a	0.97	0.80	-0.17
40	a	0.95	0.75	-0.20
41	a	1.01	0.90	-0.11
42	a	1.02	0.95	-0.07
43	a	0.63	0.60	-0.03
44	a	0.49	0.55	0.06
44	b	0.70	0.65	-0.05
44	c	0.25	0.35	0.10
45	a	0.94	0.80	-0.14
45	b	0.51	0.35	-0.16
45	c	0.88	0.75	-0.13
46	a	0.77	0.85	0.08
46	c	0.26	0.40	0.14
47	a	0.71	0.80	0.09
48	a	0.72	0.75	0.03
48	c	0.22	0.35	0.13
49	a	0.83	0.85	0.02
50	a	0.95	0.80	-0.15

Nastavak tablice 5

50	b	0.24	0.35	0.11
50	c	0.31	0.35	0.04
51	a	0.76	0.75	-0.01
51	b	0.26	0.40	0.14
52	a	0.77	0.85	0.08
53	a	0.73	0.75	0.02
54	a	0.91	0.90	-0.01
55	a	0.91	0.90	-0.01
56	a	0.86	0.90	0.04
57	a	0.75	0.75	0.00
58	a	0.84	0.85	0.01
59	a	0.95	0.90	-0.05
60	a	0.94	0.95	0.01
61	a	0.88	0.90	0.02
61	b	0.64	0.50	-0.14
62	a	0.85	0.90	0.05
63	a	0.75	0.75	0.00
64	a	0.83	0.90	0.07
64	b	0.84	0.75	-0.09
64	c	0.38	0.5	0.12
65	a	0.96	0.85	-0.11
66	a	0.84	0.95	0.11
66	b	0.99	1.00	0.01
67	a	1.01	0.90	-0.11
67	b	0.82	0.90	0.08
68	a	0.66	0.75	0.09
68	b	0.83	0.90	0.07
69	a	0.75	0.75	0.00
69	b	0.94	0.85	-0.09
70	a	0.78	0.90	0.12

Since there is no statistically significant difference between the estimated and concrete density, it can be concluded that canopy can be justifiably used as a measure of density.

Figure 42. Graphic presentation of estimated and concrete density
Slika 42. Grafički prikaz odnosa procijenjenog i konkretnog obrasta

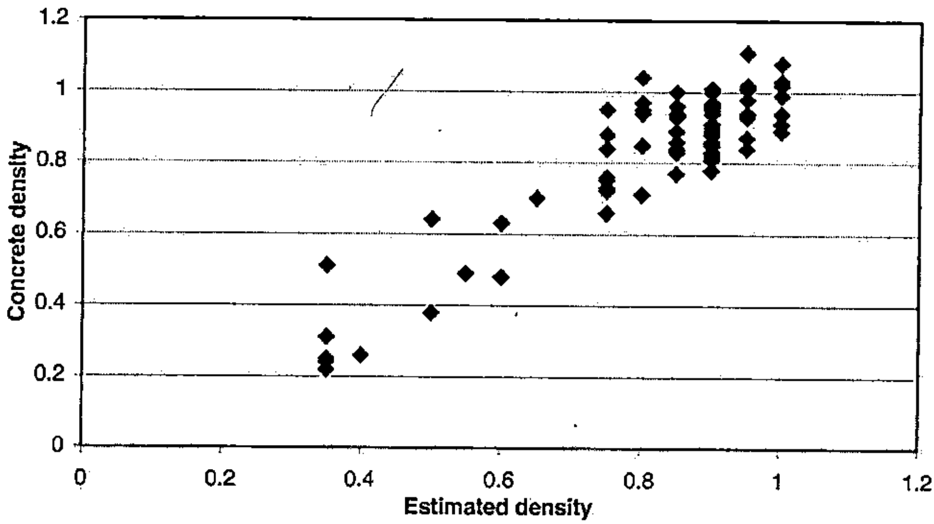
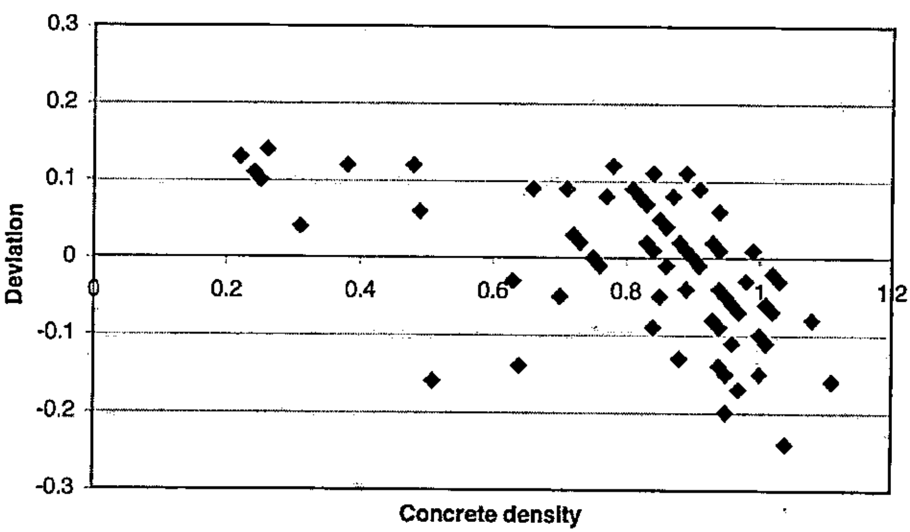


Figure 43. Graphic presentation of concrete density and deviation
Slika 43. Grafički prikaz odstupanja procijenjenog od konkretnog obrasta



CONCLUSIONS
ZAKLJUČCI

Research into estimating stand density and condition with picture histograms and visual interpretation of digital orthophotos was carried out on the example of the management unit "Jamaričko Brdo" in the Lipovac Forest Administration.

Based on the conducted research and the obtained results, the following conclusions may be drawn:

1) A histogram of a stand scene may be used purposefully in evaluating a stand condition and stand density,

2) Stands with normal density are defined with digital value classes 5, 6, 7 and 8, while stands with poor density are defined with classes 9, 10, 11 and 12. Stands with densities from 0.50 to 0.80 cannot be specified with any defined digital value classes,

3) Three basic histogram forms have been constructed which can be associated with adequate density categories,

4) The histograms of stands with normal density are simple, uniform in appearance and have one maximum, in which the largest number of pixels is found in the left part of the histogram closer to the middle of the abscissa.

5) The histograms of stands with densities lower than normal are dual in appearance. Stands in which density is slightly lower than normal have histograms resembling those of stands with normal density, but with a larger number of pixels in the right part of the histogram. Stands in which density is considerably reduced, but not so much as to be poor, have histograms with an incomplete comb-like form.

6) The histograms of stands with poor density have longer or shorter comb-like, easily recognisable forms.

7) The form of histograms of stand scenes corresponds to stand descriptions.

8) Stand descriptions should be informative; in other words, they should interpret and complement dendrometrical data in a descriptive way.

9) There are no statistically significant differences between the estimated and concrete density in the studied example. The calculated correlation coefficient is high (0.91), which indicates firm correlation between the estimated canopy (density) in aerial photographs and concrete density found in the field. It also confirms that canopy may be used as a measure of density.

10) The construction of a digital orthophoto, preferably with a large scale, is recommended for forest management and other forest activities, because it provides the user with a large number of information.

11) This paper illustrates yet another possibility of applying computer technology and remote sensing methods to forestry and to forest management in particular.

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

PROCJENA OBRASTA I STANJA SASTOJINE UPORABOM HISTOGRAMA SLIKE I VIZUALNOM INTERPRETACIJOM DIGITALNOG ORTOFOTA

SAŽETAK

U radu su prikazane mogućnosti primjene histograma sastojinske scene i vizualne interpretacije digitalnog ortofota u procjeni obrasta i stanja sastojine, na primjeru gospodarske jedinice "Jamaričko brdo", šumarije Lipovljani.

U tu svrhu korištene su crno-bijele aerofotosnimke približnog mjerila M ≈ 1: 20 000, sa 60% prijeklopom, pridobivene tijekom cikličkog snimanja Republike Hrvatske.

Prilikom kvantitativnog opisivanja sastojine najčešće korištena veličina je obrast. Obrast je jedan od najznačajnijih i najkorisnijih parametara sastojine, koji šumarskom stručnjaku ukazuje na opće stanje sastojine, dok obrast po vrstama drveća ukazuje na dosadašnje gospodarenje, ali i na buduće propisivanje i provođenje smjernica gospodarenja.

Za svaki odsjek (sastojinu) izrađen je histogram u programu Photoshop 6.0, u kojem je pored vizualne percepcije istog, moguće očitati srednje vrijednosti piksela (mean), standardnu devijaciju (Std Dev) i medijanu (median).

Budući da ljudske oči ne razlikuju svih 256 razina sivog tona, odnosno vrijednosti piksela (0-255), nego samo njih dvadesetak, pikseli su grupirani u 16 klasa, po 16 digitalnih vrijednosti.

Nakon izrađenog histograma, te na osnovi očitane srednje vrijednosti piksela, odsjeku je pridružena odgovarajuća klasa. Također, odsjeci su prethodno grupirani prema kategorijama obrasta: normalni obrast, iznad 0,80; manji od normalnog, od 0,50 do 0,80; slab, do 0,50.

Rezultati provedenog istraživanja ukazuju da postoje tri osnovna oblika histograma koji se mogu pridružiti odgovarajućim kategorijama obrasta, te da isti svrsishodno mogu poslužiti u procjeni obrasta i stanja sastojine. Također, izgledi histograma sastojinskih scena korespondiraju s opisima sastojina.

Sastojine normalnog i slabog obrasta mogu se definirati određenim klasama digitalnih vrijednosti, dok se sastojine obrasta 0,50 do 0,80 ne mogu specificirati određenim klasama digitalnih vrijednosti.

Histogrami sastojina normalnog obrasta su jednostavni, jednoličnog izgleda, s jednim maksimumom, kod koji najveći broj piksela pripada lijevom dijelu histograma, bliže sredini apscise.

Histogrami sastojina čiji su obrasti manji od normalnog, po izgledu su dvojaki. Sastojine kod kojih je obrast tek neznatno manji od normalnog, imaju histograme

slične sastojinama normalnog obrasta, ali s većim brojem piksela u desnom dijelu histograma. Sastojine kod kojih je obrast značajnije smanjen, ali ne u tolikoj mjeri da bi bio slab, imaju histograme nepotpunog češljastog oblika.

Histogrami sastojina slabog obrasta imaju duži ili kraći češljasti, lako prepoznatljiv oblik.

Ujedno izvršena je okularna procjena obrasta na osnovi sklopa sastojine, te je utvrđena čvrsta veza sa konkretnim obrastom, odnosno da se sklop može upotrebljavati kao mjera obrasta.

Prilikom uređivanja šuma i drugih šumarskih radova preporučuje se izrada digitalnog ortofota, jer isti korisniku pruža razmjerno dosta informacija, ali po mogućnosti sa snimkama krupnijeg mjerila.

Ključne riječi: histogram slike, digitalni ortofoto, obrast, sklop, opis sastojine, cikličko snimanje.

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

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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 (Gašperšič, 1985).

Successful management with all commercial, stand and silvicultural forms, the achievement of a stable and productive forest ecosystem, the application of multi-purpose 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.

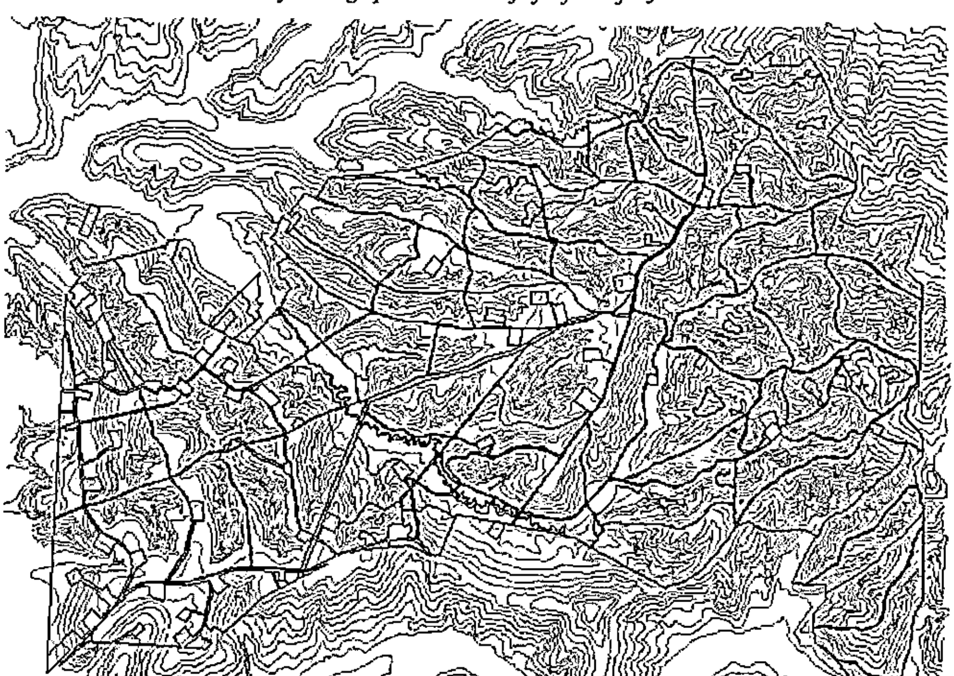
Producing an orthophoto map is a faster and more economical procedure than producing a classical or a digital map. In this case, the user takes over the role of a decoder or interpreter and interprets the shown image from his or her own experience. Such maps are exceptionally suitable for various kinds 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.

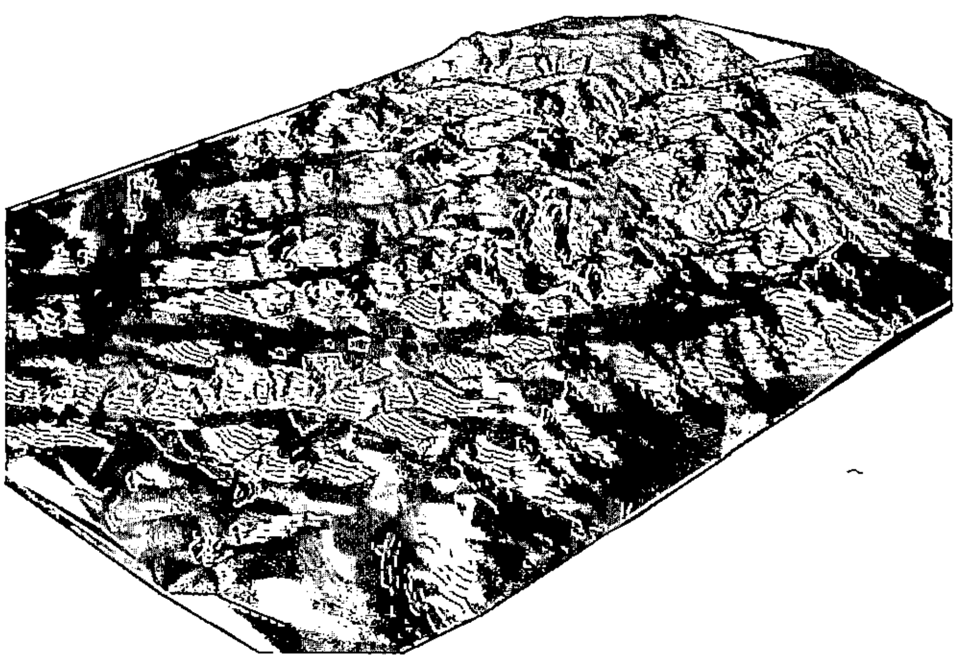
Apart from vectoring contours and external boundaries of the management unit, compartments, subcompartments, roads, trails, gas pipes, facilities, drills and streams were also vectored (Figure 2). After the contours were vectored, they were assigned numerical altitudinal signs (ID).

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

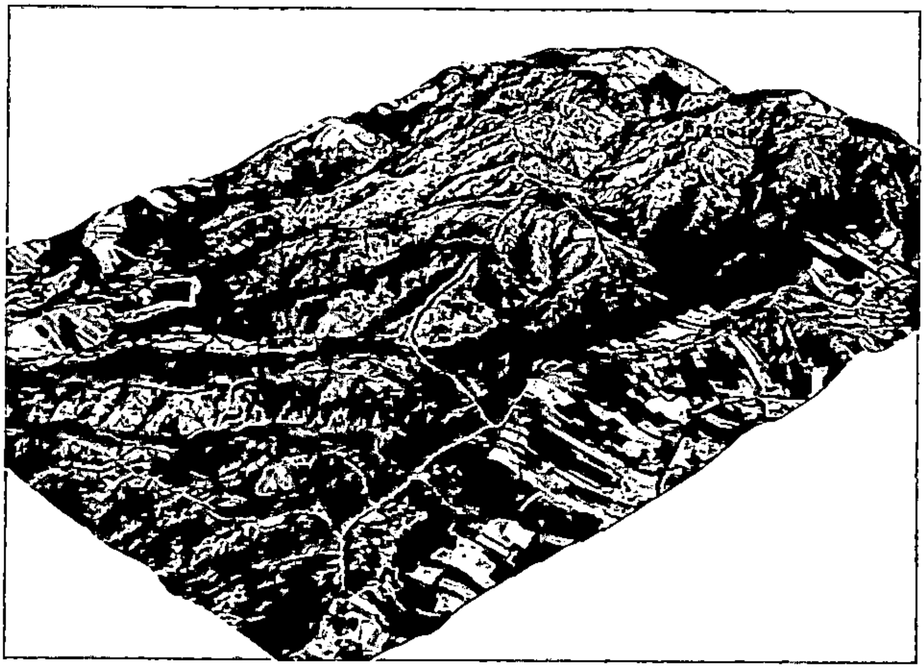
Slika 3. Trodimenzionalni prikaz šireg područja G. j. "Jamaričko brdo", izrađen pomoću z linija (slojnica) i sjenčanjem



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 m³/ha before the age of 25 in the 1st site quality, of pedunculate oak with 12.7 m³/ha as late as the age of 75, and beech with 13.5 m³/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 m³/ha or

382 m³/ha (normal growing stock) x 0.85 (density) = 325 m³/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 (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

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)

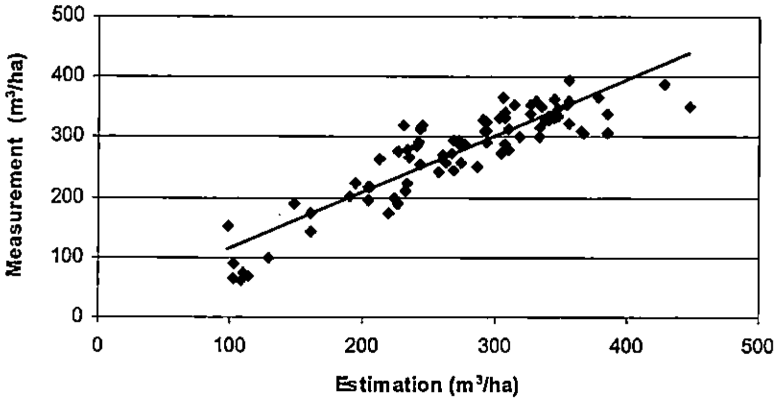
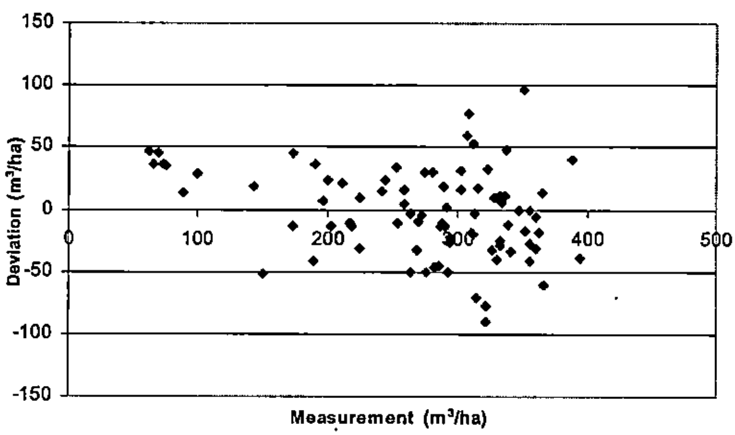


Figure 6. Graphic presentation of the deviation of estimated volume values from measured volume values (1st estimation)

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 (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 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)

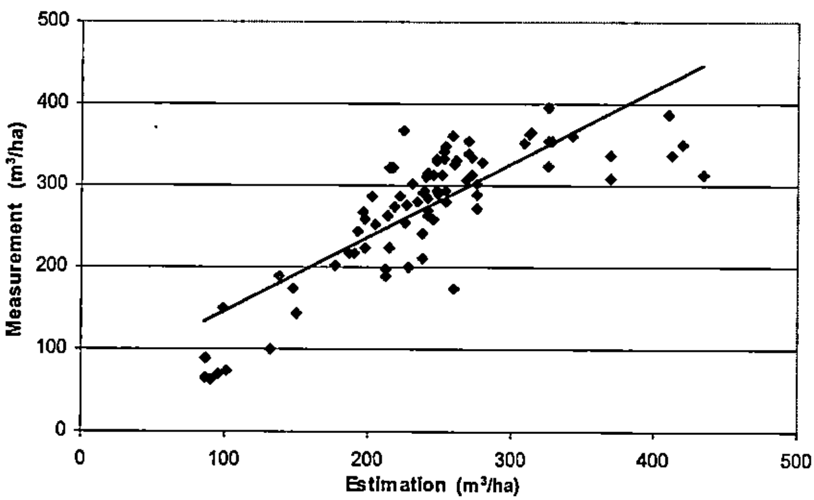
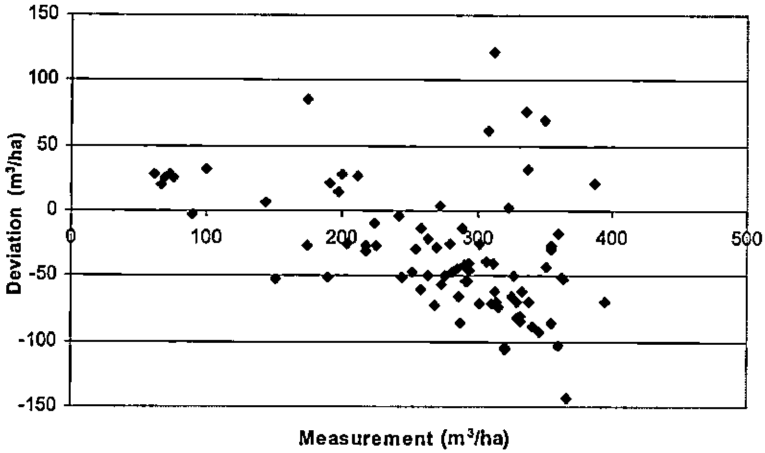


Figure 8. Graphic presentation of the deviation of estimated volume values from measured volume values (2nd estimation)

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



At estimation probability of 95%, we conclude that 241 m³/ha are in the interval from 225 m³/ha to 256 m³/ha. Analogously, starting from 99% probability, the number 241 m³/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)

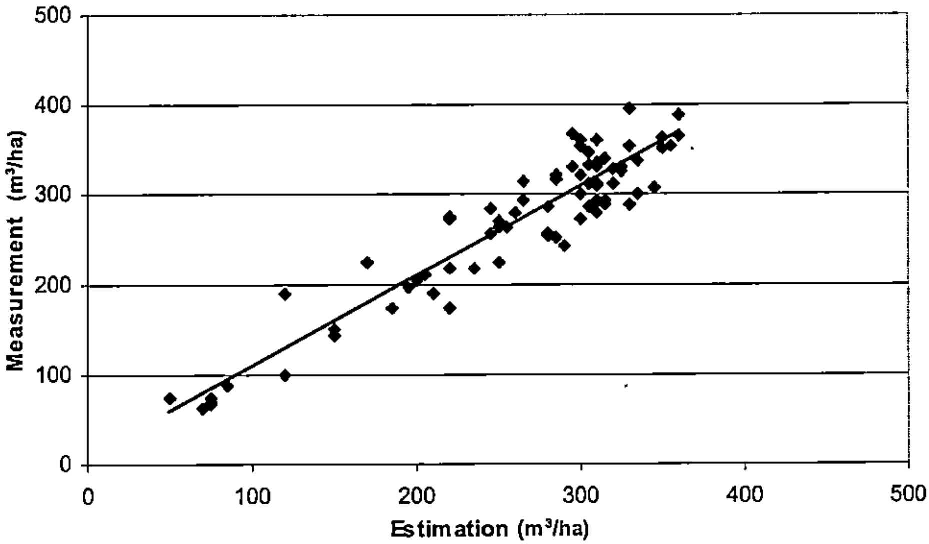
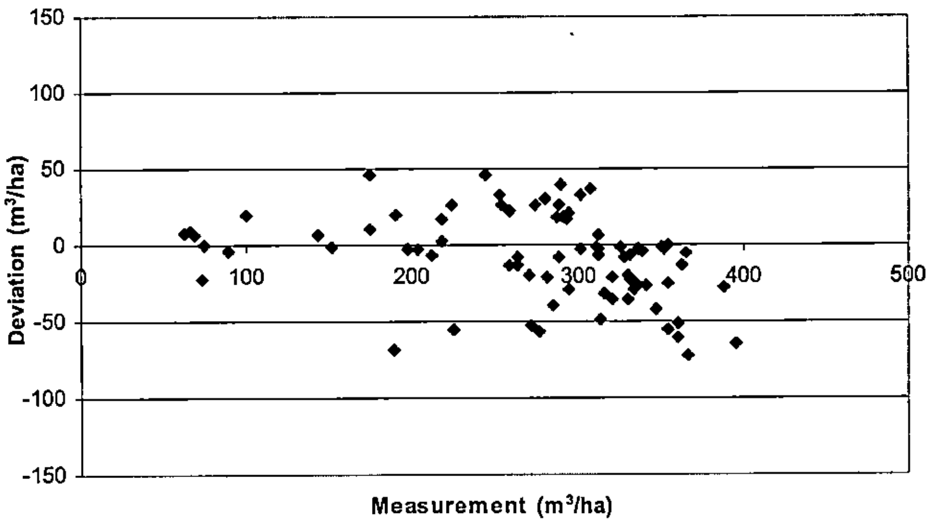


Figure 10. Graphic presentation of the deviation of estimated volume values from measured volume values (3rd estimation)

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)

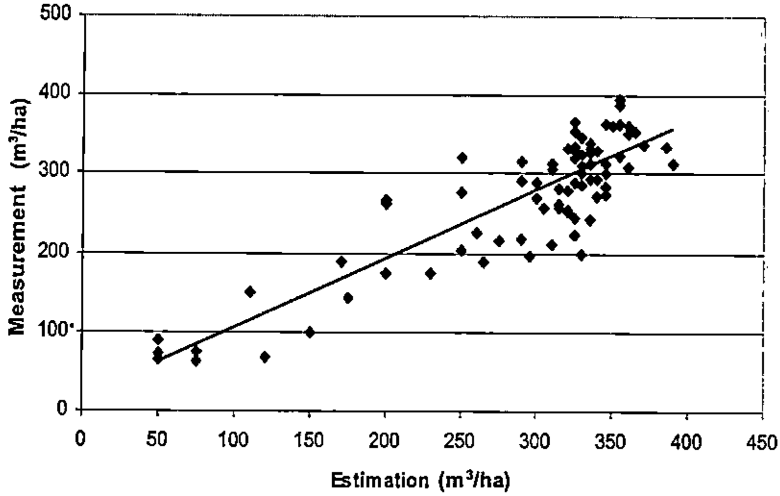
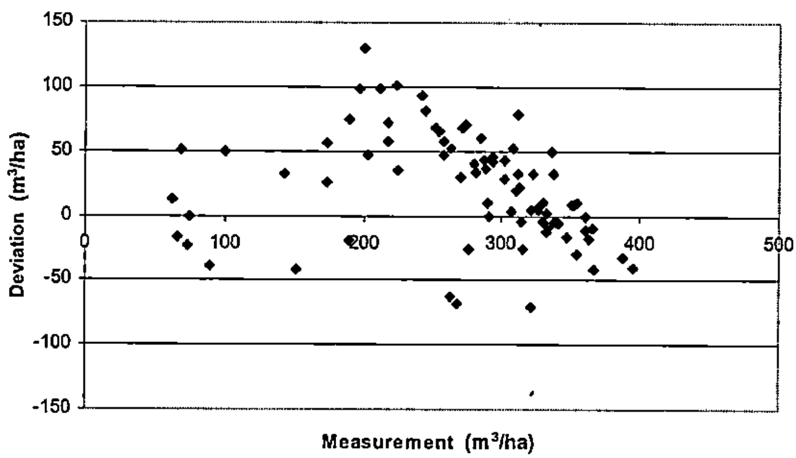


Figure 12. Graphic presentation of the deviation of estimated volume values from measured volume values (4th estimation)

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)

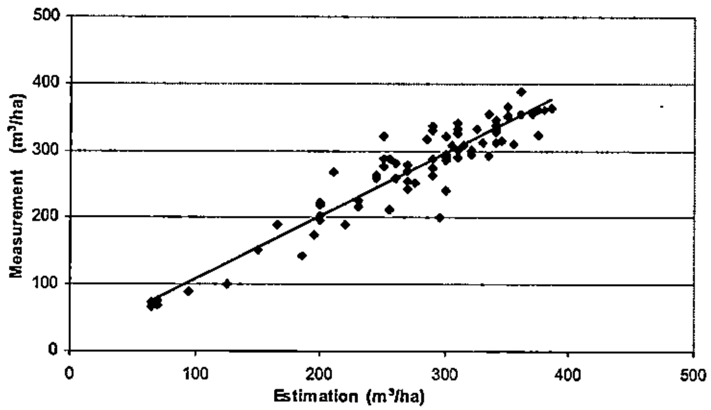
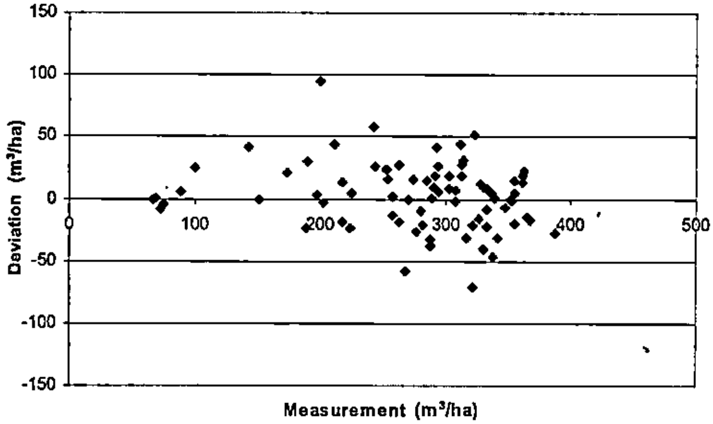


Figure 14. Graphic presentation of the deviation of estimated volume values from measured volume values (5th estimation)

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	m^3	ha	m^3	ha	m^3	ha	m^3	ha	m^3
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.

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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

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EXAMPLES OF REFERENCES:

For periodicals

Arrouays, D., & Pelissier, P., 1994: Modeling carbon storage profiles in temperate forest humic loamy soils of France. Soil Sci. 157(3): 185–192.

Matić, S., 1993: Unapređenje proizvodnje biomase šumskih ekosistema Hrvatske. Glas. šum. pokuse, pos. izd., 4:1–6.

Matić, S., 1972: Prirodno pomlađivanje u zaraženim jelovim sastojinama. Šum. list 11–12(96): 432–441.

For edited symposia, proceedings, special issues, etc.

Hampson, A. M., & Peterken, G. F., 1995: A Network of woodland habitats for Scotland. In: Korpilahti, E., Salonen, T., & Seppo, O. (eds.), Caring for the Forest: Research in a Changing World, International union of forestry research organizations, Tampere, pp. 16–17.

Matić, S., Anić, I., & Oršanić, M., 1996: Prilog poznavanju nekih šumsko-uzgojnih svojstava pionirskih listopadnih vrsta drveća. In: Mayer, B. (ed.), Unapređenje proizvodnje biomase šumskih ekosustava, Šumarski fakultet Sveučilišta u Zagrebu & Šumarski institut, Jastrebarsko, Zagreb, pp. 181–187.

For books

Burschel, P., & Huss, J., 1997: Grundriss des Waldbaus (2nd ed). Parey Buchverlag, Belin, 487 pp.

Rauš, Đ., 1987: Šumarska fitocenologija. Sveučilišna naklada Liber, Zagreb, 313 pp.

For multi-author books

Lammi, J. O., 1994: Professional ethics in forestry. In: Irland L. C. (ed.), Ethics in forestry, Timber press, Portland, pp. 49–58.

Mayer, B., 1996: Hidrološka problematika osobito s gledišta površinskog dijela krovine. In: Klepac, D. (ed.), Hrast lužnjak (*Quercus robur* L.) u Hrvatskoj, Hrvatska akademija znanosti i umjetnosti & "Hrvatske šume", p.o. Zagreb, Zagreb, pp. 55–71.

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