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ZA ŠUMSKE POKUSE

ANNALES
EXPERIMENTIS SILVARUM CULTURAE PROVEHENDIS

38

SVEUČILIŠTE U ZAGREBU
ŠUMARSKI FAKULTET
UNIVERSITAS STUDIORUM ZAGRABIENSIS
FACULTAS FORESTALIS

Glasnik za šumske pokuse

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Original scientific paper
Izvorni znanstveni članak

MORPHOMETRICAL ANALYSIS AND NEEDLE VOLATILES COMPOSITION OF SOME HARD PINE SPECIES AND THEIR HYBRIDS

MORFOMETRIJSKA ANALIZA I SASTAV ETERIČNIH ULJA IGLICA NEKIH VRSTA BOROVA I NJIHOVIH HIBRIDA

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The paper deals with nineteen morphological and anatomical traits of needles and shoots of three pine species (*Pinus nigra* J. F. Arnold, *P. densiflora* Siebold et Zucc. and *P. thunbergiana* Franco) and their four hybrids (F_1 hybrids *P. nigra* × *P. densiflora*; reciprocal hybrids *P. densiflora* × *P. nigra;* F_1 hybrids *P. nigra* × *P. thunbergiana*, and reciprocal hybrids *P. thunbergiana* × *P. nigra*). The analysed traits are as follows: needle length, fascicle sheath length, one-year shoot tracheid length and width, the number of ventral and dorsal stomatal rows, the number of stomata along one row, the number of serrations along one needle margin; needle cross-section area, needle cross-section height and diameter; stellar region cross-section area; stellar region cross-section height; stellar region cross-section diameter; the largest number of hypodermal cell layers on the needle cross-section; the number of medial resin canals on needle cross-section; the largest and the smallest number of sheath cells surrounding a single resin canal.

The possibility to differentiate the hybrids from the parent species was investigated. Based on the analysed traits, with a probability range of between 95% and 100%, it was possible to discriminate F_1 hybrids *P. nigra* × *P. densiflora, P. densiflora* × *P. nigra,* and *P. thunbergiana* × *P. nigra* from the parent species. Hybrids *P. nigra* × *P. thunbergiana* differ significantly from the male parent, the Japanese black pine, but they do not differ from the female parent, the European black pine. The features, by which it is possible to identify the hybrids, were separated by a discriminant analysis.

Chemical analytical methods (gas chromatography and gas chromatography/mass spectrometry) were used to determine, in terms of quality and quantity, the composition of needle volatile of the mentioned species and hybrids. Cluster analysis was used to determine to what degree the individual species and hybrids resemble in terms of the composition of the needle volatile. The Japanese black pine and its hybrids (*P. nigra* × *P. thunbergiana* and *P. thunbergiana* × *P. nigra*) differ greatly from other species and hybrids. The second unit consists of two groups. The first is composed of the European black pine and the hybrids *P. nigra* × *P. densiflora*. The second group consists of the Japanese red pine and the hybrids *P. densiflora* × *P. nigra*.

The proportion of α-pinene is the largest of all components in the needle volatile of all analysed species and hybrids (between 25.8% in *P. densiflora* and 42.7% in *P. nigra*), except for the Japanese black pine in which the largest proportion is that of β-pinene (34.1%).

The component which is specific of the European black pine is germacrene D, the one specific of the Japanese red pine is thunbergol, while β-pinene is specific of the Japanese black pine.

In F_1 hybrids the proportion of the individual components is larger, smaller or mostly intermediary between the respective proportions of the parent species. The following are the components whose proportions in all analysed F_1 hybrids are intermediary between the respective proportions of the parent species: α-pinene, β-bourbonene, β-caryophyllene, germacrene D and α-muurolene. These components could be used for the verification of F_1 hybrid plants.

Key words: *Pinus nigra* J. F. Arnold, *P. densiflora* Siebold et Zucc., *P. thunbergiana* Franco, interspecific hybrids, needle morphology, needle anatomy, shoot tracheids, discriminant analysis, volatiles, GC, GC/MS, terpenes, cluster analysis

INTRODUCTION
UVOD

Four pine species, the European black pine (*Pinus nigra* J. F. Arnold), Scots pine (*P. sylvestris* L.), the Japanese red pine (*P. densiflora* Siebold et Zucc.) and the Japanese black pine (*P. thunbergiana* Franco), were used at the Department of Forest Genetics and Dendrology of the Faculty of Forestry, The University of Zagreb, in the period from 1958 until 1991, for the production of the hybrids of F_1 generation, F_2 generation, back-cross hybrids and trispecies hybrids. The research was financed through the collaboration with the U.S. Department of Agriculture. The research results were published in many articles and annual reports as well as in the final reports of the following four projects:

1. The influence of irradiation of pollen on the physiology of growth, 1967-1972;
2. The effect of micro-environment on species incompatibility in hard pines, 1974-1977;
3. The factors of incompatibility between the European black pine and Scots pine and the possibilities of mass production of their hybrids, 1980-1985;
4. Improvement of forest trees, 1986-1991.

The production and evaluation of these plants is a long-term process requiring controlled hybridisation on trees, a two-year development of cones, sowing of seeds with nursery growing of plants, and establishing of test plots. A large number of the produced hybrid plants were planted on fourteen test plots in the areas of Đurđevački peski and the Lisičine Arboretum.

The research continued within the project "The Breeding of Conifers", which was sponsored by the Ministry of Science and Technology of the Republic of Croatia and conducted by Professor Želimir Borzan. The research was carried out as two projects, both financed by the Ministry of Science and Technology and the Croatian Forests Enterprise: "Hybrids of four pine species and their determination" and "Variability research in various families of interspecific hard pine hybrids".

The growth and development of the hybrid plants in relation to both control plants of pure species and other hybrid combinations have been continually monitored since the establishment of the test plots. Different morphometrical investigations have also been conducted.

This research is a contribution to the evaluation of the hybrid plants produced under control, in terms of the resemblances with the original species displayed by the individual hybrid combinations. Analyses of the needle volatiles of these species and hybrids were also done.

F_1 HYBRIDS *PINUS NIGRA* × *P. DENSIFLORA* (= *NIDE*) AND RECIPROCAL HYBRIDS *P. DENSIFLORA* × *P. NIGRA* (= *DENI*)
F_1 HIBRIDI *PINUS NIGRA* × *P. DENSIFLORA* (= *NIDE*) I RECIPROČNI HIBRIDI *P. DENSIFLORA* × *P. NIGRA* (= *DENI*)

The hybrid *P. nigra* × *P. densiflora* was first produced by Blakeslee in 1914 (Johnson 1939). This hybrid was later produced and described by Wright & Gabriel (1958), Wright (1962), Wright *et al.* (1970), Vidaković (1963, 1966), Vidaković *et al.* (1973). F_1 hybrids between the black and the Japanese red pine often blossom at the age of two or three years. Related to their parents, they are intermediary in terms of length and width of needles, the arrangement of stomata, the location of resin canals and the shape and colour of buds. As to other investigated anatomical traits (height of needle cross-section, number of hypodermal layers and number of sheath cells above the phloem) the hybrids were closer to one of the parents (Vidaković 1966). While young, they grew faster than the black pine and slower than the Japanese red pine (Vidaković 1974). They tolerated well transplantation and were resistant to *Scirrhia acicola*, syn. *Dothistroma pini* (Vidaković *et al.* 1973). When growing one next to the other, these two species often breed spontaneously (Wrigth *et al.* 1970).

When young the hybrids *P. densiflora* × *P. nigra* grew slower than the reciprocal hybrids, and are also more difficult to produce (Vidaković 1974).

The morphometrical needle analysis of these hybrids was conducted by Idžojtić (1996, 1997). The analysis of growth on test plots of twelve-year old plants was done by Borzan *et al.* (1995) and Idžojtić (1996). The respective survival percentages of the hybrids *nide, deni*, the black pine and the Japanese red pine were 67%, 57%, 24% and 59%. The largest average diameter was 15.4 cm (*nide)*; the respective average diameters of the Japanese red pine, the hybrid *deni* and the black pine were 13.4 cm, 12.1 cm and 9.3 cm.

F_1 HYBRIDS *PINUS NIGRA* × *P. THUNBERGIANA* (= *NITH*) AND RECIPROCAL HYBRIDS *P. THUNBERGIANA* × *P. NIGRA* (= *THNI*)
F_1 HIBRIDI *PINUS NIGRA* × *P. THUNBERGIANA* (= *NITH*) I RECIPROČNI HIBRIDI *P. THUNBERGIANA* × *P. NIGRA* (= *THNI*)

Successful breeding of the European and the Japanese black pine was reported by Wright & Gabriel (1958). The hybrid differed from its female parent, the European black pine, in needles and in its faster growth under nursery conditions.

Reciprocal breeding between the Japanese black pine and the European black pine was also reported by Wright & Gabriel (1958) and Wright (1962). Young plants in a nursery could be discriminated easily from both parents, and they had a small heterotic effect.

It took many years to produce different breeding combinations of two-needle pines at the Department of Forest Genetics and Dendrology of the Faculty of Forestry, University of Zagreb. The results include hybrids of the European and the Japanese black pine, and reciprocal hybrids. Borzan *et al.* (1995) and Idžojtić (1996) analysed the growth of fifteen-year old plants on test plots. The survival of the *nith* hybrids was 100%, while the respective survival percentages of *thni*, the European black pine and the Japanese black pine were 85%, 60% and 50%. The average diameters of the hybrids and the Japanese black pine were nearly the same, or considerably larger, than the diameter of the European black pine (*nith* 11.8 cm; *thni* 11.9 cm; *th* 11.7 cm; *ni* 7.8 cm).

ESSENTIAL OILS
ETERIČNA ULJA

Essential oils are volatile and odorous liquids, hydrocarbon mixtures of different composition. Contained by organs of many plants, they synthesize primarily in plastids. Transparent and colourless, essential oils darken when exposed to air; they dissolve in organic solvents, plant and animal oils and fats, and they do not mix with water. They can be of different composition. More than five hundred compounds can be separated from them (Kramer & Kozlowski 1960). Characteristic constituents of essential oils are terpenes.

More than one thousand of known different essential oils are obtained by distillation, pressing or extraction.

Balms are semi-liquid, while resins are dense or hard mixtures of essential oils (distillable) and resin acids (non-distillable), and of other substances (Denffer & Ziegler, Dell & McComb 1979).

For chemical processing, the only significant essential oils are those obtained from conifers, mainly from their needles. Pine needles contain between 0.4% and 0.5% essential oils, which are obtained by water vapour distillation. Essential oils containing esthers are particularly sweet-smelling and are used in the production of soap, perfumes, disinfectants, medicine and food industry.

Unlike fats, essential oils do not serve as food supply of plants, but are a secondary product of metabolism with undetermined metabolical role. Since many essential oils are volatile, they are continuously lost from trees through evaporation.

Conifers (*Coniferae*) contain essential oils and resins in all parts of the plant. The *Pinales* order with six hundred species is today the most significant group of gymnosperms. A large number of these species are important for the production of timber. Another economically important role is the production of resins and essential oils. Commercially significant essential oils are obtained from the species of the *Cupresaceae* family which, unlike the

TERPENES
TERPENI

Terpenes are widely spread in nature, above all in plants as components of resins and essential oils. Many terpenes are hydrocarbons, though some of them - alcohols, aldehydes and ketones - also contain oxygen. Their basic unit is the unsaturated hydrocarbon isoprene: CH_2-$C(CH_3)$-CH-CH_2. The common formula of terpene hydrocarbons is $(C_5H_8)_n$. Table 1 shows the division of terpenes per number of isoprene units. By some authors, only hydrocarbons are considered terpenes. In terms of all components, these authors name them terpenoids; however, the term terpene is also generally used with all components (Norin 1964).

Table 1. Compound-classes of terpenes
Tablica 1. Podjela terpena

Compound-class *Vrsta terpena*	No. of Isoprene Units *Broj jedinica izoprena*	Example *Primjer*
Monoterpene	2	pinene, camphor, menthol
Sesquiterpene	3	nerolidol, farnesol
Diterpene	4	vitamin A_1
Triterpene	6	squalene
Tetraterpene	8	caroten

The terpenes in conifers are component parts of the following: the essential oils in the needles (Zavarin 1970, von Rudloff 1975); the resins in the bark (Squillace 1977b, Meier & Goggans 1978) and the wood (Bannister *et al.* 1962; Franklin 1976; Green *et al.* 1974, 1975; Strauss & Critchfield 1982). Each of the sources is an independent system, which means that the resin canals of different plant organs are not interconnected (von Rudloff 1975). The composition of terpenes from needles or bark is in most cases similar (Squillace 1977b, Schiller & Grunwald 1987a).

Since 1950, chemical methods have been used in taxonomy. Mirov (1961) wrote that terpenes can be useful in differentiating many pine species. Although each species does not have a specific terpene composition, the knowledge about this composition may contribute to the understanding of geographic distribution and evolutionary history of pines. The same author wrote that the composition of terpenes and the taxonomy of the species of genus *Pinus* often coincide.

Among the authors who wrote about the analyses of terpenes and the use of gas chromatography in taxonomic research on pines were Zavarin (1968) and Turner & Flake (1974). Research on plant resins was at first motivated by commercial significance of these resins in some species such as *Pinus elliottii* (Roberts *et al.* 1982). The analysis of terpene composition as research technique became possible with the development of gas chromatography which exactly determines the composition of microgram sample quantities (Simpson 1970, Squillace 1976). The following are some of the written studies important for understanding the analysis of terpene composition: Lever & Burley (1974), von Rudloff (1975), Squillace (1976), Seal *et al.* (1977), Rudin (1979), Burley & Lockhart (1985), Birks & Kanowski (1988, 1993).

Of all plants, conifers produce the largest quantities of terpene. The biosynthesis of terpenes was investigated by Zavarin (1970), Gleizes *et al.* (1980), Bernard - Dagan (1988), Vögeli & Chappell (1990), Lewinsohn *et al.* (1991), Salin *et al.* (1995) and Socaciu *et al.* (1995). Research into the terpene metabolism was conducted by McGarvey & Croteau (1995), Chappell (1995) and others.

Terpene composition analysis is used in chemical taxonomy and in the research on geographic variability. The following are examples of such research on different pine species: *Pinus nigra* - Thorin & Nommik (1974), Gerber *et al.* (1995), Chalchat & Gorunović (1995a, b); *P. pinaster* - Baradat *et al.* (1978); *P. halepensis* Schiller & Grunwald (1987b) and Baradat *et al.* (1995); *P. brutia* - Schiller & Grunwald (1987a) and Schiller & Genzi (1993); *P. mugo* - Prinz (1990).

Of American pine species, the composition of essential oils and resins and the variability of this composition were investigated for the following species: *P. elliottii* (Gansel & Squillace 1976 and Squillace *et al.* 1980a); *P. taeda* (Rockwood 1973 and McRae & Thor 1982); *P. ponderosa* (Smith 1964, 1977, Zavarin & 1970, Adams & Edmunds 1989 and von Rudloff & Lapp 1991); *P. cembroides* (Zavarin & Snajberk 1985); *P. monophylla* (Smith & Preister 1988); *P. contorta* (Forrest 1977, 1987, von Rudloff & Nyland 1979, von Rudloff *et al.* 1985 and von Rudloff & Lapp 1987), *P. albicaulis* (Zavarin *et al.* 1991); *P. radiata* (Cool & Zavarin 1992); *P. monticola* (Townsend *et al.* 1972 and Zavarin *et al.* 1990); *P. strobus* and *P. monticola* (Hunt *et al.* 1990), and for the Central American pine species (Green *et al.* 1974, 1975, Burley & Green 1977, 1979 and Lockhart 1990a, b).

The variability of terpene composition of common pine (*P. sylvestris*), considering its wide distribution and significance, has been thoroughly investigated. Research on this was carried out by the following: Tobolski & Hanover (1971); Juvonen (1970a, b); Juvonen & Hiltunen (1972); Thorin & Nommik (1974), Hiltunen *et al.* (1975a), Hiltunen (1976); Forrest

(1980); Chalchat *et al.* (1985); Yazdani *et al.* (1985); Muona *et al.* (1986); Yazdani & Nilsson (1986); Raitio (1990); Nerg *et al.* (1994); Orav *et al.* (1996) and others.

In order to establish the possibility of using terpene composition in different types of genetic research, it was necessary to investigate the degree of genetic control, i.e. the degree of inheritance of terpene composition. Such research was done for the following species: *P. sylvestris* (Hiltunen 1975, 1976, Hiltunen *et al.* 1975b, Yazdani *et al.* 1982, Baradat & Yazdani 1988, Pohjola *et al.* 1989 and Yazdani & Leberton 1991); *P. monticola* (Hanover 1966a, b); *P. contorta* (White 1984 and White & Nilsson 1984); Hybrids *P. attenuata* × *P. radiata* (Strauss & Critchfield 1982); *P. elliottii* (Squillace 1971, 1977a, b and Squillace & Fisher 1966); *P. virginiana* (Meier & Goggans 1978); *P. taeda* (Squillace *at al.* 1980b and Squillace & 1986) and *P. banksina* (Lapp & von Rudloff 1982).

The relation between the terpene composition and the resistance to fungi was investigated by Peterson & Read (1971), de Groot (1972), Risbeth (1972), Schuck (1982), Michelozzi *et al.* (1990), Himejima *et al.* (1992), and others. The link between terpene composition and resistance to insects was also investigated (Anderson & Fisher 1960, Hanover 1975, Annila & Hiltunen 1977, Wilkinson 1980, Alfaro *et al.* 1980, 1981, Harris *et al.* 1983, Reed *et al.* 1986, Brooks *et al.* 1987a, Delorme & Lieutier 1990).

Besides pines, terpene composition of other conifers has also been investigated. Such research with firs was conducted by Smedman *et al.* (1969), Lee *et al.* (1974), von Rudloff & Grant (1982), Paule *et al.* (1988), Fady *et al.* (1992), Lang (1992, 1994) and Fady (1995). The composition of the terpene from the resin of the shoots of the European and the Japanese larch was investigated by Lang (1989). The research on the composition of the monoterpenes in the bark resin of Norway spruce was conducted by Esteban *et al.* (1976), while the composition of the needle volatile terpene of the same species was investigated by Schönwitz *et al.* (1990) and Orav *et al.* (1996). Terpene composition in the needle essential oils of the Douglas-fir was analysed by von Rudloff & Rehfeldt (1980). Geographic variability of the composition of monoterpenes in the leaves of Californian redwood was investigated by Hall & Langenheim (1987). The composition of essential oils in the leaves of giant arborvitae was analysed by Rudloff *et al.* (1988). The composition of essential oils and resin of some cypress species was investigated by Zavarin *et al.* (1971), Senter *et al.* (1975) and Schiller (1990).

Besides the identification of hybrids through morphological and anatomical traits, it is possible to use the analysis of terpene composition. Gallis & Panetsos (1997) investigated the possibility of differentiating the species *Pinus brutia* and *P. halepensis*, and their F_1, F_2 and the back-cross hybrids governed by the composition of terpene in the bark resin. There was no quality difference, but the differences in terms of quantity in several significant terpenes can be used in differentiating the species and their hybrids.

The concentration of monoterpenes in the air of coniferous forests was investigated by Evans *et al.* (1982), Yokouchi *et al.* (1983), Isidorov *et al.* (1985), Jutner (1986) and Petersson (1988).

MATERIAL
MATERIJAL

The samples for analysis were one-year old, fully developed shoots with needles, collected in late October 1996. The pine trees from which samples were taken grew in Đurđevački peski (four plots) and in the Arboretum Lisičine (five plots), while the parent trees grew in the area of the Faculty of Forestry in Zagreb. Two one-year old shoots were taken from each tree.

The samples were taken from three pine species (*P. nigra*, *P. densiflora* and *P. thunbergiana*) and four combinations of their hybrids (*P. nigra* × *P. densiflora*, *P. densiflora* × *P. nigra*, *P. nigra* × *P. thunbergiana* and *P. thunbergiana* × *P. nigra*). For each group (species and hybrid combinations respectively), the samples were taken from the largest possible number of different trees. Since this possible number of trees differed, the size of the samples differed as well. For the analysis of the European black pine, the shoots were taken from 41 trees; the shoots from forty trees were taken for the analysis of the Japanese red pine, and the shoots from nine trees for the Japanese black pine. The analysis of F_1 hybrid *nide* required samples from 29 trees; the analysis of *deni* required the samples from 10 trees, the *nith* analysis used samples from 15 trees, while the *thni* analysis had samples from 5 trees.

One-year old shoots and needles were used for the morphological and anatomical analysis. The shoots were stored in a biological chamber at 4 °C.

Essential oils were obtained from fresh needles of each of the species and hybrids by five-hour long water vapour distillation. For each species and hybrid, between 10 g and 25 g of cut up needles were distilled with the Karlsruher device (Stahl 1953). The essential oils were stored in 1.0 ml n-pentene and used in further analyses.

THE ANALYZED MORPHOLOGICAL AND ANATOMICAL TRAITS
ANALIZIRANA MORFOLOŠKA I ANATOMSKA OBILJEŽJA

To distinguish hybrids from the parent species, it is necessary to use a combination of several diagnostic characteristic. By means of analysis, the traits, by which the given groups are best distinguished, are separated from the largest possible number of traits. Kriebel (1962) wrote that every hybrid has a different combination of traits by which it is best discriminated, i.e. that once a combination of traits of one interspecific hybrid has been established, it cannot be applied to the hybrids of other pine species.

This paper deals with the following nineteen traits of needles and shoots:

1. *LI* = needle length, in cm, with an accuracy of 0.1 cm. Needles were photocopied, the photocopies were scanned and the needle length was measured by computer, using the Optimas 5.2 program package.
2. *LR* = fascicle sheath length, in cm, with an accuracy of 0.1 cm. Fascicle sheath length was measured in the same way as needle length.
3. *LT* = the wood of the shoot was macerated by cooking for 1-2 minutes in a

10% HNO_3 (according to GERLACH, 1969). The tracheids were then separated and permanent slides were mounted. Tracheid length was measured by Zeiss Axioscope connected to a computer with a video camera, in the *Optimas 5.2* program package.

4. *DT* = one-year shoot tracheid width, in μm, with an accuracy of 0.1 μm. The tracheid width was measured in the middle of the tracheid; the measuring was done in the same way as for the tracheid length.
5. *NPPU* = the number of ventral stomatal rows in the middle of the needle length.
6. *NPPV* = the number of dorsal stomatal rows in the middle of the needle length. The stomatal rows were counted under a binocular magnifying glass with a magnification of 64x.
7. *NP/cm* = the number of stomata along one stomatal row on the inner side of the needle, on a 1 cm-long segment in the centre of the needle (0.5 cm on both sides from the centre of the needle). The stomata were counted under a binocular magnifying glass with a magnification of 64×. An attempt was made to choose the central row. However, if the central stomatal row was interrupted, the closest uninterrupted stomatal row was chosen for the purpose of measuring.

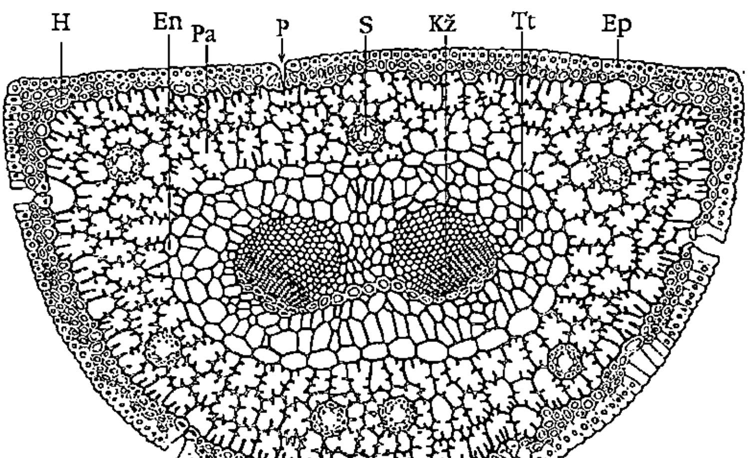

Figure 1. The European black pine needle cross-section. H = hypodermis, En = endodermis, Pa = assimilation parenchyma, P = stoma, S = resin canal, Kž = collateral vessel, Tt = transfusion tissue, Ep = epidermis (according to Denffer & Ziegler 1982)

Slika 1. Poprečni presjek iglice europskoga crnoga bora. H = hipoderma, En = endoderma, Pa = asimilacijski parenhim, P = puć, S = smolenica, Kž = kolateralna žila, Tt = transfuzijsko tkivo, Ep = epiderma (prema Denffer & Ziegler 1982)

8. *NZ/cm* = the number of serrations along one needle margin on a 1 cm-long segment in the centre of the needle (0.5 cm on both sides from the centre of the needle). The serrations were counted under a binocular magnifying glass with a magnification of 64x.
9. *PPP* = needle cross-section area, accuracy 1 μm^2. The traits 9-14 were measured on the cross-section, taken from the middle of the needle length. Permanent cross-section slides were mounted (according to GERLACH, 1969). The needle cross-section and the stellar region cross-section (traits 9-4) were measured by Zeiss Axioscope, connected to a computer with a video camera in the *Optimas 5.2* program package.
10. *HPP* = needle cross-section height, accuracy 1 µm.
11. *DPP* = needle cross-section diameter, accuracy 1 µm.
12. *PCC* = stellar region cross-section area, accuracy 1 μm^2.
13. *HCC* = stellar region cross-section height, accuracy 1 µm.
14. *DCC* = stellar region cross-section diameter, accuracy 1 µm.
15. *NHmax* = the largest number of hypodermal cell layers on the cross-section in the middle of the needle. Hypodermal cell layers were counted on the needle cross-section slides. As the number of these layers varies inside a cross-section, the largest number of layers occurring on one cross-section was recorded.
16. *NSKM* = the number of medial resin canals on the cross-section in the middle of the needle. Resin canals were counted on the needle cross-section slides.
17. *NSKH* = the number of external resin canals on the cross-section in the middle of the needle. The external and medial resin canals were counted on the same needle cross-section slides, that is both traits were recorded for each slide.
18. *NSmax* = the largest number of sheath cells surrounding a single resin canal on the cross-section in the middle of the needle. The cells were counted on the needle cross-section slides. On each cross-section, several resin canals are seen. The size of these canals as well as the number of the surrounding cells vary. On each cross-section the largest and the smallest number of sheath cells surrounding a single canal were recorded (*NSmax* and *NSmin*).
19. *NSmin* = the smallest number of sheath cells surrounding a single resin canal on the cross-section in the middle of the needle.

DISCRIMINANT ANALYSIS
DISKRIMINACIJSKA ANALIZA

The discriminant analysis is one of the statistical analyses which include several variables. Computer has simplified their application. The discriminant analysis is firstly used for finding the variables, by which the previously defined groups may be best discriminated and, secondly, for the classification of new samples into these groups. The result of the analysis are discrimination and classification functions. Though almost at the same time, the discrimination function was independently developed by Mahalanobis (1930), Hotelling (1931) and Fisher (1936).

The theory of discriminant analysis is very complex and comprehensive (Rao 1952, Snedecor & Cochran 1971, Sneath & Sokal 1973, Falkenhagen & Nash 1978, Sokal & Rohlf 1981, Mardia *et. al.* 1982, Kachigan 1991) and will not be explained in this paper.

The basic postulate is that, if the arithmetic means of the variables of different groups differ significantly, a given variable can than be used for the discrimination of these groups, i.e. for the evaluation of the classification of a new sample into one of these groups.

The first example of using a discriminant function with forest trees was the division of two forms of black locust (Hopp 1941).

Clifford & Binet (1954) further developed the discriminant theory for the purpose of classification of the members of the hybrid cluster between two eucalyptus species.

A stepwise discrimination analysis was used for the research into the morphology of pine hybrids (Mergen & Furnival 1960). Besides the description of different morphological characteristics of hybrids and their comparison with the same characteristics of the parent species, Mergen and Furnival wanted to establish which respective characteristics enabled the best discrimination between the hybrids and the parent species. The discriminant analysis was applied in order to find out by which characteristics are the species *P. thunbergiana* and *P. densiflora* distinguished in the best way, then, which are the characteristics that make their F_1 hybrids better than their parents' average, and by which characteristics are these hybrids intermediary. The analysis icluded several traits of outer appearance of the trees, the needles, the top buds and the timber. The traits by which the Japanese black pine is distinguished from the Japanese red pine were the colour of buds, the appearance of bud scales and the number of the serrations along the needle margin. In terms of height and diameter, the hybrids were better than the average of both parents, while the intermediation related to the parent species was best illustrated by the colour of buds.

A similar analysis was applied by Mergen *et al.* (1966) in the differentiation of the saplings and young plants of F_1 hybrids of two eucalyptus species (*Eucalyptus cinerea* × *E. maculosa*), both between the parent species and between these two species.

For distinguishing the provenances *P. taeda* and *P. echinata* as well as these two species from one another, Wells *et al.* (1977) included six needle traits into the discriminant analysis: needle length, needle width, the number of serrations, the number of stomatal rows, the number of stomata along one stomatal row, and the number of resin canals. The two species are mostly distinguished by needle length, although all other traits considerably contribute to their differentiation.

For distinguishing nine different hybrids between four three-needle pine species (*P. palustris, P. elliottii* var. *elliottii, P. taeda* and *P. echinata*), Snyder & Hamaker (1978) analysed nine morphological and anatomical traits of the needles of four-year old plants. Using discriminant analysis, different traits of four different breeding combinations were separated. For example, for *P. palustris* × *P. elliottii* var. *elliottii*, fascicle sheath length, needle length and the number of stomatal rows were separated, while the number of stomata per length unit, needle diameter and the percentage of resin canals touching the endoderm were all separated for *P. echinata* × *P. elliottii* var. *elliottii*.

By using different analyses with several variables, including the discriminant analysis, Calmasii *et al.* (1988) separated the following four traits by which the mutual discrimination of fourteen populations from different natural ranges of *P. brutia* would be possible: total number of stomata, the number of stomata per length unit, needle width, and the number of hypoderm cell layers.

Besides distinguishing formerly determined groups, discriminant analysis is also used in the classification of new samples into one of the groups. Governed by characteristic forms of branches, leaves and fruits, Solomon & Kenlan (1982) applied discrimination analysis to classify the interspecific and cross-specific hybrids of three birch species, *Betula alleghaniensis, B. papyrifera* and *B. populifolia.*

The mathematical problem of discrimination analysis in terms of choosing the variables whose arithmetic means significantly differs among the groups, can be taken as the problem of variance analysis. If there is only one variable, the calculation is analogous to the single variance analysis (ANOVA - analysis of variance). However, in order to see which of the variables, and to what degree, contributes to the differentiation of the groups, this research, as is usually the case with any other research, includes several variables. Thus, the procedure is analogous to the variance analysis with several variables (MANOVA - multivariate analysis of variance). Although the calculation with several variables is much more complex, the basic principle remains the same: the search for the variables that differ from one another between the groups, which is evident in the differences between the arithmetic means.

If the research involves several variables, those variables that are significant for the discrimination of the groups are analytically separated, and we say that these variables are included into the "model". In this study, the distinguishing of groups (species and breeding combinations respectively) is governed by nineteen variables, while the model includes a different number, since two separate analyses are done. The proportion of how much each of the variables contributes to group differentiation is expressed mathematically.

A case involving two groups mathematically coincides with regression analysis, while a case with several groups is solved by cananonical analysis (Namkoong 1967, Burley & Burrows 1972). It is the result of several discriminant functions and canonical roots respectively. They are independent, successive functions, and their contributions to group differentiation do not coincide. The first function expresses the largest group discrimination. It is followed by the second function, etc. The maximum number of functions equals the number of groups minus one, or a number of variables in the analysis, depending on which number is smaller. The functions are linear and of the following type:

$$a + b_1 x_1 + b_2 x_2 + ... + b_m x_m$$

$$a = \text{constant}$$

$$b_1 - b_m = \text{standardised coefficients}$$

$$x_1 - x_m = \text{dependent variables}$$

The bigger the standardised coefficient (according to its absolute value), the bigger is the contribution of the relating variable to the group discrimination by the specified discrimination function. However, these coefficients do not tell us which groups differ from one another. This can be established for each discriminant function through the arithmetic means of the functions, for every group in turns. It is tested which discriminant functions significantly contribute to group differentiation, and only these functions are included in the interpretation, while others are ignored.

Another important application of the discriminant analysis is the classification of new samples into the existing groups. With the model completed and the discriminant functions made, the issue is, how well can be estimated to which of the groups the new sample belongs. For the sake of classification, a classification function for each group is made. The required characteristics of the new sample are measured; for the function, these characteristics are variables. The measured variables are classified into each of the classification functions, while the sample itself belongs, with the highest probability, to the group where the classification result is the highest.

The discriminant analysis in this research was applied in order to establish which of the given groups (species and their hybrids respectively) are best distinguished on the basis of the combinations of nineteen analysed characteristics. A possibility of classifying new samples into given groups was also presented.

As an illustration of using this analysis for distinguishing pine species and their hybrids (*P. nigra*, *P. sylvestris*, *P. densiflora*, F_1 *nisy*, F_2 *nisy*, F_1 *nide*, F_1 *deni* and F_1 *desy*), Idžojtić (1996, 1997) analysed three morphological characteristics (needles length, number of serrations, number of stomata). Only these characteristics did not suffice for hybrid determination; it was emphasised that for the separation of the best combination of characteristics it was necessary to investigate a larger number of anatomic and morphological traits, which was done in this research. Borzan & Idžojtić (1996) increased the number of analysed characteristics for hybrids F_1 and F_2 *nisy* from three to five (needle length, number of serrations, number of stomata, tree diameter and tree height). The determination accuracy of hybrids F_1 and F_2 was increased from 53% to 66% and from 88% to 98% respectively. This proved the fact that the increase in the number of analysed characteristics increases the accuracy of determination.

GAS CHROMATOGRAPHY
PLINSKA KROMATOGRAFIJA

Gas chromatography is an instrumental chemical method used in separating and analysing chemical mixtures and for identification of simple and complex chemical compounds. Requiring just a small quantity of samples, it is used in both quality and quantity analysis. This method enables analyses of chemically very similar compounds and of those that cannot be analysed with other chemical methods. Gas chromatography is today frequently applied because of its high precision and a relatively simple use. Thus, it may determine the composition of volatiles and resins (von Rudloff 1975). A detailed illustration of this method and its theoretical base can be found in literature, e.g. Deur - Šiftar (1973), Schomburg (1987), Skoog & Leary (1992) and others.

The following equipment was used for the chromatography in this research: DANI 8610 and DANI 8400 capillary gas chromatographs (DANI, Monza, Italy). Each was equipped with a programmed temperature vaporiser (PTV), a flame ionisation detector (FID), and an LDC/Milton Roy CI - 10B integrator (LDC/Milton Roy, Riviera Beach, Florida). The samples were analysed on fused silica capillary columns with bonded phases of different polarity.

The non-polar system comprised a CP-sIL 5 CB (dimethylpolysiloxane, 50 m × 0.22 mm; film thickness 0.13 μm) capillary column (Chrompack International BV, Middelburg, Netherlands). The carrier gas (hydrogen) velocity was 43 cm/s, while the column temperature programming was 40 °C - 300 °C, with an increase of 4 °C/min, and 300 °C isothermally for 10 minutes. PTV temperature was 50 °C during injection, followed by a very rapid heating to 280 °C. The FID was operated at 310 °C.

The polar system included a DB-Wax (polyethylene glycol; 60 m × 0.32 mm i.d.; film thickness 0.25 μm) capillary column (J & W Scientific, Folsom, California). The carrier gas (hydrogen) velocity was 53 cm/s, while the column temperature programming was 40 °C held for 5 minutes, and then from 40 °C heated at 2.5 °C/min to 250 °C. PTV temperature was 50 °C during the injection, followed by a very rapid heating to 250 °C. The FID was operated at 260 °C.

The described equipment was located in the Institute for Plant Physiology of the University of Graz, Austria.

GAS CHROMATOGRAPHY/MASS SPECTROMETRY
PLINSKA KROMATOGRAFIJA/SPEKTROMETRIJA MASA

Gas chromatography combined with mass spectrometry is certainly one of the most powerful analytical instrumental methods used today in analytical chemistry. Gas chromatography separates the individual components of a mixture, as described above, while mass spectrometry is used for direct identification of mixture components.

Mass spectrometry enables the analysis of complex organic and biological compounds in terms of both quantity and quality. This spectrometry provides information on compound structure. Very precise and relatively fast, this method requires a small quantity of samples.

GS/MS was performed on a Hewlett Packard (Hewlett Packard, Paolo Alto, California) G 1800A GCD system (Electron impact voltage: 70 eV, interface temperature 320 °C, mass range 30-425 amu). The samples were analysed on a DB-1 (dimethylpolysiloxane; 50 m × 0.20 mm i.d.; film thickness 0.33 μm; J & W Scientific capillary column. Other chromatographic conditions were as follows: carrier gas (helium) at 1 mL/min.; column temperature programming: 50 °C of initial temperature held for 3 minutes, then from 50 °C heated at a speed of 4 °C/min to 320 °C; the temperature of 320 °C was held for 5 minutes. The equipment was supplied with the Wiley 275 Database and was used in sample analysis. It is situated in the Institute for Plant Physiology in Graz, Austria.

CLUSTER ANALYSIS
CLUSTER ANALIZA

Cluster analysis is a statistical analysis including several different algorithms for the classification of primarily unclassified objects. The basic question is how to organise the data into a coherent structure, that is, into a tree. In such classification, the higher degree of association the fewer are the similarities of class members. Cluster analysis is not a typcal statistical test, but a group of different algorithms which classify the data in clusters. The theoretical explanation of this analysis is complex and can be found in individual statistical handbooks, e.g. Jardine & Sibson (1971), Anderberg (1973), Sneath & Sokal (1973), Clifford & Stephanson (1975), Hartigan (1975), Späth (1975), Chatfield & Collins (1980).

In this research we used the hierarchy method of joining, that is, the tree clustering algorithm. The purpose of this algorithm is to join the objects into clusters using some similarity measures or object dissimilarities. A typical result of this method is a hierarchy tree (dendrogram), that is, the objects joined, in terms of similarity, into larger clusters, so that eventually they are all linked together. On the horizontal hierarchy tree, axis x marks the linkage distance. Accordingly, for each node, the distances at which the given objects are joined into a new cluster can be read on the diagram (the place where a new cluster is formed).

In forming a cluster, the distances, i.e. the differences between objects, can be calculated in different ways. The usual method is the calculation by means of the Euclid distance, the geometrical distance in multidimensional space.

At first, all objects are clusters and the distances between them are defined by the Euclid distance. To join the existing clusters, the methods used are the complete linkage method and the method of the furthest neighbour respectively; in other words, the distance between two clusters is determined by the longest distance of any two objects in these clusters.

Cluster analysis is a routine method for the interpretation of the data on the volatile and resin composition. For this purpose it was used with pines (Schiller & Grunwald 1987a; von Rudloff & Lapp 1987; Zavarin *et al.* 1990; Schiller & Genizi 1993; Hiltunen & Laasko 1995) and with other conifers (Schiller 1990, Chang & Hanover 1991, Lang 1994).

In this research, cluster analysis was used to determine which species and hybrids are similar as to the composition of terpene in needle volatiles. The program used was *Statistica* 5.0.

RESULTS
REZULTATI

THE RESULTS OF HYBRID IDENTIFICATION AND DISCRIMINATION
REZULTATI IDENTIFIKACIJE I RAZLIKOVANJA HIBRIDA

Descriptive statistics
Deskriptivna statistika

The description of each of the nineteen investigated morphological and anatomical characteristics of needles and shoots has been presented in the tables (2-20) for all groups together. The comparisons were made in two separate units, i.e. in two analyses. In the first, the compared groups were *ni*, *de*, *nide* and *deni*, in the second, groups *ni*, *th*, *nith* and *thni*.

The analysis included F- and t- tests for each investigated trait. F-test determined whether, in terms of the analysed characteristics, there are significant differences between the variances of the individual groups. For the groups whose variances do not differ significantly, a t-test was done to establish whether there were significant differences between their arithmetic means (for nineteen analysed traits).

The values of F- and t-tests are expressed by non-significance probabilities of the differences, i.e., if the value in the table is smaller than 0.05, the difference is significant by a probability that is higher than 95%. The testing was carried out in the program *MS Excel* 97.

Needle length, *Ll*
Duljina iglica, *Ll*

Analysis 1: *ni, de, nide, deni.* F_1 hybrids *nide* (13.0 cm) averagely have longer needles, while F_1 hybrids *deni* (11.5 cm) have shorter needles than both parent species (*ni* 12.4 cm, *de* 12.0 cm) (Table 2). Significant differences were not established for the arithmetic means of groups *ni-nide* and *de-deni*, while for other group combinations there are significant differences between the variances or between the arithmetic means.

Analysis 2: *ni, th, nith, thni.* The Japanese black pine on the average has slightly longer needles (12.7 cm) than the European black pine (12.4 cm), though the difference is not significant (Table 2). Their F_1 hybrids *nith* (10.2 cm) and *thni* (9.6 cm) have shorter needles than both parent species. As to needle length, both hybrids differ significantly from the parent species, though these two hybrids do not differ from one another significantly.

Table 2. Needle length: means (*Ll*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 2. Duljina iglica: aritmetičke sredine (*Ll*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*Ll* (cm)	*s* (cm)	*CV* (%)	*N*
ni	12.4	3.3	26.2	82
de	12.0	1.9	15.5	80
th	12.7	2.7	21.0	36
nide	13.0	2.4	18.4	58
deni	11.5	2.1	17.8	40
nith	10.2	1.9	19.0	30
thni	9.6	1.5	15.7	30

Fascicle sheath length, *LR*

Duljina rukavca oko iglica, *LR*

Analysis 1: *ni, de, nide, deni.* According to the average values, the parent species have equally long fascicle sheaths (*ni* 1.0 cm; *de* 1.0 cm); F*1* hybrids *nide* have longer fascicle sheaths (1.1 cm) than F_1 hybrids *deni* (0.9 cm) (Table 3). These differences are not significant, except for group *de - deni,* whose differences between the arithmetic means are approaching significant values.

Table 3. Fascicle sheath length: means (*LR*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 3. Duljina rukavca oko iglica: aritmetičke sredine (*LR*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*LR* (cm)	*s* (cm)	*CV* (%)	*N*
ni	1.0	0.2	20.0	82
de	1.0	0.2	17.3	80
th	1.1	0.2	14.6	36
nide	1.1	0.3	22.3	58
deni	0.9	0.1	16.5	40
nith	1.0	0.1	14.7	30
thni	1.0	0.2	20.6	30

Analysis 2: *ni, th, nith, thni.* On the average, the European black pine and F_1 hybrids *nith* and *thni* have equally long fascicle sheath lengths (1.0 cm), though slightly shorter than the Japanese black pine (1.1 cm) (Table 3). The differences between the groups are not significant.

One-year shoot tracheid length, *LT*

Duljina traheida jednogodišnjih izbojaka, *LT*

First analysis: *ni, de, nide, deni.* The Japanese red pine has the biggest average lengths of the tracheids (1.232 mm), while the respective values of the black pine are the smallest (1.055 mm). The tracheids of the F_1 hybrid *nide* (1.065 mm) and *deni* (1.087 mm) are, in terms of their mean lengths, between the parent species, though closer to the black pine (Table 4). There are no significant differences between the groups *de-nide* and *nide-deni.* The groups *ni-de* and *ni-nide* differ significantly according to the variances, while the groups *de-nide* and *de-deni* differ as to the arithmetic means.

Table 4. One-year shoot tracheid length: means (*LT*), standard deviations (*s*), variability coefficients (*CV*) and number of measured tracheids (*N*), per groups

*Tablica 4. Duljina traheida jednogodišnjih izbojaka: aritmetičke sredine (*LT*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih traheida (*N*) po grupama*

Group *Grupa*	*LT* (mm)	*s* (mm)	*CV* (%)	*N*
ni	1.055	0.114	10.8	82
de	1.232	0.154	12.5	80
th	1.430	0.153	10.7	36
nide	1.065	0.173	16.3	58
deni	1.087	0.145	13.4	40
nith	1.219	0.220	18.1	30
thni	1.366	0.207	15.2	30

Second analysis: *ni, th, nith, thni.* The Japanese black pine has the longest tracheids (1.430 mm), while the shortest are those of the European black pine (1.055 mm). The average values of the tracheids of F1 hybrid *nith* (1.219 mm) and *thni* (1.366 mm) are intermediary between the parent species, while those of hybrid *thni* are closer to the values of the Japanese black pine (Table 4); statistically, they do not differ from it significantly. The differences as to the tracheid length between other groups are significant either according to the variances or according to the arithmetic means.

One-year shoot tracheid width, *DT*
Širina traheida jednogodišnjih izbojaka, *DT*

First analysis: *ni, de, nide, deni.* In relation to the parent species (*ni* 24.1 µm; *de* 21.9 µm), F_1 hybrids *nide* (21.1 µm) have a lower average value of the tracheid width, while F_1 hybrids *deni* have an even smaller value (20.3 µm) (Table 5). While the difference between the groups *nide-deni* is insignificant, the difference between the groups *de-nide* remains at the border of significance.

Table 5. One-year shoot tracheid width: means (*DT*), standard deviations (*s*), variability coefficients (*CV*) and number of measured tracheids (*N*), per groups

*Tablica 5. Širina traheida jednogodišnjih izbojaka: aritmetičke sredine (*DT*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih traheida (*N*) po grupama*

Group *Grupa*	*DT* (µm)	*s* (µm)	*CV* (%)	*N*
ni	24.1	2.9	12.5	82
de	21.9	2.6	12.0	80
th	26.5	2.6	9.8	36
nide	21.1	2.1	9.7	58
deni	20.3	2.5	12.3	40
nith	26.9	5.3	19.5	30
thni	26.5	3.1	13.8	30

Second analysis: *ni, th, nith, thni.* The average tracheid width of the F_1 hybrid *nith* (26.9 µm) is slightly bigger than with the parent species (*ni* 24.1 µm; *th* 26.5 µm) (Table 5). The average tracheid width of F_1 hybrids *thni* (26.5 µm) equals the respective value of the Japanese black pine and is bigger than the average tracheid width of the European black pine. This is the only difference that is not significant.

The number of ventral stomatal row, *NPPU*
Broj pruga puči s unutrašnje strane iglice, *NPPU*

First analysis: *ni, de, nide, deni.* The *nide* hybrids have an equal *NPPU* as the Japanese red pine (7), while the hybrids *deni* have an equal *NPPU* as the black pine (8) (Table 6). There are no significant differences either between groups *de-nide* and *ni-deni* or between the parent species; groups *ni-nide, de-deni* and *ni-deni* differ significantly as to this trait.

Table 6. Number of ventral stomatal rows, in the middle of the needle length: means (*NPPU*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 6. Broj pruga puči s unutrašnje strane iglice, u sredini duljine iglice: aritmetičke sredine (*NPPU*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*NPPU*	*s*	*CV* (%)	*N*
ni	8	1	15.9	82
de	7	1	16.8	80
th	7	1	14.7	36
nide	7	1	17.6	58
deni	8	1	15.9	40
nith	7	1	17.4	30
thni	9	1	11.7	30

Second analysis: *ni, th, nith, thni.* Hybrids *nith* have an average *NPPU* (7) same as the Japanese black pine, while the *NPPU* of the hybrids *thni* (9) is somewhat higher than with the parent species (*th* 7, *ni* 8) (Table 6). The mutual differences are significant, except for groups *th* - *nith.*

The number of dorsal stomatal rows, *NPPV*

Broj pruga puči s vanjske strane iglice, *NPPV*

First analysis: *ni, de, nide, deni.* Related to the parent species, F_1 hybrids *nide* (11) have an intermediary average *NPPV*, while F_1 hybrids *deni* (13) have a higher *NPPV* than both parent species (*ni* 12, *de* 10) (Table 7).

Table 7. Number of dorsal stomatal rows, in the middle of the needle length: means (*NPPV*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 7. Broj pruga puči s vanjske strane iglice, u sredini duljine iglice: aritmetičke sredine (*NPPV*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*NPPV*	*s*	*CV* (%)	*N*
ni	12	2	16.7	82
de	10	2	18.6	80
th	13	2	12.8	36
nide	11	2	19.6	58
deni	13	2	14.6	40

Group *Grupa*	*NPPV*	*s*	*CV* (%)	*N*
nith	12	2	14.8	30
thni	15	2	10.3	30

The difference in the number of dorsal stomatal rows on the outer side of the needle of black pine and the hybrid *deni* is not significant, while the differences between other groups are significant.

Second analysis: *ni, th, nith, thni.* F_1 hybrids *nith* have the average *NPPV* same as the European black pine (12) and a somewhat smaller *NPPV* than the Japanese black pine (13). The reciprocal hybrids *thni* have an average *NPPV* (15) bigger than both parent species (Table 7). When all groups are mutually compared, a significant difference is absent only between groups *ni - nith.*

The number of stomata along one row, *NP/cm*

Broj puči duž jedne pruge, *NP/cm*

First analysis: *ni, de, nide, deni.* Same as with the previous analysis, an average *NP/cm* in hybrids *nide* (104) and *deni* (103) is intermediary between the respective values of the parent species (*ni* 101, *de* 119), but is closer to the values of the black pine (Table 8). There is no significant difference between groups *ni - deni* and *nide - deni*, while other groups significantly differ by this trait.

Table 8. Number of stomata along one stomatal row, on the inner side of the needle, on a 1 cm long segment from the middle of the needle: means (*NP/cm*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 8. Broj puči duž jedne pruge, s unutrašnje strane iglice, na isječku duljine 1 cm iz sredine iglice: aritmetičke sredine (*NP/cm*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*NP/cm*	*s*	*CV* (%)	*N*
ni	101	9	9.2	82
de	119	10	8.0	80
th	92	8	9.2	36
nide	104	12	11.4	58
deni	103	9	8.5	40
nith	99	7	6.8	30
thni	109	8	7.0	30

Second analysis: *ni, th, nith, thni.* With hybrids F_1 *nith*, the average *NP/cm* (99) is intermediary between the respective values of the parent species (*ni* 101, *th* 92), and is closer to the European black pine. F_1 hybrids *thni* have an average *NP/cm* (109) bigger than both parent species (Table 8). There is a significant difference between all groups, except for the European black pine related to hybrid *nith*.

The number of serrations along one needle margin, *NZ/cm*
Broj zubaca duž jednoga ruba iglice, *NZ/cm*

First analysis: *ni*, *de*, *nide*, *deni*. With F_1 hybrids *nide* (35) and *deni* (40), the average *NZ/cm* is intermediary as to the parent species (*ni* 32, *de* 54), but is closer to the values of the black pine (Table 9). There are significant differences between the variances of the groups *de - deni* and *nide - deni*, while other groups significantly differ by their arithmetic means.

Table 9. Number of serrations along one needle margin, on a 1 cm long segment from the middle of the needle: means (*NZ/cm*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 9. Broj zubaca duž jednoga ruba iglice, na isječku duljine 1 cm iz sredine iglice: aritmetičke sredine (*NZ/cm*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*NZ/cm*	*s*	*CV* (%)	*N*
ni	32	7	20.8	82
de	54	8	14.6	80
th	60	8	13.0	36
nide	35	8	22.7	58
deni	40	5	13.8	40
nith	37	9	23.8	30
thni	35	4	10.4	30

Second analysis: *ni*, *th*, *nith*, *thni*. Same as in the previous analysis, the average *NZ/cm* is intermediary as to the parent species (*ni* 32, *th* 60), but is closer to the European black pine (Table 9). All groups significantly differ from one another by this trait. Groups *ni - nith*, *ni-thni*, *th- thni* and *nith - thni* differ from one another by the variances, while groups *ni - th* and *th - nith* differ by the arithmetic means.

Needle cross-section area, *PPP*
Površina poprečnoga presjeka iglice, *PPP*

First analysis: *ni*, *de*, *nide*, *deni*. As to the average cross-section area of the F_1, the hybrids *nide* (0.8180 mm²) and *deni* (0.8142 mm²) are very similar, and these values are intermediary between the values of the parent species (*ni* 1.0031 mm²; *de* 0.5935 mm²) (Table 10). All groups are significantly different, except for F_1 hybrid *nide-deni*.

Table 10. Needle cross-section area: means (*PPP*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 10. Površina poprečnoga presjeka iglice: aritmetičke sredine (*PPP*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*PPP* (mm^2)	*s* (mm^2)	*CV* (%)	*N*
ni	1.0031	0.1985	19.8	82
de	0.5935	0.0903	15.2	80
th	1.0056	0.2011	20.0	36
nide	0.8180	0.1591	19.4	58
deni	0.8142	0.1371	16.8	40
nith	0.9799	0.1817	18.5	30
thni	1.1550	0.1536	13.3	30

Second analysis: *ni, th, nith, thni.* The European black pine (1.0031 mm^2) and the Japanese black pine (1.0056 mm^2) have approximately same average values of the cross-section area. F_1 hybrids *nith* have somewhat smaller (0.9799 mm^2) average cross-section areas than both parent species (Table 10). F_1 hybrids *thni* differ significantly by their arithmetic means from all other groups, while other groups differ significantly from one another by this trait.

Needle cross-section height, *HPP*

Visina poprečnoga presjeka iglice, *HPP*

First analysis: *ni, de, nide, deni.* F_1 hybrids *nide* (0.898 mm) are, as to the average height of the needle cross-section, intermediary between the parent species (*ni* 0.873 mm; *de* 0.898 mm) (Table 11). There is a statistically significant difference in the variances of groups *ni - de* and *de - nide*; as to the arithmetic means, there are differences between groups *ni - nide*, *ni - deni* and *de - deni.* F_1 hybrids *nide* and *deni* do not differ significantly.

Second analysis: *ni, th, nith, thni.* F_1 hybrids *nith* (0.998 mm) are intermediary, while *thni* (1.082 mm) have a higher average needle cross-section height value than the parent species (*ni* 0.959 mm; *th* 1.058 mm) (Table 11). According to the arithmetic means, groups *ni - th*, *ni - thni* and *nith - thni* differ significantly. There is no significant difference between groups *ni - nith*, *th - nith*, *th - thni* and *th - thni.*

Table 11. Needle cross-section height: means (*HPP*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 11. Visina poprečnoga presjeka iglice: aritmetičke sredine (*HPP*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*HPP* (mm)	*s* (mm)	*CV* (%)	*N*
ni	0.959	0.128	13.3	82
de	0.733	0.081	11.0	80
th	1.058	0.148	14.0	36
nide	0.873	0.110	12.6	58
deni	0.898	0.092	10.3	40
nith	0.998	0.119	11.9	30
thni	1.082	0.111	10.2	30

Needle cross-section diameter, *DPP*

Promjer poprečnoga presjeka iglice, *DPP*

First analysis: *ni, de, nide, deni.* Average needle cross section diameters of F_1 hybrids *nide* (1.313 mm) and *deni* (1.308 mm) are similar, and are intermediary between the parent species (*ni* 1.445 mm; *th* 1.135 mm) (Table 12). All groups differ from one another significantly either as to the variances or as to the arithmetic means, except for F_1 hybrids *nide* and *deni.*

Table 12. Needle cross-section diameter: means (*DPP*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 12. Promjer poprečnoga presjeka iglice: aritmetičke sredine (*DPP*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*DPP* (mm)	*s* (mm)	*CV* (%)	*N*
ni	1.445	0.148	10.3	82
de	1.135	0.088	7.8	80
th	1.379	0.138	10.0	36
nide	1.313	0.130	9.9	58
deni	1.308	0.105	8.0	40
nith	1.414	0.148	10.5	30
thni	1.520	0.136	8.9	30

Second analysis: *ni, th, nith, thni.* The needles of F_1 hybrid *nith* are intermediary as to the average width (1.414 mm), while those of the hybrid *thni* (1.520 mm) are wider than with both parent species (*ni* 1.445 mm; *th* 1.379 mm) (Table 12). As to the arithmetic means, groups *ni - th*, *ni - thni*, *th - thni* and *nith - thni* differ significantly. There is no significant difference between groups *ni - nith* and *th - thni*.

Stelar region cross-section area, *PCC*
Površina poprečnoga presjeka centralnoga cilindra, *PCC*

First analysis: *ni, de, nide, deni*. Hybrids *nide* (0.2153 mm²) and *deni* (0.2250 mm²) have an average *PCC* that is intermediary between the respective values of the parent species (*ni* 0.2724 mm²; *th* 0.1479 mm²) (Table 13). All groups differ from one another significantly, except for hybrids *nide* and *deni*.

Table 13. Stellar region cross-section area: means (*PCC*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 13. Površina poprečnoga presjeka centralnoga cilindra: aritmetičke sredine (*PCC*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*PCC* (mm²)	*s* (mm²)	*CV* (%)	*N*
ni	0.2724	0.0577	21.2	82
de	0.1479	0.0335	22.7	80
th	0.2501	0.0589	23.5	36
nide	0.2153	0.0499	23.2	58
deni	0.2250	0.0399	17.7	40
nith	0.2501	0.0443	17.7	30
thni	0.3032	0.0426	14.1	30

Second analysis: *ni, th, nith, thni*. The average *PCC* of F_1 hybrids *nith* (0.2501 mm²) is same as with the Japanese black pine and smaller than with the European black pine (0.2724 mm²). The reciprocal hybrids *thni* (0.3032 mm²) have an average *PCC* that is higher than both parent species (Table 13). As to this trait, hybrids *thni* differ significantly from both parent species, while hybrids *nith* do not differ either from the European or from the Japanese black pine.

Stelar region cross-section height, *HCC*
Visina poprečnoga presjeka centralnoga cilindra, *HCC*

First analysis: *ni, de, nide, deni*. F_1 hybrids *nide* (0.376 mm) and *deni* (0.384 mm) have average *HCC*s that are intermediary between the parent species (*ni* 0.427 mm; *de* 0.319 mm) (Table 14). All groups differ from one another significantly, except for hybrids *nide - deni*.

Table 14. Stellar region cross-section height: means (*HCC*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

Tablica 14. *Visina poprečnoga presjeka centralnoga cilindra: aritmetičke sredine (*HCC*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*HCC* (mm)	*s* (mm)	*CV* (%)	*N*
ni	0.427	0.046	10.7	82
de	0.319	0.042	13.2	80
th	0.452	0.060	13.3	36
nide	0.376	0.040	10.6	58
deni	0.384	0.043	11.1	40
nith	0.424	0.044	10.4	30
thni	0.449	0.024	5.4	30

Second analysis: *ni*, *th*, *nith*, *thni*. F_1 hybrid *nith* (0.424 mm) has a smaller average *HCC* than both parent species (*ni* 0.427 mm; *th* 0.452 mm); it is closer to the values of the European pine. The reciprocal hybrids *thni* (0.449 mm) have an average *HCC* that is intermediary between the parent species, though closer to the Japanese black pine (Table 14). Except for groups *ni* - *nith*, there are significant differences between other groups, either as to the variances (*ni* - *thni*, *th* - *thni*, *nith* - *thni*) or as to the arithmetic means (*ni* - *th*, *th* - *nith*).

Stelar region cross-section diameter, *DCC*

Promjer poprečnoga presjeka centralnoga cilindra, *DCC*

First analysis: *ni*, *de*, *nide*, *deni*. F_1 hybrids *nide* (0.717 mm) and *deni* (0.743 mm) are intermediary, as to this trait, between the respective values of the parent species (*ni* 0.796 mm; *de* 0.591 mm) (Table 15). All groups differ from one another significantly.

Second analysis: *ni*, *th*, *nith*, *thni*. F_1 hybrids *nith* (0.745 mm) have an intermediary average *DCC*, while the reciprocal hybrids *thni* (0.855 mm) have a bigger average *DCC* than the parent species (*ni* 0.796 mm; *th* 0.704 mm) (Table 15). As to this trait, all groups differ from one another significantly, except for the Japanese black pine and hybrid *nith*.

Table 15. Stellar region cross-section diameter: means (*DCC*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 15. Promjer poprečnoga presjeka centralnoga cilindra: aritmetičke sredine (*DCC*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*DCC* (mm)	*s* (mm)	*CV* (%)	*N*
ni	0.796	0.101	12.7	82
de	0.591	0.063	10.6	80
th	0.704	0.089	12.7	36
nide	0.717	0.101	14.1	58
deni	0.743	0.070	9.5	40
nith	0.745	0.086	11.6	30
thni	0.855	0.090	10.5	30

The largest number of hypodermal cell layers on the needle cross-section, *NHmax*

Najveći broj slojeva hipoderme na poprečnom presjeku iglice, *NHmax*

First analysis: *ni, de, nide, deni.* F_1 hybrids *nide* (2.4) and *deni* (2.5) have an intermediary average *NHmax* between the respective values of the parent species (*ni* 3.4; *de* 1.3) (Table 16). All groups differ from one another significantly, except for F_1 *nide* and *deni.*

Table 16. The largest number of hypodermal cell layers on the needle cross-section: means (*NHmax*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 16. Najveći broj slojeva hipoderme na poprečnom presjeku iglice: aritmetičke sredine (*NHmax*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*NHmax*	*s*	*CV* (%)	*N*
ni	3.4	0.69	20.6	82
de	1.3	0.47	35.6	80
th	3.1	0.55	18.0	36
nide	2.4	0.50	20.6	58
deni	2.5	0.51	20.3	40
nith	3.1	0.72	23.3	30
thni	3.0	0.45	15.2	30

Second analysis: *ni, th, nith, thni.* F_1 hybrids *nith* have the same average *NHmax* as the Japanese black pine (3.1), and smaller than the European black pine (3.4). The reciprocal hybrids *thni* (3.0) have a smaller average *NHmax* than both parent species (Table 16). Groups *th - nith* and *th - thni* do not differ significantly, while other groups differ from one another either significantly or as to the variances, or as to the arithmetic means.

The number of medial resin canals on needle cross-section, *NSKM*
Broj medijalno smještenih smolnih kanala na poprečnom presjeku iglice, *NSKM*

The medial resin canals of the Japanese red pine are not normally distributed, but rather according to Poisson's distribution. This is because in these species the resin canals are located near the hypoderm, while only some of them are medial. For this species, the mode and the median has been calculated as the measure of central tendency, while interquartile is the measure of variability (Table 17). An interquartile is the range between the upper and the lower quartile (Q_3 - Q_1). In the same way as the median divides the distribution members in two equal parts, quartiles divide these two parts into equal parts. Down to the lower quartile there are 25% of the distribution members, while up to the upper quartile there are 75% of the distribution members (Serdar 1961, Holman 1969).

Table 17. Number of medial resin canals on the needle cross-section: means (*NSKM*), standard deviations (*s*), variability coefficients (*CV*), mode, median (*M*), interquartile (*range* $Q_3 - Q_1$) and number of measured needles (*N*), per groups

*Tablica 17. Broj medijalno smještenih smolnih kanala na poprečnom presjeku iglice: aritmetičke sredine (*NSKM*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*), mod, medijana (*M*), interkvartil (*raspon Q_3 - Q_1*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*NSKM*	*s*	*CV* (%)	Mode *mod*	*M*	$Q_3 - Q_1$	*N*
ni	6.0	2.63	45.0				82
de				0	0	0	80
th	4.6	2.11	45.6				36
nide	5.6	2.22	39.8				58
deni	4.1	2.18	53.4				40
nith	5.5	1.72	31.3				30
thni	8.9	2.26	25.3				30

In terms of this trait, Table 17 shows the arithmetic means, the standard deviation, the variability coefficients and the number of measured needles of other species and hybrids.

First analysis: *ni*, *de*, *nide*, *deni*. According to the number of medial resin canals, hybrids *nide* and *deni* bear more resemblance to the black pine. The arithmetic means are *ni* = 6, *nide* = 5.6 and *deni* = 4.1 (Table 17). Groups *ni* - *nide* do not differ significantly, while groups *ni* - *deni* and *nide* - *deni* statistically differ significantly as to the arithmetic means. The Japanese red pine has resin canals located near the hypoderm, so that the mode, median and interquartile are zero.

Second analysis: *ni*, *th*, *nith*, *thni*. Hybrids *nith*, on the average, have an intermediary number of medial resin canals according to the parent species, while hybrids *thni* have a larger number of medial resin canals than both parent species (*ni* = 6.0; *th* = 4.6; *nith* = 5.5; *thni* = 8.9) (Table 17). Groups *ni* - *nith* differ significantly in variances, while other groups differ significantly in the arithmetic means.

The number of external resin canals on needle cross-section, *NSKH*

Broj uz hipodermu smještenih smolnih kanala na poprečnom presjeku iglice, *NSKH*

It may be supposed that the number of external resin canals in the European black pine, the Japanese black pine and their hybrids *nith* and *thni* are arranged according to Poisson's distribution. In these groups, resin canals are medial, while only some of them are situated near the hypoderm. In these groups, the mode and the median have been calculated as the measure of central tendency, while interquartile is the measure of variability (Table 18). Table 18 shows arithmetic means, standard deviation, variability coefficients and the number of measured needles of other groups.

Table 18. Number of external resin canals on the needle cross-section: means (*NSKH*), standard deviations (*s*), variability coefficients (*CV*), mode, median (*M*), interquartile (*range* $Q_3 - Q_1$) and number of measured needles (*N*), per groups

*Tablica 18. Broj uz hipodermu smještenih smolnih kanala na poprečnom presjeku iglice: aritmetičke sredine (*NSKH*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*), mod, medijana (*M*), interkvartil (*raspon $Q_3 - Q_1$*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*NSKH*	*s*	*CV* (%)	Mode *mod*	*M*	$Q_3 - Q_1$	*N*
ni				0	0	0	82
de	6.5	1.44	22.3				80
th				0	0	0	36
nide	2.1	1.97	93.1				58
deni	2.9	1.49	51.0				40
nith				0	0	0	30
thni				0	0	1	30

First analysis: *ni, de, nide, deni.* Hybrids *nide* and *deni*, according to the number of medial resin canals, are intermediary as to the parent species (the arithmetic means are *de* = 6.5; *nide* = 2.1; *deni* = 2.9; mode and median of *ni* = 0). The variability coefficient of *nide* = 93%, and of *deni* = 51% (Table 18). Groups *de - nide* differ significantly in variances, while groups *de - deni* and *nide - deni* differ as to the arithmetic means.

Second analysis: *ni, th, nith, thni.* The European black pine, the Japanese black pine and their hybrids have medial resin canals, so that the mode and the median of *NSKH* are zero. The interquartile of *ni*, *th* and *nith* is zero, while for *thni* it is one (Table 18). The maximum number of external resin canals on a needle cross section in the European black pine is one, while in other groups this number is three.

The largest number of sheath cells surrounding a single resin canal, on needle cross-section, *NSmax*

Najveći broj ovojnih sklerenhimskih stanica koje okružuju jedan smolni kanal, *NSmax*

First analysis: *ni*, *de*, *nide*, *deni*. An average *NSmax* of the F_1 hybrid *nide* (13.9) and *deni* (14.1) is larger than in both parent species (*ni* 13.4; *sy* 11.6) (Table 19). As to this trait, groups *ni* - *de*, *de* -*nide* and *de* - *deni* differ significantly.

Table 19. The largest number of sheath cells surrounding a single resin canal, on the needle cross-section: means (*NSmax*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 19. Najveći broj sklerenhimskih stanica koje okružuju jedan smolni kanal na poprečnom presjeku iglice: aritmetičke sredine (*NSmax*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*NSmax*	*s*	*CV* (%)	*N*
ni	13.4	2.17	15.9	82
de	11.6	2.16	18.6	80
th	11.3	1.96	17.3	36
nide	13.9	2.11	15.2	58
deni	14.1	1.70	12.0	40
nith	12.8	2.28	17.8	30
thni	11.7	1.18	10.1	30

Second analysis: *ni*, *th*, *nith*, *thni*. As to this trait, F_1 hybrids *nith* (12.8) and *thni* (11.7) are intermediary between the parent species (*ni* 13.4; *sy* 11.6). The average value of *NSmax* is by *nith* closer to the European black pine, and by *thni* closer to the Japanese black pine (Table 19). There are significant differences in either variances or the arithmetic means among all groups, except for the group *ni* - *nith*.

The smallest number of sheath cells surrounding a single resin canal, on needle cross-section, *NSmin*

Najmanji broj ovojnih sklerenhimskih stanica koje okružuju jedan smolni kanal, *NSmin*

First analysis: *ni*, *de*, *nide*, *deni*. An average *NSmin* of both F_1 hybrids (*nide* 8.5; *deni* 8.8) is larger than in both parent species (*ni* 8.3; *sy* 7.3) (Table 20). As to this trait, the variances of groups *de* – *nide*, *de* - *deni*, and the arithmetic means of groups *ni* - *de* differ significantly.

Second analysis: *ni*, *th*, *nith*, *thni*. The average *NSmin* value of hybrids *nith* (7.9) is intermediary between the parent species (*ni* 8.3; *th*7.8), while in hybrids *thni* (7.0) it is smaller than in both parent species (Table 20). There are significant differences among all groups, either in the variances (*ni - nith, ni - thni, th - nith, th - thni*), or in the arithmetic means (*ni - th, nith - thni*).

Table 20. The smallest number of sheath cells surrounding a single resin canal, on the needle cross-section: means (*NSmin*), standard deviations (*s*), variability coefficients (*CV*) and number of measured needles (*N*), per groups

*Tablica 20. Najmanji broj sklerenhimskih stanica koje okružuju jedan smolni kanal na poprečnom presjeku iglice: aritmetičke sredine (*NSmin*), standardne devijacije (*s*), koeficijenti varijabilnosti (*CV*) i broj mjerenih iglica (*N*) po grupama*

Group *Grupa*	*NSmin*	*s*	*CV* (%)	*N*
ni	8.3	1.44	16.7	82
de	7.3	1.74	23.8	80
th	7.7	1.43	18.7	36
nide	8.5	1.19	14.0	58
deni	8.8	1.21	13.9	40
nith	7.9	0.88	11.1	30
thni	7.0	0.72	10.3	30

Discriminant analysis
Diskriminacijska analiza

Two separate analyses were done according to how the hybrids and their parent species were grouped. The following were the input parameters for the discriminant analyses:

First analysis:

Grouping variables: *ni*, *de*, *nide* and *deni*;

Independent variables: nineteen traits

Second analysis:

Grouping variables: *ni*, *th*, *nith* and *thni*;

Independent variables: nineteen traits.

Independent variables are used for group discrimination. They are inserted into the model successively, by a *forward stepwise method.* The tolerance for all analyses was 0.01.

First analysis: *ni, de, nide, deni*
Prva analiza: *ni*, *de*, *nide*, *deni*

The analysed issue was the possibility of discriminating the F_1 hybrids *nide* and *deni* according to their parent species, the black pine and the Japanese red pine. Nineteen morphological and anatomic characteristics were included into the analysis.

According to the total data, we can say that there is a significant group discrimination.

Wilks' $\lambda = 0.03$; $F = 31.9$ (degrees of freedom 51 and 715); $p < 0.01$. The model included seventeen variables, except for *HPP* (the height of needle cross-section) and *PCC* (stellar region cross-section area), since they are not significant.

With seventeen variables and four groups, using a canonical analysis, we obtained three discriminant functions. All three functions are significant, i.e. we have three explanations how, based on seventeen variables, we can distinguish four groups (*ni*, *sy*, *nide* and *deni*).

Table 21 shows the variables in order of the contribution to group discrimination of three discriminant functions. Together with the variables, there are corresponding standardised coefficients. The discrimination defined by discriminant function 1 is mostly determined by variable *PPP*, which is followed in turns by *NSKH*, *DPP*, *NZ/cm*, *DCC*, *NHmax*, etc. The discriminant function 2 is mostly determined by variables *PPP*, *DCC*, *NSKM*, *DT*, *HCC*, *NSmax*, etc., while the discriminant function 3 is determined by variables *DCC*, *PPP*, *LR*, *DPP*, *NPPV*, *NSKM*, etc.

Table 21. Order of the variables determining most the discrimination defined by three discriminant functions, and the standardized coefficients of discriminant functions for these variables

Tablica 21. Redoslijed varijabla koje najviše određuju razlikovanje definirano trima diskriminacijskim funkcijama i standardizirani koeficijenti diskriminacijskih funkcija za te varijable

No. *Red. br.*	Discriminant Function 1 *Diskriminacijska funkcija 1*		Discriminant Function 2 *Diskriminacijska funkcija 2*		Discriminant Function 3 *Diskriminacijska funkcija 3*	
	Variable *Varijabla*	Stand. Coeff. *Stand. koef.*	Variable *Varijabla*	Stand. Coeff. *Stand. koef.*	Variable *Varijabla*	Stand. Coeff. *Stand. koef.*
1	*PPP*	- 0.988301	*PPP*	1.836850	*DCC*	- 1.00939
2	*NSKH*	- 0.585851	*DCC*	- 0.833746	*PPP*	0.66816
3	*DPP*	0.557006	*NSKM*	- 0.731004	*LR*	0.55862
4	*NZ/cm*	- 0.441530	*DT*	0.572537	*DPP*	0.54113
5	*DCC*	0.433314	*HCC*	- 0.492681	*NPPV*	- 0.41219
6	*NHmax*	0.413357	*NSmax*	- 0.428435	*NSKM*	0.40622
7	*HCC*	0.313263	*NSmin*	- 0.395780	*HCC*	- 0.37043
8	*LR*	- 0.280353	*NHmax*	0.387855	*NP/cm*	0.27708
9	*LT*	- 0.266299	*LI*	0.307097	*NPPU*	- 0.27578
10	*DT*	0.253828	*NZ/cm*	0.276056	*LI*	0.24078
11	*NSmin*	0.183619	*NPPU*	0.244271	*NZ/cm*	- 0.18117
12	*NPPU*	- 0.179180	*NSKH*	- 0.228395	*NHmax*	- 0.16730
13	*NSKM*	0.152688	*LT*	0.215444	*DT*	0.13307
14	*NPPV*	0.138614	*NPPV*	- 0.200981	*NSmin*	- 0.07626
15	*NSmax*	0.127360	*LR*	- 0.181548	*NSKH*	0.04269
16	*NP/cm*	- 0.072804	*DPP*	- 0.084881	*NSmax*	0.03060
17	*LI*	- 0.023516	*NP/cm*	0.050834	*LT*	- 0.02871
Cumul. Prop. *Kumul. prop.*		0.8493		0.9546		1.00

The last row in Table 21 shows a cumulative proportion of the explained variance of each function. The first function calculates 85% of the explained variance; the second calculated 10%, and the third the remaining 5%.

The means of the canon variables (Table 22) shows between which groups an individual function is discriminant.

Table 22. Means of variables for three discriminant functions, per groups

Tablica 22. Sredine kanonskih varijabla za tri diskriminacijske funkcije po grupama

Group *Grupa*	Discr. Function 1 *Diskr. funkcija 1*	Discr. Function 2 *Diskr. funkcija 2*	Discr. Function 3 *Diskr. funkcija 3*
ni	3.29528	1.07724	- 0.00793
de	- 4.29376	0.55715	0.02970
nide	0.84846	- 1.37805	- 0.93600
deni	0.60192	- 1.32448	- 1.40033

The first discriminant function distinguishes best the pure species, since the means of these groups are the most distant from one another (Table 22). The means of F_1 hybrids *nide* and *deni* are very close to one another and are situated between the means of the parent species, though slightly closer to the black pine. This is also seen in Figure 2, where the individual values of the first function, per group, are shown on the x-coordinate.

The second discriminant function distinguishes best F_1 hybrids *deni* and *nide* (Table 22) of the black pine. This function is graphically presented in Figure 2, coordinate y.

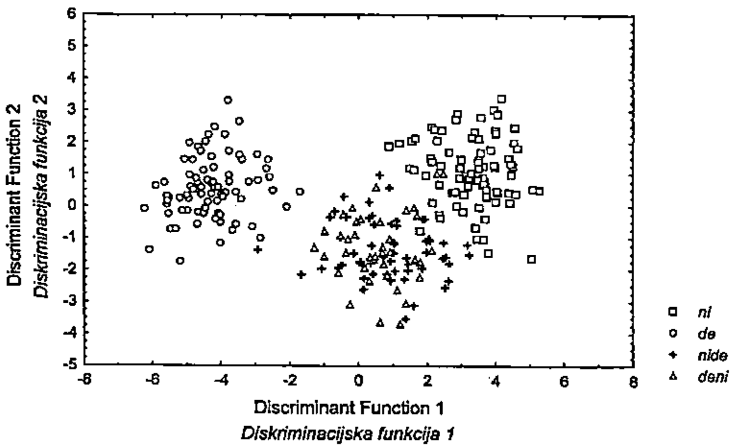

Figure 2. Graph of discriminant functions 1 and 2. Particular values for the first discriminant function are plotted on axis x, and for the second discriminant function on axis y.

Slika 2. Grafički prikaz diskriminacijskih funkcija 1 i 2. Na osi x su pojedinačne vrijednosti za prvu diskriminacijsku funkciju, a na osi y za drugu diskriminacijsku funkciju

The third discriminant function distinguishes best hybrids *nide* and *deni*, though the differences in the means are almost negligible (Table 22). This function includes only 5% of the explained variance.

The coefficients of the classification functions per group are shown in Table 23.

Table 23. Coefficients of classification functions, per groups

Tablica 23. Koeficijenti klasifikacijskih funkcija po grupama

Variable *Varijabla*	*sy*	*de*	*nide*	*deni*
NSKH	- 2.556	0.771	- 1.074	- 1.05
NHmax	14.02	7.77	10.056	10.634
NZ/cm	- 0.011	0.436	0.021	0.098
DT	4.013	3.153	3.276	3.143
NSmax	2.44	2.085	2.809	2.748
LR	- 2.013	9.375	6.41	0.085
DCC	- 40.346	- 74.342	- 39.946	- 14.012
PPP	- 542.47	- 498.992	- 552.14	- 560.207
NSKM	4.331	3.954	5.224	4.717
NSmin	1.686	0.87	1.995	2.072
NPPV	2.028	1.544	1.91	2.372
HCC	595.247	545.693	597.417	615.099
LT	0.024	0.037	0.025	0.026
NPPU	0.998	1.983	0.658	1.224
LI	0.419	0.431	0.223	- 0.002
DPP	545.345	510.785	540.001	528.327
NP/cm	1.341	1.395	1.372	1.309
Constant *Konstanta*	- 440.098	- 406.029	- 419.331	- 417.596

In the classification matrix (Table 24), all measured data are assorted in the classification functions and, according to them, arranged in groups to which they most probably belong (the rows in the table).

Table 24. Classification matrix

Tablica 24. Klasifikacijska matrica

Group *Grupa*	Percent Correct *Točno klasific.* %	*ni*		*de*		*nide*		*deni*		Total *Ukupno*
		No. *kom.*	%	No. *kom.*	%	No. *kom.*	%	No. *kom.*	%	No. *kom.*
ni	98.8	81	98.8	0	0	1	1.2	0	0	82
de	100.0	0	0	80	100	0	0	0	0	80
nide	89.7	0	0	1	1.7	52	89.7	5	8.6	58
deni	82.5	3	7.5	0	0	4	10	33	82.5	40

The classification matrix shows that, based on seventeen analysed characteristics, a safe sample classification of the Japanese red pine and the black pine is possible. There is a possibility of confusion of the black pine samples with hybrids *nide* in 1.2% of cases.

The accuracy of the classification of hybrids *nide* and *deni* is not significant. The samples of hybrid *nide* will be precisely classified in 89.7% of cases, and their misclassification as samples of the Japanese red pine (1.7%) and as reciprocal hybrids *deni* (8.6%) is possible. Based on seventeen analysed characteristics, the samples of hybrid *nide* can be perfectly discriminated from the black pine.

Hybrids *deni* will be accurately assorted with a probability of 82.5%. It is possible to mistake them for black pine (7.5%) and for hybrids *nide* (10%). The samples of hybrids *deni* can be perfectly discriminated from the samples of the Japanese red pine.

The accuracy of hybrid classification is higher if they are separately compared to the parent species. Thus, there is no possibility of mutual replacement of the hybrid samples.

The analysis of F_1 hybrids *nide*, the black pine and the Japanese red pine makes the accuracy of hybrid classification statistically significant (level 0.05), amounting to 96.6% (Table 25). In 1.7% of cases, the samples *nide* can be mistaken for the parent species.

Table 25. Classification matrix
Tablica 25. Klasifikacijska matrica

Group *Grupa*	Percent Correct *Točno klasific.* %	*ni*		*de*		*nide*		Total *Ukupno*
		No. *kom.*	%	No. *kom.*	%	No. *kom.*	%	No. *kom.*
ni	98.8	81	98.8	0	0	1	1.2	82
de	100	0	0	80	100	0	0	80
nide	96.6	1	1.7	1	1.7	56	96.6	58

With the analysis of F_1 hybrids *deni*, the black pine and the Japanese red pine, the limit of statistical significance (level 0.05) of accurate classification of hybrid *deni* is obtained (95%) (Table 25). In 5% of cases, the samples can be mistaken for black pine (Table 26).

Table 26. Classification matrix
Tablica 26. Klasifikacijska matrica

Group *Grupa*	Percent Correct *Točno klasific.* %	*ni*		*de*		*deni*		Total *Ukupno*
		No. *kom.*	%	No. *kom.*	%	No. *kom.*	%	No. *kom.*
ni	100	82	100	0	0	0	0	82
de	100	0	0	80	100	0	0	80
deni	95	2	5	0	0	38	95	40

Second analysis: *ni, th, nith, thni*

Druga analiza: *ni, th, nith, thni*

The analysed issue was the possibility of discriminating the F_1 hybrids *nith* and *thni* according to their parent species, the European black pine and the Japanese black pine. Nineteen morphological and anatomic characteristics were included into the analysis.

According to the total data, we can say that there is a significant group discrimination. Wilks' $\lambda = 0.03$; $F = 20.1$ (degrees of freedom 51 and 468); $p < 0.01$. The model included seventeen variables, except for *HCC* (stellar region cross-section height) and *PCC* (stellar region cross-section area).

Using the canonical analysis, we obtained three discriminant functions. All three functions were significant, i.e. we had three explanations how, based on seventeen variables, we could discriminate four groups (*ni*, *sy*, *nith* and *thni*).

Table 27. Order of the variables determining most the discrimination defined by three discriminant functions, and the standardized coefficients of discriminant functions for these variables

Tablica 27. Redoslijed varijabla koje najviše određuju razlikovanje definirano trima diskriminacijskim funkcijama i standardizirani koeficijenti diskriminacijskih funkcija za te varijable

No. *Red. br.*	Discriminant Function 1 *Diskriminacijska funkcija 1*		Discriminant Function 2 *Diskriminacijska funkcija 2*		Discriminant Function 3 *Diskriminacijska funkcija 3*	
	Variable *Varijabla*	Stand. Coeff. *Stand. koef.*	Variable *Varijabla*	Stand. Coeff. *Stand. koef.*	Variable *Varijabla*	Stand. Coeff. *Stand. koef.*
1	*DCC*	- 1.22007	*DPP*	- 0.857787	*DPP*	2.25252
2	*DPP*	0.90276	*PPP*	0.666934	*PPP*	- 1.69909
3	*NZ/cm*	0.85000	*LT*	0.520485	*DCC*	- 1.22032
4	*HPP*	0.58510	*LI*	- 0.469253	*HPP*	1.06493
5	*NSKM*	- 0.48740	*NPPV*	0.357597	*LI*	- 0.52102
6	*NP/cm*	- 0.44809	*NSmax*	- 0.339467	*NPPU*	- 0.43371
7	*NSmin*	- 0.31970	*NSKM*	0.307173	*LR*	0.41895
8	*LT*	0.31664	*NPPU*	0.281477	*DT*	0.40115
9	*NPPU*	- 0.28122	*NP/cm*	0.276206	*NZ/cm*	- 0.33899
10	*LR*	0.24069	*DCC*	0.261962	*NSKH*	0.29653
11	*LI*	- 0.17715	*NSKH*	0.260501	*NSmax*	0.29006
12	*NPPV*	0.17178	*LR*	0.205430	*NHmax*	- 0.28417
13	*PPP*	- 0.10307	*NHmax*	- 0.201303	*NSKM*	- 0.21410
14	*DT*	0.04062	*NZ/cm*	- 0.198195	*LT*	- 0.15167
15	*NSmax*	- 0.02233	*DT*	0.139214	*NSmin*	- 0.08799
16	*NSKH*	0.02155	*NSmin*	- 0.133255	*NPPV*	0.03331
17	*NHmax*	- 0.01758	*HPP*	- 0.004589	*NP/cm*	0.02315
Cumul. Prop. *Kumul. prop.*		0.748		0.962		1.00

Table 27 shows the variables classified by each of the discriminant functions in order of the contribution to group discrimination. Together with the variables, there are the corresponding standardised coefficients.

The discrimination defined by discriminant function 1 is mostly determined by variable *DCC*, which is followed in turns by *DPP, NZ/cm, HPP, NSKM, NP/cm*, etc. The discriminant function 2 is mostly determined by variables *DPP, PPP, LT, LI, NPPV, NSmax*, etc., while the discriminant function 3 is determined by variables *DPP, PPP, DCC, HHPP, LI, NPPU*, etc. The last row in Table 55 shows a cumulative proportion of the explained variance of each function; The first function calculates 75% of the explained variance, which means that 75% of discrimination has been explained by this function. By adding the second function, i.e. the additional 21%, 96% of the explained variance has been calculated; the contribution of the third function is the smallest, the remaining 4%.

Table 28 shows the means of the variables of the four analysed groups, for each discriminant function.

Table 28. Means of variables for three discriminant functions, per groups

Tablica 28. Sredine kanonskih varijabla za tri diskriminacijske funkcije po grupama

Group *Grupa*	Discr. Function 1 *Diskr. funkcija 1*	Discr. Function 2 *Diskr. funkcija 2*	Discr. Function 3 *Diskr. funkcija 3*
ni	-1.84827	- 0.939939	- 0.256285
th	4.88996	- 0.179911	- 0.342686
nith	0.41042	- 0.200898	1.31566
thni	- 1.21275	2.979266	- 0.160081

The first discriminant function distinguishes best the Japanese black pine and the European black pine; it distinguishes very well the Japanese black pine from hybrids *thni*, and a bit less well the Japanese black pine from hybrids *nith* (Table 28). The means of F_1 *nith* and *thni* are relatively close to one another and are situated between the means of the parent species, though slightly closer to the European black pine. This is also seen in Figure 3, where the individual values of the first function, per group, are shown on the x-coordinate.

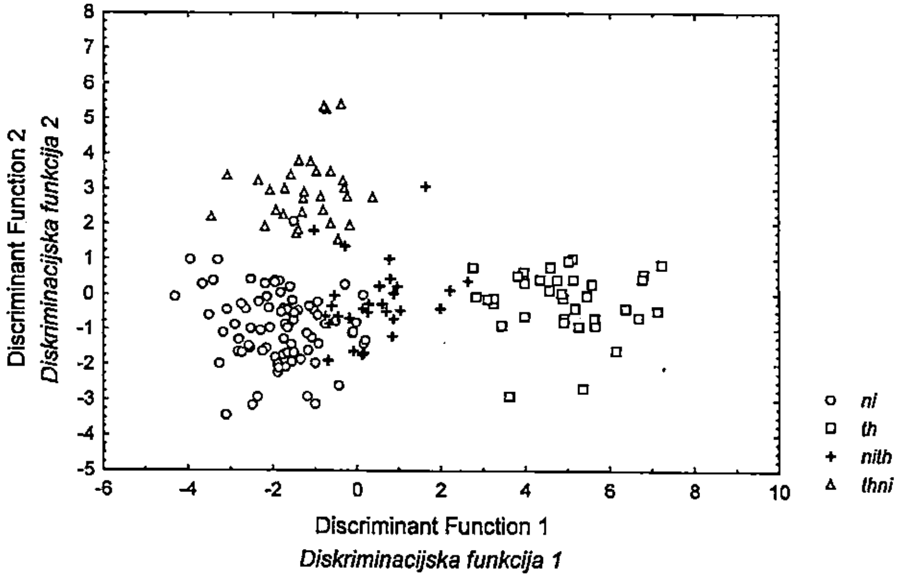

Figure 3. Graph of discriminant functions 1 and 2. Particular values for the first discriminant function are plotted on axis x, and for the second discriminant function on axis y.

Slika 3. Grafički prikaz diskriminacijskih funkcija 1 i 2. Na osi x su pojedinačne vrijednosti za prvu diskriminacijsku funkciju, a na osi y za drugu diskriminacijsku funkciju.

The second discriminant function distinguishes best F_1 hybrids *thni* from European black pine (Table 28). This function is graphically presented in Figure 3, coordinate y.

The third discriminant function includes only 4% of the explained variance.

The coefficients of the classification functions per group are shown in Table 29.

Table 29. Coefficients of classification functions, per groups

Tablica 29. Koeficijenti klasifikacijskih funkcija po grupama

Variable *Varijabla*	*ni*	*th*	*nith*	*thni*
NZ/cm	- 0.168	0.645	0.012	- 0.207
LT	21.712	37.411	27.031	35.461
NP/cm	1.798	1.467	1.707	1.892
NPPV	4.66	5.445	5.048	5.493
LI	1.344	0.753	0.729	0.558
DCC	- 133.897	- 219.258	- 182.207	- 132.453
HPP	386.815	417.475	410.662	390.451
NSmax	3.763	3.547	3.84	3.108
DPP	621.539	658.209	656.175	603.531
NSKM	- 2.028	- 3.324	- 2.546	- 1.655
NPPU	- 0.553	- 1.995	- 1.526	0.222
NSmin	1.866	0.087	1.107	1.285
LR	25.51	35.027	32.909	30.965
NSKH	8.944	9.447	10.064	10.628
PPP	- 593.355	- 593.573	- 606.247	- 580.601
DT	2.861	2.964	3.107	3.043
NHmax	16.451	16.042	15.399	15.081
Constant *Konstanta*	- 521.205	- 544.912	- 541.232	- 544.958

Classification matrix (Table 30) shows how good is the prediction of the new sample classification to the individual groups.

Table 30. Classification matrix

Tablica 30. Klasifikacijska matrica

Group *Grupa*	Percent Correct *Točno klasific.* %	*ni*		*th*		*nith*		*thni*		Total *Ukupno*
		%	No. *kom.*	%	No. *kom.*	%	%	No. *kom.*	%	No. *kom.*
ni	97.6	80	97.6	0	0	1	1.2	1	1.2	82
th	100	0	0	36	100	0	0	0	0	36
nith	73.3	5	16.7	1	3.3	22	73.3	2	6.7	30
thni	96.7	0	0	0	0	1	3.3	29	96.7	30

Based on seventeen analysed characteristics, a safe sample classification of the Japanese black pine is possible. There is a possibility of confusing the European black pine with hybrids *nith* in 1.2% of cases, and with hybrids *thni* in 1.2% of cases, i.e. the accuracy of classification is 97.6%, which is statistically significant (level 0.05).

The analysis was done to establish a possibility of discriminating the hybrids from their parent species. With hybrids *thni*, the accuracy of sample classification is satisfactory

(96.7%). There is a possibility of mistaking them for samples *nith* in 3.3% of cases. According to the analysed characteristics, hybrids *thni* can be perfectly discriminated from their parent species, the Japanese black pine and the European black pine.

The discrimination of hybrids *nith* from other groups on the basis of the analysed traits is impossible, since the accuracy of classifying their samples is only 73.3%. The highest probability of confusing them is with samples of the European black pine (16.7%), then with the samples of the *thni* hybrid (6.7%), and with the Japanese black pine (3.3%).

By comparing hybrids *nith* only with the parent species, the accuracy of hybrid *nith* classification has risen to 80%, which still does not make it significant (Table 31). This means that some other characteristics must be included into the analysis to discriminate hybrids *nith* from the parent species.

Table 31. Classification matrix

Tablica 31. Klasifikacijska matrica

Group *Grupa*	Percent Correct *Točno klasific.* %	*ni*		*th*		*nith*		Total *Ukupno*
		No. *kom.*	%	No. *kom.*	%	No. *kom.*	%	No. *kom.*
ni	98.8	81	98.8	0	0	1	1.2	82
th	100	0	0	36	100	0	0	36
nith	80.0	5	16.7	1	3.3	24	80	30

By comparing F_1 hybrids *thni* only with the parent species, the accuracy of classification has risen to 100% (Table 32), i.e. hybrids *thni*, based on the seventeen analysed characteristics, can be perfectly discriminated from the Japanese black pine and the European black pine.

Table 32. Classification matrix

Tablica 32. Klasifikacijska matrica

Group *Grupa*	Percent Correct *Točno klasific.* %	*ni*		*th*		*thni*		Total *Ukupno*
		No. *kom.*	%	No. *kom.*	%	No. *kom.*	%	No. *kom.*
ni	98.8	81	98.8	0	0	1	1.2	82
th	100	0	0	36	100	0	0	36
thni	100	0	0	0	0	30	100	30

THE RESULTS OF NEEDLE VOLATILES COMPOSITION ANALYSIS
REZULTATI ANALIZE SASTAVA ETERIČNIH ULJA IGLICA

We used fresh needles of each of the analysed pine species and hybrids to distill volatile oils. Using the previously described procedure, the volatile oils were analysed by using gas chromatography (GC) and gas chromatography/mass spectrometry (GC/MS). The results of gas chromatography were chromatograms, both graphical and numerical. Each chromatogram (of three species and four hybrids) was compared to all other chromatograms, in order to establish the concurrence of the individual components of the analysed groups. This concurrence was also tested graphically (by visual overlapping of the deviation on chromatograms) and numerically (by comparing the linear indices).

The linear indices are calculated in the following way:

$$I_x = 100\,z + 100\,[(t_R)_x - (t_R)_z] / [(t_R)_{z+1} - (t_R)_z]$$

x = component

t_R = total retention time

z = number of C atoms of the previous n-alcane standard

z + 1 = number of C atoms of the following n-alcane standard

The numerical data of the chromatogram were used to make a quantitative analysis of the single components. The area below the component deviation, calculated by the integrator, is proportional to the concentration of the sample component. This means that for each component the quantification of the analysed components was made.

To give names to the components, that is in order to determine them in terms of quality, the GC/MS analysis was used, a method enabling a direct identification of the volatile components based on the spectrum of their mass. This analysis relates to computer scanning of the known mass spectrum components database.

With the compilation of the GC and GC/MS data, tables are formed for each of the species and hybrids, including the identified components and the percentages of these components related to the the total contents of the samples.

Altogether there are 131 components (detected components); some components are present in all analysed species and hybrids, others just in a smaller number of groups; fifty-five components were identified. The different proportions of the identified components in the total content of the volatile depended on the species and hybrids (Tables 34 and 35). The detected components of all groups together were processed using *cluster* analysis in order to determine which groups to what extent are similar in terms of needle volatile composition. The input data for cluster analysis were the areas below the chromatogram peaks, calculated as quantified components in relation to the total area calculated by an integrator.

Table 33 shows a numerical position of the node, that is the linkage distance of groups in clusters. The table shows, same as the dendrogram in Figure 4, that hybrids *nith* and *thni* are the most similar as to the volatile composition (4.7). They are followed by groups *ni - nide* (8.2) and *de - deni* (11.8). The cluster *nith - thni* has a linkage distance of 19.1 with group *th*, while groups *ni - nide* and *de - deni* are linked in the cluster at a distance of 26.0. Eventually, all groups are linked at a distance of 34.8.

Table 33. Linkage distances of groups in clusters

Tablica 33. Udaljenosti povezivanja grupa u clustere

Linkage Distance *Udaljenost povez.*	1	2	3	4	5	6	7
4.7	*nith*	*thni*					
8.2	*ni*	*nide*					
11.8	*de*	*deni*					
19.1	*th*	*nith*	*thni*				
26.0	*ni*	*nide*	*de*	*deni*			
34.8	*ni*	*nide*	*de*	*deni*	*th*	*nith*	*thni*

The linkage of the individual groups into clusters is logical. Figure 4 shows that the Japanese black pine and the hybrids to which this species is one of the parents (*nith* and *thni*) form one separate group. Another group is composed of two units. The first is composed of the European black pine and the hybrids *nide*, to which this species is the female parent, while the second unit contains the Japanese red pine and the hybrids *deni*, to which this species is also the female parent.

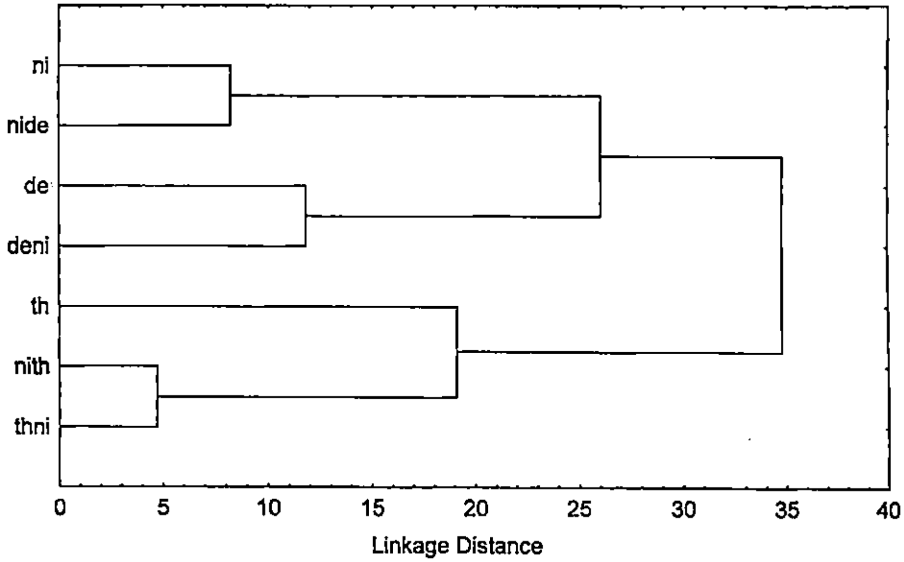

Figure 4. Horizontal hierarchical tree for seven analysed groups

Slika 4. Horizontalno hijerarhijsko stablo za sedam analiziranih grupa

The composition of the volatile is shown in two separate units, that is in two analyses. The first compares groups *ni*, *de*, *nide* and *deni*, while the second compares groups *ni*, *th*, *nith* and *thni*.

First analysis: *ni, de, nide, deni*
Prva analiza: *ni, de, nide, deni*

The needle volatile composition of the European black pine, the Japanese red pine and their F_1 hybrids *nide* and *deni* were analysed. The number of the detected components differs as to the the species and hybrids. The black pine and the Japanese red pine had 122 detected components each; the F_1 hybrids *nide* had 124 detected components, while in the reciprocal hybrids *deni* 114 components were found. Table 34 shows the identified components. In all four analysed groups, fifty-three components were identified. In the total content of the needle volatile of the European black pine, the proportion of the identified components is 94.4%. The respective proportions of the Japanese red pine, the F_1 hybrids *nide* and the reciprocal hybrids *deni* were 81.33%, 93.25%, and 88.36%. The remaining contents to 100% are the components that could not be reliably identified, and were found in small quantities.

The Japanese red pine and hybrids *deni* had a lower percentage of the identified components in the total content of the needle volatile. The reason for this was the fact that several components, some of which participated with more than 3% in the total content of the volatile, could not be identified. These were the components with linear indices higher than 2000. The same components were found either in very small quantities or in traces.

For the components that show deviations on the chromatogram - though not numerically registered, as they are found in very small quantities - there is a note in the table that they occur in traces.

Figures 5 - 8 are graphical illustrations of the components by histograms; the components, at least in one group, make a proportion higher than 10% (Figure 5); higher than 5% (Figure 6); 3% (Figure 7), and 1% (Figure 8).

In all four analysed groups, the highest proportion of all components is the proportion of α-pinene (*ni* 42.66%, *de* 25.78%, *nide* 40.55%, and *deni* 26.88%). As to the content of this monoterpene, the hybrids resemble the female parent, that is *nide* hybrids resemble the black pine, while *deni* hybrids resemble the Japanese red pine (Figure 5). The same applies to the content of β-pinene (*ni* 11.64%, *de* 5.78%, *nide* 10.93%, and *deni* 3.58%), and the content of β-phellandrene + limonene (*ni* 3.66%, *de* 10.68%, *nide* 4.73%, and *deni* 12.2%). β-phellandrene + limonene are registered on the chromatogram as one peak, while two components were detected by GC/MS method. They were all shown together, since it is impossible to express them separately in terms of quantity. According to the content of germacrene D (Figure 5), the hybrids are intermediary between the parent species (*ni* 17.72%, *de* 4.49%, *nide* 12.46%, and *deni* 13.95%).

Table 34. Volatile compounds in needle oil of Pinus nigra (= *ni*), P. densiflora (= *de*), and their F_1 hybrids (= *nide and deni*). Linear retention indices on the apolar column and quantification for all compounds are shown.

Tablica 34. Sastav eteričnih ulja iglica Pinus nigra (= ni*), P. densiflora (=* de*), i njihovih* F_1 *hibrida (=* nide i deni*). Za identificirane je komponente naveden postotni udio u ukupnom sadržaju eteričnih ulja i linearni retencijski indeksi na nepolarnoj koloni.*

Peak *Vrh*	Compound *Komponenta*	*ni*		*de*		*nide*		*deni*	
		%	Index *Indeks*	%	Index *Indeks*	%	Index *Indeks*	%	Index *Indeks*
1	trans-2-hexenal	0.1	835	0.1	835	0.08	829	0.12	834
2	tricyclene	0.19	920	0.9	918	0.72	915	0.79	919
3	α-thujene	0.28	925	0.05	922	0.14	920	0.15	924
4	α-pinene	42.66	935	25.78	930	40.55	930	26.88	932
5	camphene	1.13	943	3.41	940	2.65	938	3.02	942
6	sabinene	traces		0.37	963	0.25	961	0.45	965
7	β-pinene	11.64	971	5.78	967	10.93	966	3.58	968
8	myrcene	1.39	986	8.01	983	4.46	981	6.94	986
9	α-phellandrene	0.06	998	0.09	995	0.06	993	0.12	997
10	Δ-3-carene	0.2	1005	0.03	1002	0.04	1000	0.02	1005
11	α-terpinene	0.06	1010	0.08	1007	0.05	1005	0.06	1009
12	p-cymene	0.02	1014	0.02	1011	0.01	1009	traces	
13	β-phellandrene + limonene	3.66	1022	10.68	1018	4.73	1016	12.2	1021
14	cis-ocimene	0.02	1030	traces		0.02	1025	0.02	1029
15	trans-β-ocimene	1.03	1041	traces		1.09	1036	1.23	1040
16	γ-terpinene	0.05	1050	0.11	1046	0.06	1045	0.08	1048
17	α-terpinolene	0.61	1079	3.06	1076	2.13	1075	2.64	1078
18	linalool	0.06	1088	0.04	1085	0.04	1083	0.02	1088
19	α-campholene aldehyde	0.03	1107	0.03	1105	0.01	1104	0.02	1107
20	camphor	0.05	1122	0.02	1122	0.03	1118	0.01	1121
21	borneol	0.05	1148	0.05	1145	0.07	1144	0.11	1147
22	terpinen-4-ol	0.05	1161	0.09	1158	0.05	1157	0.06	1160
23	α-terpineol	0.19	1173	0.15	1170	0.15	1169	0.07	1172
24	methyl thymylether	0.04	1218	0.18	1215	0.06	1214	0.18	1217
25	linalyl acetate	0.22	1244	traces		0.03	1240	0.03	1243
26	bornyl acetate	0.81	1269	2.62	1267	3.18	1267	4.98	1269
27	α-terpinyl acetate	0.37	1333	0		0.07	1329	0.02	1332
28	bicycloelemene	0.02	1343	0.02	1340	0.02	1340	0.02	1342
29	geranyl acetate	0.01	1364	0.15	1363	0.09	1363	0.08	1365
30	α-copaene	0.07	1368	0.03	1365	0.06	1365	0.07	1367
31	β-bourbonene	0.23	1378	0		0.19	1374	0.13	1376
32	β-elemene	0.02	1383	0.05	1380	0.03	1379	0.1	1380
33	β-caryophyllene	5.62	1411	3.77	1406	4.05	1407	5.28	1409
34	β-cubebene	0.03	1418	traces		0.04	1415	0.03	1417
35	aromadendrene	traces		0.03	1425	0.02	1425	traces	
36	α-humulene	0.9	1442	0.59	1438	0.63	1438	0.8	1441

Peak Vrh	Compound *Komponenta*	*ni*		*de*		*nide*		*deni*	
		%	Index *Indeks*	%	Index *Indeks*	%	Index *Indeks*	%	Index *Indeks*
37	sesquiterpene hydrocarbon (M 204)	0.07	1450	0.04	1445	0.05	1447	0.06	1449
38	γ-muurolene	0		0.16	1462	0		0	
39	germacrene D	17.72	1474	4.49	1466	12.46	1470	13.95	1471
40	α-muurolene	0.26	1484	0.84	1481	0.39	1481	0.3	1483
41	β-cadinene	0.03	1494	0.03	1491	0.03	1491	0.04	1493
42	γ-cadinene	0.25	1500	0.33	1497	0.27	1497	0.27	1499
43	δ-cadinene	0.48	1510	0.61	1507	0.47	1507	0.43	1509
44	4,10-dimethyl-7-isopropyl (4,4,0)-bicyclo -1,4-decadiene	0.01	1518	traces		0.01	1515	0.01	1517
45	α-cadinene	0.03	1524	0.04	1521	0.03	1520	0.03	1523
46	endo-1-bourbonanol	0.58	1558	1.03	1555	0.56	1555	0.4	1556
47	caryophyllene oxide	0.1	1561	0.05	1558	0.03	1558	0.05	1560
48	oxygenated sesquiterpene (M 222)	0.02	1608	0.05	1606	0.02	1605	0.01	1607
49	α-cadinol	0.23	1621	0.57	1618	0.21	1618	0.18	1619
50	sesquiterpene hydrocarbon (M 204)	0.05	1624	0.14	1621	0.06	1621	0.04	1623
51	T-muurolol	0.27	1633	0.75	1630	0.25	1630	0.2	1631
52	oxygenated sesquiterpene (M 220)	0.09	1662	0.03	1659	0.03	1658	0.04	1660
53	13-epimanoyl oxyde	2.25	1973	0.32	1969	0.09	1968	0.07	1969
54	thunbergol	0.09	2031	5.56	2032	1.5	2030	1.97	2031
Σ		94.4		81.33		93.25		88.36	

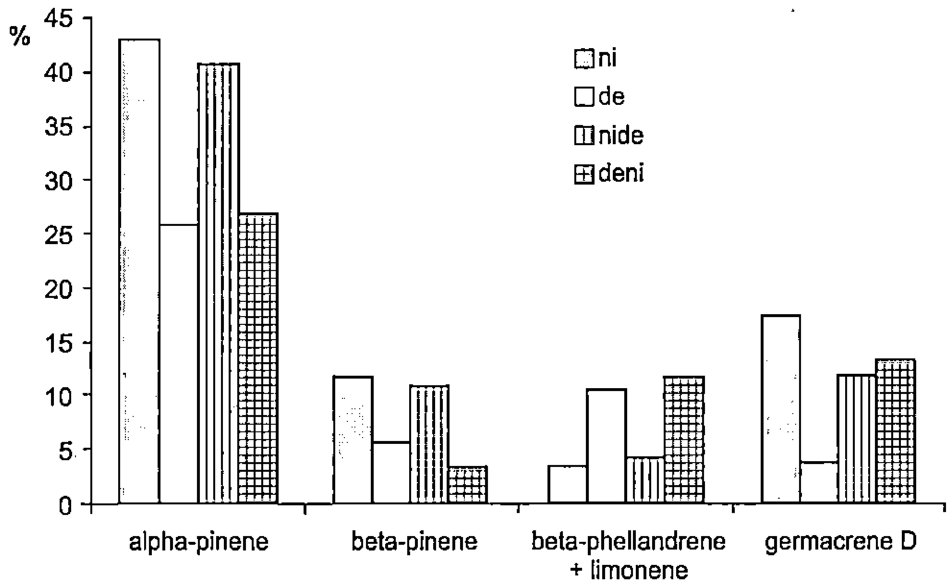

Figure 5. Components with more than 10 % of the total essential needle oil in at least one group (species or hybrid)

Slika 5. Komponente kojih je u ukupnom sadržaju eteričnih ulja iglica za barem jednu grupu (vrstu ili hibrid) više od 10 %

As to the content of myrcene (Figure 6), hybrids *nide* are intermediary between the parent species, while hybrids *deni* are closer to the female parent, the Japanese red pine (*ni* 1.39%, *de* 8.01%, *nide* 4.46%, and *deni* 6.94%).

The proportion of β-caryophyllene (Figure 6) in hybrids *nide* is closer to the Japanese red pine, while in hybrids *deni* it is closer to the black pine (*ni* 5.62%, *de* 3.77%, *nide* 4.05%, and *deni* 5.28%).

Thunbergol is a diterpene characteristic of the analysed Japanese pine species (*P. densiflora* and *P. thunbergiana*), while in the European species (*P. nigra* and *P. sylvestris*), it occurs either in very small quantities or in traces (Figure 6). Hybrids *nide* and *deni* are, as to the content of thunbergol, intermediary between the parent species, though closer to the black pine (*ni* 0.09%, *de* 5.56%, *nide* 1.5%, and *deni* 1.97%).

The proportion of camphene and α-terpinolene in both hybrid combinations is intermediary between the parent species (Figure 7), while with hybrid *deni* it is closer to the Japanese red pine (camphene: *ni* 1.13%, *de* 3.41%, *nide* 2.65, *deni* 3.02%; α-terpinolene: *ni* 0.61%, *de* 3.06%, *nide* 2.13, *deni* 2.64%).

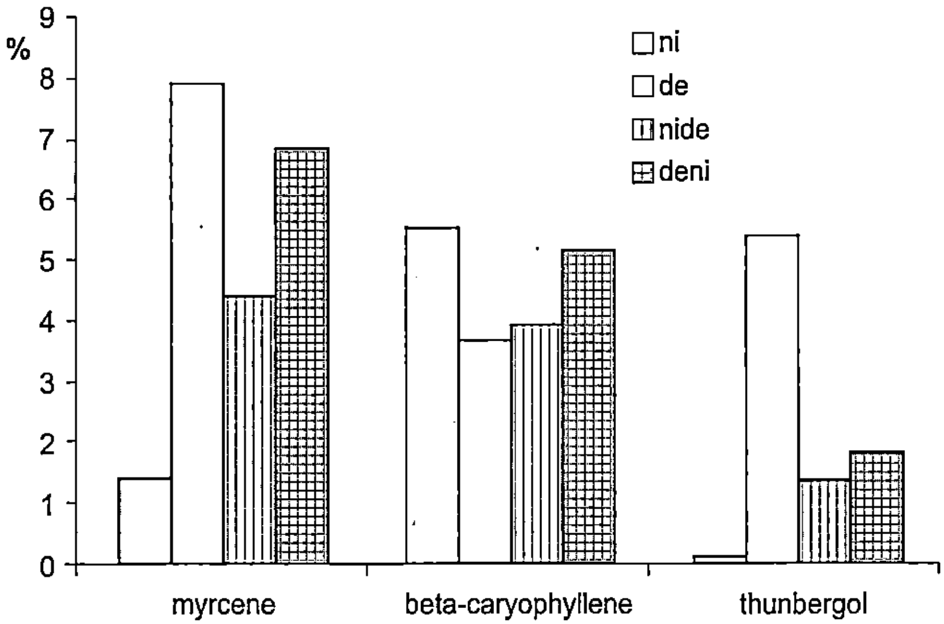

Figure 6. Components with more than 5 % of the total essential needle oil in at least one group

Slika 6. Terpeni kojih je u ukupnom sadržaju eteričnih ulja iglica za barem jednu grupu više od 5 %

Bornyl acetate (Figure 7) has a higher proportion in hybrid volatile than in the volatile of the parent species (*ni* 0.81%, *de* 2.62%, *nide* 3.18%, *deni* 4.98%).

The proportion of *trans*-β-ocimene (Figure 8) is slightly higher in hybrids than in black pine, while in the Japanese red pine it is present only in traces (*ni* 1.03%, *de* traces, *nide* 1.09%, *deni* 1.23%).

The proportions of sesquiterpene *endo*-1-bourbonanol (Figure 8) in black pine and hybrid *nide* are similar (*ni* 0.58%, *nide* 0.56%); the highest proportion was in the Japanese red pine (1.03%), and the lowest proportion was found in hybrid *deni* (0.4%).

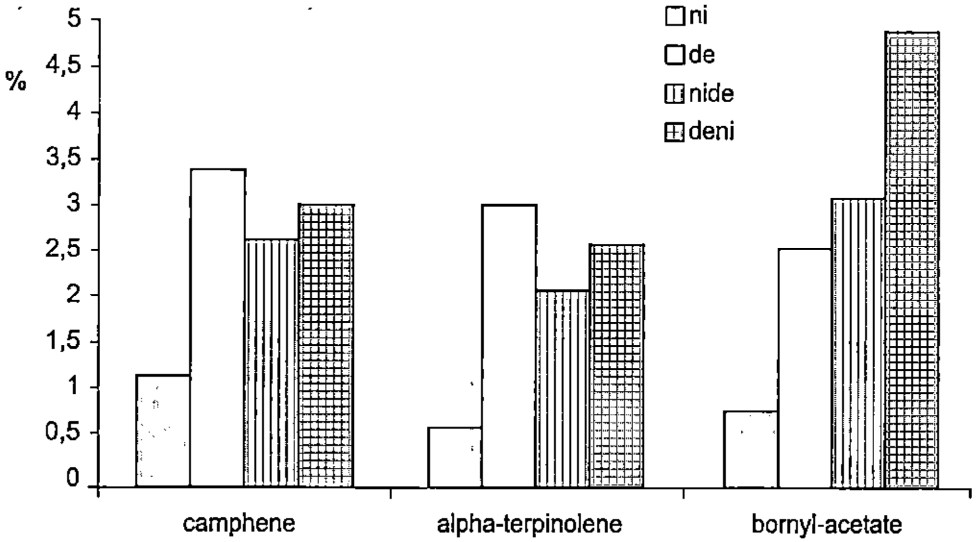

Figure 7. Components with more than 3 % of the total essential needle oil in at least one group

Slika 7. Terpeni kojih je u ukupnom sadržaju eteričnih ulja iglica za barem jednu grupu više od 3 %

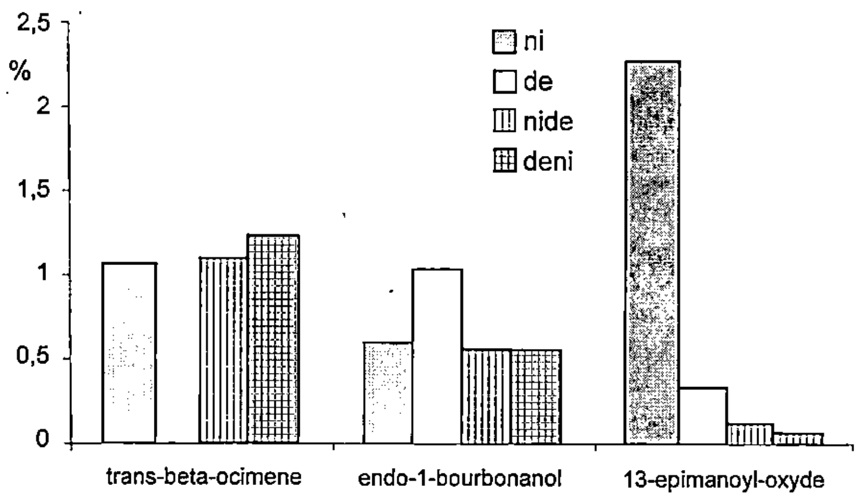

Figure 8. Components with more than 1 % of the total essential needle oil in at least one group

Slika 8. Terpeni kojih je u ukupnom sadržaju eteričnih ulja iglica za barem jednu grupu više od 1 %

The proportion of 13-epimanoyl oxyde (Figure 8) is in the black pine higher than in the Japanese red pine (*ni* 2.25%, *de* 0.32%), while the hybrids have a smaller proportion of this diterpene than their parent species (*nide* 0.09%, *deni* 0.07%).

F_1 hybrids *P. nigra* × *P. densiflora*
F_1 hibridi *P. nigra* × *P. densiflora*

Of the 124 detected components fifty-three were identified. The identified components make 93.25% of the total needle volatile. All identified components are terpenes (93.17%), except for the *trans*-2-hexenal (0.08%), which is an n-alkene (peak 1 in Table 34).

The largest number, twenty-eight, of the identified components are monoterpenes (peaks 2 - 29 in Table 34). They participate in the total content of the volatile with 71.69%, which is more than both parent species (*nide* 64.9%, *deni* 61.72%). Monoterpenes with the highest proportion in the needle volatile content are α-pinene (40.55%), β-pinene (10.93%), β-phellandrene + limonene (4.73%) and myrcene (4.46%). As to the proportion of α-pinene and β-pinene, hybrids *nide* are similar to the black pine (α-pinene: *ni* 42.66%, *de* 25.78%; β-pinene: *ni* 11.64%, *de* 5.78%). The proportion of β-phellandrene + limonene and the proportion of myrcene is in the hybrids intermediary between the parent species (Figures 5 and 6).

There are twenty-two sesquiterpenes (19.89%) (peaks 30 - 37, 39 - 52 in Table 34), of which eighteen were identified (19.73%) and four partly described (0.16%). The main components in this group of compounds are germacrene D (12.46%) and β-caryophyllene (4.05%). According to the proportions of these two components, the hybrids are intermediary between their parent species (germacrene D: *ni* 17.72%, *de* 4.49%; β-caryopyllene: *ni* 5.62%, *de* 3.77%) (Figures 5 and 6).

Two diterpenes were identified, 13-epimanoyl oxide (0.09%) and thunbergol (1.5%) (peaks 53 and 54 in Table 34).

F_1 hybrids *P. densiflora* × *P. nigra*
F_1 hibridi *P. densiflora* × *P. nigra*

Fifty-three components were identified in the 114 detected components of hybrids *deni*. The proportion of the identified components is 88.36% of the needle volatile content: 52 components are terpenes (88.24%), while one component, *trans*-2-hexenal (0.12%), is n-alkene (peak 1 in Table 34).

Monoterpenes are the main group of compounds, altogether twenty-eight (peaks 2 - 29 in Table 34). The proportion of monoterpenes in the total content of the needle volatile is 63.78%, which makes hybrids *deni* intermediary between the parent species (*ni* 64.9%, *de* 61.72%). In this group of compounds, the most significant components are α-pinene (26.88%) and β-pinene (3.58%). As to the proportion of α-pinene, β-phellandrene + limonene, myrcene and β-pinene, hybrids *deni* resemble the Japanese red pine (α-pinene: *ni* 42.66%, *de* 25.78%; β-phellandrene + limonene: *ni* 3.66%, *de* 10-68%; myrcene: *ni* 1.39%, *de* 8.01%; β-pinene:

ni 11.64%, *de* 5.78%). The proportion of bornyl acetate is higher in the hybrids than in the parent species, though closer to the Japanese red pine (*ni* 0.81%, *de* 2.62%) (Figures 5 7).

Next in significance, sesquiterpenes are the group of compounds twenty-two in number (peaks 30 - 37; 39 - 52 in Table 34). Eighteen sesquiterpenes were identified (22.27%), while four were partly described (0.15%). The most significant components in this compound group are germacrene D (13.95%) and β-caryophyllene (5.28%). The proportion of these components in hybrids *deni* is intermediary between the parent species (germacrene D: *ni* 17.72%, *de* 4.49%; β-caryophyllene: *ni* 5.62%, *de* 3.77%) (Figures 5 and 6).

The identified diterpenes are 13-epimanoyl oxide (0.07%) and thunbergol (1.97%).

Second analysis: *ni, th, nith, thni*

Druga analiza: *ni, th, nith, thni*

The needle volatile composition of the European black pine, the Japanese black pine and their F_1 hybrids *nith* and *thni* were analysed. There were 122 detected components of the European black pine and 87 components of the Japanese black pine; F_1 hybrids *nith* had 120 detected components, while 78 components were found in the reciprocal hybrids *thni*. Table 35 shows the identified components.

Fifty-three components were identified for the European black pine; 50 components of the Japanese black pine; 53 components of hybrids *nith*, and 42 components of hybrids *thni*. Of the total content of the needle volatile of the European black pine, 94.4% were identified components. The respective proportions of the Japanese black pine, F_1 hybrids *nith* and reciprocal hybrids *thni* are 94.85%, 95.99% and 96.1%.

Figures 9 - 11 present graphically in histograms the component which, at least in one group, make the proportion higher than 10% (Figure 9); higher than 3% (Figure 10), and higher than 1% (Figure 11).

Table 35. Volatile compounds in needle oil of of Pinus nigra (= *ni*), P. thunbergiana (= *th*), and their F_1 hybrids (= *nith and thni*). Linear retention indices on the apolar column and quantification for all compounds are shown.

Tablica 35. Sastav eteričnih ulja iglica Pinus nigra (= ni*), P. thunbergiana (=* th*), i njihovih* F_1 *hibrida (=* nith i thni*). Za identificirane je komponente naveden postotni udio u ukupnom sadržaju eteričnih ulja i linearni retencijski indeks na nepolarnoj koloni.*

Peak *Vrh*	Compound *Komponenta*	*ni*		*th*		*nith*		*thni*	
		%	Index *Indeks*	%	Index *Indeks*	%	Index *Indeks*	%	Index *Indeks*
1	trans-2-hexenal	0.1	835	0.49	832	0.52	829	0.18	830
2	tricyclene	0.19	920	0.44	918	0.38	916	0.62	916
3	α-thujene	0.28	925	0.04	923	0.25	921	0.36	920
4	α-pinene	42.66	935	19.56	929	31	930	30.63	928
5	camphene	1.13	943	1.8	940	1.76	939	2.49	938
6	sabinene	traces		traces		traces		0.36	962
7	β-pinene	11.64	971	34.13	969	26.45	969	22.95	966
8	myrcene	1.39	986	4.7	984	2.28	982	2.75	981
9	α-phellandrene	0.06	998	0.12	996	0.08	994	0.08	993
10	Δ-3-carene	0.2	1005	0.03	1004	0.05	1001	0.12	1001
11	α-terpinene	0.06	1010	0.05	1008	0.06	1006	0.08	1006
12	p-cymene	0.02	1014	traces		0.01	1010	0.02	1014
13	β-phellandrene + limonene	3.66	1022	10.56	1019	7.99	1018	4.69	1016
14	cis-ocimene	0.02	1030	traces		0.02	1026	0.03	1026
15	trans-β-ocimene	1.03	1041	traces		0.7	1037	0.5	1036
16	γ-terpinene	0.05	1050	0.08	1047	0.07	1045	0.08	1045
17	α-terpinolene	0.61	1079	2.64	1077	1.83	1076	3.4	1075
18	linalool	0.06	1088	0.06	1086	0.03	1084	0	
19	α-campholene aldehyde	0.03	1107	0.03	1106	0.03	1104	0	
20	camphor	0.05	1122	0.03	1121	0.03	1118	0	
21	borneol	0.05	1148	0.06	1147	0.06	1144	0.05	1145
22	terpinen-4-ol	0.05	1161	0.08	1159	0.08	1157	0.06	1157
23	α-terpineol	0.19	1173	0.45	1171	0.35	1169	0.21	1169
24	methyl thymylether	0.04	1218	0.18	1216	0.11	1215	0.06	1215
25	linalyl acetate	0.22	1244	traces		0.03	1241	0	
26	bornyl acetate	0.81	1269	1.94	1267	2.29	1267	3.13	1266
27	α-terpinyl acetate	0.37	1333	0		0.28	1330	0	
28	bicycloelemene	0.02	1343	0.03	1341	0.01	1340	0	
29	geranyl acetate	0.01	1364	0.25	1364	0.05	1363	0	

Peak *Vrh*	Compound *Komponenta*	*ni*		*th*		*nith*		*thni*	
		%	Index *Indeks*	%	Index Indeks	%	Index *Indeks*	%	Index *Indeks*
37	sesquiterpene hydrocarbon (M 204)	0.07	1450	0.03	1446	0.04	1447	0.07	1446
38	γ-muurolene	0		0.29	1463	0		0	
39	germacrene D	17.72	1474	8.33	1467	11.83	1470	13.63	1467
40	α-muurolene	0.26	1484	0.71	1481	0.34	1481	0.55	1480
41	β-cadinene	0.03	1494	0.06	1492	0.03	1491	0.02	1491
42	γ-cadinene	0.25	1500	0.47	1497	0.21	1497	0.26	1496
43	δ-cadinene	0.48	1510	0.82	1507	0.42	1507	0.51	1506
44	4,10-dimethyl-7-isopropyl (4,4,0)-bicyclo-1,4-decadiene	0.01	1518	0		0.01	1515	0	
45	α-cadinene	0.03	1524	0.04	1521	0.03	1521	0.03	1520
46	endo-1-bourbonanol	0.58	1558	0.66	1555	0.66	1555	1.14	1554
47	caryophyllene oxide	0.1	1561	traces		0.04	1558	0	
48	oxygenated sesquiterpene (M 222)	0.02	1608	0		0.02	1605	0.02	1604
49	α-cadinol	0.23	1621	0.3	1618	0.25	1618	0.33	1617
50	sesquiterpene hydrocarbon (M 204)	0.05	1624	0.08	1621	0.05	1621	0.06	1620
51	T-muurolol	0.27	1633	0.35	1630	0.32	1630	0.42	1629
52	oxygenated sesquiterpene (M 220)	0.09	1662	0.04	1658	0.04	1658	0	
53	13-epimanoyl oxyde	2.25	1973	0.07	1968	0.05	1967	0.04	1967
54	thunbergol	0.09	2031	0.67	2027	0.55	2027	1.53	2027
Σ		94.4		94.85		95.99		96.1	

The proportions of the four components shown in Figure 9 are in both hybrid cross-breeding combinations intermediary between the parent species (α-pinene: *ni* 42.66%, *th* 19.56%, *nith* 31.0%, *thni* 30.63%; β-pinene: *ni* 11.64%, *th* 34.13%, *nith* 26.45, *thni* 22.95%; β-phellandrene + limonene: *ni* 3.66%, *th* 10.56%, *nith* 7.99, *thni* 4.69%; germacrene D: *ni* 17.72%, *th* 8.33%, *nith* 11.83, *thni* 13.63%). The component, which has the highest percentage in the needle volatile of the European black pine and of hybrids *nith* and *thni*, is α-pinene, while the same applies to β-pinene in the Japanese black pine.

The proportion of myrcene in the needle volatile of the Japanese black pine is 4.7%. This proportion is 1.39% with the European black pine (Figure 10). The proportion of myrcene in the hybrids is intermediary between the parent species (*nide* 2.28%, *deni* 2.75%).

The proportion of bornyl acetate is higher in the needles of the hybrids than of the parent species (*ni* 0.81%, *th* 1.94%, *nith* 2.29, *thni* 3.13%). The proportion of this component in hybrids *nith* and *thni* is closer to the values of the Japanese black pine than those of the European black pine (Figure 10).

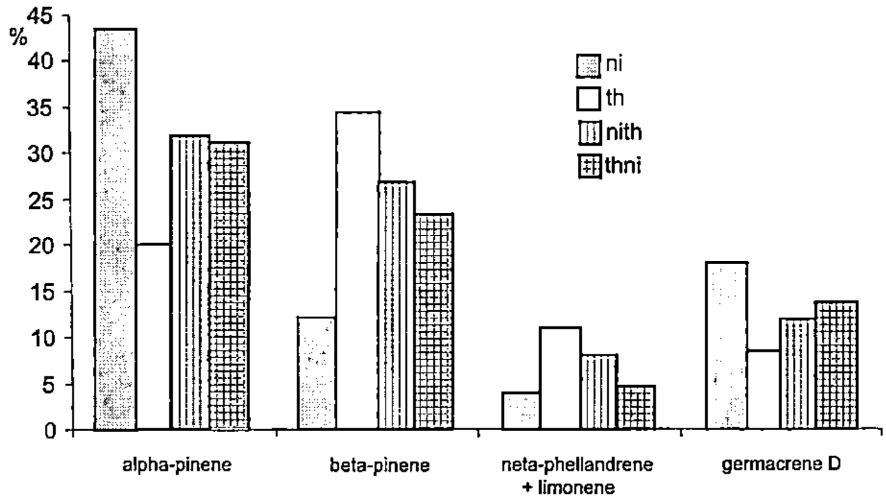

Figure 9. Components with more than 10 % of the total essential needle oil in at least one group

Slika 9. Terpeni kojih je u ukupnom sadržaju eteričnih ulja iglica za barem jednu grupu više od 10 %

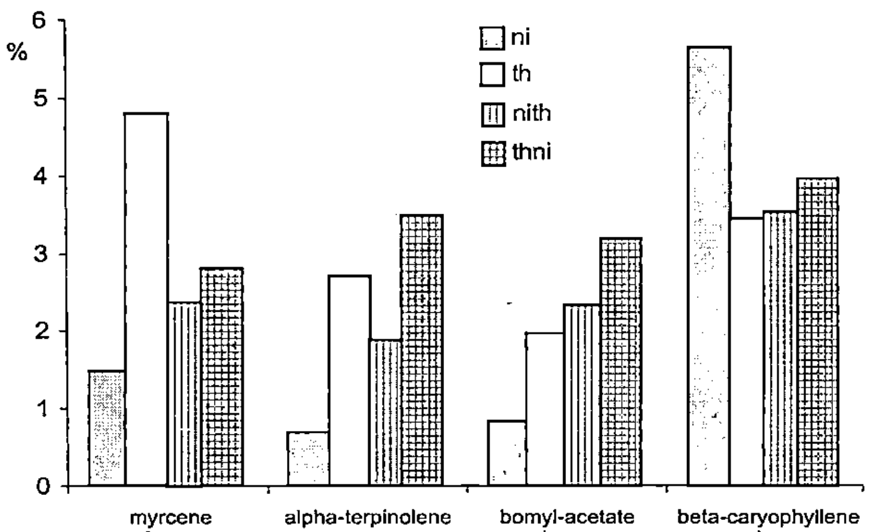

Figure 10. Components with more than 3 % of the total essential needle oil in at least one group

Slika 10. Terpeni kojih je u ukupnom sadržaju eteričnih ulja iglica za barem jednu grupu više od 3 %

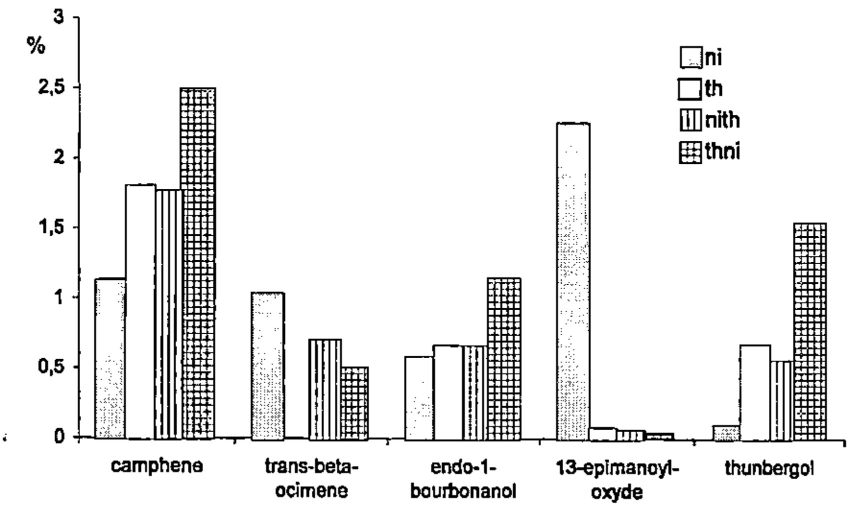

Figure 11. Components with more than 1 % of the total essential needle oil in at least one group

Slika 11. Terpeni kojih je u ukupnom sadržaju eteričnih ulja iglica za barem jednu grupu više od 1 %

Sesquiterpene β-caryophyllene (Figure 10) has the highest proportion in the needle volatile of the European black pine, while its proportions in the Japanese black pine and hybrids *nith* and *thni* are almost the same (*ni* 5.62%, *th* 3.42%, *nith* 3.5, *thni* 3.92%).

The proportion of camphene (Figure 11) is the lowest in the European black pine, the highest in hybrid *thni*, and almost the same in the Japanese black pine and hybrid *nith* (*ni* 1.13%, *th* 1.8%, *nith* 1.76, *thni* 2.49%). Similar proportions were found in sesquiterpene *endo*-1-bourbonanol and diterpene thunbergol (*endo*-1-bourbonanol: *ni* 0,58%, *th* 0.66%, *nith* 0.66, *thni* 1.14%; thunbergol: *ni* 0.09%, *th* 0.67%, *nith* 0.55, *thni* 1.53%).

The proportion of *trans*-β-ocimene in the needle volatile of the European black pine was 1.03%, while in the Japanese black pine it was found only in traces (Figure 11). The proportion of this monoterpene in hybrids is intermediary between the parent species (*nith* 0.07, *thni* 0.5%).

The proportion of diterpene 13-epimanoyl oxide (Figure 11) in the needle volatile of the European black pine is 2.25%, while a very small proportion is found in the Japanese black pine and hybrids *nith* and *thni* (*th* 0,07%, *nith* 0.05, *thni* 0.04%).

F_1 hybrids *P. nigra* × *P. thunbergiana*

F_1 hibridi *P. nigra* × *P. thunbergiana*

Of the 120 detected components, fifty-three were identified. The identified components make 95.99% of the total needle volatile of hybrid *nith*. Fifty-two components are terpenes (95.47%), except the *trans*-2-hexenal (0.52%), which is an n-alkene (peak 1 in Table 35).

The largest number, twenty-eight, of the identified components are monoterpenes (peaks 2 - 29 in Table 35). The proportion of monoterpenes in the total content of needle volatile is 76.3%, which makes hybrids *nith* similar to the Japanese black pine (*ni* 64.9%, *th* 77.26%). The proportions of the monoterpenes α-pinene (31.0%), β-pinene (26.45%) and β-phellandrene + limonene (7.99%) are the highest. The proportion of α-pinene in hybrids *nith* is intermediary between the parent species (*ni* 42.66%, *th* 19.56%). As to the proportions of β-pinene and β-phellandrene + limonene, the hybrids are more similar to the Japanese black pine (β-pinene: *ni* 11.64%, *th* 34.13%; β-phellandrene + limonene: *ni* 3.66%, *th* 10.56%) (Figure 9).

Sesquiterpenes are the next group of compounds, twenty-two in number (peaks 30 - 37; 39 - 52 in Table 35). Eighteen sesquiterpenes were identified (18.44%), while four were partly described (0.15%). The most significant components in this compound group are germacrene D (11.83%) and β-caryophyllene (3.5%). As to the proportion of these components, hybrids *nith* are more similar to the Japanese black pine than to the European black pine (germacrene D: *ni* 17.72%, *th* 8.33%; β-caryophyllene: *ni* 5.62%, *th* 3.42%) (Figures 9 and 10).

In hybrids *nith*, two diterpenes were identified, 13-epimanoyl oxide (0.05%) and thunbergol (0.55%). As to the proportions of these components (Figure 11), the hybrids resemble more the Japanese pine (13-epimanoyl oxide: *ni* 2.25%, *th* 0.07%; thunbergol: *ni* 0.09%, *th* 0.67%).

F_1 hybrids *P. thunbergiana* × *P. nigra*
F_1 hibridi *P. thunbergiana* × *P. nigra*

In hybrids *thni*, seventy-eight components were detected. According to this number, these hybrids resemble the Japanese black pine, in which eighty-seven components were detected, while 122 components were found in the European black pine. Forty-two components were identified, fewer than in the parent species (*ni* 53, *th* 50). However, these components make 96.1% of the needle volatile content, which is more than with the parent species (*ni* 94.4%, *th* 94.85%). In the identified components, forty-one are terpenes (95.92%), while one component, *trans*-2-hexenal (0.18%), is an n-alkene (peak 1 in Table 35).

Monoterpenes are the most significant group of compounds. There are twenty-one monoterpenes (peaks 2 - 17, 21 - 24 and 26 in Table 35). Their proportion in the total content of the needle volatile is 72.7%, which makes hybrids *thni* and *nith* similar to the Japanese black pine (*ni* 64.9%, *th* 77.26%). The most significant components of this group are α-pinene (30.63%), β-pinene (22.95%) and β-phellandrene + limonene (4.69%). The proportions of α-pinene and β-pinene in hybrids *thni* are intermediary as to the respective proportions in the parent species (α-pinene: *ni* 42.66%, *th* 19.56%; β-pinene: *ni* 11.64%, *th* 34.13%). As to the proportion of β-phellandrene + limonene, the hybrids are more similar to the European black pine (*ni* 3.66%, *th* 10.56%) (Figure 9).

There are eighteen sesquiterpenes (peaks 30 - 34, 36, 37, 39 -43, 45, 46, 48 - 51, Table 35). Fifteen sesquiterpenes were identified (21.53%), while three were partly described (0.15%).

The most significant components in this compound group are germacrene D (13.63%) and β-caryophyllene (3.92%). The proportion of germacrene D in hybrids *thni* is intermediary between the parent species (*ni* 17.72%, *th* 8.33%). The proportion of β-caryophyllene makes these hybrids more similar to the Japanese black pine (*ni* 5.62%, *th* 3.42%) (Figures 9 and 10).

The identified diterpenes are 13-epimanoyl oxide (0.04%) and thunbergol (1.53%) (Figure 11).

DISCUSION
RASPRAVA

DESCRIPTIVE STATISTICS
DESKRIPTIVNA STATISTIKA

Average needles and tracheids of one-year shoots in the measured sample (Tables 2 - 20) can be described in the following way:

European black pine
Europski crni bor

The average lengths of the needles and the fascicle sheath are 12.4 cm and 1 cm respectively. In the middle of the needle length there are twenty ventral stomatal rows, of which number eight are ventral and twelve are dorsal. There are 101 stomata along one stomatal row on the inner side of the needle, on a 1 cm long segment from the middle of the needle. On the same segment, along one needle margin, there are thirty-two serrations. In the middle of the needle's cross-section area there is a central cylinder, the stellar region, whose area is 0.2724 mm², its height 0.427 mm, and its diameter 0.796. The largest average number of hypodermal cell layers on the needle cross-section is 3.4, which is more than in other analysed groups. The average number of resin canals is six, and all of them are located medially. Each resin canal is surrounded by a layer of epithelial cells surrounded by sheath cells. The number of sheath cells around the canal was counted on the cross-section parts with the smallest number of cells (8.3) and the largest number of cells (13.4).

The average lengths and diameters of one-year shoot tracheids are 1.055 mm and 24.1 μm respectively. .

Japanese red pine
Japanski crveni bor

The average needle length is 12.0. The fascicle sheath length is 1.0 cm. There are seven ventral stomatal rows and ten dorsal stomatal rows in the middle of the needle length. On a 1 cm long segment in the middle of the needle along the ventral stomatal rows, there are 119 stomata, more than in all other analysed species and hybrids. On the same segment, along one needle rim, there are fifty-four serrations. The area of the needle cross-section in 0.5935 mm^2, its height 0.733 mm, and its diameter 1.135 mm. The stellar region cross-section area is 0.1479 mm^2; its height is 0.319 mm, and its diameter 0.591 mm. The average cross-section area values of the needle and of the stellar region are smaller in the Japanese red pine (it has the thinnest needles) than in other analysed groups. On a single cross-section there is the largest average number of layers of hypodermal cells (1.3). The resin canals are located near the hypoderm. Their average number is 6.5 Of all analysed groups, the Japanese red pine is the only one that typically have all resin canals located near the hypoderm. The largest number of sheath cells around the resin canal is 11.6, the smallest is 7.3, which is fewer than with other analysed groups.

The average tracheid length and width of one-year shoots are 1.232 mm and 21.9 μm respectively.

Japanese black pine
Japanski crni bor

The average needle length is 12.7 cm. The fascicle sheath length is 1.1 cm. There are twenty ventral stomatal rows, seven ventral and thirteen dorsal. On a 1 cm long segment in the middle of the needle along the ventral stomatal rows, there are ninety-two stomata, which is the smallest average number of stomata in all analysed groups. On the same segment, along one needle rim, there are sixty serrations, which is more than in other analysed species and hybrids. The average area of the needle cross-section is 1.0056 mm^2, its height is 1.058 mm, and its diameter 1.379 mm. The average stellar region cross-section area is 0.2501 mm^2; its height is 0.452 mm, and its diameter 0.704 mm. The average cross-section area values of the needle and of the stellar region of the Japanese black pine are the highest of all other analysed groups. The largest average number of layers of hypodermal cells is 3.1. The resin canals are medial, and their average number is 4.6. Of all analysed groups, the Japanese black pine has the smallest number of resin canals located in the middle along the needle length. The largest number of sheath cells around the resin canal is 11.3 - fewer than in other species and hybrids - while the smallest respective number is 7.7.

The average tracheid length and width of one-year shoots are 1.232 mm (the longest of all analysed groups) and 21.9 μm, respectively.

F_1 hybrids *nide*
F_1 hibridi *nide*

The average needle length is 13.0 cm, which means that hybrids *nide* have the longest needles of all analysed groups. The average fascicle sheath length is 1.1 cm. Altogether there are eighteen stomatal rows in the middle of the needle length, of which seven are ventral and eleven are dorsal. On a 1 cm long segment in the middle of the needle along the ventral stomatal rows, there are 104 stomata. On the same segment, along one needle rim, there are thirty-five serrations. The area of the needle cross-section is 1.8180 mm^2, its height is

0.873 mm, and its width 1.313 mm. The stellar region cross-section area is 0.2153 mm²; its height is 0.376 mm, and its diameter is 0.717 mm. The largest average number of layers of hypodermal cells on a cross-section is 1.3. Their average number of resin canals located near the hypoderm is 2.4. The average number of resin canals is 7.7, of which 5.6 are located medially, and 2.1 near the hypoderm. The largest number of sheath cells are located around the resin canals (13.9), while their smallest average number is 8.5.

The average tracheid length and width of one-year shoots are 1.065 mm and 21.1 µm respectively.

F_1 hybrids *deni*
F_1 hibridi *deni*

The average needle length is 11.5, while the average fascicle sheath length is 0.9 cm. In the middle of the needle length, there are eight ventral and eleven dorsal stomatal rows. On a 1 cm long segment in the middle of the needle along the ventral stomatal rows, there are 103 stomata. On the same segment, along one needle rim, there are forty serrations. The average area of the needle cross-section is 0.8142 mm², its height is 0.898 mm, and its width 1.308 mm. The stellar region cross-section area is 0.2250 mm²; its height is 0.384 mm, and its diameter 0.743 mm. The largest average number of layers of hypodermal cells on a cross-section is 2.5. The average number of resin canals located near the hypodermis is 2.4. The average number of resin canals is 7, of which 4.1 are located medially, and 2.9 near the hypoderm. The largest number of sheath cells are located around the resin canals (14.1), while their smallest average number is 8.8. This smallest number of cells is larger than in other analysed groups.

The average tracheid length and width of one-year shoots are 1.087 mm and 20.3 µm respectively. Hybrids *deni* have the narrowest tracheids of all analysed groups.

F_1 hybrids *nith*
F_1 hibridi *nith*

The average needle length is 10.2, while the average fascicle sheath length is 1.0 cm. In the middle of the needle length, there are seven ventral and twelve dorsal stomatal rows. On a 1 cm long segment in the middle of the needle along the ventral stomatal rows, there are ninety-nine stomata. On the same segment, along one needle rim, there are thirty-seven serrations. The average area of the needle cross-section is 0.9799 mm², its height is 0.998 mm, and its width 1.414 mm. The stellar region cross-section area is 0.2501 mm²; its height is 0.424 mm, and its diameter 0.745 mm. The largest average number of layers of hypodermal cells on a cross-section is 3.1. Resin canals are located medially, and their average number is 5.5. The largest number of sheath cells around the resin canals is 12.8, while the smallest average number is 7.9.

The average tracheid length and width of one-year shoots are 1.219 mm and 26.9 µm respectively. Hybrids *nith* have the widest tracheids of all analysed groups.

F_1 hybrids *thni*
F_1 hibridi *thni*

The average needle length is 9.6 cm. The average fascicle sheath length is 1.0 cm. In the middle of the needle length, there are nine ventral and fifteen dorsal stomatal rows. On a 1 cm long segment in the middle of the needle along the ventral stomatal rows, there are 109 stomata. On the same segment, along one needle rim, there are thirty-five serrations. The average area of th needle cross-section is 1.1550 mm^2, its height is 1.082 mm, and its width 1.520 mm. Of all analysed groups, hybrids *thni* have the largest area and height of the needle cross-section. The stellar region cross-section area is 0.3032 mm^2; its height is 0.449 mm, and its diameter is 0.855 mm. The largest average number of layers of hypodermal cells on a cross-section is 3.0. Resin canals are located medially, and their average number is 8.9, which is the largest number of medial resin canals of all analysed species and hybrids. The largest number of sheath cells around the resin canals is 11.7, while the smallest average number is 7.0.

The average tracheid length and width of one-year shoots are 1.366 mm and 26.5 µm respectively.

Table 36 shows correlation coefficients of all species and hybrids, of the traits that are expected to be related.

Table 36. Correlation coeficients
Tablica 36. Koeficijenti korelacije

Traits *Svojstva*	*ni*	*de*	*th*	*nide*	*deni*	*nith*	*thni*
LI - LR	0.60	0.39	0.52	0.67	0.76	0.29	0.76
LT - DT	0.31	0.83	0.36	0.26	0.04	0.53	0.19
NPPU - NPPV	0.67	0.58	0.52	0.63	0.28	0.43	0.49
PPP- HPP	0.81	0.56	0.87	0.82	0.74	0.76	0.80
PPP - DPP	0.93	0.87	0.97	0.95	0.98	0.91	0.94
PPP - PCC	0.93	0.89	0.94	0.95	0.93	0.94	0.87
PPP - HCC	0.84	0.75	0.90	0.87	0.87	0.72	0.58
PPP - DCC	0.90	0.82	0.87	0.92	0.87	0.86	0.87
HPP - DPP	0.65	0.36	0.81	0.69	0.72	0.52	0.66
HPP - PCC	0.75	0.37	0.87	0.78	0.76	0.78	0.82
HPP - HCC	0.67	0.29	0.86	0.73	0.67	0.55	0.55
HPP - DCC	0.73	0.45	0.79	0.75	0.82	0.76	0.79
DPP - PCC	0.88	0.71	0.92	0.93	0.90	0.82	0.78
DPP - HCC	0.73	0.49	0.81	0.83	0.82	0.56	0.38
DPP - DCC	0.91	0.84	0.91	0.94	0.87	0.82	0.86
PCC - HCC	0.90	0.89	0.91	0.92	0.95	0.80	0.73
PCC - DCC	0.95	0.81	0.95	0.97	0.88	0.89	0.94
HCC - DCC	0.76	0.52	0.75	0.83	0.72	0.47	0.50

The correlation coefficients of the species and hybrids vary between the trait pairs, needle lengths and fascicle sheath length (*LI - LR*), the one-year shoot tracheid width and length (*LT - DT*), and the number of ventral and dorsal stomatal rows (*NPPU - NPPV*). However, they are not high, and it can be concluded that all traits should be included into the discriminant analysis. Correlation coefficients higher than 0.8 are considered as high. If we look at the correlation between the area, height and width of the needle cross-section and the stellar region cross-section, we find high correlation coefficients of the following pairs of traits: the area and diameter of the needle cross-section (*PPP - DPP*); the areas of the needle cross-section and those of the stellar region (*PPP - PCC*); the area of the needle cross-section and the diameter of the stellar region cross-section (*PPP - DCC*); the diameters of the needle cross-section and those of the stellar region (*DPP - DCC*); the area and the height of the stellar region cross-section (*PCC - HCC*), except for hybrid *thni;* the area and the diameter of the stellar region cross-section (*PCC - DCC*). With no considerable significance of the accuracy of determination, it is in future sufficient to measure only one of the two traits that are mutually highly correlated.

Discriminant analysis
Diskriminacijska analiza

Table 37 shows three traits by which the analysed species and hybrids are best discriminated. This is a list of variables which best contribute to group discrimination. However, by using only these traits, the accuracy of discrimination would be lower than shown in the results of the research, where nineteen different traits were included into the analysis.

Table 37. Three traits by which the species are discriminated, separated by the discriminant analysis from nineteen analysed traits

Tablica 37. Tri svojstva po kojima se grupe najbolje razlikuju, izdvojena diskriminacijskom analizom od devetnaest analiziranih svojstava

Analysis *Analiza*	Groups *Grupe*	1st trait *1. svojstvo*	2nd trait *2. svojstvo*	3rd trait *3. svojstvo*
1	*ni - nide*	*NSKM*	*HCC*	*NHmax*
	ni - deni	*NSKH*	*DT*	*LI*
	de - nide	*PPP*	*NSKM*	*NZ/cm*
	de - deni	*PPP*	*PCC*	*DPP*
	nide - deni	*PPP*	*DCC*	*HCC*
2	*ni - nith*	*DPP*	*DCC*	*HPP*
	ni - thni	*LT*	*LI*	*HCC*
	th - nith	*NZ/cm*	*LT*	*DCC*
	th - thni	*DPP*	*DCC*	*NSKM*
	nith - thni	*DPP*	*PCC*	*NSKM*

First analysis: *ni, de, nide, deni*
Prva analiza: *ni, de, nide, deni*

F_1 hybrids *nide* best differ from the black pine by the number of medial resin canals (*NSKM*), by the height of the stellar region cross-section (*HCC*), and by the highest number of hypoderm layers in the needle cross-section (*NHmax*). The average values of all three traits are higher with black pine than with the hybrids.

In discriminating F_1 hybrid *nide* from the Japanese red pine, the following are the most useful traits: the area of the needle cross-section (*PPP*), the number of medial resin canals (*NSKM*), and the number of serrations along one needle rim on a 1 cm-long segment taken from the middle of the needle (*NZ/cm*). The average values of *PPP* and *NSKM* are higher with hybrids than with the Japanese red pine, while the values of *NZcm* are lower in hybrids and higher in the Japanese red pine.

The following three traits are best for discriminating F_1 hybrids *deni* from the European black pine: the number of external resin canals (*NSKH*); the tracheid width of one-year old shoots (*DT*), and the needle length (*LI*). The average *NSKH* is in hybrids higher than in the black pine, which has medial resin canals. The average values of *DT* and *LI* are higher in the black pine than in hybrid *deni*.

F_1 hybrids *deni* are best discriminated from the Japanese red pine by the following: the area of the needle cross-section (*PPP*); the area of the stellar region cross-section (*PCC*), and the diameter of the needle cross-section (*DPP*). The hybrids have higher average values of all three traits than the Japanese red pine. Next trait in discrimination significance is the number of medial resin canals (*NSKM*). The average *NSKM* is higher than in hybrids, since the Japanese red pine has resin canals located near the hypoderm.

The following are the most important characteristics for distinguishing F_1 hybrids *nide* and *deni*: the area of the needle cross-section (*PPP*); the diameter of the stellar region cross-section (*DCC*), and the height of the stellar region cross section (*HCC*). The average value of *PPP* is higher in hybrids *nide*, while the average values of *DCC* and *HCC* are higher in hybrids *deni*. The fourth trait in discriminating the hybrids is the sheath fascicle around the needle (*LR*), which is averagely longer in *nide* than in *deni*.

Second analysis: *ni, th, nith, thni*
Druga analiza: *ni, th, nith, thni*

F_1 hybrids *nith* best differ from the European black pine by the diameter of the needle cross-section (*DPP*), the diameter of the stellar-region cross-section (*DCC*), and the height of the needle cross-section (*HPP*). The average values of *DPP* and *DCC* are higher in the European black pine, while the average *HPP* is higher in hybrids *nith* (Table 70). The next trait for distinguishing these groups is the area of the needle cross-section (*PPP*), which is larger than in the European black pine. Since this is in correlation with the previous traits, we shall mention the fifth, needle length (*LI*), which is averagely greater than in the European black pine than in hybrids *nith* .

In discriminating F_1 hybrid *nith* from the second parent, the Japanese black pine, the following are the most useful traits: the number of serrations along one needle rim on a 1 cm-long segment taken from the middle of the needle (*NZ/cm*); tracheid length of one-year old shoots (*LT*), and the diameter of the stellar region cross-section (*DCC*). The Japanese red pine has averagely higher values of *NZ/cm* and *LT*, while hybrids have higher values of *DCC*.

The following three traits are best for discriminating F_1 hybrids *thni* from the European black pine: tracheid length of one-year old shoots (*LT*), needle length (*LI*), and the height of the stellar region cross-section (*HCC*). Hybrids *thni* have higher average values of *LT* and *HCC*, while the European black pine has higher *LI* values.

Of all analysed traits, the samples of hybrid *thni* are best discriminated from the Japanese black pine by the following: the diameter of the needle cross-section (*DPP*); the diameter of the stellar region cross-section (*DCC*), and the number of medial resin canals (*NSKM*). Hybrids *thni* have higher average values of all three traits than the Japanese black pine.

F_1 hybrids *nith* and *thni* are best discriminated from one another by the following: the diameter of the needle cross-section (*DPP*), the area of the stellar region cross-section (*PCC*), and the number of medial resin canals (*NSKM*). Hybrids *thni* have higher average values of all three traits than hybrids *nith*.

Needle volatiles composition

Sastav eteričnih ulja iglica

In terms of quality, needle volatiles of the analysed species and hybrids have similar compositions. However, they differ in terms of quantity. These differences are presented in the research results. Our research data on the composition of the European black pine volatile are comparable with those found in other literature.

The volatile composition of *P. nigra* Arnold ssp. *nigra* from Bosnia and Hercegovina was analysed by Chalcat & Gorunović (1995a). They identified 91 components with 90% of the volatile contents. (In our research, we identified fifty-three components with 94.4% of the volatile contents). Besides the differences in terms of quality, the biggest quantitative difference was the content of germacrene D, which they found in traces (in our research, germacrene D is the second (17.7%) after α-pinene as to the proportion of the volatile oil components. The needle volatile analysed by Chalachat & Gorunović (1995a) had a larger proportion of α-pinene (66.5%) and β-phellandrene + limonene (6%), and a smaller proportion of β-pinene (5.3%) than the values in our research (α-pinene (42.7%), β-phellandrene + limonene (3.7%), β-pinene (11.6%)).

The data on the content of terpenes in the European black pine, in terms of quantity, are very similar to the results of the research done by Kubeczka & Schultze (1987). The proportion of germacrene D is 18.6% (17.7% in our research), and this is also the second component after α-pinene, as to the proportion in the volatile. There are quality differences, since Kubeczka & Schultze (1987) identified only 25 components.

We made a comparison of the needle volatile contents in F_1 hybrids of the first and the second analysis. The components whose proportions in all analysed F_1 hybrids (*nide, deni, nith* and *thni*) are intermediary between the respective components in the parent species are as follows: α-pinene, β-bourbonene, β-caryophyllene, germacrene D and α-muurolene (Tables 34 and 35). These components would be suitable for the identification of the given hybrid combinations.

CONCLUSIONS
ZAKLJUČCI

1. Based on the nineteen analysed traits, it is possible, with a probability of 95% - 100%, to distinguish the hybrids *P. nigra* × *P. densiflora, P. densiflora* × *P. nigra,* and *P. thunbergiana* × *P. nigra* from their parent species. The hybrids *P. nigra* × *P. thunbergiana* are significantly different from the male parent, the Japanese black pine, but not from the female parent, the European black pine.

2. F_1 hybrids *P. nigra* × *P. densiflora* are best discriminated from the European black pine by the number of medial resin canals, the height of the stellar region cross-section, and by the largest number of hypoderm layers on the needle cross-section. The best traits for discriminating these hybrids from the Japanese red pine are the area of the needle cross-section, the number of medial resin canals and the number of serrations along one needle rim on a 1 cm large segment taken from the middle of the needle.

3. The characteristics by which F_1 hybrids *P. densiflora* × *P. nigra* are best discriminated from European black pine are the number of external resin canals, tracheid lengths of one-year old shoots, and needle length. The same hybrids are best distinguished from the Japanese red pine by the area of the needle cross-section, the area of the stellar region cross-section, and the diameter of the needle cross-section.

4. Hybrids *P. nigra* × *P. thunbergiana* are best discriminated from the European black pine by the diameters of both the needle cross-sections and the stellar regions, and the heights of the needle cross-section. Their discrimination from the Japanese black pine is best by the following: the number of serrations along one rim on a 1 cm large segment from the middle of the needle; the tracheid length of one-year old shoots, and by the diameter of the stellar region cross-section.

5. The characteristics by which hybrids *P. thunbergiana* × *P. nigra* are best discriminated from the European black pine are tracheid length of one-year old shoots, needle length and the height of the stellar region cross-section. These hybrids are best distinguished from the Japanese black pine by the diameters of the needle cross-sections, the diameters of the stellar region, and the number of medial resin canals.

6. The most important characteristics for the discrimination of hybrids *P. nigra* × *P. densiflora* and *P. densiflora* × *P. nigra* are the areas of the needle cross-sections, diameters and heights of the stellar region cross-sections.

7. The discrimination of F_1 hybrids *P. nigra* × *P. thunbergiana* and *P. thunbergiana* × *P.*

nigra is best by the diameters of the needle cross-sections, the areas of the stellar region cross sections, and the number of medial resin canals.

8. The volatile compositions of three pine species and their four hybrids, in terms of quality, are very similar, which means that there are small differences in the identified components. However, there are significant differences in terms of quantity, that is the proportions of the individual components are different in different species and hybrids.

9. In the volatiles of the analysed species and hybrids, different numbers of components were detected, ranging from 78 (*P. thunbergiana* × *P. nigra*) to 124 (*P. nigra* × *P. densiflora*). Of the detected components, forty-two were identified in *P. thunbergiana* × *P. nigra*, and fifty-three in the majority of other groups. Of the total content of volatiles, the identified components range between 81.3% (*P. densiflora*) and 96.1% (*P. thunbergiana* × *P. nigra*).

10. The identified components are terpenes, except for *trans*-2-hexenal, which is an n-alkene. Monoterpenes have the largest proportions (between 61.7% in *P. densiflora* and 77.3 % in *P. thunbergiana*), and are followed by sesquiterpenes (from 13.6% in *P. densiflora* to 27.1% in *P. nigra*) and diterpenes (from 0.6% in *P. nigra* × *P. thunbergiana* to 5.9% in *P. densiflora*).

11. Of all the components of the needle volatiles, in all analysed species and hybrids, α-pinene has the largest proportions, ranging between 25.8% in *P. densiflora* to 42.7% in *P. nigra*, except for the Japanese black pine, where β-pinene has the largest proportion (34.1%).

12. Every species has some volatile components with much higher proportions than in the volatiles of other analysed species. The component specific of the European black pine is germacrene D; thunbergol is specific of the Japanese red pine, while β-pinene has the largest proportion in the Japanese black pine.

13. In F_1 hybrids, the proportion of single components is higher, smaller or mostly intermediary when compared to the proportions of the respective components in the volatile of the parent species. The components, whose proportions in all analysed F_1 hybrids are intermediary between the respective proportions of the parent species are α-pinene, β-bourbonene, β-caryophyllene, germacrene D and α-muurolene. Bornyl acetate is a component, whose proportion in all F_1 hybrids is larger than in the parent species, while the proportions of 13-epimanoyl oxide are smaller than in the parent species. We can assume that the mentioned components could be used in the verification of hybrid plants.

14. Cluster analysis has shown that the Japanese black pine and its hybrids (*P. nigra* × *P. thunbergiana* and *P. thunbergiana* × *P. nigra*) differ to a higher degree from other species and hybrids. Another unit is composed of two groups. The first includes the European black pine and its hybrids, where the European black pine is the female parent, *P. nigra* × *P. densiflora*. The second group consists of the Japanese red pine and the hybrids to whom the Japanese red pine is the female parent, *P. densiflora* × *P. nigra*.

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MORFOMETRIJSKA ANALIZA I SASTAV ETERIČNIH ULJA IGLICA NEKIH VRSTA BOROVA I NJIHOVIH HIBRIDA

SAŽETAK

Četiri vrste borova, europski crni bor (*Pinus nigra* J. F. Arnold), obični bor (*P. sylvestris* L.), japanski crveni bor (*P. densiflora* Siebold et Zucc.) i japanski crni bor (*P. thunbergiana* Franco), upotrijebljene su u razdoblju od 1958. do 1991. godine u Zavodu za šumarsku genetiku i dendrologiju Šumarskoga fakulteta Sveučilišta u Zagrebu za proizvodnju međuvrsnih hibrida F_1 generacije, F_2 generacije, povratnih hibrida i trispecies hibrida. Proizvodnja i vrednovanje tih biljaka dugotrajan je proces. Proizvodnja je zahtijevala kontroliranu hibridizaciju na stablima, dvogodišnji razvoj češera, sjetvu sjemena i uzgoj biljaka u rasadniku, te podizanje pokusnih ploha. Proizveden je velik broj hibridnih biljaka, koje su zasađene na četrnaest pokusnih ploha na području Đurđevačkih pesaka i u Arboretumu Lisičine. Od osnutka pokusnih ploha kontinuirano se prati uspijevanje i rast hibridnih biljaka u odnosu na kontrolne biljke čistih vrsta i u odnosu na druge hibridne kombinacije, a rađena su i različita morfometrijska istraživanja.

Ovaj je rad doprinos vrednovanju kontrolirano proizvedenih hibridnih biljaka s obzirom na sličnost koju pojedine hibridne kombinacije pokazuju sa svojim ishodišnim vrstama. Opisan je veći broj morfoloških i anatomskih karakteristika iglica i izbojaka triju vrsta borova i njihove četiri hibridne kombinacije. Također je rađena analiza sastava eteričnih ulja iz iglica tih vrsta i hibrida.

Uzorci su za analizu bili jednogodišnji, potpuno razvijeni izbojci s iglicama, ubrani krajem listopada 1996. godine. Stabla borova s kojih su uzimani uzorci nalaze se na pokusnim plohama u Đurđevačkim peskima (četiri plohe) i u Arboretumu Lisičine (pet ploha), a matična se stabla nalaze na Šumarskom fakultetu u Zagrebu. Sa svakoga su stabla ubrana dva jednogodišnja izbojka. Uzorci su uzeti za tri vrste borova (*P. nigra*, *P. densiflora* i *P. thunbergiana*) i četiri kombinacije križanja tih vrsta (*P. nigra* × *P. densiflora*, *P. densiflora* × *P. nigra*, *P. nigra* × *P. thunbergiana* i *P. thunbergiana* × *P. nigra*).

Jednogodišnji izbojci i iglice rabljeni su za morfološku i anatomsku analizu. Iz svježih iglica svake od vrsta, odnosno hibrida destilacijom vodenom parom dobivena su eterična ulja koja su upotrijebljena za daljnju analizu.

Analizirana morfološka i anatomska obilježja su duljina iglica, duljina rukavca, duljina i širina traheida jednogodišnjih izbojaka, broj pruga puči s unutrašnje i s vanjske strane iglice, tpo promjeru poprečnoga presjeka iglice, površini poprečnoga presjeka centralnoga cilindra i po broju medijalno smještenih smolnih kanala.

Kemijskim analitičkim metodama (plinskom kromatografijom i plinskom kromatografijom/spektrometrijom masa) kvalitativno i kvantitativno određen je sastav eteričnih ulja iglica navedenih vrsta i hibrida.

Detektiran je različit broj komponenti (od 78 za *P. thunbergiana* × *P. nigra* do 124 za *P. nigra* × *P. densiflora*). Od detektiranih komponenti identificirano je od 42 komponente za *P.*

thunbergiana × *P. nigra* do 53 za većinu ostalih grupa. Od ukupnoga sadržaja eteričnoga ulja identificirane komponente čine od 81,3 % za *P. densiflora* do 96,1 % za *P. thunbergiana* × *P. nigra*.

Identificirane su komponente terpeni, osim *trans*-2-heksenala koji je n-alken. Najveći je udio monoterpena (61,7 % kod *P. densiflora* do 77,3 % kod *P. thunbergiana*), zatim slijede seskviterpeni (13,6 % kod *P. densiflora* do 27,1 % kod *P. nigra*) i diterpeni (0,6 % kod *P. nigra* × *P. thunbergiana* do 5,9 % kod *P. densiflora*).

Od komponenti prisutnih u eteričnom ulju iglica kod svih je analiziranih vrsta i hibrida najveći udio α-pinena (25,8 % kod *P. densiflora* do 42,7 % kod *P. nigra*), osim kod japanskoga crnoga bora kod kojega je najveći udio β-pinena (34,1 %).

Za svaku vrstu postoje komponente koje u eteričnom ulju dolaze u višestruko većem udjelu nego u eteričnom ulju ostalih analiziranih vrsta. Komponenta specifična za europski crni bor je germakren D, za japanski crveni bor tunbergol, a za japanski crni bor β-pinen.

Kod F_1 hibrida udio pojedinih komponenti je veći, manji ili najčešće intermedijaran u odnosu na udio istih komponenti u eteričnim uljima roditeljskih vrsta. Komponente čiji je udio kod svih analiziranih F_1 hibrida intermedijaran u odnosu na udio kod roditeljskih vrsta su α-pinen, β-bourbonen, β-kariofilen, germakren D i α-murolen. Bornil-acetat je komponenta čiji je udio kod svih F_1 hibrida veći nego kod roditeljskih vrsta, a 13-epimanoil-oksida ima kod svih hibrida manje nego kod roditeljskih vrsta. Navedene bi se komponente mogle rabiti za verifikaciju hibridnih biljaka.

Cluster analiza je pokazala da su po sastavu eteričnih ulja iglica japanski crni bor i njegovi hibridi (*P. nigra* × *P. thunbergiana* i *P. thunbergiana* × *P. nigra*) znatnije različiti od ostalih vrsta i hibrida. Druga je cjelina sastavljena od dviju grupa. Prvu grupu čini europski crni bor i hibridi kojima je on ženski roditelj *P. nigra* × *P. densiflora*. U drugoj su grupi japanski crveni bor i hibridi kojima je ova vrsta ženski roditelj, *P. densiflora* × *P. nigra*.

Ključne riječi: *Pinus nigra* J. F. Arnold, *P. densiflora* Siebold et Zucc., *P. thunbergiana* Franco, međuvrsni hibridi, morfologija iglica, anatomija iglica, traheide izbojaka, diskriminacijska analiza, eterična ulja, GC, GC/MS, terpeni, *cluster* analiza

UDK: 630*164

Original scientific paper
Izvorni znanstveni članak

ARE THERE ANY MORPHOMETRICAL DIFFERENCES IN THE LEAVES OF TWO SHOOT TYPES OF SILVER BIRCH (*BETULA PENDULA* ROTH, *BETULACEAE*)?

POSTOJE LI MORFOMETRIJSKE RAZLIKE IZMEĐU LISTOVA DVAJU TIPOVA IZBOJAKA OBIČNE BREZE (*BETULA PENDULA* ROTH, *BETULACEAE*)?

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This paper describes a study that was made on 7 morphometric variables of silver birch (*Betula pendula*) leaves from 5 bioclimatic regions of Croatia. Used analyses yielded statistically significant differences betwen the leaves of fertile and sterile shoots. The most prominent properties in variability evaluation of two types of annual shoots were the angle of leaf base and the distance of leaf base to its widest point. These variables could be used in future research on genetic diversity among populations of silver birch.

Key words: *Betula pendula*, fertile and sterile shoots, morphometric analysis

INTRODUCTION
UVOD

The objective of this study was to determine whether statistically significant differences exist in the morphometrical variables of 2 types of silver birch (*Betula pendula*) leaves. Most of the woody species, silver birch aswell, develop at least 2 types of highly distinguishable annual shoots: short/fertile and long/sterile. The shorter, fertile shoots produce 2 opposing leaves with terminally located female catkin (Figure 1a), while the longer, sterile shoots carry only 2 opposing leaves (Figure 1b). According to the literature, there are different methods of leaf sampling which could be used for the morphometric analyses (Thomas & Kenworthy 1980, Nygren & Kellomäki 1983, Iliev 1990, Kajba 1996). However, a separate analysis on the morphological leaf traits of 2 shoot types, which could determine the parametrical differences in the leaf morphology of both fertile and sterile *B. pendula* shoots, has not been made up to now.

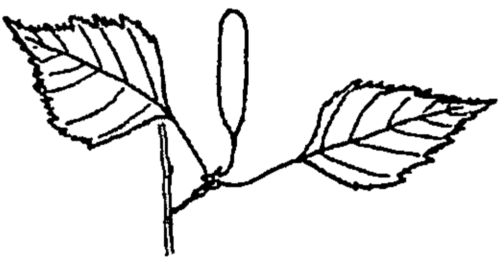

Figure 1a: Fertile shoot of silver birch with leaves and catkin

Slika 1a: Fertilni izbojak obične breze s listovima i plodnom resom

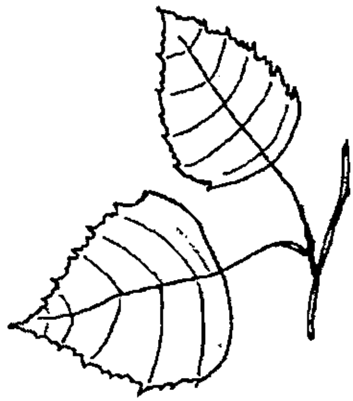

Figure 1b: Sterile shoot of silver birch with leaves

Slika 1a: Sterilni izbojak obične breze s listovima

MATERIAL AND METHODS
MATERIJAL I METODE RADA

The material for morphometric analysis of both fertile and sterile annual shoots originated from 5 disjunctive and bioclimatically diverse regions of the natural distribution of *B. pendula* in Croatia (mostly from the Sava River basin, Ilijanić 1963): on the slopes of the mountains of

Krndija and Papuk, Moslavačka gora hill, and in the regions of Gorski kotar and Lika.

Ten adult trees were selected at each locality. Solitary trees that grew along the very edge of the forest are considered to be the most suitable for sampling purposes. Such trees still have their crowns well exposed to sunshine, permitting a better expression of the leaf-genes. Fifty leaves each were gathered from both the fertile and sterile shoots of every tree. The sampling took only healthy, whole and fully developed leaves into consideration.

For each leaf 7 morphological traits were measured (Figure 2): petiole length (*ptl*), leaf blade (lamina) length (*lbl*), leaf blade width (*lbw*), distance from leaf base to widest point of leaf blade (*dlb*), angle of leaf base (*alb*), number of veins on right side of leaf blade (*nvr*) and number of teeth between 2nd and 3rd veins on right side of leaf blade (*ntr*); with the precision of 1 millimeter (mm) and 5 degrees (°).

Standard statistical analysis formulae (Snedecor & Cochran 1971, Sokal & Rohlf 1989) were used in order to obtain the most objective picture possible of the shape parameters and model of variability. Descriptive statistical methods were used to determine the mean values (x), standard deviation (SD) and coefficient of variability (CV) of the measured biometrical parameters. A complete statistical analysis was made using SAS 6.12 statistical package (*SAS* 1990).

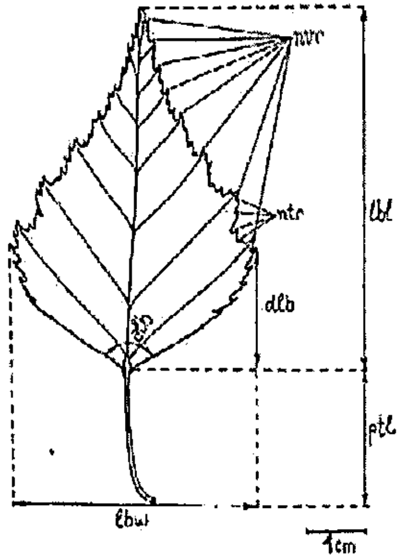

Figure 2. Measured morphometrical leaf variables of *Betula pendula*: *ptl* = petiole length, *lbl* = leaf blade length, *lbw* = leaf blade width, *dlb* = distance from leaf base to widest point of leaf blade, *alb* = angle of leaf base, *nvr* = number of leaf veins on right side of leaf blade, *ntr* = number of teeth between 2nd and 3rd vein on right side of leaf blade

Slika 2. Mjerena morfološka svojstva listova Betula pendula*: duljina peteljke (*ptl*), duljina plojke (*lbl*), širina plojke (*lbw*), udaljenost od baze do najširega dijela plojke (*dlb*), kut baze plojke (*alb*), broj žila s desne strane plojke (*nvr*) i broj zubaca između 2. i 3. žile s desne strane plojke (*ntr*)*

RESULTS AND DISCUSSION
REZULTATI ISTRAŽIVANJA I DISKUSIJA

A rigorous control of initial sampling was conducted in order to avoid possible errors and for the comparisons to be as near as possible to the real variability laws for all of the studied morphological leaf variables. The use of this uniformed sampling methods gave a balanced form to the sampling.

The descriptive statistic indicators (x, SD and CV) for all the measured traits and for 500 leaves of both fertile and sterile shoots in each of the researched populations are shown in Table 1. The leaf measurement results are given separately for both fertile and sterile shoots, as it is considered that fertile shoots show the recent condition of the species and its reproductive maturity better than sterile ones. For better perceptibility of the values between populations and the measured morphometrical traits of the leaves, the minimal x for each particular variable, according to the leaf type, were shaded in light gray, while the maximal x were shaded in dark gray.

Table 1. Descriptive statistical parameters for 500 *Betula pendula* fertile and 500 sterile shoot leaves, based on a study of 5 Croatian populations

Tablica 1. Deskriptivni statistički parametri za 500 fertilnih i 500 sterilnih izbojaka Betula pendula, *temeljeni na istraživanju 5 hrvatskih populacija*

		Fertile shoot leaves					Sterile shoot leaves				
Leaf variable	popul. param.	Krndija	Papuk	Moslavačka gora	Gorski kotar	Lika	Krndija	Papuk	Moslavačka gora	Gorski kotar	Lika
ptl	x (mm)	17.6	18.5	16.6	18.0	17.5	16.9	18.6	17.1	17.4	18.1
	SD (mm)	3.2	3.4	3.7	3.6	3.8	3.2	3.3	3.6	3.2	3.2
	CV (%)	18.2	18.6	22.3	19.9	21.7	19.0	17.7	20.9	18.5	17.7
lbl	x (mm)	42.2	43.9	41.5	44.2	43.1	44.6	46.5	43.5	44.4	44.9
	SD (mm)	4.9	6.0	6.6	6.6	6.8	6.5	6.3	6.8	6.7	6.8
	CV (%)	11.7	13.8	15.8	15.0	15.7	14.5	13.5	15.6	15.0	15.2
lbw	x (mm)	32.0	32.3	31.3	31.4	33.5	36.2	35.9	34.3	33.7	36.5
	SD (mm)	4.4	4.6	4.8	4.7	5.9	4.9	4.9	5.0	5.0	5.4
	CV (%)	13.8	14.2	15.4	14.8	17.7	13.6	13.8	14.5	14.7	14.9
dlb	x (mm)	12.6	14.4	12.9	14.5	12.6	11.5	14.5	12.7	13.9	13.1
	SD (mm)	2.2	2.8	2.3	3.0	2.9	2.6	2.9	2.2	2.9	3.0
	CV (%)	17.8	19.7	17.6	20.7	23.3	22.4	20.1	17.6	20.7	22.5
alb	x (°)	134.0	109.7	123.1	111.0	125.3	156.1	125.4	134.7	124.6	136.6
	SD (°)	26.1	15.1	16.3	10.4	15.0	17.3	15.4	19.3	14.6	18.9
	CV (%)	19.5	13.7	13.3	9.4	12.0	11.1	12.3	14.3	11.7	13.8
nvr	x (N)	7.3	6.9	7.2	7.2	6.9	7.6	7.2	7.3	7.2	7.1
	SD (N)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.8
	CV (%)	11.4	11.5	10.8	10.9	11.5	10.4	11.1	9.4	11.3	11.3
ntr	x (N)	3.3	2.9	3.0	3.2	3.2	3.5	3.2	3.2	3.3	3.6
	SD (N)	0.8	0.7	0.6	0.8	0.8	1.0	0.8	0.7	0.8	0.9
	CV (%)	25.6	23.7	21.1	24.5	24.0	29.3	24.5	21.2	23.1	24.2

Table 2. Descriptive statistical parameters for the total sampling (2500 fertile and 2500 sterile *Betula pendula* shoot leaves)

Tablica 2. Deskriptivni statistički parame-tri za cjelokupni uzorak (2500 listova fertilnih i 2500 listova sterilnih izbojaka Betula pendula*)*

Leaf variable	Parameter	Fertile shoot leaves	Sterile shoot leaves
ptl	x (mm)	17.6	17.6
	SD (mm)	3.6	3.4
	CV (%)	20.5	19.1
lbl	x (mm)	43.0	44.8
	SD (mm)	6.3	6.7
	CV (%)	14.7	14.9
lbw	x (mm)	32.1	35.3
	SD (mm)	5.0	5.2
	CV (%)	15.5	14.6
dlb	x (mm)	13.4	13.1
	SD (mm)	2.8	2.9
	CV (%)	20.9	22.1
alb	x (°)	120.6	135.5
	SD (°)	19.6	20.6
	CV (%)	16.3	15.2
nvr	x	7.1	7.3
	SD	0.8	0.8
	CV (%)	11.4	11.0
ntr	x	3.1	3.4
	SD	0.8	0.9
	CV (%)	24.3	25.3

x = mean value - *srednja vrijednost*
SD = standard deviation- *standardna devijacija*
CV = coefficient of variability - *koeficijent varijabilnosti*

Table 2 shows the same statistical indicators (x, SD and CV) as in Table 1 for all the measured properties, but it includes the whole sample, depending just upon the leaf type (2500 fertile and 2500 sterile shoot leaves).

The graphic portrayals of the x - ranges of measured traits in each population and type of leaf were given in Figures 3a – 3g.

Figure 3. Graphic comparison of mean value ranges according to measured variables and populations: 3a - petiole length, 3b - leaf blade length, 3c - leaf blade width, 3d - distance from leaf base to widest point of leaf blade, 3e - angle of leaf base, 3f - number of leaf veins on right side of leaf blade, 3g - number of teeth between 2nd and 3rd vein on right side of leaf blade

*Slika 3. Grafička usporedba raspona srednjih vrijednosti mjerenih svojstava po populacijama: 3a - duljina peteljke, 3b - duljina plojke, 3c - širina plojke, 3d - udaljenost od baze do najširega d*ijela plojke, 3e - kut baze plojke, 3f - broj žila s desne strane plojke i 3g - broj zubaca između 2. i 3. žile s desne strane plojke

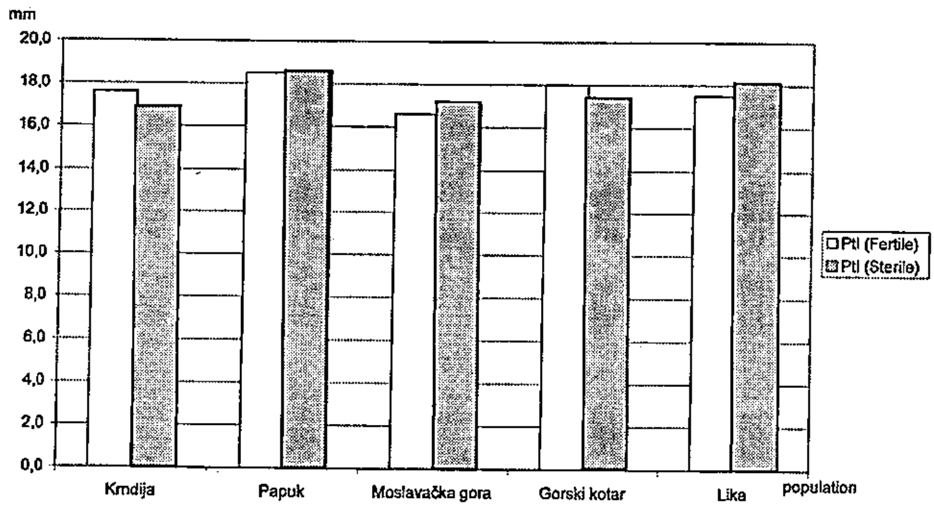

Figure 3a. Petiole length (*ptl*)
*Slika 3a. Duljina peteljke (*ptl*)*

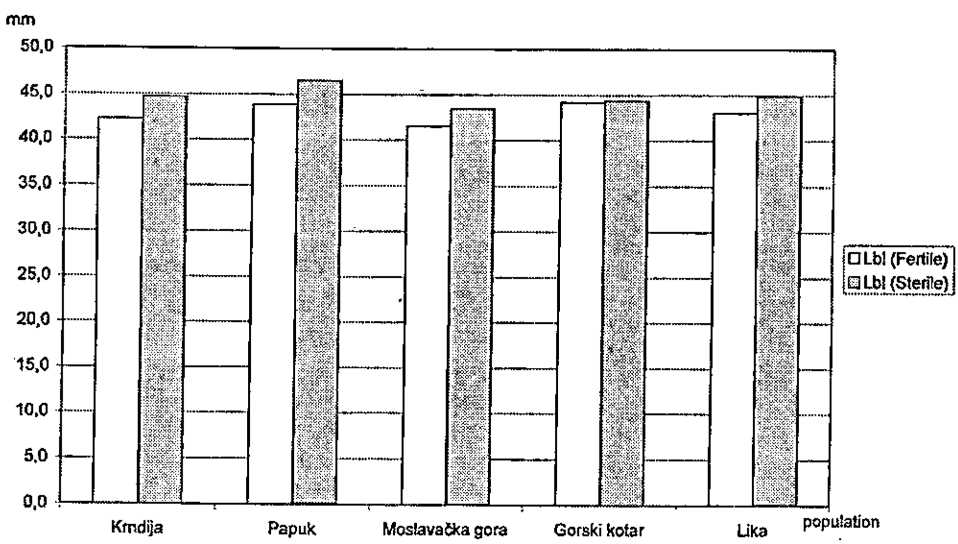

Figure 3b. Leaf blade length (*lbl*)
*Slika 3b. Duljina plojke (*lbl*)*

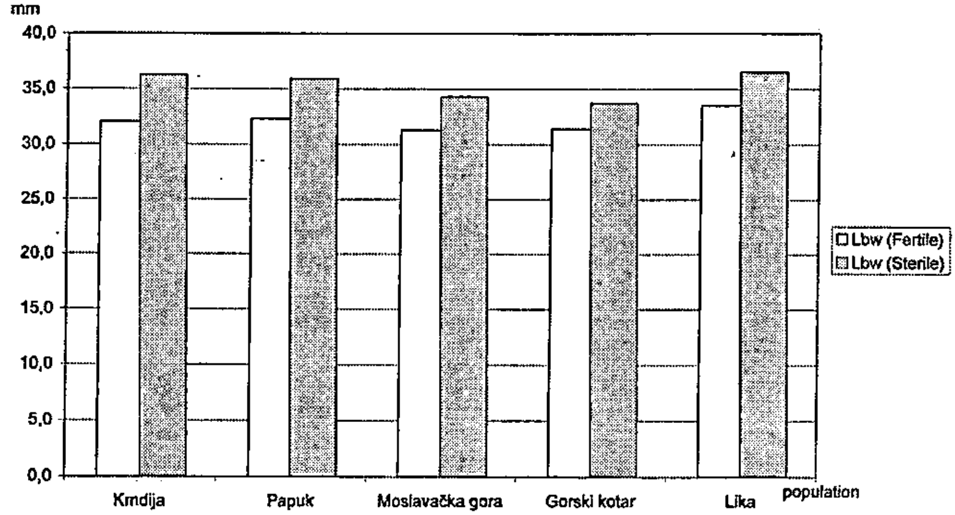

Figure 3c. Leaf blade width (*lbw*)
*Slika 3c. Širina plojke (*lbw*)*

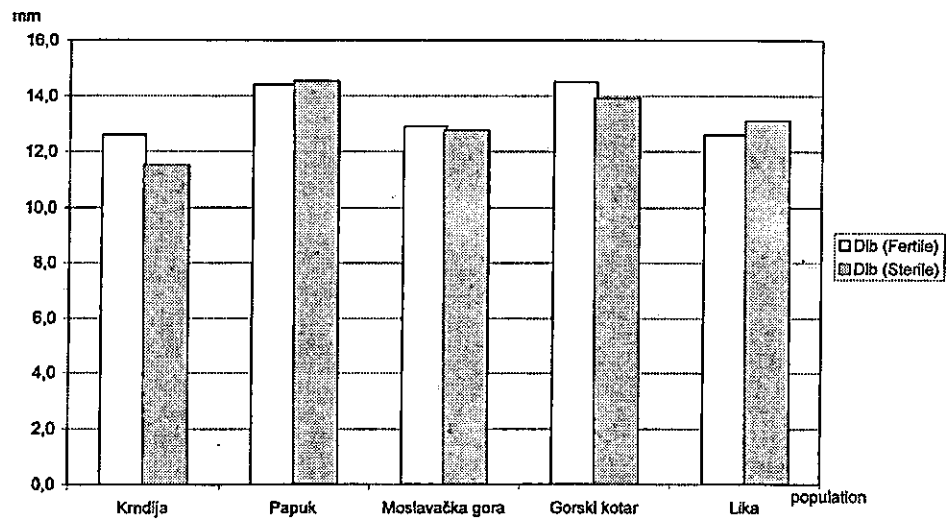

Figure 3d. Distance from leaf base to widest point of leaf blade (*dlb*)
*Slika 3d. Udaljenost od baze do najšireg dijela plojke (*dlb*)*

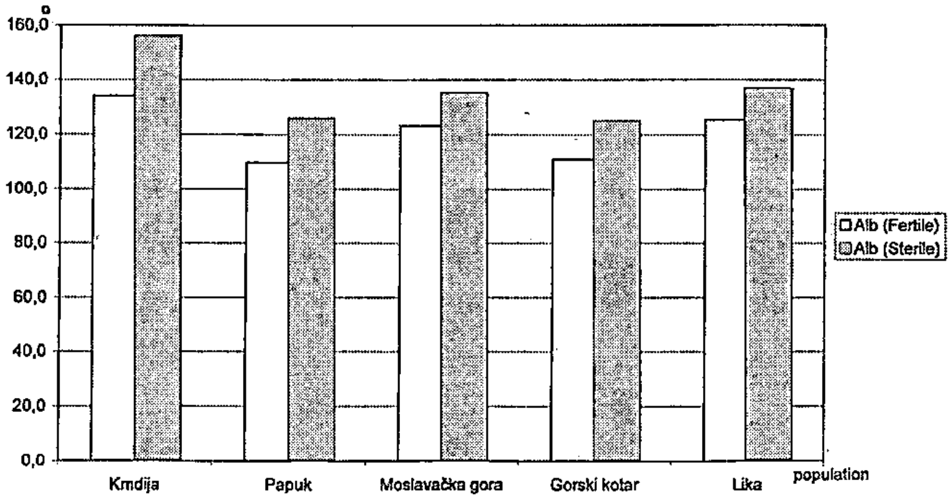

Figure 3e. Angle of leaf base (*alb*)
*Slika 3e. Kut baze plojke (*alb*)*

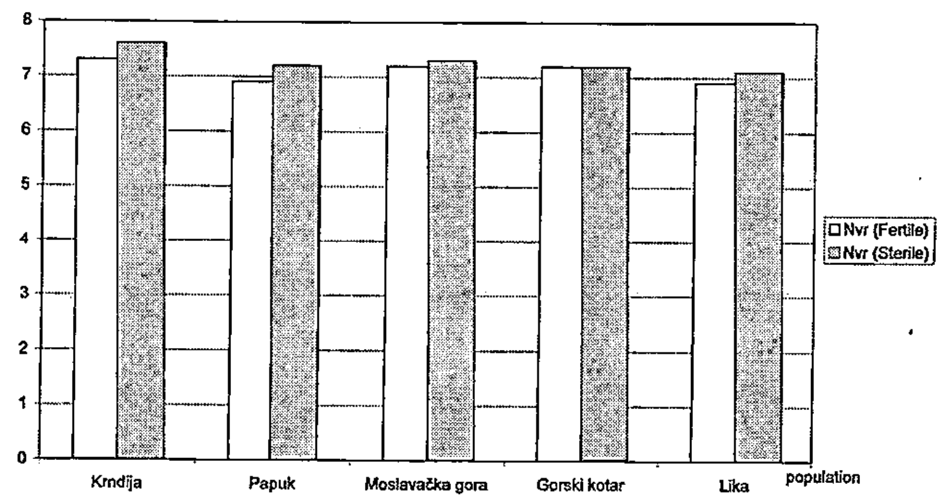

Figure 3f. Number of leaf veins on right side of leaf blade (*nvr*)
*Slika 3f. Broj žila s desne strane plojke (*nvr*)*

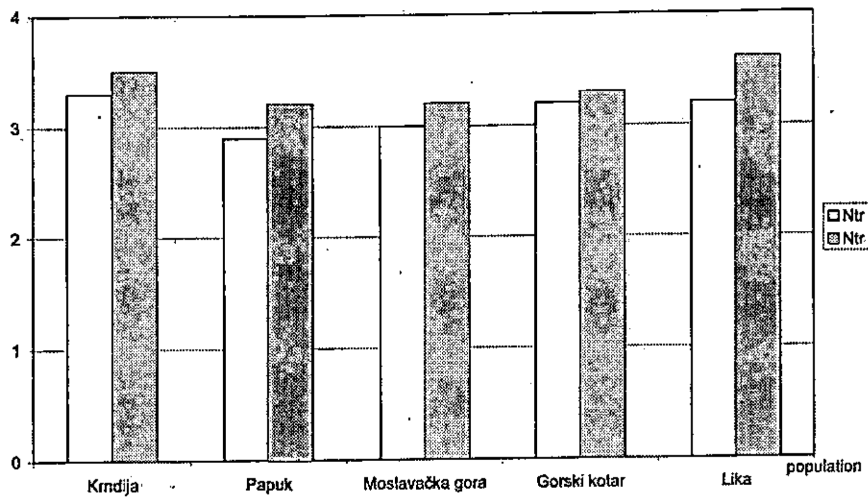

Figure 3g. Number of teeth between 2nd and 3rd vein on right side of leaf blade (*ntr*)

Slika 3g. Broj zubaca između 2. i 3. žile s desne strane plojke (nvr)

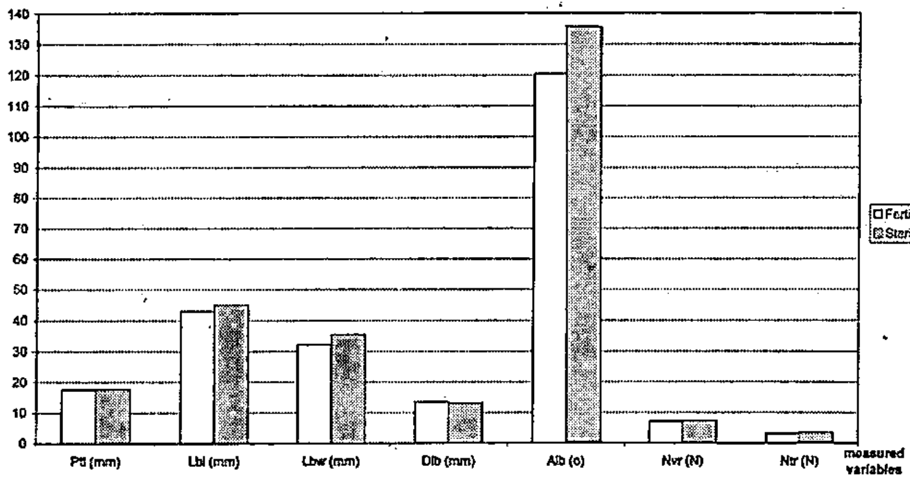

Figure 4. Graphic comparison of mean value ranges for all 7 measured variables of 2 types of leaves in total sampling

Slika 4. Grafička usporedba raspona srednjih vrijednosti za svih 7 mjerenih svojstava dvaju tipova listova u ukupnom uzorku

Figure 4 gives a comparative graphical portrayal of x for all the measured traits of all the samples, depending upon the leaf type. Attention should be drawn to the general relationships of x between fertile and sterile shoot leaves among the trees and populations:

in most cases, x for the measured traits of sterile shoot leaves were larger than x for the fertile shoot leaves.

The *ptl* variable was the same for both types of the leaves, while *dlb* is slightly larger for fertile shoot leaves, as compared to those sterile. Undoubtedly, *nvr* is the most stable variable: SD of 0.8 for the leaves of all populations and types (except sterile in Moslavačka gora population = 0.7) indicates a strong genetic control of this property.

We established the existence of statistically significant differences between populations (regardless of leaf type) with respect to 2 variables: *alb* and *dlb*. The property of *lbw* is related to these 2 properties, pointing towards significant difference between fertile and sterile shoot leaves, according to leaf shape, rather than leaf size.

CONCLUSIONS
ZAKLJUČCI

Research was conducted on the variability of morphological leaf parametres of fertile and sterile shoots of silver birch (*Betula pendula*). The study was carried out on 5 separate populations originating from various bioclimatic regions of Croatia. Leaf samples were taken from fertile and sterile shoots separately, under strictly defined conditions, as previous statistical research shown that they differ significantly. Morphometrical measurements of 7 leaf variables were taken. The properties of leaf base angle (*alb*), leaf base distance to its widest point (*dlb*) and, to some extend, related leaf blade width (*lbw*), are statistically significant in distinction of 2 types of annual shoot leaves. Angle of leaf blade (*alb*) proved to be the most prominent feature, which could be used in evaluations on the leaf variability of both shoot types and, in future, in research on genetic diversity among *B. pendula* populations. The aforementioned analysis also showed that there is no statistically-justifiable differences between fertile and sterile shoot leaves of silver birch regarding petiole lenght (*ptl*), leaf blade length (*lbl*), vein number on right side of leaf blade (*nvr*) and teeth number between second and third veins on right side of leaf blade (*ntr*). However, these morphometric analyses proved the existence of statistically significant variability for all the measured properties in each investigated population.

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POSTOJE LI MORFOMETRIJSKE RAZLIKE IZMEĐU LISTOVA DVAJU TIPOVA IZBOJAKA OBIČNE BREZE (*BETULA PENDULA* ROTH, *BETULACEAE*)?

SAŽETAK

Cilj je ovoga istraživanja bio da se utvrdi postoje li statistički značajne razlike među populacijama obične breze (*Betula pendula*) u Hrvatskoj, temeljene na morfometrijskim svojstvima listova jednoljetnih fertilnih i sterilnih izbojaka.

Materijal je za istraživanje prikupljen na 5 odvojenih i bioklimatski različitih lokaliteta s prostora prirodne rasprostranjenosti vrste: na obroncima Krndije, Papuka i Moslavačke gore, te u Gorskom kotaru i Lici. Na svakom je lokalitetu odabrano po 10 odraslih stabala obične breze, s kojih je prikupljeno po 100 zdravih, odraslih listova sa sunčane strane krošnje: 50 s fertilnih i 50 sa sterilnih izbojaka. Svakom je listu izmjereno 7 morfoloških svojstava: duljina peteljke (*ptl*), duljina plojke (*lbl*), širina plojke (*lbw*), udaljenost od baze do najširega dijela plojke (*dlb*), kut baze plojke (*alb*), broj žila s desne strane plojke (*nvr*) i broj zubaca između 2. i 3. žile s desne strane plojke (*ntr*). Deskriptivnim statističkim metodama određene su srednje vrijednosti (x), standardne devijacije (SD) i koeficijenti varijabilnosti (CV) pojedinih biometričkih parametara, odvojeno za listove fertilnih i sterilnih izbojaka. U većini slučajeva pokazalo se da su srednje vrijednosti mjerenih svojstava veće kod listova sterilnih nego kod fertilnih izbojaka. Najstabilnije i očigledno strogo genetski kontrolirano svojstvo svakako je broj žila (*nvr*), na što upućuju i vrijednosti SD.

Iako je morfometrijska analiza dokazala postojanje statistički značajne varijabilnosti za sva mjerena svojstva kod svih istraživanih populacija, najznačajnijima su se pokazali kut baze plojke (*alb*) i udaljenost od baze do najširega dijela plojke (*dlb*), te uz njih vezana širina plojke (*lbw*). Time je dokazana značajnost razlika između listova fertilnih i sterilnih izbojaka obične breze, i to ne samo na temelju veličine već i oblika listova. Tri navedena svojstva, a posebno kut baze plojke, mogu se upotrebljavati u daljnjim istraživanjima genetske raznolikosti populacija *B. pendula*.

Ključne riječi: *Betula pendula*, fertilni i sterilni izbojci, morfometrijska analiza

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Original scientific paper
Izvorni znanstveni članak

MANAGEMENT MODELS APPLIED TO FIR FORESTS IN GORSKI KOTAR

PRIMJENA MODELA PRI UREĐIVANJU JELOVIH ŠUMA GORSKOGA KOTARA

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Fir forests in Gorski Kotar have been managed with different models, the majority of which are derived from the normal method. Models resulting from the Normal Method Before and After Cutting (prescribed by the Instructions of 1903), as well as Klepac's "New System of Managing Selection Forests" and the Institute's EMTs (ecological-management types), have been used since the beginning of management with these forests.

It is clear from the position of tree number curves in "old" normal models (which represent the correction of the condition in the forest) and in the normal model of the studied EMT I-C-10b in relation to adequate Klepac's normal models that in the majority of old models the curve of the tree number is above Klepac's curve, with more significant deviations occurring (in %) in lower and higher diameter classes. This is the consequence of the condition of these forests at the time of management (the end of the nineteenth and the first several decades of the twentieth century), when these forests contained excessive growing stock resulting from extensive management. One part of these models was constructed under an unrealistic assumption that the basal areas of all diameter classes were equal. It is for this reason that the deviation of these models from the model by Klepac is the most distinct in the lowest diameter classes. It is interesting that the deviation in percentages of the Institute's normal model EGT I-C-10b, adjusted to pure fir condition before cutting, almost completely coincides with Jovanovac's normal model for the land community Benkovac from 1912. This model was made under the assumption of the equality of basal areas of all diameter classes.

Furthermore, within this EMT, represented by one model, there were stands with a wide range of quality classes, fir I/II-IV and beech II-V. Based on these facts, the use of original Klepac's normal models is recommended for managing fir selection forests. In this way, an artificial lowering of the heights of dominant trees (the result of cutting the trees above a certain maturity dimension and different ways of defining dominant heights used by some authors) will be avoided (Božić & Čavlović 2001).

Based on the position of the curves of tree numbers from different years of measurement and on their position towards the proposed model, it is possible to draw conclusions on the condition of a stand's managed status and to determine the trends of a given stand in relation to the proposed model. This, along with the record of the completed activities, may greatly assist in the future management of these stands. The proposed model by Klepac should be regarded as a transitional model rather than a permanent one until a more favourable model is found through management activities.

Key words: Gorski Kotar, forest management, models

INTRODUCTION
UVOD

The forests of Gorski Kotar are well managed and easily accessible. A good and dense network of forest roads enables intensive forest management based on management plans that are revised every ten years and reviewed every twenty years.

From the first management plans to date, the forests of Gorski Kotar have been managed with different methods set down in a number of instructions, directives and regulations that followed both foreign and Croatian scientific and specialist insights.

Models of forest management primarily refer to the ideals to be attained using a management method.

The first models used to manage the forests of Gorski Kotar and Kapela date from the end of the 19th and the beginning of the 20th century. They were the result of the normal method before and after cutting (Miletić 1951). This method was prescribed in the Instruction of 1903 (Anon. 1903) for the management of selection forests of particular public interest. According to the Instruction, a typical stand should contain the number of trees, the sum of basal areas and the growing stock (based on the concrete state in a forest) that would normally be found in one *ral* (5,754.642 m²) of a selection forest before and after cutting.

In case of selection forests, the total number of trees, the size of the basal area or the growing stock per ha to be achieved cannot be considered a model.

In order for some of the above structural elements to be regarded a model, their internal structure or the distribution by degrees (classes) should be taken into account.

Based on the Forest Law of 1929, the "Instructions for State Forest Management" were issued in 1931, which prescribed the control method for managing selection forests (Klepac 1997).

In this method, the model is not set beforehand, but is established in the course of management. As this method was not applied in practice due to extensive management, there are no data on the achieved "managed models".

The "Instructions for tree consignment and revenue definition in selection forests" were issued in 1937 as a reaction to the inability to apply the control method. The Instructions were based on the minimal growing stock to be retained in a forest after cutting.

The method of minimal stocks to be retained after cutting resulted in the graphs of the stands in which cutting was considered successful. These graphs were kept in the records and used as models in defining the structure or the curve of growing stocks after cutting in similar stands; nevertheless, they did not actually represent a model.

Models most commonly refer to the models resulting from the normal method.

With his "New System of Managing Selection Forests", Klepac (1961) reintroduces the normal method into the management of selection forests. Klepac himself states in his "New System ..." that normal models have a temporary character, as he intends to study normal models by forest types. However, normal models by forest types were not made by Klepac as was his intention, but by the staff of the Forestry Institute in Jastrebarsko headed by Cestar. They adapted the existing normal models to forest types (according to Križanec 1987).

Since the issue of the "New System" in 1962, the forests of Gorski Kotar have been managed with the normal model by Klepac (New System ...), and in the period 1968-1994 also with the Institute's normal models according to the EMTs.

The present condition of these forests and their final managed status with the existing models is the direct consequence of past management with these forests. Management has not been uniform. Apart from some general trends, different forest owners managed their property in different ways following the then valid legal regulations. For better understanding, I will give a historical survey of forest ownership, discuss past management with these forests and list the methods and legal regulations relating to the management of these forests.

RESEARCH AREA
PODRUČJE ISTRAŽIVANJA

The research was conducted in the area of Gorski Kotar.

Geographical position - Gorski Kotar is located in western Croatia; in the north and north-west it borders with Slovenia, in the south-west and south with the Croatian Littoral, and in the east with the Ogulin area. The northern, north-western, south-western and southern boundaries of Gorski Kotar are defined by natural and political-administrative boundaries, but those in the east are not so clearly defined.

Geological structure - Almost all the rocks in Gorski Kotar belong to a large group of sedimentary rocks, with the prevalence of limestones and dolomites.

Pedological features - Several main soil groups are developed in Gorski Kotar: gleysol on limestone, rendzina on dolomite, cambisols on limestone and dolomite, acid cambisols, illimerised soils on limestone, brown podzol soils and podzols and arable soils.

Climate - According to Köppen's classification, the entire area of Gorski Kotar belongs to the Cfsbx" type of climate, except the part above 1,200 m, which belongs to the Dfsbx" climate type (Seletković & Katušin 1992).

Plant communities - The north-easternmost part of Gorski Kotar is a hilly region reaching about 400 m above sea level. It is basically characterised by different oak stands. The major part of the area lying between 400 and 1,100 m above sea level contains vast forests of beech and beech and fir on different petrographic substrates. In terms of orographic, climatic, ecological-phytocoenological and forest management differences, the montane area is divided into lower and higher parts. The lower montane area is covered with pure beech forests, which follow the forests of sessile oak and common hornbeam (from the mainland) or hop hornbeam with autumn sesleria (from the littoral) hilly area. The principal physiognomic and ecological-vegetational features of the higher part are the self-growing, mixed or pure, coniferous forests, mainly fir and spruce, which grow abundantly. In terms of height, this area is located between the climatozonal regions of hilly and sub-mountainous forest of beech. The pre-mountainous area covers the highest positions in the Risnjak, Snježnik, Burni Bitoraj and Bjelolasica massifs about 1,000 m above sea level (Bertović & Martinović 1981).

SUBJECT OF RESEARCH
PREDMET ISTRAŽIVANJA

The research deals with fir forests in Gorski Kotar.

Fir forests are forests of the high silvicultural form with a mainly uneven-aged composition. They are managed selectively.

According to Schütz (2001), a selection forest is a forest made up of trees whose lateral crown sides are not in contact as a rule, but they nevertheless fill up the total vertical growing space.

The ideal selection structure of a forest is represented by trees of different heights and diameters in an area unit, in which the normal growing stock is distributed in a selection structure that ensures maximal increment, optimal natural regeneration and stability (Matić *et al.*, 1996).

A selection forest is the result of regular and systematic selection management over many years.

According to Korpel (1996), the characteristic selection structure and a balanced selection forest is not a natural phenomenon, but a consequence of systematic planned forest management, that is, of systematic selection cutting.

Pursuant to Article 4 of Forest Management Acts of 1994 and 1997, a selection forest is composed of differently-aged stands. Article 9 of the same Acts states that differently-aged stands are stands containing trees of variable heights, diameters and ages that are regenerated naturally. They may be managed with the single tree or group selection systems.

The *single tree* management system is used in stands on karst terrain with little soil, where the soil requires continuous protection from adverse abiotic factors, which frequently occur in an extreme form.

The *group* management system is applied to the stands inhabiting mild slopes with abundantly deep, nutrient-rich and moist soils. The diameter of groups ranges from 1-2 height of the tallest trees in a stand. The area supports trees of approximately equal diameters and heights.

Apart from these two methods of selection management, until the 1994 Forest Management Act, a *cluster* management method - groups with diameters higher than two heights of the tallest trees - was also envisaged. The areas in question contain trees of approximately equal diameters and heights. Groups become clusters and the bigger they grow the further away we depart from selection management and approach the regular one.

Related to cluster management, Prpić & Seletković (1996) say: "The application of cluster management method in the areal of beech-fir forests disrupts the selection structure, which is against the natural management method and represents a mistake both from ecological and biological standpoints, and consequently from the economic standpoint."

The Forest Management Act of 1994 excludes the possibility of the cluster selection management.

In the area of Gorski Kotar, fir occurs in three plant communities and forms: the Dinaric beech-fir forest (*Omphalodo-Fagetum* Marinček *et al.* 1992), fir forest with blechnum (*Blechno-Abietetum* Ht. 1950), and fir forest with reedgrass (*Calamagrostio-Abietetum* Ht. 1950) (Vukelić & Baričević 2001).

In Gorski Kotar, fir occurs in the following EMTs (ecological-management types): I-B-11, I-C-10b, I-C-11, I-C-12, I-C-40 and I-C-61 (Klepac 1997).

Based on the regulations of the 1994 Forest Management Act, forests are classified according to management classes. The 1996 Forest Management Plan of the area states that fir forests are placed in two management classes (MC): MC of fir and beech and MC of fir and spruce. The total area of fir forests in Croatia, from the same source, is 220,000 ha, of which about 100,800 ha or 46% are in the area of Gorski Kotar.

These two management classes account for 80% of the total forested area of Gorski Kotar.

THE OWNERSHIP STATUS OF THE FORESTS IN GORSKI KOTAR
VLASNIŠTVO NAD ŠUMAMA GORSKOGA KOTARA

The majority of the forests in Gorski Kotar belonged to the dukedoms of Brod, Čabar and Grobnik in the form of feudal holdings. They were first owned by the dukes of Krk, the Frankopans and the Zrinskis, and from 1572 the whole of Gorski Kotar became the property of the counts of the Zrinskis.

Following the death of the Frankopans-Zrinskis in 1671, their property was confiscated by the Austrian state. A part of the property came under state ownership, while the other, smaller part was donated to individual noblemen by royal deeds. Over the years, the property changed hands and was owned by different families (Perlazs, Batthyanyi, Paravić). In the 19th century, the entire area was the property of two aristocratic families: the German dukes of Thurn-Taxis

(1872) and the Hungarian barons Ghyczy de Ghyczy Assa et Albanczkürth (1866).

Upon the abolition of feudalism, a part of pastureland and forests belonging to feudal lords was given to former serfs (on several occasions). These forests established the grounds of land communities.

Based on the Land Reform Act of 1931, at the request of the municipalities, the forests of major landowners in Gorski Kotar were expropriated in 1932 (about 43,600 ha). Thurn-Taxis lodged a complaint in 1932 and the state returned the biggest part of the expropriated property to him and to Ghyczy by the 1939 Agreement.

The forests belonging to the state and to landed gentry formed large entities. The forests of land communities were mainly located at the edges of these complexes, or were enclaves in private ownership. They were located in the vicinity of the villages to which they belonged.

After World War II, all forests except those of small owners (so-called maximums) were proclaimed the national property. The maximum for the forests in hilly regions ranged from 15-30 ha. Land communities were abolished in 1947.

Since 1945 to date, the forests of Gorski Kotar have been managed by various forest administrations. Since 1991, they have been a component part of the Public Enterprise "Croatian Forests" Zagreb, and belong to the Forest Administration Delnice in their major part.

PAST MANAGEMENT WITH THE FORESTS OF GORSKI KOTAR
DOSADAŠNJE GOSPODARENJE ŠUMAMA GORSKOGA KOTARA

Past management with these forests has left considerable imprints on the development and the condition of forests as dynamic live organisms.

Different owners (in the past) managed their forests in different ways, and the present state of these forests is the result of their activities.

The end of the 17th century saw the beginning of exploitation of the forests near mines, sawmill, mills and similar.

New roads and the railroad led to a more intensive exploitation of Goranian forests, but again only those near these communications links. Felling activities did not affect the deeper parts of the forests, and so the majority of the area was left in its virgin form.

With reference to the forests of Gorski Kotar in mid-nineteenth century, Frančišković (1965) says that almost half of these forests were on the verge of ruin, and that the remaining, bigger part, consisted of inaccessible virgin forests in which any exploitation was impossible. At that time, the basic management postulate was irregular selection cutting. According to Šurić (1933), regulated selection cutting only began in 1926.

The selection method of management developed at the end of the 19th century in Central Europe and in Croatia (Matić 1990). At that time, some notions of regular forests were used in managing these forests: age classes, sporadically scattered over the area; rotation, divided into a certain number of cutting cycles. Rotation represented the number of years needed by a tree to achieve cutting maturity.

Tichy recommends the introduction of diameter classes. Hufnagl (1892) abandons rotations completely and introduces cutting cycles instead (Kern 1989).

Management plans from the end of the nineteen century prescribed selection management for these forests.

Selection management as a forest-management form had strong opponents, especially from the ranks of those advocating a pure land income (Frančišković 1938b). As a result, at the end of the 19th century and the beginning of the 20th century, selection management was abandoned in some state forests and in the forests owned by Thurn-Taxis in Gorski Kotar to be replaced by inexpert stereotypical shelterwood cutting with 120-year rotations and short 20-year regeneration periods. Good quality trees were cut, while overmature trees of poor quality were left. Regeneration did not take place in the planned period, and final cuts could not be carried out. For this reason, the introduction of the shelterwood cutting method in high forests on karst was harshly criticised, to be prohibited in 1919 (Milković 1979). Selection management was reintroduced, but the lost selection structure serves as a relic of the shelterwood system.

Up to the Second World War, every forest owner managed their forests in their own way. The forests owned by Thurn-Taxis were managed with a lower intensity (extensively). The focus was on hunting management, and only some small and local cutting procedures were applied. Roads were designed and built primarily for the purposes of hunting. Large amounts of growing stock, consisting mainly of mature and overmature trees, were retained in stands (in some places over 1,000 m³/ha), and regeneration was neglected.

After the Second World War, the stands mostly had the form of a disorderly selection forest type, and types of almost even-aged stands prevailed. True, all diameter classes were represented, but generally with an insufficient number of trees in thinner diameter classes, and an excessive number of thick, mature and overmature trees, which was the consequence of earlier management with these forests.

The forests owned by Ghyzy were managed with higher intensity (intensive). The stands were exploited rationally and no stocks of overmature trees were kept in them.

After World War II, the structure of these stands was approaching the selection one, while some of the stands had pure selection structures.

At that time, the forests managed by land communities resembled those formerly owned by Thurn-Taxis in terms of management intensity.

As was mentioned earlier, beech was cut intensively over the whole period, partly because its products, charcoal and potash (as well as the sleepers for the railroad under construction - from one part of the forests) were in high demand on the market; and partly because these forests were managed with Pressler's theory of pure land income with the interest of 3%. Consequently, conifers were favoured.

Beech was considered a species of the "inferior order". According to Frančišković (1938a), taxation activities included only fir together with spruce, while beech was not measured but only assessed ocularly.

The treatment of beech is best exemplified by the fact that, according to a paper from 1867, in the area of the Batthyany estate (later the estate belonging to Thurn-Taxis), beech accounted for about 67% of all the trees. In 1907, there were 54% of the beech, while at the end of the second decade of the 20th century, it accounted for 34%. Beech was radically removed to make as much space as possible for fir. This took such proportions that in places where beech could not be marketed well, trees were girdled in order to accelerate their death so that they would not cast shade over young firs. Other hardwoods were treated similarly.

According to Šafar (1968), after World War I the fear of agrarian reforms by large landowners resulted in more intensive cutting of the more profitable fir.

Forests themselves did not suffer too much harm during the Second World War. The trees along the roads and the railway line were clearcut in order to make traffic safer, but the trees deeper in the forests were not cut.

The years after World War Two bear witness to large-scale cuttings in Gorski Kotar, partly for the needs of rebuilding the country and partly for export. In 1948, as much as 1,105,166 m³ (846,903 m³ of conifers) were cut, in 1949 the amount of 914,234 m³ (626,843 m³ of conifers) was felled, while in 1950, the quantity of 703,466 m³ (460,411 m³ of conifers) was cut (Navratil 1981). In comparison, in the period 1946-1960, the amount of 433,170 m³ was cut annually on average (275,542 m³ of conifers) (Navratil 1981), while in the period 1986-1995, the average annual cut was 470,918 m³ (280,360 m³ of conifers) (Klepac 1997).

As the majority of the stands at that time contained large amounts of growing stock, the problem was not its quantity as much as the method of its exploitation.

The management plan for the management unit (MU) "Milanov Vrh" for the period 1960-1969, in the management records, page 15, says: "Forest rangers and others in charge of consignation were inadequately educated for the most part and therefore did not pay attention to silvicultural issues in selecting trees. Felling teams consisted of people who were not trained to do forest jobs and thus did not follow forest orders. Frequently, unmarked trees were cut, while marked ones were left standing. It was the technique that was important. Due to the above, overmature trees lacking any technical value were left in the stands, and now silvicultural reasons force us to keep them there."

In the difficult political situation (the conflict with Stalin) in 1948, the shelterwood cutting method was proposed for more accessible areas in order to ease the transport from felling areas and increase the concentration of cutting stock over a smaller area. After lengthy discussions, a firm opinion of an expert commission was accepted stating that the single-tree silvicultural felling should be and remain the basic guideline in forest exploitation.

Most forests in Gorski Kotar today are of different ages (neither selection nor regular). There are also well regulated selection forests of fir and beech, such as, for example the forests of the MU "Lividraga, MU "Milanov Vrh" and some privately owned forests around Prezid (Klepac 1997).

Currently, the biggest problem of selection forests in Croatia is their lost selection structure, characterised by an excessive number of trees in higher diameter classes and an insufficient number of trees in lower and medium diameter classes.

The lost selection structure is the result of too long cutting cycles, that is, of an overabundant growing stock per hectare (Matić *et al.* 1996).

METHODS OF MANAGING FIR FORESTS IN GORSKI KOTAR

METODE UREĐIVANJA JELOVIH ŠUMA GORSKOGA KOTARA

Management with forests in Gorski Kotar was regulated by different acts, instructions and decrees, which prescribed management ways and methods.

Method - a way of proceeding or doing something; a system, a planned activity undertaken with the aim of achieving a certain goal in a practical or theoretical field (Klaić 1989).

Mention should be made of the following acts regulating forest management up to 1769: the Krk Statute from 1388; the Verboczius's *Tripartitum* from 1514; the *Urbar* by Maria Theresa from 1755; the "Forest Order of the Trieste Commercial Intendance" from 1767 in the German and Italian languages (Klepac 1976).

In 1769, Maria Theresa issued a "Legal Forest Order" in the Croatian language. This Order prescribed a method of dividing forests into annual coupes. The envisaged rotation for the fir and spruce was 80 - 100 years and for the beech 120 - 150 years. The method consisted of the following: a forest was divided into as many parts (coupes) of approximately equal size as the number of years in a rotation. Every year one part was cut, and the coupes followed successively one after the other. At the end of the rotation, the whole forest was cut. Then the cutting resumed in the same place in which it had began.

In 1788 the forest order for the Kingdom of Hungary was issued, which also served as a basis for managing the forests in Gorski Kotar.

In 1798, Matija Josip Paravić, a landowner, issued an instruction on the principles of management in the Čabar estate.

The Forest Law of 1852 came into force in Croatia on January 1, 1858. According to this law, forests were divided into three categories: state, municipal (town, village, etc.) and private. Forest management was also prescribed. Paragraph 9 of this law mentions a management plan determining the cutting method and the quantity in the forests burdened with "forest usufructs".

An "Instruction for measuring, assessing and managing forests in income communities of Croatian-Slavonian *Krajina*" was passed in 1881. According to this instruction, the annual prescribed yield was determined applying the formula of the Austrian cameral tax. The basic purpose of this method was to establish a normal growing stock in a forest so that the principle of sustainable management was ensured.

The 1894 "Law prescribing expert administration and forest management in forests of particular public interest" explicitly stated that forests of particular public interests were to be managed in a sustainable manner on the basis of management plans or programmes. Forests of particular public interest were forests of land communities and income municipalities, as well as church, town and communal forests. Based on this law, in 1903 an "Order on drawing management plans and programmes and proposing annual harvesting and silvicultural practices" was passed, whose component part was the "Instruction for drawing management plans or programmes" A large number of management plans were based on this Instruction, because it was valid until 1948.

The "Instruction" of 1903 hardly treated the problem of selection forest management, although forestry practice of the time had mastered the problem of managing selection forests.

The "normal method" was prescribed for managing high selection forests (Meštrović 1987).

According to the "Instruction", the normal model had to be constructed for every management unit to serve as a management paragon or *model*.

State forests were managed (until 1931) on the basis of foreign instructions (Austrian and Hungarian).

According to Klepac (1997), until 1919 the majority of the foresters in the state forests of Gorski Kotar were Hungarians. Accordingly, they managed the forests there using the Hungarian instructions.

Based on the Forest Law of 1929, "Instructions for managing state forests" were passed in 1931, which prescribed the control method for managing selection forests.

The control method was based on systematic single-tree and repeated stock inventories, combined with accurate records of the stock utilised in the meantime. This made it possible to calculate the current increment directly, which was an important indicator for predicting future cuttings. Particular attention was paid to determining whether the cut stock per ha was too high or too low, what the tree species mix was, what the participation percentage of different diameter classes was and whether any changes were needed in that respect (Križanec 1963).

The control method, as an intensive management method, could not be applied successfully at the time when the forests were managed extensively.

For this reason, as a reaction to the inability of applying the control method, the "Instructions for tree consignation and income definition in selection forests" were passed in 1937.

The Instructions were based on minimal growing stocks to be retained in a forest after cutting, shown in Table 1.

Table 1. Minimal growing stocks to be retained in a forest after cutting (Anon 1903).
Tablica 1. Minimalne drvne zalihe koje trebaju ostati u šumi poslije sječe (Anon. 1903)

Position by altitude / *Položaj po nadm. visini*	Minimal stock after cutting per ha for a site class / *Minimalna zaliha poslije sječe po ha za bonitet*						Increament per ha for a site class / *Prirast po ha za bonitet*					
	Beech - *Bukva*			Fir and spruce - *Jela i smreka*			Beech - *Bukva*			Fir and spruce - *Jela i smreka*		
	good *dobar*	medium *srednji*	bad *loš*	good *dobar*	medium *srednji*	bad *loš*	good *dobar*	medium *srednji*	bad *loš*	good *dobar*	medium *srednji*	bad *loš*
Lower *Donji*	280	230	190	480	360	290	5.6	4.6	3.8	9.6	7.2	5.8
Middle *Srednji*	230	190	150	360	290	220	4.6	3.8	3.0	7.2	5.8	4.4
Upper *Visoki*	190	150	110	290	220	160	3.8	3.0	2.2	5.8	4.4	3.2

In terms of altitude, the positions were divided into three zones: for north-western regions, closer to the sea, the lower zone corresponded to the altitudes of 500 to 800 m, the middle zone to 800 - 1200 m, and the upper zone to 1200 m up. In central and southern regions, the zones were moved upwards by 100 - 200 m.

The prescribed yield was determined graphically; the growing stock curves by diameter classes were drawn before and after cutting. Both curves were binomial. The curve of the growing stock after cutting was determined on the basis of experience in marking and the performed cutting operations (the successful ones).

Contrary to other methods, the Instructions of 1937 were original, practical and satisfactory for the conditions of the period. They provided a basis for a large number of management plans for selection forests (Klepac 1997).

The method was appropriate for that period, when the Croatian forests contained large quantities of the growing stock and when forest management was reduced to stereotyped regulation of cutting.

Klepac (1976) mentions that the 1903 Instruction was still valid for selection forests of particular public interest, causing situations in which, in the same forest area, selection forests of some land communities (in Gorski Kotar) were managed with normal models and increment measurements, in other words, much more intensively than state forests managed with minimal stocks after cutting and increment assessment.

All that time (until the Second World War), a considerable proportion of private forests was managed by foreigners, who applied Austrian and Hungarian instructions.

According to Klepac (1997), in the period between the two World Wars, about 60% of the area in Gorski Kotar was managed using foreign models, 22% of the area was managed according to the 1903 Instruction, using the principle of strict sustainability, while 16% of the area was managed on the basis of the 1931 and 1937 Instructions applying the sustainability principle.

"Temporary Instructions for Forest Inventory" were passed in 1946. Their basic task was to find the fastest possible way of assessing what was left and what the structure was of the forests in a country devastated by the war and uncontrolled cutting. The "Temporary Instructions" prescribed management of forests for the entire territory regardless of the ownership type.

In 1948, the "General Instructions for Forest Management" were passed, thus putting the 1903 Instructions and the 1933 Instructions out of use.

According to the 1948 "General Instructions for Forest Management", "to regulate forests means to measure forest land and stands, describe stands, thus establishing the condition of a forest at the time of management, and on the basis of this condition set down guidelines for future management with forests in terms of silviculture and tending, rational and permanent exploitation, and intensify forest management in general."

After World War Two up to the "New System...", selection forests were managed with the 1937 Instruction, complemented with elements of intensive management.

The increment was not assessed but measured with Pressler's drill, the quantity of satisfactory growing stock was determined, a cutting cycle of 10 years was adopted and a management method was prescribed. The prescribed yield was calculated on the basis of the relationship between a concrete and satisfactory growing stock, the general and health status of stands and the state of natural regeneration. The cutting intensity did not exceed 25% in any of the stands (Križanec 1987).

In 1961, Klepac published the "New System of Managing Selection Forests", based on normal models (optimal state).

Normal models were intended for foresters in practice as a tool for managing and regulating selection forests.

The Forestry Secretariat of the Executive Council of the Socialist Republic of Croatia put the "New System" in use with its decision no. 05-441/2 of 12 February 1962.

The "New System" has been widely used in practice and still serves as a basis for managing Croatian selection forests (Meštrović *et al.* 1992).

The "Regulation on Drawing Forest-economic Plans, Management Plans and Programmes for Forest Improvement" of 1968 prescribed ecological-management types (EMT). The EMT is determined on the basis of the geological substrate, forest community, soil type, climate, silvicultural features, productive capacities and stand values.

According to this Regulation, as well as the Regulations of 1976, 1981 and 1985, forests and forest land are classified by EMTs, and within EMTs by management classes. In management units (MU) in which EMTs are not established, until their establishment forest management goals are determined by management classes (according to the purpose of forests and the principal tree species, on the basis of which management goals, rotation, and cutting maturity are determined).

In the period between passing the "New System" in 1962 and the Regulation of 1994, the forests in Gorski Kotar were managed with the normal method. Klepac's normal models were used all the time (the "New System..."), and the Institute's normal models based on EMT were also used in the period 1968-1994.

Bertović *et al.* (1974) state that normal models by EMTs were based on the established cutting maturity in individual forest communities, the species mix found to be the most favourable and Klepac's normal models for beech and fir.

The 1994 Regulation prescribes that selection management can only be applied in fir forests in which other tree species exceed the amount of 10% of the total growing stock. The management goal and method, as well as all the ensuing activities, are determined at the level of management classes (not EMTs any more) within a management unit.

Selection (uneven-aged) forests are managed with the normal method, or according to the "New System...". The Regulation of 1977 has retained the basic postulates of the 1994 Regulation.

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MODELS USED IN MANAGING FIR FORESTS IN GORSKI KOTAR

MODELI UPOTRIJEBLJENI PRI UREĐIVANJU JELOVIH ŠUMA GORSKOGA KOTARA

Model - pattern, design, mould (Klaić 1989)

The paper presents models (normal models) derived from the Normal method before and after cutting in Klepac's "New System ..." and EMTs.

THE NORMAL METHOD BEFORE AND AFTER CUTTING

METODA NORMALA PRIJE I POSLIJE SJEČE

The 1903 Instruction for the management of selection forests of particular public interest prescribed the normal method before and after cutting. Based on the Law of 1894, the "Law regulating expert administration and forest management in forests of particular public interest", some Croatian experts tried to find a method of regulating these selectively managed forests. According to Miletić (1951), the beginnings of this method are found in the works of Tvrdony (1897) and Kern (1898).

According to the Instruction, the number of trees, the sum of the basal areas and the growing stock should be determined (on the basis of the concrete state in the forest), which is normally found in 1 *ral* (approx. half an acre) (one *ral* = 5,754 m^2) before and after cutting in a selection forest.

Miletić (1957) divides normal models before cutting according to their origin:

1. Realistic - based on the data obtained from a selection forest itself.
2. Theoretical - based on certain regularities and gradualness, observed in normal stands; based on the elements collected in a selection forest under management.
3. Combined

Normal models resulting from managing Croatian forests are mostly realistic normal models. With regard to the manner of their origin, Miletić (1957) further divides them into:

1. Free normal models - obtained through the condition in smaller areas of typical stands;
   a) derived from a pure selection stand
   b) derived from a mixed selection stand
2. Deductive normal models - obtained as a mean of several sample areas;
3. Foreign normal models - normal models taken from a foreign source and adapted to the real conditions in a forest.

If a normal model could not be found in a forest before cutting due to past cutting activities or to some other reasons, foreign normal models were applied to this forest, or the normal model was constructed in the following way: in the plots in which the normal model was sought, the structural elements were measured, the forest cover was assessed, and the measured elements were adjusted to the total cover.

Since site and stand conditions in a karst area frequently change, it is questionable whether free normal models constructed on the basis of the condition in a smaller area can be considered a representative of the whole forest.

Different elements of the structure were used to construct the normal model before cutting (basal area, crown cover, number of trees).

The condition after cutting was assessed empirically by repeated tests. The entire final diameter class and a part of the trees from other diameter classes (surplus trees) were designated for cutting. Later, Majnarić abandons this rule and does not cut the whole final diameter class, but its major part (in the normal model for the forest of the former land community Drivenik, 90% of the final diameter class were to be cut). The normal model was considered properly established if the main condition was fulfilled: at the end of the cutting cycle, the earlier normal state before cutting was established in all the elements of the structure.

The characteristic of these normal models, apart from the fact that they envisaged high growing stock before cutting, was that their increment was based on the state after cutting, but even the increment determined in this way was not completely designated for cutting, because certain amounts were kept as a reserve in case of unplanned cutting. As the concrete productive force of the normal model was made up of an average annual volume increment (arithmetic mean of the increment before and after cutting), as well as the stocks of the trees in the measurable part of the stand, it was clear that due to the cutting which was lower even than the increment of the growing stock after cutting, the growing stock per surface unit increased.

Klepac (1962) and Križanec (1963) believe that the success of permanent regeneration of these forests was hindered precisely by the surplus of growing stock.

The normal growing stock of these forests is represented with an arithmetic mean between the normal stock before and after cutting.

THE NEW SYSTEM OF SELECTION FOREST MANAGEMENT
NOVI SISTEM UREĐIVANJA PREBORNIH ŠUMA

In 1961, Klepac drew up the "New System of selection forest management". The new system was based on knowing the optimal (normal) growing stocks, that is, those amounts of the growing stock to be retained in a forest permanently. The size and structure of such growing stocks should be such (neither too high nor too low) as to enable permanent regeneration of a forest and yield the most favourable income (Klepac 1961).

The normal state of a selection forest is based on the basic tree series of different diameters, of which every year one tree reaches the maturity dimension, and on several sets of complementary series that compensate for the trees selected by natural or artificial selection.

Normal models are based on Susmel's correlations for fir, Colette's correlations for beech and Šurić's site classes.

Table 2. Susmel's and Collete's correlations (according to Klepac 1961)
Tablica 2. Prikaz Susmelovih i Coletteovih korelacija (prema Klepcu 1961)

	Fir – *Jela* (Susmel)	Beech – *Bukva* (Colette)
V	$\frac{(h_{dom})^2}{3}$	$\frac{(h_{dom})^2}{4.23}$
q	$\frac{4,3}{\sqrt[3]{h_{dom}}}$	$\frac{4,54}{\sqrt[3]{h_{dom}}}$
G	$0,97\ h_{dom}$	$0,73\ h_{dom}$
d_{max}	$2,64\ h_{dom}$	$2,33\ h_{dom}$

h_{dom} – mean height of dominant trees (m) *srednja visina dominantnih stabala* (m)
V – normal growing stock (m^3/ha) *normalna drvna zaliha* (m^3/ha)
q – coefficient of geometric progression of a normal tree series *koeficijent geometrijske progresije normalnoga niza stabala*
G – optimal basal area (m^2/ha) *optimalna temeljnica* (m^2/ha)
d_{max} – dimension of physical maturity (cm) *dimenzija fiziološke zrelosti* (cm)

Klepac constructs his normal models in the following way:

On the basis of dominant heights taken from Šurić's site classes, he calculates the elements listed above (V, q, G, d_{max}) and on the basis of the physical maturity dimension (d_{max}) and the coefficient of geometric progression (q) determines a standard tree series (expressed by Liocourt's curve). The number of the trees to be found in an individual diameter degree is obtained from a geometric progression (q^n, q^{n-1}, q^{n-2}, ... q^2, q^1, q^0), where q^0 represents the number of trees in the diameter class which contains the dimension of physiological maturity, and n - total number of diameter classes. He goes on to calculate the basal area for every diameter class and the total basal area of the normal series. Putting the optimal basal area (G) into the relationship with the total basal area of the normal tree series, he obtains the correction factor (f), with which he multiplies the number of trees of the normal series and obtains the optimal series of the tree number. Based on the optimal series of the tree number (that should always be in the forest), he calculates the basal area and the growing stock. This concludes the procedure of constructing the normal model with the physiological maturity dimension.

Klepac (1961) says that an artificially balanced curve of the tree number, if there are reasons for this, can be stopped earlier, and so he constructs normal models with the dimension of maturity for the fir of 60 cm, and for the beech of 50 cm. The sum of the basal areas of diameter classes above a certain maturity dimension is proportionally distributed to the remaining diameter classes. Based on these increased basal areas, he calculates the number of trees and the growing stock of every one degree.

The normal state before and after cutting is obtained by differentiating frequency curves of the tree number. Dividing the difference of the tree number of two adjacent diameter degrees with the transitional time of the lower degree, and multiplying it with the tariff, he obtains the annual volume increment. By adding or subtracting the five-year increment to the growing stock of any one degree (for the cutting cycle of 10 years), he obtains its growing stock before (M) or after cutting (m). On the basis of the growing stock before or after cutting, he calculates the number of trees in any one diameter degree and its basal area.

In 1963, Škopac uses Klepac's normal models to construct mixed normal models for the III site class for different species mixes, with physiological maturity. In this case, the species mix does not represent a percentage or a relative participation of an individual species, but shows which part of the pure normal model of an individual species is taken to construct mixed normal models. For example, to construct a mixed normal model of fir 0.8 : beech 0.2, 80 % of the pure fir normal model and 20% of the pure beech normal model are taken.

Klepac (1965) points out that the 10% of beech trees do not interfere with fir's growth, and therefore, normal models can also be constructed with the following ratios: 0.9:0.2; 0.8:0.3; 0.7: 0.4, etc.

Klepac emphasises that he was led to construct normal models because of differing opinions about the optimal state of Croatian selection forests. Due to unfamiliarity with some newer theories concerning the management of selection forests, the Croatian forests were not treated scientifically. He also points out that his normal models are of a temporary character, as in his future work he plans to study the normal models by forest types (according to Križanec 1987).

NORMAL MODELS BY EMTS
NORMALE PO EGT-OVIMA

Normal models by forest types were not constructed by Klepac, as had been his intention, but by the staff of the Forestry Institute in Jastrebarsko, headed by Cestar. They adapted the existing Klepac's normal models to forest types (Križanec 1987).

According to Cestar (1987) "The ecological-management type is the basic unit of typological classification." It represents a certain area of forests and forestland with similar ecological and management characteristics that determine the management method. A forest type is established on the basis of geological substrate, soil type and forest community, as well as silvicultural features, productive capacities and stand values of natural tree species. The best stand form, rotation, cutting maturity diameter, normal production and its value and the method of management are found for each type. A sub-type can be classified within an ecological-management type, which differs from the type in the method of management with regard to some ecological characteristics."

Cestar (1967) says that work on typological activities was based on the studied, described and clearly defined forest communities, to which further research within certain components of typological studies was added following detailed methods drawn by phytocoenologists, pedologists, micro-climatologists, silviculturalists, managers and economists.

According to Hren (1990), EMTs are descriptive forms which make classification, description and comparison of empirical data easier. Concrete data were only used in comparisons and idealising with the aim of obtaining the ideal type, which served as a guideline. Therefore, a type indicates potential possibilities of an area.

Hren (1990) goes on to say that a forest type is defined by an equal level of production, while other factors, such as, for example, regeneration, structure and similar, were hardly used.

Križanec (1987) compared Klepac's normal models and the normal models by EMTs: "Klepac's normal models are flexible and can be adapted to every given forest with regard to its condition at the time of management. Cestar's normal models are not of the same diapason.

They are applicable for a given forest type with a certain maturity dimension. Klepac's models can be adapted to every maturity dimension, ranging from technical to physiological, which is indispensable in a selection forest, because there, the thicker the healthy fir trees are, the better their increment."

RESEARCH TASKS AND GOAL
ZADACI I CILJ ISTRAŽIVANJA

Present the methods serving as a source of the models used in managing these forests;

Present and compare the models to be achieved in these forests;

Compare the present structure of some stands with their former structures and with the proposed models in order to establish their deviations;

Find out if the condition of the stands managed by various owners in the past differs from the condition today, after almost half a century of management by one owner and with the same methods; establish if any possible differences could be attributed to past management (management intensity);

Propose a model or several models to which these stands should aim in order to achieve the set management goal.

METHOD OF WORK
METODA RADA

Apart from presenting models of management with fir forests in Gorski Kotar, the development of several concrete stands will be monitored and compared with their models.

DATA COLLECTION
PRIKUPLJANJE PODATAKA

COLLECTING DATA ON MODELS
PRIKUPLJANJE PODATAKA O MODELIMA

The data on the models used in managing selection forests were taken from the literature written over a wide span, starting from the 80s of the 19th century to date.

The majority of the data on the normal models based on "The normal method before and after cutting", prescribed by the 1903 Instruction, were found in the works of Miletić (1950, 1951 and 1957), while the remaining data, as well as the normal models according to "The new system ..." and EMTs come from the original works of their authors (Kern 1898, 1916, Jovanovac 1925, Cestar et al. 1986).

COLLECTING DATA ON THE STANDS
PRIKUPLJANJE PODATAKA O SASTOJINAMA

In selecting the stands to be monitored over a period of time and compared with the proposed models, I was guided by two facts: a) in the past, some of them were managed by Ghyzy and some by Thurn-Taxis, b) there are numerous data on their structure in the past period. After consulting my colleagues from the Forest Management Department in the Forest Office Delnice, I have decided to focus on the stands from the management units of "Milanov Vrh" and "Crni Lug".

According to the 1990 management plan, the sub-compartments selected for research belong to the EMT I-C-10b, which is the best represented in both MU (in the MU "Milanov Vrh" with 73.8%, and in the MU "Crni Lug" with 37.2%). Table 3 contains a part of the database for this EMT in the MU "Milanov Vrh". The database was drawn in the Excel and was used to select the stands to be measured. Two stands were selected in each MU.

Table 3. A part of the EMT I-C-10b database used to select stands to be investigated in MU "Milanov Vrh"

Tablica 3. Dio baze podataka EGT-a I-C-10b na temelju koje su odabrane sastojine u kojima će se istraživati u GJ "Milanov vrh"

Compartment *Odjel*	Sub-compartment *Odsjek*	Area (ha) *Površina (ha)*	Tree distribution *Raspored stabala*	Management class (by cover) *Uređajni razred (prema obrastu)*	Percentage of growing stock *Postotni udio drvne zalihe*					
					Fir *Jela*	Spruce *Smreka*	Beech *Bukva*	OTS *OTB*	Coniferes *Crnogorica*	Hardwoods *Bjelogorica*
1	a	13.90	Single-tree *Stablimični*	Below the norm *Ispod normale*	71	14	12	3	85	15
1	b	8.01	Cluster *Skupinasti*	Normal *Normalni*	10	67	21	2	77	23
1	c	49.01	Single-tree *Stablimični*	Normal *Normalni*	70	16	12	2	86	14
2	b	44.53	Single-tree *Stablimični*	Normal *Normalni*	75	21	4	0	96	4
...	...	...	...	...	...	...	...	...	...	...
60	a	44.50	Single-tree *Stablimični*	Below the norm *Ispod normale*	71	24	5	0	95	5
60	b	40.82	Single-tree *Stablimični*	Normal *Normalni*	70	22	8	0	92	8

The stands were selected according to the following criteria: compartment size over 10 ha; single-tree distribution; normal management class (cover). Of a total of 79 stands within the mentioned EMT, 30 satisfied these criteria. Additional criteria for the first stand required that the percentage share of the coniferous growing stock be ≥ 80%, and of the fir ≥ 70%, and for the second stand the percentage share of the hardwoods be ≥ 35% and of the fir ≥ 50%. The criteria for the first stand were met by five (1c, 2b, 9a, 9b, 16b), and for the second stand by three (13a, 18, 19a) stands. After analysing their past management plans (areas, boundaries and growing stock), I selected sub-compartment 2b for the first stand and 13a for the second stand.

Compartments 39c and 61b in the MU "Crni Lug" were selected in the same way.

For the selected stands, the data on frequency distributions of tree numbers and stocks by diameter degrees or classes were taken from the earlier management plans at my disposal. The stand parameters in these stands were measured during the summer and autumn of 1997.

I had intended to do the measurements in each of the selected stands on a sample plot sized 1 ha, but after making a round of the terrain, I noticed that the structure of the stand was heterogeneous. Therefore, I did the measurements in smaller plots in order to assess all the conditions in the stand.

Both my experience and the research by Sayn-Wittgenstein shows that a plot has an optimal size if the number of measurable trees (n) ranges from 6 - 16, depending on the dimensions of breast diameters (Pranjić 1977). This is why I chose a square plot sized 0.0578 ha and set up a total of 16 plots of 0.9248 ha in each stand. The plots were arranged as a systematic sample, and were marked with 17-m-long semi-diagonals.

Field work involved measuring breast diameters of the trees over the taxation limit (10 cm), measuring heights for the purpose of constructing a height curve, and taking increment cores for the purpose of determining the tree transition time for constructing normal models before felling. For each stand, about 90 heights were measured and as many increment cores taken.

DATA PROCESSING
OBRADA PODATAKA

PROCESSING THE DATA RELATED TO THE MODELS
OBRADA PODATAKA VEZANIH UZ MODELE

As the distribution in a part of the old normal models was expressed in diameter classes of different breadths (e.g. diameter class II; 25-34 cm; 25-37 cm; 27-40 cm, ...), I adjusted these normal models to decating diameter classes in order to present them graphically.

Adjustment was done under the assumption that the frequency curve of the tree number had the shape of Liocourt's hyperbolic curve.

For the purpose of comparison with the old normal models, I constructed (according to Klepac) pure normal models for the fir for the condition before cutting, with a cutting cycle of 10 years and the maturity dimension of 60, 65 and 70 cm and the Institute's normal model for the condition before cutting with a 10-year cutting cycle and the maturity dimension of 70 cm.

I used the New System to construct pure normal models for the II and II/III site class of fir and the II, III and III/IV site class of beech with the physiological maturity and maturity dimension of 70 cm for the fir and 50 cm for the beech, and mixed normal models of fir : beech = 60% : 40% (the II-II site class - for the purpose of comparison with the Institute's normal model EMT I-C-10b), and 70% : 40% and 60% : 50% (the II-III and the III-IV site class) of the tree number of pure normal models - models for the studied stands.

PROCESSING THE DATA OF THE SELECTED STANDS
OBRADA PODATAKA ODABRANIH SASTOJINA

The data obtained from measuring breast diameters enabled calculations of the structure by tree number (reduced to ha) per plots and compartments. By mathematical equalisation of the measured heights with Mihailo's function

$$h=b_0 \cdot e^{-b_1/d} + 1.30$$

h – tree height - *visina stabla*
d – breast diameter - *prsni promjer*
e – natural logarithm base - *baza prirodnoga logaritma*
b_0 – regression constant - *regresijska konstanta*
b_1 – regression coefficient - *regresijski koeficijent*

Fir height curves were obtained for every sub-compartment separately. The local tariffs were constructed on the basis of height curves and Špiranec's two-parameter tables of the growing stock for fir (timber) (Špiranec 1976). Based on the calculated structure by tree number and local tariff, I calculated the structure by growing stock (per ha) per plots and sub-compartments.

The analysis of the increment cores provided transition times of every sampled tree. The transition times of any one diameter class (its median, with weight) were equalised with the function $VP = b_0 + b_1/d + b_2/d^2$,

VP – transition time - *vrijeme prijelaza*
d – breast diameter - *prsni promjer*
b_0 – regression constant - *regresijska konstanta*
b_1, b_2 – regression coefficients - *regresijski koeficijenti*

RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA

THE RESULTS OF MODEL STUDY
REZULTATI ISTRAŽIVANJA O MODELIMA

The majority of the collected models related to pure normal models of both fir and beech for the condition before and after cutting. They were used for the construction of mixed normal models. In presenting the distribution of the number of trees per diameter classes in the old normal models I focused on pure fir normal models before cutting.

Kern's normal models. In my research I shall present two of Kern's normal models (pure fir - the state before cutting). The normal model for the former land community (f. l. c.) Hreljin from 1898 (1.) (the numbers in brackets relate to the ordinal number of normal model in Table 4). In the forest, Kern found a stand or its part containing full cover and regarded the measured basal area to be the normal basal area. He divided it with the number of diameter classes (5), so that each diameter class was represented by an equal basal area. The maturity dimension was 60 cm.

The normal model for the f. l. c. Crni Lug from 1916 (2.). There, Kern abandoned his thesis that individual diameter classes had equal basal areas, and said that the "sum total of basal areas will be the smallest in the lowest, and the biggest in the highest diameter class" (Kern 1916). The maturity dimension was not strictly defined, contrary to the number of trees above 51 cm in diameter.

Majnarić's normal models. A total of nine normal models, constructed in the period 1913-1941, were analysed. In the majority of the models: for f. l .c. Mrzla Vodica (vicinity of Risnjak) from 1913 (3), f. l. c. Ravna Gora (Velika Kapela - below Bjelolasica) from 1924 (4), f. l. c. Dol (vicinity of Fužine) from 1926 (5), f. l. c. Lokve from 1928 (6), f. l. c. Drivenik (vicinity of Lič above Fužine) from 1930 (7), f. l. c. Belgrad – MU Strilež-Ravno (below Viševica) from 1934 (8) and f. l. c. Fužine (new estate) from 1941 (11), Majnarić started from the fact (considered proven at the time) that the sum of basal areas of fir at full cover was about 52 m² (Miletić, 1957). More significant deviation of the basal area is expressed in the normal models for the f. l. c. Belgrad, MU Falšja Draga from 1934 (9) (41.47 m²) and the f. l. c. Novi Zagon from 1938 (10) (40.40 m²), because there were no "normal" stands of fir in these MUs. For the f. l. c. Fužine, the forest of Rogozno (the old estate), Majnarić constructed normal models for different species mixes that he found in the forest, and presented the data on the basal area and the growing stock summarily.

Jovanovac's normal models. Jovanovac based his normal models for the f. l. c. Benkovac (near Fužine) from 1912 (12) and f. l. c. Hreljin-Ružić Selo from 1914 (13) on the equality of the basal areas of individual diameter classes.

Tvrdony. In constructing a normal model for the f. l. c. Fužine (the old estate) from 1926 (14), he found that the basal area ranged widely from 31.32 - 77.70 m² per ha. He considered the basal area of 62.64 m² to be the ideal basal area before cutting, and constructed a normal model in which the sum of the basal areas was 63.81 m².

Matizović also based his normal models for the former estate Severin na Kupi from 1936 (15) and former estate Sušica na Mostu from 1929 (16) on the total basal area per ha, while *Žagar* in the normal model for the f. l. c. Crikvenica from 1935 (17) adjusted the condition in the forest to a full cover and corrected the irregularities graphically.

Šimić constructed his normal models for the management class (MC) Bijela Kosa-Bazgovac (23) and MC Makovnik-Crni Potok (24), both from 1911, for the former Ogulin property commune (vicinity of Plaško) in mixed stands of fir and beech with the 1 : 1 and 2 : 1 ratios (fir, beech). He also maintained that a pure fir stand before cutting should have about 52.2 m², and that of beech 34.8 m².

The basic postulates of Miklavžić's normal models for the f. l. c. Zlobin from 1930 (18-22) are not known.

Summary data on these normal models are given in Table 4 and the distribution of tree numbers by diameter classes for the majority of them are given in Figure 3 (3.1. - 3.4.).

The EMT I-C-10b model consists of 60% of the number of trees of pure fir and 40% of the

Table 4. Summary data on the models based on the normal method before and after cutting

Tablica 4. Sumarni podaci o modelima nastalim na temelju metode normala prije i poslije sječe

Nr. *Br.*	Author *Autor*	Formulated in *Nastala*	Site class *Bonitet*	Before cutting - *Prije sječe*			Rotation *Ophodnjica*	After cutting - *Poslije sječe*			Increament * *Prirast**	Increment ** *Prirast***	Felling *Etat*	Intensity of cutting *Intenzitet sječe*
				N	G	V		N	G	V				
		Year – *god.*		pcs/ha	m²/ha	m³/ha	Years – *god.*	pcs/ha	m²/ha	m³/ha	m³/ha	m³/ha	m³/ha	%
1.	Kern	1898.	I	1023	53	574	20		42	441			6.65	1.16
2.		1916.	I	709	53	535.88	25	610	36.58	345.01			7.63	1.42
3.	Majnarić	1913.	srednji	605	52.53	551.86	25	551	36.66	347.87	10.42	8.41	8.16	1.48
4.		1924.		644	53.07	559.96	25	508	35.50	350.43	10.78	8.70	8.38	1.50
5.		1926.	srednji	575	55.94	625.10	25	481	38.39	420.25	10.14	8.82	8.19	1.31
6.		1928.		664	57.49	586.66	25	578	40.42	386.79	10.21	8.38	8.00	1.36
7.		1930.		549	48.81	492.92	20	402	30.17	286.42	9.00	6.87	10.32	2.09
8.		1934.		791	52.48	544.25	25	659	36.11	353.87	9.83	7.92	7.62	1.40
9.		1934.		670	41.75	289.06	12	584	32.51	225.50	6.11	5.41	5.30	1.83
10.		1938.		462	40.40	392.56	30	425	29.23	261.01	5.09	4.35	4.38	1.12
11.		1941.		j:b = 0.9:0.1	53.98	688.36	20			516.27			10.22	
12.	Jovanovac	1912.		847	50.46	594.34	20	680	34.80	398.35	12.34	10.38	9.80	1.65
13.		1914.		990	59.16	652.18	20	845	43.50	460.12	11.15	9.48	9.60	1.47
14.	Tvrdony	1926.		649	63.81	729.06	20		40.02				11.80	
15.	Matizović	1936.		637	48.99	542.10	20	528	26.64	283.07	13.41	9.64	12.95	
16.		1929.		785	46.31	490.35	20	573	29.18	269.94	12.65	9.82	11.02	2.25
17.	Žagar	1935.	III	689	49.24	564.44	20	513	31.17	326.59			11.89	2.11
18.	Miklavžić	1930.	II	699	46.98	536.76	20	644	33.72	374.17	8.83	7.46	8.13	1.51
19.		1930.	III	699	46.98	426.93	20	644	33.72	284.89	7.43	6.26	6.60	1.55
20.		1930.	IV	699	46.98	305.89	20	644	33.72	201.77	7.43	6.26	5.20	1.70
21.		1930.	II	760	52.15	598.19	20	697	37.27	415.28	9.82	8.28	9.14	1.53
22.		1930.	III	Vrijedi normala od GJ A za isti bonitet										
23.	Šimić	1911.		901 j:b=2:1	46.37	429.50	30	623	28.40	252.29			5.91	1.38
24.		1911.		707 j:b=1:1	42.60	405.35	30	512	26.24	230.72			5.82	1.44

*Arithmetic means of stock increment before and after cutting; ** Stock increment after cutting

* *Aritmetička sredina prirasta zalihe prije i poslije sječe;* ** *Prirast zalihe poslije sječe*

number of trees of pure beech model (both for the II site class), with the maturity dimension of 70 cm for the fir, and of 50 cm for the beech. I constructed Klepac's normal model under the same conditions. The dominant trees, whose heights are used to construct Klepac's normal models, are defined differently by different authors, which leads to a decrease in the heights and the growing stocks of the constructed normal models (Božić & Čavlović 2001). For this reason, in constructing the normal models, I used the dominant heights that Klepac also used.

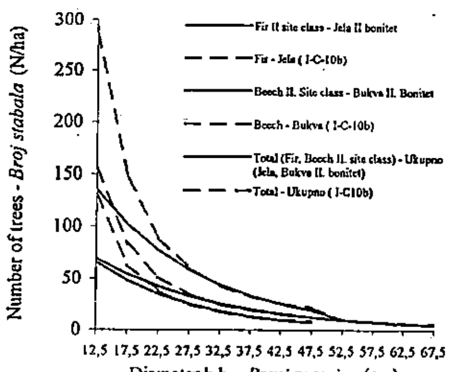


Figure 1. The position of the Institute's normal model (I-C-10b) towards Klepac's normal model

Slika 1. Položaj institutske normale prema Klepčevoj normali

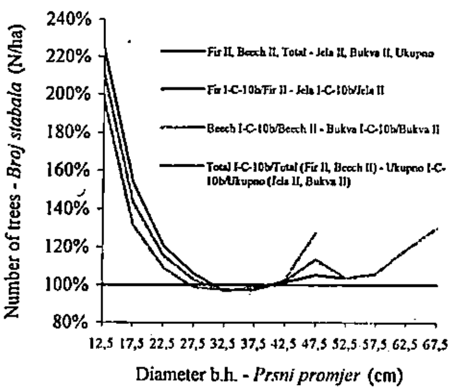


Figure 2. The relationship of the Institute's normal model (I-C-10b) and Klepac's normal model

Slika 2. Odnos institutske normale prema Klepčevoj normali

Since „old" normal models showed the condition of stands before (and after) cutting, in order to compare them with the models used more recently I used the „New System ..." to construct Klepac's and the Institute's normal model for pure fir, the condition before cutting, with a 10-year cutting cycle. The Institute's normal model was constructed with the maturity dimension of 70 cm, and Klepac's model with the maturity dimensions of 70, 65 and 60 cm.

The normal models in Figures 3.1 - 3.4 were grouped by the indicated or assumed maturity dimensions, which also served to construct Klepac's normal model. In Figure 3.1, a maturity dimension of 60 cm was indicated for the normal model of the f. l. c. Hreljin, while maturity dimensions for other normal models were not defined. As the breadth of earlier diameter classes was 10 cm in decatic division, I assumed that the breadth of the final diameter class was 10 cm. Therefore, the maturity dimension was 60 cm. The normal models shown in Figures 3.2 - 3.4 were also grouped, that is, their maturity dimensions were defined in the same way.

Figure 3.1. - *Slika 3.1.*

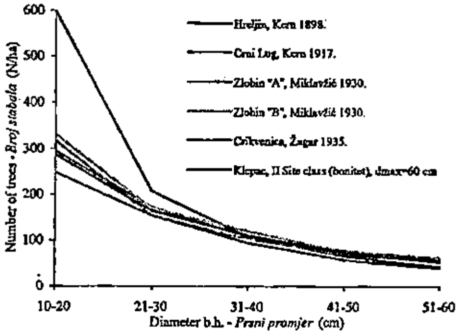


Figure 4.1. - *Slika 4.1.*

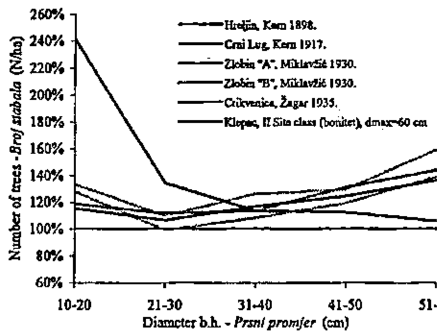


Figure 3.2. - *Slika 3.2.*

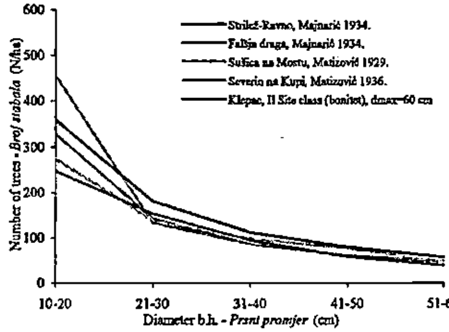


Figure 4.2. - *Slika 4.2.*

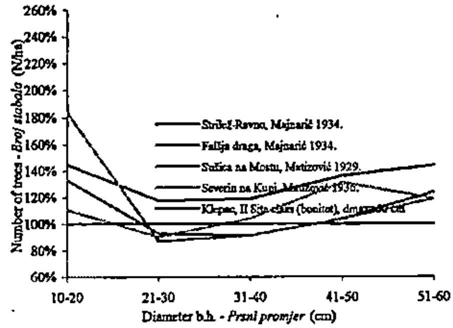


Figure 3.3. - *Slika 3.3.*

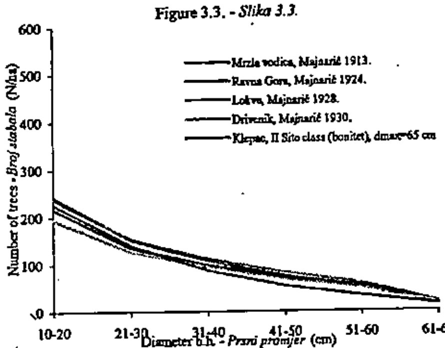
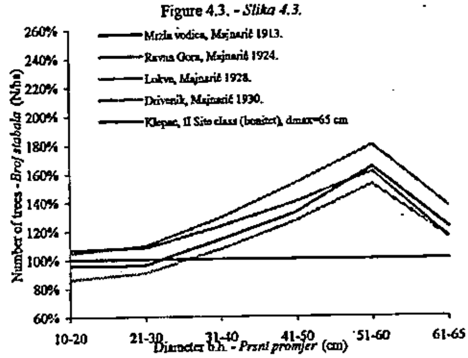
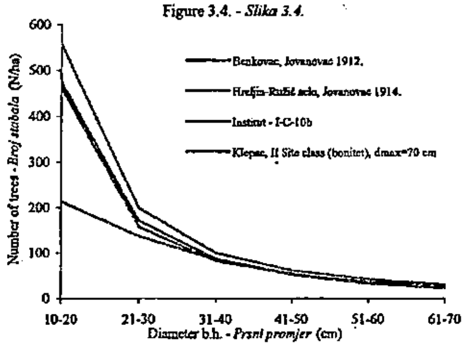


Figure 4.3. - *Slika 4.3.*





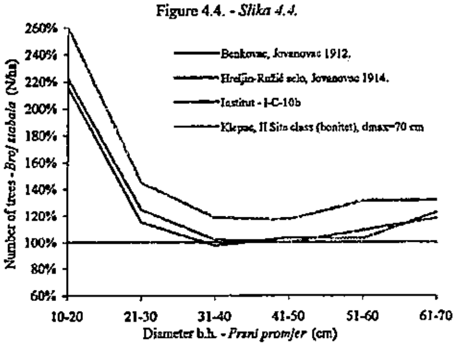


Figure 3. (3.1 - 3.4) The position of some old normal models and the Institute's model towards Klepac's model (pure fir before cutting)

Slika 3. (3.1.-3.4.) Položaj nekih starih normala te institutske normale prema Klepčevoj normali (čista jela prije sječe)

Figure 4. (4.1 - 4.4) The relation of some old normal models and the Institute's model towards Klepac's normal model (pure fir before cutting)

Slika 4. (4.1.-4.4.) Odnos nekih starih normala te institutske normale prema Klepčevoj normali (čista jela prije sječe)

THE RESULTS OF RESEARCH IN STANDS
REZULTATI ISTRAŽIVANJA U SASTOJINAMA

Under earlier management plans, the stands within the EMT I-C-10b belonged to different site classes. The selected stands were therefore compared with the normal models of the concrete site classes to which these stands belong.

Based on the measured heights, I constructed a height curve for each stand. By inserting stand height curves of the fir into the boundaries of Šurić's (Pranjić) site classes (Božić 2000), I defined (based on the dominant part of the stand) the site class to which the fir in the given stand belongs.

In the stands 39b and 61b, the fir belongs to the II, and in the stands 2b and 13 a, it belongs to the II/III site class. As the heights of the beech were not measured, the site class of beech was determined on the basis of the data from old management plans, according to which the site class of beech was worse by one site class than that of fir. Thus, the beech in the stands 39c and 61b was placed into the III, and in the stands 2b and 13a into the III/IV site class.

Table 5. The structure of a stand per hectare - sub-compartment 2b

Tablica 5. Struktura sastojine po hektaru - odsjek 2b

$d_{1.30}$	Jela - Fir			Smreka - Spruce			Bukva - Beech			Ostalo - Other			Ukupno - Total		
	N	G	V	N	G	V	N	G	V	N	G	V	N	G	V
12.5	37.8	0.46	1.93	4.3	0.05	0.22	44.3	0.54	1.77				86.5	1.06	3.92
17.5	46.5	1.12	7.25	13.0	0.31	2.02	32.4	0.78	3.57				91.9	2.21	12.85
22.5	32.4	1.29	10.80	7.6	0.30	2.52	14.1	0.56	3.09	1.1	0.04	0.24	55.1	2.19	16.65
27.5	22.7	1.35	13.24	10.8	0.64	6.30	3.2	0.19	1.23	1.1	0.06	0.41	37.8	2.25	21.19
32.5	42.2	3.50	38.25	7.6	0.63	6.87	4.3	0.36	2.55				54.1	4.48	47.67
37.5	36.8	4.06	48.05	7.6	0.84	9.89	1.1	0.12	0.93				45.4	5.01	58.87
42.5	21.6	3.07	38.21	5.4	0.77	9.55	1.1	0.15	1.30				28.1	3.99	49.06
47.5	23.8	4.21	54.71	3.2	0.57	7.46							27.0	4.79	62.18
52.5	14.1	3.04	40.71	9.7	2.11	28.18							23.8	5.15	68.89
57.5	7.6	1.96	26.90	7.6	1.96	26.90							15.1	3.93	53.80
62.5	4.3	1.33	18.51	2.2	0.66	9.25							6.5	1.99	27.76
67.5	2.2	0.77	10.92	1.1	0.39	5.46							3.2	1.16	16.38
72.5	2.2	0.89	12.72										2.2	0.89	12.72
77.5	1.1	0.51	7.32										1.1	0.51	7.32
82.5															
87.5															
92.5															
97.5															
Total	295.2	27.56	329.53	80.0	9.23	114.64	100.6	2.71	14.45	2.2	0.11	0.65	477.9	39.61	459.26

Table 6. The structure of a stand per hectare - sub-compartment 13a

Tablica 6. Struktura sastojine po hektaru - odsjek 13a

$d_{1.30}$	Jela - Fir			Smreka - Spruce			Bukva - Beech			Ostalo - Other			Ukupno - Total		
	N	G	V	N	G	V	N	G	V	N	G	V	N	G	V
12.5	96.2	1.18	4.72	5.4	0.07	0.26	45.4	0.56	3.18	1.1	0.01	0.08	148.1	1.82	8.24
17.5	44.3	1.07	6.78	10.8	0.26	1.65	28.1	0.68	4.78				83.3	2.00	13.22
22.5	45.4	1.80	14.94	8.7	0.34	2.85	17.3	0.69	5.71				71.4	2.84	23.50
27.5	33.5	1.99	19.31	2.2	0.13	1.25	15.1	0.90	8.48	2.2	0.13	1.21	53.0	3.15	30.24
32.5	23.8	1.97	21.46	4.3	0.36	3.90	20.5	1.70	17.67	2.2	0.18	1.86	50.8	4.21	44.89
37.5	18.4	2.03	23.92	1.1	0.12	1.41	15.1	1.67	18.92	2.2	0.24	2.70	36.8	4.06	46.95
42.5	28.1	3.99	49.68	2.2	0.31	3.82	17.3	2.45	29.93	1.1	0.15	1.87	48.7	6.90	85.30
47.5	19.5	3.45	45.12	4.3	0.77	10.03	13.0	2.30	29.84	1.1	0.19	2.49	37.8	6.70	87.47
52.5	4.3	0.94	12.57	1.1	0.23	3.14	3.2	0.70	9.63				8.7	1.87	25.35
57.5	7.6	1.96	27.00	1.1	0.28	3.86	0.0	0.00	0.00	1.1	0.28	4.05	9.7	2.53	34.91
62.5	7.6	2.32	32.51				1.1	0.33	5.02				8.7	2.65	37.53
67.5															
72.5				1.1	0.45	6.40							1.1	0.45	6.40
77.5															
82.5															
87.5															
92.5															
97.5															
Total	328.7	22.70	258.00	42.2	3.31	38.57	176.3	11.98	133.16	10.8	1.19	14.26	558.0	39.17	444.00

Table 7. The structure of a stand per hectare - sub-compartment 39c

Tablica 7. Struktura sastojine po hektaru - odsjek 39c

$d_{1.30}$	Jela - Fir			Smreka - Spruce			Bukva - Beech			Ostalo - Other			Ukupno - Total		
	N	G	V	N	G	V	N	G	V	N	G	V	N	G	V
12.5	18.5	0.23	0.98	1.2	0.02	0.07	32.1	0.39	1.93	1.2	0.02	0.07	53.1	0.65	3.05
17.5	19.8	0.48	3.20	1.2	0.03	0.20	21.0	0.51	3.36	1.2	0.03	0.20	43.3	1.04	6.96
22.5	16.1	0.64	5.56				11.1	0.44	3.45	2.5	0.10	0.77	29.7	1.18	9.77
27.5	12.4	0.73	7.48	2.5	0.15	1.50	13.6	0.81	7.20				28.4	1.69	16.18
32.5	12.4	1.02	11.64	2.5	0.20	2.33	9.9	0.82	8.11	1.2	0.10	1.01	26.0	2.15	23.09
37.5	7.4	0.82	10.03				11.1	1.23	13.24	1.2	0.14	1.47	19.8	2.18	24.74
42.5	12.4	1.75	22.74				12.4	1.75	20.27	1.2	0.18	2.03	26.0	3.68	45.03
47.5	7.4	1.31	17.71	1.2	0.22	2.95	9.9	1.75	21.55	1.2	0.22	2.69	19.8	3.50	44.91
52.5	8.7	1.87	26.10				4.9	1.07	13.99	1.2	0.27	3.50	14.8	3.21	43.59
57.5	4.9	1.28	18.28	3.7	0.96	13.71	1.2	0.32	4.40				9.9	2.57	36.40
62.5	8.7	2.65	38.49										8.7	2.65	38.49
67.5	1.2	0.44	6.50										1.2	0.44	6.50
72.5	2.5	1.02	15.09	2.5	1.02	15.09							4.9	2.04	30.19
77.5	6.2	2.91	43.42				1.2	0.58	9.42				7.4	3.50	52.84
82.5	1.2	0.66	9.88										1.2	0.66	9.88
87.5	3.7	2.23	33.77										3.7	2.23	33.77
92.5	1.2	0.83	12.70										1.2	0.83	12.70
97.5	1.2	0.92	14.21										1.2	0.92	14.21
Total	145.8	21.81	297.79	14.8	2.60	35.85	128.5	9.67	106.91	11.1	1.04	11.74	300.3	35.12	452.29

Table 8. The structure of a stand per hectare - sub-compartment 61b

Tablica 8. Struktura sastojine po hektaru - odsjek 61b

$d_{1.30}$	Jela - Fir			Bukva - Beech			Ostalo - Other			Ukupno - Total		
	N	G	V	N	G	V	N	G	V	N	G	V
12.5	9.7	0.12	0.48	43.3	0.53	3.46				53.0	0.65	3.94
17.5	11.9	0.29	1.86	35.7	0.86	7.14	1.1	0.03	0.22	48.7	1.17	9.21
22.5	5.4	0.21	1.82	29.2	1.16	11.09	3.2	0.13	1.23	37.8	1.50	14.15
27.5	1.1	0.06	0.65	21.6	1.28	14.06	6.5	0.39	4.22	29.2	1.73	18.92
32.5	4.3	0.36	4.07	23.8	1.97	23.79	9.7	0.81	9.73	37.8	3.14	37.60
37.5	3.2	0.36	4.41	18.4	2.03	26.47				21.6	2.39	30.88
42.5	8.7	1.23	16.04	11.9	1.69	23.67	2.2	0.31	4.30	22.7	3.22	44.01
47.5	11.9	2.11	28.84	7.6	1.34	20.06	2.2	0.38	5.73	21.6	3.83	54.63
52.5	5.4	1.17	16.55	1.1	0.23	3.70				6.5	1.40	20.25
57.5	8.7	2.25	32.68				1.1	0.28	4.66	9.7	2.53	37.34
62.5	14.1	4.31	64.03							14.1	4.31	64.03
67.5	4.3	1.55	23.28							4.3	1.55	23.28
72.5	8.7	3.57	54.44							8.7	3.57	54.44
77.5	4.3	2.04	31.32							4.3	2.04	31.32
82.5	2.2	1.16	17.89							2.2	1.16	17.89
87.5	1.1	0.65	10.18							1.1	0.65	10.18
92.5												
97.5	1.1	0.81	12.92							1.1	0.81	12.92
Total	106.0	22.23	321.45	192.5	11.10	133.43	26.0	2.32	30.09	324.4	35.64	484.98

The normal model to be achieved through management can be specified by the distribution of the tree number, basal area and growing stock (volume). The number of trees in a given diameter class, obtained from direct measurements in the forest, represents the concrete value. With a constant number of trees within a given diameter class, the basal area is always the same. However, the growing stock, whether specified by the model, or calculated in a concrete stand, is not the same under a constant number of trees in diameter classes, but depends on the applied tariff.

Different tariffs have been used to calculate the growing stock in the past fifty years. The stocks calculated with the tariffs used so far (based on the measurement of 1997) show considerable deviations (Božić 2000). For this reason, in my further work I only observed trends in the distribution of tree numbers.

Fir stands are managed with the aim of achieving the most favourable species mix ranging from 70:30 to 80:20 % (fir : beech). For the sub-compartments under research I constructed Klepac's mixed normal models (60:50 and 70:40% of the tree number of pure models), which satisfy the mentioned species mixes per growing stock. I incorporated these normal models in the distributions of tree numbers and selected the one that corresponded to the concrete data with regard to the position (Figure 5 - 16).

Figures 5 – 16 Shifts in the distribution of tree numbers in the past period and their position according to the proposed model constructed with the species mix per growing stock: fir 80%: beech 20% (N_{fir} 70%: N_{beech} 40%), and fir 70%: beech 30% (N_{fir} 60%: N_{beech} 50%), with the physiological maturity dimension (*PM*) and maturity dimension (*MD*) of 70 cm for the fir and 50 cm for the beech.

*Slike 5 – 16. Pomaci distribucije broja stabala protekom vremena te njihov položaj prema predloženomu modelu načinjenomu uz omjere smjese po drvnoj zalisi: jela 80 % : bukva 20 % (N_{fir} 70 % : N_{beech} 40 %) te jela 70 % : bukva 30 % (N_{fir} 60 % : N_{beech} 50%), uz fiziološku dimenziju zrelosti (*PM*) te dimenziju zrelosti (*MD*) od 70 cm za jelu te 50 cm za bukvu.*

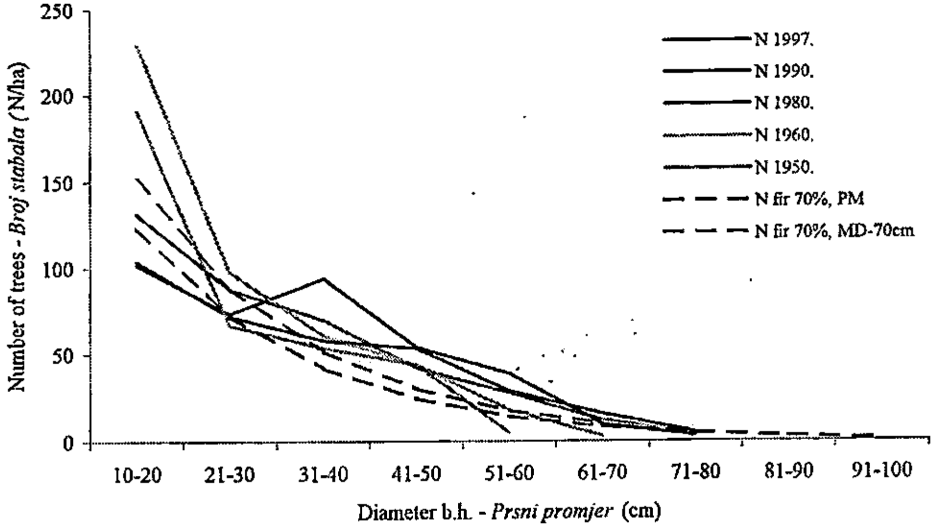


Figure 5. Sub-compartment 2b - fir II/III site class
Slika 5. Odsjek 2b - jela II/III bonitet

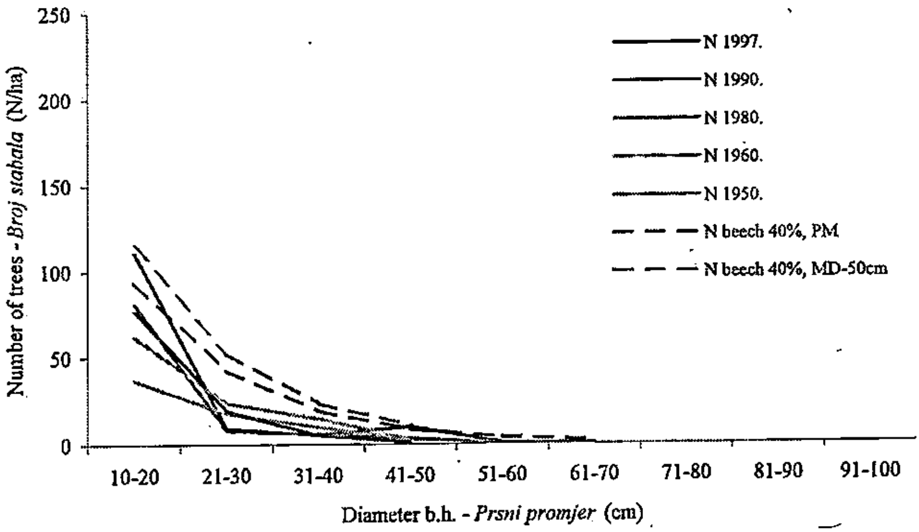


Figure 6. Sub-compartment 2b - beech III/IV site class
Slika 6. Odsjek 2b - bukva III/IV bonitet

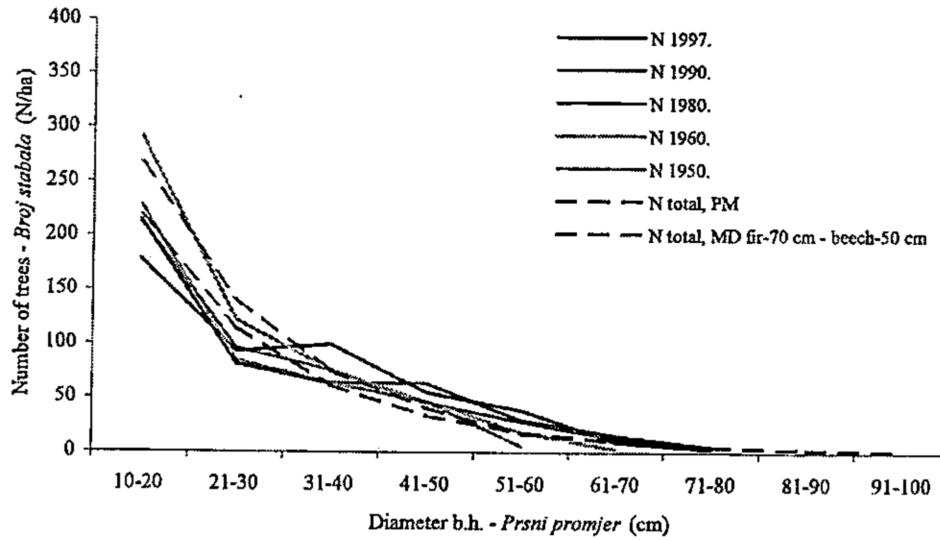


Figure 7. Sub-compartment 2b – total

Slika 7. Odsjek 2b – ukupno

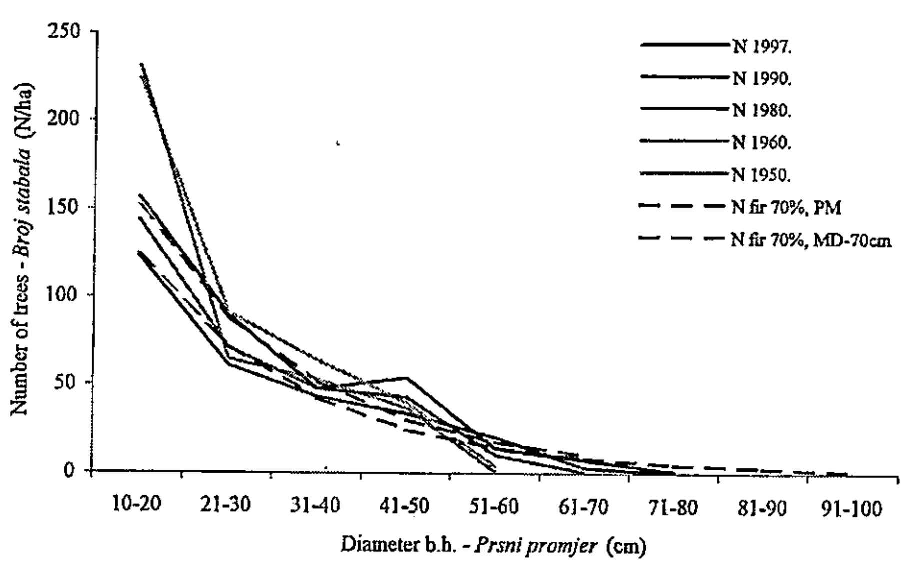


Figure 8. Sub-compartment 13a - fir II/III site class

Slika 8. Odsjek 13a - jela II/III bonitet

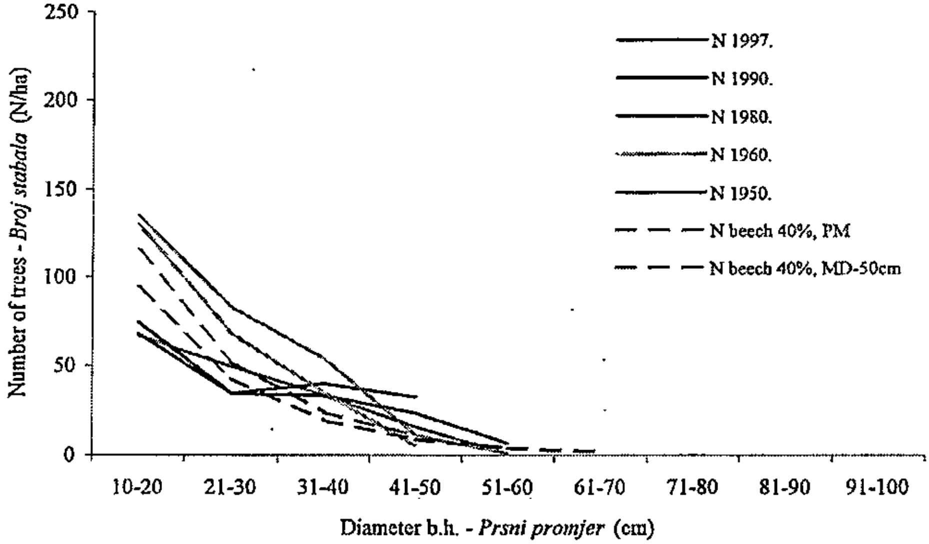


Figure 9. Sub-compartment 13a - beech III/IV site class

Slika 9. Odsjek 13a - bukva III/IV bonitet

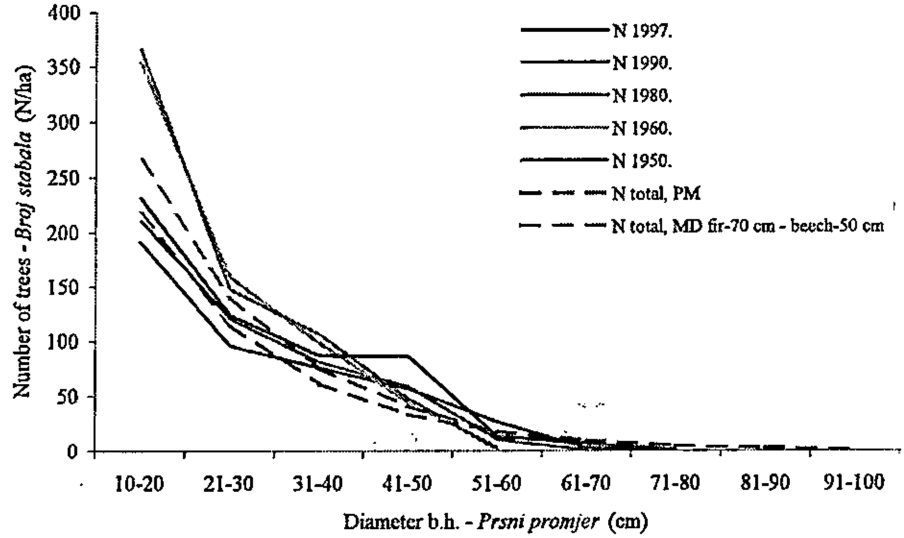


Figure 10.Sub-compartment 13a – total

Slika 10. Odsjek 13a – ukupno

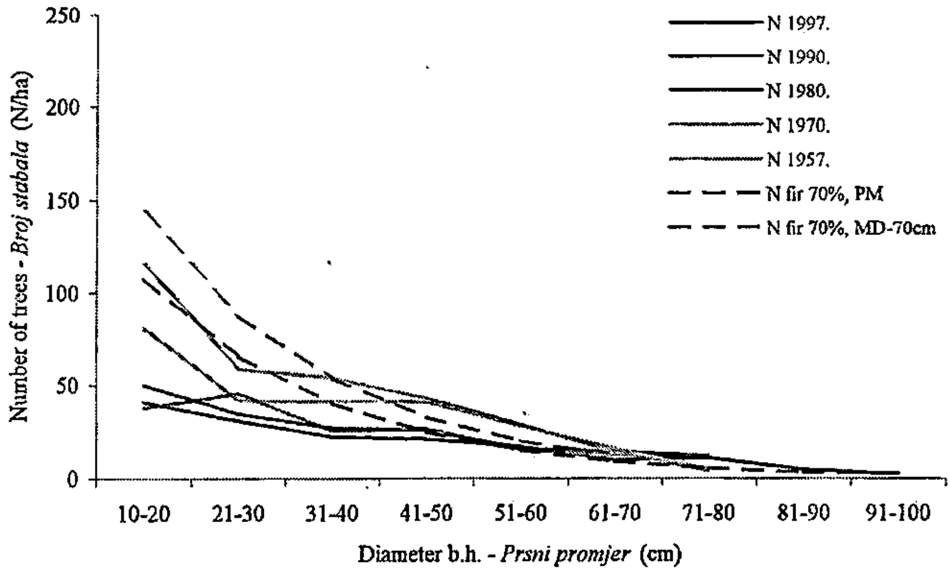


Figure 11. Sub-compartment 39c - fir II site class

Slika 11. Odsjek 39c - jela II bonitet

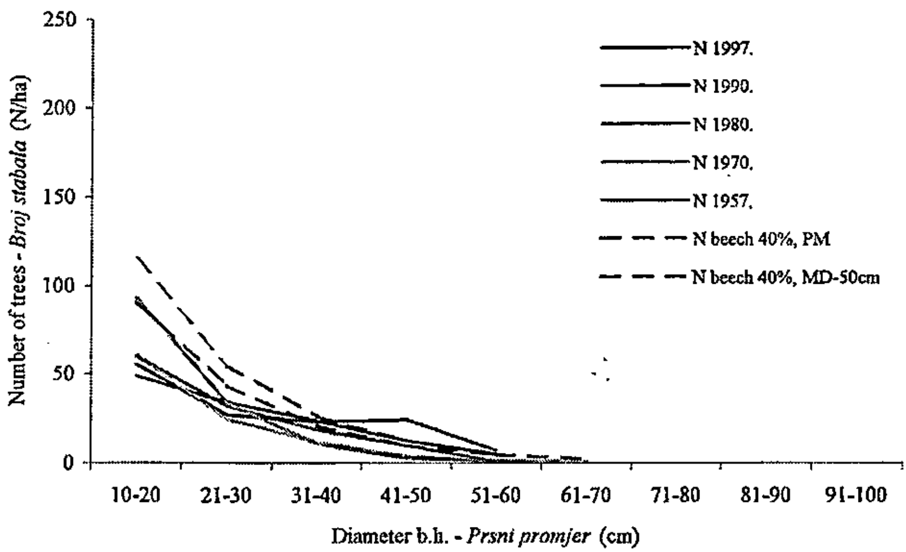


Figure 12. Sub-compartment 39c - beech III site class

Slika 12. Odsjek 39c - bukva III bonitet

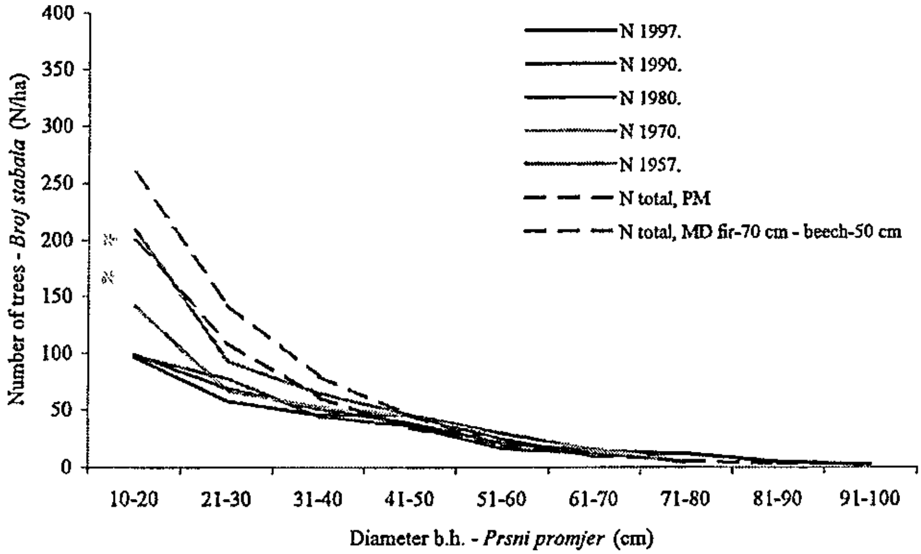


Figure 13. Sub-compartment 39c – total

Slika 13. Odsjek 39c – ukupno

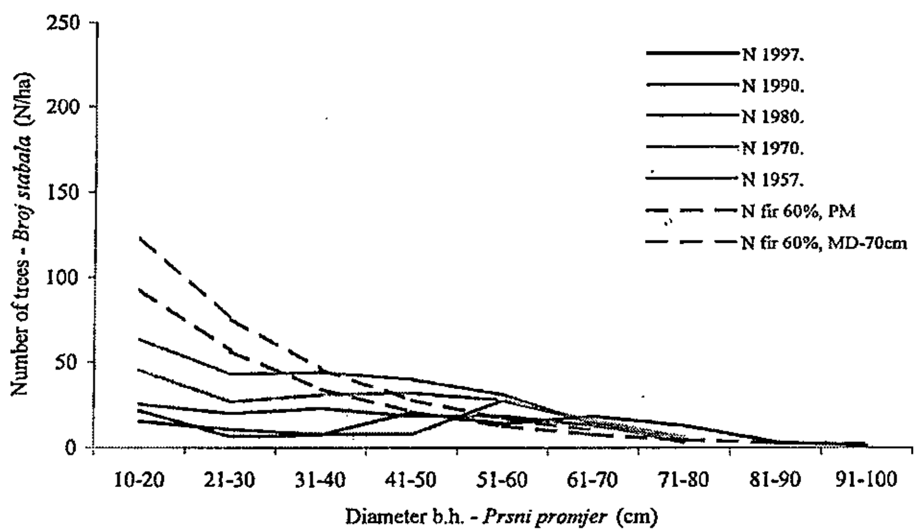


Figure 14. Sub-compartment 61b - fir II site class

Slika 14. Odsjek 61b - jela II bonitet

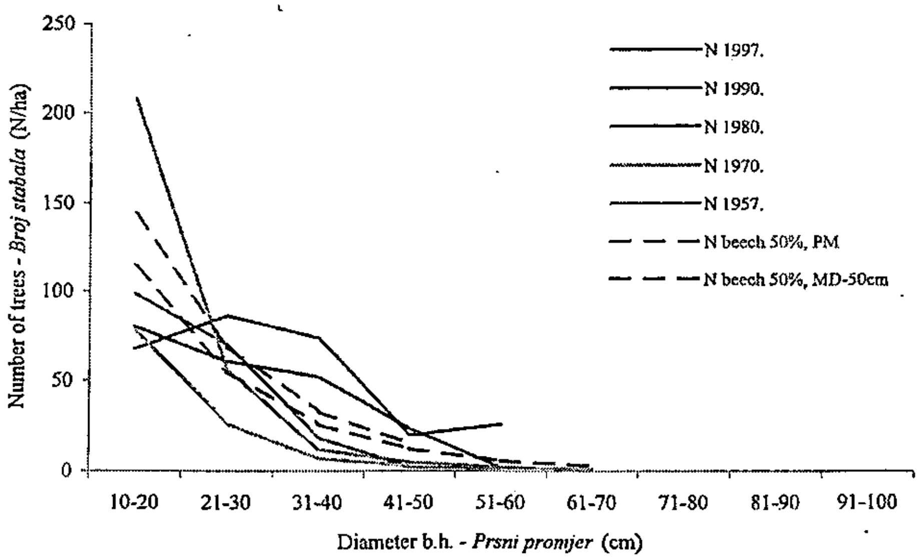


Figure 15. Sub-compartment 61b - beech III site class
Slika 15. Odsjek 61b - bukva III bonitet

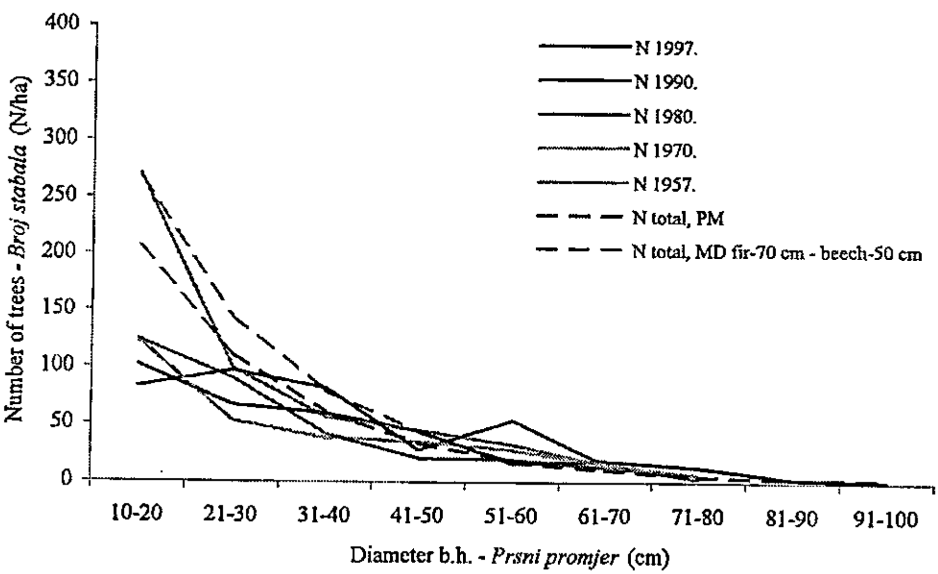


Figure 16. Sub-compartment 61b - total
Slika 16. Odsjek 61b - ukupno

DISCUSSION
RASPRAVA

DISCUSSING THE MODELS
RASPRAVA O MODELIMA

Kern's normal model for the land community (l.c.) Hreljin deviates considerably from Klepac's normal model. The deviation is the biggest in diameter class I, which contains 599 trees in Kern's normal model and 248 trees (+ 141%) in Klepac's model. In higher diameter classes the deviations decrease to + 6% in the last diameter class. The reason for such a large number of trees in lower diameter classes is the condition which was used for the construction of the model (the equality of basal areas of all diameter classes). Kern's normal model for the l.c Crni Lug is characterised by a slightly lower growing stock with a much smaller number of trees. In its construction, Kern abandoned the equality of basal areas of all diameter classes. More significant deviations from Klepac's normal models occur in the IV and V diameter class (31.23% and 44.05%).

Compared to Klepac's normal model, Majnarić's normal models are characterised by an excessive number of thick trees. This is most prominent in diameter class V, in which the number of trees is higher by 36-79% in relation to Klepac's models. In lower diameter classes deviations are less significant, and with some models the tree number curves in lower diameter classes are almost parallel to Klepac's normal model.

Miklavžić's and Žagar's normal models are similar to Kern's model for the l.c. Crni Lug.

Jovanovac's normal model was constructed under the same assumptions as Kern's model for the l.c. Hreljin (the equality of basal areas in given diameter classes). Therefore, their position and deviations in relation to Klepac's model are understandable. The smallest deviation in comparison with Klepac's model occurs in the number of medium thick trees, while it is almost equal in the normal model for the l.c. Benkovac.

With reference to normal models by EMT, Bertović *et al* (1974) say that they were constructed with the use of Klepac's models for beech and fir. What is interesting here, and can be seen in Figures 3.4 and 4.4, is that the Institute's normal model for EMT I-C-10b (recalculated for pure fir before cutting) overlaps almost completely with Jovanovac's normal model for the l.c. Benkovac.

In most of these models the growing stock exceeds 500 m^3/ha (up to 730 m^3/ha), which is understandable, since they contain a larger number of trees from higher diameter classes.

Another characteristic of the majority of these normal models is their long cutting cycle (20-30 years), with a low annual and high periodical cutting intensity. In very few cases does the annual cutting intensity exceed 2%, while the periodical one, for the length of the cutting cycle, usually amounts to about 35%, and sometimes reaches as much as 43.2%. According to the valid Forest Management Regulation, the cutting intensity in selection forests cannot exceed 25% (Anon. 1994); therefore, with regard to the silvicultural-ecological features of the species making up these forests, such high periodical intensities are beyond any comment.

In the majority of the cases the prescribed annual yield is slightly lower than the expected increment of the growing stock after cutting. The concrete stand increment is the arithmetic means between the growing stock increment before and the growing stock increment after cutting. The prescribed annual yield is considerably lower than the increment calculated in this way, which results in large quantities of growing stock in these forests.

Old normal models are characterised by the fact that they reflected the real state in the forest: thus, they testify to the appearance and condition of these forests at the time of constructing the models.

Figure 1 shows the position of the Institute's normal model for the EMT I-C-10b in relation to Klepac's normal model for the same site class, the species mix and the maturity dimension. In order to emphasise the growing stock, especially in the higher diameter classes, their mutual relationship is given in Figure 2. In both figures, the number of trees in lower diameter classes is considerably higher in the Institute's normal model. In the diameter class of 12.5 cm, the difference is the biggest in places where the number of trees in the Institute's normal model is higher by about 100 to 120% in relation to the same diameter class in Klepac's normal model. This difference decreases as the breast diameter increases. In diameter classes from 27.5 to 42.5 cm, the number of trees in both normal models is almost equal for all species. In diameter classes of 47.5 cm and higher, the Institute's normal model again shows higher values than Klepac's, which is shown in Figure 2.

The original model of the EMT-I-C-10b, with the species mix 60:40% of the pure number of firs and beeches shows the same deviation from the equivalent Klepac's model as the pure model before cutting. The deviation of fir is slightly higher than that of beech.

There is a single normal model for an EMT. It was constructed for a given site class (I-C-10b - site class II of fir and site class II of beech), while the stands classified into the type belonged to different site classes in the old management plans. The stands classified in the EMT I-C-10b were in the wide range of site classes, the fir from I/II to IV, and the beech from II to V.

STAND ANALYSIS
RASPRAVA O SASTOJINAMA

Sub-compartment 2b. In 1950, the distribution by the number of fir trees ends in the diameter class of 51-60 cm and has the shape of a falling distribution, where the slope of the falling line is not constant. The 1960 distribution retains the distribution trend of 1950, but is slightly higher and ends in the diameter class of 61-70 cm. Figure 5 shows that in the measurements of 1980-1997, the number of thin trees (10-30 cm) constantly decreases, while the number of medium thick (31-50 cm) and thick trees (51 > cm) increases. In this period, the distribution ends with the diameter class of 71-80 cm.

In relation to Klepac's normal model, the distribution of 1950 could be considered, with some slight corrections, as an achieved managed model. The 1960-1997 distributions move further away from Klepac's model, and there is a shortage of thin trees and a distinct surplus of medium thick and thick trees.

The stand contains 444.17 m³/ha of the growing stock of fir and spruce, which is almost 70% more than the stock planned in Klepac's model (70:40% with the maturity dimension of

70 cm).

In the period 1950-1990, there is an increase in the number of beech trees in lower diameter classes, while the number of medium thick and thick trees oscillates.

In relation to the normal model, there is a shortage of trees in all diameter classes, which is understandable since the real species mix in the stand is 97%:3% in favour of conifers, and not 80%:20%, as planned in the model. Had the mixed normal model been based on the real species mix, the deficit of thinner fir trees would be even more distinct, while the distribution curve of medium thick and thick trees would be closer to the model. The distribution curve of beech trees by diameter classes would be closer to the model in its entire course. The growing stock of beech is by 79% lower than the stock planned in the model.

The frequency distribution curve of the total number of trees in the stand of 1960 is higher than the curve of 1950 in its entire length. Later, the number of thin trees decreases, while the number of medium thick and thick trees increases. The distribution in 1960 is, as far as the total number of trees is concerned, the closest to the proposed model. Today, this stand has a deficit of thin and a surplus of medium thick and thick trees. The total growing stock exceeds the model by 37%.

A stronger cutting intensity and adequate consignation (of over-represented diameter degrees, classes) should stop the falling trend of thin trees and the rising trend of medium thick and thick trees; otherwise, the selection structure will be disturbed.

Sub-compartment 13a. In 1950 and 1960, the distribution of breast diameters of fir ends in the diameter class of 51-60 cm and has a falling trend, where the slope of the falling line is not constant. The 1960 curve shows slightly higher values in almost the whole length. After that, according to the measurements in 1980 and 1990, there is a considerable drop in the number of trees in the class of thin and medium thick trees and a rise in the class of thick trees. The distribution ends with the diameter class of 61-70 cm and of 71-80 cm. The last measurement shows an increase in the number of trees in all diameter classes.

The situation in the last measurement (1997) follows the proposed model most adequately. The 41-50-cm diameter class shows a more significant deviation from the model, where the number of trees in the concrete stand is considerably higher than that envisaged by the model.

There are 296.57 m^3/ha of the growing stock of fir and spruce, which is 13% higher than the stock envisaged by Klepac's normal model (70:40% with the maturity dimension of 70 cm).

The 1950 distribution of beech trees has a characteristic falling shape, which it also retains in 1960, but with a slight drop. The measurement of 1980 shows a considerable decrease in the number of trees in lower diameter classes and an increase in the number of trees in higher diameter classes. This trend continues in the next decade, which is testified by the measurement data of 1990. The situation in 1997 is similar to than in 1990, with the only difference being that medium thick trees are a little better represented than in 1990, and that there are fewer trees in the diameter class of 51-60 cm than in 1990.

In relation to the proposed model, there is also a shortage of thin trees and a distinct surplus of medium thick trees. This has resulted in the growing stock of beech in the concrete stand being double than the growing stock in the proposed model (101%).

The total number of trees in 1950 and 1960 is almost equal in all diameter classes. After that the number of trees in lower diameter classes decreases and that in the higher classes increases (visible in the 1980 measurement). This trend continues in the following decade, while the measurement of 1997 shows the distribution similar to that from 1980, but with a significantly higher number of trees in the diameter class of 41-50 cm. The total growing stock is 32% higher than the normal stock.

This stand can be considered a well-managed selection forest with a surplus of beech trees in the diameter classes of 31-40 and of 41-50 cm and fir trees in the diameter class of 41-50 cm, and a deficit of thin beech trees.

A more intensive cutting of fir and especially beech in those diameter classes in which they are over-represented should decrease the surplus growing stock and approach the distribution by tree number to the model.

Sub-compartment 39c. According to the measurement of 1997, the number of fir trees in the diameter class of thin trees is 3-3.5 times lower than in the proposed model. This difference decreases with an increase in the diameter. The stand is characterised by a large number of trees above 70 cm of breast diameter (the distribution ends in the diameter class of 91-100 cm). The growing stock is higher than the stock in the model by about 10%.

With regard to the situation in past measurements, the distribution in the first measurement (1957) is the closest to the model. At that time, the deficit of the trees in lower diameter classes was much smaller (20-30%). The diameter class of 41-50 cm and higher diameter classes were already overrepresented at that time, but the distribution ended with the diameter class of 71-80 cm. Since then, the distribution has been falling along its entire length and has progressed to the right.

Today, beech is characterised by a shortage of thin and a surplus of medium thick and thick trees. A decrease in thin trees and an increase in medium thick and thick trees, with some slight deviations, are visible throughout the observed period. The growing stock exceeds the model by 35%.

Taken as a whole, the stand today has a deficit of thin and medium thick trees and a surplus of thick trees. The total growing stock is higher by 15.5% than the stock envisaged by the normal model.

Sub-compartment 61b. In this stand, the distribution of the tree number is even more unfavourable than in sub-compartment 39c. The distribution of fir trees, based on the 1997 measurement, has a shape of a prolonged (flattened) Gauss's distribution. Thus, the number of trees in the lower diameter classes is 5-10 times smaller than in the model. The class of medium thick trees is also underrepresented, but the class of thick trees is vastly overrepresented. The distribution ends with the diameter class of 91-100 cm. Similarly to sub-compartment 39c, the situation was slightly more favourable in 1957. The number of trees in lower diameter classes is two times lower than the number of trees in the model. The diameter class of 41-50 cm and higher diameter classes were overrepresented even then, but the distribution ended with the diameter class of 71-80 cm. Since then, the distribution has decreased in almost the entire length and has been prolonged to the right.

The growing stock exceeds the stock envisaged by the model by 23.5%.

Today, beech is characterised by a shortage of thin and a distinct surplus of medium thick and thick trees. According to the 1957 measurement data, the situation was different then. The class of thin trees was overrepresented, while the class of medium thick and thick trees was underrepresented. The growing stock exceeded the stock from the model by 48.6%.

Taken as a whole, the stand presently contains a shortage of thin and medium thick trees and a surplus of thick trees. The total growing stock exceeds the stock in the model by 31%.

By comparing the distribution of the tree numbers of other stands in the EMT I-C-10b with Klepac's mixed normal model containing the species mix 70:40 for both management units, I found that the condition of these stands was similar to that in the measured stands. The stands in the MU "Milanov Vrh" have a more or less selection structure, and the stands in the MU "Crni Lug" have a mostly transitional structure.

Our activities in the forest should be aimed at retaining the selection structure in the stands of the MU "Milanov Vrh" and approaching the proposed model as closely as possible. Taking into account the changes in the stand condition (species mix, increment, health status) and comparing them with other stands, the model will be adjusted in order to achieve the highest profit, at the same time maintaining the ecological stability and applying selection management.

In the stands that have lost their selection structure, as is the case with the stands in the MU "Crni Lug", the "left side of the distribution by tree number should first be lifted" by removing overmature trees. In other words, by ample and permanent natural regeneration (if possible) a sufficient number of thin trees, the trees of the future, should be ensured.

The poor structure of these stands after the Second World War was made even worse by inadequate management procedures. The introduction of the cluster management system meant that a part of the stands was not treated for a long time. The clusters did not regenerate, which led the structure in these stands to move even further away from the selection structure.

According to Matić (1979), the growth of pure fir stands at the expense of beech, which had been cut in favour of fir in the past, as well as the surplus of the growing stock of fir per hectare and an excessive number of trees in higher diameter classes led to a disturbed selection structure. Matić *et al.* (1996) say that the present condition of selection fir forests is characterised by a disturbed and frequently disappearing selection structure, which in turn causes a series of changes (very poor or completely absent natural regeneration of fir; a decrease or an increase in the growing stock in relation to the normal stock accompanied by a decrease in the increment; ageing, physiological weakening and dieback of dominant trees; distinct negative impacts of acid rains and other air, water and soil pollutants; changes in a stand's microclimate; degradation of forest soil by weed cover, a decreased microbiological activity, erosion or accumulation of raw humus; the occurrence of secondary pests that accelerate tree dieback; aggressive onset of beech at the expense of fir, and an artificial increase in the proportion of spruce). The authors mention the causes of such a condition: misapplied silvicultural treatments, particularly those related to the cutting cycle, cutting intensity and methods; longer dry periods in the global climate; unfavourable impacts of acid rains and pollutants that pollute the air, water and soil.

Every 10 years, new forest management activities provide feedback on the success of management. Therefore, planning in forestry should be regarded as a permanent process or a never-ending activity, while forest management should be viewed as a permanent learning process (Gašperić 1987).

In managing selection forests, the O-3 form is completed for every stand. Apart from the general stand data (area, site class, canopy, cover, inclination, etc.) and the description of the site and stands, the form also contains numerical data showing the condition of the stand (growing stock, increment, distribution per number of trees, etc.).

Permanent observation and comparison with the model, as was done in this paper in figures 5-16, provides data on the success of management at the stand level.

The distribution by tree number, as a direct measurable element of a stand structure, served as a basis for comparing the collected models, for observing the selected stands and for comparing them with the proposed model. It is also possible to monitor and compare other structural elements, but account should be taken of some possible limitations (for example, the application of different tables in estimating the growing stock of a stand (Božić 2000)).

The task of forest management is to prepare adequate solutions for a variety of problems occurring in this field (Gašperić 1987). In solving a certain problem, a manager should cooperate with relevant experts. Cooperation between the manager and the one who manages the forest directly - the district ranger - silviculturalist - is the most important.

A graphic presentation of the structure of tree numbers (before cutting) and its position in relation to the normal model (after cutting) can greatly help a silviculturalist to select trees to be cut. When in doubt which tree to leave and which to cut, it may serve as a guideline and may provide information about which diameter degrees or classes are underrepresented or overrepresented.

The structure of the trees at the time of cutting can be obtained from the structure at the time of management and from the data on conversion times or diameter increment of individual diameter degrees (from management plans), in the same way in which it is done in calculating the structure during mathematical revision of management plans.

CONCLUSIONS
ZAKLJUČCI

The following conclusions may be drawn from research results and discussion:

1. The normal models from the end of the last and the beginning of this century represent, according to Liocourt's law, an adjusted situation in the forest. From the present standpoint, they are characterised by a high growing stock before cutting, long cutting cycles and a low annual and high periodical cutting intensity.
2. Frequency curves of the number of trees in almost all the studied "old" models are higher than Klepac's curves for the II site class in their entire range (pure fir - situation before cutting).
3. The frequency curve of the Institute's normal model in the ecological management type I-C-10b in relation to the equivalent Klepac's normal model is higher in almost

the entire range. Deviations of the Institute's model from Klepac's model (expressed in percentages) are the highest in the 10-20-cm diameter class, and slightly lower in the diameter class of 21-30 and of 61-70 cm.

4. The application of the normal model by EMT is not recommended, because it was constructed for a certain site class (I-C-10b-II site class of fir and the II site class of beech), and the stands selected in the type belonged to different site classes in the old management plans. The stands classified in the EMT I-C-10b were in a wide range of site classes, the fir of I/II to IV, and the beech of II to V.
5. The studied stands in the MU "Milanov Vrh" have a more or less selection character, while the stands in the MU "Crni Lug" have transitional forms (neither regular nor selection).
6. In all the stands under research, the number of medium thick and thick trees increased and that of thin trees decreased over time (from 1950-1997). A drop in the number of thin trees is particularly distinct in the stands of the MU "Crni Lug", because the number of trees in this diameter class was deficient in the first measurement as well.
7. An increase in the number of medium thick and thick trees has led to an increase in the growing stock.
8. In relation to the proposed models, the growing stock proved overabundant in all the stands under study.
9. The surplus of the growing stock can be considered one of the main causes of the deficit of trees in lower diameter classes.
10. Klepac's normal model, constructed with h_{dom} and used by himself, is recommended for the management of selection forests for relevant site classes and the species mixes to be achieved in stands (Božić & Čavlović 2001).
11. In order to obtain data on the success of management with these forests, it is necessary to monitor changes, at the stand level, in the position of breast diameter distributions by tree species in relation to past distributions and in relation to the model.
12. The cutting maturity diameter for fir in uneven-aged stands is determined by the span from 50 to 70 cm (according to the Forest Management Regulation). The cutting maturity in any one stand should be determined on the basis of the quality of the previously cut thick trees. This prevents the cutting of healthy and good quality trees in the prime of their growth.
13. Before regular marking, the distribution by tree numbers in the year of marking should be calculated with the mathematical revision method and compared with the model after cutting in order to find out in which diameter degree some tree species are overrepresented.
14. In drawing up management plans, forest rangers and other expert staff that manage a particular forest should assist managers, because they are the ones who have the best knowledge of this forest.
15. An expert managing a forest should keep a forest chronicle containing his observations on individual stands while the management plan is in force, and keep a record of the cut trees by tree species, years of cutting, distribution of cut trees by diameter classes

and the reasons why some trees have been cut. These data will be used by a manager in producing future management plans.

16. In regulating selection stands, more attention should be paid to future trees, that is, thin trees (10-30 cm) and trees below the taxation limit.
17. By monitoring the changes in a stand condition and the procedures leading to these changes (at the stand level) over a period of time, we will receive feedback on the species mix, the value of the stock and its distribution, which could represent a more favourable model than the one used currently.

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PRIMJENA MODELA PRI UREĐIVANJU JELOVIH ŠUMA GORSKOGA KOTARA

SAŽETAK

Jelove šume Gorskoga kotara uređivane su prema različitim metodama. Njima se gospodarilo različitim metodama i različitim intenzitetom s obzirom na vlasništvo nad njima. Danas se ovim šumama gospodari preborno, pri čemu osobitu pozornost treba posvetiti unutrašnjoj strukturi sastojine, odnosno raspodjeli broja stabala, temeljnice ili drvne zalihe po debljinskim stupnjevima (razredima). Raspodjela broja stabala po debljinskim stupnjevima odvija se prema Liocourtovu zakonu postupnoga i pravilnoga smanjivanja broja stabala s jačim debljinskim stupnjem, te pri grafičkom prikazu ima oblik hiperbolične krivulje.

U dosadašnjem gospodarenju ovim šumama primjenjivani su različiti modeli koje se nastojalo izgospodariti, a najveći dio tih modela izlazi iz metode normala. U vremenu od početaka uređivanja ovih šuma do danas pri uređivanju su primjenjivani modeli iz nekoliko izvora: Metode normala prije i poslije sječe (propisane Naputkom iz 1903), "Novi sistem uređivanja prebornih šuma" Dušana Klepca te institutski EGT-ovi.

Normale odnosno modeli nastali iz Metoda normala prije i poslije sječe većinom su korekcija nalaza u šumi, te je tako korigirana krivulja broja stabala bila model ili normala. Normale prije sječe Miletić (1957), prema njihovu postanku, dijeli na:

1. Realne – na osnovi podataka dobivenih iz same preborne šume
2. Teoretske – na osnovi određenih pravilnosti i postupnosti primijećenih kod normalnih sastojina; na osnovi elemenata prikupljenih u prebornoj šumi koju uređujemo
3. Kombinirane.

Normale nastale uređivanjem naših šuma mahom su realne normale. S obzirom na način kako su nastale, Miletić ih (1957) dalje dijeli na:

1. Slobodne normale — nastale nalazom na manjim površinama tipičnih sastojina
   a) izvedene iz čiste preborne sastojine
   b) izvedene iz mješovite preborne sastojine
2. Deduktivne normale – nastale kao prosjek više primjernih površina;

3. Strane normale – normale uzete sa strane te prilagođene stvarnim prilikama šume.

U slučaju da se u šumi, zbog nedavne sječe ili nekoga drugoga razloga, ne može naći normala prije sječe, pri uređivanju tih šuma upotrebljavale su se strane normale ili se pak konstruirala normala tako da su se na plohama gdje se normala tražila izmjerili elementi strukture, procijenio obrast, te su se izmjereni elementi korigirali na potpun obrast.

Stanje je poslije sječe određivano empiričkim putem, ponavljanim pokusima. Za sječu je bio predviđen cijeli zadnji debljinski razred te dio stabala iz ostalih debljinskih razreda (prekobrojna). Majnarić poslije odstupa od ovoga pravila te za sječu ne predviđa cijeli zadnji debljinski razred, nego njegov veći dio (u normali za šumu bivše zamljišne zajednice Drivenik za sječu predviđa 90 % zadnjega debljinskoga razreda). Normala se smatrala pravilno postavljenom ako je bio ostvaren glavni uvjet, a taj je da se po isteku određene ophodnjice uspostavi normalno stanje prije sječe u svim elementima strukture.

Osim što su drvne zalihe prije sječe koje su normalama predviđene bile visoke, prirast se normala određivao na osnovi stanja poslije sječe. Ni tako određen prirast nije u potpunosti bio predviđen za sječu jer su se ostavljale određene zalihe kao osiguranje za slučaj nepredviđenih sječa. Kako stvarnu proizvodnu snagu normale čini prosječni godišnji volumni prirast (aritmetička sredina prirasta prije i poslije sječe) te zaliha stabala uraslih u mjerljivi dio sastojine, jasno je da se zbog sječe, koja je manja i od prirasta zalihe poslije sječe, nagomilala drvna zaliha po jedinici površine.

Normalno stanje preborne šume Klepac zasniva na temeljnom nizu stabala različitih debljina, od kojih svake godine jedno stablo dostigne dimenziju zrelosti, i na više upotpunjavajućih nizova koji nadomještaju prirodnom ili umjetnom selekcijom izlučena stabla. Klepčeve normale nastale su na temelju visine dominantnih stabala te Susmelovih korelacija za jelu i Coletteovih za bukvu. Normala je konstruirana za stanje između dviju prebornih sječa, dok se stanje prije ili poslije sječe dobiva dodavanjem odnosno oduzimanjem l/2 godišnjega prirasta (l – duljina ophodnjice).

Normale po ekološko-gospodarskim tipovima (EGT) nastale su prilagodbom Klepčevih normala utvrđenim tipovima šuma, gdje tip upućuje na mogućnosti nekoga područja.

Iz međusobnoga položaja krivulja broja stabala "starih" normala i normale istraživanoga EGT-a I-C-10b prema adekvatnim Klepčevim normalama (slike 3 i 4) vidljivo je da je kod većine starih normala krivulja broja stabala iznad Klepčeve krivulje, s tim da su ta odstupanja značajnija (u %) u nižim i višim debljinskim razredima. To je posljedica stanja tih šuma u vrijeme uređivanja (kraj prošloga i prvih nekoliko desetljeća ovoga stoljeća) kada se u njima nalazila nagomilana drvna zaliha kao posljedica ekstenzivnoga gospodarenja. Jedan dio ovih modela nastao je uz pretpostavku jednakosti temeljnica svih debljinskih razreda (koju i autori tih modela poslije odbacuju kao nerealnu) te je zbog toga odstupanje ovih modela od Klepčeva najizraženije u najnižim debljinskim razredima. Ovdje je zanimljiva činjenica da se postotno odstupanje institutske normale EGT-a I-C-10b, korigiranoga za čistu jelu, stanje prije sječe cijelim svojim rasponom gotovo preklapa s Jovanovčevom normalom za zemljišnu zajednicu Benkovac iz 1912, koja je nastala na pretpostavci jednakosti temeljnica svih debljinskih razreda. Osim toga unutar EGT-a, koji je predstavljen jednim modelom, nalazile su se sastojine širokoga raspona bonitetnih razreda, jela I/II-IV, a bukva II-V. Na temelju tih činjenica prilikom uređivanja jelovih prebornih šuma preporučuje se upotreba Klepčevih normala (modela), i to originalnih Klepčevih normala da bi se izbjeglo umjetno snižavanje visine dominantnih stabala zbog sječe stabala iznad određene dimenzije zrelosti i različita definiranja dominantne visine pojedinih autora (Božić i Čavlović 2001).

Istraživane sastojine GJ "Milanov vrh" manje-više su prebornoga karaktera, dok su istraživane sastojine GJ "Crni lug" prelaznih oblika (ni regularne ni preborne).

U svim istraživanim sastojinama s vremenom se (1950–1997) povećao broj srednje debelih i debelih stabala, a smanjio broj tankih stabala (što je vidljivo na slikama 5–16). Smanjenje broja tankih stabala osobito je došlo do izražaja u sastojinama GJ "Crni lug", jer je broj stabala u tom debljinskom razredu bio deficitaran i prema prvom mjerenju. Zbog povećanja broja srednje debelih i debelih stabala povećana je drvna zaliha.

Drvna je zaliha u odnosu na predložene modele u svim istraživanim sastojinama previsoka. Previsoku drvnu zalihu možemo smatrati jednim od glavnih uzroka deficita broja stabala u nižim debljinskim razredima.

Distribucija broja stabala, kao neposredni mjerljivi element strukture sastojine, bila je onaj element na temelju kojega sam uspoređivao prikupljene modele, te protekom vremena promatrao odabrane sastojine i uspoređivao ih s predloženim modelom. Promatrati odnosno uspoređivati može se i neki drugi element strukture, s tim da se pri usporedbi treba voditi računa o mogućim ograničenjima (npr. primjena različitih tablica za određivanje drvne zalihe sastojine /Božić 2000/).

Radi dobivanja podataka o uspješnosti gospodarenja tim šumama potrebno je na razini sastojine pratiti promjene položaja distribucije prsnih promjera po vrstama drveća i ukupno u odnosu na prijašnje distribucije i u odnosu na normalu (model).

Promjer sječive zrelosti u raznodobnim sastojinama za jelu određen je rasponom od 60 do 70 cm (prema Pravilniku za uređivanje šuma). Sječivu zrelost u svakoj pojedinoj sastojini treba odrediti na temelju kakvoće ranije posječenih debelih stabala. Ovim bi se spriječilo da se sijeku zdrava stabla u naponu priraščivanja.

Prilikom grafičkoga prikazivanja stanja sastojine i odnosa prema normali treba prikazati normalu uz najnižu dimenziju zrelosti i fiziološku zrelost.

Prije redovite doznake, metodom računske revizije, treba izračunati distribuciju broja stabala u godini doznake, te je usporediti s normalom poslije sječe da bi se dobio uvid u kojem su debljinskom stupnju stabla pojedinih vrsta drveća prezastupljena ili premalo zastupljena. Taj podatak može dobro poslužiti revirniku kao putokaz prilikom doznake, ako se nađe u nedoumici koje stablo ostaviti, a koje posjeći.

Prilikom izrade osnove gospodarenja revirnik i ostalo stručno osoblje koje tom šumom gospodare, trebali bi biti na raspolaganju uređivačima, jer oni ipak dotičnu šumu najbolje poznaju.

Stručnjak koji konkretnom šumom gospodari treba voditi šumsku kroniku, u koju bi bilježio svoja zapažanja o pojedinim sastojinama tijekom važenja osnove gospodarenja, te evidenciju posječenih stabala po vrstama drveća, godinama sječe, raspodjeli posječenih stabala po debljinskim stupnjevima, kao i razlozima zbog kojih su pojedina stabla posječena. Ti će podaci dobro doći uređivaču prilikom izrade iduće osnove gospodarenja.

Prilikom uređivanja prebornih sastojina veću pozornost treba posvećivati stablima budućnosti, tj. stablima ispod taksacijske granice.

Protekom vremena, praćenjem promjena stanja u sastojinana i postupaka koji su do tih promjena doveli (na razini sastojine) zasigurno ćemo, kao povratnu informaciju iz šume, dobiti podatke o omjeru smjese, vrijednosti zalihe, njezinoj distribuciji koji bi za promatranu sastojinu predstavljali povoljniji model (normalu) od dotada rabljenoga.

Ključne riječi: Gorski kotar, uređivanje šuma, modeli

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INFLUENCES OF THE SOILS ON THE MORPHOLOGICAL CHARACTERISTICS OF AN AUTOCHTHONOUS NORWAY SPRUCE ON THE POKLJUKA PLATEAU[1]

UTJECAJ TLA NA MORFOLOŠKA SVOJSTVA AUTOHTONE SMREKE POKLJUŠKE VISORAVNI

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The aim of the study was to assess the influence of true different site conditions on spruce growth characteristics. Two research plots with two morphologically different subpopulations of Norway spruce (*Picea abies* (L.) Karst.) were determined in the frostened area on the Pokljuka plateau nearby high bog Šijec (altitude 1170 m). The tree height, tree diameter, needle length and needle volume of 70 approximately 120 to 200 years old trees were measured and morphometrics analysis of needles done. Soil conditions on research plots were investigated by soil sounding and by detailed analyses of soil samples from representative soil profiles. On the research plot set in the mire edge, 14 trees grow in dystric cambisols, 16 on the podzols and 5 in gleysols. On the bog site plot all 35 spruces grow in the middle deep to deep peat histosols. Spruces on organomineral soils were in average 3.8 times taller and thicker as trees on the peat bog. Needle length of trees on better growing site with mainly automorphic soils was 25.7 % longer and their needle volume was 68 % bigger than of the trees from the bog plot. The mean spruce needle length was 13.2 mm and the volume 3.2 mm^3. The morphological differences are attributed particularly to different site conditions resulting from soil conditions.

Key words: automorphic and hydromorphic soils, *Picea abies*, growth characteristics, needle length, needle volume, morphological variability, Julian Alps, Slovenia

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INTRODUCTION
UVOD

The Pokljuka plateau lies in the slovenian part of the Julian Alps. Forests cover about 20 km² of its calcareous and mixed moraines. Natural forests of European beech (*Fagus sylvatica* L.) and secondary forests of Norway spruce (*Picea abies* (L.) Karst.) on sites of primary beech forests predominate, both with a high wood productivity. At the altitude of about 1200 m a.s.l. primary and supposely authochtonous Norway spruce forests are still present and form two plant associations (Zupančič 1980, 1999).

The spruce plant association *Rhytidiadelpho lorei - Piceetum* covers automorphic soils developed on moraines, spruce growth of these stands is relatively good. The spruce association *Sphagno girgensohnii - Piceetum* var. geogr. *Carex brizoides* grows on hydromorphic soils of mires. This spruce-mire plant community on peat soils lives in extremely poor and severe site conditions, spruces there grow slowly and dwarfly similar as trees in subalpine spruce association *Adenostilo glabae-Piceetum* var. geogr. *Cardamine trifolia* which overgrows undeveloped automorphic organic soils having raw humus and overlying limestones and dolomites in the zone from about 1400 to 1550 m altitude.

Autochthonous Norway spruces on Pokljuka plateau have wide ecological valence and because of long evolution under natural selective influences are well adapted to their environment. The aim of the study was to research in greater detail soil conditions and to evaluate the growth and morphological characteristics of spruces in two primary Norway spruce associations as for studied spruce forests grow localy near but in very different site conditions.

METHODS OF RESEARCH
METODE ISTRAŽIVANJA

Two 0.2 ha big research plots were established in the natural growing sites of spruce in the frosty area on the Pokljuka plateau. The research plot "Mire" lies in the south-eastern part of the mire Šijec in the bushy and gappy spruce forest (association *Sphagno girgensohnii-Piceetum*) between dwarf-pine community (*Sphagno-Pinetum mughi*) and high spruce forest on the mire's edge. The research plot "Edge" is located on the mire's edge inside one-hectare large permanent plot "Šijec" where sites of the spruce association *Rhytidiadelpho lorei-Piceetum* predominate. The plots are located at 1170 m altitude, the distance between them is 500 m. Trees from every plot are considered as a subpopulation from the whole spruce population of mire's Šijec area. On each plot soil conditions were studied and 35 vital randomly chosen dominant spruce trees were dendrometrically analysed.

Soil conditions and morphologic properties of soil on research plots were examined with a semicircular sound, which reaches up to 110 cm depth. According to soil heterogeneity of plots locations of representative soil profiles were chosen. After the description of profiles soil samples were taken and analysed in the lab. Samples were dried on air, blended and sieved throug the 2 mm mesh sieve before analysis. For each soil sample the pH was determined photentiometricaly in the supernatant suspension with water and 0.01 mol/l $CaCl_2$. The content of $CaCO_3$ was determined after treatment of sample with 10 % HCl by using Scheibler calcimeter. The total carbon content was determined after dry combustion of sample at 1050° C. Total nitrogen was analyzed according Kjeldahl method. Contents of exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, Al^{3+}, Fe^{3+}, Mn^{2+} and H^+), cation exchange capacities, base saturation and texture classes were determined for samples from mineral parts of soils. For determination of exchangable cations samples were first extracted with a 0.1 mol/l $BaCl_2$. Exchangable acidity was determined potentiometricaly, while cations were determined by FLAAS. The soil particle size fractions were determined by the pipette method and the textural classes by using the USDA soil textural triangle (Manual... 1994).

The morphological characteristics of the subpopulations were determined by analysis of morphometric measurements of needle lengths and volumes and by dendrometric analyses of heights and diameters at the height of 1.3 m of dominant, approximately 120 to 200 years old spruce trees. Studied samples were taken from the 2 years old shoots exposed to sun in the southern upper third of the tree crown of 70 randomly chosen trees. Each tree sample consisted of 100 randomly chosen needles. All samples were taken during the second week in November 1995 and stored in the laboratory at –20 °C until further use. Morphometric analysis of fully developed *Picea abies* needles were done by using a computer – aided image systems with Optimas 5.0 programme software. For calculation of needle volume (V) the equation of Riederer *at all* (1988) was used: V (mm^3) = 0.208 x (projected needle area)$^{1.353}$. The age of trees was estimated by measuring of tree rings from the cores taken at 0.4 m using a dendrocronological table LINTAB with 1/100 mm accuracy.

RESULTS AND DISCUSSION
REZULTATI I RASPRAVA

On the bog site plot "Mire" all 35 spruces grow on hydromorphic organic soils which have the peat T horizon lying over wet, softy and gelatinous lake sediments (horizon Gy = gyttia). Thickness of the peat layer is from about 60 cm to over one meter (table 1). The reaction of its peat is very acidic (measured values of pH($CaCl_2$) are between 2.88 and 3.18). Soil is classified (according to Škorić 1986) as ombrotrophic form of the middle deep to deep subtype of peat acrohistosol. According to the FAO-Unesco (1989) and WRB (1998) soil classifications this soil belongs to soil unit of Fibric Histosols.

The ages of 35 dominant spruces on the plot "Mire" at the height of 0.4 m varied between 65 and 142 (in average 95) years, at breast height they had diameters from 6 to 19 (in average 12) centimetres and heights from 4 to 13 (in average 8) metres. Analysed needles had lengths from 7.2 to 14.3 (in average 10.5) milimeters and volumes from 0.8 to 3.9 (in average 1.9) mm^3 (Table 4 and 5).

Table 1. Soil reactions (*pH*), contents of carbonate ($CaCO_3$), organic matter (*Org. m.*), total carbon (C_{tot}) and nitrogen (N_{tot}), the ratio of organic carbon to total nitrogen (C_{org}/N) of soil samples from the representative profile of the peat soil on the plot "Mire"

Tablica 1. Reakcija tla (pH), *sadržaj karbonata* ($CaCO_3$), *organske tvari* (Org. m.), *ukupnoga ugljika* (C_{tot}) *i ukupnoga dušika* (N_{tot}), odnos između organsk*oga ugljika i ukupnoga dušika* (C_{org}/N) *za uzorke tala reprezentativnoga profila tresetnoga tla iz plohe "Treset"*

Horizon	Thickness (cm)	pH (H_2O)	pH ($CaCl_2$)	$CaCO_3$ g/kg	Org. m. g/kg	C_{org} g/kg	C_{tot} g/kg	N_{tot} g/kg	C_{org}/N
$O_{l,f}$	110 – 100	3.70	2.68	0	503.4	292.0	292.0	7.6	38
T1	100 – 70	3.85	3.18	0	479.6	278.2	278.2	11.1	25
T2	70 – 40	3.64	2.88	0	588.9	341.6	341.6	10.0	34
T3	40 – 20	3.73	2.92	0	797.8	462.8	462.8	14.5	32
T/Gy	20 – 0	3.75	3.00	0	579.4	336.1	336.1	14.2	24

On the mire edge plot "Edge" soils have developed on "mixed" moraine lying over lake chalk. Mixed moraine is composed by unconsolidated material of limestone, dolomite, marl, cherts, shales and sandstones. On this parent material heterogenous dystric soils have developed, they are covered with mainly acidophilic vegetation. Soil sounding discovered that 14 trees grow in dystric cambisols, 16 in podzols and five in gleysols. Properties of these FAO-Unesco (1989) soil units are presented with three representative soil profiles (Table 2 and 3). Dystric cambisols have under organic O horizon (acronim $_l$ means layer of litter, $_f$ = fermented organic matter, $_h$ = organic layer of (raw, moder) humus) and mostly ochric A_{oh} horizon about half to one and a half meter thick cambic $(B)_v$ horizon overlying C horizon of moraine parent material.

Table 2. Soil reactions (*pH*), contents of carbonate ($CaCO_3$), organic matter (*Org. m.*), total carbon (C_{tot}) and nitrogen (N_{tot}), the ratio of organic carbon to total nitrogen (C_{org}/N), shares of clay and sand and texture classes (*acronims: C* = clay; *L* = loam; *CL* = clayey loam; *SL* = sandy loam; *SCL* = sandy clayey loam; *SiCL* = silty clayey loam) of soil samples from the representative profiles of the plot "Edge"

*Tablica 2. Reakcija tla (*pH*), sadržaj karbonata* ($CaCO_3$), *organske tvari* (Org. m.), *ukupnoga ugljika* (C_{tot}) *i ukupnoga dušika* (N_{tot})*, odnos između organskoga ugljika i ukupnoga dušika* (C_{org}/N)*, %-ni sadržaji čestica pijeska i gline i teksturni razredi (*Tex. class; kratice: C = *glina;* L = *ilovača;* CL = *glinasta ilovača;* SL = *pjeskovita ilovača;* SCL = *pjeskovito-glinasta ilovača;* SiCL = *praškasto-glinasta ilovača) za uzorke tala reprezentativnih profila plohe "Rub"*

Horiz.	Depth (cm)	pH (H_2O)	pH ($CaCl_2$)	$CaCO_3$ g/kg	Org. m. g/kg	C_{org} g/kg	C_{tot} g/kg	N_{tot} g/kg	C/N	Clay %	Sand %	Tex. class
Profil: dystric cambisols on morrain					*Profil: distrično smeđe tlo na morenama*							
O_{Lf}	4 – 2/3	3.94	3.45	0	446.4	258.9	258.9	11.4	23	-	-	-
O_h	2/3 – 0	3.61	3.02	0	161.5	93.7	93.7	10.7	9	-	-	-
AO_h	0 – 5/7	3.63	3.11	0	113.9	66.1	66.1	3.5	19	-	-	-
A_{oh}	5/7 – 9/12	3.83	3.54	0	45.6	26.4	26.4	2.1	13	26.0	48.6	SCL
$(B)_v$	9/12 – 20	4.38	4.10	0	34.2	19.8	19.8	1.3	15	26.0	48.6	SCL
$(B)_v/C$	20 – 50	4.47	4.25	0	17.1	9.9	9.9	0.7	14	20.7	60.6	SCL
$C/(B)_v$	50 – 100	5.51	5.05	13.4	12.5	7.3	9.3	0.5	15	16.6	65.3	SL
$C(B)_{v,ca}$	100 + 150	6.70	6.50	129.6	2.7	1.6	21.0	0.3	5	17.3	62.6	SL
Profil: podzols on morrain					*Profil: podzol na morenama*							
O_l	3 – 1/2	4.33	3.89	0	715.5	415	415	7.5	55	-	-	-
O_{fh}	1/2 – 0	3.79	3.28	0	534.4	310	310	12.5	25	-	-	-
$A_{oh}O_h$	0 – 3/5	3.64	3.20	0	328.4	191	191	7.5	25	-	-	-
E	3/5 – 7/15	4.09	3.38	0	25.0	15	15	1.3	11	19.9	43.2	L
B_h	7/15 – 19	4.08	3.49	0	81.0	47	47	2.0	24	27.0	36.5	L
B_{fe}	19 – 25/30	4.36	3.77	0	56.0	33	33	1.4	23	23.3	41.7	L
$(B)_v$	25/30 – 40	4.69	4.04	0	38.8	23	23	1.4	16	33.6	43.6	CL
E	40 – 60	4.91	4.37	0	25.9	15	15	1.1	14	29.9	36.9	CL
B_t	60 – 80	4.73	4.05	0	6.9	4	4	0.6	7	39.2	25.0	CL
$B(B)_{v,ca}$	80 – 120	7.55	7.22	48.3	5.6	3	10	0.5	6	39.2	9.0	SiCL
$(B)_vC$	120 + 160	7.67	7.24	15.0	3.8	2	4	0.6	4	23.2	51.9	SCL
Profil: gleysols on morrain					*Profil: hipoglejno tlo na morenama*							
O_{Lf}	1/2 – 0	4.68	4.25	0	465.4	269.9	269.9	20.1	13	-	-	-
A_a	0 – 9/11	4.03	3.57	0	275.4	159.8	159.8	13.7	12	-	-	-
G_o	9/11 – 25	4.36	3.86	0	30.4	17.6	17.6	1.5	12	33.1	25.0	CL
G_r	25 – 55	5.61	4.90	8.9	12.9	7.4	8.8	0.7	11	53.2	7.7	C
$G_{r,ca}$	55 – 90	7.27	6.87	595.6	9.3	5.4	94.7	0.3	18	37.1	6.6	SiCL
$G_{r,ca}/C$	90 + 110	7.84	7.15	692.6	11.4	6.6	110.5	0.2	33	24.1	26.9	L

Podzols have under O and eventual A horizons usually elluvial and albic E horizon. It is from few centimetres to a half meter thick and has very acid reaction and very low base saturation level. The E horizon lyes over spodic B horizon (B_h = humospodic layer enriched with organic matter; B_{fe} = ferrispodic layer enriched with sesquioxides). In deeper parts of these automorphic soils on mixed moraine another layers as clay enriched argilic B_t horizon or calcium carbonate enriched B_{ca} layer etc can be found.

Table 3. Exchangeable cations, the sum of basic exchangeable cations (*S_B*), the sum of acid exchangeable cations (*S_A*), cation exchange capacity (*CEC*) and base saturation level (*BS*) of soil samples from the representative profiles of the plot "Edge"

Tablica 3. Razmjenljivi kationi, zbroj bazičnih razmjenljivih kationa (S_B), *suma kiselih razmjenljivih kationa* (S_A), *kapacitet razmjenjivih kationa* (CEC) *i* stupanj zasićenosti bazama (BS) *za uzorke tala reprezentativnih profila plohe "Rub"*

Horizon	Ca^{2+}	Mg^{2+}	K^+	Al^{3+}	Fe^{3+}	Mn^{2+}	H^+	S_B	S_A	CEC	BS
	cmol(+)/kg										%
Profil: dystric cambisol on morrain			*Profil: distrično smeđe tlo na morenama*								
AO_h	1.72	0.54	0.24	6.21	1.71	0.05	9.90	2.50	7.97	20.37	12.27
A_{um}	0.19	0.16	0.12	7.53	1.02	0.02	2.08	0.47	8.57	11.12	4.23
$(B)_v$	0.11	0.00	0.03	3.39	0.00	0.02	0.00	0.14	3.41	3.55	3.94
$(B)_v/C$	0.06	0.00	0.06	2.70	0.00	0.08	0.00	0.12	2.78	2.90	4.14
$(B)_{v,ca}/C$	1.94	0.03	0.08	1.14	0.00	0.10	0.00	2.05	1.24	3.29	62.31
$C(B)_{v,ca}$	8.68	0.09	0.12	0.76	0.00	0.02	0.00	8.89	0.78	9.67	91.93
Profil: podzol on morrain			*Profil: podzol na morenama*								
$A_{um}O_h$	9.11	1.66	0.76	3.44	1.65	0.17	16.95	11.53	5.26	33.74	34.17
E	0.20	0.05	0.06	4.35	1.23	0.00	3.64	0.31	5.58	9.83	3.15
B_h	1.68	0.24	0.12	11.85	3.16	0.02	5.94	2.04	15.03	23.01	8.87
B_{fe}	1.03	0.17	0.14	10.12	1.49	0.05	1.92	1.34	11.66	14.92	8.89
$(B)_v$	0.37	0.09	0.15	7.77	0.54	0.20	1.09	0.61	8.51	10.21	5.97
E	0.60	0.14	0.09	2.62	0.08	0.06	0.51	0.83	2.78	4.12	20.15
B_t	0.54	0.13	0.20	5.32	0.08	0.09	0.87	0.87	5.49	7.23	12.03
$B(B)_{v,ca}$	15.58	0.17	0.27	0.00	0.00	0.04	0.00	16.02	0.04	16.06	99.75
$(B)_vC$	10.81	0.12	0.21	0.00	0.00	0.00	0.00	11.14	0.00	11.14	100.0
Profil: hypogley on morrain			*Profil: hipoglejno tlo na morenama*								
A_a	12.17	1.18	0.57	5.14	1.25	0.64	4.95	13.92	7.03	25.90	53.75
G_o	4.28	0.38	0.12	4.78	0.00	0.34	1.00	4.78	5.12	10.90	43.85
G_r	18.33	0.85	0.26	0.00	0.00	0.28	0.00	19.44	0.28	19.72	98.58
$G_{r,ca}$	15.58	0.37	0.15	0.00	0.00	0.00	0.00	16.10	0.00	16.10	100.00
$G_{r,ca}/C$	19.28	0.38	0.09	0.00	0.00	0.02	0.00	19.75	0.02	19.77	99.90

Gleysols are found nearest to the peat bog "Šijec" and are under the influence of its groundwater. Mostly having a base saturation of less than 50 percent at least between 20 and 50 cm from the surface are classified as dystric gleysols. They have at times with water saturated gleyic G_o and permanently saturated gleyic G_r subhorizon.

The age of 35 dominant spruces in the plot "Edge" varied between 87 and 147 (in average 116) years at the height of 0.4 m, they had at breast height diameters from 31 to 60 (in average 46) centimetres and heights from 27 to 36 (in average 31) metres. Analysed needles had lengths from 9.9 to17.5 (in average 13.2) milimetres and volumes from 1.0 to 6.3 (in average 3.2) mm^3 (Table 4 and 5).

Table 4. The minimal, the maximal and the average tree age on the height of 0.4 m, diameter at 1.3 m and height of 70 dominant spruces on the research plots

Tablica 4. Najmanja, najveća i prosječna dob stabala na visini 0.4 m, promjer na visini 1.3 m i visina stabala 70 dominantnih smreka na pokusnim plohama

Parameter	Plot "Mire" – ploha "Treset"			Plot "Edge"– ploha "Rub"		
	Min.	Max.	Aver.	Min.	Max.	Aver.
Age (years) *Dob (godina)*	65	142	95	87	147	116
Diameter (cm) *Promjer (cm)*	6	19	12	31	60	46
Height (m) *Visina (m)*	4	13	8	27	36	31

Norway spruce trees on the research plots "Mire" and "Edge" differ in age structure and variability. The distinct age difference of trees on the plot "Mire" is the result of the fact that Norway spruce has spread slowly over the bare bog area under ecologically demanding growth conditions. Additional analyses (Božič 1997, Božič & Levanič 1998) indicate that true ages of selected trees on the plot "Mire" were in average about 40 to 50 years greater and on the plot "Edge" from 30 to 35 years greater as in the sampling height 0,4 m. A comparison of the age of the oldest trees on the two plots shows no essential differences. The age of the oldest trees is about 200 years.

Estimation of spruce growth considering site conditions shows that all analysed trees at the research plot "Edge" with the edaphically better growth conditions characterised by the spruce plant association *Rhytidiadelpho lorei - Piceetum* had better growth than those on the site with the spruce plant association *Sphagno – Piceetum* (the plot "Mire").

Results of morphometric measurements of needle length and volume confirmed distinct differences between spruce subpopulations under study. Needles of spruce trees in the research plot »Edge« showed significant lower variability of needle length and volumes than the needles from the plot on the mire (Levene test of homogenity of variance, $\alpha = 0.05$) while the mean needle length and mean volume were on plot »Edge« statistically significantly longer and bigger in comparison with the research plot »Mire« (Student t-test with separated variance estimate, $\alpha = 0.05$). Needle length and volume of spruces from organomineral soils were in average 25.7 % longer and 68.4 % bigger than of the trees from the bog organic soils.

Table 5. Descriptive statistic of needle length and needle volume for 3500 spruce needles per each research plot

Tablica 5. Statistički parametri duljine i obujma iglica izračunati za 3500 smrekovih iglica na svakoj pokusoj plohi

Parameters *Parametri*	Plot "Mire" – *ploha "Teset"*		Plot "Edge"– *ploha "Rub"*	
	Length (mm)	Volume (mm^3)	Length (mm)	Volume (mm^3)
	Duljina	*Obujam*	*Duljina*	*Obujam*
Mean - *Aritmetička sredina*	10.5	1.9	13.2	3.2
Median - *Medijana*	10.5	1.6	13.1	2.9
Confidence interval + 95 % *Interval konfidencije + 95 %*	10.5	1.9	13.2	3.2
Confidence interval - 95 % *Interval konfidencije - 95 %*	10.4	1.8	13.1	3.1
Minimal - *Najmanja*	7.2	0.8	9.9	1.0
Maximal - *Najveća*	14.3	3.9	17.5	6.3
Range - *Opseg*	7.1	3.2	7.6	5.4
Variance - *Varijanca*	2.8	0.6	2.9	1.6
Standard Deviation *Standardna devijacija*	1.7	0.8	1.7	1.3
Coefficient of Variation *Koeficijent varijacije*	16.0 %	41.9 %	13.0 %	40.7 %

Table 6. Number of trees (*N*), average (d_a), the smallest (d_{min}), the largest diameters at breast height (d_{max}); medium (h_a), the shortest (h_{min}), the highest heights (h_{max}); their standard deviations (*s*) and the mean slenderness stages (S_a) in spruces by soil units (dystric cambisols (*D*), podzols (*P*), gleysols (*G*), peat histosols (*H*) of one-hectare permanent research plot "Šijec".

Tablica 6. Broj drveća (N), srednji (d_a), najmanji (d_{min}), najveći promjeri stabala (d_{max}); srednje (h_a), najmanje (h_{min}), najveće visine (h_{max}); njihove standardne devijacije(s) i srednji stupnjevi vitkosti (S_a) smreka na talnim jedinicama: distrično smeđe tlo (D), podzol (P), hipoglej (G), tresetna tla (H) hektarske trajne pokusne plohe "Šijec

	N	d_a	d_{min}	d_{max}	σ_d	h_a	h_{min}	h_{max}	σ_h	S_a
D	121	40.9	13	73	9.46	30.02	7.0	36.5	4.86	73.4
P	189	41.9	17	70	9.39	30.39	12.5	38.0	4.28	72.5
G	17	41.7	32	53	6.28	29.66	27.0	33.0	1.90	71.1
H	18	41.1	31	54	7.28	26.89	20.0	32.0	3.18	65.4

Table 7. T–test of the characteristics of spruce tree height averages by soil units (dystric cambisols (*D*), podzols (*P*), gleysols (*G*), peat histosols (*H*)) of one-hectare permanent research plot "Šijec"

Tablica 7. T–test karkaterističnosti srednjih visina stabala smreke po talnim jedinicama (distrično smeđe tlo (D), podzol (P), hipoglej (G), tresetna tla (H)) hektarske trajne pokusne plohe "Šijec"

T-test	D	P	G	H
D	0.00000	0.70855	-0.28456	**-2.64162**
P	-0.70855	0.00000	-0.67964	**-3.38101**
G	0.28456	0.67964	0.00000	**-3.12042**
H	**2.64162**	**3.38101**	**3.12042**	0.00000

Note: Bold typed numbers indicate statistically significant difference between the mean tree heights on the basis of soil units.

The plot "Edge" is located inside one-hectare permanent research plot "Šijec". Data of average height, breast height diameter and slenderness coefficient (= ratio of a tree height to a breast height diameter) of spruces on this permanent research plot certify that spruces grow the most slowly and reach the shortest heights on peat soils (table 6 and 7) according to Urbančič & Kutnar (1997).

CONCLUSIONS
ZAKLJUČCI

The research plots were established on Pokljuka in sites within the area of natural distribution of Norway spruce. On both plots dominant from about 120 to 200 years old spruces were chosen. The oldest trees were growing at least 50 years before the first huge clearcuts and artificial regeneration with spruce seedlings on Pokljuka plateau in the middle of 19th century began so the analysed spruce subpopulations in the Šijec area can be regarded as autochthonous.

Vegetation of the plot "Mire" on the raised bog Šijec has been classified into the spruce association *Sphagno-Piceetum* Kuoch 1954 *corr.* Zupančič 1982. It overgrows ombrotrophic form of the middle deep to deep subtype of peat acrohistosol. On this site spruces have extremely bad growth conditions.

Vegetation of the plot on the edge of the bog mostly belongs to the spruce association *Rhytidiadelpho lorei-Piceetum* (Wraber 1953 *n. nud.*) Zupančič (1976) 1981. It overgrows three soil units : dystric cambisols, podzols and gleysols. These soils have dystric properties as very acid reactions and very low base saturation at least in the depth of a half metre under the surface. They are rather deep, have suitable loamy texture and moisture regime so they are rather fertile considering spruce which can reach tree height of almost 40 metres.

Differences in soil conditions between the research plots have been reflected in the spruce's growth. Spruces from the plot on the edge of the mire were in average 3,8 times taller and thicker as trees from the plot on the mire. Needle length and needle volume of spruces from the site with better growing conditions were 26 % longer and 68 % bigger than of the trees from the peat bog.

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UTJECAJ TLA NA MORFOLOŠKA SVOJSTVA AUTOHTONE SMREKE POKLJUŠKE VISORAVNI

SAŽETAK

Cilj je istraživanja bio ustanoviti utjecaj nejednakih stanišnih prilika na rast i prirast smreke.

Dvije su pokusne plohe bile smještene u mrazišnom području Pokljuške visoravni kod izdignutoga treseta Šijec na nadmorskoj visini 1170 m. Analizirane su dvije morfološki različite subpopulacije smreke (*Picea abies* /L./ Karst.), prva na pretežno automorfnom tlu, a druga na hidromorfnom, tresetnom tlu. Visina i promjer stabla u prsnoj visini te duljina i obujam iglica bili su izmjereni na 70 stabala smreke, starih oko 120 do 200 godina. Morfometrijska analiza iglica bila je izvedena digitalno procesiranjem njihovih slika pomoću računalnoga programa Optimas 5.0. Obujam je iglica izračunat empiričkom jednadžbom Riederera i dr. (1988). Pedološke prilike na pokusnim plohama bile su sondirane i detaljnije istražene laboratorijskim analizama talnih uzoraka s reprezentativnih pedoloških profila. Na plohi, osnovanoj na rubu bare, na distričnom smeđem tlu raslo je 14 uzorkovanih stabala smreke, na podzolu 16 i na močvarno-glejnom tlu 5. Na plohi u bari svih 35 uzorkovanih smrekovih stabala obrastalo je srednje duboko do duboko tresetno tlo. Smreke na pokusnoj plohi na organomineralnom tlu imale su u prosjeku 3,8 puta veću visinu i promjer stabla, za 25,7 % dulje iglice i za 68 % veći obujam iglica od smrekovih stabala cretnoga staništa. Prosječna smrekova iglica bila je duga 13,2 mm i imala je obujam 3,2 mm^3.

Dendrometrijska i morfometrijska analiza smreke, uz uvažavanje stanišnih prilika, pokazala je da stabla na pokusnoj plohi na organomineralnom tlu imaju mnogo bolje uvjete za rast i prirast od stabala cretne smrekove šume na organogenom tresetnom tlu. Pedološke prilike imaju u tom primjeru dominantan utjecaj na razlike u morfološkim svojstvima smreke.

Ključne riječi: automorfna tla, hidromorfna tla, *Picea abies*, prirasna svojstva, duljina iglice, obujam iglice, morfološka promjenljivost, Julijske Alpe, Slovenija

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SOIL CONDITIONS IN OLDER AUSTRIAN PINE STANDS OF THE LOW KRAS[1]

PEDOLOŠKE PRILIKE U STARIJIM SASTOJINAMA CRNOGA BORA NISKOGA KRASA

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An important role in reforestation of the Low Kras has the Austrian pine (*Pinus nigra*). In 1998 pedological, phytocenological and growth analyses were carried out on 30 research plots of 20 x 20 m in 95 to 105 year old monocultures of this allochtonous species in the Sežana-Komen Kras region. In these stands on limestones and dolomites, Lithic and Rendzic Leptosols evolved, as well as Eutric and Chromic Cambisols and Chromic Luvisols. The area shares of soil types and surface stoniness with rockiness, depth of the organic and mineral parts of the soil proved to be good indicators of site productivity. The correlation between productivity ranks of the research plots determined on the basis of soil variables with the ranks determined by the growth variables of medium height, breast height diameter, slenderness coefficient and the annual diameter increment of the dominant black pine trees were relatively close. In the researched sites covered with the antropogenic association *Seslerio autumnalis-Pinetum nigrae*, the following potential vegetation were considered: *Ostryo-Quercetum pubescentis* with a lower productivity, and *Seslerio autumnalis-Quercetum petraeae* and *Seslerio autumnalis-Carpinetum betuli* with better productivity.

Key words: forest soil, site productivity, *Pinus nigra* Arnold, real and potential vegetation, Low Kras (Karst), Slovenia

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INTRODUCTION
UVOD

About 150 years ago the Low Kras (Karst) was a treeless, stony and rocky barren landscape. In 1875 forests covered only 18 % of this lowland, 24.3 % in 1957 while today over 50 % of the area is forested (Jurhar et al. 1963, Košiček 1993). An important role in this reforestation of abandoned pastures and other agricultural areas was the allochtonous species of the Austrian pine. Its more or less clear stands on limestone and dolomite cover about 11000 ha within the Low Karst region (Počkar 1992, Prebevšek 1981, Škulj 1988).

The goal of this research was to analyse soil properties and classify them, assess site productivity, and ascertain the diversity of vegetation in older monocultures of the Austrian pine in the Sežana-Komen Karst region. The fieldwork was performed in the forestry unit Sežana on the research locations Kobjeglava and Podgovec. On each research location, 15 research plots of 20 x 20 m were randomly chosen on a 50-metre grid. Pedological, phytocenological and growth analyses were carried out on these research plots in 1998 (Urbančič et al. 1999).

METHODS OF RESEARCH
METODE ISTRAŽIVANJA

The fieldwork for the research was performed in 1998 on two research locations. The research location "Kobjeglava" is situated on limestone and occupies 42.5 hectares, where shallow and less developed recent soil is predominant. On the research location "Podgovec" (area 17.5 hectares), the parent rock consists of limestone and dolomite, as well as limestone and dolomite breccia (Jurkovšek et al. 1996). Here, deeper, more developed, relic, cambic and luvic soil predominates.

On each research location 15 research plots of 20 x 20 m were randomly chosen on the 50-metre grid and permanently marked. Soil conditions were examined with a gouge soil sampler (9 probe locations), which reaches up to 110 cm deep. The following soil-site indicators were obtained for the plots: exposition, ground slope (in %), surface stoniness and rockiness (5% accuracy), thickness of the organic and depth of the mineral part of the soil (in cm), areal shares of soil types (in %). Also, empirical assessments of site productivity were made, based on pedological indicators as well as stoniness and rockiness of sites. On the basis of growth analysis, the following indicators (for Austrian pine) were obtained for the purposes of this research: mean height and diameter at breast height, slenderness coefficient and annual diameter increment (being the average of three dominant trees on the plot). In the vegetation analysis we included one third of the research plots selected in this way within each of the research locations. In addition to these, four reference plots were chosen on the Sežana-Komen Karst, where the vegetation is relatively well preserved. We surveyed it according to the standard Central European method (Braun-Blanquet 1964). For the statistical analyses, cover degrees were modified according to van der Maarel (1979). The methods of hierarchical clustering according to Ward were used for the statistical classification of soil-site types, and the CLC (*Complete*

Linkage Clustering, method was used for the comparison of phytocoenological surveys. In both cases the Euclidic distance was the measure of similarity or dissimilarity (StatSoft 1995).

RESULTS AND DISCUSSION
REZULTATI I RASPRAVA

Pedological analyses have shown the following genetic sequence of soil types on limestone and dolomite (Škorić 1986): undeveloped soils (litosol) – soils with dominant and mostly mollic A horizon (kalkomelanosol) – postcarbonate eutric soils with cambic B horizon of a brown (kalkokambisol) and red colour (*terra rossa* (Sušin 1964)) - lessive soils with mostly red argic B horizon (luvisol). According to the FAO-Unesco classification these are the following soil units: Lithic Leptosols - Rendzic Leptosols - Eutric and Chromic Cambisols - Chromic Luvisols. Numerous subtypes, variants and forms of these five soil types were found. On 19 plots two types were found, three types on 8 plots, and four soil types on two plots. The plots were statistically classified into four main groups, that is soil-site types. The first group includes the plots with the greatest soil depths, lowest shares of Rendzic Leptosols and the highest shares of Chromic Cambisols and Chromic Luvisols. On these sites the dominant trees reached on average the greatest height ($H_{dominant}$ = 21.7 m) and the greatest slenderness coefficient (H/D = 62.3). The second group of plots (H_{dom} = 20.9 m and H/D = 57.9) is characterised by the lowest shares of stoniness and rockiness, the lowest shares of Lithic Leptosols, the highest shares of Eutric Cambisols and an average soil depth. The third group (H_{dom} = 19.3 m and H/D = 53.9) is characterised by its highest stoniness and rockiness (average share = 43 %) of the site. The fourth group of plots (H_{dom} = 18.7 m and H/D = 53.0) is characterised by the lowest soil depth and highest shares of Lithic and Rendzic Leptosols.

Table 1. Plot denotation numbers (*Plot*), average slopes of the plots, average thicknesses of the organic horizons (*O*), average depths of the mineral parts of the soil (*M* – contains less than 35 % of organic matter), sums of average thickness and depth of plot soil profiles (*O + M*), surface percentage proportions of stones and rocks (*S + R*) and soil units (Lithic Leptosols = *LPq*, Rendzic Leptosols = *LPk*, Eutric Cambisols = *CMe*, Chromic Cambisols = *CMx*, Chromic Luvisols = *LVx*), the number of soil types on the plot (*No*). Plots are classified according to empirically determined productivity ranks (*Re*)

*Tablica 1. Brojčane oznake ploha (*Plot*), njihovi prosječni nagibi (*Slope*), prosječne debljine organskih horizonata (O), prosječne dubine mineralnih dijelova tla (*M *– sadrži manje od 35 % organske tvari), zbrojevi prosječne debljine i dubine talnih profila plohe (*O + M*), postotni udjeli površinske kamenitosti sa stjenovitošću (*S + R*) i tipova tala (kamenjar = *LPq*, vapnenačko-dolomitna crnica = *LPk*, smeđe tlo na vapnencima i dolomitima = *CMe*, crvenica = *CMx*, lesivirano tlo = *LVx*), broj tipova tala na plohi (*No*). Pokusne su plohe razvrstane po rangovima produktivnosti, određenim na iskustvenoj osnovi (*Re*)*

Plot	Slope	O	M	O + M	S + R	LPq	LPk	CMe	CMx	LVx	No	Re
	(°)	(cm)	(cm)	(cm)	(%)	(%)	(%)	(%)	(%)	(%)		
1113	9	17.0	10.1	27.1	75	10	15	0	0	0	2	1
1101	10	8.0	12.0	20.0	55	25	15	5	0	0	3	2
1028	10	8.7	12.1	20.8	50	20	30	0	0	0	2	3
1020	6	9.9	14.0	23.9	45	10	45	0	0	0	2	4
1041	2	4.9	15.4	20.3	20	25	55	0	0	0	2	5
1045	5	6.3	22.3	28.6	35	10	55	0	0	0	2	6
1064	3	6.8	14.0	20.8	20	10	70	0	0	0	2	7
1004	6	5.8	14.7	20.5	5	15	80	0	0	0	2	8
2017	9	5.2	15.8	21.0	45	0	50	5	0	0	2	9
1026	8	5.4	16.6	22.0	25	5	70	0	0	0	2	10
2028	4	3.2	18.6	21.8	40	0	55	5	0	0	2	11
1103	4	5.1	20.1	25.2	40	15	30	15	0	0	3	12
1093	9	5.1	19.6	24.7	35	15	35	15	0	0	3	13
1056	5	5	25.3	30.3	5	0	95	0	0	0	1	14
2040	9	3.6	18.1	21.7	15	0	55	30	0	0	2	15
1155	12	3.1	22.6	25.7	25	0	40	35	0	0	2	16
1119	4	3.7	24.3	28.0	10	0	60	30	0	0	2	17
2042	18	4.1	28.9	33.0	40	15	20	15	15	0	4	18
2003	7	2	19.7	21.7	10	10	20	50	10	0	4	19
2013	12	4.3	29.3	33.6	35	5	30	30	0	0	3	20
2037	7	4.3	29.1	33.4	5	5	45	45	0	0	3	21
1168	11	10	31.6	41.6	40	0	15	45	0	0	2	22
2023	20	3.8	30.6	34.4	25	10	0	65	0	0	2	23
2029	9	6.2	38.4	44.6	5	0	40	55	0	0	2	24
2041	20	3.8	39.3	43.1	25	0	15	35	25	0	3	25
2018	11	5.7	49.6	55.3	10	0	30	30	30	0	3	26
2047	13	4.7	36.8	41.5	20	0	25	30	0	25	2	27
2033	4	3.7	38.4	42.1	5	20	20	20	0	35	3	28
2035	30	2.7	54.6	57.3	20	0	0	45	0	35	2	29
2059	10	1.8	66	67.8	0	0	0	65	0	35	2	30
Average *Prosječna*	10	5.5	26.3	31.7	26	8	37	22	3	4	2.4	15.5
Lowest *Najmanja*	2	1.8	10.1	20.0	0	0	0	0	0	0	1	1
Highest *Najveća*	30	17.0	66.0	67.8	75	25	95	65	30	35	4	30

Graph 1. Dendrogram of plot similarity according to stoiness and rockiness, depth and type of soil. Research plots of the location Kobjeglava have numbers from 1004 to 1168, the plots of the location Podgovec have numbers from 2003 to 2059.

Grafikon 1. Dendrogram ploha s obzirom na sličnosti površinske kamenitosti i stjenovitosti, dubine i tipove tala. Pokusne plohe s lokacije Kobjeglava imaju brojeve od 1004 do 1168, plohe s lokacije Podgovec imaju brojeve od 2003 do 2059.

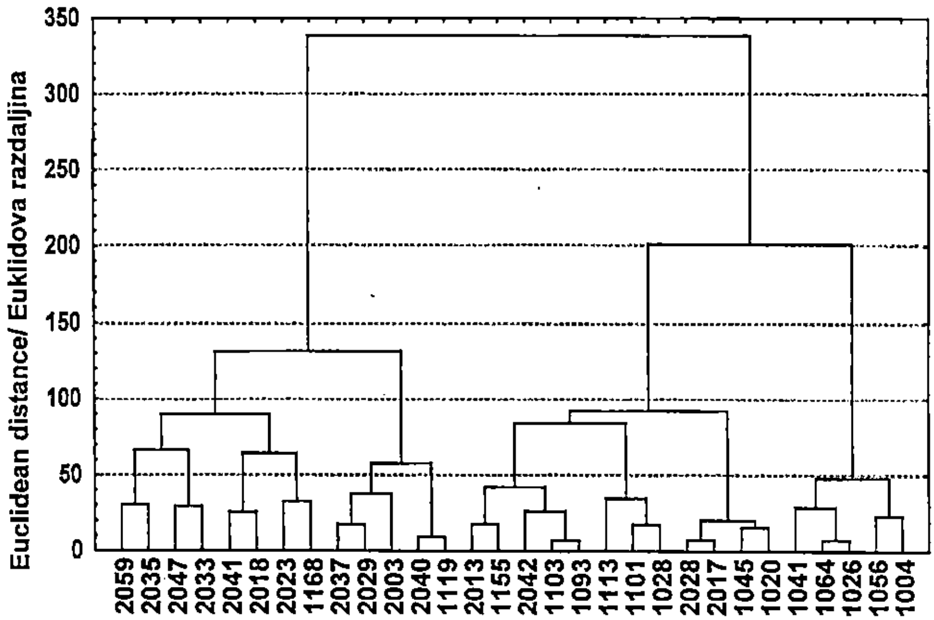

Table 2. Characteristics of four individual groups of plots according to surface stoniness and rockiness (*S* + *R*), average depth of the organic and mineral part of the soil (*O* + *M*), surface percentage proportions of soil units (Lithic Leptosols = *LPq*, Rendzic Leptosols = *LPk*, Eutric Cambisols = *CMe*, Chromic Cambisols = *CMx*, Chromic Luvisols = *LVx*).

*Tablica 2. Svojstva četiriju individualnih grupa ploha s obzirom na površinsku kamenitost i stjenovitost (*S + R*), prosječne dubine tla (*O + M*) i postotnih udjela talnih tipova (kamenjar =* LPq, *vapnenačko-dolomitna crnica =* LPk, *smeđe tlo na vapnencima i dolomitima =* CMe, *crvenica =* CMx, *lesivirano tlo =* LVx*).*

CLUSTER *KLASTER*	No[1]	S + R (%)	O + M (cm)	LPq (%)	LPk (%)	CMe (%)	CMx (%)	LVx (%)
1	7	20.00	48.71	1.43	12.19	45.00	7.86	13.57
2	4	8.75	32.00	1.25	50.00	40.00	0.00	0.00
3	12	43.33	25.58	10.42	35.00	10.42	1.25	0.00
4	5	15.00	22.80	11.00	74.00	0.00	0.00	0.00
H-test[2]	(3. 28)	18.6***	16.5***	9.7*	19.5***	19.7***	3.6^{NS}	9.7*

Note:

[1] Number of plots. Due to the age difference of the stands among plots, two younger plots have been excluded.

[2] H = test value of difference characteristics according to Kruskal-Wallis (1952, cited from StatSoft, 1995).

Analysis shows that soil type shares, soil depth and surface stoniness and rockiness are good indicators of site productivity, since the correlation between productivity ranks, determined on the basis of soil variables, and ranks, determined on the basis of dendrometric variables (mean height of dominant Austrian pine trees), is relatively close among plots ($r_s = 0.62 - 0.65^{**}$).

Table 3. Mean values and 95 % confident limits of empirically (*Re*) and statistically (*Rs*) determined productivity ranks, diameters (*D*) and heights (*H*), slenderness coefficients (*H/D*) and annual radial increments of dominant pine trees for the period 1988 – 1997 (*IR*) for four individual groups of plots

*Tablica 3. Srednje vrijednosti i 95 % granice konfidencije rangova produktivnosti, određenih na iskustvenoj osnovi (*Re*) i statistički (*Rs*), visina (*H*), promjera stabala u prsnoj visini (*D*), koeficijenata vitkosti (*H/D*), godišnjih debljinskih prirasta dominantnih stabala crnoga bora za razdoblje 1988 – 1997 (*IR*) za četiri indivdualne grupe ploha*

CLUSTER *KLASTER*	No	Re	Rs	D (cm)	H (cm)	H/D (cm)	IR (mm)
1	7	26.0 ± 2.7	26.3 ± 1.6	35.3 ± 2.4	21.7 ± 4.4	62.3 ± 5.2	0.75 ± 0.3
2	4	19.3 ± 3.4	17.0 ± 2.9	37.0 ± 12.2	20.9 ± 2.1	57.9 ± 11.9	0.87 ± 0.8
3	12	9.6 ± 4.1	8.8 ± 4.5	36.5 ± 2.2	19.3 ± 1.2	53.9 ± 4.9	0.67 ± 0.1
4	5	8.8 ± 4.3	11.6 ± 2.9	35.5 ± 1.9	18.7 ± 0.8	53.0 ± 3.5	0.69 ± 0.4
H-test [1]	(3.28)	18.6***	24.2***	0.6	12.2**	9.1*	0.5

Note:

[1] H = test value of difference characteristics according to Kruskal-Wallis (1952, cited from StatSoft, 1995).

*** = $p \leq 0.001$; ** = $0.001 < p \leq 0.01$; * = $0.01 < p \leq 0.05$

Table 4. Interdependence between productivity ranks (*Re, Rs*) and growth ability variables (*H, D, H/D, IR*) by plots.

*Tablica 4. Međuovisnost rangova produktivnosti (*Re, Rs*) i dendrometrijskih varijabla (*H, D, H/D, IR*) na pokusnim plohama*

$R_{Spearman}$	Re	Rs	D	H	H/D
Rs	0.85**				
D	0.08	-0.09			
H	0.62**	0.65**	0.10		
H/D	0.49**	0.56**	-0.70**	0.51**	
IR	0.18	0.11	0.33	0.22	0.17

Note: Spearman's rank correlations was used (N=28).

The real vegetation which appears on the research locations "Kobjeglava" and "Podgovec" belongs to the group of Austrian pine forests (*Seslerio autumnalis-Pinetum nigrae* Zupančič 1997 (*nom. prov.*). Better, less rocky and more humid plot sites are classed into potential forest sites of *Seslerio autumnalis-Quercetum petraeae* Poldini (1964, 1982). On some even more favourable meso-site conditions, a forest *Seslerio autumnalis-Carpinetum* Zupančič 1997 (*nom. prov.*) could potentially grow. On the rockiest sites (mainly on the research location "Kobjeglava") we may expect *Ostryo-Quercetum pubescentis* (Ht. 1950) Trinajstić 1974.

The hierarchical cluster analysis has classified the plot surveys into two distinctive groups (Urbančič et al. 1999). The first group comprises the majority of the plot surveys from the black pine research locations, which represent thermophile submediterranean forest sites of the association *Ostryo-Carpinion orientalis* Ht. 1954 em. 1958 of the order *Quercetalia pubescentis* Br.-Bl. (1931) 1932. The second group comprises plots with more mesophile, carpinetal elements: e.g. *Asarum Europaeum, Cyclamen purpurascens, Primula vulgaris, Lonicera caprifolium, Hepatica nobilis.* The plots are placed in the association *Quercion pubescentis-petraeae* Br.-Bl. 1931 and *Erythronio-Carpinion betuli* (Ht. 1958) Marinček, Wallnöfer, Mucina et Grass 1993. These are karst forests of *Quercus petraea* and *Carpinus betulus* on more humid and relatively colder sites. In the plot surveys from the first group more *Ostrya carpinifolia* may be found in the ground hugging vegetation, as well as *Clematis vitalba, Frangula rupestris* and *Brachypodium rupestre.* In the second group there is relatively more of *Acer campestre* and *Corylus avellana.* In the shrub and herb layers of all the studied plots, *Fraxinus ornus, Hedera helix* and *Sesleria autumnalis* appear with a high cover degrees.

The groups which were created on the basis of similarity in the vegetation structure, correlate relatively well with the soil-site types formed.

CONCLUSIONS
ZAKLJUČCI

An important role in the reforestation of the Low Kras has the allochtonous species of the Austrian pine (*Pinus nigra*). In its 95 to 105 years old monocultured stands on limestones and dolomites pedological research on 30 plots of 20 x 20 m has shown the following genetic sequence of soil types: nondeveloped soils (lithosols) - slightly developed soils (calcomelanosols) - postcarbonate cambic soils of a brown (calcocambisols) and brownish-red colour (*terra rossa*) - lessive soils (luvisols). According to the international FAO-Unesco classification (1989) these are the following five soil units: Lithic Leptosols - Rendzic Leptosols - Eutric and Chromic Cambisols - Chromic Luvisols. Numerous subtypes, variants and forms of these soil types (or soil units) were found.

The area shares of soil types and surface stoniness with rockiness, depth of the organic and mineral parts of the soil proved to be good indicators of site productivity. The correlation between productivity ranks of the research plots determined on the basis of soil variables with the ranks determined by the growth variables of medium height, breast height diameter, slenderness coefficient and the annual diameter increment of the dominant black pine trees was relatively close.

In the researched sites covered with the antropogenic association *Seslerio autumnalis-Pinetum nigrae*, the following potential vegetation were considered: *Ostryo-Quercetum pubescentis* with a lower productivity, and *Seslerio autumnalis-Quercetum petraeae* and *Seslerio autumnalis-Carpinetum betuli* with higher productivity

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PEDOLOŠKE PRILIKE U STARIJIM SASTOJINAMA CRNOGA BORA NISKOGA KRASA

SAŽETAK

Prije 150 godina niski je Kras bio pretežno kamenita i stjenovita, neplodna pokrajina bez drveća. Godine 1875. šume su obrastale 18 % ove nizine, 1957. godine 24,3 %, a danas je pod šumom više od 50 % njezine površine. Važnu ulogu u pošumljavanju zapuštenih pašnjaka i drugih poljoprivrednih površina imao je crni bor, iako je alohtona vrsta. Njegove više ili manje čiste sastojine na vapnencima i dolomitima osvojile su oko 11 000 hektara ove nizine.

U 1998. godini provedene su analize tla, biljnih zajednica te rasta i prirasta stabala na 30 pokusnih ploha površine 20 x 20 m u monokulturama crnoga bora (*Pinus nigra*) starim 95 do 105 godina na području sežansko-komenskoga Krasa. Na vapnencima i dolomitima ovih staništa pedološkim istraživanjem utvrđen je ovakav genetski slijed, tj. sekvencija tipova tala: nerazvijena tla (kamenjar ili *litosol*) – slabo razvijena tla (vapnenačko-dolomitna crnica ili *kalkomelanosol*) – kambična tla smeđe (*kalkokambisol*) i smeđocrvene (crvenica ili *terra rossa*) boje – lesivirano tlo (*luvisol*). Po međunarodnoj FAO-Unescovoj klasifikaciji odgovaraju ovim jedinicama tala: litičnomu leptosolu – rendzinskomu leptosolu – eutričnomu i kromičnomu kambisolu – kromičnomu luvisolu. Kod tih tipova tala (ili jedinica tala) pronađeni su brojni podtipovi, varijeteti i forme.

Postotni udjeli tipova tala i površinske kamenitosti sa stjenovitošću te debljina organskoga i mineralnoga dijela tla na plohama pokazali su se kao dobri indikatori produktivnosti staništa. Korelacija između rangova produktivnosti pokusnih ploha, određenih na osnovi pedoloških varijabli s rangovima, određenim dendrometrijskim varijablama (srednja visina, promjer stabla u prsnoj visini, koeficijent vitkosti, godišnji debljinski prirast dominantnih stabala crnoga bora), bila je prilično tijesna.

Na proučavanim staništima, obraslima antropogenom asocijacijom *Seslerio autumnalis-Pinetum nigrae,* bila je utvrđena ova potencijalna vegetacija: *Ostryo-Quercetum pubescentis* s nižom produktivnošću te *Seslerio autumnalis-Quercetum petraeae* i *Seslerio autumnalis-Carpinetum betuli* s višom produktivnošću.

Ključne riječi: šumsko tlo, produktivnost staništa, *Pinus nigra* Arnold, realna i potencijalna vegetacija, niski Kras, Slovenija

P. Simoničič: Soil solution quality and soil characteristics with regard to clear cutting.
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SOIL SOLUTION QUALITY AND SOIL CHARACTERISTICS WITH REGARD TO CLEAR CUTTING[1]

SVOJSTVA ŠUMSKOGA TLA I NJEGOVE OTOPINE NAKON ČISTE SJEČE

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Soil solutions have been studied on an altimountane stand of mature spruce trees and on a clear-cut subplot which was formed by a sanitary cut in the summer of 1995. Ceramic lysimeters were installed under the organic horizon and 50 cm deep in distric cambisols and podzols on mixed moraine composed of limestone and silicate stone. Samples were taken every month in the period 1997–1998. The ion structures of soil solutions at the subplots differed in the first year, especially in the layer just under the organic layer of soil, and also in the second year in the deeper horizon. In the clear-cut subplot the NO_3 concentrations were highest in the period July– October 1997 (NO_3 = 11.22–19.80 mg/l); next year concentrations were lower (NO_3 = 11.07–14.48 mg/l). Monthly concentrations of ions on the spruce stand were lower for NO_3^- (~10x), NH_4^+, K^+, Mg^{2+} (but not for Al^{3+}) than on the clear-cut subplot. The process of nitrate leaching is clearly expressed in the cleared subplot along the whole profile but during the observation period (1997–1998) it was diminished. Soil solution pH values and Ca^{2+} concentrations are highest on the spruce stand 50 cm deep as a consequence of soil and parent rock characteristics.

Soil profile descriptions and analysis are showing influence of sanitary clear-cut in the year 1995 on morphological and chemical soil properties (thickness of Ol layer, C/N ratio, C_{tot} content) what is also closely linked with lower input of literfall (4-6 x) in the clear-cut subplot in comparison to mature spruce stand subplot.

[1] This article was presented at the IXth Congress of the Croatian Society of Soil Science, Brijuni, 3-7th July 2001

According to the results, accelerated mineralization and decomposition of organic substances are clearly manifested on a clear-cut subplot.

Key words: soil, soil solution, spruce stand, clear cut, Slovenia

INTRODUCTION
UVOD

A forest ecosystem, due to its structure and compartments (living and dead biomass, mineral and organic matter), [1]has a strong regulatory function over the chemistry of water passing through it. Water, which passes with deposits into forest soils, reacts with the soil solid phase and changes and enriches its composition (Likens & Bormann 1995). Soil solution is an important element of mass flow in forests and at the same time a good indicator of ecological forest conditions.

Soil solution compounds depend on atmospheric deposition, forest structure, soil characteristics (litter quality and quantity, content of organic matter and mineral soil composition, soil-moisture characteristics, soil porosity), organic matter decomposition rate and mineralization process and on water regime (Ćirić 1984, Kölling 1993, Likens & Bormann 1995, Bäumler & Zech 1998). Different biotic and abiotic factors (forest management, N input, acid deposition, consequences of windthrows and snow breaks, forest pasture etc.), cause element fluxes flow changes and changes of soil solution chemistry in forest ecosystems. The soil solution chemistry and its composition react quickly after environmental changes and clearly reflects forest ecosystem environmental conditions (Likens & Bormann 1995).

Investigations of soil solution chemistry are mostly a part of biogeochemical cycling studies or related to atmospheric deposition and pollution, meteorological conditions (extreme events), soil characteristics (pH, C/N, CEC, BS) and different forest management and harvesting practices (Bormann & Likens 1979, 1995, Tiedemann et al. 1988, Kreutzer & Göttlein 1991, Kölling 1993, Kreutzer 1994, Bäumler & Zech 1998, Gunderson et al. 1998. Rehfuess 1999, Vries et al. 1999). These investigations have focused on critical levels for soil solutions related to nitrate and aluminium in view of groundwater pollution, ratios between different ions (NH_4: Al) to base cations in view of nutrient imbalances and leaching of nutrients from forest soils in view of acid deposition or natural processes (Vries et al. 1999).

Within studies of forest soils and rhizospheres on the Slovenian Forestry Institute permanent research plot on the Pokljuka plateau, soil solution, bulk deposition and litterfall have been intensively monitored in the period 1997–1998. Because of occasional attacks of bark beetles, sanitary felling in 1995 opened an area of about 0.3 hectare. In 1996 deposition and soil solution sampling equipment was installed on the clear-cut area (about 0.3 ha) and on a mature Norway spruce mature stand. We wanted to follow the changes in soil solution chemistry (N concentrations) one and two years after a sanitary cut and compare them to soil solution conditions in a "stable" mature spruce stand.

METHODS
METODE

Two research subplots 25 x 25 m in a mature spruce stand and on a cleared area were established (1996) inside a one ha permanent plot at Pokljuka near the Šijec bog. At plot appearance distric cambisols and podzol on mixed moraine. The plant community, which is supposedly of an autochthonous origin, is *Rhytidiadelpho lorei-Piceetum*. Plots were placed at an altitude of about 1200 m a.s.l. in a frost pocket. The yearly precipitation average is over 2000 mm. Temperatures over 5 °C appear between May and September. The described facts characterise relatively harsh climatic site conditions.

In the period January 1997-December 1999, soil solution, bulk and throughfall deposition were monthly collected. For stand throughfall (9 per subplot) and bulk deposition, rain and snow collectors were used (Anonymous 1998). Ceramic tension lysimeters (0,6 bar; P 80) were used at two depths; under the organic horizon and 50 cm below the soil surface (Meiweis et al. 1984). At each of three pits on subplot three parallel lysimeters at each depths linked to glass bottles were installed (Simončič 1996).

Parallel to input–output balance studies, descriptions of soil and nutrition status were performed.

Soil solution, stand throughfall and bulk deposition analysis (after filtering): pH (potentiometry); NO_3_N, by ion chromatography; NH_4_N by spectrophotometry (Nessler reag.); Ca, Mg by FLAAS, K by EAS and Al by graphite furnace-AAS.

RESULTS AND DISCUSSION
REZULTATI I RASPRAVA

During the monitoring period the annual precipitation varied between 1434–1750 mm outside the forest (control subplot) and on the clear-cut subplot and 1215–1414 mm on the spruce stand. Measured precipitation was below the perennial average (over 2000 mm). Precipitation pH ranged between 3.71–5.46 under the spruces and between 3.98–5.60 on the clear-cut, but mostly under 5.6, indicating weak acid deposition character. Annual precipitation, ranges of pH values and cumulative annual input for selected ions are presented in the following table (Tab 1.).

Table 1. Annual precipitation and ranges of pH values, cumulative annual input for *N_NH₄*, *N_NO₃*, *S_SO₄* and *Ca* (kg / ha year) at the Pokljuka permanent plot for the period 1997–1998.

Tablica 1. Godišnje oborine i rasponi pH-vrijednosti, kumulativni godišnji unos N_NH_4, N_NO_3, S_SO_4 *i* Ca *(kg ha^{-1} godinu^{-1}) na stalnoj plohi na Pokljuki za razdoblje od 1997. do 1998.*

Subplot	period (year)	precipitat. (mm)	pH range	N_NH_4 (kg/ha)	N_NO_3 (kg/ha)	S_SO_4 (kg/ha)	Ca (kg/ha)
Spruce Stand[1]	1997 1998	1215 1414	4.0 – 6.5	13.9 10.5	3.8 4.7	16.0 15.0	12.4 7.4
Clear Cut[2]	1997 1998	1460 1657	4.0 – 5.6	6.1 4.9	5.9 6.3	11.9 13.5	7.1 5.4
Control[3]	1997 1998	1434 1745	4.0 – 6.5	4.7 4.9	5.5 6.7	11.6 14.6	11.8 8.1

Legend :[1] throughfall; [2] bulk deposit character; [3] bulk deposit

Annual deposition of total nitrogen ($N\_NH_4^+$ and $N\_NO_3^-$) was approximately 11–12 kg per ha on control and clear-cut subplot and 30 % higher than on the spruce stand. Sulphur deposition ($S\_SO_4^{2-}$) of 11.6–14.6 kg ha^{-1} per year outside of the forest was only a little lower than in the spruce stand (15–16 kg ha^{-1} y^{-1}). All three precipitation parameters (pH, total nitrogen and sulphur deposit), vary during the year and the highest concentrations of ions and lowest pH occur in the period from February to March. Regarding the deposition analysis, it was concluded that atmospheric input of major acidification precursors are relatively low for most of the observation period and large damages were not expected due to air pollution influence.

The pH value and ion concentrations in soil solution under the organic layers and those 50 cm below the soil surface differed with regard to the depth of lysismeter installation and subplot type (Tab. 2).

On the clear-cut subplot the NO_3 volume weighted means of ion concentrations are higher (2.01-10.80 mg/l) than on the spruce stand (0.19-0.81mg/l). The process of nitrate leaching is clearly expressed in the clear-cut subplot along the profile but during the observation period (1997-1998) it was diminished (Fig. 1 and 2). The highest nitrate concentration peaks in soil solutions were on the clear cut subplot in May and June (after snow-melt in the warmer period; figures 1 and 2).

Monthly concentrations of ions on the spruce stand were relatively comparable, but lower for NH_4, K and Mg than on the clear-cut subplot (Tab. 2). Al concentrations differ at the 50 cm depth and are higher on the clear-cut than the spruce subplot. Soil solution pH values and Ca^{2+} concentrations are highest on the spruce stand 50 cm deep as a consequence of soil and parent rock characteristics.

Table 2. Ranges of soil solution pH values, volume weighted means of ion concentrations (mg/l) in soil solution of two depths on spruce stand and clear-cut subplots at Pokljuka (1997 – 1998)

Tablica 2. Rasponi pH-vrijednosti otopine tla i volumne težinske koncentracije iona (mg/l) u otopini tla na dvjema dubinama u smrekovoj sastojini i na potplohama s čistom sječom na Pokljuki (1997–1998)

site	period (year)	lysim. depth	pH range[5]	K^+ (mg/l)	NH_4^+ (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Al^{3+} (mg/l)
Spruce	1997	AL 0[1]	3.7-4.7	0.28	4.11	0.23	3.39	0.81	0.24	0.82
	1998		4.0-4.3	0.17	2.67	0.19	3.54	0.78	0.24	0.48
Stand	1997	AL 50[2]	5.5-7.7	0.19	0.44	0.81	3.65	5.65	0.23	0.15
	1998		4.7-7.1	0.19	0.21	0.63	4.13	0.84	0.18	0.03
Clear	1997	CL 0[3]	3.5-4.7	1.29	4.53	6.31	2.79	1.53	0.39	1.15
	1998		4.1-4.4	0.48	3.41	2.01	2.60	1.47	0.31	0.52
Cut	1997	CL 50[4]	4.0-5.4	0.26	0.71	10.80	4.69	1.77	0.36	1.00
	1998		4.4-5.9	0.53	0.57	6.18	3.93	1.49	0.25	0.21

Legend: [1] and [3] under organic layer; [2] and [4] 50 cm below soil surface; [5] min-max range

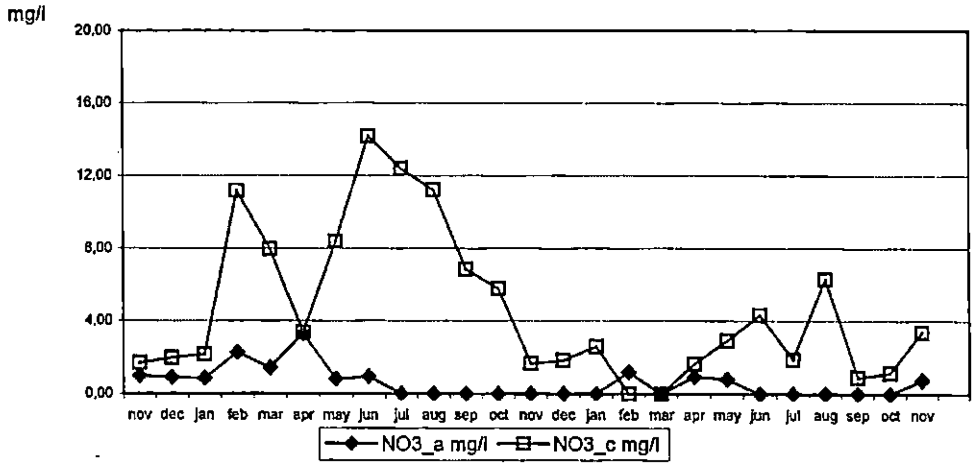

Fig. 1. Monthly soil solution NO_3 concentrations (*mg/l*) under the organic soil layer for the period 1997-1998 on the spruce stand subplot (*NO_3_a*) and clear-cut subplot (*NO_3_c*) on the Pokljuka plateau

Grafikon 1. Mjesečne koncentracije NO_3 (mg/l) *u otopini tla ispod organskoga horizonta u razdoblju od 1997. do 1998. godine na potplohi sa smrekom* (NO_3_a) *i na potplohi s čistom sječom na Pokljuki*

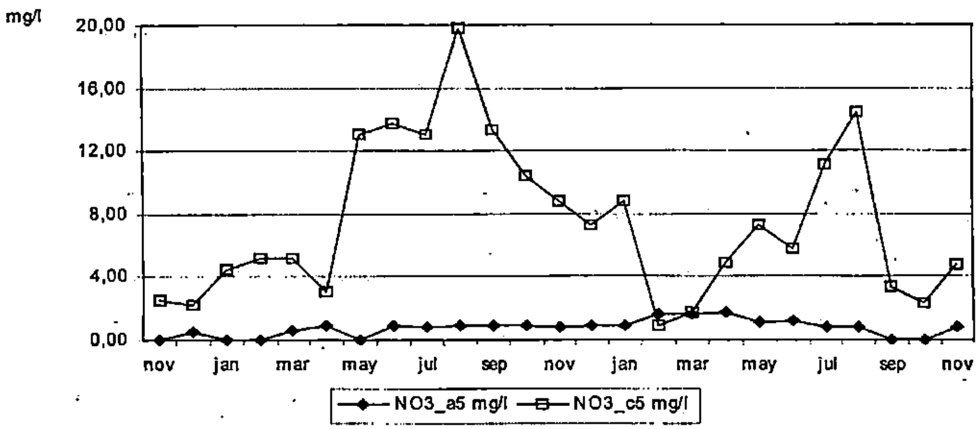

Fig. 2. Monthly soil solution NO_3 concentrations (*mg/l*) 50 cm below the soil surface for the period 1997-1998 on the spruce stand subplot (*NO_3_a5*) and clear cut subplot (*NO_3_c5*) on the Pokljuka plateau

Grafikon 2. Mjesečne koncentracije NO_3 (mg/l) *u otopini tla ispod organskoga horizonta u razdoblju 1997–1998. godine na potplohi sa smrekovom sastojinom* (NO_3_a5) *i na potplohi s čistom sječom* (NO_3_c5) *na platou Pokljuke*

Vertical distribution of ion concentrations decreased for K^+, NH_4^+ (~10 x) and Al^{3+} but increased for NO_3^- due to mineralization and oxidation of ammonia. Also possibly due to the process of denitrification during a dry summer (Bäumler & Zech 1998). Regarding sulfate concentrations, there were no pronounced difference between concentrations in the upper and lower sampling depths.

Using the chloride balance method (Anonymous 1998, Gundersen et al. 1998) flow rate we calculated for soil solutions to get information for upper and lower soil layers and leaching processes on the clear-cut *versus* the spruce stand subplot than for absolute data. In the second year after cutting (1997) more than 60 kg of nitrogen ha^{-1} $year^{1}$ (N_NO_3 and N_NH_4) was leached from deeper soil layer (50 cm under soil surface), and in 1998 nearly 40 kg of nitrogen ha^{-1} $year^{1}$ was leached from this layer. During this same period, 5–10 kg of nitrogen ha^{-1} $year^{1}$ was leached from the soil layer 50 cm below the surface of the spruce subplots.

The highest concentrations and element flux in the upper soil layer under the organic horizon occur after snow-melt in may (Figure 1) and in deeper soil layer in july and august (Figure 2).

CONCLUSIONS
ZAKLJUČCI

An interesting question regarding the research task was to distinguish between the natural processes in comparison to a man-made action – harvesting, and the reaction of the forest ecosystem respectively to soil processes. The results indicate that clear-cutting caused changes in the soil solution chemistry, especially concerning NO_3 and NH_4 concentrations and leaching from soils. Besides soil solution changes, sanitary felling also caused changes in morphological and chemical soil characteristics (quality of the organic horizon, C/N proportion, reduced litterfall etc; Simončič et al. 1998). Intensive processes characterise soil solution chemistry, especially in the first few years after clear-cutting. A higher risk to soil solution chemistry and ground water quality could arise within areas with higher nitrogen deposition (Kreutzer 1994, Callesen et al. 1999). Also natural processes (acidification) in harsh and stress climatic conditions such as those at Pokljuka cause a slightly stable status of forest ecosystems.

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SVOJSTVA ŠUMSKOGA TLA I NJEGOVE OTOPINE NAKON ČISTE SJEČE

SAŽETAK

U altimontanskoj zreloj smrekovoj šumi na potplohi, gdje je obavljena čista sječa ljeti 1995. godine, pratili smo kakvoću otopine tla. Za praćenje su bili postavljeni u tlu keramički lizimetri ispod humusnoga horizonta i na dubini od 50 cm u kiselom smeđem tlu i podzolu na moreni iz detritusa vapnenačkih i silikatnih stijena. Uzorkovanje se otopine tla obavljalo od 1997. do 1998. godine jednom mjesečno. Ionski se sastav na potplohama prve godine razlikovao, posebno u tlu ispod humusnoga horizonta. Razlike u sastavu otopine tla bile su nađene i druge godine na dubini od 50 cm. Na potplohi, gdje je bila obavljena čista sječa, bile su najveće koncentracije NO_3 u otopini tla u razdoblju od lipnja do listopada 1997. godine (NO_3 = 11,22–19,80 mg/l). Iduće su godine koncentracije bile manje (NO_3 = 11,07–14,48 mg/l). Mjesečne ionske koncentracije NO_3^- (~10x), NH_4^+, K^+, Mg^{2+} (ipak ne za Al^{3+}) bile su manje na potplohi sa smrekovom sastojinom nego na potplohi s čistom sječom. Proces ispiranja nitrata jasno se izražavao na čitavom profilu tla na potplohi s čistom sječom. Tijekom razdoblja praćenja od 1997. do 1998. godine ispiranje se smanjilo. pH-vrijednosti otopine tla i koncentracije Ca^{2+} bile su najveće na potplohi sa smrekom na dubini od 50 cm kao posljedica svojstava matičnoga supstrata.

Opis profila tla i analize pokazale su utjecaj čiste sječe u 1995. godini s obzirom na morfološka i kemijska svojstva tla (debljina Ol, C/N odnos, sadržaj C), što je vezano uz manji unos otpalih iglica (4–6x) na potplohi s čistom sječom nego na potplohi sa smrekom.

Na osnovi rezultata možemo zaključiti da se na potplohi s čistom sječom jasno izražava ubrzana mineralizacija i rastvaranje organske tvari.

Ključne riječi: tlo, otopina tla, smrekova sastojina, čista sječa, Slovenija

L. Kutnar, M. Urbančič: Soil and plant diversity in transition mire-forest
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SOIL AND PLANT DIVERSITY IN TRANSITION MIRE-FOREST ZONES ON THE POKLJUKA PLATEAU[1]

TALNA I BILJNA RAZNOLIKOST U PRIJELAZNOM POJASU IZMEĐU BARE I ŠUME NA POKLJUŠKOJ VISORAVNI

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The soil and vegetation diversity in transition zone between mires and surrounding spruce forests on the Pokljuka plateau in the Julian Alps in Slovenia (altitude 1200 m) were examined. Heterogeneous soil conditions are characteristic of researched transition zone. On 168 sampling spots different soil units were found as Rendzic Leptosols, Eutric Cambisols, Dystric Cambisols, different forms of Podzols, Gleysols and peat Histosols, and 28 lower pedosystematic units, as well. On almost one quarter of the 42 plots (2 x 4 m) we found two or even three different soil units per plot. On more than half of the plots we found two, three or even four different lower pedosystematic units. In general, dystric peat histosols are overgrown by the dwarf-pine mire plant community and the spruce-mire plant community. On average, they have low pH_{H2O} values (under 4.0), high total carbon content (above 40 %) and high C/N ratio (around 30). The eutric peat histosols are characteristic of the studied sedge fens, they have pH_{H2O} values above 5.5, high exchangeable calcium (above 80 cmol(+)/kg) and high base saturation level (above 95 %). On the automorphic soil on the mixed moraine we have determined two different types of spruce forests, one with the poorer species composition and another with richer species composition. Characteristic soil units of the first one, in which predominate acidophilic, piceetal elements, are podzols. They have low values of pH_{H2O} (less than 4.5) and high contents of exchangeable aluminium (above 8 cmol(+)/kg). In the second spruce forest community with a richer species composition we determined various soil units with significant higher pH_{H2O} values, calcium contents and base saturation level than podzols.

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Key words: automorphic and hydomorphic soils, moraine, vegetation, mire, spruce forest, Pokljuka plateau, Slovenia

INTRODUCTION
UVOD

Peatlands in Slovenia (Martinčič & Piskernik 1985, Kutnar 2000a, 2000b) are among the southernmost mires in Europe. Some important studies of mire ecology and vegetation at the southern border of the *Spagnum*-mire distribution have been already made in Slovenia (Martinčič & Piskernik 1985). However, the studies of Italian mires in the southern Alps are quite numerous (Bragazza 1994, 1996, 1997, Gerdol et al. 1994, Gerdol 1995, Bragazza & Gerdol 1996, Alber et al. 1996, Bragazza et al. 1998).

On the Pokljuka plateau in addition to true-raised bogs we also find the so-called spruce mires. In comparison with true-raised bogs (for example those of Šijec and Veliko Blejsko Barje) the spruce mires are in general, relatively insufficient investigated. They are very mosaic, transition mire-forest ecosystems characterised by the specific ecological conditions. With respect to diversity, mire site types situated on the border zones of different ecological influences are of special interest (Korpela & Reinikainen 1996a, 1996b).

The main aim of this thesis was to gain an understanding of the soil and plant diversity on the transition zone between mires and spruce forest on the Pokljuka plateau.

RESEARCH AREA AND OBJECTS
ISTRAŽIVANO PODRUČJE I PLOHE

This study was performed on mires and in surrounding forest on the Pokljuka high plateau (46°20' N, 13°59' E) on the eastern side of the Julian Alps in Slovenia (Fig. 1). The Pokljuka plateau range between 1000 meters and 1500 meters above sea level. Due to closeness of high mountains with the highest Triglav mountain (2864 meters above sea level) it is influenced by alpine climate, characterised with 1900 to 2700 mm precipitation, average annual temperature of 1.4 to 3.2 °C and duration of snow cover about 170 days. Temperature inversion are frequent because of dish-shaped relief. On the Pokljuka plateau, spruce forest prevail almost completely as a result of severe alpine climate, relief and past forest management. Until the beginning of intensive iron production at the end of the 17th century, this region was covered mainly with the beech (*Fagus sylvatica* L.) forests and mixed forests of beech, silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* (L.) Karst.) (Budnar-Tregubov 1958, Šercelj 1962, Culiberg et al. 1981), which was further reduced in the 19th century.

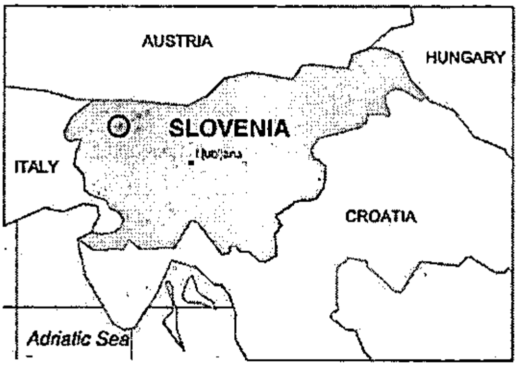

Figure 1. Position of the Pokljuka plateau
Slika 1. Položaj Pokljuške visoravni

As a result of its high usability, and for economic reasons, the spruce was favored by the forest management. Antropogenic influences in the past such as charcoal burning, cutting wood and cattle grazing changed the tree species composition from original forests to secondary spruce stands with only 1 % broad-leaved species and 1 % silver fir.

Due to specific climate and soil conditions the spruce share had already been relatively high before the intensive human intervention. The supposedly autochthonous spruce sites are also mire ecosystems.

The study was carried out on 6 different mires near bog Šijec (46°20'07"N, 13°59'57"E) and bog Veliko Blejsko barje (46°20'32"N, 13°59'43"E) on the Pokljuka plateau. The 42 (six series of seven, 2 x 4 m) plots were placed systematically to determine the biodiversity on the transition of mire to surrounding spruce forest.

On the basis of two repeated phytosociological relevés in one vegetation season we conducted a vegetation survey (Braun-Blanquet 1964) for the studied plots. On the basis of the floristic composition, the coverage of plants and vertical structure we assembled six vegetation groups of similar plots (Kutnar 2000a, 2000b, Kutnar & Martinčič 2001):

A) dwarf-pine mires (*Sphagno-Pinetum mugo* or *Pino mugi-Sphagnetum* association);
B) spruce mires (*Sphagno girgensohnii-Piceetum* var. geogr. *Carex brizoides*);
C) spruce forests with a poorer species composition of predominating acidophilic, piceetal elements (*Rhytidiadelpho lorei-Piceetum typicum* and *sphagnetosum*);
D) spruce forests with a richer species composition and with a more significant presence of species that are characteristic of less acidic soil (*Rhytidiadelpho lorei-Piceetum cardaminetosum*);
E) sedge fens (*Sphagno-Caricetum rostratae* and plant communities with dominated *Carex davalliana* or *Trichophorum alpinum*);
F) transitions of sedge fens to spruce forests.

RESEARCH METHODS
METODE ISTRAŽIVANJA

We analysed and compared vegetation groups (Kutnar 2000a, 2000b, Kutnar & Martinčič 2001) in terms of diversity of plants and soil conditions. For the analysis of the plant diversity we used Shannon index H' (Shannon & Weaver 1949). We also counted the plant species number per plots.

On the 42 research plots we described the morphology of soil units. On the corners of all research plots (168 sampling spots), we determined the soil units according to FAO-Unesco (1989) and WRB (1998) soil classifications. At the determination of lower pedosystematic units we took into consideration also some other soil classifications (Pravilnik za ocenjevanje tal 1984, Škorić 1986).

From all four plot-soil samples, we made two composite soil samples for two different depths (0-10 cm, 10-30 cm). The soil samples were tested in the laboratory of the Slovenian Forestry Institute in order to obtain the following chemical characteristics:

- pH in H_2O, and in 0.01 mol/l $CaCl_2$ (Blum et al. 1989, SIST ISO 10390);
- the amounts of total nitrogen (SIST ISO 11261) and total carbon (SIST ISO 10694),
- amounts of carbonate (SIST ISO 10693)
- quantity of exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Al^{3+}, Fe^{3+}, Mn^{2+}, H^+) with AAS (Blum et al. 1989, SIST ISO 11260, ÖNORM L 1086).

On the basis of these measurements we also calculated the amount of organic matter, the C/N ratio, the cation exchange capacity (CEC) and the base saturation level (BS).

Spearman correlation coefficient between plant diversity (species number per plot, Shannon index) and chemical soil variable of depth 0-10 centimeters were calculated.

RESULTS AND DISCUSSION
REZULTATI I RASPRAVA

PLANTS DIVERSITY
RAZNOLIKOST VRSTA

Analyses of vegetation groups showed the largest diversity of species in group F (34 species per plot), which includes the plots at the transition of the sedge fen vegetation to the spruce forest on the automorphic soil (table 1). In group E which consists of different sedge fen vegetation, there is a high number of plant species too. But we determined the smallest species diversity on plots which are covered by the dwarf-pine mire community. In group A there are on average only sixteen species per plot. About the same average number of plants we found in the group B. Plots of this group are overgrown by the spruce mire community. The significant difference of species richness between groups of different spruce forest types (C and D) have been determined.

The average Shannon index of diversity, which also takes into account the coverage of individual species, is the highest on the sedge fen plots of group E (H' = 2.42). In the vegetation type at the margin zone of fens to forest (group F), the average of index is also high. However, this index is the smallest for group C (H' = 1.52), which is a result of the significant predominance of spruce in the tree and shrub layers.

Table 1. Average species number per plot and Shannon index
Tablica 1. Prosječni broj biljnih vrsta po plohama i Shannonov indeks

group / *grupa*	A	B	C	D	E	F
species N/plot *broj vrsta po plohi*	15.7	15.9	16.2	32.3	33.4	34.0
H' H' min - H' max	1.95 1.77 - 2.35	1.91 1.57 - 2.19	1.52 0.97 - 2.14	2.14 1.78 - 2.40	2.42 1.93 - 2.78	2.36 1.96 - 2.59

DIVERSITY OF SOIL UNIT
RAZNOLIKOST TALNIH JEDINICA

On the mixed moraine on the Pokljuka plateau, heterogeneous soil conditions are typical (Urbančič & Kutnar 1997, 1998). On the research plots on mires and in surrounding spruce forest we detected a relatively large number of different soil units. We defined the following (FAO 1989, WRB 1998) soil groups and units (Table 2): Rendzic Leptosols (LPk), Eutric Cambisols (CMe), Dystric cambisols (CMd), different forms of Podzols (PZ) and Gleysols (GL) and peat (mainly Fibric) Histosols with dystric (HS,d) and eutric (HS,e) properties.

On all sampling spots of plots that are overgrown by dwarf-pine mire community (28 spots) as well by spruce mire community (36 spots) we determined the dystric histosols (Table 2). In many cases the depth of peat soil exceed 2 meters.

Group E consists of various sedge fen vegetation. It is composed of plots which have more oligotrophic character as well as plots with more mesotrophic to eutrophic character. Therefore, both kind of histosols were found in the group E. Eutric histosols are dominant soils at the edge of fens (group F). Due to influence of lower ground-water table level, gleysols are presented in this group too.

The different forms of podzols predominate in group C (Table 2). Plots of this group are covered by the spruce forest with some rare moss and herb species. Podzols were found in only one fifth of all soil samples of group D. The spruce forest with richer species composition covers very heterogeneous soils on the mixed moraine. Besides podzols we sampled also rendzic leptosols and eutric cambisols. Due to level of some plots that are below the level of neighbouring mire the predominate soil unit of group D are gleysols (GL).

Table 2. Shares of soil units in vegetation groups
Tablica 2. Udjeli talnih jedinica po vegetacijskim grupama

group / *grupa*	A	B	C	D	E	F
N of plots / *broj ploha*	7	9	9	6	7	4
N of tested spots / *broj testiranih mjesta*	28	36	36	24	28	16
soil unit designation / *oznaka talne jedinice*	share (%) / *udjel (%)*					
LPk	/	/	/	13	/	/
Cme	/	/	/	29	/	/
CMd	/	/	11	/	/	/
PZ	/	/	83	21	/	/
GL	/	/	/	33	/	19
HS,d	100	100	6	4	47	/
HS,e	/	/	/	/	53	81
SUM	100	100	100	100	100	100

On the plots we detected up to 28 lower pedosystematic units. On almost half of all sounded corners of the plots we determined the dystric histosols. On more than a fifth of the corners there were different forms of podzols. Among the soil units, eutric histosols are also common, they appear only on the plots of groups E and F.

On almost one quarter of the plots we found two or even three different soil unit per plot. And on more than half of the plots we found two, three or even four different lower pedosystematic units.

CHEMICAL SOIL CONDITIONS
KEMIJSKE ZNAČAJKE TALA

It is characteristic of plots overgrown by the sedge fen vegetation (groups E and F) that they have relatively high average pH (H_2O) values (above 5.5) in the upper (0-10cm) and lower (10-30cm) soil layers. But peat soils of groups A and B have, on average, very low pH (H_2O) values (less than 4) in both soil layers (Table 3).

Organic substances are being accumulated in the peat soil, and for this reason we found large quantities of total carbon in the mire groups A, B, E and in the transitional group F. The peat-bog soil has significantly higher C/N ratio than the peat soil of sedge fens (Updegraff at al. 1995, Grosse-Brauckmann 1996). The highest C/N ratio of the soil is in dwarf-pine mire group (in the upper soil layer the ratio is 40, in the lower soil layer it is 34). There is also a relatively high C/N ratio in spruce-mire group (30 in the upper layer, 24 in the lower).

Both groups of sedge fens have a large amount of exchangeable calcium (Ca^{2+}) in the soil. But groups A, B and C have relatively small amounts of exchangeable calcium in the soil.

The largest amount of exchangeable aluminium (Al^{3+}) is in the soil of group C, and in mire groups A and B there is a lot of aluminium in the lower layer of the soil. These three groups also contain relatively large amounts of exchangeable iron (Fe^{3+}) and hydrogen (H^+) in both soil layers. There is a particularly large amount of exchangeable hydrogen in the *Sphagnum*-peat soil (groups A and B).

The cation exchange capacity (CEC) and the base saturation level (BS) are much higher in groups E and F than in the other groups. The base saturation level is also high in group D.

Table 3. Mean values of soil parameters in groups, in depths 0-10 centimeters and 10-30 centimeters

Tablica 3. Srednje vrijednosti talnih parametra po grupama u dubinama 0-10 centimetara i 10-30 centimetara

parameters *parametri*	units *jedinice*	A		B		C		D		E		F	
		0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm
pH (H_2O)		3.76	3.74	3.62	3.75	3.86	4.34	4.75	5.81	5.55	5.55	6.06	6.44
pH ($CaCl_2$)		3.15	3.13	3.07	3.15	3.11	3.61	4.25	5.30	5.09	5.08	5.70	5.89
$CaCO_3$	g kg^{-1}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.20	4.50	2.50	10.00	8.90
C_{tot}	g kg^{-1}	430.70	440.7	418.1	399.20	155.30	28.10	183.80	75.80	385.00	402.50	344.40	225.60
org. matter	g kg^{-1}	742.60	759.8	720.7	688.20	267.70	48.40	316.80	128.40	662.80	693.40	591.60	387.10
N_{tot}	g kg^{-1}	11.00	13.30	14.50	16.90	6.80	2.10	8.80	4.90	20.50	19.40	16.00	11.20
C/N		39.99	33.76	29.57	23.86	22.07	12.99	20.71	15.38	19.26	21.44	21.40	19.62
Ca^{2+}	cmol(+)/kg	16.47	18.22	14.54	14.29	5.28	0.87	30.14	32.47	78.53	88.90	94.04	79.56
Mg^{2+}	cmol(+)/kg	4.74	2.99	3.25	1.77	1.03	0.15	2.46	1.06	3.21	1.80	5.24	2.24
K^+	cmol(+)/kg	1.54	0.65	1.69	0.53	0.57	0.10	0.51	0.12	1.43	0.20	1.58	0.12
Al^{3+}	cmol(+)/kg	3.78	6.36	4.82	7.62	8.66	8.65	2.91	2.07	0.86	0.80	0.00	0.24
Fe^{3+}	cmol(+)/kg	2.45	2.29	2.23	1.11	2.20	0.93	0.83	0.16	0.08	0.07	0.02	0.01
Mn^{2+}	cmol(+)/kg	0.02	0.01	0.02	0.02	0.01	0.01	0.06	0.02	0.10	0.02	0.04	0.00
H^+	cmol(+)/kg	32.12	28.22	30.89	23.02	18.58	3.57	4.83	0.70	0.87	0.65	0.03	0.00
CEC	cmol(+)/kg	61.12	58.73	57.44	48.36	36.33	14.28	41.74	36.60	85.08	92.44	100.94	82.16
BS	%	38.3	37.8	34.6	34.7	18.7	7.7	74.8	81.8	97.2	98.0	99.9	99.7

In forested wetland the number of species is strongly correlated to the pH-calcium gradient (Jeglum & He 1995). The species richness of the Pokljuka mires and surrounding spruce forest correlates significantly with following soil parameter at the depth 0-10 centimeters: pH_{H2O} (r_S = 0.72***), Ca^{2+} (r_S = 0.66***), Mn^{2+} (r_S = 0.69***). The significant correlation is also between species number per plot and base saturation level (r_S = 0.75***). In general, plots that are overgrown with large number of different plant species, have low Al^{3+}, Fe^{3+} and H^+ soil contents. The species number per plot correlates negatively with Al^{3+} (r_S = -0.71***), Fe^{3+} (r_S = -0.71***), and H^+ (r_S = -0.74***) content.

Furthermore, the Shannon index correlates with pH_{H2O} (r_S = 0.58***), total N amount (r_S = 0.61***), Ca^{2+} (r_S = 0.73***), Mn^{2+} (r_S = 0.71***) content, and base saturation level (r_S = 0.75***). There are significant negative correlation between Shannon index and Al^{3+} (r_S = -0.78***), Fe^{3+} (r_S = -0.53***), and H^+ (r_S = -0.56***). Correlation between species richness (N of species) and Shannon index is 0.81***.

CONCLUSIONS
ZAKLJUČCI

- On the Pokljuka plateau in Slovenia, the different types of mires could be found. In addition to some raised bogs which have more ombrotrophic character, there are also fens with mesotrophic to eutrophic character. The spruce mires could be classified as transitional bogs. Floristic elements of the spruce mires are more oligotrophic to mesotrophic.
- Due to different ecological influences on the border zone between mire and surrounding spruce forest, variety of plant species can be found. The diversity of plant and soil conditions is characteristic of the transition mire-forest zone.
- The factors which accelerate the plant diversity on the mires and in surrounding spruce forest are high soil pH value, high exchangeable Ca^{2+} content and high base saturation level. The species richness is higher at low content of soil acid cations (Al^{3+}, Fe^{3+} and H^+).
- Pokljuka mires belong to the southernmost *Sphagnum*-peat mires in Europe. Because of their location at the edge of their natural range these peat mires are especially endangered, and they are of the greatest significance.

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TALNA I BILJNA RAZNOLIKOST U PRIJELAZNOM POJASU IZMEĐU BARE I ŠUME NA POKLJUŠKOJ VISORAVNI

SAŽETAK

S obzirom na njihovu raznolikost posebno nas zanimaju staništa graničnoga područja između različitih ekoloških utjecaja. Da bismo provjerili tu činjenicu, istraživali smo raznolikost tla i vegetacije u prijelaznom pojasu između bare (creta) i okolne smrekove šume na Pokljuki u Julijskim Alpama u Sloveniji (nadmorska visina oko 1200 metara). U šest bara i na njihovim rubovima odabrali smo 42 pokusne plohe površine 2 × 4 metra.

U istraživanim prijelaznim pojasima karakteristična je raznolikost pedoloških prilika. Na 168 uglova pokusnih ploha bili su pronađeni brojni tipovi tla: rendzina, eutrično smeđe tlo, distrično smeđe tlo, smeđe podzolasto tlo, podzol, močvarno-glejna tla i tresetna tla. Na pokusnim plohama utvrdili smo 28 podtipova, varijeteta i formi tla.

Distrična tresetna tla su pronađena na gotovo polovini svih uglova ploha. Podzoli su utvrđeni na više od petine uglova. Eutrična tresetna tla su također česta.

Na gotovo četvrtini ploha pronađena su dva ili čak tri različita tipa tla. Na više od polovine ploha utvrđene su dvije, tri ili čak četiri različite niže pedosistematske jedinice.

Općenito, distrična tresetna tla obrasla su dvjema različitim barskim asocijacijama vrsta iz roda *Sphagnum*: asocijacija planinskoga bora (*Pinus mugo*) te smrekova asocijacija (*Picea abies*). U prosjeku taj tip tla ima pH_{H2O} vrijednosti ispod 4,0, visok sadržaj ukupnoga ugljika (iznad 40 %) i visok omjer C/N (oko 30).

Eutrična tresetna tla su karakteristična za staništa obrasla močvarnom vegetacijom s prevlašću vrsta iz roda *Carex*. Imaju pH_{H2O} vrijednosti oko 5,5, visok sadržaj izmjenjivoga kalcija (oko 80 cmol(+)/kg tla) i vrlo visoku zasićenost izmjenjivim bazama (oko 95 %).

Na automorfnom tlu na mješovitim morenama pronađena su dva tipa šumskih smrekovih zajednica. Karakteristični tip tla za smrekovu zajednicu s manje različitih biljnih vrsta i prevlašću acidofilnih, piceetalnih elemenata su podzoli. Podzoli imaju relativno niske vrijednosti pH_{H2O} (ispod 4,5) i visok sadržaj izmjenljivoga aluminija (oko 8 cmol(+)/kg).

U drugom tipu smrekove šumske zajednice, koja uključuje mnogo više različitih biljnih vrsta, utvrdili smo vrlo različite pedološke uvjete. Tla u tim staništima imaju u prosjeku puno više pH_{H2O} vrijednosti, viši sadržaj kalcija i visoku zasićenost izmjenjivim bazama.

Proučavane bare (cretovi) na Pokljuškoj visoravni svrstavaju se među najjužnije sfagnumske bare u Europi. Zbog činjenice da se nalaze praktično na granici prirodnoga areala sfagnumskih bara dosta su ugrožene te zbog toga imaju posebno značenje.

Ključne riječi: automorfna tla, hidromorfna tla, morena, vegetacija, bara, smrekova šuma, Pokljuška visoravan, Slovenija

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PRIMJERI NAVOĐENJA LITERATURE:

Članak iz časopisa

Arrouays, D., & P. Pelissier, 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.

Članak iz zbornika

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

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

Knjiga

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

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

Poglavlje iz knjige, monografije, enciklopedije

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

Mayer, B., 1996: Hidrološka problematika osobito s gledišta površinskog dijela krovine. In: D. Klepac (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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Lammi, J. O., 1994: Professional ethics in forestry. In: Irland L. C. (ed.), Ethics in forestry, Timber press, Portland, pp. 49–58.

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