UDK 630 ISBN 0352-3861
GLAS. ŠUM. POKUSE Vol. 43 Str. 1–93 Zagreb, 2009–2010.

Glasnik za šumske pokuse

Annales Experimentis Silvarum Culturae Provehendis

MEĐUNARODNA GODINA ŠUMA · 2011

SVEUČILIŠTE U ZAGREBU
ŠUMARSKI FAKULTET
UNIVERSITAS STUDIORUM ZAGRABIENSIS
FACULTAS FORESTALIS

ANNALES

EXPERIMENTIS SILVARUM CULTURAE PROVEHENDIS

Volumen 43

UNIVERSITAS STUDIORUM ZAGRABIENSIS

FACULTAS FORESTALIS

ZAGREB MMIX - MMX

GLAS. ŠUM. POKUSE Vol. 43 Str. 1–93 Zagreb, 2009 –10.

GLASNIK

ZA ŠUMSKE POKUSE

Knjiga 43

SVEUČILIŠTE U ZAGREBU

ŠUMARSKI FAKULTET

ZAGREB, 2009-2010.

Publisher / *Izdavač*
Faculty of Forestry, University of Zagreb
Šumarski fakultet Sveučilišta u Zagrebu
p. p. 422
HR – 10002 Zagreb

Editor-in-chief / *Glavni urednik*
Darko Bakšić

Technical editor / *Tehnički urednik*
Stjepan Mikac

Secretary / *Tajnik uredništva*
Damir Ugarković

Associate / *Tehnički suradnici*
Ivan Perković
Damir Drvodelić
Irena Šapić
Nera Marković
Vinko Paulić
Sonja Kuzmanić

Glasnik za šumske pokuse je međunarodni znanstveni časopis u kojem se objavljuju izvorni znanstveni članci, pregledni članci, prethodna priopćenja, izlaganja sa znanstvenih skupova i stručni članci. Časopis obuhvaća sve aspekte istraživanja u šumarstvu, urbanom šumarstvu, zaštiti prirode i okoliša te primijenjenoj ekologiji. Svaki članak podliježe znanstvenoj/stručnoj recenziji najmanje dvaju recenzenata.

Glasnik za šumske pokuse is an international scientific journal where original scientific articles, reviews, preliminary communication, scientific papers and professional articles are published. The journal encompasses all the aspects of research in forestry, urban forestry, environmental protection and applied ecology. Every article is reviewed by at least two scientific critics.

Tisak
Printed by
Denona d.o.o., Zagreb

GLAS. ŠUM. POKUSE Vol. 43 Str. 1–93 Zagreb, 2009 –10.

CONTENTS
SADRŽAJ

UDK: 630*114.242

Original scientific paper
Izvorni znanstveni članak

ADSORPTION COMPLEX OF SOILS ON NON-CARBONATE SUBSTRATE IN FIR AND BEECH-FIR FORESTS OF CROATIA

ADSORPCIJSKI KOMPLEKS TLA NA NEKARBONATNIM SUPSTRATIMA U JELOVIM I BUKOVO-JELOVIM SASTOJINAMA HRVATSKE

DARKO BAKŠIĆ, NIKOLA PERNAR, IVAN PERKOVIĆ

University of Zagreb, Faculty of Forestry, Department of Forest Ecology and Silviculture

Received – *prispjelo*: 1.2.2010.

Accepted – *prihvaćeno*: 9.3.2010.

Abstract

The goal of research was to determine the soil adsorption complex properties on the non-carbonate parent substrate in fir and beech-fir forests with regard to the content and relationship of exchangeable base and acid cations. The obtained results were used to establish differences in the adsorption complex in terms of locality and phytocoenosis. The adsorption complex of soils on non-carbonate substrate that mostly gives detritus poor in basic cations is researched. Mentioned main substrate, naturally acid soil and prehumid and humid climate conditions, especially in Gorski Kotar, cause leaching of basic cations from the soil. Degradation processes in dystric cambisol, brunipodzol and podzol lead towards acidification, leaching of basic cations, i.e. nutrients and destruction of clay minerals, thus worsening buffer and physical soil properties. Researches were made in Panonic Croatia region in Forestry Districts of Voćin, Kamenska, Krapina, Zagreb and Faculty's forests on Medvednica, and in Gorski Kotar region in Forestry Districts and Faculty's facilities: Vrbovsko, NPŠO Zalesina, Delnice, Fužine, Lokve, Crni Lug and Tršće.

Selection of the forest stands, in which pedological profiles were open, was based on geological, pedological and vegetation maps, considering main substrate, soil type and phytocoenosis. Pedological researches in the field were done between 8 September and 14 October 1999 and between 5 May and 16 September 2000. Three types of soil were analysed: dystric cambisol (47 profiles), brunipodzol (19 profiles) and podzol (16 profiles). Laboratory analysis of air dry soil samples determined soil texture, soil pH, organic carbon contents, total nitrogen contents, exchangeable acidity and exchangeable cations.

Collected data were processed by statistical methods in Statistica 6.0 program package.
According to the contents of particular cations, especially Al^{3+} and H^+, as well as according to the capacity of exchangeable cations two groups related to geographical area were diferentiated: Panonic Croatia and Gorski Kotar. Generally, one can say that all soils of researched sites have high to very high contents of acid exchangeable cations, with medium to low contents of basic exchangeable cations, and medium to low base saturation of adsorption complex. Cation exchange capacity is medium to high and considerable positive correlation is determined with the contents of clay texture fraction.

It should be pointed out that the analyses gave very high contents of Al^{3+} and H^+ ions in adsorption complex of soil at all sites in Gorski Kotar, as well as high contents of Al^{3+} and H^+ ions in Panonic Croatia. This result is disturbing since numerous authors speak in their researches of toxic effects of Al^{3+} and H^+ to plants, and of their antagonistic effect to accepting calcium, magnesium and phosphorus.

At all sites, among the base exchangeable cations contents of Mg^{2+} was the lowest, and this contents is considerably lower at Belevine, Crni Lug and Tršće site.

The most unfavourable rate of acid and basic cations, and the minimal base saturation of the adsorption complex among the sites in Panonic Croatia is found on Medvednica, while such sites in Gorski Kotar are Belevine, Crni Lug and Tršće.

On basis of given results, the sensitivity of researched soils to acidification could be rated as medium to high, and Gorski Kotar region is more sensitive than Panonic Croatia.

Key words: adsorption complex, buffer potential, cation exchange capacity, dystric cambisol, brunipodzol, podzol, fir forests, beech-fir forests

Sažetak

U radu je istraživan adsorpcijski kompleks tla na nekarbonatnom matičnom supstratu koji uglavnom daje bazama siromašan detritus. Navedeni matični supstrat, prirodno kiselo tlo i uvjeti perhumidne i humidne klime, posebice u Gorskom kotaru, uvjetuju ispiranje baza iz tla. Procesi degradacije kod distričnog kambisola, brunipodzola i podzola idu u smjeru acidifikacije, ispiranja baza, odnosno hraniva i destrukcije minerala gline čime se pogoršavaju puferna i fizikalna svojstva tla.

Istraživanja su obavljena na području panonske Hrvatske u šumarijama Voćin, Kamenska, Krapina, Zagreb i u Fakultetskim šumama na Medvednici, te na području Gorskog kotara u šumarijama i fakultetskim objektima: Vrbovsko, NPŠO Zalesina, Delnice, Fužine, Lokve, Crni Lug i Tršće.

Odabir primjernih objekata šumskih sastojina u kojima su otvoreni pedološki profili napravljen je na temelju geoloških, pedoloških i vegetacijskih karata pri čemu se vodilo računa o matičnom supstratu, tipu tla i fitocenozama. Terenska pedološka istraživanja obavljena su u razdoblju od 08. rujna do 14. listopada 1999. godine i od 05. svibnja do 16. rujna 2000. godine. Obrađena su tri tipa tla: distrični kambisol (47 profila), brunipodzol (19 profila) i podzol (16 profila). Laboratorijskim analizama na zrakosuhim uzorcima tla (sitnica tla) određen je mehanički sastav, reakcija tla, sadržaj humusa, sadržaj ukupnog dušika, izmjenjiva kiselost i izmjenjivi kationi.

Prikupljeni podaci obrađeni su statističkim metodama u programskom paketu Statistica 6.0. Prema sadržaju pojedinih kationa, posebno Al^{3+} i H^+, kao i prema kapacitetu izmjenjivih kationa izdiferencirale su se dvije grupe koje se slažu s geografskim položajem: panonska Hrvatska i Gorski kotar.

Općenito se može reći da sva tla istraživanih lokaliteta imaju visok do vrlo visok sadržaj kiselih kationa, uz osrednji do nizak sadržaj bazičnih kationa, te osrednju do nisku zasićenost adsorpcijskog kompleksa bazičnim kationima. Kapacitet izmjenjivih kationa je osrednji do visok, a značajna pozitivna korelacija utvrđena je sa sadržajem glinene teksturne frakcije.

Treba istaknuti da je analizama utvrđen vrlo visoki sadržaj Al^{3+} i H^+ iona u adsorpcijskom kompleksu tla na svim lokalitetima Gorskog kotara, kao i visoki sadržaj Al^{3+} i H^+ iona u panonskoj Hrvatskoj. Ovaj podatak je zabrinjavajući jer brojni autori u svojim istraživanjima govore o toksičnom utjecaju Al^{3+} i H^+ na biljke, kao i o njihovom antagonističkom učinku na primanje kalcija, magnezija i fosfora.

Na svim je lokalitetima zabilježen najmanji sadržaj Mg^{2+} iona među izmjenjivim bazičnim kationima adsorpcijskog kompleksa, a taj je sadržaj značajno manji za lokalitete Belevine, Crni Lug i Tršće.

Najnepovoljniji postotni udio kiselih i bazičnih kationa, te najmanju zasićenost adsorpcijskog kompleksa bazama od lokaliteta panonske Hrvatske ima Medvednica, dok su za Gorski kotar to Belevine, Crni Lug i Tršće.

Na osnovi dobivenih podataka osjetljivost istraživanih tala prema acidifikaciji može se ocjeniti kao osrednja do visoka s time da je područje Gorskog kotara osjetljivije od panonske Hrvatske.

Ključne riječi: adsorpcijski kompleks, puferni potencijal, kapacitet izmjenjivih kationa, distrični kambisol, brunipodzol, podzol, jelove sastojine, bukovo-jelove sastojine

INTRODUCTION
UVOD

Adsorption is one of the most important physical-chemical processes in the soil. It determines the quantity of plant nutrients, pesticides and other compounds that are bound to the surface of soil particles. For this reason, it is one of the primary processes that play an important role in nutrient transport and soil contamination (Stumm 1996).

Martinović (2003) states that soils with different adsorption complexes represent ecologically highly diverse sites and substrates. This is the reason that the condition of the adsorption complex is an excellent indicator of all kinds of processes, and particularly of degradation changes in the soil.

The condition of the adsorption complex in a soil supplies information on soil quality. According to (Gračanin and Ilijanić. 1977), in relation to the capacity extent, as well as the saturation degree and manner, the soil adsorption complex may have a decisive effect on a multitude of physical, chemical and biological properties, in other words, on soil fertility.

Of physical properties, the adsorption complex significantly affects the soil structure (Weerd at al. 1999). Soils in which the adsorption complex is saturated with calcium show considerably higher stability, a more favourable structural composition and better physiological features than soils in which the adsorption complex is saturated with Na^+ or H^+ ions (Gračanin 1947).

Cation adsorption has primary importance for plant nutrition. Cations bound to colloidal soil particles represent reserves of plant nutrients (Ca^{2+}, Mg^{2+}, Na^+, K^+, NH^{4+}). This is how soil resists the processes of nutrient leaching via descendent watercourses and retains nutrients in the rhizospheric zone (Steven 1994).

The effect of the adsorption complex on the buffer capacity is important, especially in the current conditions of adverse impacts of anthropogenically-induced soil acidification (Müchenhausen 1975, Ulrich 1982, Alekseev 1990, Glavač 1999). By buffering (neutralizing) acid depositions that reach the soil, stresses on the vegetation, as well as the soil flora and fauna are somewhat lessened.

While acknowledging the synergistic action of adverse factors, a number of authors regard forest soil acidification as the most responsible factor of forest decline in many regions of Europe (Ulrich et al. 1979, Hutchinson et al. 1986, Tamm and Hallbäcken 1986, Urlich 1991, Mayer 1998). Acidification is related to lowered pH values, decreased saturation of the adsorption complex with base cations, and increased Al^{3+} ion concentrations in the soil solution.

The adsorption complex content indicates dominant pedogenetic processes in the soil. For example, if the adsorption complex is saturated with acid cations, such as H^+, Al^{3+}, Fe^{2+} and Mn^{2+}, then the dominant processes in the soil are acidification and eluviation (podzolization).

From the standpoint of plant physiology, Al^{3+} and H^+ ions are definitely the most important. Many experiments have proved the toxic effects of Al^{3+} and H^+ ions on root growth and the antagonistic effects on cation reception (Matsumoto et al. 1976, Foy et al. 1978, Hecht-Buchholz and Foy 1981, Foy 1983, Schier 1985, Sivaguru at al. 2003 and others). Aluminium creates the gravest problems in phosphorus, calcium and magnesium reception. For this reason, the external manifestation of aluminium toxicity generally resembles the signs that characterise lack of phosphorus in nutrition (increased antocian biosynthesis) (Foy 1984).

This paper explores the soil adsorption complex on non-carbonate substrates in fir and beech-fir stands in Croatia. These stands in Pannonian Croatia cover an area of approximately 14,000 ha (Medvedović 1990). In the area of Delnice, these stands cover 6,489 ha (Management Plan of Delnice Forest Office).

The decomposition of non-carbonate parent substrates, particularly those rich in quartz and acid plagioclases, results in the predominantly sandy textures that are naturally poor in bases. In such substrates in the area of perhumid and humid climates, descendent flows are distinct. This allows the base reserves bound to the adsorption complex to leach easily, thus decreasing the soil buffer capacity against acidification. High saturation with acid cations that have a toxic effect on the roots and an antagonistic effect on the base cation reception (especially Ca^{2+} and Mg^{2+}), combined with low pH value, may represent an important negative feature in fir stands exposed to a synergistic action of adverse impacts of biotic (insects, mistletoe) and abiotic (climatic extremes, aerial pollution) factors.

The goal of research was to determine the soil adsorption complex properties on the non-carbonate parent substrate in fir and beech-fir forests with regard to the content and relationship of exchangeable base and acid cations. The obtained results were used to establish differences in the adsorption complex in terms of locality and phytocoenosis. Categories of susceptibility to acidification will be identified for the studied localities.

METHODOLOGY
METODE ISTRAŽIVANJA

Research sites
Područje istraživanja

Field pedological research was conducted in the soils developed on the non-carbonate parent substrate in the range of fir and beech-fir stands in Gorski Kotar and Pannonian Croatia.

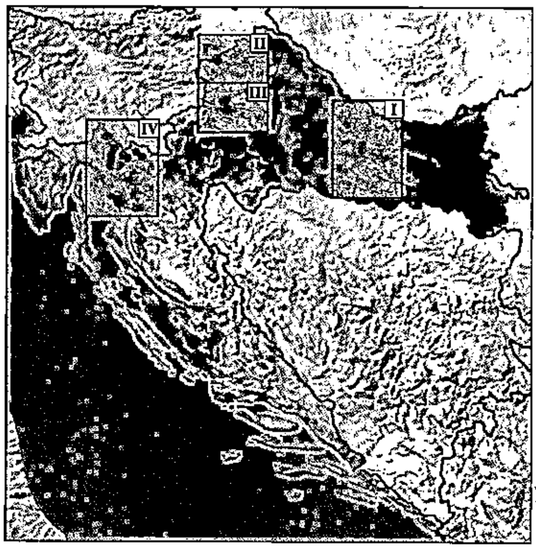


Figure 1 Research area –circles show management units in which pedological sampling was conducted
Slika 1 Područje istraživanja –krugovi prikazuju gospodarske jedinice u kojima je napravljeno pedološko uzorkovanje

Selection of sample facilities
Izbor primjernih objekata

The localities were selected on the basis of the basic pedological maps M 1:50,000 and their supplements and the detailed pedological maps made during typological forest research. These were compared with the basic geological and vegetation maps. The following criteria were followed:

a) Parent substrate: non-carbonate substrate rich in quartz and acid plagioclases conditions the development of acid soils poor in bases;
b) Soil acidity as a factor which significantly affects the adsorption complex condition: the most represented acid soils were selected: dystric cambisol, brunipodzol and podzol, while the less common soils, such as ranker, luvisol and colluvium, were excluded;
c) Climatic conditions: perhumid and humid climate also favours the genesis of acid soils;
d) Phytocoenosis: in the area of Gorski Kotar and a part of Macelj, an edaphically conditioned acidophylic association of fir with hard fern (*Blechno-abietetum*) was selected, while a typical subassociation of Pannonian beech-fir forest (*Abieti-fagetum "panonicum" typicum*), occurring on the silicate base of Macelj, Medvednica and Papuk, was selected in the remaining part of the mountains in Pannonian Croatia (Medvedović 1990).

Field research
Terenska istraživanja

Based on the knowledge of pedological parameter variability, the following conditions were set down in order to determine the positions of pedological profiles (Pernar 1996):

a) Homogeneity of the geological-lithological substrate on the basis of pedological and geological maps and field observations;
b) Undisturbed micro-relief – any possible excessive pedoturbations in the past caused by natural processes or by anthropogenic actions were excluded;
c) Extreme positions in the mezorelief – tops and stem bases – were excluded;
d) Completely closed stand canopy;
e) Sampling away from the root collar – in the outer third of crown projections of the dominant trees.

Individual samples from pedological profiles were taken by genetic horizons. The position, as well as the bioclimatic and geomorphologic parameters were determined for each profil.

The paper treats three soil types in 11 localities (Table 1): dystric cambisol – 47 profiles, brunipodzol – 19 profiles and podzol – 16 profiles. The field part of the research was conducted during 1999 and 2000.

Table 1 Number of opened pedological profiles by locality and soil type
Tablica 1 Broj otvorenih pedoloških profila po lokalitetu i tipu tla

Locality *Lokalitet*	Soil type			Number of soil profiles *Broj otvorenih pedoloških profila*
	Dystric cambisol *Distrični kambisol (DS)*	Podzol *Podzol (P)*	Brunipodzol *Brunipodzol (BP)*	
Papuk	9	0	1	10
Macelj	4	0	0	4
Medvednica	6	0	0	6
Vrbovsko	4	1	5	10
Belevine	3	5	2	10
Sungerski lug	0	1	2	3
Delnice	7	1	1	9
Fužine	5	2	3	10
Lokve	1	1	0	2
Crni Lug	5	3	0	8
Tršće	3	2	5	10
Number of soil profiles *Br. otvorenih pedoloških profila*	47	16	19	82

Laboratory analyses
Laboratorijske analize

The analyses involved air-dried soil samples, which were dried, ground and sieved through 2 mm - 0.2 mm sieves in the laboratory.

Laboratory soil analyses were conducted with the following procedures:

a) The mechanical soil composition, was determined with the pipette method after the extraction in 0.1 M $Na_4P_2O_7$;

b) The soil reaction was measured electrometrically using a combined method in the soil water suspension, that is, in 0.01 M $CaCl_2$, with 1:2,5 ratio for surface mineral and argic horizons, and with 1:10 ratio for distinctly humose surface horizons. The laboratory microprocessor pH meter MA 5736, made by Metrel, with an accuracy of ± 0,01 pH was used for measurements;
c) The humus content was determined with the bichromatic method by Tjurin;
d) The total nitrogen content was determined with the combustion method according to the Kjeldahl procedure and distillation according to Bremner at al. (1982);
e) Exchangeable acidity (H^+ i Al^{3+}) was determined with the KCl method according to Thomas G.W. (1982).

Exchange cations were determined according to Thomas G. W. (modified) by the extraction with 0.1 M $BaCl_2$. The K^+ and Na^+ in the extraction were determined flame-photometrically, and Ca^{2+}, Mg^{2+}, Fe^{2+} and Mn^{2+} were read on the atomic absorption spectrophotometer PU 9100X. Laboratory analyses were performed in the pedological laboratory of the Faculty of Forestry, University of Zagreb, and to a smaller extent in the Institute of Plant Nutrition of the Faculty of Agronomy, University of Zagreb.

Statistical data processing
Statistička obrada podataka

For purposes of data comparison, pedogenetic horizons were grouped according to depth into the mineral (humus-accumulative Aoh, Aum, A/E and eluvial E) and the argic horizon (cambic (B)v and illuvial Bs) (Vanmechelen et al. 1997). Luvisol was excluded from the analysis due to the small sample. Descriptive statistics was made for all analyzed variables: arithmetic mean, standard deviation, minimum, median, and maximum. The significance level of 5% in all the tests was considered statistically significant. Mutual correlations were made and tested for all the pedological parameters by soil type. Mutual differences for surface mineral and argic horizons among different soil types, as well as different localities were tested with an analysis of variance, on condition that variance homogeneity was satisfied (Bartlett). For variables that did not satisfy variable homogeneity, a nonparametric Kruskal – Wallis test was done (Conover 1980). If the variance analysis showed a statistically significant difference between the horizons, a multiple post hoc test (Duncan) was used to find out which horizons were responsible for the difference. Mutual differences for the horizons of dystric cambisol per phytocoenoses were tested with a t-test provided that variance homogeneity was satisfied (F-test), or with a nonparametric Mann-Whitney U test if variance homogeneity was not satisfied (Sokal and Rohlf 1995). All statistical analyses were performed in the Statistica 6.0 programme package.

RESEARCH RESULTS AND DISCUSSION
REZULTATI ISTRAŽIVANJA I RASPRAVA

Features of the adsorption complex and other pedological parameters per studied localities
Značajke adsorpcijskog kompleksa i ostalih pedoloških parametara po tipovima istraživanih tala

The results of laboratory analyses for the surface mineral and argic soil horizons per studied localities are given in Tables 2 and 3. The differences in the soil adsorption complex content between the investigated localities were best shown with statistical analyses. They cannot be presented in this paper[3] in their full scope for reasons of their size.

[3] Please contact the authors of the articles for any details related to statistical analyses.

Two groups that correspond to a geographical position have been differentiated according to the individual cation content, especially Al^{3+} and H^{+}, and according to the cation exchange capacity. These groups are Pannonian Croatia and Gorski Kotar. In all the localities in Gorski Kotar, except for Sungerski Lug, the content of changeable Al^{3+} and H^{+} in the soil is considerably higher. As an illustration, (Fig 2), the Al^{3+} content in the adsorption soil complex in the surface mineral and in the argic horizon was chosen because the differences are the most distinct.

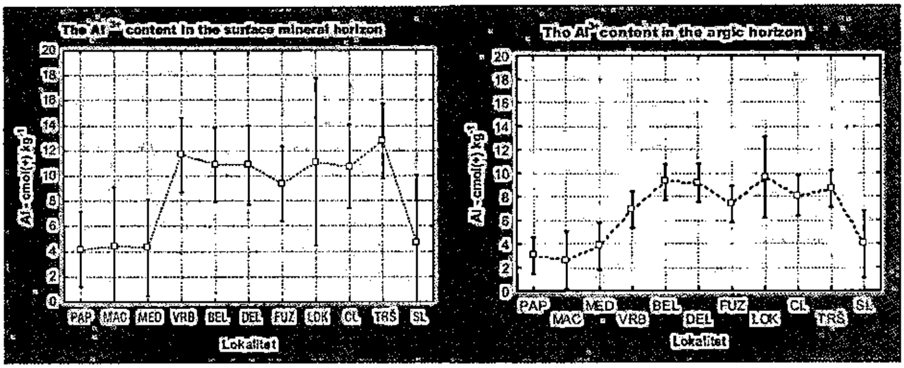


Figure 2 The Al^{3+}content in the adsorption soil complex in the surface mineral horizon and in the argic horizon of the investigated localities.
Slika 2 Sadržaj Al^{3+} u adsorpcijskom kompoleksu tla u površinskom mineralnom i kambičnom horizontu tla istraživanih lokaliteta.

The reasons should be sought in more intensive processes of eluvial-iluvial migration caused by higher precipitation quantities, which results in basic cation leaching, as well as in immission acidification that additionally burdens the adsorption soil complex. Vukadinović and Lončarić (1998) state that calcium from acid soils is leached when precipitation quantities exceed 600 – 700 mm/year. In all the studied localities, the precipitation quantity is higher than the above and reaches over 2,000 mm/year for Gorski Kotar.

The natural acidification processes, especially in the studied soils – dystric cambisol, brunipodzol and podzol – are intensified with immission acidification. This leads to the impoverishment of the adsorption complex with basic cations and consequently to a decreased buffer potential. A higher content of acid cations, primarily Al^{3+} and H^{+}, in the area of Gorski Kotar, is additionally increased by immission-induced acidification. The fact that immission acidification is the highest in Gorski Kotar, a topic treated by a number of authors (Glavač et al. 1985, Prpić 1987, Komlenović et al. 1988, Komlenović 1989, Bezak et al. 1991, Prpić et al. 1991, Vrbek et al. 1991) coincides with the unfavourable condition of the adsorption complex.

Interestingly, in terms of the adsorption complex the locality of Sungerski Lug, where pedological profiles were opened in brunipodzol and podzol, is grouped with dystric cambisols of the localities Papuk, Macelj and Medvednica. Since Sungerski Lug is situated in equal climatic and vegetational conditions as the other localities of Gorski Kotar, it can be assumed that the parent substrate has significantly affected the condition of the soil adsorption complex. The geological substrate in the area of Sungerski Lug is made up of proluvial-coluvial sediments that are in contact with the limestone dolomite substrate, which is responsible for the specific pedogenesis of these soils. More detailed pedological research in the area of Sungerski Lug should definitely be undertaken.

Table 2[1] Measures of central tendency and variability of the investigated pedological variables for the surface mineral soil horizons per studied localities.
Tablica 2. Mjere centralne tendencije i varijabiliteta istraživanih pedoloških varijabli za površinske mineralne horizonte tala po istraživanim lokalitetima.

Variable / *Varijabla*	Units / *Mjerne jedinice*	Papuk - PAP			Macelj - MAC			Medvednica - MED			Vrbovsko - VRB			Belevine - BEL			Sungerski lug - SL		
		N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.
Inclination / *Nagib*	°	10	24	8,80	4	35	5,25	6	20	3,63	10	17	8,13	10	11	6,45	3	2	2,00
Thickness / *Debljina*	cm	10	7	3,01	4	8	1,63	6	10	1,51	10	6	5,15	10	6	4,06	3	5	1,53
Particle size distribution / *Tekstura*: 2,0 - 0,2 mm	mas. %	10	29,0	10,22	4	16,3	12,42	6	19,4	9,07	10	7,6	7,42	10	18,4	9,98	3	21,7	18,85
Particle size distribution / *Tekstura*: 0,2 -0,02 mm	mas. %	10	42,8	8,18	4	57,1	13,08	6	37,7	8,13	10	49,6	5,44	10	43,3	8,99	3	31,4	13,95
Particle size distribution / *Tekstura*: 0,02 - 0,002 mm	mas. %	10	19,4	6,11	4	16,1	1,27	6	28,3	4,66	10	26,8	5,53	10	25,9	7,25	3	35,1	5,94
Particle size distribution / *Tekstura*: <0,002 mm	mas. %	10	8,8	1,87	4	10,4	1,83	6	14,6	2,29	10	16,1	4,44	10	12,4	4,69	3	11,8	4,42
pH H_2O	-	10	4,44	0,27	4	4,02	0,45	6	4,31	0,15	10	4,10	0,28	10	3,95	0,20	3	4,12	0,14
pH $CaCl_2$	-	10	3,86	0,24	4	3,41	0,36	6	3,74	0,14	10	3,58	0,29	10	3,32	0,11	3	3,40	0,08
Org C	g kg^{-1}	10	56,4	19,16	4	106,0	55,20	6	106,3	24,98	10	54,1	43,12	10	67,4	63,07	3	30,9	23,79
N tot.	g kg^{-1}	10	3,7	0,92	4	8,0	2,65	6	6,6	3,14	10	4,4	2,41	10	3,8	3,99	3	1,6	1,10
C/N	-	10	15	2,18	4	13	3,75	6	19	9,10	10	12	2,65	10	18	8,39	3	22	11,25
Soil adsorption complex / *Adsorpcijski kompleks tla*: Ca	cmol(+) kg^{-1}	10	0,87	0,79	4	2,71	0,27	6	1,08	0,86	10	0,53	0,81	10	1,42	1,64	3	0,12	0,02
Soil adsorption complex / *Adsorpcijski kompleks tla*: Mg	cmol(+) kg^{-1}	10	0,30	0,08	4	0,05	0,00	6	0,05	0,01	10	0,18	0,11	10	0,03	0,02	3	0,01	0,00
Soil adsorption complex / *Adsorpcijski kompleks tla*: Na	cmol(+) kg^{-1}	10	0,32	0,02	4	0,53	0,06	6	0,37	0,07	10	0,34	0,02	10	0,48	0,13	3	0,48	0,04
Soil adsorption complex / *Adsorpcijski kompleks tla*: K	cmol(+) kg^{-1}	10	0,79	0,15	4	1,20	0,40	6	0,89	0,08	10	0,68	0,09	10	0,80	0,29	3	0,69	0,01
Soil adsorption complex / *Adsorpcijski kompleks tla*: Al	cmol(+) kg^{-1}	10	4,19	1,91	4	4,39	2,19	6	4,29	1,23	10	11,68	4,85	10	10,89	3,25	3	4,65	2,14
Soil adsorption complex / *Adsorpcijski kompleks tla*: H	cmol(+) kg^{-1}	10	1,05	0,60	4	2,48	1,41	6	1,77	0,29	10	2,80	1,09	10	3,63	0,72	3	2,00	0,61
Soil adsorption complex / *Adsorpcijski kompleks tla*: Fe	cmol(+) kg^{-1}	10	0,10	0,09	4	0,29	0,24	6	0,13	0,06	10	0,23	0,19	10	0,56	0,31	3	0,36	0,18
Soil adsorption complex / *Adsorpcijski kompleks tla*: Mn	cmol(+) kg^{-1}	10	0,11	0,07	4	0,07	0,04	6	0,31	0,11	10	0,08	0,04	10	0,06	0,02	3	0,04	0,01
Soil adsorption complex / *Adsorpcijski kompleks tla*: BCE	cmol(+) kg^{-1}	10	2,29	0,79	4	4,49	0,62	6	2,39	0,86	10	1,73	0,90	10	2,73	2,00	3	1,29	0,06
Soil adsorption complex / *Adsorpcijski kompleks tla*: ACE	cmol(+) kg^{-1}	10	5,44	2,50	4	7,23	3,55	6	6,50	1,42	10	14,78	5,59	10	15,13	3,63	3	7,05	2,74
Soil adsorption complex / *Adsorpcijski kompleks tla*: CEC	cmol(+) kg^{-1}	10	7,72	2,32	4	11,72	4,09	6	8,89	2,13	10	16,51	5,18	10	17,86	4,10	3	8,35	2,78
Soil adsorption complex / *Adsorpcijski kompleks tla*: Base saturation	%	10	31,8	13,30	4	41,3	12,51	6	26,6	3,99	10	12,3	9,28	10	14,9	9,24	3	16,5	4,64

Variable / *Varijabla*	Units / *Mjerne jedinice*	Delnice - DEL			Fužine - FUŽ			Lokve - LOK			Crni lug - CL			Tršće - TRŠ			Test	F(H)	p
		N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.			
Inclination / *Nagib*	°	9	13	12,07	10	11	8,34	2	15	6,36	8	18,1	6,06	10	14	12,65	ANOVA	4,5318	0,0001
Thickness / *Debljina*	cm	9	3	1,00	10	4	3,00	2	6	0,71	8	6	3,42	10	9	5,57	K-W	29,6921	0,0010
Particle size distribution / *Tekstura*: 2,0 - 0,2 mm	mas. %	9	16,3	11,22	10	22,2	18,32	2	13,4	10,39	8	17,0	17,32	10	18,9	14,75	ANOVA	1,5295	0,1470
Particle size distribution / *Tekstura*: 0,2 -0,02 mm	mas. %	9	45,9	7,82	10	42,4	9,24	2	51,6	3,96	8	40,3	11,50	10	44,6	10,62	ANOVA	2,379	0,0171
Particle size distribution / *Tekstura*: 0,02 - 0,002 mm	mas. %	9	23,3	6,65	10	23,0	6,34	2	23,8	4,88	8	28,1	6,36	10	22,0	8,23	ANOVA	3,0262	0,0030
Particle size distribution / *Tekstura*: <0,002 mm	mas. %	9	14,5	5,94	10	12,4	4,23	2	11,2	1,56	8	14,7	5,99	10	14,5	6,17	K-W	16,9492	0,0755
pH H_2O	-	9	4,07	0,26	10	4,09	0,26	2	4,01	0,05	8	3,96	0,16	10	4,18	0,18	ANOVA	3,25	0,0017
pH $CaCl_2$	-	9	3,46	0,24	10	3,45	0,21	2	3,33	0,02	8	3,28	0,16	10	3,52	0,14	K-W	36,9121	0,0001
Org C	g kg^{-1}	9	100,9	71,70	10	89,6	63,78	2	66,2	42,51	8	106,7	64,91	10	60,7	40,35	K-W	19,892	0,0303
N tot.	g kg^{-1}	9	8,6	7,54	10	6,3	3,04	2	8,3	3,61	8	6,1	3,94	10	4,8	2,33	K-W	23,8874	0,0079
C/N	-	9	13	3,81	10	13	4,93	2	8	1,77	8	18	3,46	10	12	5,07	K-W	23,024	0,0107
Soil adsorption complex / *Adsorpcijski kompleks tla*: Ca	cmol(+) kg^{-1}	9	1,86	1,59	10	1,25	1,30	2	0,35	0,09	8	1,25	0,96	10	0,95	1,13	K-W	21,4283	0,0183
Soil adsorption complex / *Adsorpcijski kompleks tla*: Mg	cmol(+) kg^{-1}	9	0,36	0,13	10	0,25	0,16	2	0,25	0,22	8	0,03	0,02	10	0,09	0,08	K-W	59,663	0,0000
Soil adsorption complex / *Adsorpcijski kompleks tla*: Na	cmol(+) kg^{-1}	9	0,36	0,08	10	0,30	0,11	2	0,37	0,05	8	0,39	0,03	10	0,39	0,11	K-W	34,8863	0,0001
Soil adsorption complex / *Adsorpcijski kompleks tla*: K	cmol(+) kg^{-1}	9	0,88	0,27	10	0,71	0,12	2	0,80	0,28	8	0,65	0,06	10	0,80	0,33	K-W	22,5715	0,0124
Soil adsorption complex / *Adsorpcijski kompleks tla*: Al	cmol(+) kg^{-1}	9	10,86	6,07	10	9,37	5,31	2	11,13	2,58	8	10,76	5,54	10	12,76	7,05	K-W	38,8138	0,0000
Soil adsorption complex / *Adsorpcijski kompleks tla*: H	cmol(+) kg^{-1}	9	2,86	1,00	10	2,63	1,32	2	3,78	0,18	8	3,67	1,70	10	2,84	1,32	K-W	33,5268	0,0002
Soil adsorption complex / *Adsorpcijski kompleks tla*: Fe	cmol(+) kg^{-1}	9	0,38	0,23	10	0,36	0,23	2	0,73	0,40	8	0,33	0,13	10	0,31	0,22	K-W	29,9835	0,0009
Soil adsorption complex / *Adsorpcijski kompleks tla*: Mn	cmol(+) kg^{-1}	9	0,06	0,02	10	0,09	0,13	2	0,04	0,01	8	0,11	0,13	10	0,07	0,02	K-W	25,6662	0,0042
Soil adsorption complex / *Adsorpcijski kompleks tla*: BCE	cmol(+) kg^{-1}	9	3,46	1,91	10	1,52	1,48	2	1,77	0,46	8	2,32	1,03	10	2,24	1,41	K-W	18,6131	0,0455
Soil adsorption complex / *Adsorpcijski kompleks tla*: ACE	cmol(+) kg^{-1}	9	14,17	7,05	10	12,45	6,25	2	15,67	3,15	8	14,87	7,14	10	15,97	8,27	K-W	37,6281	0,0000
Soil adsorption complex / *Adsorpcijski kompleks tla*: CEC	cmol(+) kg^{-1}	9	17,63	6,11	10	14,96	6,00	2	17,44	3,61	8	17,19	7,40	10	18,20	8,22	K-W	34,8927	0,0001
Soil adsorption complex / *Adsorpcijski kompleks tla*: Base saturation	%	9	22,4	14,14	10	19,1	12,50	2	10,1	0,53	8	14,2	5,12	10	14,0	8,99	K-W	29,3675	0,0011

[1] BCE - basic cation exchange; ACE - acid cation exchange; CEC - cation exchange capacity

Table 3 Measures of central tendency and variability of the investigated pedological variables for the agric soil horizons per studied localities.
Tablica 3. Mjere centralne tendencije i varijabiliteta istraživanih pedoloških varijabli za argiloakumulativne horizonte tala po istraživanim lokalitetima.

	Variable *Varijabla*	Units *Mjerne jedinice*	Papuk - PAP			Maceli - MAC			Medvednica - MED			Vrbovsko - VRB			Belevine - BEL			Sungerski lug - SL		
			N	Arit. sr.	St. dev.	N	Arit. sr.	St. dev.	N	Arit. sr.	St. dev.	N	Arit. sr.	St. dev.	N	Arit. sr.	St. dev.	N	Arit. sr.	St. dev.
	Inclination *Nagib*	°	10	24	8,80	4	35	5,25	6	20	3,63	10	17	8,13	10	11	6,45	3	2	2,00
	Thickness *Debljina*	cm	10	70	14,36	4	56	12,87	6	37	9,99	10	67	15,15	10	48	10,54	3	50	8,39
Particle size distribution *Tekstura*	2,0 - 0,2 mm	mas. %	10	34,2	13,70	4	16,4	15,35	6	18,0	6,83	10	10,8	10,39	10	17,9	11,32	3	19,8	17,04
	0,2 -0,02 mm	mas. %	10	31,2	6,72	4	55,6	17,67	6	24,6	6,79	10	40,8	4,54	10	35,3	6,75	3	31,0	17,57
	0,02 - 0,002 mm	mas. %	10	20,8	5,84	4	15,7	4,75	6	37,8	2,29	10	28,1	6,90	10	26,7	7,85	3	31,6	4,39
	<0,002 mm	mas. %	10	13,8	2,60	4	12,4	2,58	6	19,7	3,14	10	20,4	3,74	10	20,0	6,75	3	17,6	1,83
	pH H_2O	-	10	4,84	0,22	4	4,80	0,42	6	4,76	0,24	10	4,42	0,23	10	4,40	0,19	3	4,50	0,09
	pH $CaCl_2$	-	10	4,18	0,12	4	4,19	0,18	6	4,13	0,12	10	4,07	0,12	10	3,82	0,12	3	3,98	0,13
	Org C	g kg^{-1}	10	12,8	5,17	4	13,8	8,66	6	32,6	16,24	10	20,1	5,83	10	23,1	13,09	3	18,0	5,71
	N tot.	g kg^{-1}	10	1,5	0,25	4	3,4	2,08	6	2,3	0,87	10	2,0	0,42	10	1,5	0,76	3	1,3	0,51
	C/N	-	10	8	2,48	4	4	1,09	6	15	6,71	10	10	2,65	10	16	7,44	3	14	5,64
Soil adsorption complex *Adsorpcijski kompleks tla*	Ca	cmol(+) kg^{-1}	10	0,40	0,33	4	0,59	0,31	6	0,32	0,32	10	0,23	0,29	10	0,53	0,30	3	1,09	0,97
	Mg	cmol(+) kg^{-1}	10	0,18	0,10	4	0,02	0,02	6	0,01	0,01	10	0,11	0,12	10	0,02	0,01	3	0,01	0,00
	Na	cmol(+) kg^{-1}	10	0,32	0,02	4	0,48	0,04	6	0,36	0,05	10	0,33	0,03	10	0,45	0,14	3	0,42	0,04
	K	cmol(+) kg^{-1}	10	0,84	0,16	4	0,76	0,12	6	0,58	0,07	10	0,57	0,04	10	0,72	0,10	3	0,60	0,01
	Al	cmol(+) kg^{-1}	10	3,00	0,96	4	2,63	0,91	6	3,78	1,18	10	6,89	2,61	10	9,21	2,74	3	3,95	0,54
	H	cmol(+) kg^{-1}	10	0,34	0,24	4	0,59	0,23	6	0,85	0,35	10	0,96	0,39	10	1,59	0,46	3	0,91	0,35
	Fe	cmol(+) kg^{-1}	10	0,06	0,02	4	0,31	0,30	6	0,08	0,04	10	0,08	0,04	10	0,27	0,19	3	0,15	0,06
	Mn	cmol(+) kg^{-1}	10	0,05	0,01	4	0,05	0,01	6	0,11	0,08	10	0,06	0,01	10	0,08	0,08	3	0,05	0,01
	BCE	cmol(+) kg^{-1}	10	1,73	0,38	4	1,84	0,29	6	1,28	0,38	10	1,24	0,45	10	1,72	0,40	3	2,12	0,97
	ACE	cmol(+) kg^{-1}	10	3,44	0,98	4	3,58	1,26	6	4,81	1,43	10	7,99	2,89	10	11,14	3,04	3	5,05	0,93
	CEC	cmol(+) kg^{-1}	10	5,18	1,03	4	5,42	1,54	6	6,09	1,41	10	9,22	2,71	10	12,85	3,07	3	7,17	0,97
	Base saturation	%	10	34,2	7,91	4	35,4	6,66	6	21,9	7,28	10	14,9	8,52	10	13,9	4,16	3	29,3	11,55

	Variable *Varijabla*	Delnice - DEL			Fužine - FUŽ			Lokve - LOK			Crni lug - CL			Tršće - TRŠ			Test	F(H)	p
		N	Arit. sr.	St. dev.	N	Arit. sr.	St. dev.	N	Arit. sr.	St. dev.	N	Arit. sr.	St. dev.	N	Arit. sr.	St. dev.			
	Inclination *Nagib*	9	13	12,07	10	11	8,34	2	15	6,36	8	18	6,06	10	14	12,65	A	4,5318	0,0001
	Thickness *Debljina*	9	49	16,20	10	58	6,62	2	30	4,95	8	44	13,79	10	62	13,46	A	5,583	0,0000
Particle size distribution *Tekstura*	2,0 - 0,2 mm	9	13,6	9,32	10	18,3	12,38	2	14,2	9,33	8	13,7	17,02	10	17,1	16,86	A	2,0785	0,0375
	0,2 -0,02 mm	9	32,6	4,43	10	33,9	5,53	2	44,8	1,27	8	30,7	7,25	10	36,7	6,18	K-W	32,3283	0,0004
	0,02 - 0,002 mm	9	28,9	8,33	10	28,0	9,42	2	22,4	6,58	8	31,7	8,83	10	26,5	9,59	A	3,2565	0,0016
	<0,002 mm	9	24,8	4,62	10	19,7	2,82	2	18,6	4,03	8	23,8	4,44	10	19,7	7,45	K-W	31,1664	0,0006
	pH H_2O	9	4,42	0,17	10	4,57	0,18	2	4,48	0,01	8	4,46	0,17	10	4,54	0,20	A	4,49	0,0001
	pH $CaCl_2$	9	4,00	0,12	10	4,09	0,19	2	3,99	0,04	8	3,88	0,15	10	3,97	0,13	A	5,83	0,0000
	Org C	9	32,1	14,89	10	37,5	10,13	2	30,6	5,65	8	29,7	13,14	10	27,1	8,35	A	4,3156	0,0001
	N tot.	9	2,8	0,75	10	3,7	0,82	2	3,1	2,47	8	1,8	0,45	10	2,9	0,45	K-W	45,7638	0,0000
	C/N	9	11	3,55	10	11	4,68	2	16	14,85	8	19	11,41	10	10	2,60	K-W	26,842	0,0028
Soil adsorption complex *Adsorpcijski kompleks tla*	Ca	9	0,34	0,43	10	0,38	0,23	2	0,41	0,28	8	0,27	0,33	10	0,42	0,25	A	1,8543	0,0665
	Mg	9	0,12	0,04	10	0,08	0,02	2	0,19	0,05	8	0,01	0,00	10	0,07	0,08	K-W	60,8735	0,0000
	Na	9	0,32	0,02	10	0,33	0,02	2	0,33	0,05	8	0,38	0,02	10	0,37	0,09	K-W	39,3043	0,0000
	K	9	0,64	0,14	10	0,62	0,08	2	0,57	0,06	8	0,58	0,02	10	0,75	0,30	K-W	35,6373	0,0001
	Al	9	9,14	2,19	10	7,33	2,79	2	9,63	0,74	8	8,08	3,44	10	8,65	3,18	K-W	46,8277	0,0000
	H	9	0,90	0,69	10	0,93	0,63	2	1,75	0,35	8	1,35	0,75	10	1,36	0,44	A	4,8426	0,0000
	Fe	9	0,13	0,02	10	0,12	0,07	2	0,24	0,05	8	0,18	0,21	10	0,21	0,15	K-W	35,3451	0,0001
	Mn	9	0,06	0,02	10	0,05	0,01	2	0,03	0,02	8	0,06	0,01	10	0,05	0,02	K-W	14,558	0,1490
	BCE	9	1,42	0,45	10	1,41	0,28	2	1,49	0,44	8	1,23	0,31	10	1,61	0,39	A	2,6352	0,0087
	ACE	9	10,24	2,38	10	8,43	3,37	2	11,64	0,32	8	9,66	4,34	10	10,27	3,60	K-W	47,0231	0,0000
	CEC	9	11,66	2,57	10	9,84	3,38	2	13,14	0,75	8	10,89	4,37	10	11,87	3,67	K-W	46,2373	0,0000
	Base saturation	9	12,5	3,30	10	15,9	6,07	2	11,3	2,70	8	12,4	4,39	10	14,9	6,84	A	12,4046	0,0000

Further discussion dealing with the adsorption complex structure is based on the classification provided by the Forest Soil Coordinating Centre (Vanmechelen et al. 1997) because this classification is the result of the latest research in forest ecosystem soils. All the data, as well as the classification of the adsorption complex of European forest soils are based on the soil samples from central and northern Europe. Some caution should be taken here since there are no data for southern and southeastern Europe.

The average content of basic cation exchange (BCE) ranges from the minimal 1.3 cmol(+) kg^{-1} in Sungerski Lug to the maximal 4.5 cmol(+) kg^{-1} on Macelj for the surface mineral horizon, and from 1.2 cmol(+) kg^{-1} in Crni Lug to 2.1 cmol(+) kg^{-1} in Sungerski Lug for the argillic-accumulative horizon (Figure 3).

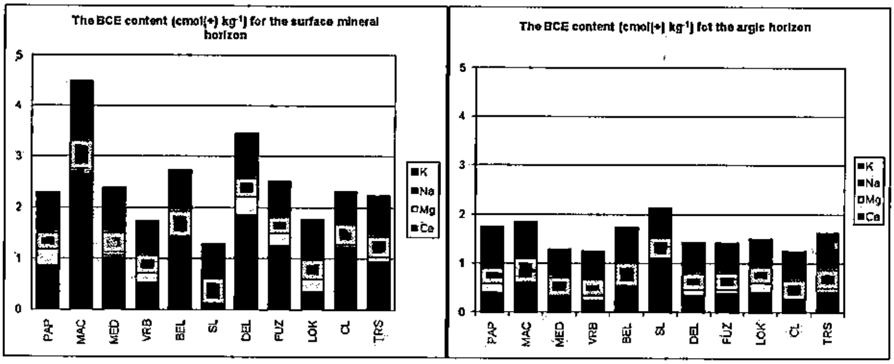


Figure 3 The BCE content for the surface mineral and argic horizon per localities
Slika 3. Sadržaj IBK u površinskom mineralnom i kambičnom horizontu po lokalitetima

As a comparison, a date was given of the BCE content reaching as much as 100 cmol(+) kg^{-1} in clayey soils with a high participation of smectite clay, but in general (in about 90% of the plots) it amounts to less than 20 cmol(+) kg^{-1} for the argic horizon and 25 cmol(+) kg^{-1} for the surface mineral horizon. The majority of forest soils are acid. As a result, acid cations prevail in the adsorption complex, so the basic cation exchange content is often very low; for over 50% of the forest soils it amounts to less than 1 cmol(+) kg^{-1} in the argic- horizon (Vanmechelen et al. 1997).

The most common basic cation exchange in the surface mineral horizon of the investigated soils in most of the localities is Ca^{2+}, followed by K^+, then Na^+ and finally Mg^{2+}, while the argic horizon is dominated by K^+ ion in all the localities except in Sungerski Lug. A relatively high participation of K^+ may be explained by the composition of the parent substrate (the sandstone detritus contains relatively large quantities of muscovite, feldspat, particularly orthoclass and mica).

In terms of basic cation exchange, in all the investigated localities the smallest amount of Mg^{2+} was contained in the soil adsorption complex.

Ulrich (1995) states that magnesium deficiency has in the past several decades become a widely recognized phenomenon in acid forest soils exposed to acid deposition, because exchangeable Mg^{2+} are leached.

Komlenović and Cestar (1983) also point to inadequate nutrition of spruce with magnesium and to lowered magnesium concentrations in fir needles, measured in the period of 15 years in similar sites.

The average content of acid cation exchange (ACE) ranges from the minimal 5.4 cmol(+) kg^{-1} on Papuk to the maximal 16.0 cmol(+) kg^{-1} in Tršće for the surface mineral horizon, and from 3.4 cmol(+) kg^{-1} on Papuk to 11.6 cmol(+) kg^{-1} in Lokve for the argic (Fig. 3). The results for Lokve should be taken with precaution because only two pedological profiles were opened for sampling.

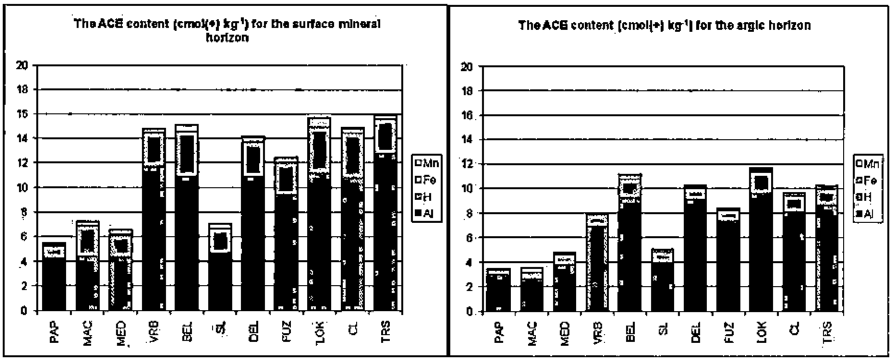


Figure 4 The ACE content for the surface mineral and argic horizon per localities.
Slika 4 Sadržaj IKK u površinskom mineralnom i kambičnom horizontu po lokalitetima.

The ACE values in the surface mineral horizon obtained by research were higher than those listed for the majority of European forest soils in all the localities. They range from 0.5 to 5 cmol(+) kg^{-1} of the soil. However, these values may even exceed 50 cmol(+) kg^{-1} of the soil (Vanmechelen et al. 1997).

The average values of the adsorption complex saturation with bases are range from the minimal 10% in Lokve to the maximal 39% on Macelj for the surface mineral horizon, and from 11% in Lokve to 38% on Macelj for the argic horizon.

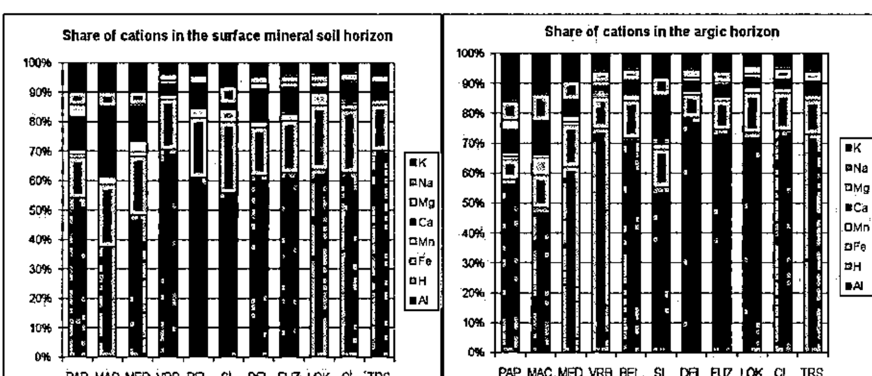


Figure 5 Share of cations in the adsorption complex of the surface mineral and argilc soil horizons per localities.
Slika 5. Udio kationa u adsorpcijskom kompleksu površinskog mineralnog i kambičnog horizonta tla po lokalitetima.

Generally speaking, all the soils in the investigated localities have a high to very high acid cation content, especially Al^{3+} and H^{+}, and a medium to low basic cation content, as well as medium to low adsorption complex saturation with basic cations. The cation exchange capacity (CEC) is medium to high.

Based on the obtained results, the sensitivity of the investigated soils to acidification may be estimated as medium to high (Vanmechelen et al. 1997). The soils of fir and beech-fir forests in Pannonian Croatia show less sensitivity to acidification than those in Gorski Kotar. Of all the localities in Pannonian Croatia, Medvednica has the least favourable acid and basic cation ratio percentage, and the lowest adsorption complex saturation with bases.

The Mn^{2+} content is interesting in that the surface mineral horizon on Medvednica differs significantly from all the other localities, while the argillic-accumulative horizon shows no differences. This unexpected phenomenon requires further study.

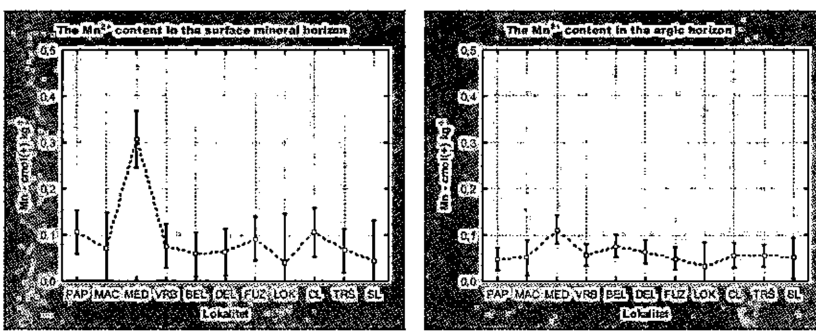


Figure 6 The Mn^{2+}content in the adsorption soil complex in the surface mineral horizon and in the argic horizon of the investigated localities.
Slika 6 Sadržaj Mn^{2+} u adsorpcijskom kompoleksu tla u površinskom mineralnom i kambičnom horizontu tla istraživanih lokaliteta.

Ulrich (1991) states that the increased Mn^{2+} content in CEC and in plant organs indicates the initial stage of acidification.

This coincides with research by Komlenović (1989), who claims that the highest forest damage was recorded in the area of Zagreb and Gorski Kotar, and with research by Medvedović et al. (1998), who point to increased input of deposition substances in the forest ecosystem of beech and fir on Medvednica.

Sungerski Lug is an exception, since in terms of the adsorption complex structure it shares similar characteristics with the soils in Pannonian Croatia. However, in terms of climatic and vegetational features it belongs to Gorski Kotar.

For the other localities in Gorski Kotar there are generally no significant differences in the basic and acid exchange cation content and in the adsorption complex saturation with bases. All these localities are consequently equally sensitive or highly sensitive to acidification. With reference to the least favourable BCE and ACE ratio, as well as the pH reaction and base saturation, I would single out the localities of Crni Lug, Belevine, Lokve and Tršće. Interestingly, Belevine, Crni Lug and Tršće have a significantly lower Mg^{2+} content in comparison with the other localities in Gorski Kotar.

A very high Al^{3+} and H^{+} ion content in all the localities of Gorski Kotar, as well as a high Al^{3+} and H^{+} content in Pannonian Croatia arouse considerable concern. This attitude is based on the results of research that deal with the antagonistic action of Al compounds on the Ca^{2+} and Mg^{2+} reception, the toxic effect on the bacteria and plant roots, and the inhibitory action on root growth, which leads to increased vulnerability to drought (Foy 1984, Kauppi et al. 1986, Asp et al. 1988, Bengtsson et al. 1988, Kreutzer 1989, Godbold et al. 1991, Boudot et al. 1994, Vanmechelen et al. 1997).

Phosphorus deficiency in acid soils is related to the formation of Fe and Al phosphates, which are insoluble and inaccessible for most plants. Therefore, we may talk of the inhibitory action of Al on P reception (Foy 1984). Additionally, research by Jung (1984) showed that an increase in aluminium content decreases potassium reception.

It ensues from the above that the inhibitory action of aluminium on root growth, which reduces the area with which the young plant receives nutrients and water from the soil, as well as the antagonistic effect on Ca^{2+}, Mg^{2+} and $H2PO_4^-$, and on HPO_4^{2-} reception, may affect fir regeneration. This should be verified with further research.

Since fir in Croatia occurs on the southern boundary of its distribution range, adverse climatic changes in the sense of reduced precipitation and increased temperatures and the occurrence of droughts in the vegetation period, coupled with increased aluminium-induced vulnerability to drought, lead to a gradual decrease in vitality and eventually, in combination with other unfavourable abiotic and biotic ecological factors, to tree dieback. Generally, increased temperatures are followed by increased plant sensitivity to pollutants (Guderian 1967, Rist and Davis 1979). Intensive fir dieback in the locality of Fužine, or more precisely MU Brloško, has been the subject of several investigations (Šafar 1969, Komlenović et al. 1991, Matić et al. 1998).

Properties of the adsorption complex and other pedological parameters of dystric cambisol in relation to phytocoenoses

Značajke adsorpcijskog kompleksa i ostalih pedoloških parametara distričnog kambisola prema fitocenozama

A comparison of differences between the arithmetic means in the two studied phytocoenoses: the Pannonian beech-fir forests (*Abieti-Fagetum "pannonicum"* Rauš 1969) and the fir forest with hard fern (*Blechno-Abietetum* Ht. 1950) that occur on the same soil type – dystric cambisol, but in different ecological conditions, has shown significant differences in the soil texture, soil reaction, Org C and N tot content, as well as in acid cation exchange (ACE) content, cation exchange capacity (CEC) and the adsorption complex saturation with basic cations (Tables 5 and 6). Judging by the soil texture, dystric cambisol in the fir forest with hard fern has a heavier texture with a significantly higher participation of clayey fraction. The soil reaction manifested lower pH values, or higher acidity in the community *Blechno-Abietetum*, which coincides with the acidophilic character of this community. Higher acidity is related to a higher acid cation exchange content. *Blechno-Abietetum* has a significantly higher Al^{3+}, H^+ and Fe^{2+} content in the A horizon, while *Abieti-Fagetum* has a higher Mn^{2+} content, which can be related to the initial stage of the acidification process (Ulrich 1991). In the (B)v horizon, *Blechno-Abietetum* has a higher Al^{3+}, H^+ ion content. *Abieti-Fagetum* has a more favourable condition of the adsorption complex saturation with bases than *Blechno-Abietetum,* This relation is significantly better in the (B)v horizon. In terms of the adsorption complex situation and the soil pH values, it can be said that *Blechno-Abietetum* is more susceptible to acidification effects. The CEC in *Blechno-Abietetum* is higher, which concords to the significantly higher clayey fraction participation. The accumulation of Org. C and N tot in the A horizon is higher in *Blechno-Abietetum* at a similar C/N ratio.

Table 4 Test of differences in pedological parameters for the A horizon of the Pannonian beech-fir forest (*Abieti-Fagetum* "pannonicum" Rauš 1969) and the fir forest with hard fern (*Blechno-Abietetum* Ht. 1950)

Tablica 4. T-test za varijable A horizonta u Panonskoj bukovo-jelovoj šumi (Abieti-Fagetum "pannonicum" Rauš 1969) i jelovoj šumi s rebračom (Blechno-Abietetum Ht. 1950)

Varijabla	*Abi.-Fag. arit. sred.*	*Ble.-Abi. arit. sred.*	*Abi.-Fag. std. dev.*	*Ble.-Abi. std. dev.*	t	U	p
Nagib	23	19	8,950	9,725	1,38335	-	0,174045
Debljina	8	6	3,150	4,024	1,93137	-	0,060370
KP	23,4	10,7	10,399	7,807	4,50749	-	**0,000054**
SP	44,4	49,4	11,341	5,298	-	-1,75828	0,078700
P	21,7	25,8	7,166	5,338	-2,11641	-	**0,040426**
G	10,5	14,0	3,250	4,138	-2,89962	-	**0,005979**
pH H_2O	4,40	4,08	0,285	0,363	2,89986	-	**0,005975**
pH $CaCl_2$	3,80	3,52	0,230	0,369	2,61444	-	**0,012446**
C org	69,8	115,4	26,511	61,002	-	-2,29341	**0,021825**
N uk	4,8	8,0	1,854	4,721	-	-2,62468	**0,008673**
C/N	15	15	3,519	4,194	0,06121	-	0,951491
Ca	1,46	2,13	1,529	1,468	-1,40690	-	0,166992
Mg	0,18	0,25	0,139	0,188	-1,25089	-	0,218066
Na	0,37	0,37	0,076	0,138	-	-0,93011	0,352317
K	0,83	0,83	0,114	0,294	-	0,43320	0,664870
Al	3,81	9,18	1,264	4,562	-	-4,48490	**0,000007**
H	1,32	2,91	0,666	1,252	-	-3,94977	**0,000078**
Fe	0,11	0,38	0,092	0,301	-	-3,31271	**0,000924**
Mn	0,20	0,09	0,176	0,102	-	2,16600	**0,030312**
BCE	2,83	3,58	1,550	1,538	-1,52735	-	0,134354
ACE	5,44	12,56	1,805	5,493	-	-4,43393	**0,000009**
AcExc	5,13	12,09	1,768	5,378	-	-4,47215	**0,000008**
CEC	8,26	16,14	2,252	4,909	-	-4,58682	**0,000005**
Baze	34,21	25,45	13,968	17,570	1,66553	-	0,103432

Table 5 Test of differences in pedological parameters for the (B)v horizon of the Pannonian beech forest (*Abieti-Fagetum* "pannonicum" Rauš 1969) and the fir forest with hard fern (*Blechno-Abietetum* Ht. 1950)

Tablica 5. T-test za varijable (B)v horizonta u Panonskoj bukovo-jelovoj šumi (Abieti-Fagetum "pannonicum" Rauš 1969) i jelovoj šumi s rebračom (Blechno-Abietetum Ht. 1950)

Varijabla	*Abi.-Fag. arit. sred.*	*Ble.-Abi. arit. sred.*	*Abi.-Fag. std. dev.*	*Ble.-Abi. std. dev.*	t	U	p
KP	24,8	11,5	12,9250	9,1921	3,90088	-	**0,000349**
SP	33,4	36,2	14,8414	5,8189	-	-1,83473	0,066547
P	25,7	30,0	9,8922	7,0818	-1,66394	-	0,103750
G	16,2	22,2	5,6499	5,0400	-3,58608	-	**0,000885**
pH H2O	5,00	4,60	0,5913	0,5079	2,32179	-	**0,025291**
pH CaCl2	4,32	4,11	0,5562	0,4623	1,33145	-	0,190396
C org	16,0	27,4	10,2922	12,6824	-3,00760	-	**0,004484**
N uk	1,8	2,4	0,7092	1,2375	-	-1,37605	0,168808
C/N	9	13	4,6927	8,2313	-	-2,26793	**0,023334**
Ca	1,01	0,52	2,2985	0,6107	-	0,50965	0,610299
Mg	0,11	0,10	0,1092	0,1213	0,19318	-	0,847772
Na	0,36	0,36	0,0580	0,0637	-0,28494	-	0,777122
K	0,74	0,65	0,1608	0,1973	1,61707	-	0,113534
Al	2,83	7,45	1,2666	2,9872	-	-4,53586	**0,000006**
H	0,44	1,05	0,3122	0,5335	-	-3,45286	**0,000555**
Fe	0,08	0,13	0,0502	0,1266	-	-1,98762	**0,046854**
Mn	0,11	0,05	0,1463	0,0159	-	0,54787	0,583781
BCE	2,22	1,63	2,2792	0,7289	-	1,29960	0,193739
ACE	3,46	8,69	1,3375	3,4791	-	-4,51038	**0,000006**
AcExc	3,27	8,50	1,4136	3,4206	-	-4,54860	**0,000005**
CEC	5,68	10,31	1,8670	3,3546	-	-4,25555	**0,000021**
Baze	36,10	18,43	18,0929	16,0263	3,29483	-	**0,002036**

CONCLUSIONS
ZAKLJUČCI

A total of 82 profiles were opened in 11 localities for the research. Three soil types were encompasses: dystric cambisol, brunipodzol and podzol. The cation content of the soil adsorption complex is an excellent indicator of dominant pedogenetic processes, nutrient reserves and buffer potential, but unfortunately there are no data for other sites and plant communities in Croatia to be compared with the obtained results. There are no previous measurements in the studied localities, so no conclusions can be made on any changes in the adsorption complex content and other soil parameters in a given time period.

The following conclusions can be drawn on the basis of the obtained results:

The adsorption complex content is a good indicator of variable site conditions. Cluster analysis resulted in two groups that correspond to the geographic position: Pannonian Croatia and Gorski Kotar, with the exception of Sungerski Lug. Further research should show whether the basic reason for this is the parent substrate.

The percentage ratio of basic cation exchange and acid cation_exchange for the soils in the studied localities is similar for the surface mineral and argic horizon, while as a rule, absolute values are higher in the surface mineral horizon.

In general, all the soils in the investigated localities have a high to very high acid cation content, especially of Al^{3+} and H^+, and a medium to low basic cation content, as well as medium to low adsorption complex saturation with basic cations. The cation exchange capacity (CEC) is medium to high. Based on the obtained data, the sensitivity of the studied localities to acidification can be graded as medium to high. The soils of beech and beech-fir forests in Pannonian Croatia manifest lower sensitivity to acidification than those in Gorski Kotar. Of the localities in Pannonian Croatia, Medvednica has the most unfavourable percentage ratio of acid and basic cations, and the lowest adsorption complex saturation with bases, while in Gorski Kotar this refers to Belevine, Crni Lug and Tršće.

In comparison with all the other localities, that of Medvednica has a significantly higher exchangeable Mn^{2+} content in the adsorption complex of the surface mineral horizon. The reasons should be further investigated.

In terms of basic cation exchange, the lowest Mn^{2+} content was recorded in the adsorption complex in all the localities under study. The localities with the highest Al^{3+} ion content and the least favourable adsorption complex content, which include Belevine, Crni Lug and Tršće, also have a significantly lower Mn^{2+} content of all the other localities. The negative effects of Mg deficiency are expected to occur in these localities first.

A very high Al^{3+} and H^+ ion content in all the localities of Gorski Kotar, as well as very high Al^{3+} and H^+ in Pannonian Croatia arouse concern. This is based on literature findings on the toxic effects of Al^{3+} and H^+, as well as on their antagonistic effect on calcium, magnesium and phosphorus reception.

The Pannonian beech-fir forest (*Abieti-Fagetum "pannonicum"* Rauš 1969) and the fir forest with hard fern (Blechno-Abietetum Ht. 1950) that occur in the same soil type – dystric cambisol, but in different ecological conditions, have manifested considerable differences in soil texture, soil reaction, the Org. C and N tot content, as well as in the acid cation exchange (ACE) content, the cation exchange capacity (CEC) and the adsorption complex saturation with basic cations. The results for the adsorption complex indicate that the fir forest with hard fern is more sensitive to acidification than the Pannonian beech-fir forest.

REFERENCES
LITERATURA

Alekseev, V. A., 1990: Lesnie ekosistemi i atmosfernoe zagrjaznemie, "Nauka", Leningrad.

Asp, H., B. Bengtsson, P. Jensen, 1988: Growth and cation uptake in spruce (*Picea abies* Karst.) grown in sand culture with various aluminium contents, Plant Soil 111, p. 127-133.

Bengtsson B., A. Asp, P. Jensen, Berggren, 1988: Influence of aluminium on phosphate and calcium uptake in beech (*Fagus silvatica*) grown in nutrient solution and soil solution. Phisiol Plant 74, 299-305.

Bezak, K., V. Krejči, B. Vrbek, 1991: Propadanje jele praćeno promjenama vitalnosti i prirasta šuma bukve i jele od 1969–1990. godine, Radovi, Vpl. 26, Br. 1: p. 115-128, Zagreb.

Boudot, J.P., T. Becquer, D. Merlet, J. Rouiller, 1994: Aluminium toxicity in declining forests: a general overview in the Vosges mountains (France), Ann. Sci. For., 51: p. 27-51.

Bremner, J. M., and C. S. Mulvaney. 1982. Nitrogen - Total. In: Methods of Soil Analysis (A. L. Page et al., ed.). Agronomy Monograph 9, Part 2, 2nd ed. American Society of Agronomy, Madison, WI. p. 595-624.

Conover, W., J., 1980: Practical Nonparametric Statistics, 2nd ed, John Wiley & Sons, New York.

Foy, C. D., 1983: Plant adaptation to mineral stress in problem soils, Iowa State J Res 57, p: 339-354.

Foy, C. D., R.L. Chaney, M.C. White, 1978: The physiology of metal toxicity of plants, Ann. Rev. Plant Physiol 29, p. 511-566.

Foy, C.D., 1984: Phisiological effects of hydrogen, aluminium, and manganese toxicities in acid soil, In: Soil Acidity and Liming, 2 nd ed (Adams, F., ed.) Agronomy Monograph N° 12, ASA-CSSA-SSSA, WI 53711, USA, p. 57-97.

Glavač, V., 1999: Uvod u globalnu ekologiju, Državna uprava za zaštitu prirode i okoliša i Hrvatske šume, Zagreb, p. 211.

Glavač, V., H. Koenies, B. Prpić, 1985: O unosu zračnih polutanata u bukove i bukovo-jelove šume Dinarskog gorja sjeverozapadne Jugoslavije, Šumarski list 9-10, p. 429-447, Zagreb.

Godbold D.L., 1991: Aluminium descreases root growth and calcium and magnesium uptake in Picea abies seedlings, In: Plant-soil Interactions at Low pH.

Gračanin, M. & Lj. Ilijanić, 1977: Uvod u ekologiju bilja, Školska knjiga, Zagreb, 318 str.

Gračanin, M., 1947: Pedologija (tloznanstvo), II dio, fiziografija tala, Poljoprivredni nakladni zavod, Zagreb, p. 233.

Guderian, R., 1967: Air Pollution, Ecological Studies 22, Springer, Berlin, Heidelberg, New York.

Hecht-Buchholz, C. & C.D. Foy, 1981: Effect of aluminium toxicity on root morphology of barley, Plant Soil 63, p. 95.

Hutchinson, T. C., L. Bozic, G. Munoz-Vega, 1986: Response to five species of conifer seedlings to aluminium strees, Water, Air and Soil Pollution 31: p. 283-294.

Jung, U., 1984: Sterilkultur als Modellsystem zur Unterschung des Mechanismus der Aluminium-Toxizität bei Fichtenkeimlingen (*Picea abies* Karst.) Diss. Univ. Göttingen.

Kachigan, S. K., 1991: Multivariate Statistical Analysis, 2 nd ed, New York.

Kauppi, P., J. Kämäri, M. Posch, L. Kauppi, 1986: Acidification of forest soils, Model development and application for analyzing impacts of acidic deposition in Europe. Ecological Modelling, 33, p. 153-231.

Komlenović, N & D. Cestar, 1983: Istraživanje stanja ishrane obične jele (*Abies alba* Mill.) po utvrđenim ekološko – gospodarskim tipovima šuma u SR Hrvatskoj, Radovi Šumarskog instituta Jastrebarsko, br. 45, p. 1-37.

Komlenović, N., 1989: Utjecaj SO_2 i nekih drugih polutanata na šumsko drveće s posebnim osvrtom na SR Hrvatsku, Šumarski list CXIII, p. 243-260.

Komlenović, N., J. Gračan, N. Pezdirc, P. Rastovski, 1988: Utjecaj polutanata na bukove šume i kulture smreke u sjeverozapadnoj Hrvatskoj, Šumarski list, CXII, p. 195-215.

Komlenović, N., Rastovski P., Pezdirc, N., 1991: Odnos ishrane i oštećenosti obične jele (*Abies alba* Mill.) u šumi jele s rebračom na području Fužina, Radovi Šumarskog instituta, Vol. 26, br. 2: p. 187-198, Zagreb.

Kreutzer, K., 1989: Hipoteze i rezultati ispitivanja uloge tla u "Novim šumskim štetama", Šumarski list, CXIII, p. 261-278.

Martinović, J., 2003: Gospodarenje šumskim tlima u Hrvatskoj, Jastrebarsko, p. 92-101.

Matić, S., M. Oršanić, I. Anić, 1998: Utjecaj klimatskih promjena na strukturu i razvoj šumskih ekosustava, Zbornik radova znanstvenog skupa s međunarodnim sudjelovanjem "Prilagodba poljoprivrede i šumarstva klimi i njenim promjenama", HAZU, Zagreb, p. 239-250.

Matsumoto, H., F. Hrasawa, E. Torikai, and E. Takahashi, 1976: Location and absorption of aluminium in pea roots and its binding to nucleic acids, Plant Cell Physiol. 17, p. 127-137.

Mayer R., 1998: Soil acidification and cycling of metal elements: cause–effect relationships with regard to forestry practices and climatic changes, FB 13 University Gh Kassel, Gottschalkstrasse 28, Kassel D-34109, Germany , Agriculture, Ecosystems & Environment, Volume 67, Issues 2-3, p. 145-152.

Medvedović J., J. Milković, B. Vrbek, I. Pilaš, I. Seletković, N. Potočić, D. Novosel, 1998: Motrenje stanja šume bukve i jele na pokusnoj plohi "Sljeme" (Monitoring the Condition of a Beech and Fir Forest on the Experimental Plot "Sljeme"), Rad. Šumar. Inst. 33 (2): p. 31-49, Jastrebarsko.

Medvedović, J., 1990: Sinekologija zajednica obične jele (*Abies alba* Mill.) u sjevernoj Hrvatskoj i floristički parametri važni za gospodarenje bukovo jelovim šumama, doktorska disertacija, Šumarski fakultet Zagreb, p. 126.

Mückenhausen, E., 1975: Die Bodenkunde, DLG – Verlag, Frankfurt am Main.

Pernar, N., 1996: Uzroci varijabilnosti organskog kompleksa kalcikambisola na kršu zapadne Hrvatske, Disertacija, Sveučilište u Zagrebu, Šumarski fakultet, p. 121.

Prpić, B., 1987: Sušenje šumskog drveća u SR Hrvatskoj s posebnim osvrtom na opterećenja Gorskog kotara kiselim kišama s teškim metalima, Šumarski list, CXI, p. 53-60

Prpić, B., Z. Seletković, M. Ivkov, 1991: Propadanje šuma u Hrvatskoj i odnos pojave prema biotskim i abiotskim činiteljima danas i u prošlosti, Šumarski list CXV, p. 107-129.

Rist, D. L. & D. D. Davis, 1979: The influence of exposure temperature and relative humidity on the response of pinto bean foliage to sulfur dioxide, The American Phitopathological Society 69, 3, p. 231-235.

Schier, G. A., 1985: Response of red spruce and balsam fir seedlings to aluminium toxicity in nutrient solutions, Can. J. For. Res. 15, p. 29-33.

Sivaguru, M., Sharon P., & Tobias I. B., 2003:1Aluminum Rapidly Depolymerizes Cortical Microtubules and Depolarizes thePlasma Membrane: Evidence that these Responses are Mediated by a Glutamate Receptor , Plant Cell Physiol. 44(7): p. 667–675.

Sokal, R. R. & F. J. Rohlf, 1995: Biometry, W. H. Freeman, New York.

Steven, C. Hodges., 1994: Soil fertility basics, Soil science Extension, North Carolina State University, p. 75.

Stumm, W., 1996: Correcting Surface Charge and the Electric Double-Layer. In Chemistry of the Solid-Water Interface, Jhon Wiley & Sons, New York.

Šafar, J., 1969: Prilozi rješavanju problema o održavanju i pomlađivanju jele na području Gorskog kotara, Šumarski list, p. 26-35.

Tamm, C. O. & L. Hallbäcken, 1986: Changes. in Soil pH over a 50-year period under different forest canopies in SW Sweden, Water, Air and Soil Pollution 31: p. 337-341.

Thomas, G. W., 1982: Method of soil analysis, Part 2, in the series Agronomy Chemical and Microbiological Properties, Second Edition, ASA, SSSA, Madison, Wisconsin, USA.

Ulrich, B., 1982: Soil acidity and its relations to acid depozition, Effects of Accumulation of Air Pollutants ih Forest Ecosystems, Proceedings of a Workshop held at Göttingen, Dordrecht, D. Reidel Publishing Company, p. 127-147

Ulrich, B., 1991: An Ecosystem Approach to Soil Acidification, U: Ulrich, B. & M. E. Sumner (ur.), Soil Acidity, Springer-Verlag Berlin Heidelberg, p. 28-79.

Ulrich, B., 1995: The history and possible causes of forest decline in Central Europe, with particular attention to the German situation, Environmental Reviews, Canada, Invited paper.

Urlich, B., B. Mayer, P.K. Khanna, 1979: Die Deposition von Luftverunreinigungen und ihre Auswirhungen in Waldökosystemen im Solling, Schriften der Forstwissenschaftlichen Fakultät der Universität Göttingen, p. 58.

Vanmechelen, L., R. Groenmans, E. Van Ranst, 1997: Forest soil condition in Europe, Results of a Large-Scale Soil Survey, Forest Soil Coordinating Centre, Brussels, Ganeva.

Vrbek, B., M. Vrbek, J. Vukelić, 1991: Zakiseljavanje tla i nakupljanje Pb, Cu, i Zn u jelovim zajednicama Nacionalnog parka Risnjak, Šumarski list br. 3-5/91, p. 163-171.

Vukadinović V. & Z. Lončarić, 1998: Ishrana bilja, Sveučilište Josipa Jurja Srtossmayera u Osijeku, Poljoprivredni fakultet Osijek.

Weerd, van de H., W. H. van Riemsdijk., A. Leijnse., 1999: Modeling the Dynamic Adsorption/Desorption of a NOM Mixture: Effects of Physical and Chemical Heterogeneity, Environ. Sci. Technol., 1999, 33 (10), p. 1675–1681.

\UDK: 630*181.22+181.31

Original scientific paper
Izvorni znanstveni članak

DIEBACK OF SILVER FIR (*Abies alba* MILL.) IN GORSKI KOTAR IN CORRELATION WITH PRECIPITATION AND TEMPERATURE

ODUMIRANJE STABALA OBIČNE JELE (Abies alba MILL.) U GORSKOM KOTARU U ODNOSU NA KOLIČINE OBORINA I TEMPERATURE ZRAKA

DAMIR UGARKOVIĆ[1], IVICA TIKVIĆ[1], ZVONKO SELETKOVIĆ[2], MILAN ORŠANIĆ[1], IVAN SELETKOVIĆ[2], NENAD POTOČIĆ [2]

[1] *University of Zagreb, Faculty of Forestry, Department of Ecology and Silviculture*
[2] *Croatian Forestry Institute, Department of Ecology and Silviculture*

Received – *prispjelo*: 27.1.2010. Accepted – *prihvaćeno*: 1.3.2010.

Abstract

Silver fir is the most widely distributed and the most important commercial conifer species in Croatia. However, it is also the most threatened. The first records of its dieback in Croatia date from the beginning of the 20[th] century. Dieback has since evolved into a worrying phenomenon and a significant forestry problem. Dieback of silver fir is attributed to different causes. The objective of this work is to present the dynamics and intensity of silver fir dieback and establish the correlation between tree dieback and climatic factors in the area of two management units in Gorski Kotar. The data collected from two management units in Gorski Kotar (management units Brloško and Ravna Gora) over a ten-year period relate to dead trees of silver fir across the entire management unit area. The management units of Brloško and Ravna Gora epitomize a typical area of fir forests in Croatia. Regression models were used to obtain data on temperature and precipitation quantity for each compartment /subcompartment. Linear correlation coefficients were applied to establish the correlation between dieback intensity and climatic factors. The dynamics of tree dieback was analyzed on the basis of tree number and volume. There was a statistically significant increase in air temperature values in relation to the normal series of 1961 – 1990 in the study area. Precipitation decrease was also present, but it was not statistically significant. Considerable dieback of fir trees was recorded on the edge of the distribution range and in stands with a disturbed selection structure. A strong correlation was also found between air temperature, precipitation and growing stock of silver fir and dieback intensity. The paper also discusses the already familiar causes of silver fir dieback.

Key words: silver fir, dieback, dieback intensity, temperature, precipitation

Sažetak

Obična jela je najraširenija i gospodarski najznačajnija četinjača u Hrvatskoj, ali istodobno i najugroženija šumska vrsta drveća. Prvi zapisi o njenom odumiranju u Hrvatskoj datiraju s početka prošlog stoljeća. Od tog vremena pa do danas ono je više ili manje zabrinjavajuća pojava i značajan problem u šumarstvu. Pojava odumiranja obične jele pripisuje se različitim uzročnicima. Cilj rada je bio prikazati dinamiku i intenzitet odumiranja stabala obične jele, te utvrditi ovisnost odumiranja stabala o klimatskim čimbenicima, na području dviju gospodarskih jedinica u Gorskom kotaru. Na području Gorskog Kotara (gospodarske jedinice Brloško i Ravna Gora) prikupljeni su podaci o odumrlim stablima obične jele na razini cijele gospodarske jedinice za desetgodišnje razdoblje. Gospodarske jedinice Brloško i Ravna Gora predstavljaju tipično područje jelovih šuma u Hrvatskoj. Regresijskim modelima dobiveni su podaci o temperaturi i količini oborina sa svaki odsjel/odsjek. Lineranim korelacijskim koeficijentima utvrđena je poveznost između intenziteta odumiranja i klimatskih čimbenika. Dinamika odumiranja stabala je analizirana na temelju broja stabala i volumena. Na području istraživanja utvrđeno je statistički značajno povećanje vrijednosti temperatura zraka u odnosu na normalni niz 1961.-1990. Smanjenje oborina je prisutno, ali nije statistički značajno. Utvrđeno je značajno odumiranje jelovih stabala na rubu areala i u sastojinama narušene preborne strukture, kao i jaka korelacija vrijednosti temperatura zraka, oborina i *drvne zalihe obične jele sa intenzitetima odumiranja. U radu su raspravljeni već poznati uzroci odumiranja stabala obične jele.*

Ključne riječi: Obična jela, odumiranje, inenzitet odumiranja, temperatura, oborine

INTRODUCTION
UVOD

Dieback of single trees in forest ecosystems of Croatia has assumed catastrophic features, especially in view of the fact that this phenomenon primarily affects Croatia's principal tree species. Participating in the growing stock of Croatian forests with 9.4%, silver fir is the most threatened forest tree species in this country (Meštrović, 2001).

Silver fir dieback has been recorded in the whole of Europe, but in spite of numerous hypotheses related to this problem, differences in factors such as soil, climate and degree of air pollution make it difficult to establish the main causes (Krause et al., 1986).

The phenomenon termed "forest dieback" was confirmed in the Dinaric range of Croatia around 1954. This problem was first noted in fir and beech stands in the area of Fužine forest office (Glavač et al., 1986). Five-year research into the causes of fir dieback in Lika and Gorski Kotar was launched in 1968. Silver fir dieback is very important from a silvicultural aspect due to the consequences it produces, such as the absence of natural regeneration and disturbances in the management with forests (Malek, 1981; Korpel, 1985; Andrzejczyk et al., 1987; Matić et al., 2001). Fir forests are currently also characterized by a disturbed and unstable selection structure, which is responsible for a number of changes. These changes include very poor or completely absent natural regeneration of silver fir, a decrease in the growing stock in relation to the normal one, physiological weakening and decline of dominant trees, changes in the stand's microclimate, degraded forest soils caused by excessive weeds and erosion, reduced microbiological activity of the soil, the increasingly frequent onset of secondary pests that accelerate the process of tree dieback, and the aggressive expansion of common beech throughout the former sites of silver fir. According to Matić (1996), such a condition can be attributed to three groups of causes. The first group refers to inappropriate silvicultural treatments, the second to the occurrence of longer dry periods on the global and local level, and the third to the effects of acid rains and pollutants which reflect unfavourably on the air, water, soil and organisms. As shown by research of Glavač et al. (1986), beech and beech-fir forests in the Dinaric range of north-western Croatia are severely affected by remote air pollution. The authors confirmed a coincidence between the sites affected by air pollution and the sites of fir dieback. The negative effect of chemical substances in the atmosphere is progressively increasing, as confirmed by global climate changes every year (Schlaepfer, 1993; Mindaš et al., 2000). According to Prpić (1975), climate changes form the basic predisposition for the occurrence of silver fir dieback. Among these changes, warming and decreased humidity in the sites of fir forests are the most distinctive. In the view of the same author, the incidence of silver fir dieback is much lower in the optimum of the distribution range and much higher on the boundary of the distribution range towards warmer regions. Changes in the nutritional and physiological status, brought about by insufficient precipitation, are considered the main cause of decline and dieback of Spanish fir in the Pyrenees (Fromard et al., 1991).Dry periods as stress factors are one of the main reasons for dieback, increased damage and declining health of forest ecosystems of silver fir in Europe (UN-ECE and EC, 2003). Dry periods, especially in soils poor in calcium, have a negative effect on the Ca status and vitality of silver fir trees (Potočić et al., 2005).

According to Oszlànyi (1997), drought, climate change, and abrupt and sudden temperature oscillations are stress factors that result in the damage of forest ecosystems, the decline of the tree's assimilation apparatus and the subsequent degradation of the entire ecosystem.

Seletković et al. (1993) analyzed meteorological data collected from the Meteorological Station Zagreb – Grič to detect changes in temperature and precipitation regimes over the last 100 years. According to Matić et al. (1998), climate change is responsible for dieback of several tree species and of silver fir in particular, for the formation of stands with varying tree species ratios in the tree species composition, and even for the occurrence of other tree species. In commercial forests the intensity of tree dieback, as well as the health status of a stand, is illustrated by the volume of dead trees, or the volume of trees removed by salvage cuts (Capecki, 1981). Dieback intensity can also be expressed as the mortality percentage calculated as the ratio between the number of dead trees and the number of living trees (Busing et al., 1994; Markalas, 1992, Stanovsky, 2002; Tikvić et al., 2004; Turčani et al., 2003), or it can be expressed in absolute values in m^3 or m^3/ha (Siwecki et al., 1988). The objective of this work was to determine trends in macro-climatic elements (air temperature and precipitation quantity) and their deviations from the normal series 1961 – 1990 (according to WMO, 2001), and establish their correlation with the condition and trends in silver tree dieback in the study area.

RESEARCH FIELD, MATERIAL AND WORKING METHODS
PODRUČJE ISTRAŽIVANJA, MATERIJALI I METODA RADA

Field research conducted in the distribution range of beech-fir forests in Gorski Kotar encompassed the area of the management units of Brloško, Fužine Forest Office, and Ravna Gora, Ravna Gora Forest Office, part of Delnice Forest Administration (Figure 1). The climate in the study area is temperate warm rainy climate, with the mean annual air temperature ranging between 6.3 and 7.7 °C and the mean annual precipitation quantity ranging from 1,600 mm in the eastern part to 4,000 mm in the western part of Gorski Kotar (Lividraga) over the past three decades (Seletković, 2001). The parent material of the management units, according to the data from the management plans, is composed of limestones and dolomites of varying ages. The dominant soils are melanosol, brown and illimerized soil, rendzinas, dystric brown soil and brunipodzol. The relief is highly indented and irregular, being intersected by elevations, ditches, valleys and ridges. The management unit of Brloško is at an altitude between 720 and 1,090 m, and the management unit of Ravna Gora is at an altitude between 719 and 1,346 m.

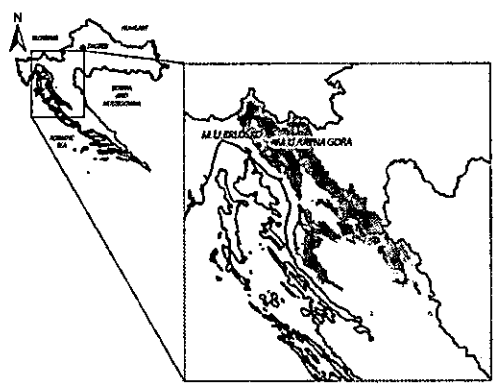


Figure 1 Position of the studied management units in the distribution range of silver fir (*Abies alba* Mill.) in Croatia.
Slika 1 Položaj istraživanih gospodarskih jedinica u arealu obične jele (Abies alba Mill.) u Hrvatskoj.

The management unit of Brloško is situated on the edge of the silver fir range towards the sea. The selection structure has been disturbed by tree dieback. The growing stock is predominantly accumulated on old trees above 50 cm dbh. The average growing stock in the management unit amounts to 276 m^3/ha, and the maximal growing stock reaches the amount of 726 m^3/ha. In terms of the percentage share of salvage cuts of silver fir trees in the total prescribed cut, the condition of silver fir trees is worse compared to the trees in the management unit of Ravna Gora (Management plans for management units of Brloško and Ravna Gora).

The management unit of Ravna Gora is situated in the interior of Gorski Kotar. The trees are in very good condition, and the stands contain the optimal growing stock. The average growing stock amounts to 163 m^3/ha and the maximal one to 380 m^3/ha.

The analysis of climate and climatic features in the research area was based on data on air temperatures and precipitation quantities collected from representative meteorological stations over a prolonged monitoring period (Table 1).

Table 1 List of meteorological stations with monitoring periods in the study area
Tablica 1 Popis meteroloških postaja na području istraživanja sa razdobljem motrenja

Meteorological station *Meteorološka postaja*	Type of met. Station *Tip meteorološke postaje*	Altitude *Nadmorska visina*	Monitoring period *Razdoblje motrenja*
Vrelo Ličanke	Standard met. station	750	1975 - 2004
Lokve Brana	Standard met. station	774	1961 - 2004
Ravna Gora	Subordinate met. station	793	1961 - 2004

Linear trends of annual air temperatures and precipitation quantities were calculated (simple regression) and differences in annual values were tested with the Student's t-test using the data obtained from the mentioned meteorological stations and monitoring periods.

Mean annual air temperatures and mean annual precipitation quantities for the period 1995 – 2004 were tested with the T-test of independent samples and compared with mean annual values of the normal reference series 1961 ('75) – 1990. Dry years were determined using the normal series percentage method and the percentile method.

Data on the number and wood volume of dead silver firs by compartment and subcompartment in each management unit were obtained on the basis of annual assessment of the forest's health condition. The data refer to the ten-year period (1995 – 2004) and to the compartments and subcompartments in which tree dieback occurred over the monitored period.

The average rate of dieback change at the level of the whole management unit for the ten-year period was calculated using the chain index and the following formula:

$$DC = ((\,dead_{year+1}/dead_{year-1})*100) - 100$$

The mortality rate of silver fir is presented in absolute values (m^3 and m^3/ha).

Since the referent meteorological stations are situated at lower altitudes than those of the monitored compartments and subcompartments, regression models were used to obtain theoretical changes in mean annual air temperatures (°C) and mean annual precipitation quantities (mm) in correlation with altitude (Zaninović et al., 2004; Gajić-Čapka et al., 2003). Temperatures and rainfall were calculated for each monitored compartment /subcompartment.

A correlation analysis was used to establish the correlation between silver fir dieback and climatic, structural and relief factors.

Multiple regression was used to test the dependence of tree dieback on climatic, structural and relief factors. All the data were processed in the Statistica 6.0 and Klimasoft 2.0 programmes.

RESEARCH RESULTS AND DISCUSSION
REZULTATI ISTRAŽIVANJA I RASPRAVA

Changes in climatic features
Promjene klimatskih obilježja

Of all the climatic elements, air temperature and precipitation quantity are the ones most firmly linked to silver fir dieback. It is for this reason that we investigated their changes for as long a monitoring period as possible.

Linear trends in mean annual air temperatures (Table 2) have a positive prefix, which means that the temperature in the study area is rising. A trend in temperature increase is statistically significant, except for vegetation temperatures in the area of Lokve Brana Meteorological Station.

Table 2 Linear trends in annual and vegetational air temperatures and their significance.
Tablica 2 Linerani trendovi godišnjih i vegetacijskih temperatura zraka i njihova signifikantnost.

Met. Station *Meteorološka postaja*	Mean annual air temperatures (°C) *Prosječna godišnja temperatura zraka* (°C)		
	Linear trend	t	p
Vrelo Ličanke	y = 0,0643x + 6,3028	t (28) = 5,3869	0,0000*
Lokve Brana	y = 0,0164x + 6,7921	t (42) = 2,2895	0,0271*
Met. Station *Meteorološka postaja*	Mean annual vegetational air temperatures (°C) *Prosječna god. vegetacijska temp. zraka* (°C)		
Vrelo Ličanke	y=0,0779x + 11,3170	t (28) = 5,8804	0,0000*
Lokve Brana	y = 0,0158x + 12,277	t (42) = 1,9023	0,064

*significant at the level of 95 %

Air temperatures in the area of Vrelo Ličanke Meteorological Station on the edge of the distribution range, which contains the management unit of Brloško, increased more than air temperatures in the area of Ravna Gora Meteorological Station in the interior of Gorski Kotar, housing the management unit of "Ravna Gora".

According to the t-test results for mean annual air temperatures for the period 1995-2004 in relation to the referent series, a statistically significant increase in mean annual air temperatures of 1.1 °C and mean vegetation air temperatures of 1.2 °C was recorded in the area of Vrelo Ličanke Meteorological Station. These changes are also statistically significant for the interior of Gorski Kotar, but much less so than those on the edge of the distribution range. Thus, mean annual air temperatures increased by 0.48 °C in the area of the meteorological station Lokve Brana, and mean vegetational ones by 0.54 °C (Table 3). In their study of silver fir dieback in Northern Velebit, Tikvić et al. (2008) found that mean vegetational air temperatures rose by 1.1 °C and 0.7 °C in the area of Gospić and Zavižan Meteorological Stations, and that vegetational precipitation quantities dropped by 24.6 mm (Gospić) and 83.3 mm (Zavižan).

Table 3 Results of the Student's t-test of comparisom of annual and vegetational air temperatures for the period 1995 – 2004 with the referent series for Vrelo Ličanke and Lokve Meteorological Stations.
Tablica 3 Rezultati Studentovog t-testa usporedbe godišnjih i vegetacijskih temperature zraka razdoblja 1995. – 2004. sa referentnim nizom za meteorološke postaje Vrelo Ličanke i Lokve.

Station *Postaja*	Temperature *Temperatura*	Period *Razdoblje*	Mean *Aritm. sred.*	t-value	df	p
Vrelo ličanke	Annual *Godišnja*	1975 – 1990	6,82	-4,595	24	0,000*
		1995 – 2004	7,92			
	Vegetational *Vegetacijska*	1975 – 1990	11,96	-4,123	24	0,000*
		1995 – 2004	13,19			
Lokve	Annual *Godišnja*	1961 – 1990	7,02	-2,205	38	0,033*
		1995 – 2004	7,5			
	Vegetational *Vegetacijska*	1961 – 1990	12,46	-2,095	38	0,042*
		1995 – 2004	13			

* significant at the level of 95%

An increase in the mean annual and vegetational air temperature and the onset of climatic excesses important for the present climate change may cause stress conditions in tree species of narrow ecological valence, such as the silver fir. This refers primarily to direct ecological factors (warmth and water).

In addition to air temperature, which depends on cloudiness and air insolation, rainfall also has the greatest importance for the growth of vegetation, since it is one of the main sources of moisture in the soil and as such decisive for the supply of water to vegetation. The lack of precipitation, coupled with high air temperatures, weakens the resistance of silver fir to adverse factors. Changes in air temperatures also reflect on precipitation conditions (Kirigin 1975), which results in unfavourable conditions for the growth and development of forest vegetation.

Table 4 Linear trends in annual and vegetational precipitation quantities and their significance.
Tablica 4 Linerani trendovi godišnjih i vegetacijskih količina oborina i njihova signifikantnost.

Met. Station *Meteorološka postaja*	Annual precipitation quantities (mm) *Prosječna god. količina oborina* (mm)		
	Linear trend	t	p
Vrelo Ličanke	y= -14,145x + 2813,2	t (28) = -1,8595	0,0734
Ravna Gora	y= -2,53x+ 1977,5	t (42) = -0,8044	0,425
Met. Station *Meteorološka postaja*	Vegetational precipitation quantities (mm) *Vegetacijska količina oborina* (mm)		
Vrelo Ličanke	y= -6,1085x + 1093,9	t (28) = -1,1817	0,2472
Ravna Gora	y= -1,83x + 952,7	t (42) = -0,7608	0,451

* significant at the level of 95%

Linear equations of trends in precipitation quantities have a negative prefix, which means that the quantity of precipitation in the study area is decreasing. Linear trends are not statistically significant.

A decrease in precipitation quantities in the area of Vrelo Ličanke Meteorological Station on the edge of the distribution range is bigger than in the area of Ravna Gora Meteorological Station in the interior of Gorski Kotar.

Apart from an abrupt decrease in precipitation quantities, which has an adverse effect on the physiological tree functions, there is also an increase in air temperatures. This is particularly conducive to the development and spread of harmful insects, which inflict further stresses and damage the trees (Androić, 1969).

An increase in mean annual and vegetation air temperatures and the occurrence of climatic excesses important for the current climate change may cause stress conditions in tree species of narrow ecological valence, such as the silver fir. This refers particularly to direct ecological factors (warmth and water). Air temperature and soil moisture are limiting factors for the distribution of the majority of European forest tree species (Berninger, 1997).

Table 5 Results of Student's t-test comparing annual and vegetational precipitation quantities in the period 1995 – 2004 with the referent series for Vrelo Ličanke and Ravna Gora Meteorological Stations.
Tablica 5 Rezultati Studentovog t-testa usporedbe godišnjih i vegetacijskih količina oborina razdoblja 1995 – 2004 sa referentnim nizom za meteorološke postaje Vrelo Ličanke i Ravna Gora.

Station *Postaja*	Precipitation *Količina oborina*	Period *Razdoblje*	Mean *Aritm. sred.*	t-value	df	p
Vrelo ličanke	Annual *Godišnja*	1975 – 1990	2639,13	0,282	23	0,779
		1995 – 2004	2592,06			
	Vegetational *Vegetacijska*	1975 – 1990	1023,99	0,253	24	0,801
		1995 – 2004	997,35			
Ravna Gora	Annual *Godišnja*	1961 – 1990	1915,65	-0,662	38	0,511
		1995 – 2004	1982,88			
	Vegetational *Vegetacijska*	1961 – 1990	923,34	-0,087	38	0,93
		1995 – 2004	929,82			

A decrease in the quantity of precipitation on the edge of the distribution range of silver fir forests differs from that in the interior of the range. For the meteorological station Vrelo Ličanke, a decrease in annual precipitation quantities for the period 1995 – 2004 in relation to the "normal series" is 47 mm, and in vegetational ones it is 27 mm. For the meteorological station Ravna Gora, annual precipitation quantities decreased by 47 mm, whereas vegetational quantities decreased by only 6.50 mm. This decrease in precipitation quantities and in linear trends is not statistically significant (Table 5).

Tree dieback
Odumiranje stabala

Silver fir dieback in the management unit of Brloško for the period 1995 – 2004 is given in Figure 2. The lowest dieback intensity was recorded in 1998, when 3,852 m³ died, and the highest in 1995, when 14,020 m³ died.

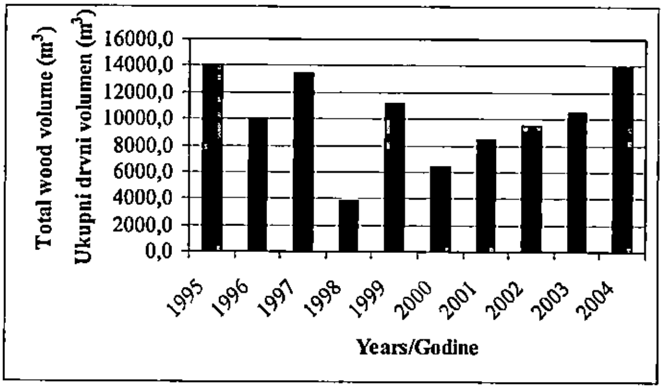


Figure 2 Total wood volume of dead silver fir trees in the management unit of Brloško from 1995 to 2004.
Slika 2 Ukupni drvni volumen odumrlih stabala obične jele u gospodarskoj jedinici Brloško od 1995.. do 2004. godine.

According to the results presented in Figure 3, the lowest quantity of dead trees in the management unit of Ravna Gora for the period 1995 – 2004 was recorded in the year 2000. The quantity amounted to 425.9 m³. The highest number of dead trees was recorded in 1996 and amounted to 3,340.8 m³.

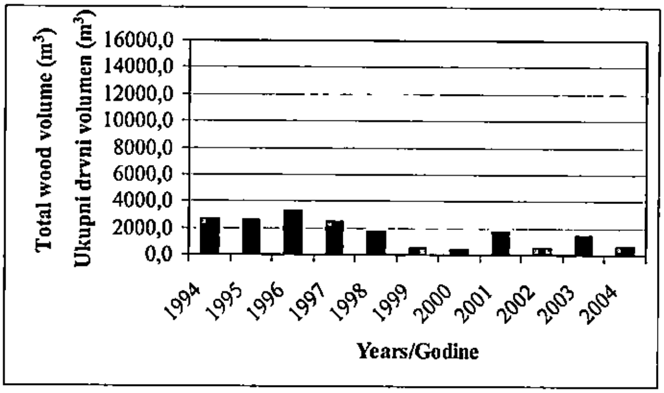


Figure 3 Total wood volume of dead silver fir trees in the management unit of Ravna Gora from 1995 to 2004.
Slika 3 Ukupni drvni volumen odumrlih stabala obične jele u gospodarskoj jedinici Ravna Gora od 1995. do 2004. godine.

In terms of mortality rate expressed as the volume of dead trees (m³) in Figures 2 and 3, significantly more severe silver fir dieback was recorded in the management unit of Brloško compared to that in the management unit of Ravna Gora.

Table 6 Rate of change by years and the average rate of change for the volume of dead trees (m^3) for the period 1995 – 2004.

Tablica 6 Stopa promjene po godinama i prosječna stopa promjene za volumen odumrlih stabala (m^3) za razdoblje 1995 – 2004. godine.

Year / *Godina*	Management Unit / *Gospodarska jedinica* Brloško %	Ravna Gora %
1995	0	0
1996	-28,85	28,96
1997	34,69	-25,13
1998	-71,33	-30,22
1999	188,57	-71,4
2000	-42,18	-14,68
2001	31,7	311,47
2002	11,9	-67,92
2003	11,46	150,8
2004	31,71	-55,5
$\hat{S}$	-0,09	-13,65

$\hat{S}$ – Average rate of change (*prosječna stopa promjene*)

The average rate of change for the management unit of Brloško related to dead wood volume (m^3) is - 0.09%, which represents slightly lower dieback intensity from 1995 to 2004. The management unit of Ravna Gora experienced a decrease in the mortality rate of silver fir. From 1995 to 2004, the average rate of change for dead wood mass (m^3) amounts to -13.65% (Table 6).

In the period between 1995 and 2004, the years 2000, 2001 and 2003 were dry years in the area of Vrelo Ličanke Meteorological Station. For the meteorological station of Lokve, dry years were 1995, 2000, 2001 and 2003, while 2000 and 2001 were dry years for the meteorological station of Ravna Gora (source DHMZ – State Hydro-Meteorological Office).

According to the results of chain indices and the rate of change of dead tree volume presented in Table 6, stands in the management unit of Brloško react more strongly to dry years compared to stands in the management unit of Ravna Gora. In the management unit of Brloško, every dry year is followed by an increase in dead tree volume; however, this is not the case with the management unit of Ravna Gora.

According to archive records, the summer of 2003 was by far the warmest since the year 1500 (Luterbacher et al., 2004). In that year the rate of change in the volume of dead trees in the area of Brloško increased by 11.46%, while in 2004 it increased by 31.71%. The rate of change of dead tree volume in the area of Ravna Gora increased by no less than 150.80% in 2003, whereas in 2004 it decreased by -55.50%.

Table 7 Average annual dieback intensities (m³/ha, N/ha) and increment of silver fir (*Abies alba* Mill.) in the compartments and subcompartments affected by tree dieback (Management plans for the management units of Brloško and Ravna Gora).

Tablica 7 Prosječni godišnji intenziteti odumiranja (m³/ha, N/ha) i prirast obične jele (Abies alba Mill.) u odjelima i odsjecima u kojima se pojavilo odumiranje stabala (Programi gospodarenja gospodarskim jedinicama "Brloško" i "Ravna Gora").

Management Unit *Gospodarska jedinica*	Dieback Intensity *Intenzitet odumiranja*		Annual Increment *Godišnji prirast*
	m^3/ha	N/ha	(m^3/ha)
Brloško	48,04	14	8,25
Ravna Gora	4,71	2	4,24

Dieback intensities in the area of Brloško exceed the increment several times, which has resulted in decreased growing stock of silver fir in some stands affected by catastrophic tree dieback.

The stands in the area of Brloško have higher increment (m^3/ha) in relation to the stands in the area of Ravna Gora. This is due to the fact that the accumulation of the growing stock in Brloško is above the normal model and that there are more trees in the third diameter class above 50 cm $d_{1.30}$ cm.

Intensive dieback leads to the formation of bigger or smaller gaps in stands, as well as to broken canopies, especially in cases in which the amount of salvage cutting is above the prescribed annual yield. Intensive salvage cuts alter the age structure and tree species composition of particular tree species (Stanovsky, 2002).

According to research by Idžojtić et al. (2005), such compartments are very vulnerable to intense infestations with the parasite European mistletoe (*Viscum album* ssp. abietis), and the situation is likely to deteriorate. The mortality rate of firs coincides with the intensity of mistletoe infestation (*Viscum album* ssp. abietis). There is a correlation between damage in silver fir forests and the incidence of mistletoe (Hofstetter, 1988).

According to Turčàni et al. (2003), salvage cuts are more frequently applied and are of a statistically significantly larger scale in more "polluted" stands. Since the forests of silver fir in Gorski Kotar are permanently exposed to harmful impacts of polluted air and precipitation, silver fir dieback will continue to affect them despite constant applications of salvage cuts.

Table 8 Average annual dieback intensity (m³/ha) and participation percentage per diameter class in the studied management stands.

Tablica 8 Prosječni godišnji intenzitet odumiranja (m³/ha) i postotak zastupljenosti po debljinskim razredima na području istraživanih gospodarskih jedinica.

Diameter class *Debljinski razred*	Brloško		Ravna Gora	
(cm)	m^3/ha	%	m^3/ha	%
I (10 – 30)	0,87	2	0,21	4
II (30 – 50)	7,05	15	0,79	17
III (> 50)	40,12	83	3,72	79

The largest dead wood mass of silver fir (m^3/ha) is in the third diameter class. As a rule, this refers to older and physiologically weaker trees. The highest values of dead wood mass (m^3/ha) per diameter class (Table 8, Figure 4) were recorded in the management unit of Brloško.

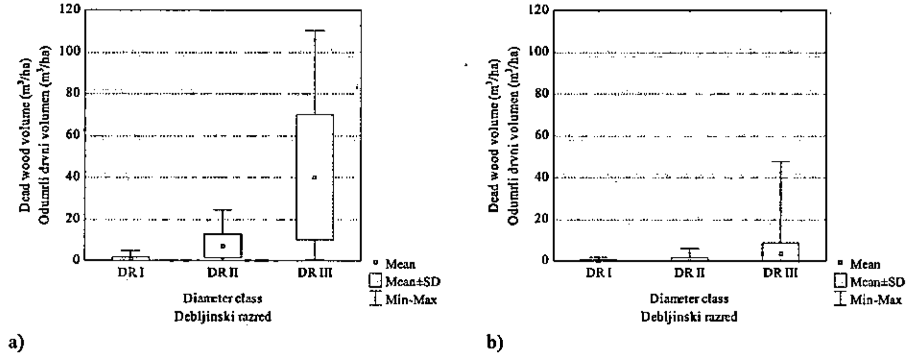


Figure 4 Dead wood volume of silver fir trees (m^3/ha) per diameter class, a) Brloško, b) Ravna Gora
Slika 4 Odumrli drvni volumen stabala obične jele (m^3/ha) prema debljinskim razredima a) Brloško, b) Ravna Gora

The participation percentage of salvage cuts or of dead wood mass of silver fir according to the prescribed annual yield in the management unit of Ravna Gora reaches up to 10%, whereas in the management unit of Brloško it reaches 100%. According to Oszlànyi (1997), a high percentage of salvage cuts (about 60% of the prescribed annual yield) is an indicator of disturbed ecological conditions and deteriorated health of forest ecosystems.

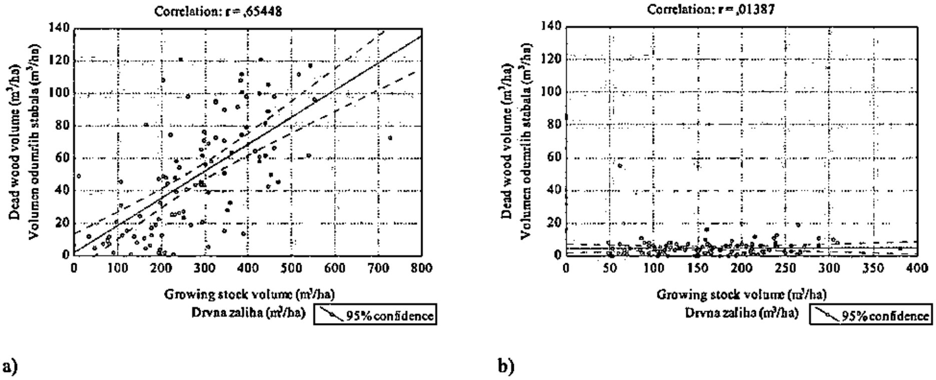


Figure 5. Statistical analysis of growing stock volume and dead wood volume (m^3/ha), a) management unit of Brloško, b) management unit of Ravna Gora.
Slika 5. Statistička analiza volumena drvne zalihe i volumena odumrlih stabala (m^3/ha) obične jele a) g.j. "Brloško" i b)"Ravna Gora".

A strong, positive and statistically significant correlation (r=0.65*) between the volume of dead silver fir trees (m^3/ha) and the growing stock of silver fir trees was found in the area of Brloško. The value of silver fir growing stock in the area of Brloško amounts to 726 m^3/ha, which is twice as much as the normal model for selection forests. The stands in Brloško have an unstable and disturbed selection structure, which Matić (1996) considers the reason for numerous changes.

These changes include, among other things, the absence of natural regeneration, an increase in the growing stock in relation to the normal one, ageing and physiological weakening, and the death of dominant trees. In contrast to Brloško, there is no correlation between the dead wood mass of silver fir (m^3/ha) and the growing stock of silver fir (m^3/ha) in the management unit of Ravna Gora. The growing stock of silver fir assumes values of up to 400 m^3/ha, which corresponds to the prescribed normal model for selection stands in this area (Figure 5).

A strong, positive and statistically significant correlation was established between dead wood mass (m^3/ha) and the stand's growing stock, mean annual temperatures and vegetation air temperatures (°C). A strong, negative and statistically significant correlation was established between dead wood mass of silver fir (m^3/ha) and annual and vegetation quantities of precipitation (mm) (Table 9).

Table 9 Linear correlation coefficient of silver fir mortality rate and climatic elements for the management unit Brloško.
***Tablica 9** Linerani korelacijski koeficijent intenziteta odumrlih stabala obične jele i klimatskih elemenata za gospodarsku jedinicu Brloško.*

	m^3/ha	m^3	Annual temp. *God. temp.*	Veg. temp. *Veg. temp.*	Annual prec. *God. oborina*	Veg. prec. *Veg. oborina*
m^3/ha	1					
m^3	0,75*	1				
Annual temp. *God. temp.*	0,55*	0,32*	1			
Veg. temp. *Veg. temp.*	0,55*	0,32*	1,0*	1		
Annual prec. *God. oborina*	-0,55*	-0,32*	1,0*	-1,0*	1	
Veg. prec. *Veg. oborina*	-0,55*	-0,32*	-1,0*	-1,0*	1,0*	1

* significant at the level of 95%

With increased mean annual and vegetational air temperatures and decreased annual and vegetational precipitation quantities, the quantity of dead wood volume of silver fir trees increases statistically significantly. These results correspond to the results of other authors (Markalas, 1992; Thomas et al., 2002; Tikvić et al., 2008).

The compartments/subcompartments in Brloško manifest an accumulation of the growing stock and a disturbed selection structure (Figure 4a). Such stands are non-resistible to climate change and oscillations of macroclimatic elements.

According to research by Usčupulić et al. (2007), climate was the main factor in the process of tree dieback in forests of Bosnia and Herzegovina. Long-lasting droughts stretching over several years had an adverse effect on plant vitality and their resistance to biotic pests (mistletoe, fungi and insects), and favoured an excessive proliferation of bark beetles beyond their population threshold.

Multiple regression results presented in Table 10 for the area of Brloško show that the growing stock (m^3/ha) and the quantity of precipitation in the vegetation period (mm) have a statistically significant effect on the volume of dead trees (m^3/ha). The growing stock Increased above the normal model and lower precipitation quantities as independent variables explain the dependent variable, i.e. the volume of dead silver fir trees (m^3/ha) with 47%.

Table 10 Multiple regression (forward stepwise) for mortality rate of silver fir trees (m³/ha) in the management unit of Brloško.

Tablica 10 Multipla regresija (forward stepwise) za intenzitet odumrlih stabala obične jele (m³/ha) na području gospodarske jedinice Brloško.

Regression Summary for Dependent Variable: dead m³/ha R= ,69362600 R²= ,48111703 Adjusted R²= ,47084212 F(2,101)=46,824 p						
	Beta	Std.Err.	B	Std.Err.	t(101)	p-level
Intercept *Intercept*			133,784	41,50538	3,22329	0,001707*
Growing stock m³/ha *Drvna zaliha m³/ha*	0,502235	0,085987	0,1283	0,02197	5,84082	0,000000*
Veg. prec. *Veg. oborina*	-0,275596	0,085987	-0,1083	0,0338	-3,20509	0,001808*

*significant at the level of 95%

In 1988, the forest range of Greek fir (*Abies cephalonica* L.) in Greece received only 60% of annual precipitation amounts, and 26% of annual precipitation in the vegetation period compared to the referent series of 1961 – 1987. Drought affecting Greece in 1988 caused physiological weakening of Greek fir and a gradation of secondary pests, which all resulted in catastrophic tree dieback in 1989 across Greece. The volume of dead trees was 2.2 times higher than the annual volume increment (Markalas, 1992). Markalas (1992) also recorded a significantly higher mortality rate of Greek fir in larger diameter classes, especially in those over 72 cm dbh.

As shown by the data in Table 11, no statistically significant correlations were established between dead wood mass and climatic elements in the management unit of Ravna Gora. Only between dead wood mass of silver fir and growing stock of silver fir was the correlation found to be positive, strong and statistically significant. The compartments / subcompartments in the management unit of Ravna Gora have the optimal growing stock and selection structure. As such, the stands are healthy and resistant to negative oscillations of macro-climatic elements.

Table 11 Linear correlation coefficient of mortality rates in silver fir and climatic elements for the management unit of Ravna Gora.

Tablica 11 Linerani korelacijski koeficijent intenziteta odumrlih stabala obične jele i klimatskih elemenata za gospodarsku jedinicu Ravna Gora.

	m³/ha	m³	Annual temp. *God. temp.*	Veg. temp. *Veg. temp.*	Annual prec. *God. oborina*	Veg. prec. *Veg. oborina*
m³/ha	1					
m³	0,54*	1				
Annual temp. *God. temp.*	0,02	0	1			
Veg. temp. *Veg. temp.*	0,02	0	1,0*	1		
Annual prec. *God. oborina*	-0,02	0	-1,0*	-1,0*	1	
Veg. prec. *Veg. oborina*	-0,02	0	-1,0*	-1,0*	1,0*	1

* significant at the level of 95%

The climate in the area of Ravna Gora does not have any significant effects on the volume of dead trees. As stated in the results of multiple regression, the volume of dead trees (m³/ha) is statistically significantly affected by the inclination and the stands' growing stock (m³/ha).

An increase in terrain slope and stands' growing stock above the normal model as an independent variable in the area of Ravna Gora explain the volume of dead trees by 6% (Table 12).

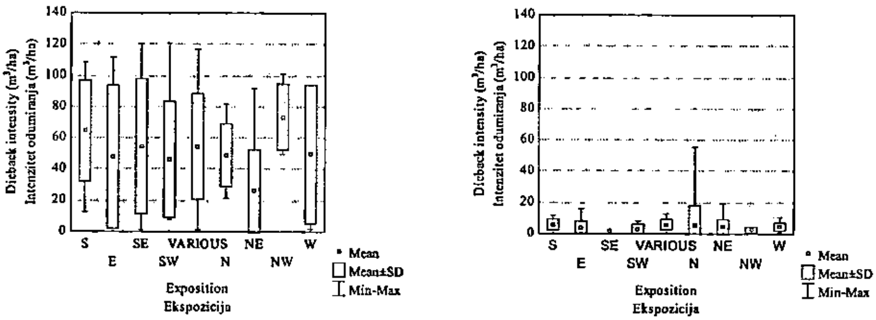
Table 12 Multiple regression (forward stepwise) for mortality rate (m^3/ha) in the management unit of Ravna Gora.
Tablica 12 Multipla regresija (forward stepwise) za intenziteta odumrlih stabala (m^3/ha) na području gospodarske jedinice Ravna Gora.

Regression Summary for Dependent Variable: odumrlo m^3/ha, R=,28947615 R^2=,08379644 Adjusted R^2=,06758045 F(2,113)=5,1675 p						
	Beta	Std.Err.	B	Std.Err.	t(113)	p-level
Intercept *Intercept*			-1,88322	2,398404	-0,785195	0,433982
IncL *Nagib*	0,301004	0,093738	0,33155	0,10325	3,211121	0,001722*
Growing stock m^3/ha *Drvna zaliha m^3/ha*	0,097537	0,093738	0,00812	0,007801	1,040532	0,300314

* significant at the level of 95%

Stanovsky (2002) studied the influence of climatic factors on the health condition of forest ecosystems in the Czech Republic. Over the monitored ten-year period (1991 – 2000), the mortality rate trend coincided with the length of dry periods. Using a cross-correlation function he found statistically significant dependence between the length of the dry period (days) and the volume of dead trees. According to this author, the cause of catastrophic decline of lowland forest ecosystems in the Czech Republic lies in low amounts of precipitation in the vegetation period and secondary pest gradation. Despite climate changes or oscillation, the biggest problem in selection forests of beech and fir in Croatia is the irregular selection structure and excessive growing stock in relation to normal one. In some areas this leads to intensive silver fir dieback, as confirmed by the example of the management unit of Brloško. Matić et al. (1996) arrive at similar results and conclude that the biggest problem of selection forests of fir and beech in Croatia is their irregular selection structure. The authors believe that selection structure is the basic prerequisite for good-quality functioning of selection forests of fir and beech.

Fir dieback is caused by a combination of several factors, of which one can be dominant in one area, while some other can dominate in another area (Šafar, 1965; Prpić et al., 2001).



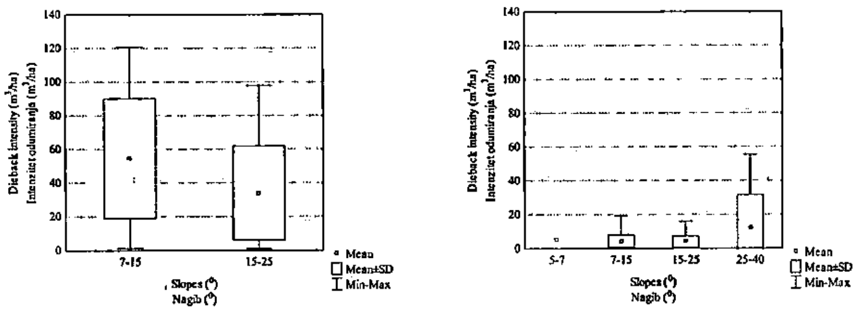
a) b)

Figure 6 Dieback intensity of silver fir trees according to exposition classes a) Brloško, b) Ravna Gora.
Slika 6 Intenziteti odumiranja stabala obične jele prema klasama ekspozicije a) Brloško, b) Ravna Gora.

The lowest mortality rate in the area of Brloško was recorded on northern slopes, while the highest was noted in the subcompartments in north-westerly, southerly and westerly expositions. With regard to rising trends in mean annual and vegetation air temperatures, southerly and westerly expositions are becoming increasingly unfavourable for tree species with narrow ecological valence, such as the silver fir (*Abies alba* Mill.)

The lowest mortality rate of silver fir in the area of Ravna Gora was found in northerly and south-easterly expositions, while the highest was found in the subcompartments in different expositions.

Research undertaken by Tikvić et al. (2008) into silver fir dieback in Northern Velebit revealed the lowest volume of dead trees in northerly expositions and the highest in different variants of southerly expositions, as well as in subcompartments at different expositions.

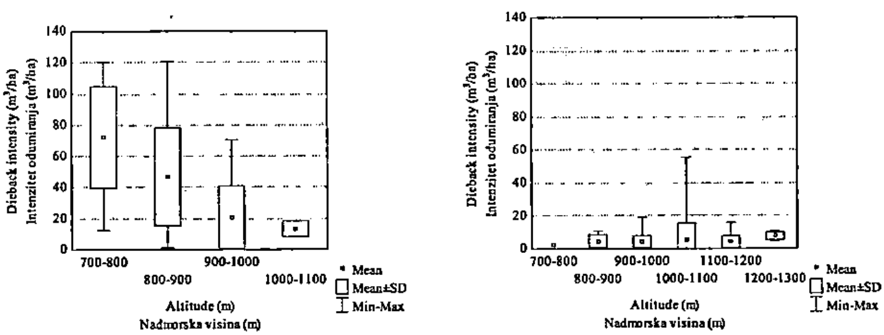


a) b)

Figure 7 Dieback intensity of silver fir trees according to classes of terrain slope a) Brloško, b) Ravna Gora.
Slika 7 Intenzitet odumiranja stabala obične jele prema klasama nagiba terena a) Brloško, b) Ravna Gora.

The highest values of dead tree volume in the management unit of Brloško were found at lowest altitudes and milder slopes (Figure 7 and Figure 8).

The most severe dieback in the management unit of Ravna Gora occurs on very steep slopes, whereas on other slopes dieback of silver fir trees is more or less even (Figure 7).



a) b)

Figure 8 Dieback intensity of silver fir trees according to altitude classes a) Brloško, b)Ravna Gora.
Slika 8 Intenzitet odumiranja stabala obične jele prema klasama nadmorske visine a) Brloško, b) Ravna Gora.

The highest mortality rate in the management unit of Ravna Gora occurred beyond 1,200 m above the sea and the lowest between 700 and 800 m above the sea (Figure 8). According to the multiple regression results in this research (Tables 10 and 12), an increase in the stand growing stock is proportionately related to the increase in the dieback index of silver fir trees. Stands with larger growing stock were found at lower altitudes. They manifested a higher index of silver fir dieback compared to higher altitudes. The largest mortality rate values (m^3 and m^3/ha) were confirmed at lowest altitudes and milder slopes. The same results were also obtained by Tikvić et al. (2008) and Ugarković (2009). Interestingly, meteorological stations at lower altitudes recorded bigger climate changes and a larger number of dry years than those at higher altitudes (Tikvić et al. 2008). The management unit of Brloško is situated on the boundary of silver fir distribution range in Gorski Kotar. This in itself places it into a climatically adverse area for the development of these forest ecosystems.

CONCLUSIONS
ZAKLJUČCI

In relation to the referent series, mean annual air temperatures in the area of Vrelo Ličanke and Lokve Meteorological Stations rose by 0.5 to 1.1 °C in the period 1995 to 2004, while vegetational temperatures rose by 0.6 to 1.2 °C. This increase in air temperatures is not statistically significant. Lower annual precipitation quantities of 47 mm and vegetational quantites of 27 mm were recorded in relation to the referent series. Decreased precipitation quantities are not statistically significant.

The average rate of change in dieback intensity (m^3) is mildly falling and amounts to -0.09 % in the area of Brloško MU, while in the area of Ravna Gora MU it amounts to -13.65 %.

The highest mortality rate of silver fir was recorded in the management unit of Brloško, with the average annual mortality rate reaching 48 m^3/ha or 14 trees per ha. The average annual mortality rate in the management unit of Ravna Gora is 5 m^3/ha or 2 trees per ha.

Dieback intensities calculated for the stands affected by dieback in the area of Brloško MU were on average six times higher than stand increments. Dieback intensities were slightly higher than stand increments in the management unit of Ravna Gora.

The highest percentage of dead trees, as well as the average value of dead trees (m^3/ha) is in diameter class III.

The correlation between dead volume of silver fir (m^3/ha) and annual and vegetational air temperatures is positive, strong and statistically significant, while that between dead wood mass and annual and vegetational precipitation quantities is negative.

No correlation was found between the volume of dead silver firs and climatic elements in the area of the management unit Ravna Gora.

The correlation between the volume of dead silver firs and the stands' growing stock is strong, positive, and statistically significant in the area of Brloško, whereas in the area of Ravna Gora it does not exist.

Dead silver fir trees were found in all expositions, as well as in all classes of altitude and terrain slope.

In the area of Brloško the lowest rate of tree dieback was recorded in northerly, and the highest in north-westerly, southerly and westerly expositions. In the area of Ravna Gora, the lowest rate of tree dieback was also recorded in northerly expositions, while the highest was found in subcompartments at different expositions.

In Brloško, the highest rate of tree dieback occurs on mildly sloping terrains, whereas in Ravna Gora it takes place on very steep slopes.

In Brloško, the highest rate of tree dieback was recorded at lowest altitudes, but in Ravna Gora it was recorded at highest altitudes.

REFERENCES
LITERATURA

Asp, H., B. Bengtsson, P. Jensen, 1988: Growth and cation uptake in spruce (*Picea abies* Karst.) grown in sand culture with various aluminium contents, Plant Soil 111, p. 127-133.

Androić, M., 1969: Problem sušenja jele u Gorskom kotaru, Lici i Sloveniji. Šumarski list, br.1-2

Andrzejczyk, T., S. Mišcicki, T. Zachara, M. Zwieniecki, 1987: Natural regeneration of White fir in dying outstands of Puszcza Jodlowa (white fir primeval forest). Ann. Wars. Agr. Univ. 35, 3-10.

Berninger, R., 1997: Effects of drought and phenology on GPP in *Pinus sylvestris*: A simulation study along a geographical gradient. Funct. Ecol. 11: 33-42.

Busing, R. T., F. F. Pauley, 1994: Mortality trends in a southern Appalachian red spruce population. Forest Ecology and Management, 64: 41-45.

Capecki, Z., 1981: The rules of prediction of vulnerability and protection of spruce forests against insect pests following after damage caused by wind and rime. Prace Inst. Bad. Leśn., 584, p. 3-44.

Fromard F., J. Dagnac, T. Gauqelin, V. Cheret, 1991: Results of research into decay of the fir (*Abies alba* Mill.) in the Pyrenees, New Data about Nutritional and Physiological Disturbances. U: Acid Deposition. Origins, Impacts and Abatement Strategies. Springer-Verlag, Berlin, str. 109–122.

Gajić-Čapka, M., M. Perčec Tadić, M. Patarčić, 2003: Digitalna godišnja oborinska karta Hrvatske. Hrvatski meteorološki časopis 38: 21-33.

Glavač, V., H. Koenies, B. Prpić, 1986: O unosu zračnih polutanata u bukove i bukovo-jelove šume Dinarskog gorja Sjeverozapadne Jugoslavije. Šumarski list CIX: 429-446.

Hofstetter, M., 1988: Über die Verbreitung der Mistel in der Schweiz. Schweiz. Z. Forstwes. 139 (2): 97-127.

Idžojtić, M., M. Glavaš, M. Zebec, R. Pernar, M. Dasović, N. Pavlus, 2005: Zaraza obične jele (*Abies alba* Mill.) bijelom imelom (Viscum album L. spp. Abietis /Wiesb./ Abrom.) u Hrvatskoj. Šumarski list 11-12: 559-573.

Korpel, S., 1985: Stav a vyvoj jedle na Slovensku vo vztahu k jej odumieraniu. Acta. Fac. For. 27, 79-102 (in Czech, with English abstract).

Krause, G., U. Arndt, C.,J. Brandt, J. Bucher, G. Kenk, E. Matzner, 1986: Forest decline in Europe: Development and possible causes. Water, Air and Soil Poll. 31: 647-668.

Luterbacher, J., D. Dietrich, E. Xoplaki, M. Grosjean, H. Wanner, 2004: European seasonal and annual temperature variability, trends and extremes since 1500. Science 303: 1499-1503.

Málek, J., 1981: Jedle v pralesovitych rezervacich a vybernych lesich. Les. Pr. 6, 255-259.

Markalas, S., 1992: Site and stand factors related to mortality rate in a fir forest after a combined incidence of drought and insect attack. Forest Ecology and Management, Vol.47: 367-374.

Matić, S., Oršanić, M., Anić, I., 1998.: Utjecaj klimatskih promjena na strukturu i razvoj šumskih ekosustava, HAZU, str. 239-250.

Matić, S., Oršanić, M., Anić, I., 1996.: Neke karakteristike i problemi prebornih šuma obične jele (*Abies alba* Mill.) u Hrvatskoj, Šumarski list br.3-4: 91-99.

Matić, S., I. Anić, M. Oršanić, 2001: Silvicultural procedures in selection forests. In: Prpić B (ed) Silver fir in Croatia. Academy of Forests Science, Zagreb, p 407-443

Meštrović, Š., 2001: Managing forests of silver fir. In: Prpić B (ed) Silver fir in Croatia. Academy of Forests Science, Zagreb, p 529-547

Mindáš, J., J.Škvarenina, K. Střelcova, T. Priwitzer, 2000: Influence of climatic changes on Norway spruce occurrence in the west Carpathians. Journal of Forest Science, Vol.46: 249-259.

Oszlànyi, J., 1997: Forest health and environmental pollution in Slovakia, Environmental Pollution, Vol.98, No.3, p. 389-392.

Potočić, N., T. Ćosić, I. Pilaš, 2005: The Influence of Climate and Soil Properties on Calcium Nutrition and Vitality of Silver Fir (*Abies alba* Mill.). Environmental Pollution, 137/3: 596- 602.

Program gospodarenja gospodarskom jedinicom "Brloško" 2000 – 2009 godina

Program gospodarenja gospodarskom jedinicom "Ravna Gora" 2001 – 2010 godina

Prpić, B., Z. Seletković, P. Jurjević, 2001: Dieback of Fir and changes in the "Chemical climate". In: B. Prpić (ed) Silver fir in Croatia. Academy of Forest Science, Zagreb, p 299–312.

Prpić, B., 1975: Zakorijenjivanje i hidratura obične jele. Radovi, 23: 41-53.

Schlaepfer, R., 1993: Long-term implications of climate change and air pollution on forest ecosystems. Progress report of the IUFRO Task Force Forest Climate Change and Air Pollution. Vienna, IUFRO, Birmensdorf, WSL. IUFRO Series 4:132.

Seletković, Z., 2001: Klima i hidrološke prilike u dinarskim jelovim šumama u Hrvatskoj. U: Prpić, B. (ur.), Obična jela (Abies alba Mill.) u Hrvatskoj, Akademija šumarskih znanosti i Hrvatske šume, p.o. Zagreb, Zagreb, 133–141.

Seletković, Z., M. Ivkov, I. Tikvić, 1993: Prilog istraživanjima klimatskih elemenata i pojava u zagrebačkoj regiji tijekom ovog stoljeća. Glasnik za šumske pokuse 4: 25-34

Siwecki, R., K. Ufnalski,1998: Review of oak stand decline with special reference to the role of drought in Poland, Eur. J. For. Path. 28 : 99-112.

Stanovsky, J., 2002: The influence of climatic factors on the health condition of forests in the Silesian Lowland. J. For. Science, 48:451-458.

Šafar, J., 1965: Problem sušenja jele i način gospodarenja na Macelj gori. Šumarski list 1-2:1-16.

Thomas, L. A., C. J. Gegout, G. Landmann, E. Dambrine, D. King, 2002: Relation between ecological conditions and fir decline in a sandstone region of the Vosges mountains (northeastern France), Annales of Forest Science, 59: 265-273.

Tikvić I, Z. Seletković, 2004: Propadanje stabala i poremetnja stabilnosti nizinskih šumskih ekosustava. Bilten Parka prirode Lonjsko polje 6: 58-67.

Tikvić, I., Z. Seletković, D. Ugarković, S. Posavec, Ž. Španjol, 2008: Dieback of Silver Fir (*Abies alba* Mill.) on Northern Velebit (Croatia). Periodicum Biologorum 110 (2): 137-143.

Turčani, M., W. Grozdki, P. Fleischer, J. Novotny, B. Hrašovec, 2003: Can air pollution influence spruce bark beetle population in the central European mountains? Ekologia (Bratislava), 22: 371-382.

Ugarković, D., 2009: Utjecaj stanišnih i strukturnih čimbenika na odumiranje obične jele (Abies alba Mill.) u Gorskom kotaru. Disertacija, Šumarski fakultet, Zagreb, str. 200.

UN-ECE, EC 2003: The Condition of Forests in Europe. Federal Research Centre for Forestry and Forests Products, Geneva, Brussels.

Usčupulić, M., M. Dautbašić, T. Treštić, E. Selman, O. Mujezinović, T. Nišić, B. Jokanović 2007: Bolesti i štetnici obične jele (Abies alba Mill.) u Bosni i Hercegovini. Društvo za zaštitu bilja u Bosni i Hercegovini. Str. 114. Sarajevo.

WMO, 2001: Climate Change 2001, IPCC Third assessment reports WG1, WG2, WG3, IPCC Summaries for politymakers WG1, WG2, WG3, IPCC Synthesis Report to the TAR.

Zaninović, K., L. Srnec, M. Perčec Tadić, 2004: Digitalna godišnja temperaturna karta Hrvatske. Hrvatski meteorološki časopis 39: 51-58.

www.dhmz.hr

UDK: 630*231.321

Original scientific paper
Izvorni znanstveni članak

NATURAL REGENERATION OF SILVER FIR (*Abies alba* MILL.) ALONG THE EDGE OF THE ZAGREB – RIJEKA MOTORWAY

PRIRODNO POMLAĐIVANJE OBIČNE JELE (Abies alba MILL.) NA RUBNOM POJASU AUTOCESTE ZAGREB – RIJEKA

IGOR ANIĆ[1], MARKO PERKOVIĆ[2], STJEPAN MIKAC[1]

[1]University of Zagreb, Faculty of Forestry, Department of Forest Ecology and Silviculture,
[2]Klađe 39, 51322 Fužine

Received – *prispjelo*: 17.12.2009. Accepted – *prihvaćeno*: 26.2.2010.

Abstract

The paper analyses the qualitative and quantitative characteristics of natural young growth on the edge of a beech-fir stand. Research was undertaken in Gorski Kotar. The research site is situated within Fužine Forest Administration, in the management unit of Brloško, the forest district of Gorica, compartment 70, along the southward lane of the Zagreb – Rijeka motorway, at the section between the Bajer viaduct and the Tuhobić tunnel. The altitude is 770 meters, the exposition is northern, and the terrain inclination is 10 – 25 °. The investigated stand grows on dystric brown soil and belongs to the forest community of fir forest with hard fern (*Blechno-Abietatum* Ht. 1950). The seedlings and the young growth were measured in four edge zones with different conditions of stand closure and illumination. Four square plots of 4 m² each placed five metres apart were set up within each zone. The quantitative and qualitative features of natural young growth on the edge of the studied stand change in dependence on the stand canopy closure. The most densely regenerated part is the outer edge zone. Compared to other zones, this zone features the largest number of silver fir plants above 50 cm, as well as their best growth. In all the zones the ratio between the length of the terminal and the first lateral shoot is less than one. Pioneer tree species occur on the outer edge of the regeneration area. Marking should include only broken, rotting, diseased, canker-affected and similar trees in the part of the outer forest edge. Since this part is exposed to sufficient quantities of light, excessive cutting might result in the spread of weeds in the site. Groups of young plants should be gradually freed in order to enable their undisturbed growth and penetration into the upper stand layers.

Key words: Abies alba Mill., edge regeneration, forest edge, Zagreb – Rijeka motorway

Sažetak

U radu su analizirane kvalitativne i kvantitativne značajke prirodnoga pomlatka u rubnom pojasu jelovo-bukove sastojine. Istraživanje je obavljeno u Gorskom kotaru. Lokalitet istraživanja nalazi se na području šumarije Fužine, u Gospodarskoj jedinici Brloško, šumski predjel Gorica, odjel 70, uz južni prometni trak autoceste Zagreb – Rijeka, na dionici između vijadukta Bajer i tunela Tuhobić. Nadmorska visina je 770 metara, ekspozicija sjeverna, a nagib terena 10 – 25%. Sastojina u kojoj je obavljeno istraživanje pripada šumskoj zajednici jelove šume s rebračom (Blechno-Abietetum Ht. 1950), na distričnom smeđem tlu. Mjerenje ponika i pomlatka obavljeno je u četiri zone rubnoga pojasa koje predstavljaju različite uvjete sastojinskog sklopa i osvjetljenja. Unutar svake zone, na razmacima po pet metara, postavljene su četiri plohe kvadratnoga oblika, svaka površine 4 m². Kvantitativne i kvalitativne značajke prirodnoga pomlatka na rubu istraživane sastojine se mijenjaju ovisno o sastojinskom sklopu. Najgušće je pomlađena vanjska rubna zona. U toj je zoni ustanovljen najveći broj biljaka obične jele iznad 50 cm te njezin najbolji rast u odnosu na druge zone. U svim je zonama odnos duljine vršnog i prvog lateralnog izbojka manji od jedan. Pionirske vrste drveća se pojavljuju na vanjskom dijelu rubne pomladne površine. Doznaku treba provoditi na način da se u dijelu vanjskog ruba šume doznačuju samo prelomljena, natrula, bolesna, rakasta i slična stabla.

U ovom dijelu ima dovoljno svjetla, pa prekomjerna sječa može dovesti do zakorovljenja staništa. U unutarnjoj rubnoj zoni treba postupno oslobađati grupe pomlatka kako bi se omogućio njihov nesmetan razvoj i urastanje u gornje slojeve sastojine.

Ključne riječi: Abies alba Mill., rubno pomlađivanje, šumski rub, autocesta Zagreb – Rijeka

INTRODUCTION
UVOD

Forests represent an ecological stronghold of an area. In Croatia, they are officially considered a kind of an infrastructural system (Physical Planning Programme of the Republic of Croatia, Official Gazette 50/99). Fir-beech forests in the Croatian Dinaric range have particular importance. Since they extend across a belt with the highest quantity of precipitation in Europe, their hydrological and water-protective function is exceptionally significant. Together with mountain beech forests, maritime beech forests and forests of pubescent oak, they considerably affect the balance of water relations and the purification of water that penetrates into the karst underground. Other non-wood forest functions, especially those related to the tourist function of a forest, such as aesthetic, recreational and climatic, gain particular importance in the littoral karst space, and so does the wind-protective element of the climatic forest function. In winter and during severe winds it protects the roads from winds and rock slides, and in higher areas from snow drifts (Prpić 2001).

The construction of infrastructural facilities, such as motorways, transmission lines, oil and gas pipe networks and similar through forest complexes is perceived as one of the factors that threaten sustainable development and cause problems in the management with Croatian forests (Matić et al. 2005, Matić 2004). Thus, a part of the forest land and fir-beech forests in Gorski Kotar, the most forested part of the Republic of Croatia, has been lost to the motorway between Zagreb and Rijeka. Moreover, the route of the motorway has altered the site and structural features and has curtailed the possibility of natural regeneration on the edge of the stands along the motorway.

The goal of this research was to examine the qualitative and quantitative features of natural regeneration on the forest edge along the motorway that runs through fir-beech forests in Gorski Kotar. Based on the results, a method of tree marking was proposed for the edge of these stands.

With the exception of the altimontane belt, the motorway network in the Republic of Croatia intersects all forest vegetation belts. Gorski Kotar was selected for research because forests are its basic natural resource. Consequently, every impact on the forest is directly reflected on general life conditions in this area. According to Pavić (1981), 75% of the area of Gorski Kotar is covered with forests. Silver fir is a skiophilic and climatogenic tree species and as such is exceptionally vulnerable to sudden changes in structural and site conditions. Research was aimed at determining how the conditions on the forest edge affect the possibility of its natural regeneration.

The research, was conducted in the Institute of Forest ecology and Silviculture of the Faculty of Forestry, University of Zagreb in the form of graduate work (Perković 2008). The work was performed within the project entitled 'Regeneration Dynamics of Beech-Fir Virgin Forests in the Croatian Dinaric Mountains' (No. 068-0682041-1950) of the Ministry of Science, Technology and Sports of the Republic of Croatia.

RESEARCH AREA
PODRUČJE ISTRAŽIVANJA

Research was undertaken not far from the town of Fužine in Gorski Kotar. Gorski Kotar is situated in the western part of the Dinaric range in the Republic of Croatia. In the north it borders with Slovenia, in the west with the Rijeka littoral, in the south with Lika and in the east with the area of the town of Ogulin. The research site is located within Fužine Forest Administration, in the management unit of Brloško, the forest district of Gorica, compartment 70, along the southward lane of the Zagreb – Rijeka motorway, at the section between the Bajer viaduct and the Tuhobić tunnel. The altitude is 770 m, the exposition is northern and the terrain slope is 10 – 25°.

According to Seletković (2001), the average annual precipitation amount in the area is 2,000 mm and air moisture is 88%. The mean annual air temperature is 7 °C. Absolute minimal and maximal temperatures are -33.3 °C and 34.0 °C. The warmest month is July, which is also the month with the least amount of precipitation. The average air temperature in July is 17 °C. With the average air temperature of -3.9 °C, January is the coldest month.

The plot where research was conducted lies on dystric brown soil. This soil type, along with brunipodzol and podzol, is characteristic of Palaeozoic and Triassic clastites and schists in Dinaric fir forest of Croatia (Pernar 2001).

The investigated stand belongs to the forest community of fir forest with hard fern (*Blechno-Abietetum* Ht. 1950). The tree layer is dominated by silver fir (*Abies alba* Mill.), which is regularly accompanied by spruce (*Picea abies* Karst.) and mountain ash (*Sorbus aucuparia* L.), as well as by less vigorous beech (*Fagus sylvatica* L.), as reported by Vukelić and Baričević (2001). The forest stands have a group structure, and the form of management is selection with group felling (Matić et al. 2001).

RESEARCH METHODS
METODE ISTRAŽIVANJA

After the study area has been surveyed, the locality representing the average stand and site conditions at the forest edge was selected.

The seedlings and the young growth were measured in four edge zones which represent different conditions of stand canopy and light. Zone A, located in the interior of the forest stand, is the control zone. It is fully canopied and is not directly influenced by lateral light. Zone B is situated on the inner edge of the stand. It receives some lateral light although the canopy is complete. Zone C is situated on the outer edge of the stand. The canopy is broken and is directly affected by light coming from the sides and the above. Zone D extends over a bare area. This is the outer edge of the stand fully exposed to daylight. It is sheltered by tree shadows in late afternoon hours. The distance among the zones has not been determined beforehand; instead, it has been regulated by the canopy and light. Four square plots of 4 m² each (2 x 2 m) were set up five metres apart in every zone. The young generation of all tree species was measured in each plot. The following variables were measured for the fir: plant height, the length of the terminal shoot and the length of the first lateral shoot. Tree age was obtained by counting the internodes. The parameters for the beech and mountain ash included height (vertical distance from the soil to the terminal bud) and the length of the bole from the root base to the terminal bud. All trees with dbh of 3 cm were included in the measurement.

The entire edge belt is comprised within a plot in which breast diameters, heights, position coordinates, the crown plan and profiles of all the trees with dbh exceeding 3 cm were measured. The plot covers an area of 1,100 m² (25 x 44 m).

The plot lies on the terrain whose profile mainly follows the average slope of 22.8°. The highest part of the plot is at an altitude of 770 m and the lowest part before the cutting slope of the motorway is about 760 m above the sea.

The obtained data were processed and tested by means of Excel and Statistica software. Stand Visualisation System (SVS) was used to draw the stand profile and crown projections. The measurements were performed in July 2006.

RESEARCH RESULTS AND DISCUSSION
REZULTATI ISTRAŽIVANJA I RASPRAVA

Stand profile and horizontal crown projection on the forest edge
Profil sastojine i horizontalna projekcija krošanja na rubnom šumskom pojasu

An ideal selection structure of a stand consists of trees of different dimensions whose distribution across a surface unit mirrors the characteristic selection tree distribution, where a normal amount of wood supply is distributed in such a way as to ensure the maximal increment, optimal natural regeneration, and ecosystem stability (Matić et al. 2001). Such a structure of selection stands in the Croatian Dinaric range is defined by normal models (Klepac 1997, 1962, 1961). According to the Management Plan (2000 – 2009), the investigated stand has the volume of 399.53 m^3/ha, of which 5% is accumulated on trees with dbh up to 30 cm, 39% on medium thick trees with dbh between 31 – 50 cm, and the rest of 56% is accumulated on trees with dbh over 51 cm. The stand composition is dominated by silver fir which participates with 77.30%, followed by beech with 21.47%, common spruce with 1.13% and other species accounting for 0.10%. It is interesting to note that there are no silver firs among thin trees with dbh up to 30 cm. In this class the dominant species is common beech. The majority of silver firs are mature trees with dhb over 50 cm. Stand density is 0.62 and the annual current volume increment is 6.04 m^3/ha. What follows is the description of the stand: "An uneven-aged fir stand in the stage of thick and medium thick trees. Beech occurs individually or in smaller groups and is in the stage of medium thick trees. In parts with less dense canopy there are small groups of young beech growth and some sporadic groups of young growth and saplings of fir. The fir's health status is poor." The management guidelines state the following: "the prescribed yield for the fir should relate only to dying and dead trees, while the difference up to the full yield should be realized by cutting mature and mechanically damaged trees in parts in which they interfere with the young generation. In terms of beech, only some individual beeches that are damaged should be cut down. In parts with fully canopied mature trees felling should be applied in order to open up groups where regeneration will be initiated".

Regular and salvage felling of snags in the period 2000 – 2009 included a total of 205 m^3/ha, of which fir accounted for 94%. Thus, the cutting amount exceeded the planned prescribed yield in the stand with reduced density. These data relate to the average picture of the stand as a whole.

Similar situations were obtained with the analysis of stand edge structure. Forty-seven trees in all were counted in the studied plot, of which 10 were firs, 30 beeches, 3 mountain ashes and 4 birches. Their spatial distribution with crown profiles and projections by edge zones are given in Figure 1. Zone A is characterized by a vertical rather than a selection form of canopy, as a result of the lack of trees in the lower stand profile layer. The ground plan shows that the soil is multiply shaded with the crowns, because silver firs and common beeches with occasional mountain ashes grow one next to the other and one above the other in the top and medium layer.

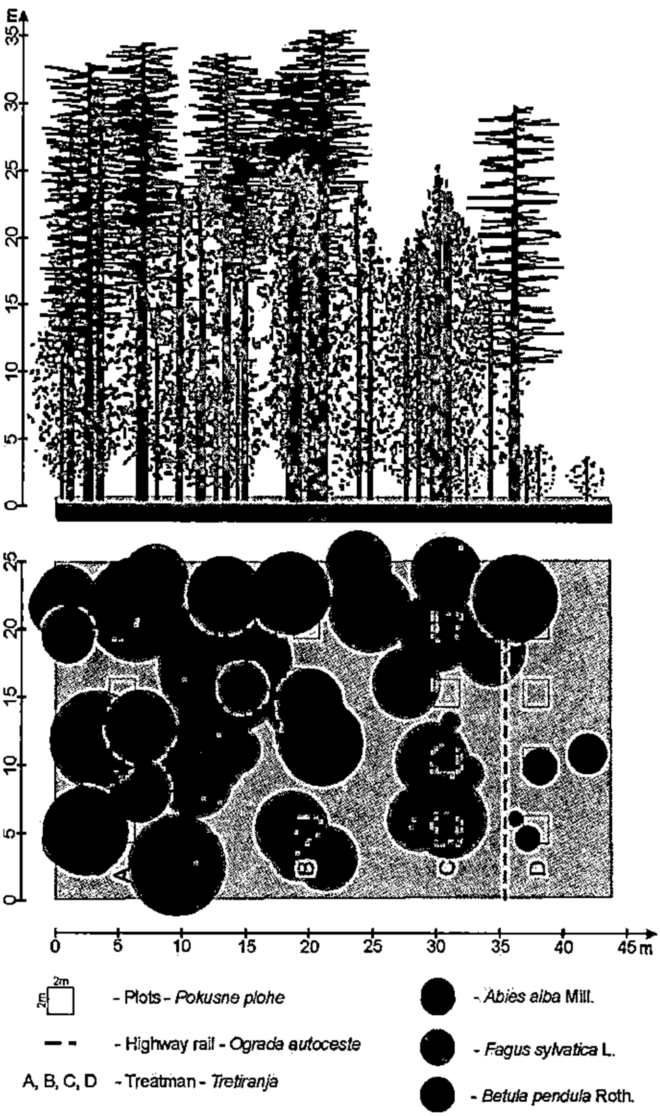


Figure 1 Stand profile and horizontal crown projection in the zones A – D of the forest edge.
Slika 1 Profil sastojine i horizontalna projekcija krošanja u zonama A – D rubnog šumskog pojasa.

Zone B is the inner, and zone C the outer part of the stand edge. Whereas zone B contains mature fir trees that dominate in the stand profile, this is not the case with zone C. Here, fir trees have been removed due to desiccation. Only beech trees from the middle stand layer have remained. Zone C is covered with some sporadic groups of birches and some single trees of silver fir. The canopy is broken. Zone D contains single birches which announce the beginning of forest succession.

The structure of the young growth
Struktura mladog naraštaja

Table 1 shows the structure of the young growth by tree species and plots, separately for each zone. In the 16 plots distributed over four zones of the forest edge, 603 seedlings and saplings, or an average of 9 plants per square metre, were identified. The highest amount of the young growth was recorded in the outer edge (zone C). The average number of seedlings and saplings in zone A is 3 pcs/m² and in zone B it is 10 pcs/m². Zone C is the most densely regenerated (20 pcs/m²), while zone D contains an average of four plants per square metre.

Table 1 Average density of the young growth by tree species and edge zones.
Tablica 1 Prosječna gustoća pomlatka po vrstama drveća i zonama rubnog pojasa.

Zone *Zona*	Plot *Ploha*	*Abies alba*	*Fagus sylvatica*	*Sorbus aucuparia* / *Betula pendula*	Total *Ukupno*
		pcs/4 m² – kom/4 m²			
A	1	18	6	5	29
	2	2	3	0	5
	3	2	11	1	14
	4	1	5	1	7
	Σ/N	**5,75**	**6,25**	**1,75**	**13,75**
B	1	26	10	0	36
	2	32	10	3	45
	3	35	17	3	55
	4	16	9	1	26
	Σ/N	**27,25**	**11,50**	**1,75**	**40,50**
C	1	54	11	5	70
	2	73	5	1	79
	3	77	6	4	87
	4	69	11	1	81
	Σ/N	**68,25**	**8,25**	**2,75**	**79,25**
D	1	0	0	5	5
	2	2	0	9	11
	3	17	2	5	24
	4	26	2	1	29
	Σ/N	**11,25**	**1,00**	**5,00**	**17,25**

The most represented species in the young growth is silver fir (75%), followed by common beech (18%), and mountain ash and birch (7%). Silver fir has manifested the best regeneration results in the inner and outer edge zone (zones B and C). In other zones, its regeneration was equal to that of other tree species. The comparison of these results with the results of other research into the density of natural young growth in identical stands (Matić et al. 1996; Matić 1992, 1972) shows that, on average, silver fir regenerates well. However, the analysis by zones shows a somewhat different picture.

Fir seedlings occur is equally distributed in all the zones. Fir plants up to 50 cm in height are the most numerous in the inner zone (zone B, 6 pcs/m²) and the outer edge zone (zone C, 14 pcs/m²). On average, two plants of silver fir per square metre exceeding 50 cm were identified in zone C, whereas such plants are absent from zone B. In the inner part of the stand (zone A), the average density is less than one fir per square metre. Fir also regenerates in zone D. Here, the young growth is sporadically distributed and never exceeds the height of 50 cm.

This is the zone of birch and mountain ash regeneration, mainly along the cutting slope of the motorway.

Analysis of the young growth
Analiza pomlatka

The age and height of the young growth of silver fir are compared in Figure 2. The data were equalized by means of a second degree polynomial. An increase in the age of young firs is accompanied with abrupt increase in the scope of height distribution. Accordingly, by counting internodes the height of the young growth can be assessed with an accuracy of 65% (R^2=0.65). For example, the height of the silver fir at age 15 can oscillate between 10 centimetres to almost 140 centimetres. This result can be attributed to the skiophilic nature of the silver fir. Plants that live in the shade for longer periods have lower values of the height increment and lower total height in relation to plants of the same age which are exposed to more light. In the first 10 years of life, all the plants have similar heights, which rarely exceed 20 cm. After this, plants which receive more light show sudden upward growth.

The same ratio was analyzed in terms of individual zones (Figure 3). The least difference was found in those young plants of silver fir which grow in conditions of full stand canopy (zone A). In the first ten years these plants did not reach more than 20 cm in height. A similar situation was found in the plants growing in the bare area (zone D). As a skiophilic and climatogenic tree species, silver fir reacted to both minimal and maximal amounts of light with poor height growth in the first decade of life. After this, the young growth disappeared. Its stagnation and disappearance in zone A is attributed to the absence of light and to disturbed structural stand conditions, and in zone D to excessive light. In the inner and outer zone of the forest edge the young growth survived even after 10 years of life and began to grow in height intensively, with the difference that in zone B the growth was even, while in zone C it was uneven. At age 11, the average age of young growth of silver fir is the largest in zone C and the smallest in zone D.

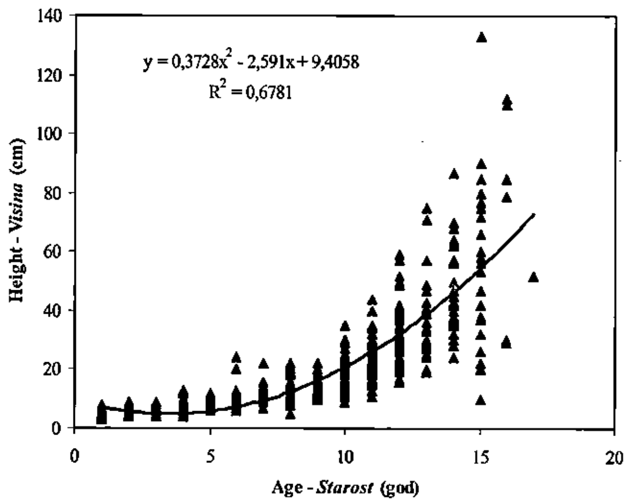


Figure 2 Age to height ratio of the young growth of silver fir.
Slika 2 Odnos između dobi i visine pomlatka obične jele.

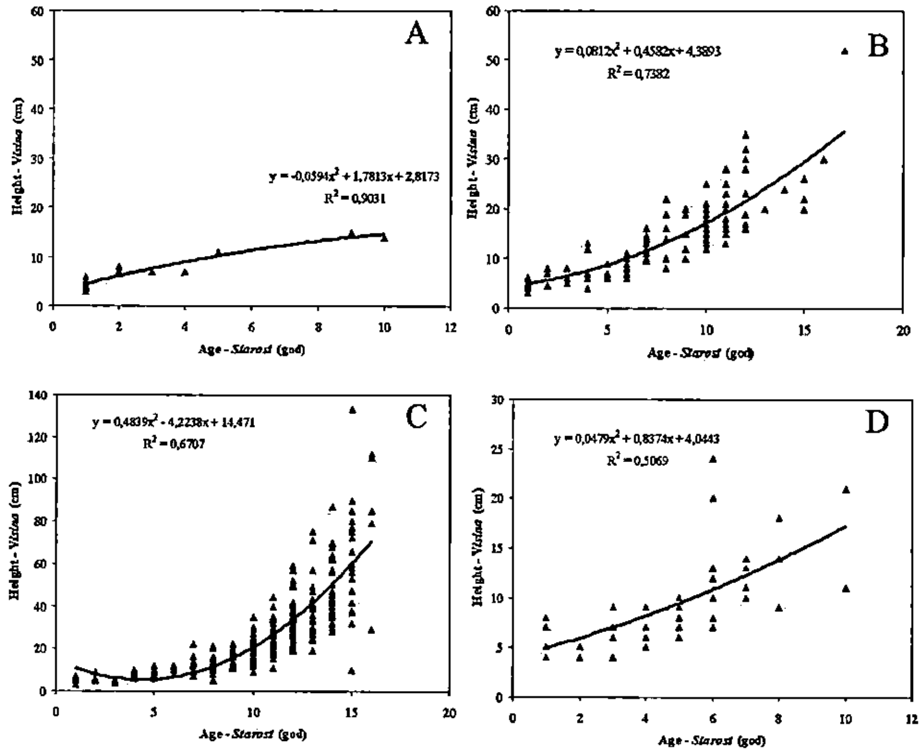


Figure 3 Age to height ratio of the young growth per treatment.
Slika 3 Odnos između starosti i visine pomlatka po tretiranjima.

The average height increment (*ih*) was obtained as the ratio between the height and age of the young growth. With 2.52 cm, the average height increment was the largest in zone C. In terms of the average height increment, zone C differs significantly from zones A, B and D. There is no significant difference in the average height increment among zones A, B and D (Tables 2 and 3).

Table 2 Analysis of the average height increment per zone.
Tablica 2 Analiza prosječnog visinskog prirasta po zonama.

Zone *Zona*	Mean *Aritm. sred.*	Std. Err. *Std. pogreška*	-95%	95%	N
A	1,87	0,47	0,95	2,79	5
B	1,78	0,11	1,57	1,99	94
C	2,52	0,06	2,40	2,65	262
D	1,86	0,18	1,50	2,23	32

Table 3 Differences in the average height increment per zone.
***Tablica 3** Razlike u prosječnom visinskom prirastu po zonama.*

Zone *Zona*	A	B	C
A			
B	1,000000		
C	0,986135	0,000000	
D	1,000000	1,000000	0,004676

Figure 4 shows the ratio between the terminal and the first lateral shoot of the young growth of silver fir. In all the zones this ratio is less than 1, which means that the lateral shoot is longer than the terminal one. In zones A, C and D the ratio is 0.43, and in zone B it is 0.29. There are significant differences only between the zones B and C, as seen in Tables 4 and 5, where p<0.5. This is an indication of aggravated conditions for the growth of young silver fir plants.

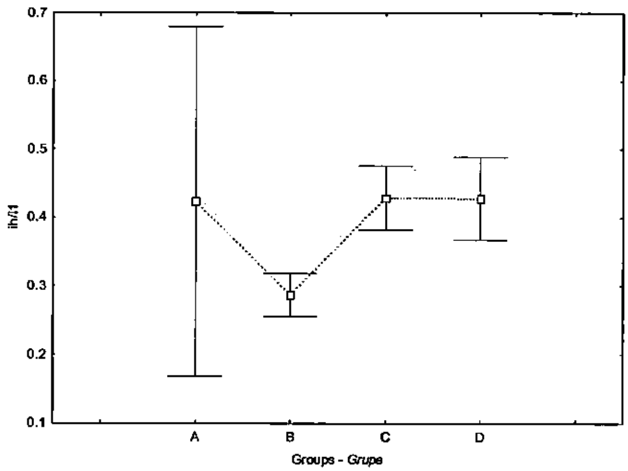


Figure 4. Ratio between the terminal and lateral shoot of the young growth of silver fir.
***Slika 4.** Omjer terminalnog i lateralnog izbojka pomlatka obične jele.*

Table 4 Ratio between the terminal and lateral shoot per zone.
***Tablica 4** Omjer terminalnog i lateralnog izbojka po zonama.*

Zone *Zona*	Mean *Aritm. sred.*	Std. Err. *Std. pogreška*	-95%	95%	N
A	0,42	0,15	0,13	0,72	5
B	0,29	0,03	0,22	0,35	94
C	0,43	0,02	0,39	0,47	262
D	0,43	0,06	0,31	0,54	32

Table 5 Differences within the treatments per terminal and lateral shoot ratio.
Tablica 5. Razlike unutar tretiranja po omjeru vršnog i lateralnog izbojka.

Zone *Zona*	A	B	C
A			
B	1,000000		
C	1,000000	0,002518	
D	1,000000	0,231095	1,000000

The seedlings and young growth of beech participate with 18% in the total number of measured seedlings and young growth. For this reason, it was not statistically processed as the young growth of silver fir. The length and height ratio of beech young growth is given in Figure 5, where the height of beech young growth equals its length in the amount of 95% (R^2=0,95). Accordingly, young plants of common beech do not manifest any significant deformations in height growth, which points to their successful regeneration and growth in the first years of life.

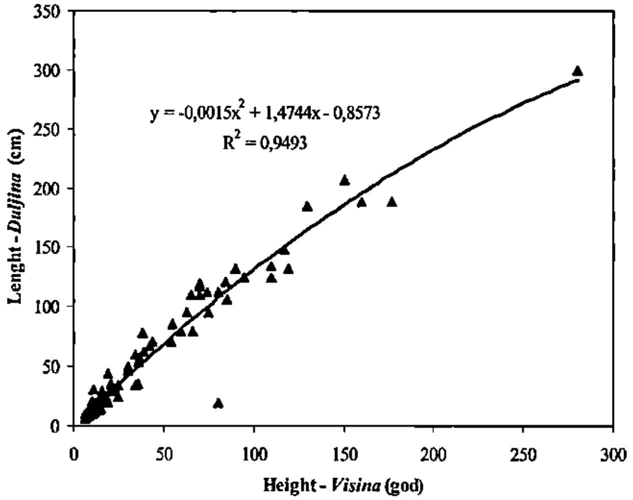


Figure 5 Ratio between the length and height of the young growth of common beech.
Slika 5. Odnos između duljine i visine pomlatka obične bukve.

CONCLUSIONS
ZAKLJUČCI

It can be concluded that the edge of fir-beech forests along the Zagreb – Rijeka motorway shows good natural regeneration and that the amount of seedlings and young growth is satisfactory. The outer edge zone contains groups of young growth of silver fir. The inner zone of the edge features sufficient quantities of natural young growth of silver fir up to 50 cm tall. However, plants taller than 50 cm are missing. There is no young growth taller than 50 cm in the interior of the forest, whereas that up to 50 cm is sparsely distributed.

This condition should be attributed to the reduced amount of light that reaches the understory, as well as to the disturbed stand structure. Pioneer tree species growing in the bare area outside the stand edge regenerate well.

Tree marking on the edge of the fir-beech forest should follow the consistent application of the principles of group selection management in the interior of the forest stand. Groups of young growth in the inner zone of the edge should be gradually freed in order to ensure their undisturbed development and penetration into the upper stand layers. Only broken, rotting, diseased, canker-affected and similar trees should be marked in the outer zone of the edge. Since this area receives sufficient quantities of light, excessive cutting could lead to site weeding. The process of natural regeneration of pioneer tree species growing in the bare area outside the stand edge should be favoured. Groups of young growth of different tree species should be tended with the goal of increasing the diversity and stability of tree groups in this zone, accelerating their development and positively affecting the aesthetic experience along the motorway.

REFERENCES
LITERATURA

Klepac, D., 1997: Novi sistem uređivanja prebornih šuma. Hrvatske šume d. o. o., Zagreb.

Klepac, D., 1962: Novi sistem uređivanja prebornih šuma (dodatak). Poljoprivredno-šumarska komora, Zagreb.

Klepac, D., 1961: Novi sistem uređivanja prebornih šuma. Poljoprivredno-šumarska komora, Zagreb, 46 str.; pretisak, Hrvatske šume, d.o.o. Zagreb, 1997, 36 str.

Matić, S., I. Anić, M. Oršanić, 2005: Uzgojni zahvati u funkciji poboljšanja protuerozijske i vodozaštitne uloge šuma. Šumarski list, posebni broj, 17 – 30.

Matić, S., 2004: Održivi razvoj hrvatskih šuma ugrožen je zbog nepoštivanja Ustava i Zakona o šumama Republike Hrvatske. U: M. Maceljski (ur.), Alternativna biljna proizvodnja u strukturnim promjenama hrvatske poljoprivrede. Hrvatska akademija znanosti i umjetnosti, Znanstveno vijeće za poljoprivredu i šumarstvo, Zagreb, 82 – 84.

Matić, S., I. Anić, M. Oršanić, 2001: Uzgojni postupci u prebornim šumama. U: B. Prpić (ur.), Obična jela (Abies alba Mill.) u Hrvatskoj. Akademija šumarskih znanosti, Zagreb, 407 – 460.

Matić, S., Oršanić, M., Anić, I., 1996: Neke karakteristike i problemi prebornih šuma obične jele (*Abies alba* Mill.) u Hrvatskoj. Šumarski list CXX(3–4): 91–99.

Matić, S., 1992: Selection Beech and Fir Forests in Croatia in Todays Ecological and Economical Circumstances. U: B. Prpić, Z. Seletković (ur.), VI IUFRO Tannensymposium, Šumarski fakultet, 123–132, 1992, Zagreb.

Matić, S., 1972: Prirodno pomlađivanje kao faktor strukture sastojina u šumama jele s rebračom (*Blechno-Abietetum* Horv.). Magistarski rad. Šumarski fakultet, 77 str., Zagreb.

Osnova gospodarenja za šumskogospodarsku jedinicu Brloško za razdoblje 2000 – 2009. godine

Prpić (ur.), Obična jela (*Abies alba* Mill.) u Hrvatskoj, Akademija šumarskih znanosti, Zagreb, 407 – 460.

Pavić, R., 1981: Zemljopisno-povijesni pregled. Monografija Gorski kotar, Fond knjige „Gorski kotar, Delnice, 7 – 35.

Perković, M., 2008: Prirodno pomlađivanje bukovo-jelovih šuma na rubnom pojasu autoceste Zagreb – Rijeka. Šumarski fakultet Sveučilišta u Zagrebu, Zagreb, 28 str.

Pernar, N., 2001: Tla jelovih šuma u Hrvatskoj. U: B. Prpić (ur.), Obična jela (Abies alba Mill.) u Hrvatskoj. Akademija šumarskih znanosti, Zagreb, 107 – 120.

Program prostornog uređenja Republike Hrvatske, NN 50/99

Prpić, B., 2001: Preborna šuma kao infrastrukturna kategorija prostora. U: B. Prpić (ur.), Obična jela (Abies alba Mill.) u Hrvatskoj. Akademija šumarskih znanosti, Zagreb, 283 – 291.

Seletković, Z., 2001: Klima i hidrološke prilike u dinarskim jelovim šumama u Hrvatskoj. U: B. Prpić (ur.), Obična jela (Abies alba Mill.) u Hrvatskoj. Akademija šumarskih znanosti, Zagreb, 133 – 141.

Vukelić, J., D. Baričević, 2001: Šumske zajednice obične jele u Hrvatskoj. U: B. Prpić (ur.), Obična jela (Abies alba Mill.) u Hrvatskoj. Akademija šumarskih znanosti, Zagreb, 162 – 186.

J. Vukelić, D. Baričević, I. Šapić, S. Kuzmanić: Phytocoenological characteristics of beech forests on the southern slopes of Medvednica. Glas. šum. pokuse, Vol. 43, 49 – 60, Zagreb, 2009–10.

UDK: 630*182.3

Original scientific paper
Izvorni znanstveni članak

PHYTOCOENOLOGICAL CHARACTERISTICS OF BEECH FORESTS ON THE SOUTHERN SLOPES OF MEDVEDNICA

FITOCENOLOŠKE ZNAČAJKE BUKOVIH ŠUMA NA JUŽNIM OBRONCIMA MEDVEDNICE

JOSO VUKELIĆ[1], DARIO BARIČEVIĆ[1], IRENA ŠAPIĆ[1], SONJA KUZMANIĆ[1]

[1]University of Zagreb, Faculty of Forestry, Department of Ecology and Silviculture

Abstract

Phytocoenological research of beech forests comprised the southern slopes of Medvednica in the broader area of Adolfovac. Two forest communities were identified by means of phytocoenological relevés based on the standard method of the Central European Phytocoenological School and on statistical testing of the results. These are beech forest with woodrush (*Luzulo-Fagetum*) and beech forest with deadnettle (*Lamio orvalae-Fagetum*). Although these communities have already been described in Croatia, this is the first time that they have been identified in the study area. Phytocoenological analysis was accompanied by an ecological characterization of particular ecological factors on the basis of Ellenberg's values of the floristic composition. The compared sites and communities showed significant differences in terms of light, humidity, acidophility and nutrient content.

Key words: forest communities of common beech, floristic composition, Medvednica, Ellenberg, ecoindicator values

Sažetak

Na južnim padinama Medvednice, u širem području Adolfovca, provedena su fitocenološka istraživanja bukovih šuma. Fitocenološkim snimanjem standardnom metodom srednjoeuropske fitocenološke škole i statističkom provjerom rezultata utvrđene su dvije šumske zajednice: šuma bukve s bekicom (*Luzulo-Fagetum*) i šuma bukve s mrtvom koprivom (*Lamio orvalae-Fagetum*). Obje zajednice su već opisivane u Hrvatskoj, no prvi puta na istraživanom području. Uz fitocenološku analizu provedena je ekološka karakterizacija pojedinih ekoloških čimbenika na temelju Ellenbergovih vrijednost florističkog sastava. Rezultati su pokazali znatne razlike između istraživanih sastojina u pogledu svjetla, vlage, acidofilnosti i sadržaja hraniva na uspoređivanim staništima, odnosno zajednicama.

Ključne riječi: šumske zajednice obične bukve, floristički sastav, Medvednica, Ellenberg, ekoindikatorske vrijednosti

INTRODUCTION
UVOD

The first phytocoenological surveys of forest vegetation on Medvednica were undertaken by Ivo Horvat in 1938. Within the description of the association *Fagetum sylvaticae croaticum boreale montanum*, he provides 9 heterogeneous phytocoenological relevés from Medvednica, which are currently classified within three different associations (Horvat 1938). After Horvat, there has been little research into forest vegetation of Medvednica, with the exception of recent detailed research into the forests of sessile oak (Vukelić 1991), sweet chestnut (Medak 2004) and beech and fir (Medvedović 1991, Dobrović et al. 2006, Vukelić & Baričević 2007).

Forest stands featuring common beech as the edifying species cover almost half of the forest area of Croatia; consequently, they deserve much more attention, study and evaluation. Guided by their significance, we investigated beech stands in the area of Adolfovac, where we expected to find several plant communities in a small area. Research into beech forests of neighbouring areas, in the first place of Samoborsko Gorje, Macelj, Strahinšćica, Ivanšćica, Bilogora and Zrinska Gora (Šegulja 1974, Regula-Bevilaqua 1978, Vukelić & Baričević 2002, Vukelić et al. 2003, Đodan 2005, Baričević et al. 2009) has shown all the complexity of phytocoenological analysis and interpretation of the community. A number of plant communities, which are diagnostically very important for Illyrian beech forests north of the Dinaric range, are either absent from these forests or are present to a much lesser degree.

MATERIAL AND METHODS
MATERIJALI I METODE

Research area
Područje istraživanja

Mount Medvednica (Zagrebačka Gora) is a mountain massif situated north of Zagreb. Extending in the north-east – south-west direction, it comprises the total length of 42 km. The Adolfovac area is situated in the management unit "Sljeme-Medvedgradske Šume", Zagreb Forest Administration, Zagreb Forest Office (Figure 1). The name of this unit is a combination of the names of two localities: the first is the highest peak of Sljeme and the second is the medieval castle of Medvedgrad. The management unit "Sljeme-Medvedgradske Šume" lies on the southern and south-western slopes of Mount Medvednica. The highest point of this MU is the peak Sljeme (1,032 m), while the lowest point is found in compartment 40 e (Vrapčak stream, 170 metres above sea level). MU "Sljeme-Medvedgradske Šume" is divided into 57 compartments consisting of a total of 411 sub-compartments, of which 17 are situated in selection forests (Management Plan of the Management Unit "Sljeme-Medvedgradske Šume" 2008 – 2017). This project was conducted in compartments 1-4 as part of the research graduate thesis of Sonja Kuzmanić.

As stated in the Management Plan of the Management Unit "Sljeme-Medvedgradske Šume", the dominant soil type in the study area is dystric cambisol.

According to the data from the Meteorological Station Puntijarka, the mean annual air temperature is 6.2 °C, while the annual pattern of precipitation is continental. The least rainfall occurs during winter, with the minimum in February (73 mm) and the maximum in June (138 mm). The average annual precipitation is 1,249 mm with oscillations ± 157 mm.

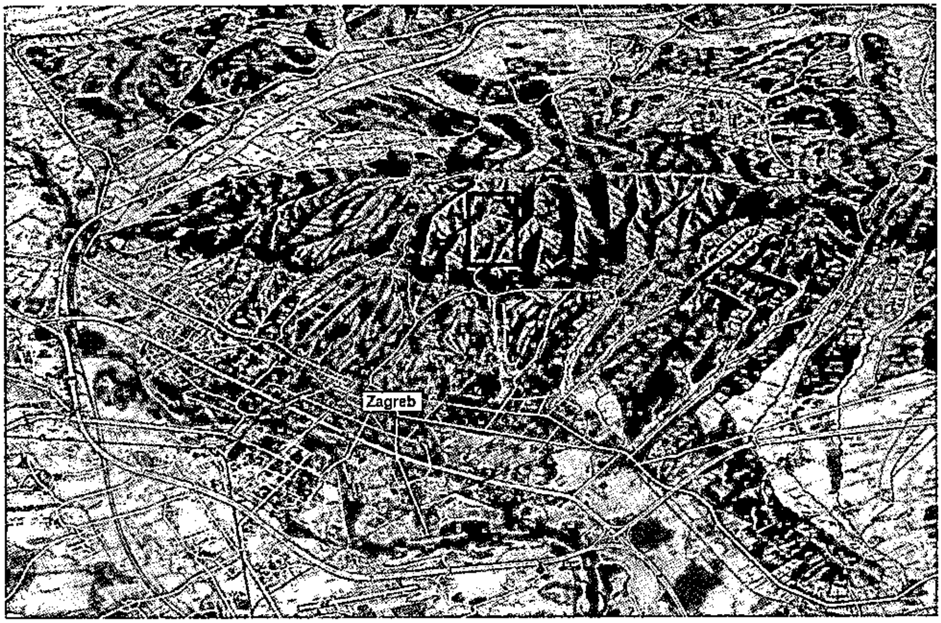


Figure 1 Adolfovac area.
Slika 1 Područje Adolfovca.

Phytocoenological survey was conducted in fifteen localities using the classical Central European phytocoenological method (Braun-Blanquet 1964). Phytocoenological relevés were entered into the Turboveg database (Hennekens 1995) and processed using Syn-Tax 2000 (Podani 2001). Two methods of numerical analyses were employed: Cluster Analysis and Multidimensional Scaling.

Average Ellenberg's values were calculated for each relevé using JUICE 6.3 software (Tichý 2002). The obtained data were processed in STATISTICA 8.0 (StatSoft Inc. 1984-2008). The data were grouped into two clusters, which were then compared with the t-test in order to determine the extent to which the diversity of the floral composition coincides with the ecological factors in different plant communities.

The Latin names of the plant species were adjusted to the Internet source – Flora Croatica Database (2004) (http://hirc.botanic.hr/fcd/).

RESULTS AND DISCUSSION
REZULTATI ISTRAŽIVANJA I RASPRAVA

The analysis of the floristic composition of 15 phytocoenological relevés (Table 1) and statistical data processing with cluster analysis (Figure 2) showed the presence of two beech forest associations in the study area: forest of beech and woodrush (*Luzulo-Fagetum* Meusel 1973, relevés 1, 5, 7, 11 and 12), and beech forest with deadnettle (*Lamio orvalae-Fagetum* (Horvat 1938) Borhidi 1963, relevés 3, 4, 6, 8-10 and 13.15). This is also confirmed by the results of multidimensional scaling with the PCoA method. However, due to the restricted space, these results are not presented here.

The results of these investigations show fundamental differences between the two associations in terms of the floristic composition, syntaxonomic affiliation and ecological conditions. They will be described in brief.

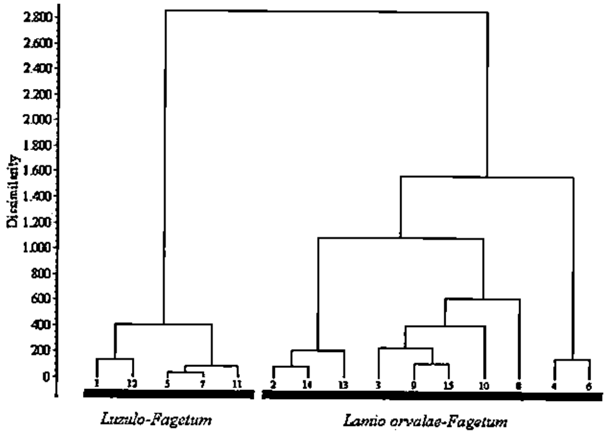


Figure 2 Dendrogram constructed by cluster analysis - Incremental sum of squares.
Slika 2 Dendrogram izrađen klasterskom analizom - Incremental sum of squares.

Beech forest with woodrush
Luzulo-Fagetum Meusel 1937

Beech forest with woodrush represents a basic community of acidophilic beech forests in the major part of Europe. It is of a relatively homogeneous and poor floral composition throughout its vast distribution range. It is distributed in the mountains of north-west Croatia (Macelj, Ivanščica, Medvedica, Samoborsko Gorje), as well as on Papuk and Psunj, reaching the altitude of 800 m. On Mount Medvednica it inhabits smaller areas on steep, erosion-exposed terrains, generally forming enclaves within the beech forest with deadnettle.

The community grows over silicate lithological bedrock overlaid by shallow dystric cambisols and podzolized soils. It can also occur secondarily over carbonate parent material as the result of profile acidification. The soils are of acidic reaction, and are shallower and poorer in humus than the soils inhabited by stands of beech forest with deadnettle.

As seen in Table 1, the phytocoenosis is relatively poor in species. Common beech plays the dominant role in the tree layer, but sweet chestnut and sessile oak have also been recorded.

The shrub layer is composed of beech, sweet chestnut and bilberry (*Vaccinium myrtillus*).

The ground layer is dominated by species that indicate acidity: *Luzula luzuloides, Hieracium murorum, Hieracium racemosum, Melampyrum pratense and Prenanthes purpurea.* These are also differentiating species in relation to other beech communities. Some drier and more exposed fragments are dominated by roadside fescue (*Festuca drymeia*), but this fact does not suffice to join these stands to the subassociation *Luzulo-Fagetum festucetosum drymeiae*, which was described by Hruška del Uomo (1974) on Garjevica, and later by Baričević (2002) in the mountains of Požega (Požeško Gorje). After completing research of a broader area, this subassociation will most probably also be confirmed on Medvednica.

Table 1 Floristic composition of the investigated beech communities on Mt. Medvednica.
Tablica 1. Floristicki sastav istraživanih bukovih zajednica na Medvednici.

Association *Asocijacija*		*Luzulo-Fagetum*					Participation degree *Stupanj udjela*	*Lamio orvalae-Fagetum*										Participation degree *Stupanj udjela*	Lectotypus *Lamio orvalae-Fagetum*
Number of relevé Broj snimke		1	12	5	7	11		2	14	13	3	9	15	10	8	4	6		18
Date (2008. year) *Datum* (2008. *godina*)		12.6.	12.6.	25.4.	25.4.	12.6.		12.6.	12.6.	12.6.	12.6.	25.4.	12.6.	25.4.	25.4.	25.4.	25.4.		
Površina snimke Record area (m^2)		400	400	400	400	400		400	400	400	400	400	400	400	400	400	400		400
Altitude *Nadmorska visina* (m)		410	490	360	430	390		450	600	550	750	500	750	600	450	270	420		680
Exposition *Ekspozicija*		I	I	SI	I	SI		SI	SI	I	J	I	J	I	I	SI	SI		SSZ
Inclination *Nagib* (°)		25	20	20	20	25		5	25	10	5	20	10	20	15	30	10		16
Cover of tree layer *Pokrovnost sloja drveca* (%)		85	70	100	100	75		95	100	90	80	100	70	100	100	100	80		
Cover of shrub layer *Pokrovnost sloja grmlja* (%)		40	40	60	15	60		20	5	10	5	5	5	5	60	90	40		
Cover of layer ground vegetation *Pokrovnost sloja prizemnog bilja* (%)		50	90	50	80	70		80	40	100	80	60	100	70	40	50	90		
Number of species *Broj vrsta*		12	21	17	12	18		37	31	41	36	25	33	43	26	29	31		
Floral composition - Florni sastav																			
Characteristic and differentiating species of the alliances *Luzulo-Fagion*, *Quercion robori-petraeae* and other acidofil species *Svojstvene i razlikovne vrste sveze Luzulo-Fagion, Quercion robori-petraeae i ostale acidofilne vrste*																			
Castanea sativa	A	+	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Castanea sativa	B	.	+	+	.	.	2	.	.	+	.	.	.	.	.	.	.	1	.
Vaccinium myrtillus	B+C	3	+	.	1	.	3	.	.	.	.	.	.	.	.	.	.	.	.
Luzula luzuloides	C	2	3	3	5	3	5	1	1	+	.	+	.	+	.	+	.	3	.
Melampyrum pratense		+	2	3	2	3	5	+	+	.	.	.	.	+	.	.	.	2	.
Hieracium murorum		+	+	3	3	2	5	+	+	.	.	.	.	.	.	+	.	2	.
Prenanthes purpurea		+	.	+	+	2	4	+	1	+	.	.	.	.	.	+	+	3	.
Hieracium racemosum		.	1	+	.	1	3	.	.	.	.	.	.	.	.	.	.	.	.
Festuca heterophylla		2	.	.	1	.	2	+	+	+	+	.	.	+	.	.	.	3	.
Polypodium vulgare		+	.	.	.	+	2	.	.	.	.	.	.	.	.	.	.	.	.
Luzula pilosa		.	.	+	+	.	2	.	.	.	.	.	.	.	.	.	.	.	.
Pteridium aquilinum		+	.	.	.	.	1	.	.	1	.	.	.	.	.	.	2	1	.
Chamaecytisus supinus		.	+	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Solidago virgaurea		.	+	.	.	.	I	.	.	.	.	.	.	.	.	.	.	.	.
Lathyrus venetus		.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	1	.
Hieracium sphaerocephalum		.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	1	.

Association *Asocijacija*		*Luzulo-Fagetum*					Participation degree *Stupanj udjela*	*Lamio orvalae-Fagetum*										Participation degree *Stupanj udjela*	Lectotypus *Lamio orvalae-Fagetum*
Characteristic and differentiating species of the alliance *Aremonio-Fagion* *Svojstvene i razlikovne vrste sveze Aremonio-Fagion*																			
Cyclamen purpurascens	C	.	.	.	.	.	.	+	2	1	+	1	1	+	+	3	2	5	+
Lamium orvala		.	.	.	.	.	.	+	.	+	1	+	+	1	+	+	+	5	1
Dentaria trifolia		.	.	.	.	.	.	2	3	3	+	+	1	.	.	1	.	4	+
Vicia oroboides		.	.	.	.	.	.	+	.	1	.	.	2	+	+	.	.	3	.
Aposeris foetida		.	.	+	.	.	1	+	.	+	+	.	.	+	.	.	.	2	.
Dentaria enneaphyllos		.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	1	1
Erythronium dens-canis		.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	1	.
Hacquetia epipactis		.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	1	.
Characteristic and differentiating species of the alliance *Carpinion betuli* *Svojstvene i razlikovne vrste sveze Carpinion betuli*																			
Carpinus betulus	A	.	.	.	.	.	.	.	.	.	.	+	+	.	1	.	.	2	.
Carpinus betulus	B	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	1	+
Prunus avium		.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	1	.
Acer campestre		.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1	.
Stellaria holostea	C	.	.	.	.	.	.	.	.	.	+	.	1	.	.	.	.	1	.
Prunus avium		.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	1	+
Acer campestre		.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1	.
Characteristic and differentiating species of the order *Fagetalia* *Svojstvene i razlikovne vrste reda Fagetalia*																			
Fagus sylvatica	A	5	4	5	5	4	5	5	5	5	5	5	4	5	5	5	4	5	4
Fagus sylvatica	B	1	3	4	2	3	5	1	+	.	+	+	+	1	+	5	3	5	2
Acer pseudoplatanus		.	.	.	.	.	.	1	.	.	+	.	.	.	1	+	+	3	1
Acer platanoides		.	.	.	.	.	.	1	.	+	+	.	.	.	.	.	.	2	+
Fraxinus excelsior		.	.	.	.	.	.	.	.	.	.	1	.	+	.	.	2	2	.
Daphne mezereum		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	+
Fagus sylvatica	C	.	1	3	3	2	4	+	+	2	.	1	.	3	.	1	3	4	.
Galium odoratum		.	+	+	.	+	3	1	2	2	2	2	3	2	1	3	2	5	2
Pulmonaria officinalis		.	+	+	.	.	2	.	1	+	+	+	2	1	+	+	1	5	+
Carex pilosa		.	.	1	.	.	1	3	+	5	+	3	5	.	+	3	5	5	+
Lathyrus vernus		.	.	.	.	.	.	+	2	1	+	1	1	1	.	2	1	5	.
Dryopteris filix-mas		.	.	.	.	.	.	+	+	+	+	+	.	+	1	1	+	5	.
Dentaria bulbifera		.	.	.	.	.	.	1	1	1	1	1	+	2	3	2	+	5	2
Sanicula europaea		.	.	.	.	+	1	1	1	2	.	+	.	+	.	1	1	4	+
Mycelis muralis		.	.	.	.	.	.	+	+	+	+	+	+	+	1	.	.	4	1
Acer pseudoplatanus		.	.	.	.	.	.	+	+	+	+	+	+	+	.	.	.	4	+
Viola reichenbachiana		.	.	.	.	.	.	+	+	+	+	.	.	+	+	1	+	4	+
Galium sylvaticum		.	+	1	+	2	4	1	+	+	+	+	.	1	.	.	.	3	.

Association *Asocijacija*		*Luzulo-Fagetum*					Participation degree *Stupanj udjela*	*Lamio orvalae-Fagetum*										Participation degree *Stupanj udjela*	Lectotypus *Lamio orvalae-Fagetum*
Platanthera bifolia		.	+	+	.	1	3	.	+	+	.	.	.	+	+	.	1	3	.
Phyteuma spicatum		.	.	+	+	+	3	+	1	1	+	.	.	+	.	+	.	3	.
Epipactis helleborine		.	+	.	.	.	1	+	+	1	+	.	+	.	.	.	.	3	.
Melica uniflora		.	.	.	.	.	.	+	.	1	4	.	2	2	.	.	.	3	.
Mercurialis perennis		.	.	.	.	.	.	+	.	2	2	3	2	2	.	.	.	3	.
Athyrium filix-femina		.	.	.	.	.	.	.	.	.	+	.	.	+	1	.	.	2	.
Acer platanoides		.	.	.	.	.	.	.	.	.	+	+	+	+	.	.	.	2	.
Euphorbia dulcis		.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	+	2	+
Polygonatum multiflorum		.	.	.	.	.	.	.	.	.	+	.	+	+	.	.	.	2	+
Symphytum tuberosum agg.		.	.	.	.	.	.	+	.	.	+	.	+	.	.	.	.	2	+
Scrophularia nodosa		.	.	.	.	.	.	.	+	+	.	.	.	+	.	.	.	2	.
Festuca drymeia		.	5	.	+	+	3	1	.	.	.	.	+	.	.	.	.	1	.
Euphorbia amygdaloides		.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	1	+
Circaea lutetiana		.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	1	.
Geranium robertianum		.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	1	+
Stachys sylvatica		.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	1	.
Galeobdolon luteum		.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.
Polystichum aculeatum		.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	.
Carex sylvatica		.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	1	+
Veronica montana		.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	1	.
Brachypodium sylvaticum		.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	1	.
Actaea spicata		.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1	.
Epilobium montanum		.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1	.
Ranunculus lanuginosus		.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	1	+
Asarum europaeum		.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1	.
Heracleum sphondylium		.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1	+
Campanula trachelium		.	.	.	.	+	1	.	.	.	.	.	.	.	.	.	.	.	+
Characteristic and differentiating species of the order *Quercetalia pubescentis* *Svojstvene i razlikovne vrste reda Quercetalia pubescentis*																			
Fraxinus ornus	B	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	1	.
Sorbus torminalis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.
Cephalanthera damasonium	C	.	.	.	.	.	.	+	+	.	.	.	.	+	.	.	+	2	.
Tamus communis		.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	2	+
Cephalanthera longifolia		.	1	.	.	.	1	.	.	+	.	.	.	.	.	.	.	1	.
Campanula persicifolia		.	+	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.
Melittis melissophyllum		.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	1	.

Association *Asocijacija*		*Luzulo-Fagetum*					Participation degree *Stupanj udjela*	*Lamio orvalae-Fagetum*										Participation degree *Stupanj udjela*	Lectotypus *Lamio orvalae-Fagetum*
Characteristic and differentiating species of the class *Querco-Fagetea* *Svojstvene i razlikovne vrste razreda Querco-Fagetea*																			
Quercus petraea	A	+	+	.	.	.	2	.	+	.	.	+	.	.	+	.	2	2	.
Corylus avellana	B	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	1	+
Anemone nemorosa	C	.	.	.	.	.	.	1	1	2	+	1	1	1	+	.	.	4	.
Hedera helix		.	.	.	.	.	.	+	.	+	+	.	.	+	2	2	+	4	2
Quercus petraea		.	+	.	.	.	1	.	.	.	.	+	.	.	.	.	1	1	.
Convallaria majalis		.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1	.
Other species - *Ostale vrste*																			
Abies alba	A	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1	.
Abies alba	B	.	+	.	.	.	1	+	+	+	.	.	.	.	.	.	.	2	.
Picea abies		.	.	1	+	+	3	.	+	.	.	.	.	.	.	.	.	1	.
Sambucus racemosa		.	.	.	.	.	.	.	.	+	.	.	+	+	3	.	.	2	+
Doronicum austriacum	C	.	.	1	.	1	2	2	1	2	.	.	1	+	1	.	+	4	.
Rubus hirtus		.	.	.	.	.	.	.	+	+	.	.	+	.	.	+	1	3	.
Fragaria vesca		.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	+	2	+
Silene dioica		.	.	.	.	.	.	.	.	+	+	.	.	.	+	.	.	2	.
Alliaria petiolata		.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	2	.
Cephalanthera rubra		.	1	.	.	.	1	.	.	1	.	.	.	.	.	.	.	1	.
Veronica chamaedrys		.	+	.	.	+	2	.	.	.	.	+	.	+	.	.	.	1	.
Senecio ovatus		.	.	.	.	+	1	.	.	+	.	.	.	.	.	.	+	1	1
Festuca gigantea		.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	1	.
Lunaria rediviva		.	.	.	.	.	.	.	.	.	+	.	.	.	1	.	.	1	+
Primula vulgaris		.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	1	.
Sambucus racemosa		.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.
Petasites albus		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.
Bromus racemosus		.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	1	.
Vicia sp.		.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	1	.
Galeopsis tetrahit		.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	1	.
Gentiana asclepiadea		.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	+	1	.
Laburnum sp.		+	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.

The nomenclatural type features the following species - U nomenklaturnom tipu pojavljuju se još vrste:

A *Ulmus glabra* (+), *Malus sylvestris* (+)

B *Daphne laureola* (+), *Euonymus latifolia* (+), *Rubus* sp. (+), *Crataegus* sp. (+), *Cornus mas* (+), *Clematis vitalba* (+), *Viburnum lantana* (+)

C *Arum maculatum* (2), *Corydalis cava* (2), *Paris quadrifolia* (1), *Galanthus nivalis* (1), *Scilla bifolia* (1), *Anemone ranunculoides* (1), *Eranthis hiemalis* (1), *Glechoma hederacea* (1), *Scrophularia vernalis* (1), *Isophyrum thalictroides* (1), *Carex digitata* (+), *Urtica dioica* (+), *Scolopendrium vulgare* (+), *Chelidonium majus* (+), *Aremonia agrimonoides* (+), *Oxalis acetosella* (+), *Aegopodium podagraria* (+), *Aconitum lycoctonum* ssp. *vulparia* (+)

Beech trees are of relatively good quality. The soil, however, is often degraded due to being intensively trampled on by visitors to Medvednica.

In some earlier works, the association *Luzulo-Fagetum* was subordinated to the alliance *Luzulo-Fagion* Lohm. et R. Tüxen in R. Tüxen 1954, but more recently it has been reduced to the level of sub-alliance *Luzulo-Fagenion* Lohm. et R. Tüxen in R. Tüxen 1954 within the alliance *Fagion sylvaticae* Luquet 1926. The most commonly cited reason for this is the absence of characteristic species needed for the rank of alliance, since only *Luzula luzuloides* (Oberdorfer 1994, Willner & Grabherr 2007 et al.) is mentioned as a weak characteristic species.

Beech forest with deadnettle
Lamio orvalae-Fagetum (Horvat 1938) Borhidi 1963

This is a climatozonal community of the montane belt of Croatia. In the continental part of the Dinaric area it occurs between 400 and 800 m and continues over the northern slopes of Mala Kapela to the mountains of north-western Croatia. According to the published phytocoenological relevés, the floristically impoverished community is found in Samoborsko Gorje, on Macelj and on Medvednica. Its eastern distribution is yet to be investigated, although its range largely coincides with the range of the species *Lamium orvala*. Since this community does not have a uniform composition across its distribution range in Croatia, two variants can easily be distinguished: the southern one in the Dinaric part and the northern one in the uplands of north-western Croatia.

The lithological parent material that supports the community is composed of limestone and dolomite. The community can also grow on silicate rocks, but only in fragmentary form. The soil is predominantly calcocambisol of very good properties (pH above 7, deep, humous in the upper horizon, of good consistency and rich in nutrients). The results of statistical comparison of these two communities show that the soil properties are more favourable in relation to the soil properties of the association *Luzulo-Fagetum* (Table 2).

Beech forest with deadnettle was identified in ten relevés in the study area. As seen in Table 1, the main edifying species in the tree layer is common beech, while several of the relevés also feature sessile oak and common hornbeam.

The shrub layer has the least cover and is mostly composed of beech, maples (*Acer pseudoplatanus* and *Acer platanoides*), common ash (*Fraxinus excelsior*), mezereon (*Daphne mezereum*), and silver fir (*Abies alba*) in higher positions.

The layer of ground vegetation is marked by a medium cover. The stronger or weaker characteristic and differentiating species of Illyrian beech forests (alliance *Aremonio-Fagion*) include *Lamium orvala*, *Cyclamen purpurascens*, *Dentaria trifolia*, *Vicia oroboides* and others, and the species characteristic of European beech forests consist of *Galium sylvaticum*, *Carex sylvatica*, *Mercurialis perennis*, *Galium odoratum*, *Sanicula europaea*, *Pulmonaria officinalis*, *Hedera helix*, *Dryopteris filix-mas* and other, even more widespread species.

The association *Lamio orvalae-Fagetum* is rarely cited in literature under this name as an independent association; it is more often analyzed within Horvat's complex Fagetum sylvaticae montanum croaticum. Consequently, emphasis should be made of some of its specific features, which this research has also done. In relation to the distribution range of the community in the Dinaric part of Croatia (Horvat, Glavač & Ellenberg 1974, Vukelić & Baričević 2002), the northern part of the association's range does not contain any important Illyrian species, such as *Rhamnus fallax*, *Calamintha grandiflora* and *Omphalodes verna*. Moreover, no important species of the northern part of the range of beech forest with deadnettle have been found in Adolfovac, although they were identified in this association in Samoborsko Gorje (Vukelić, Baričević & Drevenkar 2003) and in beech-fir forests on Medvednica (Vukelić & Baričević 2007): *Aremonia agrimonoides*, *Ruscus hypoglossum*, *Cardamine trifolia*, *Cardamine waldsteinii*, *Daphne laureola*, *Epimedium alpinum*, *Polystichum setiferum* and others. This is attributed to the relatively small size of the research area, as well as to the predominantly silicate lithological base which sporadically supports more acidophilic soils. However, the presence of the diagnostically most important species *Lamium orvala* and *Cardamine enneaphyllos*, which are considered the characteristic species of the association (Marinček et al. 1993) and other species of the alliance *Aremonio-Fagion*, indicates that this is an impoverished variant of beech forest with deadnettle. To prove this point, we present relevé No. 18 in Table III from Horvat's paper from 1938, also labeled as the nomenclatural type (lectotype) in the cited work of Marinček et al. from 1993.

The Central European elements of the alliance Fagion and the order Fagetalia have a significant share in the forest of beech with deadnettle.

The phytocoenological table reveals not only the floristic differences between the described forest communities, but also the differences in particular ecological parameters that characterize their sites (Table 2). After the average ecoindicator values (Ellenberg 1979) were calculated with STATISTICA 8.0, the t-test was used to obtain the following results:

Table 2 T-test results.
Tablica 2. Rezultati T-testa.

Variable *Varijabla*	Mean	Mean	t-value	df	p	Valid N	Valid N	Std.Dev.	Std.Dev.	F-ratio	p
	Luzulo-Fagetum	*Lamio-Fagetum*				*Luzulo-Fagetum*	*Lamio-Fagetum*	*Luzulo-Fagetum*	*Lamio-Fagetum*	Variances	Variances
Light *Svjetlost*	4,24	4,04	2,19	13	0,0478	5	10	0,21	0,15	2,08	0,3318
Temperature *Temperatura*	5,05	5,27	-1,65	13	0,1226	5	10	0,41	0,12	12,24	0,0022
Continentality *Kontinentalnost*	3,37	3,35	0,3	13	0,7721	5	10	0,14	0,09	2,4	0,2536
Moisture *Vlaga*	4,88	5,13	-3,34	13	0,0045	5	10	0,19	0,09	4,73	0,0495
Soil reaction *Reakcija tla*	4,98	6,53	-5,59	13	0,0001	5	10	0,85	0,21	15,98	0,0008
Nutrients *Hraniva*	4,17	5,62	-5,99	13	0,0005	5	10	0,5	0,41	1,5	0,5624

According to the results, these two groups of relevés do not show statistically significant differences in the ecological factors of temperature and continentality. However, there are statistically significant differences in terms of light, humidity, soil reaction and nutrients. In relation to the community *Luzulo-Fagetum*, the forest community *Lamio orvalae-Fagetum* occurs in the sites with more light and humidity.

The differences are even bigger in terms of soil reaction and nutrient supply. In the community *Luzulo-Fagetum* the value of soil reaction is 4.98, which represents a moderately acid site, while the community *Lamio orvalae-Fagetum* reaches the value of 6.53, which denotes weakly basic soil. In terms of nutrients there is similar relationship: the community *Luzulo-Fagetum* is poor with nutrients (nitrogen) – value 4.24, whereas the site of the community *Lamio orvalae-Fagetum* is richer in nutrients, i.e. nitrogen, and reaches the value of 5.62.

CONCLUSIONS
ZAKLJUČCI

Based on the analysis of phytocoenological relevés of beech forests shows in the study area, we can conclude that there are two associations with the related systematics.

Class: *Querco-Fagetea* Braun-Blanquet et Vlieger 1937
  Order: *Fagetalia* Pawlovski in Pavlovski et al. 1928
    Alliance: *Luzulo-Fagion* Lohmeyer et R. Tüxen in R. T Tüxen 1954
      Association: *Luzulo-Fagetum sylvaticae* Meusel 1937
    Alliance: *Aremonio-Fagion* (I. Horvat1938) Borhidi in Török et al. 1989
      Sub-alliance: *Lamio orvalae-Fagenion* Borhidi ex Marinček et al. 1993
        Association: *Lamio orvalae-Fagetum* (I. Horvat 1938) Borhidi 1963

Beech forest with woodrush covers some twenty percent of the study area and has typical floral composition of this community. There are sporadic occurrences of Festuca drymeia in drier and warmer sites, which confirms the similarity of this site with other mountains between the rivers Sava and Drava in Croatia.

Beech forest with deadnettle is the dominant community in the investigated area. It is poorer in the species of the Illyrian-Dinaric distribution from the southern part of its range, as well as in some species which were found in beech forests in the neighbouring mountains and in beech-fir forests on Mount Medvednica. Nevertheless, the existing diagnostic species allow us to describe them as the association Lamio orvalae-Fagetum. These species show more similarity to this association than to other beech communities known in Croatia to date.

The differences in the floral composition are the reflection of different site conditions in which these two communities occur. This is also confirmed by the result of the ecoindicator value analysis. According to these values, the sites of the investigated phytocoenoses differ significantly in terms of the amount of light and humidity, soil reaction and nutrient quantity.

REFERENCES
LITERATURA

Baričević, D., 2002: Sinekološko-fitocenološke značajke šumske vegetacije Požeške i Babje gore. Disertacija, Šumarski fakultet Sveučilišta u Zagrebu, 175 p.

Baričević, D., J. Vukelić, I. Šapić, 2009: Ass. Polysticho setiferi-Fagetum Zupančič et al. 2000 in forest vegetation of Zrinska Gora, Hladnika, Vol 23, p 81-91.

Braun-Blanquet, J., 1964: Pflanzensoziologie. Grundzüge der Vegetationskunde. Springer, Wien, No 12, p 19–29.

Dobrović, I., T. Safner, S. D. Jelaska, T. Nikolić, 2006: Ekological and phytosociological characteristics of the association Abieti-Fagetum "pannonicum" Rauš 1969 prov. on Mt. Medvednica (NW Croatia). Acta Bot. Croat. No 65 (1), p 41-55.

Đodan, M., 2005: Fitocenološka obilježja bukovih šuma na Bilogori, Diplomski rad, Sveučilište u Zagrebu, Šumarski fakultet, 35 p.

Ellenberg, H. 1979: Zeigerwerte der Gefäßpflanzenflora Mitteleuropas. Scripta Geobot. No 9, p 9–160.

Flora Croatica Database (2004) (http://hirc.botanic.hr/fcd/).

Hennekens S. M., J. H. J. Schaminée, 2001: TURBOVEG, a comprehensive data base management system for vegetation data. Journal of Vegetation Science, 12: 589 –591.

Horvat, I., 1938: Biljnosociološka istraživanja šuma u Hrvatskoj. Glas. šum. pokuse, No 6, p 127–279.

Horvat, I., V. Glavač, H. Ellemberg, 1974: Vegetations Südosteuropas, G. Fischer Verlag, Stuttgart, 768 p.

Hruška-Dell'Uomo, K., 1974: Biljni pokrov Moslavačke gore. Disertacija, Sveučilište u Zagrebu, 312 p.

Marinček, L., L. Mucina, M. Zupančič, L. Poldini, I. Dakskobler, M. Accetto, 1993: Nomenklatorische revision der Illyrischen Buchenwälder (Verband Aremonio-Fagion). Studia Geobotanica, No 12 (1992), p 121–135.

Medak, J., 2004: Fitocenološke značajke šuma pitomoga kestena u sjeverozapadnoj Hrvatskoj. Magistarski rad, Šumarski fakultet Sveučilišta u Zagrebu, 125 p.

Medvedović, J., 1991: Sinekologija zajednica obične jele (Abies alba Mill.) u sjevernoj Hrvatskoj i floristički parametri važni za gospodarenje bukovo - jelovim šumama, Šumarski list, No 6-9, p 303-316.

Oberdorfer, E., 1994: Pflanzensoziologische Exkursionsflora, 7. Aufl. Verlag Eugen Ulmer, Stuttgart.

Osnova gospodarenja Gospodarske jedinice "Sljeme-Medvedgradske šume" 2008.-2017.

Podani, J., 2001: Syn-Tax 2000. Computer Programs for Data Analysis in Ecology and Systematics. Budapest, Scientia Publishing

Regula-Bevilaqua, Lj., 1978: Biljni pokrov Strahinščice u Hrvatskom zagorju. Disertacija, Sveučilište u Zagrebu, 261 p.

StatSoft, Inc., 2008: STATISTICA (data analysis software system), version 8.0; www.statsoft.com

Šegulja, N., 1974: Biljni pokrov Vukomeričkih gorica. Disertacija, Sveučilište u Zagrebu, 232 p.

Tichý, L., 2002: JUICE 6.3, software for vegetation classification. Journal of Vegetation Science, 13: 451-453.

Vukelić, J., 1991: Šumske zajednice i staništa hrasta kitnjaka (Quercus petraea Liebl.) u gorju sjeverozapadne Hrvatske. Glas. šum. pokuse, No 27: 1-82.

Vukelić, J., D. Baričević, 2002: Novije fitocenološke spoznaje o bukovim šumama u Hrvatskoj, Šumarski list, Vol. 126, No 9-10, p 439–457.

Vukelić, J., D. Baričević, D. Drvenkar, 2003: Fitocenološke karakteristike bukovih šuma u Samoborskom gorju, Šumarski list, Vol 127, No 11-12, p 531–544.

Vukelić, J., D. Baričević, 2007: Nomenklaturno-sintaksonomsko određenje panonskih bukovo-jelovih šuma (Abieti-Fagetum „pannonicum") u Hrvatskoj. Šumarski list, Vol 131, No 9-10, p 407-429.

Willner W., Grabherr G.(eds.), 2007: Die Wälder und Gebüsche Östererichs. Ein Bestimmungswerk mit Tabellen. 1. Textband, 302 p., 2. Tabellenband, 290 p.

UDK: 630*232.318

Original scientific paper
Izvorni znanstveni članak

IMPACT OF ROOT GROWTH POTENTIAL ON EUROPEAN BLACK PINE (*Pinus nigra* Arnold) SEEDLING SURVIVAL

UTJECAJ POTENCIJALA RASTA KORIJENA NA PREŽIVLJAVANJE I RAST SADNICA CRNOG BORA (Pinus nigra Arnold)

MILAN ORŠANIĆ[1], DAMIR DRVODELIĆ[1], DIANA BOBINEC MIKEK[2], VINKO PAULIĆ[1]

[1]University of Zagreb, Faculty of Forestry, Department of Ecology and Silviculture
[2]Hrvatske Šume d.o.o., Zagreb, Forest Administration Koprivnica, Forestry Varaždin

Abstract

This paper deals with the impact of root growth potential on the survival of the European Black Pine (Pinus nigra Arnold) seedlings in the period between 2004 and 2007. The root growth potential of the sampled two-year-old seedlings (2+0) was evaluated according to Burdett's scale after the seedlings transplanted in containers were left in a greenhouse for 28 days at optimum conditions for root development. The seedlings were laid out in the nursery in a randomized block and their survival was researched.

The seedlings whose root growth potential on Burdett's scale was 0,1 did not survive in the nursery part of the experiment while those whose potential measured 2,3,4 had a very high survival percentage. The comparison of seedlings classified according to Burdett's scale with the classes used in today's Croatian forestry reveals big differences and discrepancies. Many seedlings from lower classes or the discarded ones have a very high potential on Burdett's scale and would be much more suitable for field planting than the seedlings classified according to morphological parameters.

Key words: root growth potential (RGP), Burdett's scale, seedling survival, seedling quality, European Black Pine.

Sažetak

U radu je istraživan utjecaj potencijala rasta korijena na preživljavanje sadnica crnog bora u periodu od 2004-2007. godine. Uzorak ispitivanih sadnica bio je starosti 2 godine (2+0), njima je određen potencijal rasta korijena metodom presadnje sadnica u posude, stavljene 28 dana u staklenik na optimalne uvijete za razvoj korijena, nakon čega je prema Burdett-ovoj skali određena vrijednost potencijala rasta korijena. Sadnice su rasađene u rasadnik slučajnim blok rasporedom i utvrđivano je njihovo preživljavanje.

Sadnice sa potencijalom rasta korjena prema Burdettu 0 i 1 nisu preživjele u rasadničkom djelu testa, dok su sadnice s potencijalom 2,3,4 preživjele s vrlo velikim postotkom. Usporedbom sadnica razvrstanih prema Burdetovoj skali s klasama koje se koriste danas u šumarstvu Hrvatske, vidi se veliko ostupanje i nepodudaranje. Mnoge sadnice koje pripadaju nižim klasama ili otpadu imaju veliki potencijal prema Burdetu i bile bi puno bolje za sadnju na terenu nego sadnice klasirane prema morfološkim parametrima.

Ključne riječi: potencijal rasta korijena (PRK), Burdett-ova skala, preživljavanje sadnica, kvaliteta sadnica, crni bor.

INTRODUCTION
UVOD

Owing to its wide ecological valency the Black Pine is a species suitable for reforestation of difficult terrains (rocky grounds, quick sands, ravines etc.) (Ivančević, 1995). Although it easily adapts to all sites the seedlings of better quality guarantee a better reforestation success. The standard for seedling quality HRN D. Z2. 110 which has been in use in the nurseries in our country for a number of years classifies seedlings into quality classes with respect to their heights and/or root collar diameter.

However, these parameters for determining quality classes of forest seedlings do not tell us anything about the physiological condition of a plant which is crucial for its survival on the site.

Root growth potential-RGP, also known as root growth capacity, can be defined as the capacity of a seedling to initiate and develop new roots when growing in favourable conditions such as the temperature of 20°C, 16-hour photo period with minimum 25% of full sun light and optimum water and nutrient supply (Ritchie 1984). Initiation and development of several new roots over a short period of time ensures a better survival and growth of seedlings (Sutton 1980). There is a high correlation between root growth potential and the performance after transplanting. There are two ways of interpreting practical values of the root growth potential test. In this study we used the Burdett's scale for testing root growth potential (Burdett 1979). In most countries it has been accepted as a standard as it saves time and effort when measuring the growth of new roots.

Table 1 Burdett's scale for evaluating RGP (Burdett, 1979).
Tablica 1. Burdettova skala (Burdett, 1979) za procjenu PRK.

Root growth evaluation *Procjena rasta korijena*	Number of new roots *Broj novih korjenčića*
0	None *Ništa*
1	A few roots not longer than 1 cm *Poneki korjenčić, ne dulji od 1 cm*
2	1-3 roots longer than 1 cm *1-3 korjenčića duljih od 1 cm*
3	4-10 roots longer than 1 cm *4-10 korjenčića duljih od 1 cm*
4	11-30 roots longer than 1 cm *11-30 korjenčića duljih od 1 cm*
5	31-100 roots longer than 1 cm *31-100 korjenčića duljih od 1 cm*
6	101-300 roots longer than 1 cm *101-300 korjenčića duljih od 1 cm*
7	More than 300 roots longer than 1 cm *Više od 300 korjenčića duljih od 1 cm*

Root growth potential is just a possibility for roots to grow, which means it may or may not be fully expressed when a seedling is transplanted into an open field. According to the definition of the root growth potential, if a plant is transplanted into an environment with optimum conditions for root growth, it will fully express its root growth potential and vice versa. In winter and early spring the site factors are rarely favourable for root growth and the root growth potential will rarely reach ideal levels after a plant has been transplanted into a field. The timing for evaluation of seedling quality, including the root growth potential test, is very important. In terms of reforestation the best time for evaluating seedling quality, including the root growth potential, is as close to the transplantation as possible, as the seedling quality can change during storage and handling. Another ideal time for taking samples is just before a seedling is transported from the nursery.

According to Burdett (1987) root growth potential tests do not predict a real seedling survival which depends on the field conditions, but only the potential for its survival. In unfavourable field conditions the seedling potential may not be expressed. Root growth potential as an indicator of the capacity of a seedling to survive or grow has been used for many species such as Ponderosa Pine (*Pinus ponderosa* Dougl et Laws), (Stone and Jenkinson, 1971), Sitka Spruce (*Picea sitkensis* (Bong.) Carr), (Deans et al. 1990), Lodgepole Pine (*Pinus contorta* Dougl ex Loud), (Burdett et al 1983, Simpson 1990), Western Hemlock (*Tsuga heterophylla* (Raf.) Sarg.), (Simpson 1990), White Spruce (*Picea glauca* (Moench) Voss x *Picea engelmanni* Parry.) (Simpson 1990, Simpson et al. 1994) and Common Ash (*Fraxinus excelsior* L.) (O'Reilly et al. 2002).

Burdett (1987) claims that the root growth potential of a seedling also indicates its frost and stress resistance and sees a correlation with frost damages on the Black Spruce (*Picea mariana* (Mill.) Britton, Sterns at Poggenb) (Columbo and Glerum 1984). Our understanding of the relationship between the physiological status and the growth of new roots is a limiting factor for the application of the test. According to Folk and Grosnickle (1997) the problem can be solved by limiting field conditions during evaluation of the root growth potential and simulating real site conditions. When predicting reforestation success a better result is achieved if more methods for seedling quality evaluation are combined together. Jacobs (2009) gives a model of multiple morphological parameters as a much better method for evaluation of the capacity of a seedling to grow compared to single morphological parameters used for bare root seedlings of hardwood species in the central forest areas of the USA. In a research into the survival of Loblolly Pine (*Pinus taeda* L.) the criterion for determining stock quality with respect to their survival was the number of new roots whose length was 0,5 cm or more for evaluating root growth potential, and the seedling height/root length ratio calculated for 80% of the survived seedlings in the first year after the transplantation (Larsen et al. 1986). A successful integration of physiological and morphological parameters can enhance the evaluation of seedling quality.

MATERIAL AND METHODS
MATERIJALI I METODE

The forest management unit Zelendvor stretches between 16°11'1" and 16°13'20" of eastern longitude and between 46°9'48" and 46°21'51" of northern latitude.

The Black Pine seedlings were grown from the seed sown in 2002 and 2003. The seed was obtained from the Croatian Forest Research Institute, Jastrebarsko. According to the certificate it was collected in the Forest Administration Senj, Forestry Senj, Forest Unit Biljevine, section 7 from the natural seed stand not listed in the Register of Recognized Seed Stands (Article 60, NN 68/1998) in autumn 1997 by the workers from the Nursery Production Unit of the Croatian Forest Research Institute, Jastrebarsko. The seed was clean, its germination energy after 10 days was 73,5% and the seed germination 90,3%. There was 5% of empty seed. The moist content was 6,3%, the usage value 90,3% and the seed was sound. The seed was sown in germination beds in the nursery Zelendvor, Forestry Varaždin and on beds in the Nursery Močile, Forest Administration Koprivnica, Forestry Koprivnica. In the first year of the experiment (2004) two-year-old black pine seedlings were lifted from the nursery Zelendvor. At the beginning of March, 85 seedlings were randomly lifted from the germination beds as a larger quantity of seedlings was not available in the nursery. The following year a sample of 120 seedlings was taken from the nursery Močile. As the seedlings originated from the same seed lot (both nurseries have similar natural characteristics and the same production methods) they were treated as one group. We used a meter to measure seedling heights, a calliper to measure root collar diameter and a ruler do determine the total root length. After root pruning the seedlings were transplanted into round 22-litre containers filled with the media for growing conifers produced by Klasmann Gmbh. There were five seedlings in each container, and each container represented one repetition, i.e. there were a total of 41 repetitions. After the seedlings were watered to saturation, they were transported to the greenhouse of the Faculty of Forestry in Zagreb where they were kept for 28 days in the following conditions: 75-90 % of moist which was constantly checked with a hygrometer and air temperature from 22°C to 25°C. During the 13-hour photo period the seedlings were watered by misting every half an hour in order to supply them with a sufficient moist. Twenty-eight days later we manually counted the number of new roots and used a ruler to measure their length. After the root growth potential was evaluated on the Burdett's scale, the seedlings were placed back into the media filled containers where they were kept for a week to let them adjust to the temperature change after the greenhouse and in order to avoid the shock after transplanting into an open field.

The seedlings were planted into the soil which had been ploughed to about 25 cm depth the previous autumn and finely worked, manured and fertilized the following spring same as for the other seedlings in the nursery. In both nurseries the seedlings were laid out in random rectangular blocks. The spacing between the rows was 40 cm and between the seedlings 30 cm. In 2005 the procedure was repeated with 120 seedlings from the same seed lot taken from the nursery Močile, Forest Administration Koprivnica, Forestry Koprivnica. The seedlings were put in the greenhouse of the Agricultural and Veterinary School Arboretum Opeka, Vinica. They were watered by misting, the moist was kept between 75% and 90% and the day light temperature between 22°C and 25°C. Twenty-eight days later new roots were counted and measured. After evaluating the root growth potential on Burdett's scale the seedlings were put back into the media-filled containers where they stayed for a week to let them adjust to the temperature change outside the greenhouse in order to avoid the shock when transplanted into an open field. The seedlings were planted on the ground which had been ploughed to about 25 cm depth the previous autumn and finely worked, manured and fertilized the following spring same as for the other seedlings in the nursery. During the three-year period standard measures for preventive protection against fungal diseases, pests and weed were carried out on the fields with the test seedlings.

RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA

Seedling survival
Preživljenje sadnica

The total of 205 two-year-old sampled seedlings (2+0) fell into 5 quality classes of root growth potential on Burdett's scale-class 0, class 1, class 2, class 3 and class 4. Only one seedling or 0,5% belonged to class 0, 10 seedlings or 5,0% belonged to class 1, 90 seedlings or 44,0% belonged to class 2, class 3 contained 82 or 39,8% of seedlings and in class 4 there were 21 or 10,7% of seedlings. The survived seedlings all belonged to classes 2, 3 and 4. The survival rate was not shown graphically over the years as the cases of dead seedlings were recorded only during the first year after transplanting while the number of seedlings remained stationary in the following years. The graph shows that seedling survival increases with a higher root growth potential and that the seedlings whose root growth potential on Burdett's scale was 0 or 1 did not survive.

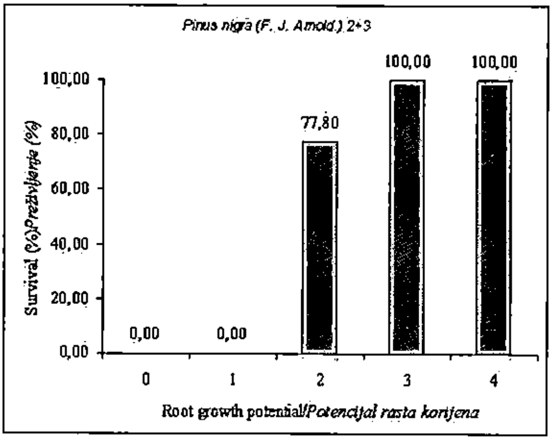


Figure 1 Survival of Black Pine seedlings (2+3) expressed in percentages based on the determined root growth potential (RGP).

Slika 1 Preživljenje sadnica crnog bora 2+3 u ovisnosti o potencijalu rasta korijena (PRK).

Table 2 Survival of Black Pine seedlings (2+3) expressed in percentages with respect to the determined root growth potential.
Tablica 2 Preživljenje sadnica crnog bora 2+3 u ovisnosti o potencijalu rasta korijena (PRK).

RGP *PRK*	Total of seedlings (pcs) *Ukupan broj sadnica (kom)*	Percentage of seedlings from samples (%) *Postotak sadnica iz uzorka (%)*	Survived (pcs) *Preživjelo (kom)*	Dead (pcs) *Propalo (kom)*	Survived (pcs) *Preživjelo (kom)*	Dead (pcs) *Propalo (kom)*
0	1	0,5	0	1	0	100
1	10	5	0	10	0	100
2	90	44	70	20	77,8	22,2
3	83	39,8	83	0	100	0
4	21	10,7	21	0	100	0
Total *Ukupno*	205	100	174	31	84,9	15,1

As seen from Table 2 most sampled seedlings fell into root growth potential classes 2, 3 and 4. 77,8% of the seedlings with root growth potential 2 survived while the seedlings with root growth potential 3 and 4 had a 100% survival rate. In the nurseries of Hrvatske Šume d.o.o., Zagreb, the largest producer of seedlings in Croatia, the classification of seedlings with respect to their height is performed on the basis of a reference table which includes age, production method, i.e. the time spent in germination beds or growing beds (table 3).

We will compare seedling heights based on age and the determined root growth potential with the classes corresponding to these heights if the seedlings were classified according to the methods used in the nurseries of Hrvatske Šume d.o.o., Zagreb.

Table 3 Reference table of height classes of the company Hrvatske Šume d.o.o.
Tablica 3 Visinske klase sadnica crnog bora koje se koriste u poduzeću „Hrvatske šume" d. o. o.

Age *Starost*	Visina (cm) *Seedling height (cm)*	Kvalitativna klasa *Quality class*
1+0	5-8	II. Klasa
1+0	8-12	I. Klasa
2+0	10-15	II. Klasa
2+0	15-20	I. Klasa
1+1	8-10	II. Klasa
1+1	10-15	I. Klasa
1+2	20-30	II. Klasa
1+2	30-40	I. Klasa
1+3	35-40	II. Klasa
1+3	40-50	I. Klasa
2+1	15-25	II. Klasa
2+1	25-30	I. Klasa
2+2	25-35	II. Klasa
2+2	35-50	I. Klasa

Table 4 shows numbers and percentages of the survived Black Pine seedlings of different ages and height classes as used in the nurseries of Hrvatske Šume d.o.o. with respect to the determined root growth potential.

Table 4 Height classes for Black Pine seedlings of different ages as used in the nurseries of Hrvatske Šume d.o.o. with respect to the determined root growth potential.
Tablica 4 Visinske klase sadnica crnog bora različite dobi used in the nurseries of Hrvatske Šume d.o.o. s obzirom na utvrđeni potencijal rasta korijena.

Age/RGP	2					3					4				
	>I	I	II	<II	Σ	>I	I	II	<II	Σ	>I	I	II	<II	Σ
2+0	2	21	39	8	70	4	25	41	13	83	3	14	4	0	21
%	2,86	30	55,71	11,43	100	4,82	30,12	49,4	15,66	100	14,29	66,67	19,05	0	100
2+1	3	15	49	3	70	5	16	55	7	83	2	10	9	0	21
%	4,29	21,43	70	4,29	100	6,02	19,28	66,27	8,43	100	9,52	47,62	42,86	0	100
2+2	-	-	-	-	-	1	22	52	8	83	2	8	11	0	21
%	-	-	-	-	-	1,2	26,51	62,65	9,64	100	9,52	38,1	52,38	0	100

The correlation between the heights of Black Pine seedlings 2+0 and root growth potential
Ovisnost visina sadnica crnog bora 2+0 i potencijala rasta korijena

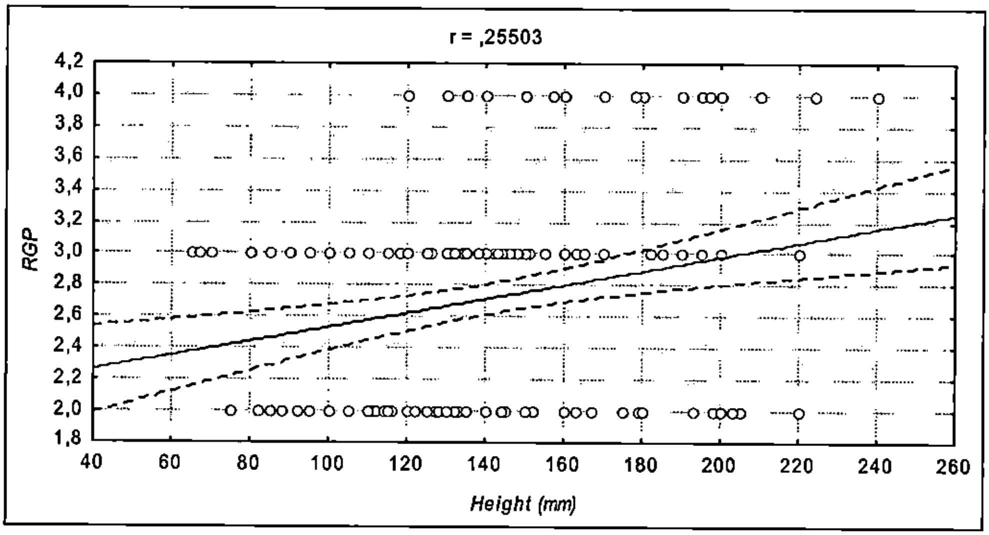


Figure 2 Correlation between the heights of Black Pine seedlings 2+0 and root growth potential
Figure 2 Korelacija između visina sadnica crnog bora 2+0 i potencijala rasta korijena

The correlation between seedling heights and root growth potential (r=0,25503) is positive.

Table 5 The variance analysis of Black Pine seedling heights 2+0 with respect to root growth potential.
Tablica 5 Analiza varijance visine sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

Source of variability *Izvor varijabilnosti*	SS	DF	MS	F	p
Constant *Konstanta*	**2654816**	**1**	**2654816**	**2026,34**	**0,000000**
RGP	**28485**	**2**	**14243**	**10,871**	**0,000036**
Deviations *Odstupanje*	222726	170	1310		

The variance analysis of Black Pine seedling heights 2+0 with respect to root growth potential showed a statistically significant difference (F=10,871, p=0,000036).

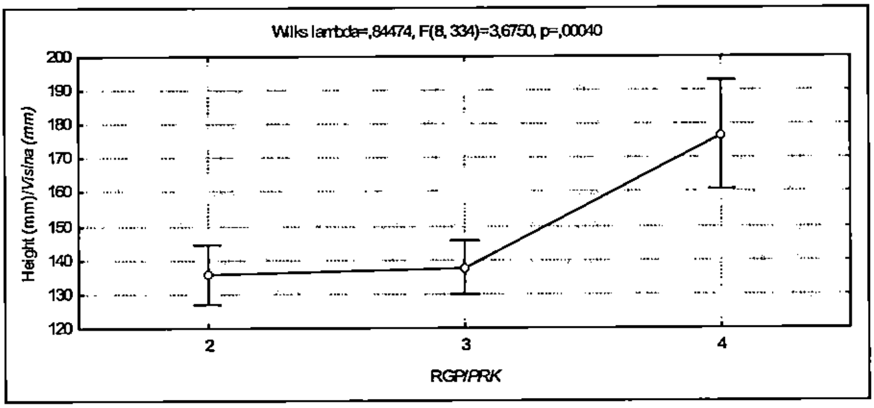


Figure 3 The variance analysis of Black Pine seedling heights 2+0 with respect to root growth potential.
Slika 3. Analiza varijance visina sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

Table 6 Tukey's *post hoc* test for Black Pine seedling heights 2+0 with respect to root growth potential.
Tablica 6. Tukeyev post hoc test visina sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

RGP *PRK*	2 (135,74)	3 (137,63)	4 (176,80)
2		0,944892	**0,000043**
3	0,944892		**0,000061**
4	**0,000043**	**0,000061**	

Tukey's *post hoc* test proved there was a statistically significant difference between seedling heights with root growth potential 4 and those with root growth potential 3 (p=0,000061) and 2 (p=0,000043). A statistically significant difference was also established for the seedlings aged 2+1 (F=4,791, p=0,009448). The heights of seedlings with root growth potential 4 were significantly different from those with root growth potential 3 (p=0,007933) and 2 (p=0,011739). A statistically significant difference was established for the seedlings aged 2+2 (F=6,606, p=0,001729). The heights of seedlings with root growth potential 4 were significantly different from those with root growth potential 3 (p=0,002387) and 2 (p=0,000832). A statistically significant difference (F=8,135, p=0,000422) was obtained for the seedlings aged 2+3.

There was a statistically significant difference between the heights of seedlings with root growth potential 4 and those with root growth potential 3 (p=0,002279) and 2 (p=0,000189).

Figure 3 clearly shows significant differences between the heights of seedlings with root growth potential 4 and those with root growth potential 2 and 3. The seedling heights with root growth potential 4 had an arithmetic mean of 176 mm and it ranged from 161 mm to 190 mm. The average value for the seedling heights with root growth potential 3 was 138 mm and it ranged from 129 mm to 146 mm. The seedling heights with root growth potential 2 had an average value of 136 mm, ranging from 128 mm to 144 mm.

The correlation between the shoot/root ratio of Black Pine seedlings2+0 and root growth potential

Ovisnost između odnosa duljine nadzemnog i podzemnog dijela sadnica crnog bora 2+0 i potencijala rasta korijena

None of the seedlings with root growth potential 0 and 1 survived. The shoot/root ratio of the seedlings was round 1 or somewhat below. Table 7 shows the results of descriptive statistics for the shoot/root ratio of Black Pine seedlings 2+0 with respect to root growth potential.

Table 7 Descriptive statistics of the shoot/toot ratio of Black Pine seedlings 2+0 with respect to root growth potential.
Tablica 7. Deskriptivna statistika odnosa duljine nadzemnog i podzemnog dijela sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena

RGP	N	Mean *Aritm. sred.*	Std. dev. *Std. dev.*	Std. err. *Std. pogreška*	-95,00%	95,00%
2	71	0,686401	0,196886	0,023366	0,639799	0,733004
3	83	0,675145	0,180872	0,019853	0,63565	0,714639
4	20	0,81725	0,250482	0,05601	0,700021	0,934479
Total	174	0,696072	0,20007	0,015167	0,666135	0,726009

Table 7 clearly shows that the mean value of the shoot/root ratio of the seedlings with root growth potential 2 was 0,69. It does not statistically and significantly differ from the mean value of the shoot/root ratio of the seedlings with root growth potential 3 which was 0,68 but it differs from the seedlings with root growth potential 4 whose ratio was 0,82. The variance analysis of the shoot/root ratio of Black pine seedlings 2+0 with respect to root growth potential revealed a statistically significant difference (F=4,369, p=0,014104).

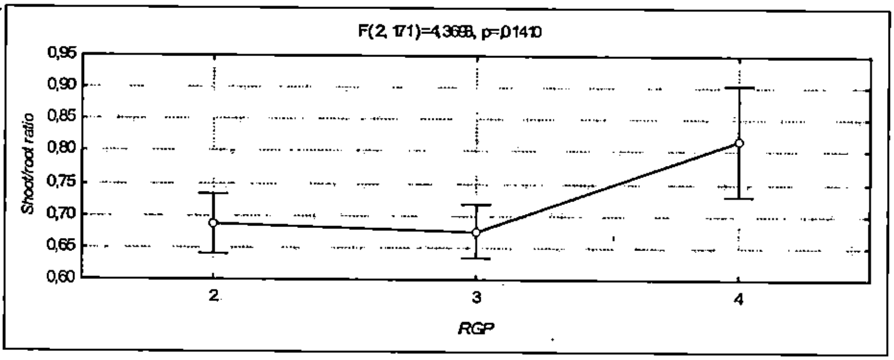


Figure 4 The variance analysis of the shoot/root length ratio of Black Pine seedlings 2+0 with respect to root growth potential.
Slika 4 Analiza varijance odnosa duljine nadzemnog i podzemnog dijela sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

Table 8 Tukey's post hoc test for the shoot/root length ratio of Black Pine seedlings 2+0 with respect to root growth potential.
Tablica 8 Tukeyev post hoc test odnosa duljine nadzemnog i podzemnog dijela sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

RGP *PRK*	2 (0,68640)	3 (0,67514)	4 (0,81725)
2		0,932983	**0,023014**
3	0,932983		**0,010227**
4	**0,023014**	**0,010227**	

Tukey's *post hoc* test established a statistically significant difference in shoot/root length ratio between the seedlings with root growth potential 4 and those with root growth potential 3 (p=0,010227) and 2 (p=0,023014).

DISCUSSION
RASPRAVA

The success of reforestation depends on the use of seedlings whose morphological and physiological characteristics ensure desirable heights, survival and a certain level of tolerance to unfavourable site conditions. It is the seedling quality that determines desirable height and survival after transplanting (Duryea 1985, Mattsson1997). The quality of a seedling is directly correlated to its genetic characteristics, size, vitality and especially the environment conditions at transplanting. It is directly influenced by the production method, the way of planting and storing. There are many studies on the quality of seedlings (Sutton1979, Ritchie 1984, Duryea 1985, Puttonen 1989, Grossnickle and Folk 1993, Mattsson 1979, Mohammed 1997, Puttonen 1997, Sampson et al. 1997, Tanaka et al. 1976). They mostly focused on the soil characteristics and physiological vitality of seedlings and less on the quality of the root system. However, there have been a few short studies directed towards morphological and physiological features of the root system with the purpose to determine methods for evaluating root system in seedlings.

A successful forest establishment largely depends on the ability of seedlings to form new roots fast (Grosnickle 2005). Formation of new roots can overcome transplantation shock and reduce a possible effect of slower seedling growth caused by poor adaptation to new site conditions (Rietveld 1989). Transplantation shock caused by water stress (Burdett 1990, Haase and Rose 1993) results in a reduced root growth and lesser contact between the soil and the root (Burdett 1990). The problem is more emphasized with bare root seedlings where the contact between the root and the soil is disturbed due to the loss of fine roots during lifting (Nambiar 1980, Struve and Joly 1992). The growth of new roots helps overcome the problem (Burdett et al. 1990, Nambiar and Sands 1993). The growth of new roots in conifers depends on photosynthesis (Van den Driessche 1987, Burdett 1990) and the level of water potential immediately after transplanting (Burdett 1990).

Among the total number of tested seedlings we determined the following 5 classes on Burdett's scale of root growth potential: class 0, class 1, class 2, class 3 and class 4. During the evaluation of RGP we did not use artificial light, which is partially why the seedlings did not exhibit a higher root growth potential than 4 on Burdett's scale.

The seedlings whose root growth potential on Burdett's scale was 0 and 1 did not survive the experiment. We can therefore conclude that the seedlings whose root growth potential is very low or inexistent, are not suitable for field planting as they are very unlikely to survive.

The seedlings with root growth potential 2 on Burdett's scale had a survival rate of 77,8%.

It can, therefore, be concluded that the seedlings with root growth potential 2 on Burdett's scale can be used for field planting. All the seedlings with root growth potential higher than 2 were among the survived ones, which means that the use of such seedlings ensures successful reforestation.

Morphological characteristics which can be easily measured (Ritchie 1984) are most frequently used in the process of seedling quality evaluation. The height and root collar diameter which are often used as parameters for determining nursery quality of seedlings are in many cases correlated to the survival of seedlings or to their height after transplanting (Thompson 1985, Bayley and Kietzka 1997,Jacobs 2009). However, long ago it was found out that seedling height and root collar diameter before reforestation cannot be correlated to seedling performance after transplanting (Chavase 1977, Thompson and Schultz 1995, Jacobs 2009). According to Wakeley (1949) there is very little interdependence between the height of southern pine seedlings and their survival after transplanting. Stone (1959) found out that the physiological condition of seedlings, especially expressed as the values of root growth potential at transplanting, can show a potential for the growth of root and stem if the seedlings have a certain level of tolerance to stress caused by reduced moist. When such research first started in the mid-twentieth century very few studies focused on the evaluation of the seedling root system as measuring root system is a hard and time consuming process dependent on soil characteristics.

The seedlings which according to the reference table of Hrvatske Šume d.o.o., Zagreb were mostly in height class 2 had the root growth potential 2 on Burdett's scale. The percentage of class 2 seedlings in our sample ranged from 55.71% for two-year-old seedlings to 70% for three-year-old seedlings and to 71.43% for four-year-old seedlings. The percentages of class 1 seedlings were much lower: 30% for two-year-old seedlings, 21.43% for three-year-old seedlings and 17.14% for four-year-old seedlings. The seedlings with height values below class 2 or above class 1 had the lowest percentages. There were 11.43% of two-year-old seedlings, 4.28% of three-year-old seedlings and 8.57% of four-year-old seedlings with height below class 2. There were 2.86% of two-year-old, 4.28% of three-year-old and 2.86% of four-year-old seedlings with heights above class 1.

The largest percentage of seedlings from height class 2 according to the reference table of Hrvatske Šume d.o.o., Zagreb had the root growth potential 3 on Burdett's scale. There were 49.40% of two-year-old, 66.26% of three-year-old and 62.65% of four-year-old seedlings. Among class 1 seedlings there were 30.12% of two-year-old, 19.28% of three-year-old and 26.51% of four-year-old seedlings. The seedlings with height values below class 2 or above class 1 had the lowest percentages. There were 15.66% of two-year-old, 8.44% of three-year-old and 9.64% of four-year-old seedlings with heights below class 2.

There were 4.82% of two-year-old, 6.02% of three-year-old and 1.20% of four-year-old seedlings with heights above class 1.

The largest percentage of seedlings with root growth potential 4 on Burdett's scale belonged to height classes 1 and 2 from the reference table of Hrvatske Šume d.o.o., Zagreb.

In class 1 there were 66.67% of two-year-old, 47.62% of three-year-old and 38.10% of four year-old seedlings. In class 2 there were 19.05% of two-year-old, 42.86% of three-year-old and 52.38% of four-year-old seedlings. The seedlings above class 1 values had the lowest share. It can also be observed that the group of survived seedlings with root growth potential 4 on Burdett's scale does not contain the seedlings with height values below class 2, unlike root growth potential 2 and 3 on Burdett's scale.

Among the seedlings with values above class 1 there were 14.28% of two-year-old, 9.52% of three-year-old and 9.52% of four-year-old seedlings.

Out of the total number of the survived seedlings 44% had the determined root growth potential 2 according to Burdett, 39.8% had the determined root growth potential 3 according to Burdett and for only 10.7% the determined root growth potential was 4 on Burdett's scale.

We noticed that the group with root growth potential 2 on Burdett's scale contained a large percentage of class 2 seedlings according to the classification system of Hrvatske Šume d.o.o., Zagreb. It is therefore evident that the stock group with root growth potential 2 on Burdett's scale is most similar to height class 2.

We also observed that the percentage of class 2 seedlings is lower for the group with root growth potential 3 on Burdett's scale, while the group with root growth potential 4 on Burdett's scale has a significant number of class 1 seedlings and there are no seedlings with heights below class 2 values. The stock group with root growth potential 4 on Burdett's scale is of different quality compared to the group with root growth potential 2 and 3 with respect to seedling heights. The result is also a hundred percent survival rate at the age of five.

The research established a statistically significant correlation between the height of seedlings and root growth potential. The variance analysis revealed a statistically significant difference in heights of Black pine seedlings 2+0 with root growth potential 4 compared to the heights of seedlings with root growth potential 2 and 3. There are statistically significant differences in seedling heights with higher root growth potential values.

A favourable shoot/root ratio has an important impact on the survival of seedlings after planting (Lopushinsky and Beebe 1976). A statistically significant difference in shoot/root ratio was established with respect to root growth potential. The shoot/root ratio of seedlings with root growth potential 4 was statistically different from the values for the seedlings with the determined root growth potential 2 and 3.

CONCLUSIONS
ZAKLJUČCI

The seedlings with root growth potential 2 (according to Burdett) had a survival rate of 77,8%. The seedlings with root growth potential 3 and 4 had a survival rate of 100%. The seedlings whose root growth potential was 0 and 1 (on Burdett's scale) did not survive.

There is a positive and strong correlation between root growth potential and seedling survival.

Root growth potential is a better indicator of nursery quality of seedlings compared to the height classes currently used in the nurseries in Croatia as they give a better insight into a potential for seedling survival at reforestation.

Seedling with higher root growth potential have better *shoot/root ratio.*

Performing root growth potential test usually requires a longer period of time. Therefore, this method can be suitable only for larger seedling lots while some other methods based on morphological parameters will continue to be used.

In order to get a better insight into the impact of root growth potential on seedling survival, further research should be done with field transplantation of seedlings in more severe conditions.

REFERENCES
LITERATURA

Bayley, A. D., J. W. Kietzka, 1997: Stock quality and field performsnce of *Pinus patula* seedlings produced under two nursery growing regimes during 7 different nursery production periods. New Forest, 13: 341-356.

Burdett, A. N., 1979: New methods for measuring root growth capacity their value in assessing lodgepole pine stock quality. Can. J. Forest Res., 9: 63-67.

Burdett, A. N., D. G. Simpson, C. F. Thompson, 1983: Root development and plantation establishment success. Plant and Soil, 71:103-110.

Burdett, A. N., 1987: Understanding root growth capacity: teoreticaly consideration in assesing planting stock quality by means of root growth test. Can. J. F. Res., 17: 768-775.

Burdett, A. N., 1990: Physiological processes in plantation stablishment and development of specifications for forest planting stock. Can. J. F. Res., 20: 415-427.

Chavasse, C. G. R., 1977: The significance of planting height as an indicator of subsequent seedlings growth. New Zealand J. For., 22: 283-296.

Colombo, S. J., C. Glerum, 1984: Winter injury to shoot as it affect root activity in black spruce container seedlings. Ca. J. F. Res., 14: 31-32.

Deans, J. D., C. Lundberg, M. G. R. Cannell, M. B. Murray, L. J. Sheppard, 1990: Root system fibrosity of Sitka spruce transplants: relationship with root growth potential. Forestry, 63: 1–7.

Duryea, M. L., 1985: "Evaluating seedlings quality importance to reforestration", u: Duryea, M. L. (ed.), Evaluating seedlings quality: Principles, Procedures and Predictiv Abilities o Major Tests, Forest Research Laboratory, Oregon State Universty, Corvallis, str. 1-6.

Folk, R. S., S. C. Grossnickle, 1997: Determining field performance potential with the use of limiting environmental conditions. New For., 13: 121-138.

Grossnickle, S. C., R. S. Folk, 1993: Stock quality assessment forecasting survival or performance on a reforestration site. Tree Planters Notes, 44: 113-121.

Grossnickle, S. C., 2005: The importance of root growth in overcoming planting stres. New Forests, 30: 273-294.

Hase, D. L., R. Rose, 1993: Soil moisture stres induces transplant shock in stored and unstored 2+0 Douglas-fir seedlings of vary root volume. For. Sci., 39: 275-294.

HRN D. Z2.110, http://www.hzn.hr/pdf/Oglasnik109.pdf

Ivančević, V., 1995: Šume i šumarstvo dijela hrvatskog primorskog krša tijekom XIX i XX vijeka (disertacija), Šumarski fakultet, Zagreb.

Jacobs, D. F., 2009: Drought susceptibility and recovery of transplanted *Quercus rubra* seedlings in relation to root system morphology. Annals of Forest Science, 66.

Lafayete IN, USA 19-20 October 2004, USDA For. Ser. Nord Central Research Station.

Larsen, H. S., D. B. South, J. M. Boyer, 1986: Root growth potential, seedling morfology and bud dormancy correlae with survival of loblolly pine seedlings planted in December in Alabama, Heron Publishing Victoria, Canada. Tree Physiology, 1: 253-263.

Lopushinsky, W., T. Beebe 1976: Relationship of shoot-root ratio to survival and growth of outplanted Douglas-fir and ponderosa pine seedlings. U.S.D.A. Forest Service. Pacific Northwest Forest and Range Experiment Station. Research Note PNW-274 7 p.

Mattsson, A., 1997: Predicting field performance using seedlings quality assessment. New Forest, 13: 227-252.

Mohammed, G. H., 1997: The status and future of stock quality testing. New Forest, 13: 491-514.

Nambiar, E. K. S., R. Sands, 1993: Competition for water and nutrients in forest. Can. J. For. Res., 23: 1955-1968.

O'Reilly, C., C. Harper, M. Keane, 2002: Influence on physiological condition at the time of lifting on the cold storage tolerance of the field performance of ash and sycamore. Forestry, 75: 1-12.

Puttonen, P., 1989: Criteria for using seedlings performance potential tests. New Forest, 3: 67-87.

Rietveld, W. J., 1989: Transplanting stres in bareroot coniffer seedlings, its development and progresion to establishment. North J. Appl. For., 6: 99-107.

Ritchie, G. A., 1984: "Assessing seedling quality", u: Forest nursery manual: production of bareroot seedlings, Edited by M. L. Duryea and T. D. Landis Martinus Nijhoff/Dr. W. Junk Publishers, The Hague, str. 243-266.

Sampson, P. H., C. W. G. Templeton, S. J. Colombo, 1997: An overview of Ontario stock quality assessments program. New For., 13: 469-487.

Simpson, D. G., 1990: Frost hardiness, root growth capacity and field performans relationship in interior spruce, lodgepole pine, Douglas-fir and western hemlock seedlings. Can. J. For. Res., 20: 566-572.

Simpson, D. G., C. F. Thompson, C. D. Southerland, 1994: Field performance of interior spruce seedlings effects of stres tretments and prediction by root growth potential and needle conductance. Can. J. For. Res., 24: 576-586.

Stone, E. C., G. H. Schubert, 1959: Root regeneration by ponderosa pine seedlings lifted at diferent times of the year. For. Sci., 5: 322-332.

Stone, E. C., J. L. Jenkinson, 1971: Physiologycal grading of ponderosa pine nursery stock. J. For., 69: 31-33.

Struve, D. K., R. J. Joly, 1992: Transplanted red oak seedlings mediate transplant shock by reducing leaf area and altering carbon allocation. Can. J. For. Res., 22: 1441–1448.

Sutton, R. F., 1979: Planting stock quality and grading. For. Ecol. Manage, 2: 123-132.

Sutton, R. F., 1980: Root system morphogenesi. N. Z. J. For. Sci., 10: 264-292.

Tanaka, Y., J. D. Walstad, J. E. Borrecco, 1976: The efect of wrenching on morphology and field performance of Douglas-fir and loblolly pine seedlings. Can. J. For. Res., 6: 453-458.

Thompson, B. E., 1985: "Seedlings morphologycal evaluation: what you can tell by looking", u: Duryea, M. I., Evaluating seedlings quality: Principels, Procedures and Predictive Ability of Mayor Tests, Oregon State University, Corvallis, OR, str. 59-71.

Von den Driessche, R., 1987: Importance of current photosynthate to new root growth in planted conifera seedlings. Can. J. For. Res. 17: 776-782.

Wakeley, P. C., 1949: "Physiologic grades of southern pine nursery stock", u: Shirley, H. I. (ed.), Proceeding of the 1948 Society of American Forest Annual Convention, Boston, MA USA.

UDK 630*434

Preliminary communication
Prethodno priopćenje

EFFECTS OF PINE CULTURES ON A DEGRADED SITE IN THE TRANSITIONAL SUBMEDITERRANEAN AREA

UTJECAJ BOROVIH KULTURA NA DEGRADIRANO STANIŠTE U PRIJELAZNOM PODRUČJU SUBMEDITERANA

ŽELJKO ŠPANJOL[1], DAMIR BARČIĆ[1], ROMAN ROSAVEC[1], ANTE TOMAŠEVIĆ[1], NERA MARKOVIĆ[1], SANDRA POKAS

[1]University of Zagreb, Faculty of Forestry, Department of Ecology and Silviculture

Received – *prispjelo*: 16.12.2009. Accepted - *prihvaćeno* 28.09.2010.

Abstract

The paper analyzes the impact of pioneer forest vegetation (pines) on a degraded site afforested seventy years ago. In the meantime, research activities were undertaken in 1977 and 1991. Sample plots were established in pine cultures, while control plots intended for pedological research were established outside the stand. Measurements included phytocoenological research, stand structure research and previous pedological research. The condition of seedlings and young growth representing the return to climatozonal vegetation was monitored. Research was conducted in the transitional area of the sub-Mediterranean and eu-Mediterranean vegetation zone. This is the Musapstan area within the forest office of Zadar. According to our research, the regeneration process of climatozonal deciduous vegetation is slow. Among other factors, this is attributed to the unfavourable structure of the stand for regeneration. The productive capacity of pine cultures is satisfactory, so they simultaneously fulfill their protective role in the climate of the Mediterranean karst area. The absence of silvicultural treatments is becoming an important factor in the context of increased danger of forest fires. In case of a fire, the already slow succession processes would be additionally aggravated.

Key words: amelioration, forest cultures, Mustapstan, climatozonal vegetation

Sažetak

U radu je istražen problem odnosa i utjecaja pionirske šumske vegetacije (borova) na degradirano stanište koje je bilo pošumljeno prije sedamdeset godina. U međuvremenu su obavljena istraživanja 1977. i 1991. godine. Na pokusnim plohama unutar borovih kultura su postavljene pokusne plohe i kontrolne usporedne izvan sastojine samo za pedološka istraživanja. Izmjerom su obuhvaćena fitocenološka, istraživanja strukture sastojine, te prethodna pedološka istraživanja. Nadalje praćeno je stanje ponika i pomlatka što predstavlja odnos prema povratku klimazonalne vegetacije. Za istraživanje je odabrano prijelazno područje submediteranske i eumediteranske vegetacijske zone. Radi se o predjelu Musapstan u šumariji Zadar. Istraživanjima je pokazano kako je proces obnove klimazonalne vegetacije listača usporen. Razlozi tome su i u nepovoljnoj strukturi sastojine za obnovu. Zadovoljavajuća je proizvodna sposobnost borovih kultura koje istovremeno ispunjavaju i zaštitnu ulogu u uvjetima podneblja na mediteranskom prostoru krša. Nedostatak šumsko-uzgojnih radova postaje bitan u kontekstu veće opasnosti od šumskog požara. U tom slučaju bili bi otežani ionako spori sukcesijski procesi.

Ključne riječi: melioracije, šumske kulture, Musapstan, klimazonalna vegetacija

INTRODUCTION
UVOD

The choice of an amelioration method depends on a number of degradation factors and site conditions. There are several ameliorative treatments, including a ban on grazing, resurrection felling and the introduction of new tree and shrub species. Pioneer species are introduced into distinctly degraded sites owing to their ability to adapt to adverse site conditions.

Their positive impact on soil productivity and on the protective role of climatozonal vegetation in the process of its regeneration is also of utmost importance. Regression and erosion processes in degraded sites should be halted (Requena et al. 2001; Clemente et al. 2004). Mediterranean conditions pose a number of aggravating obstacles to the regeneration process. Court-Picon et al. (2004) point out summer dry periods and high carbonate content in the soil. Rambal (1993) stresses water and dry periods as the prime limiting factors in plant development. The success of afforestation depends on the choice of the species to be used for a particular afforestation area, as well as on their silvicultural characteristics. For this reason, the afforesting species included conifers, mostly pines. Other Mediterranean countries meet with similar problems (Maestre & Cortina 2004). The role of pines can be highlighted through improved soil fertility and structure, which guarantees progressive succession in a degraded site (Kutiel & Naveh 1987, Certa 1998, Barčić et al. 2006).

One of the main goals of the work was to assess the ameliorative impact of pioneer pine species on a degraded site. Positive impacts of pines on long-term succession processes of broadleaved species and the regeneration of site conditions are highlighted (Montero and Alcanda, 1993, Gil and Aránzazu 1993, Lookinbill and Zavala 2000). Another objective was to find out the extent to which some significant changes in the soil - vegetation interaction can be manifested over a period of thirty years. The next aim of this research was to determine the productive capacity of the site if pioneer pine species are planted. The investigated ameliorative effect is manifested in the following: the relationship towards site quality, the return of climatozonal deciduous vegetation, the preservation of productive soil capacity, the fulfillment of non-market functions of forests and forest soil in the Mediterranean karst area.

MATERIAL AND METHODS
MATERIJALI I METODE

Research area
Područje istraživanja

As defined by the Management Plan for the management unit Musapstan (2005 - 2014), the management unit Musapstan, Zadar Forest Office, is situated very close to the City of Zadar. Unlike the major part of the Adriatic coast, there are no mountain chains in the immediate hinterland; rather, the macro-relief is a spacious limestone plateau. The micro-relief of the area is composed of stone blocks of limestone that resurface up to 0.5 m. The highest point in this management unit is in compartment 18c, at an altitude of 110 m (the hill of Čubrijan). The lowest point is situated in compartment 59d at 10 m above sea level. The inclination generally does not exceed 8 %. The exposition is northern, contributing to the strong impact of bura (the northerly wind) in the area (Management Plan, 2005). The wider Zadar area is situated in the climatic zone marked as *Csa*. According to Šegota and Filipčić (2003), this is the climate of the warmest part of Littoral Croatia and is characterized by hot summers. The basic climatic indicators are presented in the climatogram in Figure 1.

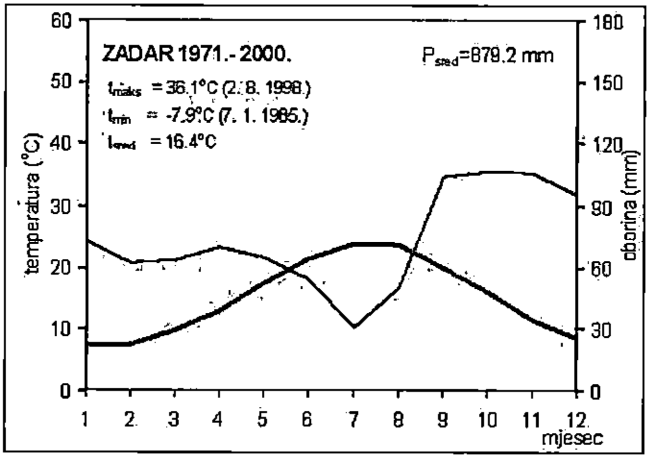


Figure 1 Climatic diagram for Zadar according to Walter (1955) for the period 1971 – 2000.
Slika 1. Klimatski dijagram za Zadar prema Walteru (1955) za razdoblje 1971-2000.

According to the Management Plan for the Management Unit Musapstan (2005 - 2014), the dominant soil type in a broader research area in cambisol on limestone and dolomite (96.2% of the management unit), and the rest are anthropogenized soils. There are sporadic occurrences of parts of massive rocks of varying dimensions, including larger rock fragments on different depths. In between, there are shallow skeletoidal and skeletal soils and thicker soil accumulations.

The vegetation of Musapstan is presented according to the works of Horvat (1950), Horvatić (1957), Bertović (1975), Bertović and Lovrić (1985), Trinajstić et al. (1992), Vukelić and Rauš (1998).

Class: *Quercetea ilicis* Br.-Bl. 1947
Order: *Quercetalia ilicis* Br.-Bl. (1931) 1936
Alliance: *Quercion ilicis* Br.-Bl. (1931) 1936
As: *Fraxino orni – Quercetum ilicis* H-ić 1956/1958

Class: *Querco-fagetea* Br.-Bl. Et Vlieger 1937
Order: *Quercetalia pubescentis* Br.-Bl (1931) 1932
Alliance: *Ostryo-Carpinion orientalis* Ht. (1954) 1958
As: *Querco-Carpinetum orientalis* H-ić 1939
Subas: *Phillyrea media*

Class: *Brachypodio-chrysopogonetea*
Order: *Scorzonero-chrysopogonetalia*
Alliance: *Chrysopogoni-satureion*
As: *Koelerio-festucetum illyricae* Trinajstić 1992

Field work
Terenska istraživanja

The management unit of "Musapstan" is situated at the transition from the eu-Mediterranean into the sub-Mediterranean area. The largest part of the management unit belongs to the natural range of forests of pubescent oak of the alliance *Ostryo-Carpinion orientalis*. A smaller part along the southwestern boundary, and especially the southern part, belongs to the natural range of forests of holm oak of the alliance *Quercion ilicis*. The forest of holm oak, as well as the forest of pubescent oak, occurs here in its degraded form - maquis, which sporadically turns into garrigue, i.e. scrub or pseudomaquis. Silvicultural treatments are applied in accordance with the Management Plan of this area. These treatments mainly involve afforestation and thinning. The relatively densely populated area and the vicinity of a larger city are responsible for the distinct impact of man through several centuries (grazing, recreation). A significant portion of the area is covered by forest cultures of allochthonous conifers, which includes the pine culture on Musapstan, one of the largest and best preserved in the Adriatic region. The predominantly mixed composition of the culture consists of approximately equal shares of Aleppo pine (*Pinus halepensis* Mill.), maritime pine (*Pinus pinaster* Aiton) and stone pine (*Pinus pinea* L.). Of other species there are black pine (*Pinus nigra* Arnold) and cypress (*Cupressus sempervirens* L.), as well as small amounts of cedar (*Cedrus deodara* (Roxb.) G. Don.). Field measurements were conducted in the management unit of Musapstan, in compartments 18a, 26a and 27a. Five plots (plot size 25 m x 4 m) were established in each compartment. Tree heights and breast diameters above the taxation limit of 7 cm were measured in each plot. The obtained data were used to calculate the main structural elements (number of trees, basal area and volume). Measurements in the sample plots also included the structure of seedlings and young growth by height classes and tree species. Phytocoenological relevés were made according to the plant sociology method (Braun-Blanquet 1964).

RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA

Past research in the management unit of Musapstan conducted by Tomašević (1994) was used as a basis for comparative analysis with new data and for the analysis of the obtained data.

The situation recorded in the plot set up in compartment 27a (16) was as follows: 319 stone pines, 112 cypresses and 117 Aleppo pines per hectare. Research undertaken thirty years later showed 320 stone pines, 120 cypresses and 80 Aleppo pines per hectare. In 1977, there were a total of 574 trees per hectare, compared with 520 trees per hectare today. With an insignificant decrease in the number of trees per hectare, the basal area rose from 31.30 m^2/ha to 60.60 m^2/ha, and volume from 205.6 m^3/ha to as much as 510.8 m^3/ha. In compartment 27a (16) the mean height of the stone pine was 12.6 m, and the mean diameter of the stone pine was 26.6 cm. Our research related to the stone pine showed the mean height of 16.7 m, and the mean diameter of 34.2 cm.

In the plot of compartment 181 (12), Tomašević (1994) recorded 139 stone pines, 60 cypresses and 373 trees of Aleppo pine per hectare, totalling 575 trees per hectare. Today, the same stand contains 80 stone pines, 260 Aleppo pines and 180 cypresses per hectare, which amounts to 520 trees per hectare in all. The number of trees decreased in this stand as well, but the basal area increased significantly from 28.44 m^2/ha to 87.20 m^2/ha, and so did the volume from 214.83 m^3/ha to 330.60 m^3/ha. In compartment 18a (12) containing a mixed culture, the mean tree diameter for Aleppo pine was 27.4 cm and the mean height was 16.4 m. In our research, the mean diameter for Aleppo pine was 40.6 cm, and the mean height was 19.0 m.

Table 1 Stand structure per hectare (ha) Forest office Zadar; Management unit Musapstan; Compartment: 27a (16); Year of measurement: 1977; Source: Tomašević (1994).
Tablica 1. Struktura sastojine po hektaru (ha) Šumarija Zadar; gospodarska jedinica Musapstan; odjel: 27a (16); godina izmjere: 1977; izvor: Tomašević (1994).

Tree species *Vrsta drveća*	Stone pine (*Pinus pinea* L.) *Pinija*			Aleppo pine (*Pinus halepensis* Mill.) *Alepski bor*			Mediterranean cypress (*Cupressus sempervirens* L.) *Obični čempres*			Maritime pine (*Pinus pinaster* Aiton) *Primorski bor*			Total - *Ukupno*		
Diameter classes (cm) *Debljinski razred* (cm)	N	G	V	N	G	V	N	G	V	N	G	V	N	G	V
5 - 10							13	0,05	0,4	1	0,0002	0,02	14	0,05	0,42
11 - 20	56	1,43	8,1	8	0,23	1,3	91	1,71	10,7	15	0,28	1,4	170	3,65	21,5
21 - 30	189	9,69	59,5	37	2,1	13,8	8	0,29	2,1	5	0,31	2,1	239	12,39	77,5
31 - 40	73	6,55	41,5	51	4,98	36,3				4	0,34	2,3	128	11,87	80,1
41 - 50	1	0,13	0,9	19	2,79	21,7							20	2,92	22,6
51 - 60				2	0,42	3,5							2	0,42	3,5
Σ	319	17,8	110	117	10,52	76,6	112	2,05	13,2	25	0,93	5,8	573	31,3	205,6

Table 2 Stand structure per hectare (ha) Forest office Zadar; Management unit Musapstan; Compartment 27a (16); Year of measurement: 2008.
Tablica 2. Struktura sastojine po hektaru (ha) Šumarija Zadar; gospodarska jedinica Musapstan; odjel: 27a (16); godina izmjere: 2008.

Tree species *Vrsta drveća*	Stone pine (*Pinus pinea* L.) *Pinija*			Aleppo pine (*Pinus halepensis* Mill.) *Alepski bor*			Mediterranean cypress (*Cupressus sempervirens* L.) *Obični čempres*			Total - *Ukupno*		
Diameter classes Debljinski razred (cm)	N	G	V	N	G	V	N	G	V	N	G	V
11 - 20												
21 - 30				1	0,05	0,45	2	0,08	0,66	3	0,13	1,11
31 - 40	11	1,16	8,7	1	0,1	0,79	4	0,38	3,22	16	1,64	12,71
41 - 50	4	0,6	4,99	1	0,15	1,27				5	0,75	6,26
51 - 60				1	0,22	2,23				1	0,22	2,23
61 - 70	1	0,29	3,23							1	0,29	3,23
Σ (5 x 100 m^2)	16	2,05	16,92	4	0,52	4,74	6	0,46	3,88	26	3,03	25,54
Per ha *Po ha*	320	41	338,4	80	10,4	94,8	120	9,2	77,6	520	60,6	510,8

Table 3 Structure of seedlings and young growth by height class and tree species in compartment 27a (16).
Tablica 3. Struktura ponika i pomlatka po visinskim klasama i vrsti drveća u odjelu 27a (16).

Tree species *Vrsta drveća* Height classes *Visinska klasa* (cm)	Mediterranean cypress (*Cupressus sempervirens* L.) *Obični čempres*	Stone pine (*Pinus pinea* L.) *Pinija*	Holm oak (*Quercus ilex* L.) *Hrast crnika*	Maritime pine (*Pinus pinaster* Aiton) *Primorski bor*	Aleppo pine (*Pinus halepensis* Mill.) *Alepski bor*	Total *Ukupno*	Total per ha *Ukupno po ha*
– 25	18	34	5	5	2	64	1280
26 -50	53	83	3	20	3	162	3240
51 – 75	35	25		7	1	68	1360
76 – 100	11	2		4		17	340
101 – 125	3					3	60
126 – 150							
151 – 175							
176 – 200							
201 – 225							
226 – 250							
251 – 275							
276 – 300							
Total *Ukupno*	120	144	8	36	6	314	6280
Total per ha *Ukupno po ha*	2400	2880	160	720	120		

Table 4 Stand structure per hectare (ha) Forest office Zadar; Management unit Musapstan; Compartment 18a (12); Year of measurement: 1977; Source: Tomašević (1994).
Tablica 4. Struktura sastojine po hektaru (ha) Šumarija Zadar; gospodarska jedinica Musapstan; odjel: 18a (12); godina izmjere: 1977; izvor: Tomašević (1994).

Tree species *Vrsta drveća*	Stone pine (*Pinus pinea* L.) *Pinija*			Aleppo pine (*Pinus halepensis* Mill.) *Alepski bor*			Mediterranean cypress (*Cupressus sempervirens* L.) *Obični čempres*			Himalayan cedar (*Cedrus deodara* (Roxb.) G. Don) Himalajski cedar			Total - *Ukupno*		
Diameter classes Debljinski razred (cm)	N	G	V	N	G	V	N	G	V	N	G	V	N	G	V
5 – 10	1	0,0003	0,02				17	0,01	0,5	2	0,01	0,03	20	0,02	0,55
11 – 20	59	1,42	8	58	1,36	9,2	38	0,66	3,8	1	0,01	0,03	156	3,45	21,03
21 – 30	72	3,51	22,1	219	11,4	88	4	0,18	1,3				295	15,09	111,4
31 – 40	7	0,62	4,1	90	8,29	69,3	1	0,08	0,6				98	8,99	74
41 – 50				6	0,89	7,8							6	0,89	7,8
51 - 60															
Σ	139	5,55	34,2	373	21,94	174,3	60	0,93	6,2	3	0,02	0,06	575	28,44	214,83

Table 5 Stand structure per hectare (ha) Forest office Zadar; Management unit Musapstan; Compartment 18a (12); Year of measurement: 2008.
Tablica 5. Struktura sastojine po hektaru (ha) Šumarija Zadar; gospodarska jedinica Musapstan; odjel: 18a (12); godina izmjere: 2008.

Tree species *Vrsta drveća*	Stone pine (*Pinus pinea* L.) *Pinija*			Aleppo pine (*Pinus halepensis* Mill.) *Alepski bor*			Mediterranean cypress (*Cupressus sempervirens* L.) *Obični čempres*				Total - *Ukupno*		
Diameter classes Debljinski razred (cm)	N	G	V	N	G	V	N	G	V		N	G	V
11 – 20							1	0,03	0,19		1	0,03	0,19
21 – 30	1	0,07	0,54	3	0,18	1,42	6	0,24	1,81		10	0,49	3,77
31 – 40	3	2,48	0,31	7	0,7	5,94	2	0,16	1,3		12	3,34	7,55
41 – 50				3	0,5	5,02					3	0,5	5,02
Σ (5 x 100 m^2)	4	2,55	0,85	13	1,38	12,38	9	0,43	3,3		26	4,36	16,53
Per ha *Po ha*	80	102	17	260	2,76	247,6	180	8,6	66		520	87,2	330,6

Table 6 Structure of seedlings and young growth by height class and tree species in compartment 18a (12).
Tablica 6. Struktura ponika i pomlatka po visinskim klasama i vrsti drveća u odjelu 18a (12).

Tree species *Vrsta drveća* / Height classes *Visinska klasa* (cm)	Mediterranean cypress (*Cupressus sempervirens* L.) *Obični čempres*	Stone pine (*Pinus pinea* L.) *Pinija*	Holm oak (*Quercus ilex* L.) *Hrast crnika*	Aleppo pine (*Pinus halepensis* Mill.) *Alepski bor*	Pubescent oak (*Quercus pubescens* Willd.) Hrast medunac	Total *Ukupno*	Total per ha *Ukupno po ha*
– 25	2		5	5	1	13	260
26 -50	6	1	3	6		16	320
51 – 75	12		3			15	300
76 – 100	7		3			10	200
101 – 125	3		4			7	140
126 – 150	6					6	120
151 – 175	2					2	40
176 – 200	2					2	40
201 – 225							
226 – 250							
251 – 275							
276 – 300							
Total *Ukupno*	40	1	18	11	1	71	1420
Total per ha *Ukupno po ha*	800	20	360	220	20		

Table 7 Stand structure per hectare (ha) Forest office Zadar; Management unit Musapstan; Compartment 26a (11); Year of measurement: 1977; Source: Tomašević (1994).
Tablica 7. Struktura sastojine po hektaru (ha) Šumarija Zadar; gospodarska jedinica Musapstan; odjel: 26a (11); godina izmjere: 1977; izvor: Tomašević (1994).

Tree species *Vrsta drveća*	Stone pine (*Pinus pinea* L.)			Aleppo pine (*Pinus halepensis* Mill.)			Mediterranean cypress (*Cupressus sempervirens* L.)			Maritime pine (*Pinus pinaster* Aiton)			Total - Ukupno		
Diameter classes Debljinski razred (cm)	N	G	V	N	G	V	N	G	V	N	G	V	N	G	V
11 – 20	79	1,93	9,2	5	0,12	0,5	4	0,05	0,2	1	0,02	0,1	89	2,12	10
21 – 30	294	15,38	98,5				1	0,04	0,3	4	0,21	1,2	299	15,63	100
31 – 40	124	11,14	61,4	2	0,19	1,1				4	0,34	1,2	130	11,67	63,7
41 – 50	9	1,39	8,2										9	1,39	8,2
51 - 60	1	0,22	1,4										1	0,22	1,4
Σ	507	30,06	178,7	7	0,31	1,6	5	0,09	0,5	9	0,57	2,5	528	31,03	183,3

Table 8 Stand structure per hectare (ha) Forest office Zadar; Management unit Musapstan; Compartment 26a (11); Year of measurement: 2008.
Tablica 8. Struktura sastojine po hektaru (ha) Šumarija Zadar; gospodarska jedinica Musapstan; odjel: 26a (11); godina izmjere: 2008.

Tree species *Vrsta drveća*	Stone pine (*Pinus pinea* L.)			Mediterranean cypress (*Cupressus sempervirens* L.)			Total - Ukupno		
Diameter classes Debljinski razred (cm)	N	G	V	N	G	V	N	G	V
11 – 20									
21 – 30	6	0,41	3,2	1	0,05	0,37	7	0,46	3,57
31 – 40	20	1,87	14,63				20	1,87	14,63
41 – 50	2	0,14	2,97				2	0,14	2,97
51 - 60									
Σ (5 x 100 m²)	28	2,42	20,8	1	0,05	0,37	29	2,47	21,17
Per ha *Po ha*	560	48,4	416	20	1	7,4	580	49,4	423,4

Table 9 Structure of seedlings and young growth by height class and tree species in the compartment 26a (11).
Tablica 9. Struktura ponika i pomlatka po visinskim klasama i vrsti drveća u odjelu 26a (11).

Tree species *Vrsta drveća* / Height classes *Visinska klasa* (cm)	Mediterranean cypress (*Cupressus sempervirens* L.) *Obični čempres*	Stone pine (*Pinus pinea* L.) *Pinija*	Holm oak (*Quercus ilex* L.) *Hrast crnika*	Total *Ukupno*	Total per ha *Ukupno po ha*
– 25	4	5	4	13	260
26 -50	12	29	3	44	880
51 – 75	10	22	1	33	660
76 – 100	2	1		3	60
101 – 125	2	1		3	60
126 – 150					
151 – 175		1		1	20
176 – 200					
201 – 225					
226 – 250					
251 – 275					
276 – 300					
Total *Ukupno*	30	59	8	97	1940
Total per ha *Ukupno po ha*	600	1180	160	1940	

The compartment 26a (11) features a pure stone pine stand with only a few Aleppo pines, cypresses and Himalayan cedars. In 1977, there were 507 stone pine trees of the total of 528 trees in the plot. In 2008, there were 560 stone pine trees and 580 trees in all. An increase in the number of trees is attributed to newly formed gaps and to natural regeneration of Aleppo pine in the plot. Basal area rose from 31.03 m^2/ha to 49.40 m^2/ha, and volume rose from 183.3 m^3/ha to 423.40 m^3/ha. In compartment 26a (11), the mean height of the stone pine was 10.8 m, and the mean tree diameter was 27.5 cm, while today the mean height of the stone pine is 16.6 m, and the mean diameter is 32.4 cm.

The basic soil properties are also provided in the description of the profile (Tomašević, 1994) that presents this pedosystematic unit (terra rossa, lessivated, colluvial, clayey). This soil type is found in the pine cultures in compartments 26a, 27a, and 18a. The profile was taken from a smaller plateau in compartment 27a. The rockiness of the area around the profile is 40% and towards the edge part of the plateau it increases to as much as 90% of the area.

O1 (3-1cm) undissolved pine needle litter without any dissolution signs.

Oh (1-0cm) thin layer of humified pine needle litter, dark and affiliated with mold micelia. It breaks up into larger horizontal rag-like patches.

Aoh (0-3cm) silty non-structural loam with about 30% of limestone skelet, dark brown in dry condition, densely intertwined with rootlets of ground vegetation, porous and friable, soil mass non-carbonate. In a diffuse state it transforms into:

E (3-19cm) silty-clayey loam, light reddish, medium granular to blocky subangular structure. Contains about 70% of rock fragments. Rooting is very dense. Gradually transforms into:

(B)rz, t (19-50cm) clayey loam to loamy clay, red. Has a characteristic polyedric structure. Thin light membranes on the surface of structural aggregates are visible, relatively deep rooting. Transforms abruptly into:

R (over 50 cm) massive compact limestone rock.

One of the important factors in the comparison of ameliorative effects on a degraded site is the relationship towards the return of climatozonal vegetation. The basic issue is whether the conditions for a more abundant occurrence of main deciduous species from the climatogenic forest community are ensured. Table 10 shows species abundance and changes in the process of vegetation succession relative to the investigation period. This is a thirty-year period, although we should point out that progressive succession has been going on for a number of decades, or more precisely, for a hundred and more years. Succession is largely dependent on anthropogenic impacts and climatic conditions.

DISCUSSION
RASPRAVA

Mixed stands of Aleppo pine and stone pine are found in compartments 27a and 18a, and a pure stone pine culture occurs in compartment 26a. According to Tables 1, 2, 4, 5, 7 and 8, the number of trees of the main species has not changed significantly in the past 30 years.

Structural analysis of the stands shows their development; thus, the present stands aged about 70 achieve considerable wood production. A comparison of the results with those of Tomašević (1995) reveals that the soil has retained its productive capacity. The growing stock in the sample plots ranges from 330 to 510 m^3/ha. This confirms the fact that pioneer species, in this case the stone pine, can fulfil their ecological, social and commercial function in a degraded site (Plaisance 1977).

Table 10 Phytocoenological relevés in the sample plots in 1976 (1 – symbol n the table) and 2008 (2 – symbol in the table).
Tablica 10 Fitocenološke snimke na pokusnim plohama 1976. (1– oznaka u tablici) i 2008. (2- oznaka u tablici) godine.

Potential vegetation *Potencijalna vegetacija*	*Querco-Carpinetum orientalis*																													
Compartment *Odjel*	27a(16)										18a(12)										26a(11)									
Plot dimension *Veličina plohe m²*	625										625										625									
Parent material Matična podloga	Limestone *Vapnenac*																													
Soil *Tlo*	*Vapnenačko dolomitna crnica posmeđena, smeđe tlo na vapnencu tipično, plitko*																													
Exposure *Ekspozicija*	Straight *Ravno*										Straight *Ravno*										Straight *Ravno*									
Inclination *Inklinacija*	Straight *Ravno*										Straight *Ravno*										Straight *Ravno*									
Culture *Kultura*	*Pinus pinea, Pinus halepensis, Cupressus sempervirens*										*Pinus pinea, pinus halepensis*										*Pinus pinea*									
Survey *Izmjera*	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Plot *Ploha*	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
Tree coverage % *Pokrovnost sloja drveća (%)*	90	100	75	100	90	100	85	100	90	95	90	95	90	95	90	95	90	100	80	95	90	90	90	90	75	85	75	95	90	95
Shrub coverage % *Pokrovnost sloja grmlja (%)*	15	5	10	90	10	5	10	5	5	15	20	60	15	70	35	85	25	50	25	65	25	3	20	5	25	20	25	5	20	10
Ground vegetation coverage % *Pokrovnost sloja prizemnog rašća (%)*	80	85	90	25	70	85	70	70	60	95	60	25	60	85	60	10	60	60	70	70	60	100	60	100	60	100	80	100	60	10
Bursts coverage % *Pokrovnost sloja mahova (%)*	10	-	10	80	10	-	10	10	10	20	5	-	5	20	5	30	5	55	5	5	5	-	5	45	10	-	5	-	10	-
Total coverage % *Ukupna pokrovnost (%)*	100		100		100		100		100		100		100		100		100		100		100		100		100		100		100	
SLOJ DRVEĆA																														
Pinus pinea L.	2	3	2	4	2	5	2	4	3	4	2	3	1	3	1	3	1	3	1	2	4	5	4	5	4	5	4	5	4	5
Pinus halepensis Mill.	2	1	2	1	2	1	2	2	2	2	3	2	2	1	3	2	4	2	3	3	.		.		+		.		+	
Cupressus sempervires L.	1	1	+	1	+	+	1	3	+	1	+	2	+	2	1	1	+	1	+	1	.		.		.		.		.	
Cedrus deodara (Roxb.) G. Don	.		.		.		.		.		.		.		.		.		+		.		.		.		.		.	
Pinus nigra Arnold	.		.		+		.		.		.		.		.		.		.		.		.		.		+		.	
Pinus pinaster Aiton	+		+		.		.		.		.		.		.		.		.		.		.		.		.		.	
Quercus ilex L.	+		.	1	.		.	+	.		.	1	.	1	.	1	.		.	1	.		.		.	+	.		.	
SLOJ GRMLJA																														
Juniperus oxycedrus L.	2		2	1	2		2		2		3	+	2	+	2		2		2	+	2		2		3	1	3		3	+
Phillyrea media L.	1	+	+	1	2	1	1	1	1	+	+	1	+	1	+	1	+		+	1	+	1	+	+	.	2	+	+	+	+
Paliurus aculeatus Mill.	1		.		1		+		.	+	+		1		+		+		.		+		+		.		.		+	
Rubus discolor Weihe et.Ness	+	1	.	1	.	+	.		+		1	1	+		+	+	+	+	+	1	+		+		.	1	+		+	+
Quercus pubescens L.	+	1	+		+		.	+	+	+	.	+	.		+	+	.	+	+	+	+	+	+	+	.	+	+		.	+

Culture *Kultura*	*Pinus pinea, Pinus halepensis, Cupressus sempervirens*										*Pinus pinea, pinus halepensis*										*Pinus pinea*									
Survey *Izmjera*	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Plot *Ploha*	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
Cuperssus sempervirens L.	+		+	2	.	1	.	+	.	1	.	+	.	1	+	+	+		+	1	+		.		.		.		+	
Rosa sempervirens L.	.	1	.		.		.	+	.		.		.		.		.	+	.		+		+		.		.		+	+
Prunus mahaleb L.	+		.	1	.		+	+	+		.	+	.	+	.		.	+	.		+		+		+	+	.		.	
Lonicera etrusca Santi	+		+		.		.		.		.	+	.		.		.		.	1	+		.		.		+		.	
Quercus ilex L.	1		+	1	1		2	+	1	+	.	2	.	+	.	1	.	+	.	2	.	+	.		.	+	.	+	.	+
Acer Monspessulanum L.	.		.		+		.		+		+	+	.		.		.		.		.		.		.		.		.	
Quercus cerris L.	+		.		.		.		.		+		.		.		.		.		.		.		.		.		.	
Cedrus deodara (Roxb.) G. Don	.		.		.		.		.		.		+		.		.		+		.		.		.		.		.	
Crataegus transalpina Jacq.	.		.		.		.		.		.		.		.		+		+		.		.		.		.		.	
Rhamnus intermedia Steud. Et Hohst.	.		.		.		+		.		.		.		.		.		.		.		+		.		.		.	
Pinus pinea L.	.	+	.		.		.	1	.	1	.		.	2	.	+	.	1	.	1	.		.	+	+	1	.		.	+
Fraxinus ornus L.	.		.	+	+		.		+	+	.		.		.		.		.	+	.		.		.		.		+	
Viburnum tinus L.	.		.		.		.		.		.		.		.		.		.		.		.		.		.		+	
Osyris alba L.	+		.	1	+	+	.		+		.		.		.		.		.		.		.		.		.		.	
Libustrum vulgare L.	+		.		+		.		+		.		.		.		.		.		.		.		.		.		.	
Ostrya carpinifolia Scop.	.		+		.		.		.		.		.		.		.		.		.		.		.		.		.	
Sorbus domestica L.	.		.		+		.		.		.	+	.		.		.		.		.		.		.		.		.	
Prunus avium L.	.		.		+		.		.		.		.		.		.		.		.		.		.		.		.	
Acer obtusatum Waldst. Et Kit. Ex Willd	.		.		.		.		+		.		.		.		.		..		.		.		.		.		.	
Pinus halepensis Mill.				1				1		2				4		4		3		1						+				+
Prunus spinosa L.								+																						
Ruscus aculeatus L.												+		+																
SLOJ PRIZEMNOG RAŠĆA																														
Asparagus acutifolius L.	+	+	+		+	+	.	+	+		+		+	+	+		+	+	+	+	+	+	+	+	+		+	+	+	+
Hieracium pillosela Vill.	+		+		+		.	1	+		+	+	+		+	+	+		+		+		+		+		.	+	+	+
Rubus discolor Weihe et Ness	+	+	+	+	.	+	+		+		+	+	+		+		+		+	+	1		1		+		+		+	
Teucrium polium L.	+		+		+		+	1	+		+		1		+		1		+		+		+		+		+		+	
Sesleria autumnalis (Scop.) F.W.Schultz	+		1		+	3	1		2		3		2		+		2		+		2		1	3	1	3	1	4	+	1
Asphodelus microcarpus Mill.	+		+	+	+		1		.		1		+		1		+		+		+		+		+		+		+	
Stachys pratensis	+		+		+		+		.		+		+		+		+		.		+		+		+		+		+	
Potentilla erecta L.	+		+		+		+		+		+		+		+		.		+		+		+		+		+		+	
Clematis flammula L.	+		+		+		+	+	+		+		+		.		+		+		+	+	+	+	+		+		.	

Culture *Kultura*	*Pinus pinea, Pinus halepensis, Cupressus sempervirens*										*Pinus pinea, pinus halepensis*										*Pinus pinea*									
Survey *Izmjera*	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Plot *Ploha*	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
Teucrium chamaedrys L.	+		+		+		+		+		+		.		+		+		+	+	+		+	+	.	+	+		+	
Rhamnus intermedia Steud. Et Hohst.	+		+		+		+		+		1		1		1		+		+		.		+		+		+		+	
Euphorbia fragifera Jan	+		+		.		+		+		+		+		+		+		+		+		+		1		+		1	
Crepis paludosa (L.) Moench	+		+		+		+		+		+		+		+		.		+		+		+		+		+		+	
Helianthemum ovatum L.	+		+		+		+		+		1		1		1		+		+		.		+		+		+		+	
Chalinus hyspanicus	+		+		+		+		+		1		1		1		1		1		+		+		+		+		1	
Quercus pubescens Willd.	+	+	+	+	+		+		1		.	+	1	+	+	+	+	+	+		1		+	+	+		+		+	
Pinus halepensis Mill.	+	+	1		1		1		1	+	+	+	1		1	1	+		1	+	.		.		.	+	.		.	
Thymus serpyllum L.	.		+		.		+		.		+		+		1		+		+		.		+		.		+		+	
Phillyrea media L.	+		+	1	+		+		.		+		.	+	+		+	+	+	+	.		+		+		+		+	
Sanquisorba minor Scop.	.		.		.		+		+		+		+		+		+		+		+		+		1		1		1	
Eryngium amethysti-num L.	.		.		+		+		+		+		+		+		.		+		+		+		+		+		+	
Galium lucidum All.	.		.		.		+		.		+		+		+		+		+		+		+		+		+		+	
Bromus erectus Huds.	.		+		+		+	1	+		+		.		+		+		+		+		+		1		2		.	
Cephalaria leuchanta (L.) Roem. Et Schult.	+		+		+		+		+		+		.		.		.		+		+		+		+		+		+	
Filipendula hexapetala Moench.	+		+		+		+		+		.		+		+		.		+		1		1		.		+		+	
Rosa sempervires L.	.		+		.		+	+	.		+		.		+		+		.		+		.		.		.		+	
Rubia peregrina L.	+	+	+	+	+		.	+	+	+	+	+	.		.	+	+	+	.	1	+	+	+	+	.		+	+	.	+
Trifolium pratense L.	R		.		.		.		.		+		.		+		+		+		.		.		+		+		.	
Cupressus sempervirens L.	1		+		+	+	+		1	+	+	+	+	+	+		.		+		.		.		.		.		.	
Astragalus sp.	.		+		+		+		+		+		.		+		+		+		+		.		.		.		.	
Doricnum germanicum (Gremli) Rikli	+		+		.		.		+		+		+		.		.		+		+		+		.		.		+	
Cardus pycnocepha-lus L.	.		.		.		+		.		+		+		+		+		+		+		+		.		+		.	
Doricnium hirsutum (L.) Ser.	.		+		.		+		.		.		.		+		+		+		+		.		+		.		.	
Prunus mahaleb L.	.	+	.		+	+	+	+	+	+	.	+	.	+	.		+		+		+		.		+		+		+	
Verbascum flomoides L.	.		.		+		+		+		+		+		+		+		+		+		.		.		.		.	
Pinus pinea L.	1	+	1		+	+	.		+	+	.		.		.	+	.		.	+	1		1	+	1		1		1	+
Festuca heterophylla Lam.	.		+		+		2		1		.		.		.		.		.		1		1	1	1	2	1	−	.	
Prunella laciniata L.	+		.		+		+		.		.		1		+		+		+		.		+		.		.		.	
Echynops ritro L.	.		.		.		.		.		+		.		.		.		.		+		.		+		+		+	
Oryganum majorana L.	.		+		.		.		.		+		.		.		.		.		+		.		.		+		.	
Tamus communis L.	+		.		.		+		.		+		.		.		.		+		+		.		.		.	+	.	

Culture *Kultura*	*Pinus pinea, Pinus halepensis, Cupressus sempervirens*										*Pinus pinea, pinus halepensis*										*Pinus pinea*									
Survey *Izmjera*	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Plot *Ploha*	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
Smilax aspera L.	+		.		:		.		.		+		:		.		.		+		+		:		:		+	+	.	
Ligustrum vulgare L.	.		.		.		.		+		+		:		.		+		.		.		+		+		.		.	
Laurus nobilis L.	.		.		.		.		.		+		+		+		:		+		+		.		.		.		.	
Celtis australis L.	.		.		.		.		.		+		+		.		+		+		+		.		.		.		.	
Juniperus oxycedrus L.	.		1	1	.		.		.		+	+	.	+	.		+		.		+		1		.		.		.	
Hedera helix L.	1		.		.		+	1	+		.		.		+		+		.	+	:		+		.		.		.	
Geranium valentianum L.	.		.		.		.		+		.		+		.		.		.		.		+		+		+		+	
Fraxinus ornus L.	.		.		.		.		.	+	.	+	+		.		:		.	+	.		+		+	+	.		+	
Pistacia lentiscus L.	.		.		.		+		.		.		+		.	+	.		.		+		+		+		.		.	
Helichrysm italicum G. Don.	.		.		.		.		.		+		.		+		+		+		.		.		+		.		.	
Acer monspessu-lanum L.	.		.		.		+		+		.		+		.		.		.		.		+		.		.		.	
Quercus ilex L.	.		.	+	+		+		+		.	+	+	+	.	+	.	+	.	+	.		.		.		.		.	
Osyris alba L.	+		+	1	+	+	.		+		:		.		.		.		.		.		.		.		.		.	
Centaurea montana	.		.		.		.		.		.		.		.		.		.		+		+		+		+		.	
Fragaria vesca L.				+																										
Sorbus domestica L.												+																		
Arhenatherum elatius L.		1		+																										
Geranium roberticenum L.		+		+																										
Brachypodium sylvaticum (Huds.) P.B.				1				1				1						1		1		1								1
Festuca ovina L.				+						1		1						1		+										1
Koeleria gracilis Pers.				+																										
Carduus acanthoides L.		+																												
Dachylis hispanica Roth		1												+		+		+				1								1
Brachypodium pimcetum (L.) Beauv.		1								3												5								
Sanguisorba umricaba L.				+						+																				
Carduus pycnocephalus L.								+																						
Cynosurus echinatus L.						1		1																						
Koeleria pyramidula (Lam.) Dimin								1																						
Festuca capillata Lam.		1						1																						
Avena pubescens Huds.						1		2		1																				
Arrhenatherum elatius (L.) C.Presl						1																1		1		2				
Genista dalmatica Bartl.				+										+		+														

Culture *Kultura*	*Pinus pinea, Pinus halepensis, Cupressus sempervirens*										*Pinus pinea, pinus halepensis*										*Pinus pinea*									
Survey *Izmjera*	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Plot *Ploha*	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
Cuperssus sempervirens L.	+		+	2	.	1	.	+	.	1	.	+	.	1	+	+	+		+	1	+		.		.		.		+	
Rosa sempervirens L.	.	1	.		.		.	+	.		.		.		.		.	+	.		+		+		.		.		+	+
Prunus mahaleb L.	+		.	1	.		+	+	+		.	+	.	+	.		.	+	.		+		+		+	+	.		.	
Lonicera etrusca Santi	+		+		.		.		.		.	+	.		.		.		.	1	+		.		.		+		.	
Quercus ilex L.	1		+	1	1		2	+	1	+	.	2	.	+	.	1	.	+	.	2	.	+	.		.	+	.	+	.	+
Acer Monspessulanum L.	.		.		+		.		+		+	+	.		.		.		.		.		.		.		.		.	
Quercus cerris L.	+		.		.		.		.		+		.		.		.		.		.		.		.		.		.	
Cedrus deodara (Roxb.) G. Don	.		.		.		.		.		.		+		.		.		+		.		.		.		.		.	
Crataegus transalpina Jacq.	.		.		.		.		.		.		.		.		+		+		.		.		.		.		.	
Rhamnus intermedia Steud. Et Hohst.	.		.		.		+		.		.		.		.		.		.		.		+		:		.		.	
Pinus pinea L.	.	+	.		.		.	1	.	1	.		.	2	.	+	.	1	.	1	.		.	+	+	1	.		.	+
Fraxinus ornus L.	.		.	+	+		.		+	+	.		.		.		.		.	+	.		.		.		.		+	
Viburnum tinus L.	.		.		.		.		.		.		.		.		.		.		.		.		.		.		+	
Osyris alba L.	+		.	1	+	+	.		+		.		.		.		.		.		.		.		.		.		.	
Libustrum vulgare L.	+		.		+		.		+		.		.		.		.		.		.		.		.		.		.	
Ostrya carpinifolia Scop.	.		+		.		.		.		.		.		.		.		.		.		.		.		.		.	
Sorbus domestica L.	.		.		+		.		.		.	+	.		.		.		.		.		.		.		.		.	
Prunus avium L.	.		.		+		.		.		.		.		.		.		.		.		.		.		.		.	
Acer obtusatum Waldst. Et Kit. Ex Willd.	.		.		.		.		+		.		.		.		.		.		.		.		.		.		.	
Pinus halepensis Mill.				1				1		2				4		4		3		1						+				+
Prunus spinosa L.								+																						
Ruscus aculeatus L.												+		+																
SLOJ PRIZEMNOG RAŠĆA																														
Asparagus acutifolius L.	+	+	+		+	+	.	+	+		+		+	+	+		+	+	+	+	+	+	+	+	+		+	+	+	+
Hieracium pilloscla Vill.	+		+		+		.	1	+		+	+	+		+	+	+		+		+		+		+		.	+	+	+
Rubus discolor Weihe et Ness	+	+	+	+	.	+	+		+		+	+	+		+		+		+	+	1		1		+		+		+	
Teucrium polium L.	+		+		+		+	1	+		+		1		+		1		+		+		+		+		+		+	
Sesleria autumnalis (Scop.) F.W.Schultz	+		1		+	3	1		2		3		2		+		2		+		2		1	3	1	3	1	4	+	1
Asphodelus microcarpus Mill.	+		+	+	+		1		.		1		+		1		+		+		+		+		+		+		+	
Stachys pratensis	+		+		+		+		.		+		+		+		+		.		+		+		+		+		+	
Potentilla erecta L.	+		+		+		+		+		+		+		+		.		+		+		+		+		+		+	
Clematis flammula L.	+		+		+		+	+	+		+		+		.		+		+		+	+	+	+	+		+		.	

Culture *Kultura*	*Pinus pinea, Pinus halepensis, Cupressus sempervirens*										*Pinus pinea, pinus halepensis*										*Pinus pinea*									
Survey *Izmjera*	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Plot *Ploha*	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
Agrimonia eupatoria L.								+						+		+		+												
Leontodon hispidus L.								1																						
Geranium columbinum L.										+				1		1														
Centaurea jacea L.										+																				
Carex strigosa Huds.																				+	1									
Salvia pratensis L.																								+		+				
Genista sylvestris Scop.																				1				+		+		+		+
Carex humilis Leyss.																								1						
Carex sempervirens Vill.												+				+								1		2				1
Hieracium bauhinii Schult.																				1				1		2				
Brachypodium ramosum (Pers.) P.Beauv.																												1		+
Melica nutans L.												1		1		1		2		1										
Actaea spicata L.																				1										
Sonchus blaberrimus L.												+			+					+										
Avena pratense L.																				+										
Cytisus hirsutus L.												+				+														
Senecio sylvaticus L.														+																
Trifolium campestre Schreb														1		1														
Sanguisorba minor Scop.														+		+														
Festuca duriuscula L.														+		+														
Crepis biennis L.														+		+														
Sonchus tenerimus L.														+		+														
Melica nutans L.												1		1		1		2		1										
Actaea spicata L.																				1										
Sonchus blaberrimus L.												+			+					+										
Avena pratense L.																				+										
Cytisus hirsutus L.												+				+														
Trifolium campestre Schreb														1		1														
Sanguisorba minor Scop.														+		+														
Festuca duriuscula L.														+		+														
Crepis biennis L.														+		+														
Sonchus tenerimus L.														+		+														
Crepis biennis L.														+		+														
Sonchus tenerimus L.														+		+														

The analysis of the measured seedlings and young growth in the sample plots in the cultures (Tables 3, 6 and 9) shows the exceptionally weak (Table 10) occurrence of autochthonous elements of the climatozonal community of pubescent oak and oriental hornbeam (*Querco-Carpinetum orientalis* H-ić 1939). This suggests the initial stage of succession processes, which is still insufficient for more satisfactory natural regeneration. The prevalence of pines indicates early succession species (xerophytes, heliophytes); in contrast, the prevalence of holm oak or pubescent oak denotes late succession species (Papió 1994, Retana et al. 1996, Broncano et al. 1998). Since the Musapstan area is the contact zone between the forest of pubescent oak and oriental hornbeam (*Querco-Carpinetum orientalis* H-ić 1939) and the forest of holm oak and manna ash (*Fraxino orni-Quercetum ilicis* H-ić 1956), there are holm oak seedlings in the area (Tables 3, 6 and 9) but almost no pubescent oaks. Even those rare samples that do exist are less than 1 m tall. The reasons can most probably be attributed to the naturally formed micro-gaps (wind broken and fallen trees, dieback) which are re-colonized by conifers, so that the structure of the seedlings and young growth are dominated by the species of the culture itself, i.e. cypress, Aleppo pine and stone pine. Owing to the density of the culture, only some individual species in the seedling and young growth structure have reached a height above 100 cm. The reason lies in the absence of intensive cleaning and thinning treatments in the culture. Since the canopy does not open, growth and development of the seedlings and young plants is restricted. In terms of amelioration, the targeted role has not been fulfilled in the sense of the return of climatozonal vegetation. Naturally, the defined goals of establishing the culture should also be taken into account; in other words, was the initial intention to establish a commercial stand or to achieve subsequent stand conversion? For this reason, it is difficult to predict any more favourable impacts on the sites of pure or mixed cultures. In order to make any such predictions, it would have been necessary to apply silvicultural treatments during the rotation and undertake research into the quantity and composition of the forest floor. Our investigations reveal the still unfavourable site conditions. The frequent occurrence of juniper (*Juniperus oxycedrus* L.) in the cultures, which is also present in the areas outside the culture, is indicative. At the same time, the surrounding area has been exposed to severe anthropogenic impacts for decades, resulting in the dominance of degraded and devastated forms of forest vegetation.

Phytocoenological relevés of Tomašević (1994) and our research of 2008 also confirm very slight share of woody autochthonous elements in the shrub and ground vegetation layers.

Only one pedosystematic unit was identified in compartments 26a, 27a and 18a in the investigated pine cultures. This is terra rossa, lessivated, colluvial and clayey. The soil has the following profile: O1 - O h - AE - (B) - R (Tomašević 1994).

The restricted, humus-rich O horizon consists of two sub-horizons: the O1, with undissolved litter that consists of the needles, and the Oh horizon, in which microbiological transformation has affected the litter to such a degree as to make it impossible to determine the character of the original material. It is dark in colour and breaks horizontally into larger fragments of organic mass. The entire mass of this horizon is intertwined with mould fungi mycelia. In general, the humus accumulative horizon in the profile of 3 - 5 cm depth is poorly developed. It occurs in the form of a thin, dark surface layer which is friable, silty and of undefined structure in dry condition. The dark humus accumulative horizon is gradually followed by the light-red initial eluvial horizon, whose depth reaches up to 20 cm. It has been formed by the eluvial migration of clay from this horizon. Three are indications that it also contains traces of allochthonous, so-called loess-like material, mentioned by Škorić (1979) for the area of Istria. The horizon is gradually converted into the (B) horizon in which the membranes of chloride accumulations indicate the illuvial process. In terms of the relief, this pedosystematic unit is found in the lowest parts of weakly pronounced, plate-like micro-depressions. These geomorphological forms are generally characterized by the slight rockiness of the lowest parts and a gradual increase in the rockiness towards the edge of these depressions.

The analysis of Tomašević's pedological results (1994) shows that in terms of mechanical composition, the soil in the Musapstan cultures is heavy clay. Compared with the soil in the clearings, the soils under the forest vegetation manifest a higher percent content of clay and coarse sand fractions. Of other physical features, the lowest porosity, i.e. the highest compactness, was found in the soil without any forest vegetation. The highest value was recorded in the pure stone pine culture. Similar relations were also found for water and air holding capacity of soil. Forest vegetation improves porosity and consequently, water-air relations.

There are irregularities in terms of the humus content. As the forest cover progresses, the humus content in the surface horizon increases. It is the lowest in the clearing. There are also differences related to the nitrogen content. There is sufficient nitrogen in both mixed stands, but the highest nitrogen content was found in the pure stone pine stand. This is the result of the specific profile stratigraphy, where the humus-rich horizon of high humification degree occurs below the leaf litter and the restricted humus horizon.

High regularity of the C/N ratio in the investigated soils was determined with certainty. Nitrogen release and assimilation capacity in higher plants begins only when the C/N ratio is lower than 25. Total assimilation by microorganisms occurs when the C/N ratio is higher than 33 (biological immobilization). At the same time, the narrowing down of the C/N ratio to between 10 and 12 does not ensure sufficient energy needed by microorganism metabolism; as a result, the mineralization process is halted (Vukadinović, Lončarić, 1998). The C/N ratio between 12 and 25 is considered favourable for higher plants.

The lowest C/N ratio in the investigated soils (8, 6, 4) was found in the soil without any forest vegetation. Namely, the influx of organic matter from scarce natural vegetation is very modest. This matter is prone to relatively rapid humification, ending with relatively mature humus. The C/N ratio broadens with the increased presence of coniferous species in both mixed stands and amounts to 19.9 and 28.3, similarly to the pure stone pine culture where the ratio is 35.7. The C/N ratio in all the soils decreases with an increase in depth.

Tomašević (1994) conducted certain microclimatic measurements within his research. The results of his measurements show that light intensity in the pure stone pine culture, compartment 26a (11), amounts to 17.80 %. Day air temperature in the forest and in the open space ranged from 17.71 °C to 22.60 °C. The oscillation amounted to 4.89 °C. In the open space, the temperature ranged from 19.10 °C to 22.70 °C, with the oscillation reaching 3.69 °C. Relative air humidity in the forest oscillated between 73% and 90%, whereas in the clearing it was between 64% and 82%. Assumption is that relations in the stand are still the same. In that period between there were no application of silvicultural treatments. Silvicultural treatments could have impact on the ecological factors.

The oscillation of the soil surface geo-temperature was 3.74 °C in the forest and 4.10 °C in the open space. As the depth increases, the difference in geo-temperatures becomes smaller. From 30 cm depth onwards there are no significant differences between the temperature in the forest and in the open space.

CONCLUSIONS
ZAKLJUČCI

The choice of an ameliorating method to be used in a certain area depends on the condition of the site to be ameliorated. The types of amelioration treatments differ accordingly. The most important activity in degraded sites relates to the introduction of primarily pioneer tree species, since these species possess the capacity to adapt to adverse site conditions. Their growth and development in such terrains can have a favourable effect on site conditions; in turn, this opens the possibility of regeneration for climatozonal broadleaved vegetation. However, the introduction of pioneer species does not automatically guarantee regeneration success. Success also depends on the knowledge of biological properties, ecological requirements and silvicultural characteristics of the species to be used for amelioration. Ameliorative activities should be followed by silvicultural activities, which will contribute to the qualitative improvement of the stand. Our research confirmed the absence of this vital segment in stand management.

According to earlier research by Tomašević (1994 and 1995) and the latest research of 2008, in the past the Musapstan area suffered devastation from the vegetational aspect and degradation from the pedological aspect. Pioneer species were primarily intended to improve soil productivity and progressive vegetation succession. Naturally, the exceptional aesthetic and protective character that these species enhance should not be neglected. Afforestation can provide multiple benefits; however, it should be pointed out that these benefits can only be achieved if clearly defined goals are set and if the prescribed silvicultural activities are implemented during the rotation. Otherwise, the results will be disappointing.

Our research confirmed that the existing pioneer vegetation encourages, albeit very slowly, the return of autochthonous broadleaved vegetation. The structure of the seedlings and young growth revealed hesitant return of deciduous species, whereas pioneer conifers occurred by natural succession. This can be attributed to the still unfavourable conditions for regeneration in the site. A special problem arises from the non-application of intensive silvicultural treatments of tending and thinning. The use of these treatments will lead to more optimal relationship towards light as an ecological factor of regeneration.

ACKNOWLEDGEMENTS
ZAHVALA

We wish to extend our thanks to the employees of the company Hrvatske Šume, Zadar Forest Office, for their material help in the field part of this work and in the dissertation work. Our special thanks go to Mr Mislav Maršić, MSc, and Mr Dejan Žagar, BSc, Forest Office Manager.

REFERENCES
LITERATURA

Barčić, D., Ž. Španjol, R. Rosavec, 2006: Uloga borovih kultura u zaustavljanju degradacije staništa na mediteranskom kršu. Glas. šum. pokuse, pos. izd. 5, p. 191-200.

Bertović, S., 1975: Prilog poznavanju klime i vegetacije u Hrvatskoj. Acta biologica, Vol VII/2, p. 89-215.

Bertović, S. & A.Ž. Lovrić, 1985: Vegetacijska karta Hrvatske, Šumarska enciklopedija 3, Zagreb.

Braun-Blanquet, J., 1964: Pflanzensoziologie. Grundzüge der Vegetationskunde, ed. 3. Springer Verlag, Wien.

Broncano, M.J., M. Riba, J. Retana, 1998: Seed germination and seedling performance of two Mediterranean tree species, holm oak (*Quercus ilex* L.) and Aleppo pine (*Pinus halepensis* Mill.): a multifactor experimental approach. Plant Ecology, Vol 138, p. 17-26.

Cerda, A., 1998: Soil aggregate stability under different Mediterranean vegetation types. Catena, Vol 32, p. 73-86.

Clemente, A.S., C. Werner, C. Maguas, M.S. Cabral, M.A. Martins-Louçao, O. Correoa, 2004: Restoration of a limestone quarry: effect of soil amendments on the establishment of native Mediterranean sclerophyllous shrubs. Res. Ecol., Vol 12, p. 20-28.

Court-Picon, M., C. Gadbin-Henry, F. Guibal, M. Roux, 2004: Dendrometry and mophometry of *Pinus pinea* L. In Lower Provence (France): adaptability and variability of provenances. For. Ecol. Manage. Vol 194, p. 319-333.

Gil, L. & M. Aránzazu, 1993: Los pinos como especies básicas en la restauración forestal en el medio mediterráneo. Ecologia, Vol 7, p. 113-125.

Horvat, I., 1950: Šumske zajednice Jugoslavije. Institut za šumarska istraživanja, Zagreb, p. 73.

Horvatić, S.,1957: Pflanzengeographische Gliederung des Karstens Kroatiens und der angrenzenden Gebiete Jugoslawiens. Acta Bot. Croatica, Vol 16, p. 33-52.

Kutiel, P., Z. Naveh, 1987: Soil properties beneath *Pinus halepensis* and *Qurcus calliprinos* trees on burned and unburned mixed forest on Mt. Carmel Israel. For. Ecol. Manage., Vol 20, p. 11-24.

Lookingbill, T.R. & M.A. Zavala, 2000: Spatial pattern of *Quercus ilex* and *Quercus pubescens* recruitment in *Pinus halepensis* dominated wood-lands. J. Veg. Sci., Vol 11, p. 607-612.

Maestre, F.T. & J. Cortina, 2004: Are *Pinus halepensis* plantations useful as a restauration tool in semiarid Mediterranean areas? For. Ecol. Manage., Vol 198, p. 303-317.

Montero, J.L. & P. Alcanda, 1993: Reforestación y biodiversidad. Montes, Vol 33, p. 57-76.

Papió, C., 1994: Ecologia del foc r regeneració en garrigues i pinedes mediterránies. Institut d'Estudis Catalans, Barcelona.

Plaisance, G., 1977: Le pin parasol. For. Priv., Vol 115, p. 47–54.

PG, 2005: Program gospodarenja za gospodarsku jedinicu Musapstan 2005.-2014.

Rambal, S., 1993: The differential role of mechanisms for drought resistance in a Mediterranean evergreen shrub: a simulation approach, Plant Cell Environ., Vol 16, p. 35–44.

Requena, N., E. Perez-Solis, C. Azcon-Aguilar, P. Jeffries, J.M. Barea, 2001: Management of indigenous plant-microbe symbioses aids restoration of desertified ecosystems. Appl. Environ. Microbiol. Vol 67, p. 495-498.

Retana, J., J.M. Espelta, M. Gracia, 1996: Caracterización de masas mixtas de pino carrasco y encina en el Montseny (nordeste de la Península Ibérica). Cuadernos de la SECF 3, p. 166-179.

Specht, R.L., E.J. Moll, F. Pressinger, J. Sommerville, 1983: Moisture regime and nutrient control of seasonal growth in Mediterranean ecosystems. In: F.J. Kruger, D.T. Mtchell, J.U.M. Jarvis (ed.), Mediterranean-type ecosystems. The role of nutrients. Springer-Verlag, Berlin, p. 120-132.

Šegota, T. & A. Filipčić, 2003: Koppenova podjela klima i hrvatsko nazivlje. Geoadria, Vol 8/1, p. 17-37.

Škorić, A., 1979: Tipovi naših tala. Sveučilišna naklada Liber. Zagreb.

Tomašević, A., 1994: Meliorativni utjecaj kulture alepskog bora (*Pinus halepensis* Mill.) i pinije (*Pinus pinea* Endl.) na degradirano stanište hrasta medunca (*Querco pubescentis-Carpinetum orientalis* H-ić, Anić 1959) u zadarskom području. Glas. šum. Pokuse, Vol 30, p. 223-298.

Tomašević, A., 1995: Komparativni prikaz uspijevanja alepskog bora (*Pinus halepensis* Mill.) i pinije (*Pinus pinea* L.) u mješovitim sastojinama u G.J. "Musapstan" šumarija Zadar. Šum. list, Vol 1-2, p. 3-13.

Trinajstić, I., Đ. Rauš, J. Vukelić, J. Medvedović, 1992: Karta šumskih zajednica Hrvatske. U Đ. Rauš, (ed.), Šume u Hrvatskoj. Šumarski fakultet i «Hrvatske šume» d.o.o., Zagreb, p. 79-80.

Vukadinović, V. & Z. Lončarić, 1998: Ishrana bilja. Sveučilište Josipa Jurja Strossmayera u Osijeku, Poljoprivredni fakultet Osijek, 293 str.

Vukelić, J. & Đ. Rauš, 1998: Šumarska fitocenologija i šumske zajednice u Hrvatskoj. Sveučilište u Zagrebu, Šumarski fakultet, p. 310, Zagreb.

Walter, H., 1955: Die Klima-Diagramme als Mittel zur Beurteilung der Klimaverhältnisse für ökologische, vegetationskundliche und landwirtschafliche Zwecke. Ber. Deutsch Bot. Ges. Vol 68, p. 321-344.

GLASNIK ZA ŠUMSKE POKUSE – JOURNAL OF FOREST EXPERIMENTS

Namjena

Glasnik za šumske pokuse međunarodni je časopis u kojem se objavljuju izvorni znanstveni članci, pregledni članci, prethodna priopćenja, izlaganja sa znanstvenih skupova i stručni članci. Časopis obuhvaća sve aspekte istraživanja u šumarstvu, urbanom šumarstvu, zaštiti prirode i okoliša te primjenjenoj ekologiji. Svaki članak podliježe međunarodnoj recenziji najmanje dvaju recenzenata.

Dostava rukopisa

Rad s prilozima na engleskom jeziku treba poslati u elektroničkom obliku na e-poštu glavnog urednika (baksic@sumfak.hr). Opseg rada s prilozima može iznositi maksimalno 25 stranica (prored 1,5 – 1,5 line spacing). Autor je odgovoran za točnost engleskoga teksta te za uporabu mjernih veličina i jedinica. Preporuča se uporaba SI mjernih jedinica.

Osim e-poštom, rad je moguće poslati i regularnom poštom na adresu Uredništva:

Uredništvo časopisa Glasnik za šumske pokuse
Šumarski fakultet Sveučilišta u Zagrebu
p. p. 422
HR – 10002 Zagreb

Ukoliko se rad šalje regularnom poštom potrebno je poslati tri jednostrano ispisana primjerka rukopisa te jednu elektroničku inačicu zajedno s tablicama i slikama (CD, DVD). Također treba priložiti i izjavu da poslani članak nije već objavljen ili prijavljen za objavu u nekoj drugoj publikaciji.

Priprema rukopisa
Rad treba oblikovati prema slijedećim uputama:

- dokument spremiti u MS Word programu (*.doc format);
- stranica veličine A4;
- slova Times New Roman, 12 pt;
- prored 1,5 (1,5 line spacing)
- sve margine 2,5 cm;
- ne koristiti nikakve stilove (ne numerirati niti oblikovati naslove, ne koristiti bold slova)
- ne uređivati zaglavlje (Header) niti podnožje (Footer) dokumenta;
- obavezno numerirati stranice u donjem desnom uglu
- slike i tablice s pripadajućim legendama treba priložiti na kraju dokumenta iza poglavlja "Literatura", svaki na posebnoj stranici

Struktura članka

Naslov – Treba biti što je moguće kraći te istodobno davati dobar uvid u problematiku rada.

Autori rada – Pišu se ispod naslova rada bez titula. Prvo se piše ime, a zatim prezime autora. Autori se odvajaju zarezom.

Sažetak – Opisuje se istraživani problem, primjenjene metode i materijal, područje istraživanja, te kratki prikaz najvažnijih zaključaka. Treba sadržavati najviše do 250 riječi. Na kraju sažetka obavezno treba navesti do 7 ključnih riječi temeljem kojih je članak prepoznatljiv.

Titule i adrese autora – Pišu se nakon sažetka. Uz titulu te ime i prezime treba napisati točnu adresu autora i e-poštu.

Glavni tekst rada – Glavni bi tekst rada trebao biti podijeljen u odgovarajuća poglavlja. Pojedina se poglavlja mogu prilagoditi predmetnom radu. Osnovna poglavlja trebala bi biti:

UVOD
INTRODUCTION
Uvod je kratak i jasno prikazuje područje koje se obrađuje. Glavna zadaća autora je da argumentima obrazloži zbog čega se odlučio na takvo istraživanje te što je novost koju rad donosi. Uvod treba dati kratki pregled najznačajnijih ranijih istraživanja. Na kraju uvoda autor mora jasno navesti hipotezu i zadane ciljeve svog istraživanja. Uvod ne sadržava rezultate i zaključke.

MATERIJALI I METODE
MATERIALS AND METHODS
Sadrži podatke o vremenu i mjestu provođenja istraživanja (lokalitet), kriterije izbora pokusnih ploha, korištene materijale i metode, korištene metode statističke analize

Statistička analiza
Statistic analysis
Autori trebaju navesti sve primijenjene statističke testove. Također je potrebno navesti unaprijed izabranu razinu značajnosti (p), odnosno koju su vrijednost p autori smatrali statistički značajnom (0,05 ili 0,01). Na kraju odlomka potrebno je navesti korišteni računalni statistički program, proizvođača i verziju.

REZULTATI ISTRAŽIVANJA
RESEARCH RESULTS
Rezultati rada prikazuju se jasno i precizno, u obliku teksta, tablica ili grafičkih prikaza, dajući prvo najvažnije rezultate. Rezultate treba popratiti razumnim brojem tablica i slika. Rezultate prikazane ili tablicom ili grafom ne treba ponavljati u tekstu, već samo naglasiti najznačajnija zapažanja. Za sve testirane razlike nužno je navesti točno dobivenu p vrijednost cijelim brojem (primjerice pisati $p=0,048$ umjesto $p<0,05$).

Tablice
Tables
Tablice trebaju sadržavati samo rezultate istraživanja, tj. brojčane vrijednosti. Treba izbjegavati tablice koje imaju samo tekstualne podatke. Takve je podatke bolje prikazati u obliku natuknica. Svaka tablica mora imati naslov i redni broj koji se povezuje s tekstom (u radu se navode kao Table 1 itd.). Svaki stupac mora imati kratki naziv, a detaljnije objašnjenje može se napisati u legendi ispod tablice. Sve neuobičajene kratice također je potrebno objasniti u legendi.

Table 1 Measures of central tendency and variability of the investigated pedological variables for the surface mineral soil horizons per studied localities

Tablica 1 Mjere centralne tendencije i varijabiliteta istraživanih pedoloških varijabli za površinske mineralne horizonte tala po istraživanim lokalitetima.

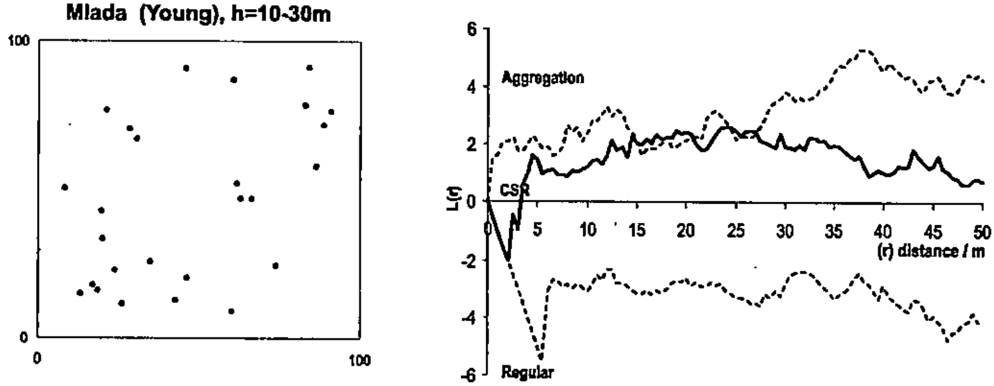
Variable *Varijabla*		Units *Mjerne jedinice*	Papuk - PAP			Macelj - MAC			Medvednica - MED			Vrbovsko - VRB		
			N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.
Inclination		°	10	24	8,80	4	35	5,25	6	20	3,63	10	17	8,13
Thickness		cm	10	7	3,01	4	8	1,63	6	10	1,51	10	6	5,15
Particle size distribution *Tekstura*	2,0 - 0,2 mm	mas. %	10	29,0	10,22	4	16,3	12,42	6	19,4	9,07	10	7,6	7,42
	0,2 -0,02 mm	mas. %	10	42,8	8,18	4	57,1	13,08	6	37,7	8,13	10	49,6	5,44
	0,02 - 0,002	mas. %	10	19,4	6,11	4	16,1	1,27	6	28,3	4,66	10	26,8	5,53
	<0,002	mas. %	10	8,8	1,87	4	10,4	1,83	6	14,6	2,29	10	16,1	4,44
pH H_2O		-	10	4,44	0,27	4	4,02	0,45	6	4,31	0,15	10	4,10	0,28
pH $CaCl_2$		-	10	3,86	0,24	4	3,41	0,36	6	3,74	0,14	10	3,58	0,29
Org C		g kg^{-1}	10	56,4	19,16	4	106,0	55,20	6	106,3	24,98	10	54,1	43,12
N tot.		g kg^{-1}	10	3,7	0,92	4	8,0	2,65	6	6,6	3,14	10	4,4	2,41
C/N		-	10	15	2,18	4	13	3,75	6	19	9,10	10	12	2,65
Soil adsorption complex *Adsorpcijski kompleks tla*	Ca	cmol(+) kg^{-1}	10	0,87	0,79	4	2,71	0,27	6	1,08	0,86	10	0,53	0,81
	Mg	cmol(+) kg^{-1}	10	0,30	0,08	4	0,05	0,00	6	0,05	0,01	10	0,18	0,11
	Na	cmol(+) kg^{-1}	10	0,32	0,02	4	0,53	0,06	6	0,37	0,07	10	0,34	0,02
	K	cmol(+) kg^{-1}	10	0,79	0,15	4	1,20	0,40	6	0,89	0,08	10	0,68	0,09
	Al	cmol(+) kg^{-1}	10	4,19	1,91	4	4,39	2,19	6	4,29	1,23	10	11,68	4,85
	H	cmol(+) kg^{-1}	10	1,05	0,60	4	2,48	1,41	6	1,77	0,29	10	2,80	1,09
	Fe	cmol(+) kg^{-1}	10	0,10	0,09	4	0,29	0,24	6	0,13	0,06	10	0,23	0,19
	Mn	cmol(+) kg^{-1}	10	0,11	0,07	4	0,07	0,04	6	0,31	0,11	10	0,08	0,04
	BCE	cmol(+) kg^{-1}	10	2,29	0,79	4	4,49	0,62	6	2,39	0,86	10	1,73	0,90
	ACE	cmol(+) kg^{-1}	10	5,44	2,50	4	7,23	3,55	6	6,50	1,42	10	14,78	5,59
	CEC	cmol(+) kg^{-1}	10	7,72	2,32	4	11,72	4,09	6	8,89	2,13	10	16,51	5,18
	Base saturation	%	10	31,8	13,30	4	41,3	12,51	6	26,6	3,99	10	12,3	9,28

Slike

Figures

Slike su crteži, karte, grafikoni, dijagrami i fotografije. Kolor slike objavljuju se o trošku autora. Svaka slika treba biti označena naslovom i rednim brojem, prema redosljedu kojim se pojavljuje u tekstu članka. Fotografije treba priložiti kao zaseban dokument u jednom od formata *.tiff ili *.jpg u rezoluciji 300 dpi, dok crteže, grafove i dijagrame treba slati u rezoluciji 600 dpi. Redni broj slike i naslov stavljaju se ispod slike. Ključne informacije potrebne za razumijevanje slike nalaze se ispod naslova ako nisu već navedene unutar same slike.

Crteže, grafove i dijagrame preporučljivo je, osim u jednom od gore navedenih rasterskih formata, poslati i u izvornom vektorskom obliku u jednom od formata *.eps, *.cdr, *.dxf, *.xls, *.sta



Slika 1. Horizontalna projekcija stabala na pokusnoj plohi lijevo, rezultati PP analize desno

RASPRAVA
DISCUSSION

U raspravi autor bi trebao naglasiti najvažnija saznanja provedenog istraživanja i nastojati ne ponavljati do u detalje sve svoje rezultate. Potom treba razmotriti sve moguće razloge zbog kojih su dobiveni upravo takvi rezultati te načiniti usporedbu s drugim relevantnim navodima iz literature. Osobito je važno istaknuti ograničenja vlastitog istraživanja te naposlijetku navesti kako se dobiveni rezultati odražavaju na buduća istraživanja.

ZAKLJUČCI
CONCLUSIONS

Zaključke treba povezati s navedenim ciljevima istraživanja. Treba istaknuti samo najznačajnije zaključke.

Zahvala
Acknowledgements

Na kraju članka moguće se zahvaliti svima koji su imali izjestan doprinos u radu, a nisu autori (osobe, institucije, tvrtke, projekti itd.)

Uredništvo preporuča da glavni tekst rada ima gore navedena poglavlja, ali je moguće pojedina poglavlja i spojiti (npr. rezultati istraživanja i rasprava) ili dodati neka dodatna poglavlja i potpoglavlja koja je nužno navesti zbog specifičnosti istraživanja.

LITERATURA

REFERENCES

Radovi se u tekstu navode prema harvardskom sustavu. U zagradi se nalazi prezime prvoga i možebitno drugoga autora rada, nakon čega slijedi godina izdanja, npr. (Vukelić 2006) odnosno (Vukelić & Baričević 2006). Ako rad potpisuje više od dva autora, nakon prezimena prvog autora treba rabiti kraticu *et al*, npr. (Vukelić et al. 2006). Ako se uzastopno navodi više radova, podaci za pojedine radove odvajaju se zarezom, a u slučaju više radova istog autora u jednoj godini treba ih razlučiti dodavanjem latiničnih slova, npr. (Vukelić 2006a, Vukelić 2006b).

Popis literature nalazi se u posebnom poglavlju na kraju članka poredan abecednim redom prema prezimenu prvog autora. Ako je izvor literature knjiga ili članak, bibliografska jedinica mora sadržavati ove sastavnice (ovim redom):

Ime autora (ako je on nepoznat, ime urednika odnosno naziv organizacije izdavatelja)

Godinu izdanja

Naslov rada

Puno ime, godište i broj publikacije u kojoj je rad objavljen te broj stranica za knjigu, odnosno početna i završna stranica za članak iz časopisa

Naziv izdavača i mjesto izdanja (za knjige)

Ako je izvor na interetu, potrebno je navesti datum i mrežnu adresu korištenih dokumenata

Primjeri navođenja literature:

Časopis

Pernar, N., D. Bakšić, O. Antonić, M. Grubešić, I. Tikvić, M. Trupčević, 2006: Oil residuals in lowland forest soil after pollution with crude oil. Water, Air and Soil pollution, Vol 177, No 1-4, p 267-284.

Knjiga

Vukelić, J. & Đ. Rauš, 1998: Šumarska fitocenologija i šumske zajednice u Hrvatskoj. Sveučilište u Zagrebu, Šumarski fakultet, p. 310, Zagreb.

Poglavlje iz knjige, monografije, enciklopedije

Matić, S., I. Anić, M. Oršanić, 2003: Uzgojni postupci u bukovim šumama), In: S. Matić (ed.), Obična bukva (*Fagus sylvatica* L.) u Hrvatskoj). Akademija šumarskih znanosti, Zagreb, p. 340-380.

Članak iz zbornika

Škvorc, Ž., J. Franjić, Z. Liber, 2003: RAPD differentiation of the Croatian populations of Quercus pubescens sensu lato (Fagaceae). In: Redžić S. & S. Đug (eds.), Book of abstracts. Third International Balkan Botanical Congress "Plant resources in the Creation of New Values" Sarajevo, p. 170-170.

Internetska stranica
Journal of Forest experiments (2007) http://www.sumfak.hr/~jfe (01.veljace 2007.) (treba napraviti adresu stranice).

Norme, zakoni, pravilnici

ISO 11261:2004 - Soil quality - Determination of effective cation exchange capacity and base saturation level using barium chloride solution

Zakon o šumama (Forest law?) (2005) Official Gazzette of the Republic of Croatia. NN 140/05

Disertacija

Baričević, D., 2002: Sinekološko-fitocenološke značajke šumske vegetacije Požeške i Babje gore (Synecological-phytocoenological research into the forest vegetation of Požeška and Babja Gora). Disertacija, Sveučilište u Zagrebu, Šumarski fakultet, 175 p.

Rukopisi koji odstupaju od navedenih uputa bit će vraćeni autoru na doradu prije recenzije. Autorima će se prije konačnog tiska dostaviti primjerak tiskanoga sloga na korekturu. Ispravci će biti ograničeni samo na tiskarske greške. Promjene u tekstu neće biti dopuštene.

GLASNIK ZA ŠUMSKE POKUSE – JOURNAL OF FOREST EXPERIMENTS

Purpose

Glasnik za šumske pokuse (Journal of Forest Experiments) is an international journal where original scientific articles, reviews, preliminary communication, scientific papers and professional articles are published. The journal encompasses all the aspects of research in forestry, urban forestry, environmental protection and applied ecology. Every article is reviewed by at least two international critics.

Delivery of manuscripts

Texts written in English should be sent in electronic form to Editor's e-mail address (baksic@sumfak.hr). One text with supplements may contain maximum twenty pages (line spacing 1.5). Authors are responsible for the accuracy of English texts and the use of measurement units. The use of SI measurement units is recommended.

In addition to e-mail, texts may be sent by regular mail to the Editor's address:

Editorial council
Journal of Forest Experiments
Faculty of Forestry, University of Zagreb
P.O.B. 422
HR – 10002 Zagreb

In case that a text is sent by regular mail, it should consist of three copies, with sheets printed one-sidedly, plus one electronic version, together with tables and figures (CD, DVD). A written statement confirming that the article has not been either published or sent to any other publication should also be enclosed.

Preparation of the manuscript

Texts should be formed according to the following instructions:

- Document stored in MS Word program (*.doc format);
- Page size: A4;
- Font: Times New Roman, 12 pt;
- 1.5 line spacing
- All margins 2.5 cm;
- Do not use any styling (numbering, title design, bold letters);
- Do not arrange either the header or the footer of the document;
- Page numbering bottom right;
- Figures and tables with respective legends should be enclosed at the end of the document after the chapter "Literature", each on a separate page.

Article structure

Title – As short as possible, giving a clear picture of the issue.

Authors – Names without titles written under the heading: name first, then surname, divided by a comma.

Abstract – Description of the issue, the applied methods and materials, research area, and a short presentation of the main conclusions. Contains maximum 250 words. A abstract should end with up to seven key words that are characteristic of the article and translate on Croatian language.

Authors' titles and addresses – Written after the abstract. Author's name and titles are accompanied by address and e-mail.

Main text – The main text of the paper should be divided into chapters. The following are the basic chapters:

INTRODUCTION
UVOD
The introduction is a short and clear presentation of the research area. The main task of the author is to justify the reasons for carrying out such research, support them by arguments, and to explain what is expected that this research will reveal. The introduction should end with a hypothesis and the aims of the research. It does not contain the results and conclusions.

MATERIALS AND METHODS
MATERIJAL I METODE
The data on the time and place of the research (location), the criteria of choosing the test plots, the used materials and methods, and the applied methods of statistic analysis.

Statistic analysis
Statističke analize
Authors should include all applied statistic tests, and the preliminary chosen level of significance (p), i.e. the p-value they considered statistically significant (0.05 or 0.01). This passage should end with the data on the used computer statistics program, its producer and version.

RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA
Research results are presented clearly and precisely in text form, tables or graphs, so that the most significant results are given first. The results should be illustrated by a reasonable number of tables and figures. The results given in tables or graphs need not be repeated in the text, while the most important remarks are to be pointed out. It is important that with all tested differences the accurate p-value is given as a full number (e.g. $p = 0.048$ instead of $p>0.05$).

Tables
Tablice
The tables should contain only the research results, i.e. the numerical values. Tables with verbal data should be avoided. Instead, such data could be presented as prompts. The tables should be marked by headings and numbers (in the text they are referred to as Table 1, Table 2, etc.). Each column must have a short heading, while a more detailed explanation can be put into the legend below the table. All unusual abbreviations must also be explained in the legend.

Table 1 Measures of central tendency and variability of the investigated pedological variables for the surface mineral soil horizons per studied localities

Tablica 1 Mjere centralne tendencije i varijabiliteta istraživanih pedoloških varijabli za površinske mineralne horizonte tala po istraživanim lokalitetima.

Variable *Varijabla*		Units *Mjerne jedinice*	Papuk - PAP			Macelj - MAC			Medvednica - MED			Vrbovsko - VRB		
			N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.	N	Mean	St. dev.
Inclination		°	10	24	8,80	4	35	5,25	6	20	3,63	10	17	8,13
Thickness		cm	10	7	3,01	4	8	1,63	6	10	1,51	10	6	5,15
Particle size distribution *Tekstura*	2,0 - 0,2 mm	mas. %	10	29,0	10,22	4	16,3	12,42	6	19,4	9,07	10	7,6	7,42
	0,2 -0,02 mm	mas. %	10	42,8	8,18	4	57,1	13,08	6	37,7	8,13	10	49,6	5,44
	0,02 - 0,002	mas. %	10	19,4	6,11	4	16,1	1,27	6	28,3	4,66	10	26,8	5,53
	<0,002	mas. %	10	8,8	1,87	4	10,4	1,83	6	14,6	2,29	10	16,1	4,44
pH H_2O		-	10	4,44	0,27	4	4,02	0,45	6	4,31	0,15	10	4,10	0,28
pH $CaCl_2$		-	10	3,86	0,24	4	3,41	0,36	6	3,74	0,14	10	3,58	0,29
Org C		$g\,kg^{-1}$	10	56,4	19,16	4	106,0	55,20	6	106,3	24,98	10	54,1	43,12
N tot.		$g\,kg^{-1}$	10	3,7	0,92	4	8,0	2,65	6	6,6	3,14	10	4,4	2,41
C/N		-	10	15	2,18	4	13	3,75	6	19	9,10	10	12	2,65
Soil adsorption complex *Adsorpcijski kompleks tla*	Ca	$cmol(+)\,kg^{-1}$	10	0,87	0,79	4	2,71	0,27	6	1,08	0,86	10	0,53	0,81
	Mg	$cmol(+)\,kg^{-1}$	10	0,30	0,08	4	0,05	0,00	6	0,05	0,01	10	0,18	0,11
	Na	$cmol(+)\,kg^{-1}$	10	0,32	0,02	4	0,53	0,06	6	0,37	0,07	10	0,34	0,02
	K	$cmol(+)\,kg^{-1}$	10	0,79	0,15	4	1,20	0,40	6	0,89	0,08	10	0,68	0,09
	Al	$cmol(+)\,kg^{-1}$	10	4,19	1,91	4	4,39	2,19	6	4,29	1,23	10	11,68	4,85
	H	$cmol(+)\,kg^{-1}$	10	1,05	0,60	4	2,48	1,41	6	1,77	0,29	10	2,80	1,09
	Fe	$cmol(+)\,kg^{-1}$	10	0,10	0,09	4	0,29	0,24	6	0,13	0,06	10	0,23	0,19
	Mn	$cmol(+)\,kg^{-1}$	10	0,11	0,07	4	0,07	0,04	6	0,31	0,11	10	0,08	0,04
	BCE	$cmol(+)\,kg^{-1}$	10	2,29	0,79	4	4,49	0,62	6	2,39	0,86	10	1,73	0,90
	ACE	$cmol(+)\,kg^{-1}$	10	5,44	2,50	4	7,23	3,55	6	6,50	1,42	10	14,78	5,59
	CEC	$cmol(+)\,kg^{-1}$	10	7,72	2,32	4	11,72	4,09	6	8,89	2,13	10	16,51	5,18
	Base saturation	%	10	31,8	13,30	4	41,3	12,51	6	26,6	3,99	10	12,3	9,28

Figures

Slike

The figures are drawings, maps, graphs, diagrams and photographs. Figures in colour will be published at author's expense. Each figure should be named and numbered, according to the sequence found in the text of the article. Photos are to be enclosed as a separate document in one of the formats *tiff, or *jpg, resolution 300 dpi, while resolution 600 dpi is required for drawings, graphs and diagrams. The names and ordinal numbers of figures are put under them. The key information is placed below the name, unless already in the figure

In addition to the above mentioned raster formats, we recommend that drawings, graphs and diagrams be also sent in the original vector form, in one of the following formats:*eps, *cdr, *dxf, *xls, or *sta.

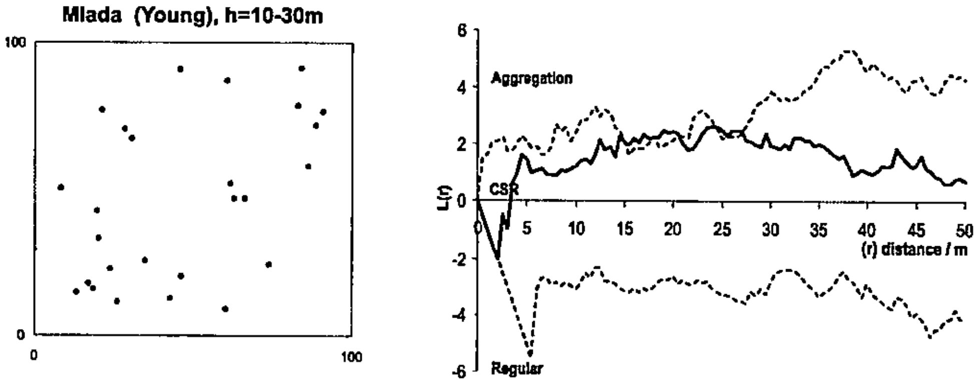


Fig.1 Horizontal projection of trees on test site on the left, results of PP analysis on the right.

Slika 1. Horizontalna projekcija stabala na pokusnoj plohi lijevo, rezultati PP analize desno

DISCUSSION
RASPRAVA

This chapter should contain the major findings of the research, without detailed repetitions of all results. All possible reasons for the achievement of such results should be discussed. Comparison with other relevant quotations from the literature should be made. It is particularly important to point at the limitations of the authors' own research. It should be concluded how the achieved results reflect upon future research.

CONCLUSIONS
ZAKLJUČCI

The conclusions should be connected with the related research aims. Only the most significant conclusions should be mentioned.

Acknowledgements
Zahvala

At the end of the article the authors may express their gratitude to all who have contributed to the research and are not considered the authors themselves (persons, institutions, firms, projects, etc.).

The editor recommends that the main text of the article contain the above listed chapters. However, some of them may be joined (e.g. research results and discussion), or some additional chapters and subchapters may be introduced due to the specific features of the research.

REFERENCES

LITERATURA

Literature references in the text are quoted according to the Harvard system. The surname of the first author (or the first and the second authors' surnames) in the brackets is followed by the publishing year, e.g. (Vukelić 2006) (or: (Vukelić & Baričević 2006)). If the paper is signed by more than two authors, the surname of the first author is followed by *et al.*, e.g. (Vukelić *et al.* 2006). If several references are quoted one after another, the data of the individual ones are divided by commas. Latin letters should mark several references of the same author in the same year, e.g. (Vukelić 2006a, Vukelić 2006b).

References are listed in a separate chapter at the end of the article, in alphabetical order by author. If the reference source is a book or article, the bibliographic unit should contain the following components (in this order):

Author's name (if unknown, Editor or Publisher)

Publishing year

Title

Full name, publishing year and number of the publication in which the reference was published, with the number of pages (book), or the initial and ending page (journal article).

Publisher's name and place of publication (books).

If the reference source is Internet, date and web address of the used documents should be quoted.

Examples:

Journal

Pernar, N., D. Bakšić, O. Antonić, M. Grubešić, I. Tikvić, M. Trupčević, 2006: Oil residuals in lowland forest soil after pollution with crude oil. Water, Air and Soil pollution, Vol 177, No 1-4, p 267-284.

Book

Vukelić, J. & Đ. Rauš, 1998: Šumarska fitocenologija i šumske zajednice u Hrvatskoj. Sveučilište u Zagrebu, Šumarski fakultet, p. 310, Zagreb.

Book chapter, monographs, encyclopedias

Matić, S., I. Anić, M. Oršanić, 2003: Uzgojni postupci u bukovim šumama), in: S. Matić (ed.), Obična bukva (*Fagus sylvatica* L.) u Hrvatskoj). Akademija šumarskih znanosti, Zagreb, p. 340-380.

Article from collected papers

Škvorc, Ž., J. Franjić, Z. Liber, 2003: RAPD differentiation of the Croatian populations of Quercus pubescens sensu lato (Fagaceae). In: Redžić S. & S. Đug (eds.), Book of abstracts. Third International Balkan Botanical Congress "Plant resources in the Creation of New Values" Sarajevo, p. 170-170.

Internet page

Journal of Forest experiments (2007) http://www.sumfak.hr/~jfe (January 1 2007.) (Page address should be made)

Standards, laws, statutes

ISO 11261:2004 - Soil quality - Determination of effective cation exchange capacity and base saturation level using barium chloride solution

Forest Law (2005, Official Gazette of the Republic of Croatia. NN 140/05

Doctor's thesis

Baričević, D., 2002: Sinekološko-fitocenološke značajke šumske vegetacije Požeške i Babje gore (Synecological-phytocoenological research into the forest vegetation of Požeška and Babja Gora). Disertacija, Sveučilište u Zagrebu, Šumarski fakultet, 175 p.

The manuscripts that do not comply with these instructions will be returned to their authors for correction. Before the final print, the authors will receive typescript copies of their articles for correction. The corrections will relate only to typing errors. No text changes will be permitted.

GLAS. ŠUM. POKUSE Vol. 43 Str. 1–93 Zagreb, 2009 –10.

CONTENTS
SADRŽAJ

ISSN 0352-3861
9 770352 386008