UDK 630 ISSN 0352–3861
GLAS. ŠUM. POKUSE Vol. 42 Zagreb, 2007– 08.

GLASNIK
ZA ŠUMSKE POKUSE

ANNALES
EXPERIMENTIS SILVARUM CULTURAE PROVEHENDIS

42

SVEUČILIŠTE U ZAGREBU
ŠUMARSKI FAKULTET
UNIVERSITAS STUDIORUM ZAGRABIENSIS
FACULTAS FORESTALIS

Glasnik za šumske pokuse

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Volumen 42

UNIVERSITAS STUDIORUM ZAGRABIENSIS
FACULTAS FORESTALIS
ZAGREB MMVII – MMVIII

GLAS. ŠUM. POKUSE Vol. 42 Str. 1–96 Zagreb, 2007– 08.

GLASNIK

ZA ŠUMSKE POKUSE

Knjiga 42

SVEUČILIŠTE U ZAGREBU
ŠUMARSKI FAKULTET
ZAGREB, 2007–08.

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

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 međunarodnoj 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 international critics.

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

FOREWORD

An international scientific symposium *Virgin Forest Ecosystems of Dinaric Karst and Nature-Based Forest Management in Croatia* was held in the Croatian Academy of Sciences and Arts on 27th and 28th September 2007. The symposium, organized by the Forestry Section of the Scientific Council for Agriculture and Forestry of the Croatian Academy of Sciences and Arts, marked the 50th anniversary of the beginning of systematic scientific forestry research in Croatian virgin forest ecosystems. It was in September 1957 that Academician Milan Anić and his associates established a permanent experimental plot and performed the first measurements in the virgin forest of Čorkova Uvala. This experimental plot has since been a source of invaluable data on beech-fir virgin forests in the Dinaric karst region. The symposium was co-organized by the international association *Pro Silva Europa*, the Academy of Forestry Sciences and the Plitvice Lakes National Park.

The goals of the symposium were to:

- present the achievements of forestry and associated sciences related to the study of beech and beech-fir virgin forest ecosystems on Dinaric karst and demonstrate their application on the development of nature-based management with forests,
- explain why all forests cannot be virgin forests and what is nature-based forest management in Croatia,
- draw the attention of broader scientific and professional public to the value of natural forest ecosystems in Croatia on the threshold of Croatia's accession to the European Union.

Fourteen papers were presented at the symposium. They will be published in a proceedings edited by the Croatian Academy of Sciences and Arts. This volume of the journal "Glasnik za šumske pokuse" contains seven articles chosen by the editors and submitted to international revision for publication in the English language.

The authors of the papers are members of the Croatian Academy of Sciences and Arts and the Academy of Forestry Sciences, scientists of the Biotechnical Faculty of Ljubljana University and the Faculty of Forestry of Zagreb University and the Forest Research Institute in Jastrebarsko.

It is a fact that Croatian forests have always been managed on a close-to-nature principle. The results of such practice are their natural and well preserved conditions, especially where forest management has been applied continuously for almost two and a half centuries. The natural approach to forest management in Croatia is staunchly advocated and developed by the Faculty of Forestry of Zagreb University through the *Zagreb School of Silviculture*.

We hope that this scientific symposium will contribute to better public understanding of nature-based forest management and promote forestry as a science, profession and art of managing and preserving forest ecosystems.

Editor in Chief

PROSLOV

U palači Hrvatske akademije znanosti i umjetnosti održan je 27. i 28. rujna 2007. godine međunarodni znanstveni skup *Prašumski ekosustavi dinarskoga krša i prirodno gospodarenje šumama u Hrvatskoj*. Skup je organizirala Sekcija za šumarstvo Znanstvenoga vijeća za poljoprivredu i šumarstvo Hrvatske akademije znanosti i umjetnosti povodom 50. obljetnice početka sustavnih šumarskih znanstvenih istraživanja u hrvatskim prašumskim ekosustavima. Naime, u rujnu 1957. godine akademik Milan Anić sa svojim je suradnicima postavio trajnu pokusnu plohu i obavio prvu izmjeru u prašumi Čorkova uvala. Ta je pokusna ploha do danas ostala dragocjeni izvor podataka o bukovo-jelovim prašumama dinarskoga krša. Suorganizatori skupa bili su međunarodna udruga *Pro Silva Europe*, Akademija šumarskih znanosti i Nacionalni park Plitvička jezera.

Skup je organiziran s ciljevima:

- prezentacije dosega šumarske i srodnih znanosti na istraživanju bukovih i bukovo-jelovih prašumskih ekosustava na dinarskom kršu te uporabe tih rezultata u razvoju prirodnoga gospodarenja šumama
- odgovoriti na pitanja zašto sve šume ne mogu biti prašume i što je prirodno gospodarenje šumama u Hrvatskoj
- ukazati široj znanstvenoj zajednici i stručnoj javnosti na vrijednosti prirodnih šumskih ekosustava Hrvatske na pragu pristupanja Europskoj uniji.

Na znanstvenom skupu je prezentirano četrnaest radova koji će se tiskati u posebnom Zborniku, u izdanju Hrvatske akademije znanosti i umjetnosti. U ovom volumenu časopisa *Glasnik za šumske pokuse* donosimo sedam članaka koje je uredništvo izabralo i podvrgnulo međunarodnoj recenziji za tisak na engleskom jeziku.

Autori radova su članovi Hrvatske akademije znanosti i umjetnosti i Akademije šumarskih znanosti, znanstvenici Biotehničkog fakulteta Sveučilišta u Ljubljani, Šumarskoga fakulteta Sveučilišta u Zagrebu i Šumarskoga instituta, Jastrebarsko.

Činjenica je kako je šumarstvo oduvijek znalo kako prirodno gospodariti hrvatskim šumama. Najbolji dokazi tomu su njihova prirodnost i očuvanost koji su posebice izraženi upravo tamo gdje se šumama u kontinuitetu gospodari gotovo dva i pol stoljeća. Prirodni pristup gospodarenju šumama u Hrvatskoj se prepozanje kroz *zagrebačku školu uzgajanja šuma* koju njeguje i razvija Šumarski fakultet Sveučilišta u Zagrebu.

Vjerujemo kako će ovaj znanstveni skup pridonijeti senzibilizaciji svekolike javnosti za prirodno gospodarenje šumama i promociji šumarstva kao znanosti, struke i umijeća gospodarenja te očuvanja šumskih ekosustava.

Glavni urednik

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UDK: 630*228.81

Original scientific paper
Izvorni znanstveni članak

THE RELATIONSHIP BETWEEN CLOSE TO NATURE MANAGEMENT AND LIFE STAGES IN THE DEVELOPMENT OF A VIRGIN FOREST

VEZA IZMEĐU PRIRODNOG GOSPODARENJA I ŽIVOTNIH FAZA U RAZVOJU PRAŠUME

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Received – *Prispjelo*: 15. 10. 2007.

Accepted – *Prihvaćeno*: 15. 1. 2008.

In forest management, the forestry profession advocates the principle of sustainability, also known as the principle of sustainable development. According to this principle, tending treatments are applied with the goal of improving the existing forests while regeneration treatments are aimed at raising new generations of forests. Thanks to the principle of sustainability, which has been continuously applied to Croatian forestry since 1765, Croatian natural forests have survived to the present day. Close to nature management is based on forest tending and regeneration treatments, whose core postulates are found in a virgin forest. This refers both to selection forests (fir-beech forests) and regular forests (forests of all other tree species in Croatia). Due to their stability and eternity, naturally managed forests provide a firm ecological and commercial stronghold in all life conditions, including adverse ones. A forest which develops under the influence of man, who applies nature-based tending and regeneration activities since the beginning, is a natural commercial forest. Conversely, a forest which has always developed without any human impacts is a virgin forest. During its development of several centuries, a virgin forest undergoes developmental cycles that alternate through three different stages. These are the initial, the optimal and the terminal stage. The stages coincide with developmental stages, such as, for example, the stage of ageing, decomposition and selection. The time period lapsing between the occurrence and the disappearance of a generation in a virgin forest of fir and beech is about 400 to 500 years. Of this long period, slightly less than half relates to desirable, stable and productive structural conditions for forest growth. The longer part of this period, between 200 and 300 years, relates to unfavorable structural and physiological conditions. The first, favorable and desirable period, comprises those stages that are applied to selection forest management (selection and initial optimal stage), and to regular forest management (optimal and initial stage). By applying tending and regeneration treatments with selection cutting in a selection forest in which the growing stock is maintained at approximately 400 m^3/ha before and 300 m^3/ha after the cut, we preserve the natural structure that favors optimal natural regeneration, maximal increment, desirable biological diversity, naturalness, stability and eternity of selection forests. Tending operations in a regular forest eliminate superfluous and poor quality individuals from stands similarly to natural mortality that takes place during virgin forest development. Regeneration treatments in a regular forest, which has matured and reached a structure similar to that in the optimal stage of a virgin forest, are intended to regenerate it naturally and ensure its eternity. The above treatments in commercial natural forests mirror the events in virgin forests, with the only difference that a tended natural forest, unlike a virgin forest, always puts forth good quality commercial and non-commercial production. When it reaches the ageing stage, it is naturally regenerated. In today's disturbed ecological conditions, forests lacking the natural structure are the most susceptible to dieback. It is owing to close to nature management that Croatian forests are among the most stable in Europe. However, some legal acts, probably written under the strong pressure of "nature lovers", green activists, "environmentalists" and similar groups, show lack of understanding about how forests function, erroneously prescribe passive protection and ban tending and regeneration treatments. If we want to preserve good quality natural forests for future generations, these acts should urgently be mended. We all love our forests, but love should be complemented with knowledge of forests. Love alone will surely lead our forests to ruin.

Key words: close to nature management, natural forest, virgin forest, tending, regeneration

INTRODUCTION
UVOD

Uncontrolled cutting of forests that took place during the early stage of capitalism in Europe led to a number of devastating consequences, such as a reduction in the forest area, absence of regeneration and catastrophic ecological and economic impacts. This prompted urgent establishment of the forestry profession, whose main task was to protect, exploit and regenerate forests on the basis of specialist and scientific knowledge (Matić 1990).

In Croatia, then a part of the Habsburg Monarchy, the Military Border was established in 1702. The forestry service based on military principles was introduced in 1746 over the entire area (Klepac 2001). The area of eleven regiments comprised 741,908 ha of forests. A military forestry service was set up in each of these areas. The year 1765 deserves special mention, because it was the year when the first management plan was drawn up and the first forest offices were founded (Krasno, Oštarije and Petrova Gora). The Krasno forest office is still active (Matić et al. 2001).

A well organized forestry profession follows the principle of sustainability, also known as the principle of sustainable development. Its application ensures permanent survival of forests in an area. The principle of sustainable management has always played an important role in the Croatian forestry legislation. This is confirmed by the Forest Order issued by Maria Theresa (1769), the forest laws of 1852 and 1894, and the many progressive forest laws issued since (Matić 2004).

Nature-based management, the implementation of the above laws, and probably the fact that forestry was part of the military administration were all responsible for the preservation of natural forests in Croatia today. Owing to this, the Republic of Croatia has 2,688,687 ha of forests and forestland, of which 98% is of natural character. These forests contain 398 million m^3 of growing stock. Growing stock increases by 10.5 million m^3 annually, corresponding to the amount of the annual current increment.

Forests in Croatia are natural because they originate from natural seed regeneration. Seed reaches the forest floor from the crowns of mature trees before they are cut. These forests are tended and regenerated in accordance with the basic principles that reign in a virgin forest. Virgin forests are natural forests which develop exclusively under the influence of natural factors.

Depending on different biological properties and ecological requirements of tree species and their adaptation to certain site conditions, there are two basic methods of forest tending and regeneration. One method involves forest stands of even-aged structure, and the other forest stands of selection structure. An even-aged stand contains trees of similar heights, breast diameters and ages, because they have sprouted almost simultaneously from the seeds of mature trees. Selection stands relate exclusively to the distribution range of silver fir accompanied by common beech and sometimes by common spruce. Since these species and silver fir in particular, are skiophilic, they are capable of forming a selection structure. Such a stand contains trees of different heights and breast diameters per surface unit. In the structural and light conditions, selection stands of fir, in community with beech and spruce, have an excellent regeneration and survival rate. An even-aged and selection structure of a forest stand may also be formed in a virgin forest. However, each represents only one of the several life stages of a virgin forest.

Close to nature management is the most perfect method of forest management. Forests managed according to natural principles maintain the optimal natural structure, which ensures their naturalness, diversity, stability, maximal production, optimal natural regeneration and eternity. Conversely, the clear-cutting management method still applied in some European countries, achieves contrary effects and leads to site degradation and the disappearance of climatogenic or basic tree species and their stands. This is the reason that Croatian forests have for centuries been managed according to natural principles. As a management method, clear cutting has always been banned by law, which is one of the particularities of Croatian forestry.

In close to nature management, forest tending and regeneration follows the results of research in the life stages of a virgin forest. Thus, the application of natural laws stemming from the selection phase of a fir-beech virgin forest is important in the management with a fir-beech selection stand. Even-aged stand management relies on the insights related to the optimal virgin forest stage. However, in the several-hundred-year life cycle of a virgin forest there are periods of dieback, rotting and decomposition. Viewed from generally beneficial (ecological, social and socio-ecophysiological) and management standpoints, these are periods with negative effects.

Only one period in the long developmental cycle of a virgin forest is acceptable and useful for man and the environment. This is the period of selection and a part of the optimal phase. The remaining period of a virgin forest development relates to the decomposition of the old and the formation of the new generation of a forest stand.

Those who insist on permanent and passive protection of forest, and particularly of forests in national parks, are often ignorant of the above facts. If naturally managed forests are not tended and regenerated and are allowed to grow spontaneously, they will gradually assume the structure of secondary virgin forests. In this manner we expose them to the above mentioned processes of forest structure decomposition and the accumulation of growing stock. This cannot be a model for natural commercial forests, from which we expect eternity and stability, as well as the provision of both non-commercial and commercial goods.

The value of virgin forests as natural amenities that serve for extensive natural-scientific research is exceptional. There are currently ten virgin forests in Croatia extending over a total area of 848.41 ha (Anić 2004). Of these, six are beech-fir virgin forests, two are beech forests, one is a beech-sessile oak forest and one is a pedunculate oak virgin forest. The diversity, quantity and area of virgin forests place Croatia among the richer European countries.

The objective of this work is to present tending and regeneration treatments in natural forests and their relationship to spontaneous processes occurring in a virgin forest. Special focus will be placed on the frequently applied and harmful practice of passive forest protection, which causes forests to convert into secondary virgin forests due to the absence of tending and regeneration treatments. Without human intervention, they are gradually self-decomposed, while their regeneration is generally long-lasting and of unsatisfactory quality. The man, the society and the environment thus lose both non-commercial and commercial values that a natural commercial forest is capable of providing.

DEVELOPMENT OF VIRGIN FORESTS AND CLOSE TO NATURE FOREST MANAGEMENT
RAZVOJ PRAŠUME I PRIRODNO GOSPODARENJE ŠUMAMA

The forest is represented by the forest soil coherently covered with forest trees, shrubs and ground vegetation, which permanently produce wood matter and goods of general benefit expressed in ecological (protective), social and socio-ecophysiological forest functions. It is characterized by a balance between life community or biocoenosis (plants, animals, microorganisms) and site (soil, climate, relief) (Matić 1996a).

A forest which has always developed without any organized human impacts and has prospered exclusively under the impact of natural factors is a virgin forest (Prpić et al. 2001). A naturally managed forest is a forest developed under the organized impact of man, who follows the principles of virgin forests in tending and regeneration (Matić 1990).

In its growth of several centuries a virgin forest goes through developmental cycles which, according to Korpel (1996), alternate and intertwine in three different stages: the initial, the optimal and the decomposition stage. Each of these stages has a characteristic structure, growing stock and duration. These developmental cycles and stages constitute the life cycle of a virgin forest. It embraces a period from the establishment of one generation of trees to the death of the very last tree of that generation. This period lasts about 400 to 500 years for fir-beech virgin forests (Korpel 1995, Mayer et al. 1980).

A virgin forest lacks a homogenous structure. Indeed, it displays a variety of developmental phases which differ in terms of tree heights, wood volume, the amount of dead wood, quantity of young generation, tree vitality, crown canopy and similar (Anić 2004). The developmental phases extend over 0.5 to 1.5 ha and are distributed mosaic-like across the virgin forest area. These stages are called the initial, the selection, the optimal and the terminal stage with the sub-stages of ageing and decomposition.

The terminal phase with the sub-phases of ageing and decomposition is marked with breakdown and decomposition of growing stock and the simultaneous occurrence of a new, young generation. Such a structure in a fir-beech virgin forest may last for 80 to 120 years (Saniga 2002). During this period, trees of the old virgin forest generation decompose and a new generation starts to form. The next phase is the initial phase marked with intensive growth of trees of the new generation and their penetration from the lower to the upper stand layers. The selection phase is next. It is marked by tree species which are characteristic for a selection forest and selection structure. This is a short phase lasting for only 20 to 30 years (Saniga 2002). In beech-fir virgin forests in the Dinaric range, due to the mosaic of microsites caused by karst phenomena and varying soil depths, the selection structure is formed in almost all developmental stages and phases of a virgin forest (Prpić et al. 2001). The initial and the selection stage in a beech-fir virgin forest last for about 100 to 140 years. Next is the optimal phase, in which the basal area and the volume achieve maximal values, the canopy is complete, the number of trees per surface unit is large and regeneration is poor. This phase, lasting for 80 to 120 years, is characterized by the attainment of maximal values of growing stock of about 1,400 m^3/ha. The optimal phase is followed by the terminal phase, in which the old generation of the virgin forest is decomposed and the new one is formed.

During the life cycle of a virgin forest lasting for several centuries, natural regeneration becomes more intensive at the end of the optimal phase. This is marked by the gradual reduction of the growing stock, the formation of light and soil conditions for seed germination and the growth of the young generation. The selection stage is too short for the young generation to survive. It disappears due to intensive growth of dominant trees, the formation of the horizontal canopy and the lack of light. This leads to the rapid disappearance of the selection phase and the onset of the optimal phase, in which conditions for natural regeneration are minimal.

In selection management, the structure of the selection and the initial part of the optimal phase is permanently maintained. In a commercial selection stand mature trees are cut and natural regeneration is stimulated. If these operations are missing, the structure of the stand will assume the features of the optimal, and later of the terminal virgin forest phase.

In order to maintain the selection stand in optimal structural conditions, permanent silvicultural treatments should be applied. This involves selection cuts in which the value of the increment is cut and the optimal growing stock maintained (Matić et al. 2001). During the entire life cycle of a fir-beech virgin forest, the recorded tree mortality ranged from 21.41 to 29.24%, or 25% on average (Saniga 2002). This result firmly confirms the fact that the cutting intensity of 25% in selection management has been properly determined and that is conforms to nature. If silvicultural treatments are lacking or are misapplied, e.g., if lower cutting intensity is applied, the selection stand will lose its optimal structure, while over-mature and physiologically weakened trees will decline and die. Natural regeneration in such a forest is absent, increment is reduced and so is the production of commercial and non-commercial goods.

The structure of the optimal phase in a virgin forest offers insights on tending and regeneration of even-aged stands. The structural features of old even-aged stands are almost identical to the structure of the optimal phase of a virgin forest. In the developmental stage of the old stand, a decrease in the increment and visible physiological weakening of trees call for the application of treatments based on natural regeneration. In the course of two to five cuts the number of trees is gradually reduced, while simultaneous protection of the soil encourages the growth of the new stand generation. Thus, by adhering to natural processes which occur relatively briefly in one of the phases of virgin forest growth, we ensure optimal natural development of an even-aged stand.

In regular forests with silvicultural forms of high forest, coppice with standards and coppice, natural regeneration includes silvicultural treatments of tending and regeneration. Tending begins after natural regeneration and lasts almost throughout the stand's life or rotation, i.e. since the beginning of regeneration. Tending ensures the optimal, natural structure which forms good stand climate, develops the forest soil and allows optimal production of market and non-market values, biological diversity and the possibility of natural regeneration (Matić 1996). Regeneration of regular forests involves the replacement of an old and mature stand, using shelterwood cuts, with a young one. In the process, any stresses for the forest floor and the young generation are avoided. Further tending treatments maintain the optimal natural structural and site condition in all age classes. Such an optimal condition in a regular forest may be compared with the optimal stage in the development of a virgin forest.

Nature-based silvicultural tending and regeneration treatments in regular forests maintain the natural development of a forest, similar to that in a virgin forest (optimal stage and growing stage) (Korpel 1995, 1996). The decomposition stage has thus been purposefully avoided and those useful natural processes occurring in the most natural of all forests – the virgin forest – have been consequently followed. Our treatments accelerate the processes and increase the quality of a stand.

SOME EVENTS THAT JEOPARDIZE CLOSE TO NATURE MANAGEMENT
NEKE POJAVE KOJE DOVODE U PITANJE PRIRODNO GOSPODARENJE ŠUMAMA

During the 20th century close to nature management was abandoned in many European countries. Clearcutting as a method of management and establishment of forests was introduced in practice for reasons of economic nature. However, in current ecological and economic conditions profit in forest management is a rather dubious category.

It is important to determine what amount of financial means should be returned to a forest through tending and regeneration so that the forest soil is saved from degradation and the quality of commercial and non-commercial forest functions is preserved. Non-commercial forest functions are divided into ecological (hydrological, water-protective, anti-erosion, climatic and anti-emission), social (aesthetic, health, recreational and tourist) and socio-physiological functions (genetic, biological-diverse, natural-protective and physiological) (Prpić 2003). The society makes good use of these forest products. Their quality is higher if close to nature forest management is more intensive and better. Regrettably, these functions do not have any market value at present day and are therefore not calculated as income realized by forests and forestry.

The present is marked by disturbed global ecological conditions and frequent ecological disasters caused by human activities which, among other things, result in the weakening, dieback and mortality of forests (Matić 2003). To counteract such a situation, a large number of citizens' associations and political parties ("lovers of nature", "green activists", "environmentalists", and similar) have been established with the mission to alert the public of this problem. Despite not having proper knowledge on forests and forestry, they generally blame all the problems on foresters, oppose any treatments in forests and insist on the protection of large natural forest complexes and their exclusion from normal (natural) management.

Such an attitude is, unfortunately, becoming a rule of conduct even in those countries which still have natural forests and in which clearcutting is banned by law. The example of Croatia illustrates that forested areas under some kind of protection are increasing almost on a daily basis. In such areas natural management is either not allowed or is reduced to the minimum (Matić 1999). The total forest area enjoying some kind of protection amounts to 610,510 ha or to 29.4% of all forests in Croatia (Matić 2006). Management is completely excluded from some of these areas. In others, it is allowed but is strictly limited. As a rule, limitations are set by those circles and institutions which cannot boast many forestry experts. It should be pointed out, however, that it was precisely the Croatian forestry experts who have created our natural forests during 240 years of organized management.

Passive forest protection excludes close to nature management, gradually depletes the optimal natural structure and significantly decreases non-commercial and commercial forest values. In addition, it causes worsened site conditions, aggravates regeneration, increases the number of old and physiologically weakened trees, debilitates the vitality, stability and productivity of forests, reduces the diversity of flora, fauna and microorganisms, etc. All the above is responsible for the fact that such forests assume the character of virgin forests in the subphases of ageing and decomposition. Sadly, forests with a disturbed structure provide minimal commercial and generally beneficial goods.

CONCLUSIONS
ZAKLJUČCI

Sustainable management, applied in central Europe since the 18th century, is the principal reason that natural forests and close to nature management has survived to date. Close to nature management focuses on tending and regeneration, as well as the production of commercial and non-commercial values. At the same time, it maintains the optimal natural stand structure and ensures permanent protection and development of forest soil.

Close to nature management in selection and regular forests is based on natural laws reigning in a virgin forest, with the only difference that the applied silvicultural treatments accelerate natural processes and achieve better quality and eternity of forests.

Clearcutting as a management method has contributed to the loss of respect for forestry as a profession on the European scale. This method is motivated by economic indicators in which profit has a dominant role at the detriment of natural forests and functions of general benefit.

Forests lacking close to nature management are heading towards destruction. Close to nature management has been and will be the only guarantee of protection, survival and eternity of forests. All those that insist on passive forest protection and mask their ignorance with "love" for forests, should know that they take enormous responsibility. They should also know that love alone leads forests to destruction.

REFERENCES
LITERATURA

Anić, I., 2004: Prašume i njihovo značenje za gospodarenje šumama u Hrvatskoj. Glasnik zaštite bilja 6: 85–96.

Anić, I., S. Matić, M. Oršanić, 2005: Natural Forests of Pendunculate Oak (*Quercus robur* L.) in Croatia. U: Commarmot, B., Hamor, F. D. (ur.): Natural Forests in Temperate Zone of Europe–Values and Utilisation. Swiss Federal Research Institute WSL, Carpathian Biosphere Reserve, Birmensdorf-Rakhiv, pp. 135–141.

Klepac, D., 2001: Razvoj gospodarenja u jelovim šumama. U: Prpić, B. (ur.), Obična jela (*Abies alba* Mill.) u Hrvatskoj, Akademija šumarskih znanosti, Zagreb, 25–89.

Korpel, Š., 1995: Die Urwaelder der Westkarpaten. Gustav Fisher Verlag, Stuttgard-Jena-New York, str. 310.

Korpel, Š., 1996: Razvoj i struktura bukovo - jelovih prašuma i njihova primjena kod gospodarenja prebornom šumom. Šumarski list CXX (3–4): 203–209.

Matić, S., 1990: Šume i šumarstvo Hrvatske–jučer, danas, sutra. Glasnik za šumske pokuse 26: 35–56.

Matić, S., 1996: Uzgojni radovi na obnovi i njezi sastojina hrasta lužnjaka. U: Klepac, D. (ur.), Hrast lužnjak (*Quercus robur* L.) u Hrvatskoj, Hrvatska akademija znanosti i umjetnosti, Hrvatske šume, p. o. Zagreb, Zagreb-Vinkovci, 167–212.

Matić, S., 1996a: Šumarstvo Hrvatske od osnivanja modernog sveučilišta u Zagrebu (1874.) do danas. U: Mrzljak, P. G. (ur.), Znanost u Hrvata: prirodoslovlje i njegova primjena. Ministarstvo znanosti i tehnologije Republike Hrvatske, Zagreb, 516–533.

Matić, S., 1999: The forests of Croatia – country report. U: Diaci, J. (ur.), Virgin forests and forest reserves in Central and East european countries, Department of forestry and renewable forest resources, Biotechnical faculty, Ljubljana, 17–24.

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

Matić, S., 2003: Neki problemi koji opterećuju hrvatsko šumarstvo u današnjim gospodarskim, društvenim i ekološkim uvjetima. Šumarski list 5 – 6 (CXVII): 211–216.

Matić, S., B. Prpić, I. Anić, M. Oršanić, 2003: Bukove prašume. U: Matić, S., (ur.), Obična bukva (*Fagus sylvatica* L.) u Hrvatskoj, Akademija šumarskih znanosti, Zagreb, 414–434.

Matić, S., 2004: Održivi razvoj hrvatskih šuma ugrožen je zbog nepoštivanja Ustava i Zakona o šumama Republike Hrvatske. U: Maceljski, M. (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., 2006: Natural management as an important factor of forest protection and survival. U: Diaci, J. (ur.), Nature–based Forestry in Central Europe, Alternatives to Industrial Forestry and Strict Preservation, Department of Forestry and Renewable Forest Resources-Biotechnical Faculty, Ljubljana, 19–26.

Prpić, B., S. Matić, J. Vukelić, Z. Seletković, 2001: Bukovo-jelove prašume hrvatskih Dinarida. U: Prpić, B. (ur.), Obična jela (*Abies alba* Mill.) u Hrvatskoj, Akademija šumarskih znanosti, Zagreb, 479–494.

Prpić, B., 2003: Općekorisna uloga bukovih šuma. U: Matić, S. (ur.), Obična bukva (*Fagus sylvatica* L.) u Hrvatskoj, Akademija šumarskih znanosti, Zagreb, 213–227.

Saniga, M., 2002: Štruktura pralesa. U: Slavik, D. (ur.), Dobročsky prales–Narodna prirodna rezervacia, UVVP LVH SR, Zvolen, 30–34.

VEZA IZMEĐU PRIRODNOG GOSPODARENJA I ŽIVOTNIH FAZA U RAZVOJU PRAŠUME

SAŽETAK

Šumarska struka u gospodarenju šumama primjenjuje načelo potrajnosti ili načelo održivog razvoja. Na taj se način zahvatima njege šuma unapređuju postojeće, a zahvatima obnove ili pomlađivanja šuma podižu nove generacije šuma. Zahvaljujući načelu potrajnosti, koje se u hrvatskom šumarstvu primjenjuje od 1765. godine, naše prirodne šume su opstale do današnjih dana. Prirodno gospodarenje se temelji na zahvatima njege i obnove šuma kojima temeljna načela nalazimo u prašumi. To se odnosi kako na preborne (jelovo-bukove šume), tako i na regularne šume (šume svih ostalih vrsta drveća u Hrvatskoj). Tako gospodarene šume su stabilne i vječne. One predstavljaju čvrsto ekološko i gospodarsko uporište u svim, pa i nepovoljnim životnim uvjetima. Ako se šuma od svog nastanka razvija pod utjecajem čovjeka koji obavlja radove njege i obnove temeljene na prirodnim načelima tada govorimo o prirodnoj gospodarskoj šumi. Nasuprot tome, ako se šuma oduvijek razvijala bez utjecaja čovjeka, onda je riječ o prašumi. Prašuma u svom višestoljetnom razvoju proživljava razvojne cikluse u kojima se izmjenjuju tri različita stadija: inicijalni, optimalni i terminalni stadij. Stadiji se preklapaju s razvojnim fazama, primjerice starenjem, raspadanjem i prebornom fazom. Razdoblje od nastanka do nestanka jedne generacije u jelovo-bukovoj prašumi traje približno 400 – 500 godina. Nešto manje od polovice toga razdoblja šume provedu u poželjnim, stabilnim i produktivnim strukturnim prilikama. Dulji dio toga razdoblja, 200 do 300 godina, ona se nalazi u nepovoljnim strukturnim i fiziološkim prilikama. Povoljno i poželjno prvo razdoblje obuhvaća faze koje primjenjujemo u gospodarenju prebornom šumom (preborna i početak optimalne faze) odnosno regularnom šumom (optimalna i inicijalna faza). Obavljajući zahvate njege i obnove prebornom sječom u prebornoj šumi održavamo drvnu zalihu od približno 400 m^3/ha prije i 300 m^3/ha nakon sječe, osiguravamo prirodnu strukturu u kojoj se događa optimalno prirodno pomlađivanje, maksimalan prirast, poželjna biološka raznolikost, prirodnost, stabilnost i vječnost prebornih šuma. Isto tako, obavljajući zahvate njege u regularnoj šumi eliminiramo iz sastojine prekobrojne i nekvalitetne jedinke, slično prirodnom mortalitetu koji se događa tijekom razvoja prašume. Zahvatima pomlađivanja u regularnoj šumi koja je doživjela zrelost i strukturu sličnu optimalnoj fazi u prašumi, prirodno je obnavljamo i osiguravamo joj vječnost. Navedeni zahvati koje provodimo u gospodarskim prirodnim šumama imaju uzor u prašumama s razlikom što njegovana prirodna šuma, za razliku od prašume, uvijek ima kvalitetnu gospodarsku i općekorisnu proizvodnju, a u fazi starenja je prirodno obnavljamo. U današnjim poremećenim ekološkim uvjetima najviše se suše šume koje nemaju prirodnu strukturu. Zahvaljujući prirodnom gospodarenju naše šume spadaju među najstabilnije u Europi. Ipak, neki naši zakonski akti, vjerojatno napisani pod jakim utjecajem «ljubitelja prirode», «zelenih», «ekologista» i sl., zahvaljujući nepoznavanju funkcioniranja šume, pogrešno insistiraju na pasivnoj zaštiti, bez zahvata njege i obnove. To ugrožava kvalitetu i opstanak šuma. Ako ne želimo u budućnosti ostati bez kvalitetnih prirodnih šuma to treba hitno mijenjati. Svi mi volimo naše šume, ali pored ljubavi moramo o njima dovoljno i znati. Ljubav bez znanja je put koji šume vodi u propast.

Ključne riječi: prirodno gospodarenje, prirodna šuma, prašuma, njega, pomlađivanje

UDK: 630*228.81+535

Original scientific paper
Izvorni znanstveni članak

LONG-TERM CHANGES IN TREE SPECIES COMPOSITION IN OLD-GROWTH DINARIC BEECH-FIR FOREST

DUGOROČNE PROMJENE U SASTAVU VRSTA DRVEĆA DINARSKIH BUKOVO-JELOVIH PRAŠUMA

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Received – *Prispjelo*: 15. 10. 2007. Accepted – *Prihvaćeno*: 14. 3. 2008.

Successive inventories of individual old-growth beech–fir forests from Dinaric mountains show structural changes during the last half a century. To be aware of these trends is important for general understanding of regeneration processes in old-growth forests, as well as for stating appropriate silvicultural aims. However, no study comparatively investigated data sets from several old-growth forests. We analyzed data from 31 inventories of growing stock in seven old-growth forests representing large area stretching from the north-west of the Dinaric mountain range in Slovenia to the central part in Croatia. All forests experienced a decrease in the proportion of silver fir in the growing stock. The decrease was of a different magnitude in individual old-growth forests. However, the overall growing stock in the majority of old-growth forests didn't fluctuate as expected due to the silver fir decline. The diameter distribution of five selected forests was closer to a rotated sigmoid than to a negative exponential distribution in spite of relatively large areas which were inventoried. The curves for growing stock according to dbh revealed, that beech and silver fir occupy different niche within ecosystem. In the lower diameters beech is more frequent and competitive, while silver fir compensates for this in larger diameters (and heights).Both curves from most reserves were not stable in time. The most apparent and worrying trend in Slovenia was the decrease of the silver fir curve over the entire range of the diameter distribution, with peaks in the lowest and largest diameters. Moreover, the silver fir regeneration > 20 cm was almost completely absent due to high densities of large herbivores. While Čorkova Uvala appears to be a very balanced reserve in regard to all sampled parameters. The results revealed a general synchronous trend of silver fir replacement by beech on a broader geographical scale. The complex reasons for this are discussed and some general guidelines for the silviculture in managed beech fir forests are given.

Keywords: old-growth forest, beech-fir forest, virgin forest, diameter distribution, growing stock, species composition, alternation of tree species, long-term inventories.

INTRODUCTION
UVOD

Beech-fir forests form one of the largest areas of continuous forest in south-central Europe. In the north-western part of the Balkan Peninsula, they stretch over the Dinaric Mountain range along the Adriatic Sea coast, covering some 163.500 ha in Slovenia and 140.000 ha in Croatia. They serve as both an important wood source and a key habitat for several important and endangered animal species. During the last century the tree species composition of this forest changed dramatically, especially in Slovenia (Ficko in Boncina, 2006), where once silver fir (*Abies alba* Mill.) dominated forest is now in some areas dominated by beech (*Fagus sylvatica* L.). The mechanisms behind the alternation in dominance that occurred over the past century are not entirely clear. There are several possible reasons, including reintroduction of red deer in the late 19th century, silver fir decline, which started in the 50's (Bončina et al. 2003), different management regimes that changed the stand climate in favor of beech and natural processes of tree species replacement (Brinar 1969; Forcier 1975; Fox 1977; Gašperšič 1974; Mlinšek 1967). The silver fir decline in old-growth forests suggests that management was not the predominant factor triggering it. Although repetitive studies of structural changes of single old-growth forests from Dinaric mountains are frequent (e.g. (Hartman 1987; Turk et al. 1985; Roženbergar 2000), there is no overview of structural changes in old-growth forest from several sites. In this study long-term data about structure and tree species composition of mature stands and regeneration was analyzed from several selected old-growth forest reserves in the area of Dinaric beech–fir forests in Slovenia and Croatia. The aims of the study were to: (1) examine if virgin forest from different geographical regions of Dinaric mountain chain show similar trends of structural changes over the time, (2) propose ecological reasoning for the changes, (3) identify possible future trends of forest structures and (4) develop general recommendations for managed forests.

METHODS
METODE

Research sites
Područje istraživanja

The research was performed in 7 natural old-growth forest reserves. Forest reserves Rajhenavski Rog (RR), Pečka (PE), Strmec (ST), Krokar (KR) and Bukov vrh (BV) are located in Slovenia, while Čorkova uvala (CU) and Devčića tavani (DT) in Croatia (Figure 1). In all cases the site conditions were similar (Table 1) and forests were dominated by beech - fir (*Fagus sylvatica* L. and *Abies alba* Mill.) communities, which are typically located between 700-1200 meters in the Dinaric mountain range. Other less abundant species were also present in forest stands, including sycamore maple (*Acer pseudoplatanus* L.), wych elm (*Ulmus glabra* Huds.), spruce (*Picea abies* (L.) Karsten), common ash (*Fraxinus excelsior* L.), and large-leaved lime (*Tilia platyphyllos* Scop.).

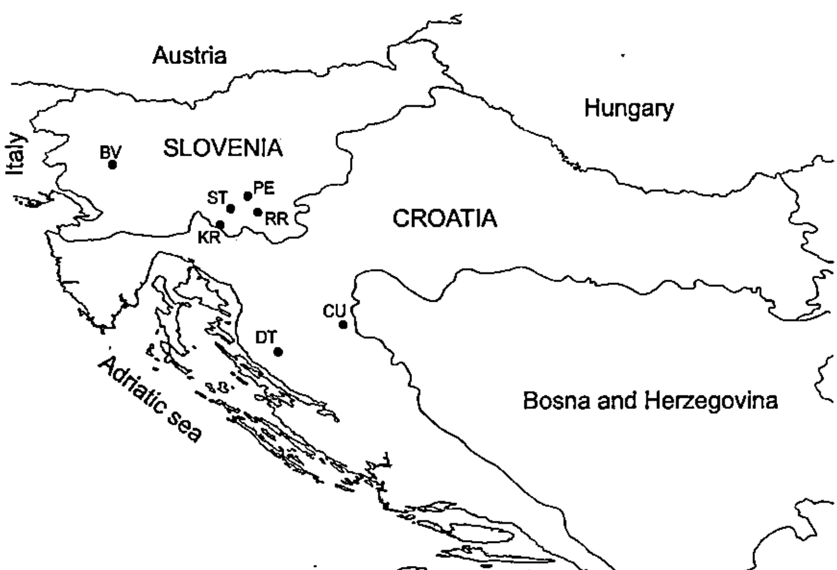

Figure 1: Locations of the old-growth beech–fir forest reserves included in the research (Rajhenavski Rog – RR, Pečka – PE, Strmec – ST, Krokar – KR, Bukov vrh – BV, Čorkova uvala – CU and Devčića tavani – DT)

Slika 1. Bukovo-jelove prašume uključene u istraživanje (Rajhenavski Rog – RR, Pečka – PE, Strmec – ST, Krokar – KR, Bukov vrh – BV, Čorkova uvala – CU i Devčića tavani – DT)

Two of the selected research sites, namely Krokar and Bukov vrh, are located on the edge of beech–fir forest distribution area. The conditions are not as favorable for silver fir growth as in other cases; therefore the proportion of silver fir on these locations is by nature lower compared to other analyzed forest reserves (Kordiš, 1985). Krokar is situated on a plateau just above the Kolpa river with more intensive exposure to warm air which is lifting up along the cliffs above the river. The large area of the reserve is also covered with dolomite parent material changing to some extend the soil conditions to more uniform which promotes beech as dominant tree species (Zeibig, 2001). Bukov vrh on the other hand is close to altitude border of silver fir distribution with colder mountain climate.

Typically Dinaric Mountains consist of dolomite and limestone parent material; therefore the soils are in all cases free draining, ranging from rendzinas to calcareous brown soils (calcocambisol) of variable depths. Macro- and microtopography of the research sites are diverse, changing the site conditions significantly over very small spatial scales. Karst phenomena such as sinkholes and rock outcrops at or close to the surface are common on all sites.

Table 1. Basic data of the research sites (RR – Rajhenavski rog, PE – Pečka, KR – Krokar, ST – Strmec, BV – Bukov vrh, DT – Devčića tavani, CU – Čorkova uvala)
Tablica 1. Osnovni podaci o istraživanim lokalitetima (RR – Rajhenavski rog, PE – Pečka, KR – Krokar, ST – Strmec, BV – Bukov vrh, DT – Devčića tavani, CU – Čorkova uvala)

Research site / *Lokalitet*	RR	PE	KR	ST	BV	DT	CU
Area / *Površina* [ha]	52.1	59.5	74.5	15.6	9.3	100	79.5
Location *Položaj*	45°40'N 15°01'E	45°46'N 15°00'E	45°33'N 14°47'E	45°38'N 14°49'E	46°00'N 13°53'E	44°88'N 15°04'E	44°55'N 15°32'E
Altitude *Nadm. vis.*	740-880	795-910	840-1170	840-940	1200-1313	1192-1295	860-1030
Annual precipitation *God. padal.* [mm]	~1650	~1220	~1526	~1556	~3000	1875	~1650
Average annual temperature *Prosj. god. temp.* [°C]	7	14.3	8.4	8.3	6.2	5	7
Meteorological statiom *Meteor. postaja*	Kočevje, Žaga Rog	Novo mesto	-	GGN Koče	Vojsko	Zavižan	Plitvička jezera
Forest site classification *Šumarska zajednica*	*Omphalodo-Fagetum*	*Omphalodo-Fagetum*	*Omphalodo-Fagetum, Lamio orvalae-Arunco-Fagetum*	*Omphalodo-Fagetum*	*Omphalodo-Fagetum*	*Omphalodo-Fagetum*	*Omphalodo-Fagetum*
Country / *Država*	SLO	SLO	SLO	SLO	SLO	CRO	CRO

Field methods and data analyses
Prikupljanje i analiza podataka

Three basic approaches were used in this study. First was the analysis of changes in the total volume and beech and silver fir proportion over the research period, which was completed for 7 locations (Table 1). The second was the examination of the long term data on number of trees and living volume according to the diameter at breast height (dbh) performed for 5 research sites and the third was the analysis of regeneration in two selected old-growth forest reserves.

First information about the tree species composition in Rajhenavski rog and Pečka dates back to 1883 and 1893 respectively, when the first management plans for the area were done (Hufnagel, 1893). All the rest of the long term data were gathered as a part of management activities after year 1950 with 10 years period between the measurements until today. In most of the cases dbh was measured and tree species defined for all trees in the reserve (full callipering). In the case of Čorkova uvala measurements were made on a systematic grid over the whole area of the reserve two times. Also the data gathered on 1 ha plots in most representative part of the reserve in CU and DT are included in this analysis, but just to observe the changes in tree species composition. In all cases only trees above 10 cm in diameter were included in the analysis. 5 cm diameter classes (up to 100 cm diameter) were used to show the distribution of number of trees and volume per hectare according to dbh. In cases where previous measurements were performed only up to certain dbh, all trees above that dbh were put together in the last diameter class in all following data sets.

Between 2001 and 2004, under different light conditions in gaps, under stands surrounding the gaps, and under the closed canopy a N-S oriented 5x5 m grid was established and 773 - 1,5 x 1,5 m plots were established on the grid intersections. On each plot all seedlings of each tree species were counted and categorized within several height classes: 1 year-old seedlings, <20 cm height, 21 - 50 cm, 51 - 90 cm, 91 - 130 cm, 131 - 200 cm, 201 - 300 cm and >300 cm.

RESULTS
REZULTATI

Long-term changes in tree species composition and growing stock
Dugoročne promjene smjese vrsta drveća i drvne zalihe

Seven old-growth forest under investigation cover substantial range from the very start of the Dinaric mountain range in Trnovski gozd Slovenia, represented by Bukov vrh, to the core area in Croatia, represented by Čorkova Uvala and Devčića tavani. In the 50' the share of silver fir in growing stock of all live trees amounted on average between 50-65% (Figure 2). Values below 30% were measured in Krokar and Bukov vrh. First is only partly covered by beech–fir ecosystem, while Bukov vrh represents a transition towards high mountan beech forests. However, from 1950 on, all old-growth forests demonstrate a decrease of silver fir share in the growing stock of all live trees. This reduction is less pronounced in Croatia compared to Slovenia. Still, also within countries significant differences in decrease exist. The steepest decrease took place in Pečka in Slovenia, where silver fir share declined from 58 % in 1893 to 17 % in 2003, which represents a 41 % decrease in about 100 years. It appears that old-growth forest at the edge of Dinaric mountain chain (for example Pecka with 20 % decrease over the last 20 years) or at the edge of the beech-fir ecosystems within the Dinaric mountains (Krokar with 17 % decrease in the last 40 years) demonstrate a more noticeable decrease. The decrease of the silver fir was not constant over the time. Two old-growth forests show a more pronounced decrease in the last interval between the measurements, namely Pečka and Devčića tavani, while the change is not so evident in case of Bukov vrh and Rajhenavski Rog. The majority of others show a decrease of ca. 5 %. Observing longer periods of time we can see different patterns, as for example a relatively constant and lately accelerated decrease in Pecka and an increase until 50' followed by a gradual decrease in Rajhenavski Rog.

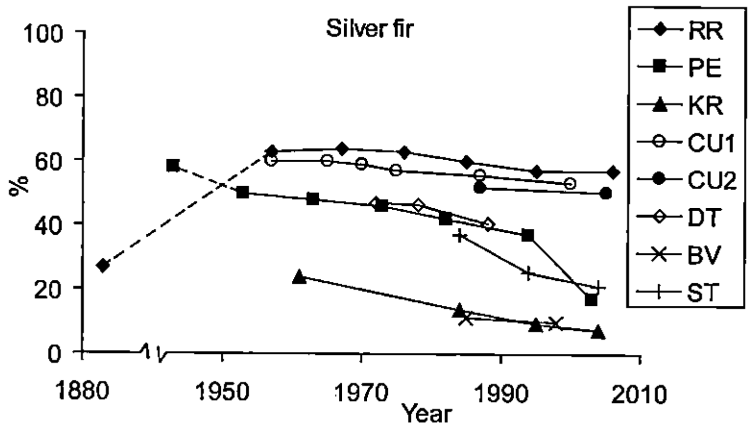

Figure 2: Long-term changes in proportion of silver fir in living volume in seven beech-fir old-growth forests in Dinaric mountains

Slika 2. Dugoročne promjene volumnog udjela obične jele u sedam dinarskih bukovo-jelovih prašuma

The most important species competing with silver fir is beech, all the remaining species from Norway spruce to sycamore maple represent a minor share of maximum 5 % in some reserves. The trends of beech proportion in the growing stock of all live trees were reciprocal to those demonstrated by silver fir (Figure 3), as expected. The beech share in all old-growth forests exceeds 40 %. The most silver fir dominant forests remain Corkova Uvala and Rajhenavski Rog.

The growing stock of old-growth forest was in an interval form slightly above 500 m³/ha on more extreme sites as Bukov vrh, to 942 m³/ha in Pecka in 50' (Figure 4). The average value of most representative beech-fir old-growth forests was about 800 m³/ha (RR, PE, CU), the rest of old-growth forest with lower growing-stock include also additional less productive sites in inventoried protected compartments. Most of the variation intervals of growing stock in the observed time are close to 100 m³/ha, which seems reasonable in regard to relative large areas under investigation (from 10 to 100 ha). The maximal decrease of growing stock was observed in Pecka. Here it declined form 942 m³/ha in 1953 to 698 m³/ha in 2003. The highest increase of almost 150 m³/ha over 45 years was recorded in Krokar. In some old-growth forests (e.g. RR) the growing stock remained relatively constant over almost 60 years. In the period between last two measurements there is an noticeable trend of growing stock decrease in all forest reserves with the exception of CU2.

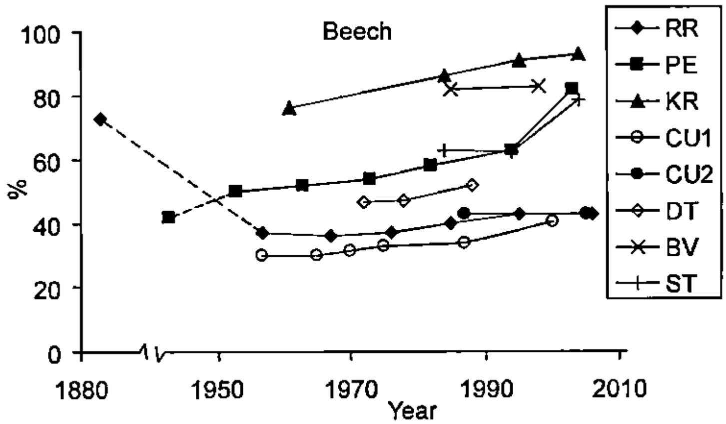

Figure 3: Long-term changes in share of beech in living volume in seven beech–fir old-growth forests in Dinaric mountains

Slika 3. *Dugoročne promjene volumnog udjela obične bukve u sedam dinarskih bukovo-jelovih prašuma*

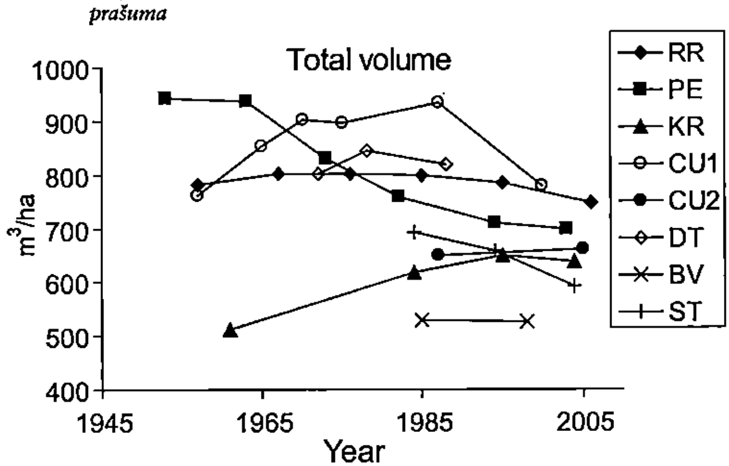

Figure 4: Long-term changes in amount of growing stock of live trees in seven beech–fir old-growth forests in Dinaric mountains

Slika 4. *Dugoročne promjene prosječne drvne zalihe živih stabala u sedam dinarskih bukovo-jelovih prašuma*

Changes in tree species frequency and growing stock distributions according to dbh

Promjene distribucija vrsta drveća i drvne zalihe s obzirom na prsni promjer

From seven old-growth forests, five with complete data sets for the last two inventories in 1980' and 2000', respectively were selected for a detailed analysis of diameter and growing stock distributions. The diameter distributions including all tress showed more tendency towards the rotated sigmoid than the negative exponential distribution (Figure 5). The closest to the reverse J-shaped curve was the distribution from Corkova Uvala and Strmec, if we neglect the larger diameter sizes above 19 dbh. The curve from Čorkova uvala was also the most stable in time, while the curves form Slovenian old-growth forest showed changes in the shape of the curve. However, this was different from forest to forest. For example, in Pecka, Strmec and Krokar we noticed a decrease in small diameters and an increase in large ones, while in Rajhenavski rog there was a decrease in the middle diameters. The closer look into the diameter distribution of each species reveals the nature of changes for the curve of total stems in reserve. There are differences between countries and among individual reserves. The curves for both species seem to be relatively stable for both species in Čorkova uvala, while in Slovenia the curves for species show significant differences in time. The most apparent and worrying trend is the decrease of the silver fir curve along whole range of the diameter distribution. Still, this is most pronounced in the lowest and larges diameters. On the other hand the beech shows a decrease of curves among the youngest diameters and increase among the largest. This trend points to the severe mortality among the young beech generation which competed for space in the gaps created after the most severe decline of silver fir, which was followed by two successive windthrows. The gaps were partially closed by the growth of the advanced regeneration and partially by lateral extensions of the crowns of surrounding trees. The exception is Rajhenavski rog where the decrease of silver fir and increase of beech in the low diameter classes seem to be slow and thus synchronous. In all reserves the inverse sigmoid curve was more expressed with beech than with silver fir.

In the last two decades the growing stock curve for all live trees has shifted towards right hand side of the figure in all Slovenian old-growth forests, whilst it stayed relatively stable in Čorkova uvala (Figure 6). This is probably due to more pronounced silver fir decline in Slovenia, which triggered lush ingrowth of beech. This phenomenon is more pronounced if we analyze growing stock distributions per dbh for beech and silver fir separately. The beech curve had the strongest shift towards right in Pečka, followed by Krokar and Strmec. This curve seems relatively stable in Rajhenavski rog and Čorkova uvala. However, the silver fir curve showed the strongest decrease in Pečka, followed by Strmec and Krokar. In Rajhenavski rog and Čorkova uvala it stayed stable with a slight move to the right hand side. To allow comparability the diameters above dbh class 20 were merged into 20th dbh class for Pečka, Rajhenavski rog and Čorkova uvala. For Krokar and Strmec all higher diameters were merged into 16th dbh class. Still, from the graphs we could see the general rule that beech and silver fir supplement each other within the curves. In the lower diameters beech is more frequent and competitive, while silver fir compensates for this in larger diameters (and heights). The beech curve usually finishes with 19th dbh class, while silver fir often attains diameters up to 24th dbh class, with individual trees up to 32th class.

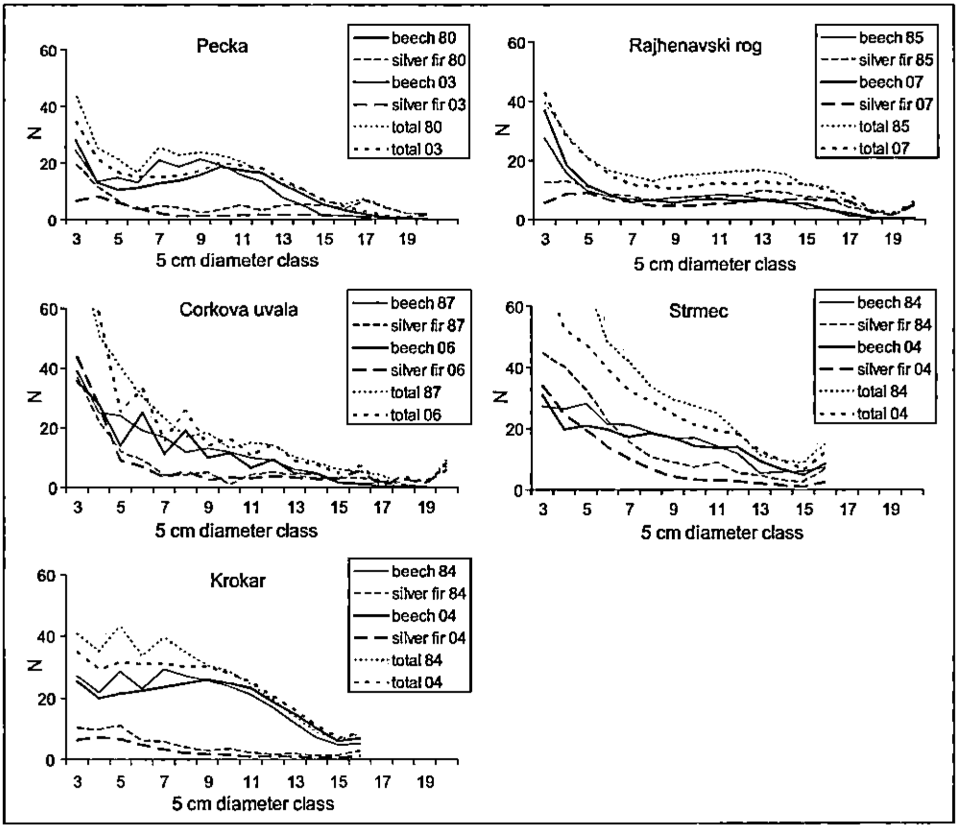

Figure 5: Comparison of diameter distributions of five beech–fir old-growth forests according to tree species between the last two inventories

Slika 5. Usporedba distribucija prsnih promjera za posljednje dvije inventure na primjeru pet bukovo-jelovih prašuma

Regeneration tree species composition and height distribution
Struktura pomlatka po vrstama drveća i visinama

The density of regeneration in total was almost five times higher (62.066 per ha) in Rajhenav compared to the Čorkova uvala (13.083 per ha) forest reserve (t = 19,4586, p = 0,0000), which is mostly due to an almost ten-fold increase (54.699 versus 5588 per ha) in the density of beech at Rajhenav (Figure 1 right). However, the total density of silver fir was more than twice as high (6312 versus 3187 per ha) in Čorkova uvala (t = -5,7711, p = 0,0000). In spite of the fact that there was much less silver fir in the upper storey, the density of one year old and up to 20 cm tall silver fir seedlings in Rajhenav was higher than in Čorkova uvala. However, the density of silver fir seedlings taller than 20 cm was higher in Čorkova uvala, as there were no seedlings taller than 50 cm in the Rajhenav old-growth forest reserve (Figure 1 left). Lower densities of beech seedlings in Čorkova uvala could be explained by lower radiation levels

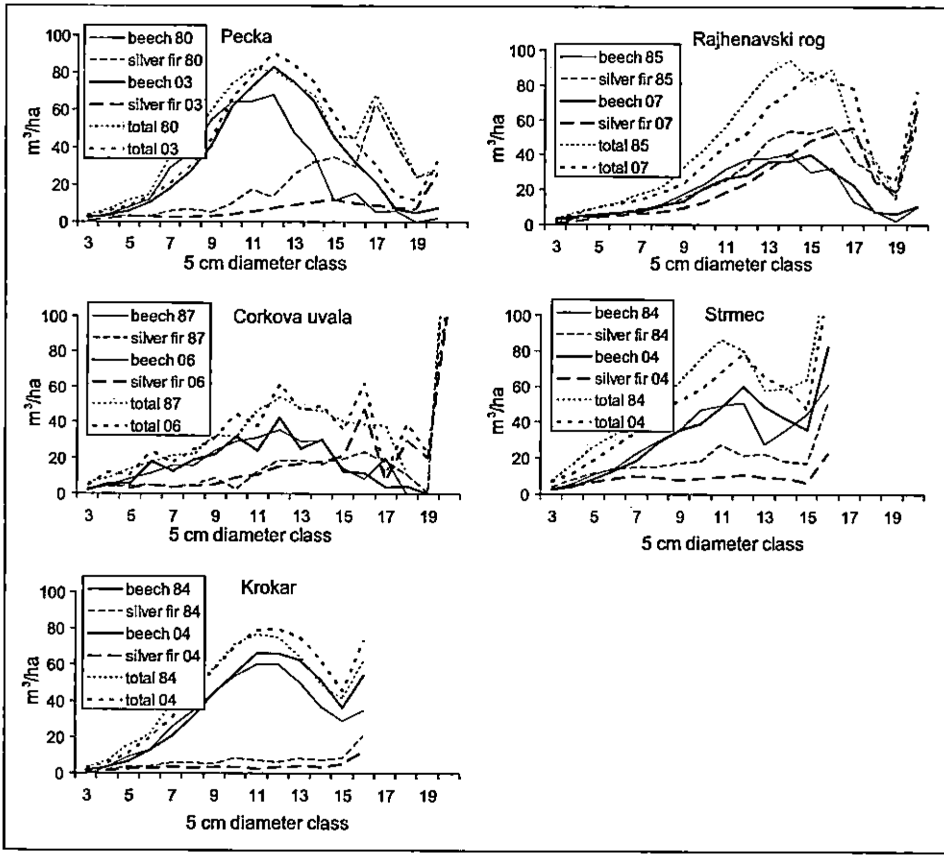

Figure 6: Comparison of distributions of growing stock in relation to DBH of five beech–fir old-growth forests between the last two inventories

Slika 6. Usporedba distribucija drvne zalihe za posljednje dvije inventure na primjeru pet bukovo-jelovih prašuma

and smaller gaps compared to Rajhenav, and also by much more intensive competition from the herb layer in Čorkova uvala. The main reason for the dramatically low density of fir seedlings above 20 cm tall in Rajhenav is the heavy browsing pressure, due to a high population density of red and roe deer in the Dinaric mountains in Slovenia. This also explains the much denser coverage of ground vegetation in Čorkova uvala, especially *Rubus* species, which is highly desired by deer.

DISCUSSION
RASPRAVA

Seven examined beech–fir old-growth forests covering broader geographical scale from north-west to central Dinaric Mountains showed a significant decrease

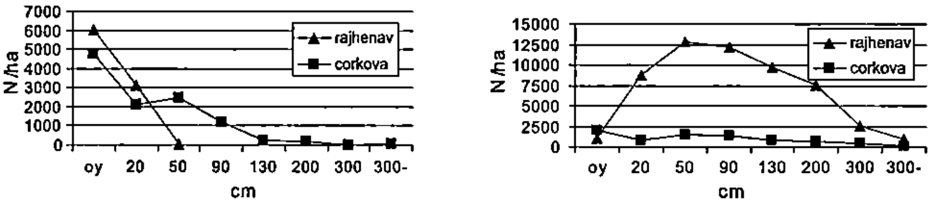

Figure 7: Density (n ha^{-1}) of fir (left) and beech (right) one year old (oy) and older seedlings in different height classes (cm) in Rajhenav and Čorkova uvala

Slika 7. Gustoća (n ha^{-1}) jelovog (lijevo) i bukovog (desno) ponika i pomlatka po visinskim klasama (cm) u prašumama Rajhenav i Čorkova uvala

of silver fir share in growing stock in the last half of the century. Similar trends were reported for managed forests many times during the period of acute silver fir decline form 1950' to mid 80' (Šafar 1964; Kandler 1992; Korpel 1985; Larsen 1986; Leibundgut 1974; Mlinšek 1964). The decrease of silver fir in growing stock was of a different magnitude among individual virgin forests, still it appears to slow down in recent decades. This is conform with the findings from managed forests were first observations of improved health status of silver fir were reported in the last decades (Dobrowolska 1998). The exceptions were Devčića tavani and Pečka, the last being hit by two successive windstorms (Nagel and Diaci 2006; Nagel et al. 2006).

In all studied forests silver fir was replaced by the beech. This is a common trend often reported for individual reserves and managed forests (Bončina et al. 2003; Diaci 1994). In spite of significant tree species replacement the overall growing stock in the majority of old-growth forests didn't fluctuate as expected. Exception was the old-growth Pecka, due to above mentioned reasons.

The causes for silver fir decline are complex, however they are of natural, anthropogenic and mixed origin. The anthropogenic reasons include the pollution of ecosystems on a local and global scale, climate change, high densities of the ungulates and non adapted silvicultural systems to the silver fir ecology. The last, appears not to be one of the primary causes due to the silver fir decline in old-growth forests. However, forestry might have an effect, through building of fine forest road network and thus changing the local forest climate, removal of CWD on which silver fir often regenerates and changing from single tree selection to irregular shelterwood system in Slovenia.

The most important natural cause of silver fir decline is the tree species alternation in persistent (climax) communities. The word alternation of species was proposed by a French forester in 1905 (Schaeffer and Moreau 1958) and then often observed or researched in temperate forests (Forcier 1975; Fox 1977; Watt 1947), including Croatia and Slovenia (Šafar 1967; Gašperšič 1974). Initially, the alternation was understood mostly on the local scale, from one or to at most few large canopy trees. Here, most processes affecting density and species composition operate, except dispersal (Fox 1977). (Watt 1947) was the first wrote about this issue; the alternation was reflected in the spatial mosaic of the community. Later (Fox 1977) found that sapling abundance was lower beneath the canopies of the same species.

Similar results were reported also for Dinaric beech–fir forests (Gašperšič 1974). There are several mechanisms behind the alternation (Fox 1977):

1. The substrate and micro-relief variability could be important on the diverse carstic conditions of Dinaric Alps. Short (climate, seed bed) and long-term (nutrients, chemical properties) influences of CWD could be added to this group, although they operate also tree species specific.
2. Demographic causes of alternation - each species inhibits the survival and growth of its own species most severely (autoinhibition):
   – parent tree is a source of predators and pathogens: herbivorous insects, other predators, toxins
   – conspecific trees my be thinned more severely: similar niche and need for resources, e.g. soil, light with temporal variability, variability in quality
   – other reasons: lover abundance of long living species - they take long to pass a certain dangerous height range
   – tolerance relations: adaptation to specific disturbance regime (small and large gaps); expected crown diameter at death is favoring another species; different crown size between conifers and broadleaves (silver fir - beech)
   – better growth of evergreens underneath of broadleaves
   – plants create individual microhabitats (light, precipitation).

However, also regional and global factors might have an important effect on the species alternation as shown in this study. For example different densities of ungulates, which hindered the regeneration of silver fir in Slovenia completely in last 30 years, and various silvicultural regimes operate on a regional scale. Moreover, the global climate change, with higher temperatures, more severe disturbance regime is less favorable for silver fir compared to beech. Similar replacements of both species have been found after the last ice ages (Andric and Willis 2003; Šercelj 1996). Finally, it appears very difficult to draw a line between different scales of operation of species alternation and natural versus anthropogenic factors.

The examined old-growth forest covered mainly large areas, however the diameter distribution of individual old-growth forest did not follow the negative exponential distribution as reported from many studies in old-growth forests (Lorimer 1980) (Leak 1996). The reverse negative exponential distribution suggest similar growth and mortality rates across the diameter range. The observed curves were closer to a rotated sigmoid distribution. This observation is not a new one (Goff and West 1975; Hartman 1987; Leibundgut 1982; Westphal et al. 2006). The deviation from the negative exponential curve might be due to higher mortality in lower and higher diameter classes and/or faster diameter growth in the mean classes. It is interesting that the rotated sigmoid distribution was found to provide the best fit also for managed equilibrium state plenter beech–fir forest in Switzerland (Schütz 2001).

The curves for growing stock per dbh revealed that beech and silver fir occupy different niche within ecosystem. In the lower diameters beech is more frequent and competitive, while silver fir compensates for this in larger diameters (and heights). This was already reported for two beech–fir old-growth forests in Slovenia (Hartman 1987; Turk et al. 1985). A general observation from most reserves was, that the diameter and volume curves were not stable in time.

A comparison of Slovenian old-growth forests with Čorkova Uvala in Croatia revealed a strong decrease of the silver fir curve in Slovenia along all the diameter distribution, with peaks in the lowest and largest diameters. If we add to this also the almost absent regeneration of silver fir in Slovenia, than it is obvious that silver fir is significantly more endangered in Slovenia than Croatia.

The worrying trends of silver fir decline in Slovenian old-growth forests require a continuation of special management procedures for controlling the roe and red deer density. The different niche occupation of silver fir and beech within the same ecosystem call for a individual silvicultural treatment of each species, e.g. different rotation periods, target diameters, modes of regeneration. Shaded silver fir regeneration and mature trees of high volume and age allow silver fir to develop the full competition potential. Still, the silver fir decline is partially also a natural phenomenon linked to species replacement, therefore more unpredictability and flexibility should be integrated in the silvicultural systems.

REFERENCES
LITERATURA

Andric, M., K. J. Willis, 2003: The phytogeographical regions of Slovenia: a consequence of natural environmental variation or prehistoric human activity? Journal of Ecology. 91: 807-821.

Bončina, A., F. Gašperšic, J. Diaci, 2003: Long-term changes in tree species composition in the Dinaric mountain forests of Slovenia. Forestry Chronicle. 79: 227-232.

Brinar, M., 1969: Vpliv svetlobe na razvoj bukovega mladja. Zbornik - Research reports. 7: 61-144.

Diaci, J., 1994: Spreminjanje naravne gozdne vegetacije ob višinskem gradientu Veže - Dleskovške planote v Savinjskih Alpah. Zb. gozdarstva in lesarstva: 45-84.

Dobrowolska, D., 1998. Structure of silver fir (*Abies alba* Mill.) natural regeneration in the 'Jata' reserve in Poland. Forest Ecology and Management. 110: 237-247.

Ficko, A., A. Boncina, 2006: Silver fir (*Abies alba* mill.) distribution in Slovenian forests. Research Reports - Forestry and Wood Science and Technology, 79: 19-35.

Forcier, L. K., 1975: Reproductive Strategies and Co-Occurrence of Climax Tree Species. Science. 189: 808-810.

Fox, J. F., 1977: Alternation and coexistence of tree species. The American Naturalist. 111: 69-89.

Gašperšič, F., 1974: Zakonitosti naravnega pomlajevanja jelovo-bukovih gozdov na visokem krasu Snežniško-Javorniškega masiva. *In* Strokovna in znanstvena dela. Biotehniška fakulteta, Ljubljana. p. 133.

Goff, F. G., D. West, 1975: Canopy-understorey interaction effects on forest population structure. For. Sci. 21: 98–108.

Hartman, T., 1987: Gozdni rezervati Slovenije - Pragozd Rajhenavski Rog. Univerza Edvarda Kardelja v Ljubljani, Biotehniška fakulteta, Ljubljana, p. 99.

Hufnagel, L., 1893: Wirtschaftsplan der Betriebsklasse III. Hornwald. Kočevje

Kandler, O., 1992: No relationship between fir decline and air pollution in the Bavarian Forest. For. Sci. 38: 866-869.

Kordiš, F., 1985: Gozdni rezervati Slovenije - Pragozd Bukov vrh, Univerza Edvarda Kardelja v Ljubljani, Biotehniška fakulteta, Ljubljana, 77 pp.

Korpel, S., 1985: Stav a vyvoj jedle na Slovensku vo vztahu k jej odumieraniu. Acta Fac. For. 27: 79-102.

Larsen, B. J., 1986: Das Tannensterben: Eine neue Hypothese zur Klärung des Hintergrundes dieser Rätselhaften Komplexkrankheit der Weisstanne (*Abies alba* Mill.). Forstw. Cbl. 105: 381-396.

Leak, W. A., 1996: Long-term structural change in uneven-aged northern hardwoods. For. Sci. 42: 160–165.

Leibundgut, H., 1974: Zum Problem des Tannensterbens. Schweizerische Zeitschrift für Forstwesen. 125: 476 - 484.

Leibundgut, H., 1982: Europäische Urwälder der Bergstufe. Haupt, Bern. p. 308.

Lorimer, C. G., 1980: Age Structure and Disturbance History of a Southern Appalachian Virgin Forest. Ecology. 61: 1169-1184.

Mlinšek, D., 1964: Sušenje jelke v Sloveniji - prvi izsledki. Gozdarski vestnik. 22: 145-159.

Mlinšek, D., 1967: Pomlajevanje in nekatere razvojne značilnosti bukovega in jelovega mladja v pragozdu na Rogu=Verjüngung und Entwicklung der Dickungen im Tannen-Buchen Urwald "Rog" (Slowenien). Zbornik BF. 15: 7-32.

Nagel, T. A., J. Diaci, 2006: Intermediate wind disturbance in an old-growth beech-fir forest in southeastern Slovenia. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere. 36: 629-638.

Nagel, T. A., M. Svoboda, J. Diaci, 2006: Regeneration patterns after intermediate wind disturbance in an old-growth Fagus-Abies forest in southeastern Slovenia. Forest Ecology and Management. 226: 268-278.

Roženbergar, D., 2000: Razvojne značilnosti sestojev v pragozdnih ostankih Pečka in Rajhenavski Rog = Stand dynamics of the virgin forest remnants of Pečka and Rajhenavski Rog. *Gozdarski vestnik* 58: 53-55.

Schaeffer, R., R. Moreau, 1958: L'alternance des essences. *In* Soc. Forest. France-Compté Bull. 1-12, 76-84, pp. 277-298.

Schütz, J. P., 2001: Der Plenterwald und weitere Formen strukturierter und gemischter Wälder. Parey, Berlin, p. 207.

Šafar, J., 1964: Problem sušenja jele i načina gospodarenja na Macelj Gori. Šumarski list: 1-16.

Šafar, J., 1967: Izmjena bukve i jele na panonskim gorama. Šumarski list: 291-298.

Šercelj, A., 1996: The origins and development of forests in Slovenia. *In* Opera. Academia scientiarum et artium Slovenica, Classis IV: Historia naturalis, Ljubljana.

Turk, V., A. Kastelic, T. Hartman, 1985: Gozdni rezervati Slovenije - Pragozd Pečka. Univerza Edvarda Kardelja v Ljubljani, Biotehniška fakulteta, Ljubljana, p. 75.

Watt, A. S., 1947: Pattern and process in the plant community.

Westphal, C., N. Tremer, G. V. Oheimb, J. Hansen, K. V. Gadow, W. Hardtle, 2006: Is the reverse J-shaped diameter distribution universally applicable in European virgin beech forests? Forest Ecology and Management. 223: 75-83.

Zeibig, A., 2001: Lückenstörungmuster eines montanen illyrischen Buchenurwaldes der Assoziation Isopyro-Fagetum im Reservat Krokar der Borovška Gora im südwestlichen Slowenien - Diplomarbeit. Dresden, Fakultät Forst-, Geo- und Hydrowissenschaften der Technischen Universität Dresden, str. 92.

DUGOROČNE PROMJENE U SASTAVU VRSTA DRVEĆA DINARSKIH BUKOVO-JELOVIH PRAŠUMA

SAŽETAK

Uzastopne inventure dinarskih bukovo-jelovih šuma tijekom prošlog stoljeća su pokazale promjene u njihovoj strukturi. Te su spoznaje važne za razumijevanje procesa pomlađivanja u prašumama i gospodarenje šumama. Ipak, nijedna studija nije uspoređivala nizove podataka iz nekoliko prašuma. Analizirali smo podatke o drvnoj zalihi iz 31 inventure u sedam prašuma koje se prostiru od sjeverozapadnih Dinarida u Sloveniji do njihova središnjeg dijela u Hrvatskoj. U svim je šumama ustanovljeno smanjenje udjela obične jele u drvnoj zalihi. Smanjenje udjela jele je različito među pojedinim prašumama. Ukupna drvna zaliha u većini prašuma ne pokazuje očekivane promjene s obzirom na odumiranje jele. Distribucija prsnih promjera u pet odabranih prašuma bliža je obrnuto sigmoidalnoj nego negativno eksponencijalnoj funkciji, unatoč relativno velikom području uzorkovanja. Distribucije volumena po debljinskim stupnjevima pokazuju kako bukva i jela zauzimaju različite niše unutar ekosustava. Bukva je više zastupljenija u nižim debljinskim stupnjevima, dok jela kompenzira taj prostor u višim debljinskim stupnjevima i visinama. Obje krivulje za sve istraživane rezervate pokazuju nestabilnost u vremenu. Najjasniji i zabrinjavajući trend u Sloveniji je opadanje udjela jele unutar čitavog opsega distribucije prsnih promjera, s najvišom točkom u nižim i višim stupnjevima. Osim toga, pomlatka jele iznad 20 cm visine nema zbog visoke gustoće populacije divljači. Čorkova uvala u odnosu na sve ostale istraživane prašume čini se najuravnoteženijom s obzirom na analizirane parametre. Rezultati pokazuju generalni istovremeni trend zamjene jele običnom bukvom na većoj geografskoj razdiobi. U radu su prikazani mogući razlozi tih promjena te su date preporuke za uzgajanje bukovo-jelovih šuma.

Ključne riječi: prašuma, bukovo-jelove šuma, distribucija prsnih promjera, drvna zaliha, sastojinski oblik, izmjena vrsta drveća, dugoročne izmjere.

UDK: 630*228.81+230.2

Original scientific paper
Izvorni znanstveni članak

REGENERATION IN CANOPY GAPS OF THE DINARIC BEECH-FIR VIRGIN FORESTS

ZNAČAJKE POMLAĐIVANJA U PROGALAMA DINARSKIH BUKOVO-JELOVIH PRAŠUMA

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Received – *Prispjelo*: 15. 10. 2007. Accepted – *Prihvaćeno*: 22. 2. 2008.

The research was carried out in two typical Dinaric beech-fir (*Omphalodo-Fagetum* Marinček et al. 1992) virgin forests: Čorkova Uvala (Croatia) and Rajhenavski Rog (Slovenia). Growing under similar habitat conditions, both virgin forests stretch across a range of between 740 m and 1030 m above the sea level, upon a typical karst relief, the geological parent rock of chalk, at an average yearly air temperature of 6°C – 8°C, and with a yearly precipitation ranging between 1600 mm and 2000 mm. Twelve canopy gaps were taken as samples in both forests. Upon the rectangular 5m x 5m square nets laid in each gap quantitative and qualitative properties of the seedlings and the relative vegetation cover of the ground vegetation species were measured. For light analysis, hemispheric photography was taken of each plot.. In Rajhenavski Rog we established extremely poor regeneration of the silver fir, while the common beech regenerated considerably better when compared to the virgin forest of Čorkova Uvala. There were considerable differences between the two virgin forests in terms of the areas of canopy gaps and the levels of diffuse and direct radiation. The very poor regeneration of the fir in Rajhenavski Rog is the consequence of excessive number of game, as compared to the Čorkova Uvala virgin forest. The much better regeneration of the beech in Rajhenavski Rog is caused by the higher level of light upon the larger areas of the canopy gaps, which is the result of the fir dieback.

Key words: canopy gap, natural regeneration, diffuse and direct light, Dinaric virgin forests, *Fagus sylvatica* L., *Abies alba* Mill.

INTRODUCTION
UVOD

The stability of forest ecosystems depends on the interaction of abiotic and biotic factors, that either directly or indirectly affect the morphology and dynamics of stands (Kimmins, 2004; Franklin, 2002; Frelich, 2003). The abiotic and biotic factors in forest ecosystems cause various disturbances. Thus, the wind, fungi, and insects through interaction cause the fall of a dead standing tree, initiating the formation of canopy gaps. These openings are considered as basic initiators of virgin forest dynamics in the European moderate zone (Diaci et al., 2003; Korpel 1989; Nagel et al., 2006). The newly formed openings are the places where the natural regeneration of a forest stand begins (Watt, 1923). It is there where the dynamic process of forest stand regeneration takes place (Watt, 1923). The size of the canopy gap changes the ecological conditions that define the occurrence of the species and the density of the seedlings. The new growth within the canopy gaps depends on a number of factors such as the interracial and introracial competition, mortality, game, pests and diseases. They are responsible for the development and survival of the seedlings (Kimmins, 2004).

The research was carried out in the canopy openings of the Dinaric beech-fir virgin forests (*Omphalodo-Fagetum* Marinček et al. 1992.). Beech-fir forests are the most significant forest ecosystems of the Dinaric mountain massif in southeastern Europe. These forests have a preserved stand structure and they regenerate naturally. The permanent natural regeneration secures their stability and sustainability. In the last several decades, the Dinaric beech-fir forest ecosystems have been under the impact of a number of unfavourable factors that have affected their stability and sustainability. Some of these factors are climatic changes, soil acidification, re-introduction of herbivores, harmful insects, economic errors, etc. Consequently, significant changes in the beech-fir mixture ratio and continuous absence of fir regeneration have taken place (Diaci et al., 2007; Boncina et al., 2003; Roženbergar, 2000, Matić et al., 1996). The beech-fir virgin forest ecosystems can also be directly affected by harmful factors. However, these can serve as a direct example of natural forest stand dynamics under such conditions. The aim of this research is to compare the properties of the seedlings in the canopy gaps of the beech-fir virgin forests, in relation to the light and habitat conditions.

MATERIAL AND METHODS
MATERIJAL I METODE RADA

The research was carried out in the virgin forests of Čorkova Uvala (Croatia) and Rajhenavski Rog (Slovenia). Growing under similar habitat conditions (Table 1), both stands are considered as typical examples of the Dinaric beech-fir virgin forests (*Omphalodo-Fagetum* Marinček et al. 1992.).

Table 1. Characteristics of the studied sites and stands
Tablica 1. Značajke istraživanih staništa i sastojina

	Čorkova uvala	Rajhenavski rog
Location / *Lokacija*	44°55'N/15°32'E	45°66'N/15°01'E
Area (ha) / *Površina (ha)*	80,5	52,1
Level above sea (m) / *Nadmorska visina (m)*	860 - 1030	740 - 880
Average yearly temperature (°C) *Prosječna godišnja temperatura (°C)*	7	6 - 8
Average yearly precipitation (mm) *Prosječna godišnja količina oborina (mm)*	1600 - 1700	1500 - 1900
Wood stock (m^3/ha) / *Drvna zaliha (m^3/ha)*	671	758
Soil / *Tlo*	Brown soil on limestone / *Smeđe tlo na vapnencu*	
Parent rock / *Geološka podloga*	Limestones with dolomite inserts *Vapnenci s uloščima dolomita*	

Twelve canopy gaps were chosen for the research. Five of them were in the virgin forest of Čorkova Uvala, while seven gaps were in the virgin forest of Rejhenavski Rog. The margins of the gaps formed by the canopy rims of the surrounding trees were measured with GPS devices. These gaps appeared some ten years ago. They are covered by 3 m-high-seedlings. Regular 5m x 5m square networks are laid over the gaps in the direction north – south. Over the network intersections there are 1.5m x 1.5m test plots. On an area of 2.25 m^2 of each plot a relative coverage (($\pm$1 %)) of seedlings, ground vegetation, leaf litter, rock, dead wood, naked soil and moss has been estimated. The density of the saplings and seedlings of the woody species according to the following height classes was measured: sapling/seedlings up to 50cm, and over 51 cm. Besides the number of the seedlings, the damage caused by the game was estimated (1 – damaged; 0 – undamaged). Upon each plot, at a height of 1.30 m above the ground, hemispheric photography was taken using Nikon 995 digital camera and calibrated hemispheric lenses for the purpose of calculating the relative amount of average yearly quantity of direct (FDIR%) and diffuse (FDIF%) radiation. The hemispheric photography was carried out by the WinSCANOPY 2003b programme (Règent Instruments inc.). Four separate microhabitat groups were defined on the basis of the relation between the diffuse (FDIF%) and direct (FDIR%) radiations. Within each microhabitat group of both virgin forests, the differences in regeneration and habitat properties were determined by means of the Kruskal-Wallis ANOVA test. The differences in light and regeneration density were analysed with the Mann-Whitney U test (λ=0.05). The ground vegetation analysis was carried out by comparing the Ellenberg eco-indicator indexes (Ellenberg, 1992).

RESULTS
REZULTATI

Gap morphology and light
Morfologija progala i svjetlo

The average area of canopy gaps in the Rajhenavski Rog virgin forest was 640.15±166 m^2, while the one in Čorkova Uvala was 486.50±91 m^2 (Z=-2.2162; P=0.026678).

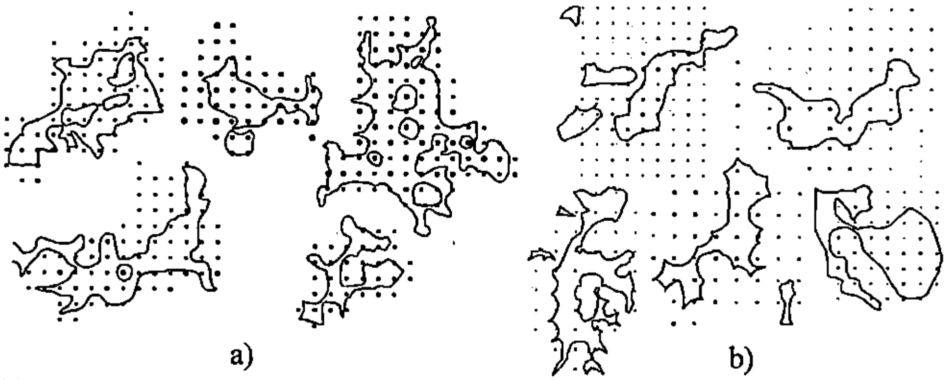

Figure 1: Ground plan of sampled gaps with a network od experimental plots: a) Rajhevanski Rog, b) Čorkova uvala

Slika 1. Tlocrt uzorkovanih progala s mrežom pokusnih ploha: a) Rajhenavski rog, b) Čorkova uvala

The average value of the diffuse radiation (FDIF%) measured in the Rejhenavski Rog gaps was 10.88%, compared to the respective Čorkova Uvala value of 7.23% (U=47972.50,00; P<0.0000). The average direct radiation (FDIR%) in Rajhenavski Rog was 8.13%, while the one in Čorkova Uvala was 4.88% (U 55263.50; P< 0.0000).

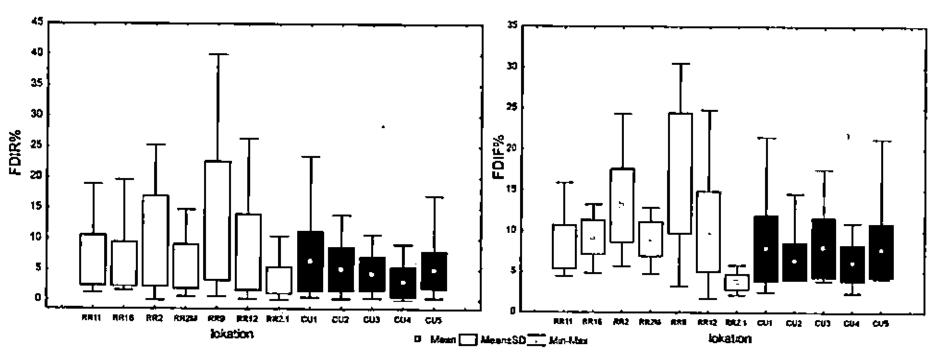

Figure 2: Average relative values of dffuse (FDIF%) and direct (FDIR%) solar radiation in the gaps of virgin forests of Rajhenavski Rog (RR) and Čorkova Uvala (CU)

Slika 2. Prosječne relativne vrijednosti difuznog (FDIF%) i direktnog (FDIR%) sunčevog zračenja u progalama prašuma Rajhenavski rog (RR) i Čorkova uvala (CU)

Regeneration
Pomlađivanje

Significant differences in the young growth density according to the defined height classes (Table 2) were established of all variables except for the total saplings and the saplings of the beech and fir. The average sapling density was 1.98 pcs/m² in Čorkova Uvala and 1.90 pcs/m² in Rajhenavski Rog (U=1438.5; P=0.083105).

Table 2. Average density values of seedlings and saplings by tree species in Rajhenavski Rog and Čorkova Uvala; the results of Mann-Whitney U-test for the selected variables

Tablica 2. Prosječne vrijednosti gustoće ponika i pomlatka prema vrstama drveća u Rajhenavskom rogu i Čorkovoj uvali; rezultati Mann-Whitney U-testa za odabrane varijable

Variables - *Varijable*	Rajhenavski rog	Čorkova uvala	U	p
	pcs/m² - *kom/m²*			
Total seedling / *Ukupni ponik*	1.90	1.98	1438.50	0.08311
Fagus seedling / *Bukov ponik*	0.72	1.10	10879.00	0.11993
Abies seedling / *Jelov ponik*	1.08	1.35	568.00	0.81051
Sapling, h<50 cm / *Pomladak*	2.01	0.69	44594.50	0.00000
Fagus sapling, h<50 cm / *Bukov pomladak*	1.74	0.23	31577.00	0.00000
Abies sapling, h<50 cm / *Jelov pomladak*	0.27	0.46	64838.50	0.00484
Sapling, h>50 cm / *Pomladak*	2.67	0.50	37321.50	0.00000
Fagus sapling, h>50 cm / *Bukov pomladak*	2.67	0.33	32289.00	0.00000
Abies sapling, h>50 cm / *Jelov pomladak*	-	0.17	61117.50	0.00006

The beech sapling density was 1.10 pcs/m² in Čorkova Uvala, and 0.72 pcs/m² in Rajhenavski Rog ((U=10879, P=0,119926). The fir sapling density in Čorkova Uvala was 1.35 pcs/m², and in Rajhenavski Rog it was 1.08 pcs/m² (U=568; P=0.810512). The average density of the ≤ 50 cm seedlings was 2.01 pcs/m² in-Rajhenavski Rog, while the one in Čorkova Uvala was 0.69 pcs/m² (U=44594.50; P=0.00000). The ≤ 50 cm beech density in Rajhenavski Rog was 1.74 pcs/m², while the respective value in Čorkova Uvala was 0.23 (U=31577; P=0.00000).

Unlike beech, the average density of the fir up to 50 cm height was 0.46 pcs/m², which is twice as big than in Čorkova Uvala, while in Rajhenavski Rog it was 0.27 pcs/m² (U=64838.50; P=0.00006). The average > 50 cm beech density is eight times higher than in Rajhenavski Rog, i.e. 2.67 pcs/m², while in Čorkova Uvala it is 0.33 pcs/m² (U-32289; P=0.00000). Unlike the beech, the fir seedlings higher than 50 cm are entirely absent in Rajhenavski Rog, while in Čorkova Uvala its density is 0.17 pcs/m² (U=61117.50; P=0.00006).

Analysis of microsite conditions
Analiza mikrostanišnih prilika

The analysis of the young growth, the ground vegetation, and the quantity of regeneration according to the defined microhabitat types as to the relation between

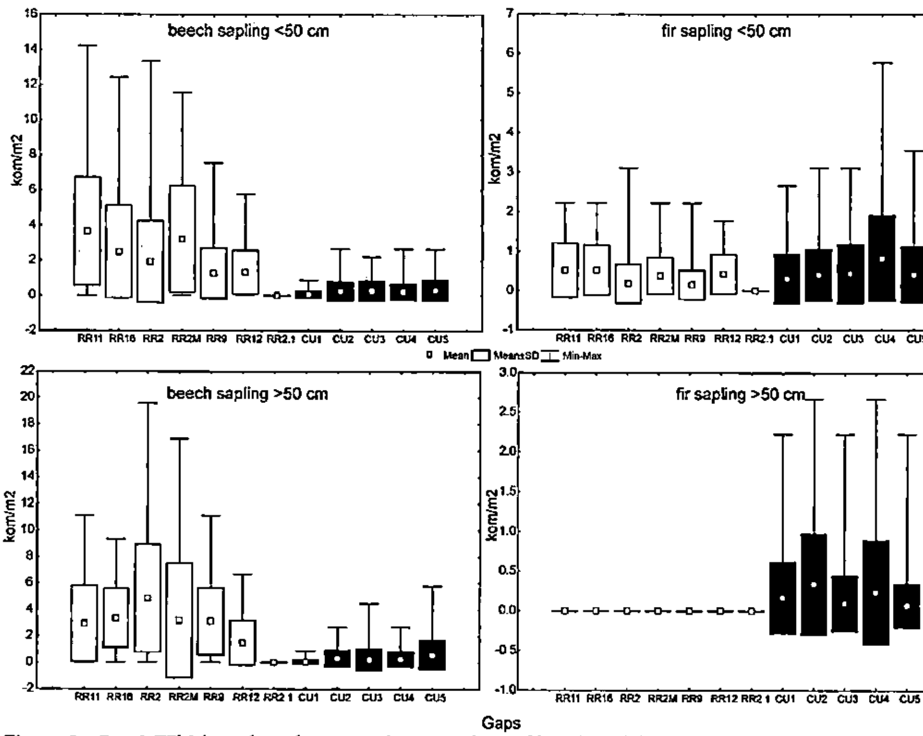

Figure 3: Box&Whisker plot of average density values of beech and fir seedlings [pcs/m²] in the investigated gaps of Rajhenavski Rog (RR) and Čorkova Uvala (CU) by height class

Slika 3. Box&Whisker prikaz prosječnih vrijednosti gustoće pomlatka bukve i jele [kom/m²] u istraživanim progalama Rajhenavskog roga (RR) i Čorkove uvale (CU) prema visinskim klasama

the diffuse (FDIF%) and direct (FDIR%) radiation has revealed significant differences between all variables except for the beech young growth in Rajhenavski Rog (Table 3). In Čorkova Uvala significant differences were determined only in the relative soil coverage by ground vegetation.

Table 3 shows the highest frequency of relative young growth coverage in Rajhenavski Rog in the habitat of type B (high level of diffuse and direct radiation). The fir saplings in Rajhenavski Rog most frequently occur as type C, which is defined by a low level of solar radiation. The fir seedlings mostly occur here as type D, under the conditions of much diffuse radiation and a low level of direct radiation. In Čorkova Uvala, the ground vegetation is the mostly developed as type A, with more direct and less diffuse radiation.

Analysis of seedling increment and damage
Analiza prirasta i oštećenosti pomlatka

The average height of the beech young growth in Rajhenavski Rog is 140 cm, while in Čorkova Uvala it is 122 cm (U=15976.50; P=0.000001). The length of

Table 3. Average values of tested variables with the Kruskal-Wallis test for microsite types determined with the level of diffuse and direct solar radiation

Tablica 3. Prosječne vrijednosti testiranih varijabli Kruskal-Wallis testom za tipove mikrostaništa određene razinom difuznog i direktnog sunčevog zračenja

	Microhabitat type according to solar radiation *Tip mikrostaništa s obzirom na sunčevo zračenje*				
	A	B	C	D	
	DIF%<Med >DIR%	DIF%>Med >DIR%	DIF%<Med <DIR%	DIF%>Med <DIR%	
Rajhenavski rog	(N = 71)	(N = 147)	(N = 147)	(N = 70)	*p*-value
Regeneration / *Pomlađivanje* (%)	63	72	43	48	0.00000
Ground vegetation / *Prizemno rašće* (%)	17	10	15	13	0.00000
Beech-seedling / *Bukov ponik* (N/ha)	6385	3447	1935	889	0.00010
Fir-seedling / *Jelov ponik* (N/ha)	3693	3326	7317	5968	0.00000
Beech / *Bukva* (N/ha)	43631	61285	59834	64698	0.06200
Fir / *Jela* (N/ha)	2128	2147	3296	5206	0.00010
Čorkova uvala	(N = 81)	(N = 88)	(N = 87)	(N = 82)	*p*-value
Regeneration / *Pomlađivanje* (%)	21	24	16	17	0.80120
Ground vegetation / *Prizemno rašće* (%)	46	40	37	31	0.00670
Beech-seedling / *Bukov ponik* (N/ha)	1481	1162	4138	1355	0.58130
Fir-seedling / *Jelov ponik* (N/ha)	4444	4394	4342	5908	0.78350
Beech / *Bukva* (N/ha)	6584	5707	6079	3957	0.08670
Fir / *Jela* (N/ha)	5322	7677	5977	6179	0.72600

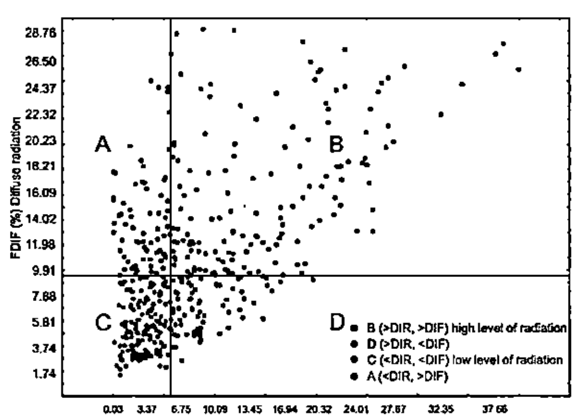

Figure 4: Relationship of direct (FDIF%) and diffuse (FDIF%) average solar radiation in the gaps of Rajhenavski Rog. Full lines indicate median values for both components. A, B, C and D are defined microsite types with regard to the median value of particular components of solar radiation.

Slika 4. Odnos između direktnog (FDIF%) i difuznog (FDIF%) prosječnog sunčevog zračenja u progalama Rajhenavskog Roga. Pune linije predstavljaju vrijednosti mediane za obje komponente. A, B, C i D definirani tipovi mikrostaništa obzirom na medianu vrijednosti pojedine komponente sunčevog zračenja.

the top shoot is 16.87 cm in Rajhenavski Rog, and in Čorkova Uvala it is 12.32 cm (U=15262; P==000001). In Čorkova Uvala, the average height of the fir is 74 cm, with the length of the terminal shoot of 5.61 cm. In Rajhenavski Rog, no fir higher than 50 cm was measured. The average damage of the beech seedlings in Rejhenavski Rog is 26.3%, while in Čorkova Uvala the respective value is 13.9% (U=22774; P=0.0001). The fir damage of 31.8% is also higher in Rajhenavski Rog. In Čorkova Uvala this value is 11.3% (U=9424; P<0.0001).

Analysis of ground vegetation
Analiza prizemnog rašća

The analysis of the floral composition by means of the Ellenberg eco-indicator values included only the species the relative proportion of which on the plots was higher than 1% (Table 4). Table 4 shows that *Cardamine trifolia has* the highest frequency of 22.44% on the Rajhenavski Rog plots. The percentage of the same species in Čorkova Uvala was 0.28%. In Čorkova Uvala, the highest proportion in the floral composition was that of *Rubus hirtus* (43.15%), while in Rajhenavski Rog the respective value was only 0.4%. The species that grow in Rajhenavski rog at a high proportion of 91% are represented in Čorkova Uvala by only 19%.

The eco-diagram (Figure 5) shows significant deviations between the Ellenberg indicator values of light and soil acidity. Čorkova Uvala shows lower pH values, while Rajhenavski Rog has a lower level of relative light.

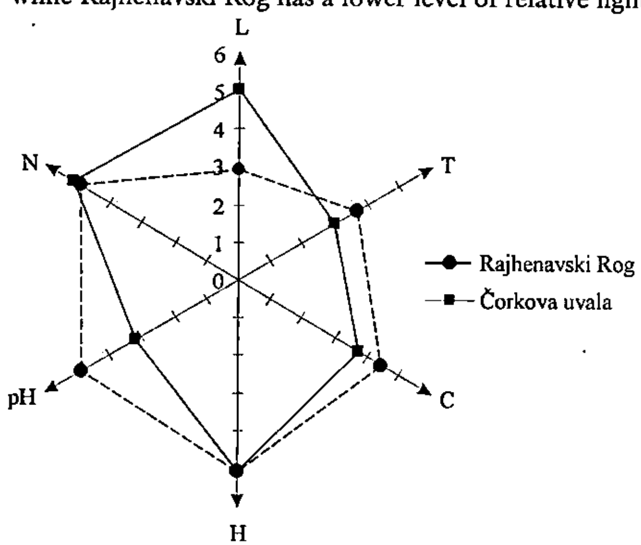

Figure 5: Ecodiagram of Ellenberg's indicator values calculated on the basis of relative participation of the species with cover exceeding 1% in the sample plots, with L (light), T (temperature), C (continentality), H (humidity), pH (acidity), N (nitrogen)

Slika 5. Ekodijagram Ellenbergovih indikatorskih vrijednosti izračunatih na osnovi relativne zastupljenosti vrsta pokrovnosti veće od 1% na pokusnim plohama gdje su: L (svjetlost), T (temperatura), C (kontinentalnost), H (vlaga), ph (kiselost), N (dušik)

Table 4. Species from the layer of ground vegetation with relative cover exceeding 1% in sample plots. Ellenberg's indicator values: L (light), T (temperature), C (continentality), H (humidity), pH (acidity), N (nitrogen). PER – relative frequency in sample plots, x – no indicator value exists for a given element. AVERAGE** - average of Ellenberg's indicator values multiplied by the percentage participation of a given species in sample plots.

*Tablica 4. Vrste iz sloja prizemnog rašća s relativnom pokrovnošću većom od 1% na pokusnim plohama. Ellenbergove indikatorske vrijednosti: L (svjetlost), T (temperatura), C (kontinentalnost), H (vlaga), ph (kiselost), N (dušik). PER – relativna učestalost na pokusnim plohama, x – ne postoji indikatorska vrijednost za određeni element. AVERAGE** - prosjek Ellenbergovih indikatorskih vrijednosti pomnožen postotnim učešćem određene vrste na pokusnim plohama.*

Species list *Vrsta*	Ellenberg indicator values *Ellenbergov koeficijent*						Rajhenavski Rog	Čorkova uvala
	L	T	C	H	pH	N	PER	PER
Rosa arvensis	5	5	2	5	7	5	1.68%	-
Senecio fuchsii	7	x	4	5	x	8	1.71%	0.19%
Lamiastrum galeobdolon	2	4	5	5	7	5	1.98%	0.07%
Anemone nemorosa	x	x	4	x	5	x	2.03%	0.02%
Brachypodium sylvaticum	4	5	5	5	6	6	6.26%	0.03%
Sanicula europaea	4	5	5	5	8	6	9.40%	0.01%
Galium odoratum	2	5	4	5	x	5	12.94%	4.76%
Oxalis acetosella	1	x	4	6	x	7	15.67%	13.95%
Cardamine trifolia	3	4	4	5	8	6	22.44%	0.28%
Omphalodes verna	4	6	6	5	7	0	14.20%	-
Daphne mezereum	4	x	4	5	7	5	2.44%	0.23%
AVERAGE**	3	4	4	5	5	5	90.75%	19.54%
Geranium robertianum	4	6	5	4	5	5	-	1.33%
Athyrium filix-foemina	3	4	4	5	0	5	0.15%	2.92%
Galium odoratum	2	5	4	5	x	5	12.94%	4.76%
Rhamnus fallax	6	4	5	4	8	3	-	5.38%
Sambucus nigra	7	5	4	5	x	9	-	6.36%
Dryopteris filix-mas	3	x	5	5	5	6	0.34%	13.86%
Oxalis acetosella	1	x	4	6	x	7	15.67%	13.95%
Rubus hirtus	7	4	3	5	4	4	0.64%	43.15%
AVERAGE**	5	3	4	5	3	5	29.74%	91.71%

DISCUSSION AND CONCLUSIONS
RASPRAVA SA ZAKLJUČCIMA

The canopy gaps in the Rajhenavski Rog virgin forest have a more complex shape and a bigger average area than the ones in Čorkova Uvala. The reasons for this may be connected with a rather intensive fir dieback in Rajhenavski Rog at the end of the last century (Bončina et al., 2002). The bigger gap areas are related to higher levels of light, which accounts for the five times higher density of the beech young growth in Rajhenavski Rog than in Čorkova Uvala. On the other hand, the fir young growth density in Čorkova Uvala (0.63 pcs/m^2) is twice as high as in Rajhenavski

Rog (0.27 pcs/m²). Such a small number of fir saplings are insufficient for a normal inflow of the fir young growth into the stands (Jarni et al., 2005). In addition, in Rajhenavski Rog any fir higher than 50 cm has not been recorded, while in Čorkova Uvala their number is 0.17 (pcs/m²). A high density of herbivores in Slovenia explains the deficit of the fir in higher height classes in Rajhenavski Rog. The research on the young growth damage established twice as big beech damage, and three times as big fir damage in Rajhenavski Rog than in Čorkova Uvala. The population density of the doe in Rajhenavski Rog is 0.9 pcs/100 ha (Jerina, 2006), while in Čorkova Uvala the respective value is 0.8 pcs/ha (Anonymous, 2007). The population of the deer in Rajhenavski Rog is 6.6 pcs/ha, which is thirty times more than in Čorkova uvala (0.2 pcs/100 ha). In Čorkova Uvala a normal density of 1 piece/100 ha of the herbivore population was estimeted (Meyera (1977). According to Senn (2003), silver fir is the species most damaged by game in south and south-east Europe. We consider the high number of herbivores as the reason of the poor inflow of the silver fir into the higher height classes, which resulted in the break of the most important link in the circle of natural regeneration in the virgin forest of Rajhenavski Rog. In future, this may lead to serious changes in the structure and shape of these virgin forests.

The microhabitat analysis defined by the proportion of the diffuse and direct light established a higher occurrence of fir saplings under the conditions of low radiation of diffuse and direct light. This is the microhabitat type C (Table 3), which is the commonest type under the stand canopy. The young growth of the silver fir in Rajhenavski Rog appears within an ecological niche, with plenty of direct light (microhabitat type D). As a rule, this coincides with the area under the canopy, on the northern sides of the gaps. Diaci 2002, Grassi et al., 2004, and Stancioniu and O'Hara 2006 achieved similar results with the fir young growth. In Čorkova Uvala no significant difference was established between the occurrence of fir and beech in the defined microhabitat types. The beech saplings grow in the conditions of high diffuse radiation (microhabitat type A), which as a rule coincides with the gap itself. The proportion of older beech young growth in all microhabitat types can be explained by the relative sciophilous character of the species and the possibility of polycyclic growth (Collet et al, 2001).

The analysis of the ground vegetation established the differences of the acidity in the top layer of the soil and the differences of light levels. According to Ellenberg eco-indicator indexes, the pH value in Čorkova Uvala is lower than in Rajhenavski Rog. Bakšić et al. (2007) established a low pH value in the beech-fir forest in Čorkova Uvala. According to Matić (1983), the lower pH values stimulate forest regeneration. The comparison of the average values of eco-indicator indexes was used to establish the differences in the light quantity and the pH level.

The conclusion is that natural regeneration is the most significant segment of sustainability and stability of any forest ecosystem. A continuous regeneration process ensures the permanent continuity of benefits offered by the forest ecosystems through economic and non-commercial functions. A successful natural regeneration of the beech and fir is a very complex process depending on a number of ecological factors, primarily on the light. The impact of one among the exogenous factors, in this case the excessive number of herbivores, is essential for successive regeneration of the silver fir, particularly when it comes to virgin forest stands in protected nature areas, where there are no classical forms of ecosystem management.

The paper also presents the ecological niches in terms of light, in which beech and fir grow. Further research should be extended to other beech-fir virgin forests and management forests, particularly for the research on other ecological factors, in order to describe the regeneration variability as thoroughly as possible. In this way we could collect the data on the mechanism of natural regeneration, to be used in sustainable management and the preservation of these forest ecosystems.

REFERENCES
LITERATURA

Anonymous, 2007: Popis brojnog stanja divljači u lovačkim udrugama Krivi javor, Golo trlo, Vrhovine i Klekovača. Lovačke udruge Republike Hrvatske.

Bakšić, D., S. Mikac, N. Pernar, I. Anić, 2007: The effect of soil reaction to the fir and beech regeneration in the virgin forest of Čorkova uvala. The Virgin Forest Ecosystems of the Dinaric Karst and the Nature-based forest Managment in Croatia. The Croatian Academy of Science and Arts The Scientific Council for Agriculture and Forestry. Scientific Symposium. Zagreb, 17–19.

Boncina, A., J. Diaci, L. Cencic, 2002: Comparison of the two main types of selection forests in Slovenia: distribution, site conditions, stand structure, regeneration and management. *Forestry* . 75, 365–373 .

Boncina, A., F. Gaspersic, J. Diaci, 2003: Long-term changes in tree species composition in the Dinaric mountain forests of Slovenia. *Forest Chronicle*. 79, 227–232.

Diaci, J., 2002: Regeneration dynamics in a Norway spruce plantation on a silver fir-beech forest site in the Slovenian Alps. *Forest Ecology and Management* (161): 27-38.

Diaci, J., D. Rozenbergar, A. Bončina, 2003: Interactions of light and regeneration in Slovenian Dinaric Alps: patterns in virgin and managed forests. *In Natural Forests in the Temperate Zone of Europe–Values and Utilisation*. B. Commarmot (ed). Swiss Federal Research Institute WSL , Birmensdorf, pp. 154 – 160.

Diaci, J., D. Roženbergar, S. Mikac, I. Anić, T. Hartman, A. Bončina, 2007: Long-term changes in the tree species composition in the Dinaric beech-fir forests. The Virgin Forest Ecosystems of the Dinaric Karst and the Nature-based forest Managment in Croatia. The Croatian Academy of Science and Arts The Scientific Council for Agriculture and Forestry. Scientific Symposium. Zagreb, 9–11.

Ellenberg, H., 1992: Zeigerwerte der Gefäßpflanzen (ohne *Rubus*). 2nd ed. Scripta Geobotanica 18: 9–166.

Franklin, J. F., T. A. Spies, R. V. Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, J. Chen, 2002: Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* (155): 399-423.

Frelich, L. E., 2003: Forest Dynamics and Disturbance Regimes. Studies from Temperate Evergreen – Deciduous Forests. Cambridge University Press.

Grass, G., G. Minotta, G. Tonon, U. Bagnaresi, 2004: Dynamics of Norway spruce and silver fir natural regeneration in a mixed stand under uneven-aged management. *Canadian Journal of Forest Research*. 34, 141–149.

Jarni, K., D. Robič, A. Bončina, 2005: Analysis of the influence of ungulates on the regeneration of Dinaric fir-beech forests in the research site Trnovec in the Kočevje forest management region. *Zbornik gozdarstva i lesarstva.* 74, 141–164.

Jerina, K., 2006: Prostorska razporeditev, območja aktivnosti in telesna masa jelenjadi (*Cervus elaphus* L.) glede na okoljske dejavnike. University of Ljubljana, Biotehniška fakulteta, Ljubljana, pp 193 .

Kimmins, J. P., 2003: Forest Ecology, The University of British Columbia, New Jersey.

Korpel, Š., 1989: Pralesy Slovenska, Bratislava.

Matić, S., 1983: The impact of ecological and structural factors on natural regeneration of fi r and beech selection forests in Gorski Kotar. *Glasnik za šumske pokuse.* 21, 223–400.

Matić, S., 1983: The impact of ecological and structural factor on natural regeneration of fir and beech selection forests in Gorski kotar. Glasnik za šumske pokuse 21, 223–400 (in Croatian with extended summary in English).

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

Mayer, H., M. Neumann, 1981: Struktureller und entwicklugsdynamischer Vergleich der Fichten –Tannen – Buchen – Urwälder Rothwald/Niederösterreich und Čorkova Uvala/ Kroatien. *Forstw. Cbl.* 100,111–132 .

Nagel, T. A., M. Svoboda, J. Diaci, 2006: Regeneration patterns after intermediate wind disturbance in an old-growth Fagus–Abies forest in southeastern Slovenia. *Forest Ecology and Management* (226): 268-278.

Regent, 2003: WinSCANOPY for Hemispherical Image Analysis – Manual . Regent Instruments Inc., Chemin Sainte-Foy, pp. 104.

Rozenbergar, D., 2000: Razvojne značilnosti sestojev v pragozdnih ostankih Pećka in Rajhenavski Rog (Stand dynamics of the virgin forest remnants of Pecka and Rajhenavski Rog). *Gozdarski vestnik* 58: 53–55.

Senn, J., W. Sute, 2003: Ungulate browsing on silver fir (*Abies alba* Mill.) in the Swiss Alps: beliefs in search of supporting data. *Forest Ecology and Management* (181): 151-164.

Stancioiu, P. T., K. L. O'Hara, 2006b: Regeneration growth in different light environments of mixed species, multiaged, mountainous forests of Romania. *European Journal of Forestry Research.* 125, 151–162.

Watt, A. S., 1925: On the ecology of British beechwoods with special reference to their regeneration: part II, sections II and III. The development and structure of beech communities on the Sussex Downs . *Journal of Ecology.* 13, 27–73.

ZNAČAJKE POMLAĐIVANJA U PROGALAMA DINARSKIH BUKOVO-JELOVIH PRAŠUMA

SAŽETAK

Istraživanje je obavljeno u dvije tipične dinarske bukovo-jelove (*Omphalodo-Fagetum* Marinček et al. 1992.) prašume: Čorkova uvala (Hrvatska) i Rajhenavski rog (Slovenija). Obje prašume pridolaze u sličnim staništim prilikama. Prostiru se u rasponu nadmorskih visina 740 – 1030 m, na tipičnom krškom reljefu, geološkoj podlozi vapnenca, uz prosječnu godišnju temperaturu zraka od 6 – 8 °C i oborine u rasponu 1600 – 2000 mm/god. U obje prašume uzorkovano je 12 progala. Unutar svake progale postavljena je pravokutna kvadratna mreža dimenzija 5 x 5 m. Na mreži su mjerene i analizirane kvantitativne i kvalitativne osobine pomlatka te relativna pokrovnost vrsta prizemnog rašća. Na svakoj plohi snimana je hemisferna fotografija u svrhu analize svjetla. U prašumi Rajhenavski rog ustanovljeno je izrazito slabo pomlađivanje obične jele i znakovito bolje pomlađivanje obične bukve u usporedbi s prašumom Čorkova uvala. Ustanovljene su značajne razlike u površinama progala i razinama difuznog i direktnog zračenja između dvije prašume. Izrazito slabo pomlađivanje jele u Rajhenavskom rogu posljedica je prekobrojnog stanja divljači u usporedbi sa prašumom Čorkova uvala. Znakovito bolje pomlađivanje obične bukve u Rajhenavskom rogu posljedica je veće razine svjetla prouzrokovane relativno većom površinom progala prouzrokovanom odumiranjem jele.

Ključne riječi: progala, prirodno pomlađivanje, difuzno i direktno svjetlo, dinarske prašume, *Fagus sylvatica* L., *Abies alba* Mill.

UDK: 630*228.81+230.2

Original scientific paper
Izvorni znanstveni članak

GAP CHARACTERISTICS AND DEVELOPMENT OF REGENERATION FOLLOWING A BLOWDOWN IN THE OLD-GROWTH FOREST REMNANT PEČKA

UTJECAJ VJETROIZVALA U PRAŠUMSKOM REZERVATU PEČKA NA ZNAČAJKE PROGALA I DINAMIKU POMLAĐIVANJA

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Received – *Prispjelo*: 15. 10. 2007.

Accepted – *Prihvaćeno*: 18. 3. 2008.

Small-scale endogenous disturbances are the most frequent type of disturbance in the dinaric silver fir-beech old-growth forests in the high karst region. However, periodic intermediate- or large-scale exogenous disturbances also occur. In the silver fir-beech old-growth forest remnant Pečka, one such intermediate windthrow event occurred in 1983.

In order to examine gap characteristics and gap closure by regeneration, we analysed 3 medium-sized and 1 large-sized gap, which formed during the windthrow in 1983. Within each gap, we inventoried gap-edge canopy trees and regeneration in height class layers of 0,1-2,5 m, 2,6-5 m, 5,1-10 m, 10,1-15 m and 15,1-20 m.

The analysed windthrow gaps were being closed in several phases and by different generations of regeneration. In medium-sized gaps, regeneration between 5 and 15 m was dominant, while in the large-sized gap pole stage regeneration between 2,6 and 5 m, which established soon after the windthrow, was dominant. The tree species composition was exclusively beech (*Fagus sylvatica* L.). Other tree species, such as silver fir (*Abies alba* L.), maple (*Acer pseudoplatanus* L.), wych elm (*Ulmus glabra* Huds.) and norway spruce (*Picea abies* (L.) H.Karst) were present, but occured very infrequently.

Gap formation caused an influx of light, which resulted in lateral growth of the crown of the gap-surrounding trees, followed by a height growth response of the advanced regeneration that established prior to gap formation, and last by the formation of new regeneration. Advanced regeneration plays a very important role in closing the gaps. The development dynamics of the gaps caused great heterogenity and variety of the stands. Finally, strong competition from beech prevented the development of light dependent tree species, even in larger-sized gaps.

Key words: old-growth forest/windthrow/gaps/regeneration

INTRODUCTION
UVOD

Wind disturbance plays an important role in old-growth forest structure and regeneration dynamics in many forest ecosystems. In temperate forests worldwide, many research studies have focused on large, catastrophic windthrows, such as tornados and hurricanes (Peterson and Pickett 1995; Foster et al. 1998; McNab et al. 2004), and on small canopy gaps, formed by death of individual trees or small group of trees (Runkle 1982; Boncina and Diaci 1998; Ziebig et al. 2005). However, few studies have examined the effects of intermediate wind disturbance on forests, especially on old-growth forests (Greenberg and McNab 1998; Canham et al. 2001; Woods 2004; Nagel and Diaci 2005; Nagel et al. 2006).

In Central Europe, strong winds associated with severe local thunderstorms are quite common (Schelhaas et al. 2003), and suggests an important potential role of intermediate wind disturbance in forest dynamics. This type of disturbance can create gaps ranging in size from single-tree gaps to several hectare multi-tree openings (Greenberg and McNab 1998), resulting in a fine to coarse grained mosaic of canopy damage in a matrix of undisturbed forest (Boncina 2000; Nagel et al. 2006). Larger openings in the stand canopy increase influx of light to the understory, which may play an important role in maintaining shade intolerant tree species in the stand species composition (Peterson and Pickett 1995; Diaci 2006).

The main goal of our research was to examine the response of woody vegetation in intermediate openings formed during a windthrow in 1983. We examined the following hypotheses: 1) The gaps are closing by different generations of regeneration; 2) The highest portion of regeneration has the regeneration stratum up to 2,5 m in height, while higher stratums of regeneration represent advanced regeneration; 3) The portion of light dependent tree species in windthrow gaps will be higher than in the rest of the stand.

MATERIALS AND METHODS
MATERIJAL I METODE

Study area
Područje istraživanja

We conducted our study in the Pecka forest reserve, a 60,20 ha old-growth stand, which is located on a high karst plateau (795-910 m a.s.l.) on the northeastern edge of the Kocevski Rog region, southern Slovenia. The micro-topography is very diverse and rocky. Calcareous brown soils and rendzinas were developed from the limestone parent material which dominates the region (Turk et al. 1985). The mean annual temperature in the region is 8,3°C with a mean annual precipitation of around 1500 mm.

The Pecka forest reserve is a typical representative of the Dinaric Silver Fir (*Abies alba* Mill.) – European beech (*Fagus sylvatica* L.) forest type. The dominant forest association is *Omphalodo–Fagetum* (Tregubov 1957) Marincek et al. 1992, with many different subassociations. The stands are dominated by beech (81 %) and fir (19 %); Norway spruce (*Picea abies* Karst.), maple (*Acer pseudoplatanus* L.), elm (*Ulmus glabra* Huds.) and wild cherry (*Prunus avium* L.) occur very infrequently. In 2003 the growing stock of living trees above 10 cm in dbh was 698 m^3 ha^{-1} with only 16 % of fir, since the portion of fir in Pecka and also in the entire country of Slovenia has been declining rapidly over the second half of the 20th century (Turk et al. 1985; Rozenbergar 2000; Nagel et al. 2006).

The optimal phase of old-growth forest was dominant in 1980, covering 82 % of the area, while the initial phase occupied 10 %, and the terminal phase 8 % (Turk et al. 1985).

During the summer of 1983 a severe thunderstorm damaged canopy trees in an area of 11,74 ha. 322 canopy trees was uprooted or snapped, which represented 2,7 % of the growing stock of forest reserve (Turk et al. 1985). The wind caused many small sized and some intermediate and larger gaps, which initiated a strong regeneration response.

Field sampling
Rad na terenu

A detailed inventory and map of all windthrown trees were made immediately after the storm (Mlinsek and Tarman 1984). We examined 3 medium-sized windthrow-gaps (gaps 1, 9 and 11) and 1 larger windthrow-gap (gap 4). For comparison purposes, we also analysed 3 medium-sized gaps outside the areas affected by the windthrow (gaps N1, N2, N3). These non-windthrow gaps were chosen in the way that there was no evidence of exogenic disturbance agents, so that the origin of the gap was obviously endogenic, like slow death of individual trees.

We analysed each gap by measuring gap-edge canopy trees, which had to be at least 20 m tall and/or at least 25 cm in diameter at breast height. For each tree we recorded the species, dbh, height, height of branchless trunk, and mapped the tree location and crown projection. These measurements allowed us to define both the »expanded« and »canopy gap« (see Runkle 1982). The expanded gap is bounded by the polygon which links together the central points of edge-gap trees, while the canopy gap is the area defined by the tree-crowns inside the expanded gap.

Regeneration within the windthrow gaps was analysed by inventorying individuals in different height class layers. According to two independent studies (Mlinsek 1967; Nagel et al. 2006), we assumed that the beech regeneration grew between 7,1 and 16,7 cm in height per year, and averaged between 10 and 12 cm (10,05 cm according to Mlinsek 1967; 11,9 cm according to Nagel et al. 2006). Based on this

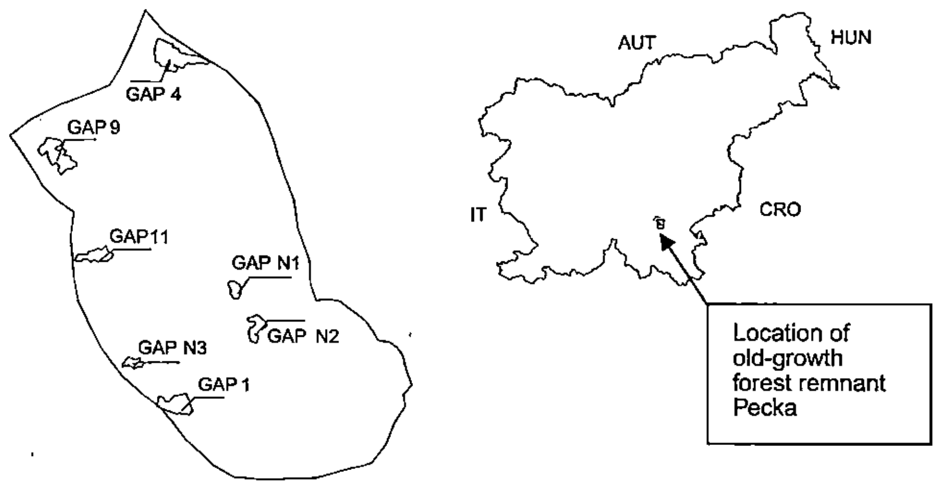

Figure 1: Scheme of examined windthrow gaps positions and the position of old-growth forest remnant Pecka

Slika 1. Shema položaja istraživanih progala i prašumskog rezervata Pečka

data, we assumed that regeneration higher than 2,5 m could be advanced regeneration, but if it was higher than 4 m, it was undoubtedly advanced regeneration (Nagel et al. 2006). The gap was assumed to be filled when the upper layer of regeneration was higher than 20 m. Accordingly, we created five height class layers of regeneration (HCL):

- height class layer HCL 1: 0,1 – 2,5 m
- height class layer HCL 2: 2,6 – 5 m
- height class layer HCL 3: 5,1 – 10 m
- height class layer HCL 4: 10,1 – 15 m
- height class layer HCL 5: 15,1 – 20 m

We classified different patches of regeneration into height class layers defined by the height of saplings in the upper story. On each patch of regeneration we established one sample plot (dimensioned as »upper border of height class in [m] × ½ of upper border of height class of the patch in [m]«) to estimate the density and share of cover area of each tree species.

GIS and statistical analysis
GIS i statistička analiza

We used CartalLinks, Idrisi 32 and ArcView/GIS 3.2 software to create sketches of gaps and to analyse gap characteristics. For statistical analysis we used descriptive statistics and non-parametric tests (Kruskal-Wallis test, Mann-Whitney test).

RESULTS
REZULTATI

Characteristics of gaps and regeneration
Značajke progala i pomlađivanja

Expanded gaps of medium-sized windthrow gaps measured from 2052 to 3778 m^2, and averaged 2938 m^2, while the canopy gap versus expanded gap ratio was only 0,28 in the average, respectively. For the large-sized windthrow-gap, the expanded gap measured 5059 m^2 and its canopy gap 2817 m^2 (the ratio of 0,56) (Table 1).

The dominant species among gap-edge canopy trees was beech, with an average portion of 84 %, whereas the portion of fir was only 16 %. The low portion of fir corresponds to the fact that fir's portion in the growing stock has been declining during the second half of the 20th century (Gaspersic 1972; Turk et al. 1985; Rozenbergar 2000).

The analysis of the windthrow-gap regeneration showed that the layer from 5 to 10 m in height prevails in the medium-sized gaps, while in the large-sized gap regeneration from 2,5 up to 5 m was dominant (Table 1).

Table 1. Characteristics of windthrow-gaps and the areas of height class layers (HCL) [m^2]
Tablica 1. Značajke progala i pomlatka po visinskim klasama (HCL) [m^2]

		Medium-sized windthrow gaps *Progale srednje veličine*				Large-sized gap *Velika prog.*
		Gap 1 *Prog. 1*	Gap 9 *Prog. 9*	Gap 11 *Prog. 11*	Mean *Sredina*	
Gaps *Progale*	Expanded gap [m^2] - *Površina progale s rubnim pojasom* [m^2]	2984	3778	2052	2938	5059
	Canopy gap [m^2] - *Površina progale* [m^2]	1305	635	504	815	2817
	(Canopy gap/Exp. gap) ratio - *odnos pov. progale/ pov. progale s rub. pojasom*	0.44	0.17	0.25	0.28	0.56
	Gap makers[n]	6	6	6	6	24
	Number of gap-edge trees [n] - *Broj graničnih stabala oko progale* [n]	48	63	36	49	93
Regeneration [m^2] *Pomlađivanje* [m^2]	HCL 1– 0,1-2,5 m	545	1228	357	710	1758
	HCL 2 – 2,6-5,0 m	146	215	508	290	4388
	HCL 3 – 5,1-10,0 m	265	2477	1121	1288	1678
	HCL 4 – 10,1-15,0 m	1722	451	596	923	189
	HCL 5 – 15,1-20,0 m	0	56	16	24	0

The results do not confirm our hypothesis that the highest portion of regeneration will be in the height class layer up to 2,5 m. There was a surprisingly large area covered by regeneration of the 3rd and 4th height class layer in the medium-

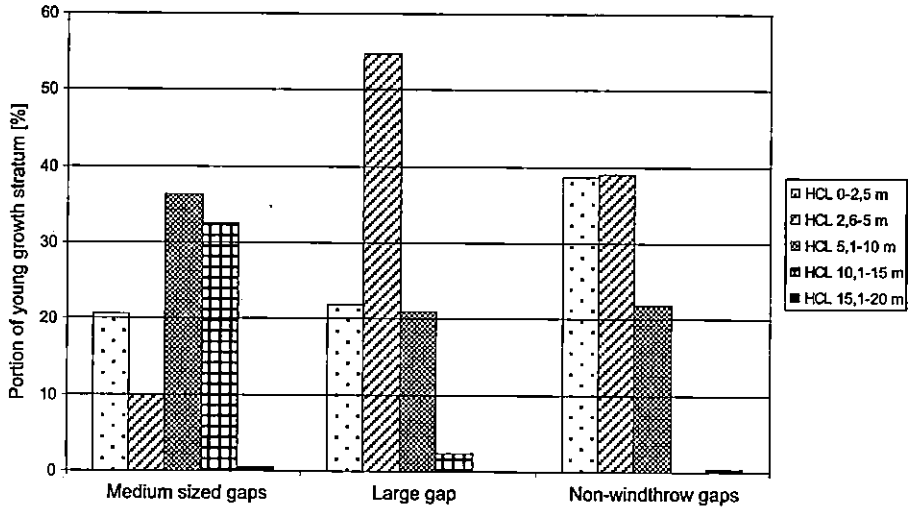

Figure 2: Portion of regeneration height class layers in view of size of the expanded gaps and origin of the gaps

Slika 2. Udjel mladoga naraštaja po visinskim klasama s obzirom na veličinu i postanak progale

sized gaps and of the 3rd height class layer in the large-sized gap. Regeneration of these height classes represents a generation of advanced regeneration which was established prior to the windthrow in 1983.

The Box-and-Whisker plot in Figure 3 shows that regeneration of 5,1 to 10 m in height created the largest patches. If we consider that new regeneration established after the windthrow could grow at most 3,5 m in height (Nagel et al. 2006), this result confirms the importance of advanced regeneration in closing of the gaps.

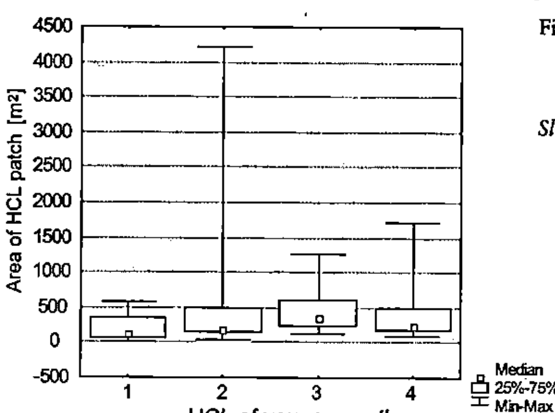

Figure 3: Box-and-Whisker plot of the median patch sizes of regeneration in different height class layers across all gaps

Slika 3. Box-and-Whisker prikaz strukture pomlatka po visinskim klasama u svim progalama

The Kruskal-Wallis non-parametric test of differences in patch sizes between HCL did not show significant results (p=0,095). In a posterior analysis the Mann – Whitney non-parametric u-test of differences between two independent samples showed that there are statistically significant differences in size of regeneration patches between 15 and 20 m in height (HCL 5) and patches of other regeneration height class layers (HCL 1-HCL 5 – p=0,004, HCL 2–HCL 5 – p=0,018, HCL 3–HCL 5 – p=0,017, HCL 4–HCL 5 – p=0,024). Between other pairs of height class layers, u-tests did not show any statistically significant differences.

Beech was the dominant species in abundance and in cover within all of the gaps (Table 2). We found a few individuals of fir in the advanced regeneration layer, as well as scattered individuals of maple, elm, and spruce. Fir, maple and elm were severely damaged by herbivores, what makes it impossible for them to grow into the canopy of the stand (personal observation). The different tree species mixture found in mature trees surrounding the gaps and in the regeneration (Table 2) points out the continuation of the process of beech domination in the future.

Table 2. Portion of dominant species in canopy tree layer and in regeneration layers [%]
Tablica 2. Udjel glavnih vrsta drveća u prostoru krošanja i u sloju mladoga naraštaja [%]

		Gap 1 *Progala 1*	Gap 9 *Progala 9*	Gap 11 *Progala 11*	Gap 4 *Progala 4*	Average *Prosječno*
Gap- edge trees *Rubna stabla progale*	*F. sylvatica*	69	86	89	91	84
	A. alba	29	14	11	9	16
Regeneration *Pomladak*	*F. sylvatica*	100	92	95	100	97
	A. alba	0	8	5	0	3

Example of large windthrow gap closure
Primjer zatvaranja sklopa velike progale

The large windthrow gap differed from the rest of the gaps in its size and in its way of closing the gap. The regeneration between 2,6 and 5 m height (HCL 2) covered approximately 4388 m^2, which was about 58 % of the regeneration in the gap. This height class layer was mainly in the central and western parts of the gap (figure 3), which were mostly formed in the windthrow of 1983.

The simultaneous regeneration immediately after the windthrow resulted in a large scale patch of even-aged regeneration of HCL 2. There was also abundant regeneration in HCL 1 (1758 m^2 or 22 % of all gap regeneration) and HCL 3 (1678 m^2 or 21 % of all gap regeneration). However, there was not much in regeneration of HCL 4 (186 m^2) and none in HCL 5.

The margins of the regeneration patches in each height layer were not clearly evident. In most cases, there was a continuous transition between patches making the border hard to define, or patches of taller regeneration were covering lower regeneration (figures 4 and 5). Where overlap between two patches of regeneration was present, a small-scale two-layered stand structure occurred. The reason for that could be a greater influx of light, which resulted in development of new seedlings under advanced understory regeneration.

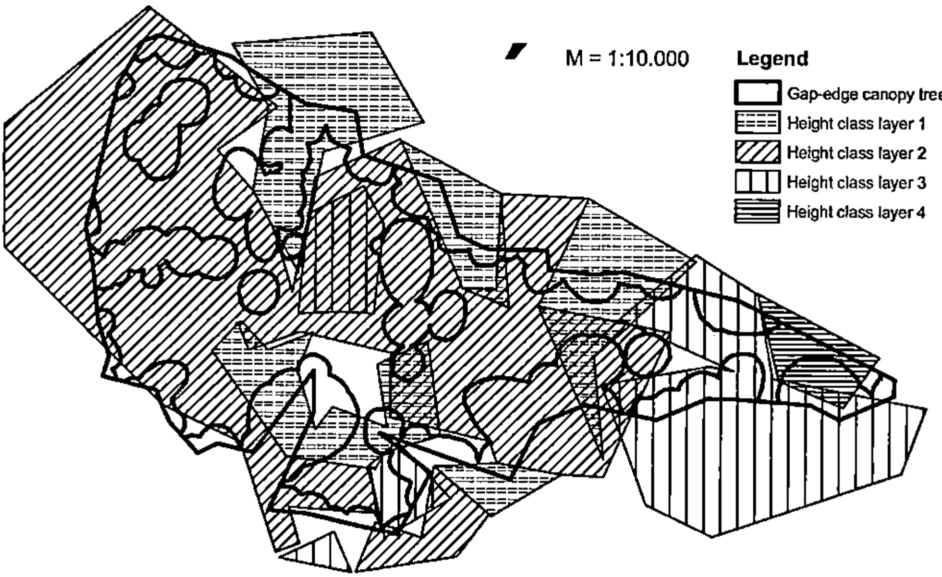

Figure 4: Patches of regeneration in the large windthrow gap
Slika 4. Grupe pomlatka na velikoj progali

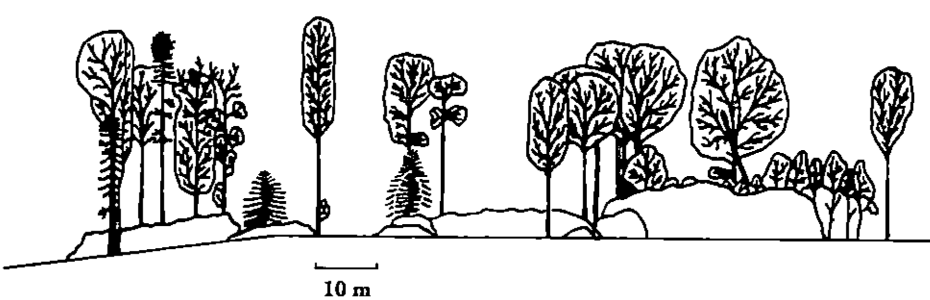

Figure 5: Profile-view of the large windthrow gap
Slika 5. Profil velike progale

Analysis of non-windthrow gaps and comparison to windthrow gap characteristics
Analiza i usporedba progala nastalih vjetrolomom s drugim progalama

The analysed non-windthrow gaps were 2,9-fold or for 1768 m^2 smaller than the windthrow gaps, respectively. An average expanded gap of non-windthrow gaps measured 1170 m^2 with a canopy gap of 473 m^2.

The portion of young regeneration up to 5 m (HCL 1 and 2) was 27 % higher in the non-windthrow gaps than in the windthrown gaps (figure 2). The average portion of HCL 1 in the non-windthrow gaps was as high as 39 %. The portion of advanced regeneration (HCL 3, 4, 5) in the non-windthrow gaps was 8,8 % lower than in the windthrow gaps, respectively. The median patch size of regeneration height class layer 3 in the windthrow gaps was 271 m² greater than in the non-windthrow gaps (Mann-Whitney u-test: z=1,97, p=0,049), respectively.

The advanced understory regeneration in the windthrow gaps developed faster and on larger areas than in the non-windthrow gaps due to greater influx of light. This may also be due to the greater abundance of advanced understory seedlings and saplings in the area of the forest reserve that was damaged by windthrow.

DISCUSSION
RASPRAVA

The 1983 windthrow in the Pecka forest reserve could be categorized as an intermediate disturbance in an old-growth forest ecosystem (Greenberg and McNab 1997; Nagel and Diaci 2005). The analysed windthrow gaps areas were larger than the average area of the old-growth forest-gaps assessed by different authors in Pecka (Turk et al. 1985; Rozenbergar 2000) and elsewhere (Runkle 1982; Boncina and Diaci 1998; Konecnik and Zaplotnik 2001; Ziebig et al. 2005; Mocilnikar 2006). The average gap size in old-growth forests is often reported as smaller than 500 m², and in some forests even less than 100 m² (Runkle 1982; Konecnik and Zaplotnik 2001). Greenberg and McNab (1998) suggest that wind disturbance can make larger gaps than endogenous factors of gap formation.

There are many different mechanisms for closing gaps in mixed conifer-broadleaf forests. First, gap-edge trees, especialy beech, respond with the lateral growth of the crown (Runkle 1982; Ulanova 2000; Kozjek 2005). Beech trees form very asymmetric treetops with the longer axis towards the source of the light influx (Kozjek 2005). Small-size canopy gaps are often closed by such lateral growth of tree-crowns (Smirnova 1994; Smirnova and Shaposnikov 1997 both in Ulanova 2000; Konecnik and Zaplotnik 2001). The second phase of gap closure is characterised by the rapid development of the advanced understory regeneration, if it occurs in the understory before gap formation. The third phase is characterised by the reaction of the newly-established regeneration on the intensified light influx (Runkle 1982; Ulanova 2000).

The regeneration between 2,6 and 10 m prevailed in the analysed windthrow gaps. Because of the broad interval of the regeneration height we can assume that there were different generations of seedlings and saplings, from an older advanced generation of undestory trees to seedlings and saplings that established after the 1983 windthrow. Marinsek (2002) found similar results following a windthrow in a similar old-growth forest reserve in Slovenia.

The most interesting finding of our analysis was that the advanced regeneration between 5 and 15 m in height was abundant in all groups of gaps, and it also prevailed in the medium-sized windthrow gaps. We can assume this was the advanced regeneration on the base of assessments by Mlinsek (1967) and Nagel et al. (2006), who found that beech saplings in Pecka could grow at most 3,5 m in height in 21 years. Mlinsek (1967) recorded an average height increment of 12,8 cm per year of understory beech saplings and claimed that the maximum height of beech saplings was up to 3,2 m. Nagel et al. (2006) found that the average annual height growth of beech saplings in the windthrow area was 11,9 cm per year and that all saplings germinated after the 1983 windthrow were less than 3,5 m in height. Kordis (1977) similarly established that the maximum height of 20-year old beech saplings in managed forests on a comparable site was 4,0 m. It is obvious that the role of the advanced understory regeneration in closing the medium-sized gaps is greater that it was believed before. The importance of advanced regeneration for canopy gap closure was also found by Pugashevsky (1992 in Ulanova 2000).

The regeneration in the large windthrow gap germinated approximately at the same time (quite equal height) and on a larger area (approximately 4300 m^2). The majority of the regeneration was between 3 and 4 m tall. Based on findings of Nagel et al. (2006) we can assume that the saplings in that regeneration height layer germinated very soon after the 1983 windthrow or even before and waited under the canopy for a short period of time. If this regeneration germinated after the windthrow, the yearly height increment was greater than that found by Nagel et al. (2006), probably because of the higher light influx (larger canopy gap). Due to better growing conditions in the large gap, height growth was more similar to beech saplings in managed forests (Kordis 1977). The large area of an even-aged young stand confirms the affirmation of Boncina (2000) that the appearance of even-aged stands in the old-growth forest is the consequence of natural disturbances, such as a windthrow or ice-breakage.

Our analysis has demonstrated at least three different scenarios of regeneration reaction to a canopy opening. In the medium-sized windthrow gaps the advanced undestory regeneration played the main role in closing the gaps through a fast height-growth reaction to the increased light influx. In the large windthrow gap the regeneration established immediately after or just prior to the windthrow. A similar pattern was observed in the non-windthrow medium-sized gaps. It is evident that the gap size and shape (= present disturbance) alone do not define the process of gap closure. Moreover, the former structure of the forest (e.g. advance regeneration present or not = past disturbance) is perhaps even more important. Many generations of advanced regeneration in the medium windthrow gaps suggest successive openings in the canopy occurred already before the windthrow. The large windthrow gap was created in a stand of optimal phase, which prevailed over large areas of the reserve before the 1983 storm (after the map of developmental phases in Turk et al. 1985). The difference between large windthrow and non-windthrow gaps was in the amount of yearly height increment and in density of saplings (both were greater in the large windthrow gap).

The importance of newly-established regeneration in the process of gap closing was also found by Clinton and Baker (2000). In closing of the small-sized canopy gaps the lateral growth of gap-edge trees treetops, secondary sprouts and advanced regeneration are supposed to have the major role (Clinton and Baker 2000). Ulanova (2000) found that the process of closing canopy openings differs geographically and by stand type.

Beech was the dominant species in the regeneration of all gaps and of all height class layers. Fir, spruce, elm and maple were found only individually and rarely. Fir as one of the dominant species in the canopy was present only as an advanced understory sapling or tree or as a seedling up to 0,5 m in height (personal observations). The dominance of beech could be the consequence of a combination of different processes: the alternation of tree-species (Gaspersic 1972; Mlinsek 1985), a declining health condition of fir (Debeljak 1997), and especially severely browsed fir saplings and seedlings (Robic and Boncina 1990; Diaci et al. 2005; Kozjek 2005).

We expected a higher portion of light demanding tree species (e.g. maple) due to a greater light influx in the windthrow gaps. However, there were almost no seedlings or saplings of maple, which were winning the height growth race against the most competitive tree species on these sites, beech. Runkle (1982) suggests that a canopy gap of approximately 400 m^2 should be enough for the survival of maple. But according to our results and the findings of Kozjek (2005), maple saplings and seedlings on sites such as the Pecka old-growth forest need at least 1000 m^2 or more. Furthermore, Kordis (1977) stated that a canopy gap that is large enough allows light demanding tree species to compete with light non-demanding species (mainly with beech), due to greater light influx and consequently greater yearly height increment in the first years of their existence.

Intermediate windthrow disturbances play an important role in forest dynamics. Many studies have suggest that intermediate sized canopy openings formed during windthrow events are quite common (Greenberg and McNab 1998; Canham et al. 2001; Nagel and Diaci 2005) and that their meaning in regeneration cycles of Central European forest is much bigger as it was thought in the recent past (Nagel et al. 2006). Our results are in agreement with these studies, so that further research examining the role of intermediate disturbance must be carried on in the future.

REFERENCES
LITERATURA

Attiwill, P. M., 1994: The disturbance of forest ecosystems: the ecological basis for conservative management. Forest Ecology and Management, Vol 63, p. 247-300.

Baker, C. R. et al., 2002: Effect of vegetation on the impact of a severe windthrow in the southern Rocky Mountains, USA. Forest Ecology and Management, Vol 168, p. 63-75.

Boncina, A., 2000: Primerjava strukture gozdnih sestojev in sestave rastlinskih vrst v pragozdu in gospodarskem gozdu ter presoja uporabnosti izsledkov za gozdarsko načrtovanje. Zbornik gozdarstva in lesarstva, Vol 63, p. 153-181.

Bončina, A., J. Diaci, 1998: Contemporary research on regeneration patterns of central European virgin forests with recomendations for future research. Zbornik gozdarstva in lesarstva, Vol 56, p. 33-53.

Canham, C. D., M. J. Papaik, E. F. Latty, 2001: Interspecific variation in susceptibility to windthrow as a function of tree size and storm severity for northern temperate tree species. Canadian Journal of Forestry Research, Vol 31, p. 1-10.

Clinton, B. D., C. R. Baker, 2000: Catastrophic windthrow in the southern Appalachians: characteristics of pits and mounds and initial vegetation responses. Forest Ecology and Management, Vol 126, p. 51-60.

Debeljak, M., 1997: Jelka v pomladku pragozda Pečka v zadnjih 30 letih. Zbornik gozdarstva in lesarstva, Vol 53, p. 29-48.

Diaci, J., A. Ziebig, 2001: Natural gaps in beech forests in Slovenia. In: Mountford E. P. (ed.), Naturaly canopy gap characteristics in European beech forests: Deliverable 6 of the Nat-Man Project. Diaci, J., R. Pisek, A. Boncina, 2005: Regeneration in experimental gaps of subalpine Picea abies forest in Slovenian Alps. European Journal of Forest Research, Vol 124, p. 29-36.

Diaci, J., 2006: Gojenje gozdov. Oddelek za gozdarstvo in obnovljive gozdne vire, Ljubljana, p. 348.

Foster, D. R., D. H. Knight, J. F. Franklin, 1998: Landscape patterns and legacies resulting from large, infrequent forest disturbances. Ecosystems, Vol 1, p. 497-510.

Gaspersic, F., 1972: Zakonitosti naravnega pomlajevanja jelovo - bukovih gozdov na Visokem Krasu snežniško - javorniškega masiva. Disertacija. Samozal., Ljubljana, p. 145.

Greenberg, C. H., W. H. McNab, 1998: Forest disturbance in huricane-related downbursts in the Appalachian mountains of North Carolina. Forest Ecology and Management, Vol 104, p. 179-191.

Konecnik, K., V. Zaplotnik, 2001: Pragozdni rezervat Strmec: diplomska naloga. Samozal., Ljubljana, p. 107.

Kordis, F., 1977: Vitalnost in konkurenca v mešanem gozdu bukve in plemenitih listavcev na rastišču *Abieti – Fagetum dinaricum*. Inštitut za gozdno in lesno gospodarstvo pri biotehniški fakulteti, Ljubljana, p. 125.

Kozjek, L., 2005: Vpliv zastora krošenj na razrast bukovih gošč v pragozdovih jelke in bukve: diplomska naloga. Samozal., Ljubljana, p. 62.

Lässig, R., S. A. Mocalov, 2000: Frequency and characteristics of severe storms in the Urals and their influence on the development, structure and management of the boreal forests. Forest Ecology and Management, Vol 135, p. 179-194.

Marinšek, A., J. Diaci, 2004: Razvoj inicialne faze na vetrolomni površini v pragozdnem ostanku Ravna gora. Zbornik gozdarstva in lesarstva, Vol 73, p. 31-50.

Mlinšek, D., 1967: Pomlajevanje in nekatere značilnosti bukovega in jelovega mladja v pragozdu na Rogu. Zbornik Biotehniške fakultete, Vol 15, p. 7-32.

Mlinšek, D. et al., 1980: Gozdni rezervati v Sloveniji. Inštitut za gozdno in lesno gospodarstvo pri Biotehniški fakulteti, Ljubljana, p. 413.

Mlinšek, D., B. Tarman, 1984: Karta vetrolomne površine v pragozdnem ostanku Pečka (delovno gradivo).

Mlinšek, D., 1985: Naraven gozd v Sloveniji. In: Gozdni rezervati Slovenije (Strokovna in znanstvena dela, 84). Biotehniška fakulteta, VTOZD za gozdarstvo, Ljubljana, p. 48.

Mocilnikar, H., 2006: Obnovitveni cikli pragozdnega ostanka Rajhenavski rog: diplomsko delo. Samozal., Ljubljana, p. 75.

Nagel, T. A., J. Diaci, 2006: Intermediate wind disturbance in an old-growth beech-fir forest in southeastern Slovenia. Canadian Journal of Forest Research, Vol 36, p. 629-638.

Nagel, T. A., M. Svoboda, J. Diaci, 2006: Regeneration patterns after intermediate wind disturbance in an old-growth *Fagus-Abies* forest in southeastern Slovenia. Forest Ecology and Management, Vol 226, p. 268-278.

Peterson, C. J., S. T. A. Pickett, 1995: Forest Reorganization: A case study in an old-growth forest catastrophic blowdown. Ecology, Vol 76, Iss 3, p. 763-774.

Robic, D., A. Boncina, 1990: Sestava in struktura naravnega mladovja bukve in jelke v dinarskem jelovem bukovju ob izključitvi vpliva rastlinojede parkljaste divjadi. Zbornik gozdarstva in lesarstva, Vol 36, p. 69-78.

Rozenbergar, D., 2000: Razvojne značilnosti sestojev v pragozdnih ostankihmPečka in Rajhenavski Rog. Gozdarski vestnik, Vol 58, p. 53-55.

Runkle, J. R., 1982: Patterns of disturbance in some old-growth mesic forests of Eastern North America. Ecology, Vol 63, Iss 5, p. 1533-1546.

Schelhaas, M. J., G. J. Nabuurs, A. Schuck, 2003: Natural disturbance in the European forests in the 19th and 20th centuries. Global Change Biology, Vol 9, p. 1620-1633.

Turk, V. et al., 1985: Gozdni rezervati Slovenije – Pragozd Pečka: (Strokovna in znanstvena dela). Univerza Edvarda Kardelja v Ljubljani, Biotehniška fakulteta, VTOZD za gozdarstvo, Ljubljana, p. 75.

Ulanova, N. G., 2000: The effects of windthrow on forests at different spatial scales: a review. Forest Ecology and Management, Vol 135, p. 155-167.

Ziebig, A. et al., 2005: Gap disturbance patterns of a *Fagus sylvatica* virgin forest remnant in the mountain vegetation belt of Slovenia. Forest Snow Landscape Research, Vol 79, Iss 1/2., p. 69-80.

UTJECAJ VJETROIZVALA U PRAŠUMSKOM REZERVATU PEČKA NA ZNAČAJKE PROGALA I DINAMIKU POMLAĐIVANJA

SAŽETAK

Najčešći tip poremećaja u dinarskim bukovo-jelovim šumama su endogeni poremećaji malih razmjera (Mlinšek 1967, Konečnik i Zaplotnik 2001, Ziebig *et al.*, 2005). Povremeno se događaju srednji do veliki egzogeni poremećaji (Bončina i Diaci 1998, Ulanova 2000). U bukovo-jelovoj prašumi Pečka srednji poremećaj kojeg je izazvao vjetar (vjetroizvala) dogodio se 1983. godine (Nagel i Diaci 2005). Kako bi ispitali utjecaj razvojnih faza na pojavljivanje vjetroizvale načinjena je komparativna analiza digitalizirane karte razvojnih faza i karte vjetroizvaljenih stabala. Osim toga, analizirane su tri srednje velike i jedna velika progala s ciljem istraživanja njihovih karakteristika i razvoja pomlatka unutar njih. U svakoj progali kartirana su i izmjerena rubna stabla te pomladak prema visinskim klasama: 0,1 – 2,5 m; 2,6 – 5 m; 5,1 – 10 m; 10,1 – 15 m i 15,1 – 20 m. Razvojna faza u kojoj je zabilježen najveći mortalitet bila je terminalna faza, u ranom i kasnom stadiju. Najmanje utjecana bila je preborna razvojna faza. Analizirane progale obrasle su s nekoliko različitih generacija pomlatka. U srednje velikim progalama dominira pomladak visina između 5 i 15 m, dok u velikim progalama dominira pomladak između 2,6 i 5 m visine. U sastavu vrsta drveća prevladava bukva (*Fagus sylvatica* L.). Druge vrste drveća koje se pojavljuju su rjeđe: obična jela (*Abies alba* L.), gorski javor (*Acer pseudoplatanus* L.), gorski brijest (*Ulmus glabra* Huds.) i smreka (*Picea abies* (L.) Karst.). Nastanak progala prouzročio je priliv svjetla koje je prouzročilo bočni rast krošanja rubnih stabala, pojačani visinski rast predrasta i formiranje nove generacije pomlatka. Predrast ima važnu ulogu u zatvaranju progale. Razvojna dinamika otvora uzrokuje veliku raznolikost i varijabilnost sastojine. Konačno, jaka kompeticija bukve sprječava razvoj heliofilnih vrsta drveća, čak i u velikim otvorima.

Ključne riječi: prašuma, poremećaj, progala, razvojne faze, predrast

UDK: 630*228.81+230

Original scientific paper
Izvorni znanstveni članak

THE EFFECTS OF STAND STRUCTURE ON REGENERATION DYNAMICS OF FIR AND BEECH FORESTS IN RISNJAK NATIONAL PARK

UTJECAJ STRUKTURE SASTOJINE NA DINAMIKU RAZVOJA MLADOGA NARAŠTAJA U BUKOVO-JELOVIM ŠUMAMA NACIONALNOG PARKA "RISNJAK"

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Received – *Prispjelo*: 15. 10. 2007.   Accepted – *Prihvaćeno*: 10. 3. 2008.

The article deals with the results of research involving the condition of the structure, regeneration processes, features of the young growth, conditions of its development and survival, crown damage of beech and fir, as well as the possibility of applying new methods of monitoring stand development, such as three-dimensional visualization of the horizontal and vertical stand structure in forests of protected areas. The results are based on almost decade-long (1998-2007) monitoring undertaken in a permanent experimental plot in the forest of beech and fir (*Omphalodo-Fagetum* Marinček et al. 1992) in Risnjak National Park.

The results of stand structure measurements suggest a disturbed uneven-aged structure. Fir is practically absent from the lower classes of diameter distribution and scarcely represented in the middle classes, thus indicating insufficient fir recruitment over the last few decades. Fir in the lower part of diameter distribution is replaced with beech of low quality, which indicates species alternation. An over-excessive canopy cover, the absence of canopy layering, and growing stock accumulated on old, physiologically weak trees imply an inadequate uneven-aged stand structure. A combination of the above has had an unfavorable effect on the abundance, quality and survival of young plants. The results also make the expected normal process of natural regeneration uncertain.

Owing to their role, stability and sustainability, protected forest ecosystems require a more active approach to protection by enhancing positive natural processes. The results of this research, combined with past insights reached by a number of forestry scientists, allow us to conclude that Croatian foresters, armed with their rich forestry tradition, have sufficient knowledge and possibilities, but also the obligation to help forest ecosystems to permanently fulfill their role in s stable and sustainable manner.

Key words: National park, uneven-aged stand structure, natural regeneration, fir, beech

INTRODUCTION
UVOD

Research, whose results are presented in this article, continues on previous research into the protected natural values in which forest communities have a dominant role. Permanent experimental plots were established for this purpose in the national parks of Risnjak, Plitvice Lakes, Paklenica, Mljet and Brijuni in 1998. The natural composition of forests has been profoundly changed by human activities in most countries of the world. In view of inescapable global changes occurring in forest ecosystems, compared to other European countries Croatia still represents an "island" of preserved natural forests with high biological diversity. This is the result of the rich tradition of Croatian forestry, which has always followed the principles of natural forest management. The presently popular and generally adopted concept of sustainable management has been known to the Croatian forestry profession for as many as 240 years. It should be pointed out that sustainable management has always formed the basic postulate of Croatian forestry. Adhering to this basic postulate (whose roots are found in the first written documents from 1769, the Forest Law of 1852, and especially in the Law of 1894, where Article 3 explicitly states: "Municipal forests shall be managed in a sustainable manner"), the main prerequisite is that, due to their primary role of fulfilling commercial and non-commercial functions, forest ecosystems must be kept in their optimal condition. One of the most vital indicators of the optimal condition and naturalness of forests is natural regeneration. Close-to-nature management based on tending treatments and natural regeneration improves and enhances the production of both market and non-market forest values (ecological and social), preserves the optimal natural stand structure and permanently protects and develops forest soil and sites (Matić 2006). A proper natural forest (virgin forest) is such a formation of forest vegetation which has developed without any human impacts; in other words, man has neither directly nor indirectly changed its composition nor affected its development. The study of a virgin forest allows us to understand the causes and consequences of various phenomena in commercial forests. The best preserved and the most numerous virgin forests in Croatia are those of beech and fir growing on Dinaric karst. At the level of forest-management area, uneven-aged forests in the Republic of Croatia extend over 318 875 ha (Forest-Management Area Plan for 2006 – 2015). Uneven-aged forests have a distinct ecological, economic and social importance. These forests have developed from a virgin forest structure and have preserved their natural characteristics. Today, natural regeneration of forests has been seriously endangered by negative ecological changes in forest ecosystems and by subjective management failures. The task of the forestry profession is to seek and find solutions that will mitigate negative impacts on forest ecosystems. The task of silviculturalists in commercial forests is to gear every forest ecosystem towards progressive development which will guarantee maximal production and yet preserve its stability and natural regeneration. Forest ecosystems in national parks should be treated according to the adopted principles of the forestry science, at the same time acknowledging the effects of the natural structure and their intended role, which dictates management guidelines. Protected forest ecosystems, including national parks, are important for the development of basic and applied natural sciences. Their references are vital for the evaluation of forest management efficiency (Diaci et al, 2006).

Forest development in natural conditions has been studied by a number of forestry experts. As many as 70 years ago Professor I. Horvat launched the first systematic phytocoenological research of Risnjak. The beginnings of scientific forestry research in Croatian virgin forests may be attributed to the study of Čorkova Uvala in Plitvice Lakes National Park, started by Academician Milan Anić in 1957. With the goal of monitoring forest development in natural conditions in Plitvice Lakes National Park, Cestar and a group of associates established four "forest reserves" covering 1,347 ha: Medveđak (1982), Čorkova Uvala-Čudinka (1983), Kik-Visibaba (1984) and the forest reserve of Riječica-Javornik (1984). We should draw attention to research undertaken by Cestar et al. (1982), who conducted typological investigation and suggested that the applied management methods did not favor the occurrence of young growth and of young growth of beech in particular. Hren (1972) studies the virgin forest of Ramino Korito as a relict-forest of former extensive virgin forests on Velebit. Prpić (1972) investigates the features of the virgin forest of Čorkova Uvala. Klepac (1984) advocates active forest protection in Plitvice Lakes National Park. In 1994 he proposes ecological forest management and emphasizes that forests should be allowed to regenerate naturally on a permanent basis. Poštenjak and Gradečki (1994) find that stands of beech and fir in Risnjak National Park are heading towards species conversion and propose adequate interventions.

Research to date (structural features and the abundance and quality of the young generation) suggests that satisfactory natural regeneration in the studied plots in the national parks is relatively unlikely (Krejči and Dubravac 2001, Dubravac et al. 2004, 205, 2006, 2007). The insights gained so far clearly show that, despite the fact that nature is running its course, its activities do not give grounds for satisfaction. Passive protection evidently does not yield the expected results.

The goal of this research is to illustrate the structural status, regeneration processes, the characteristics of the young growth, and the conditions of its development and survival in view of the internal stand structure in Risnjak National Park. It will also illustrate the crown damage status and explore the possibility of applying new methods of monitoring stand development using three-dimensional visualization of the horizontal and vertical stand structure.

Research area
Područje istraživanja

During the 1930s, the well known professor of botany I. Horvat, initially alone and later with his numerous associates, launched a cycle of scientific research on Risnjak. At his proposal Risnjak was proclaimed a national park on 15 September 1953. His reasons illustrate the basic characteristic of the park: "Natural phenomena and beauty on Risnjak cohabitate one along the other, whereas in all other places they are scattered far apart. In addition, Risnjak was spared management impacts in the past to such a degree that its natural vegetation picture has remained almost unchanged. Even if there are some occasional changes caused by management effects, the original natural state can be restored relatively quickly" (Horvat, 1953a).

Research was undertaken in a permanent experimental plot established in the forest community of beech and fir (*Omphalodo-Fagetum* Marinček et al. 1992) which, according to Vukelić (1985), is the most dominant forest in the area of Risnjak National Park. The plot is situated at an altitude of 680 m (Leska Valley) on a geological dolomite substrate. The soil type is rendzina and in the sinkhole it is luvisol. According to Vrbek and Gašparac (1992), limestone and dolomite rocks prevail in the Park, whereas the most common soil type is brown soil on limestone and dolomite (calcocambisol). The National Park covers a total area of 6,400 ha. The largest part of the area is forested (6101.5 ha or 95.3 %), while the rest relates to meadows, mountain clearings and rocks. The highest peak of the Park is situated 1,528 m above the sea (Veliki Risnjak), and the lowest point is 290 m above the sea (near the place of Hrvatsko).

METHODS
METODE RADA

A permanent experimental plot of 100 x 100 m was established in 1998 following the methodology of Dubravac and Novotna (1992). The experimental plot is a part of the network of permanent experimental plots set up in Croatian national parks (Risnjak, Plitvice Lakes, Paklenica, Mljet, and Brijuni) for the purpose of monitoring forest ecosystems dynamics under conditions of strict nature protection (Krejči and Dubravac 2001). A sub-plot sized 60 x 60 m was placed within the plot. Diameters, total heights, stem lengths and spatial distribution (position) of all the trees thicker than 7.5 cm at breast height were recorded. Horizontal crown projections (Figure 1A) were also recorded on all the trees. The stand structure was re-measured in 2007.

A laser measurement device LaserAce 300 (Measurements Devices Ltd., Great Britain) was used to measure the heights of terrain contour lines at the root base of every tree and at several additional, characteristic terrain points. The obtained points with the respective *x*, *y* and *z* coordinates were interpolated using the ESRI ArcMap software package to construct a digital terrain model (Figure 1B) of the experimental plot (Hayakawa et al. 2007). Horizontal crown projections were also

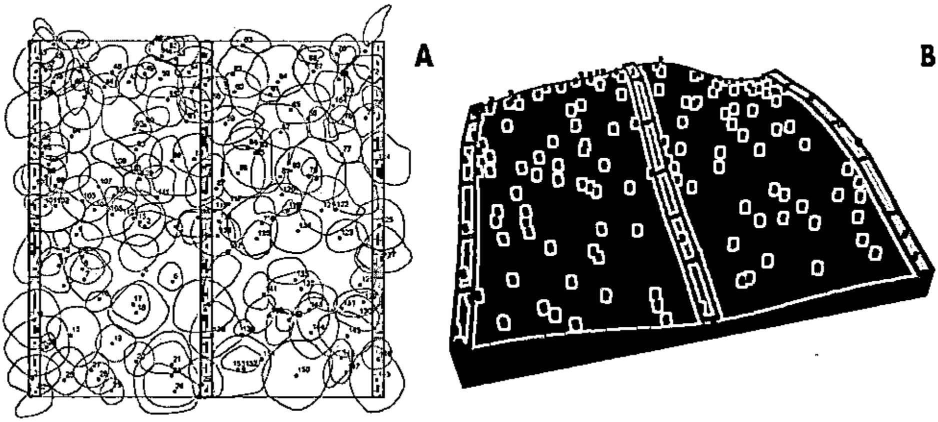

Figure 1: Map of crown projections on the subplot (A) and 3D model of subplot terrain with superimposed contour lines, postition of trees and strips for monitoring of regeneration (B)

Slika 1. Horizontalne projekcije krošanja stabala na podplohi (A) i 3D reljef terena podplohe s preklopljenim slojnicama, položajima stabala i prugama na kojima je mjeren pomladak (B)

digitalized in the ArcMap program and maps of soil coverage with crowns in terms of tree species and stand layers were also produced. The sum of crown projections by hectare in the absolute and relative amount was calculated, and so were the gaps, the mean projection and the mean crown diameter.

The structure and abundance of the young growth and the shrub layer in the sub-plot were recorded in four measurements (1998, 2001, 2003 and 2007) performed in three strips of 2 x 60 m (360 m^2). During the 2007 measurement, each strip was divided into 6 small plots of 2 x 10 m.

Crown damage was assessed using the unique method prescribed by the International Co-operative Program on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). Monitoring was executed in 1998, 2001, 2003 and 2005 and the results were compared with commercial forests at the level of Croatia for the period 1995 to 2006.

To visualize the experimental plots according to the measured tree and terrain relief features, a Stand Visualization System and EnVision (USDA Forest Service, USA) were used, as well as the 3D Max software package.

RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA

Stand structure
Struktura sastojine

Table 1 presents the basic structural features of the experimental plot (measurements in 1998 and 2007). The total wood mass of 614 m^3/ha (1998), or 683.50 m^3/ha (2007) is significantly higher than the theoretical one which, according to

Cestar et al. (1986) amounts to 325.56 m^3/ha, and according to Klepac (1961) to 346 m^3/ha. With regard to diameter degrees involving those of up to 30 cm, from 31 to 50 cm and from 51 cm upwards, this stand has the following percentage relations: 10% : 18% : 72% (1998), or 9% : 16% : 75% (2007) in relation to the theoretical-ideal ones amounting to 20% : 30% : 50%. Fir participates with 32 % in the species mix (theoretical model is 50%), beech with 66 % (theoretical model is 50%), while other species participate with 2%. The above data clearly show that the stand does not even remotely have a favorable uneven-aged structure. The growing stock is predominantly accumulated on a small number of over-mature, physiologically weakened fir trees (Figure 2). Research undertaken in Slovakian virgin forests (Korpel 1996), as well as the excessive amount of growing stock with a low number of large fir trees and a high number of thin beech trees confirm the occurrence of the developmental decomposition stage with the expansion of beech. Poštenjak and Gradečki (1994) arrived at the same results in their study of beech-fir stands in Risnjak National Park.

Table 1. Basic structural elements of forest stand on experimental plot in 1998 and 2007
Tablica 1. Osnovna strukturna obilježja sastojine na pokusnoj plohi 1998. i 2007. godine

Species / *Vrsta*	1998.			2007.			Difference (2007-1998) *Razlika* (2007-1998)		
	N	G	V	N	G	V	N	G	V
	kom/ha	m^2/ha	m^3/ha	kom/ha	m^2/ha	m^3/ha	kom/ha	m^2/ha	m^3/ha
Fir / *Jela*	114	29.88	503.76	111	32.60	549.34	-3	+2.72	+45.58
Beech / *Bukva*	231	9.47	103.88	230	11.27	127.52	-1	+1.8	+23.65
Other / *Ostalo*	6	0.52	6.36	5	0.52	6.64	-1	+0.01	+0.28
Total / *Ukupno*	351	39.87	614.00	346	44.40	683.50	-5	+4.53	+69.51

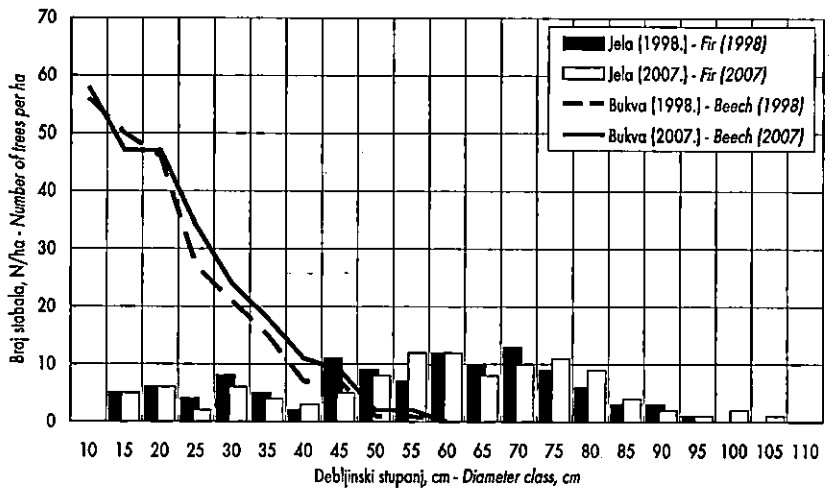

Figure 2: Diameter distribution of trees for measurements in 1998 and 2007
Slika 2. Distribucija stabala po debljinskim stupnjevima 1998. i 2007. godine

Tree number distribution in both measurements (1998 and 2007) indicates a disturbed selection structure and the absence of fir in the thinnest diameter degrees, as well as the absence of medium-thick trees (Figure 2). As breast diameter increases, this difference disappears in medium-thick trees (above 55 cm). Above this diameter there is a surplus of old, over-mature and physiologically weakened trees. The results show that in the past several decades there has been no fir recruitment from natural regeneration. The consequences are reflected in the natural crop rotation with a trend of beech expansion, in other words, in tree species alternation. The same has been confirmed by research of Šafar (1954). Thus, the biologically more aggressive beech in the subordinate layer has filled the space, as seen clearly in the vertical stand profile (Figure 3A). In Slovenia, Bončina et al. (2003) report a constant decrease in the participation of thin fir trees both in managed and in virgin forests during the last 100 years. A similar process has also been observed in some managed fir-beech forests (Čavlović 2000, Matić et al. 2001, Janeš 2006). The stand layer and its quality represent a biologically important, possibly the most important part of the stand, which is of exceptional value for its regeneration, stability, preservation of the structure and future sustainability.

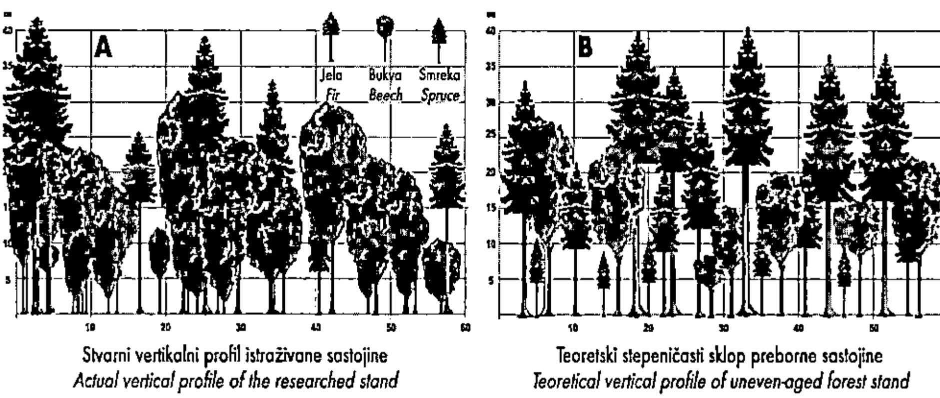

Figure 3: *Vertical stand profile: A – Actual profile of the studied stand; B – Theoretical (ideal) profile of uneven-aged forest stand*

Slika 3. Vertikalni profil sastojine: A – stvarni profil istraživane sastojine; B – teoretski (idealni) profil preborne sastojine sa stepenastim skolopom

The constructed stand profile (Figure 3A) shows dense canopy (the crowns of adjacent trees penetrate one another). It is also clear that this is a vertical canopy form. Namely, due to the disturbed natural structure (the absence of thin and medium-thick fir trees in the tree layer), the typical uneven-aged canopy profile is absent (Figure 3B). The crown canopy and its structure represent a distinctly essential factor for the regulation of ecological conditions (light, precipitation, stand climate, temperature and humidity, as well as mineralization and humification of the soil organic matter), and especially the conditions for regeneration, with fir in particular due to its narrow ecological amplitude.

The vertical and horizontal crown structure was obtained with a detailed analysis of digitalized horizontal tree crown projections in the subplot (Figure 1A and Figure 4). Soil coverage with crowns was found to be 88.5%. The total sum of horizontal crown projections is 10 941.21 m^2/ha, of which 3584.55 m^2 (32.8 %) refers to the upper fir layer and 7356.12 m^2 or 67.2 % refers to the lower beech layer. The gap in the forested area amounts to 11.54 %. The average surface of the horizontal crown projection of fir is 36.01 m^2 and of common beech it is 33.86 m^2, whereas the mean crown diameter of fir is 6.37 m and that of common beech is 6.25 m.

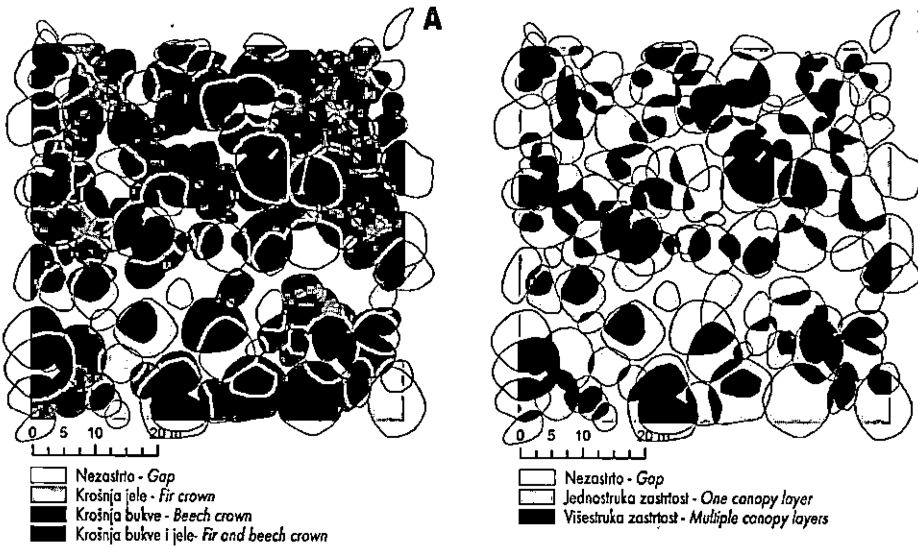

Figure 4: Canopy cover by tree species (A) and canopy layers (B)
Slika 4. Zastrtost tla krošnjama prema vrstama drveća (A) i prema slojevima sastojine (B)

The analysis of the canopy cover by tree species (Figure 4A) shows that beech and fir crowns overlap in 25.0% of the area, beech crowns alone cover 48.9% and fir crowns cover only 13.2 % of the subplot area. The total canopy cover with beech crows (independently or overlapping with fir crowns) is as much as 73.9 %. The absence of the typical uneven-aged canopy profile in the researched stand is also shown in Figure 4B, where the analysis of the canopy layer is presented according to stand layers. Only one third of the area (34.3%) is covered with multiple layers, while a single canopy layer covers 52.8% of the subplot area.

Information on the stand structure (spatial tree distribution, tree dimensions and especially crown dimensions) can currently be visually presented using one of the numerous computer programs. The stand structure in this research was visualized in two software packages: EnVision (USDA Forest Service, USA) and 3D Max. Figure 5 shows stand visualization in the EnVision program. Based on the digital model of crown projections, the parameters measured in the field (tree height, stem length, crown length and width) and the constructed base, a three-dimensional photo-realistic digital model of the stand was created in the 3D Max software package

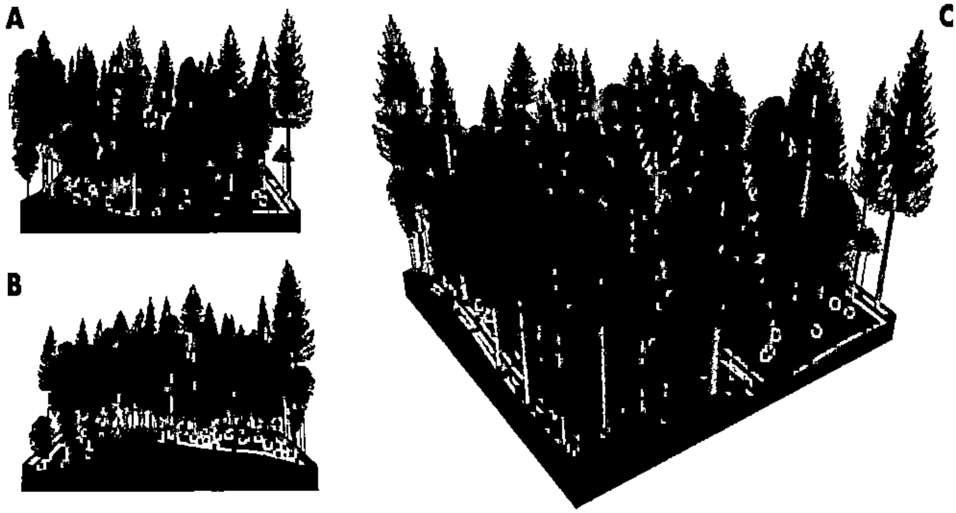

Figure 5: Stand visualization in the program EnVision (USDA Forest Service. USA); A – stand profile viewed from the north; B – stand profile viewed from the south; C – stand from bird's perspective. NE view

Slika 5. Vizualizacija sastojine na pokusnoj plohi u programu EnVision (USDA Forest Service, USA): A – profil sastojine sa sjeverne strane; B – profil sastojine s južne strane; C – izgled sastojine iz ptičje perspektive sa sjeveroistočne strane

(Figure 6). In constructing the model, account was taken of the spatial distribution of the trees and the phenotypical crown forms (Dubravac 2005). Both constructed models give a faithful presentation of basic structural stand problems which have a negative effect on regeneration processes: over-excessive canopy layer, the absence of uneven-aged canopy profile and a two-layered stand.

Structure of young growth
Struktura mladoga naraštaja

Based on the condition of the structure and the abundance and quality of the young growth recorded in 4 successive measurements (Table 2), we concluded that natural regeneration of fir is questionable. Although a significant number of fir individuals amounting to 8,945 trees per hectare were measured in 1998, it is clear that the majority (as many as 82%) of fir individuals are in the seedling developmental stage and only 12 % are in the sapling developmental stage. During the second measurement a decrease of 19 % was observed in the number of young fir plants. During the third measurement the number of individuals remained approximately the same, while the fourth measurement (2007) revealed 4,697 individuals of fir regeneration per hectare, which is a decrease of 38% in relation to the previous one. It should also be pointed out that even such a small number of young fir regeneration is threatened by deer game. The tallest fir individual recorded in the plot was only 8 m tall (Krejči

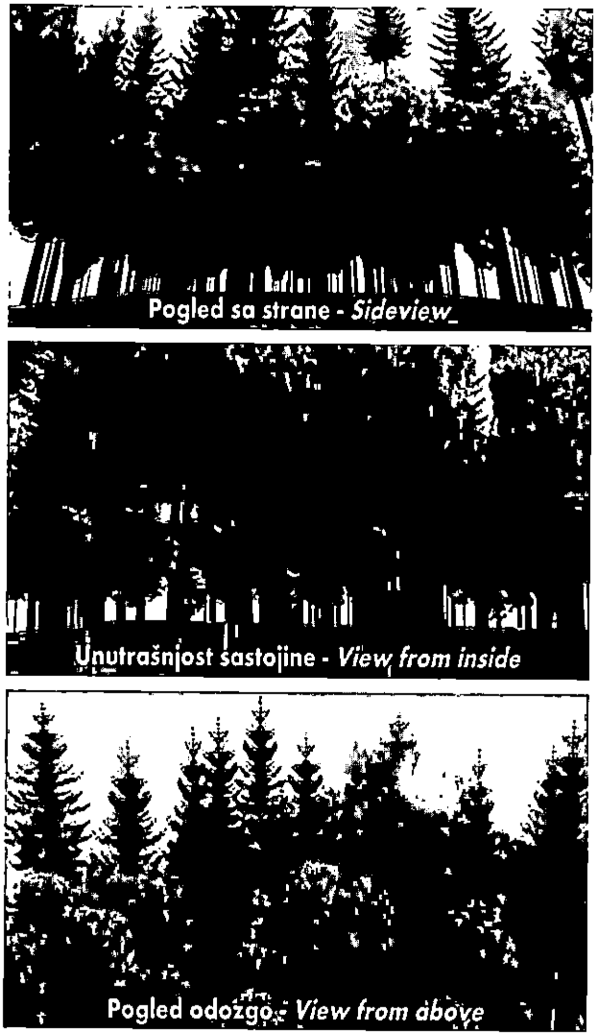

Figure 6: Three-dimensional stand model (3D Max)
Slika 6. Trodimenzionalni model sastijine (3D Max)

and Dubravac, 2001). Matić et al. (1996) detected 5,450 fir seedlings in commercial beech and fir forests. The reasons for the occurrence of regeneration elements, despite the unfavorable uneven-aged structure (the diameter class relationship is 4% : 7% : 89 %, which is similar to ours) are attributed to excessive soil humidity which plays an important role in an uneven-aged forest. Research by Šafar (1954) treats the role of air humidity and the occurrence of young fir regeneration.

The first measurement undertaken in 1998 registered 11,111 of fir germinants, while the last measurement in 2007 recorded 18,805 pieces per hectare.

It is clear that fir germinants occur in large numbers but their further survival and development is threatened. This information testifies to an adequate yield of fir seed and its good germination, but also to its disappearance after one year. The disappearance of the young growth is attributed to lack of humidity in the soil and air as a consequence of adverse, primarily structural and ecological conditions (Matić et al. 1996).

According to research by Mazur (1989), a large number of fir seedlings (one-year plants) does not play an important role if seedlings that occur abundantly after mast crop generally die in the first year of life. Dobrowolska (1998) obtained much better results of natural fir regeneration in Poland. Some research suggests that fir regenerates much better under the crowns of some tree species that under its own canopy (Runkle 1981, Dobrowolska 1998). During the first three measurements, young beech regeneration was constantly increasing. A distinct increase in beech regeneration from 15,971 (2001) to 41,389 (2003) individuals is the consequence of ample beech mast in 2001. The fourth measurement revealed a decrease in beech regeneration by 31% in relation to the previous one. Some of the beeches were over 2.5 m tall, but they were stunted and of low quality, and had an umbrella-like form. They represent the basis of a future stand which will, apart from other tree species, also feature an occasional sycamore and rowan.

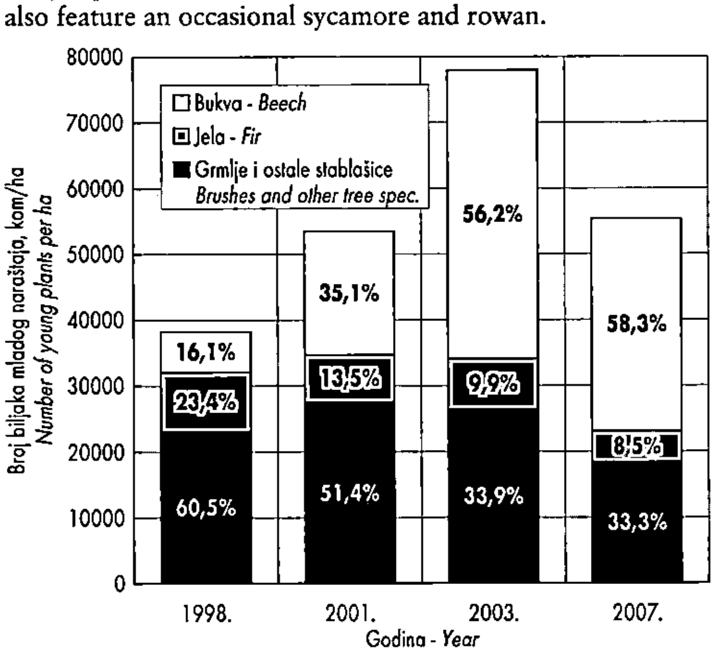

Figure 7: Share of fir, beech and shrubs and other tree species in the total number of young plants during monitoring period

Slika 7. Ukupan broj biljaka mladoga naraštaja te udio bukve, jele, te grmlja i ostalih stablašica tijekom godina izmjere

In view of the above and of the fact that the plot is in the national park, it is illusory to expect better natural regeneration of fir in the future. How much time will elapse until this takes place? The reasons lie in a set of interacting factors, and espe-

Table 2. Structure of young growth of fir, beech, other tree species and shrubs by height classes
Tablica 2. Struktura mladog naraštaja po vrstama drveća i visinskim klasama i gustoća grmlja

Height age class cm / *Visinsko-starosni razred cm*		Measurement 1998 *Izmjera 1998.*				Measurement 2001 *Izmjera 2001.*				Measurement 2003 *Izmjera 2003.*				Measurement 2007 *Izmjera 2007.*			
		Fir *Jela*	Beech *Bukva*	Tree s. *O.stabl.*	Bushes *Grmlje*	Fir *Jela*	Beech *Bukva*	Tree s. *O.stabl.*	Bushes *Grmlje*	Fir *Jela*	Beech *Bukva*	Tree s. *O.stabl.*	Bushes *Grmlje*	Fir *Jela*	Beech *Bukva*	Tree s. *O.stabl.*	Bushes *Grmlje*
		Number of plants per ha - *Broj biljaka po ha*															
<30	1-year old Jednog.	7306	83	7056	556	3805	1333	1778	1083	2944		305	278	1528	56	861	444
	Older *Višegod.*	1639	3833	9333	2833	3416	14638	16805	2805	4667	41389	16861	3444	3167	28603	9611	2028
Total <30 *Ukupno <30*		8945	3916	16389	3389	7221	15971	18583	3888	7611	41389	17166	3722	4695	28659	10472	2472
31-60			1194	139	2361		1749	1306	2278		1083	1833	2056		1694	2417	1444
61-130			417	28	1333		333	56	1194		589	167	1139		1056	528	1028
131-150			28				167		167		56	28	194		222		222
151-200			83				56				167		83		83		139
201-250			139				139				55				167		
>250			361	28			361				500		28		333	28	
Total *Sveukupno*		8945	6138	16584	7083	7221	18776	19945	7527	7611	43839	19194	7222	4695	32214	13445	5305

cially in the disturbed uneven-aged structure, distinctly dense canopy in the lower beech layer, excessive presence of herbivores which browse on young fir growth and disturb the stability of forest ecosystems (Krejči and Dubravac 2001), as well as in climatic changes (droughts).

The percentage share of fir in the total number of young plants is constantly falling and so is the number of shrubs and other trees. The share of fir decreased from 23.4 % to 8.5 %, of shrubs and other trees from 60.5 % to 33.3 %, whereas the share of beech went up from the initial 16.1 % in 1998 to as much as 58.3 % in 2007 (Figure 7). It can be concluded that beech, whose increment in its youth exceeds that of fir, has better chances for future development and dominance in a stand with a disturbed uneven-aged structure and worsened ecological conditions. This is also corroborated by research of Šafar (1954). The abundance of the young growth of other plants in the areas dominated by the sycamore and the shrubs (generally buckthorn, hazel, elderberry, mezereon), which has a vital effect on natural regeneration, did not change fundamentally during the first three measurements. It should be noted that during the last measurement (2007) the number of young growth of all the species decreased significantly, which can probably be attributed to the exceptionally dry year of 2003.

Crown damage
Oštećenost krošanja

Forests in Risnjak National Park, together with all the other forests in Gorski Kotar, are susceptible to mortality and dieback. An aerial survey of the Park conducted in 1988 showed that as much as 93.4% of the fir was significantly damaged (damage over 25 %), and so were 12.5 % of the beech, and 58% of the spruce (Kušan et al. 1994). It should be pointed out that the survey encompassed the total old Park area (3,400 ha). No research linked to forest dieback has been done since. Research should definitely be resumed. The crown damage status in the experimental plot (1998, 2001, 2003, 2005), and the comparison with the average values in the Republic of Croatia (Potočić and Seletković 2006) are given in Figure 8. The data show a percentage share of significantly damaged trees of beech and fir.

The highest proportion ever of significantly damaged trees of silver fir amounting to 74.1% was recorded during 2006. This is an increase of 0.3 % in relation to the assessment of 2005. The damage trend in recent years indicates further alarming dieback of silver fir in Croatia. A slightly better situation, but still very worrying, occurs in Risnjak National Park, where the growing trend of significant damage from 50 % to 63.6 % in 2005 has shown a mild decrease to 56.8 % of significantly damaged trees.

Average damage of common beech in recent years of monitoring has not changed drastically, and has ranged from 4 – 11 %. The year 2006 saw the highest ever significant beech damage of 12. 7 %, but the beech still retains the epithet of the most resistant Croatian tree species. Monitoring in Risnjak National Park shows

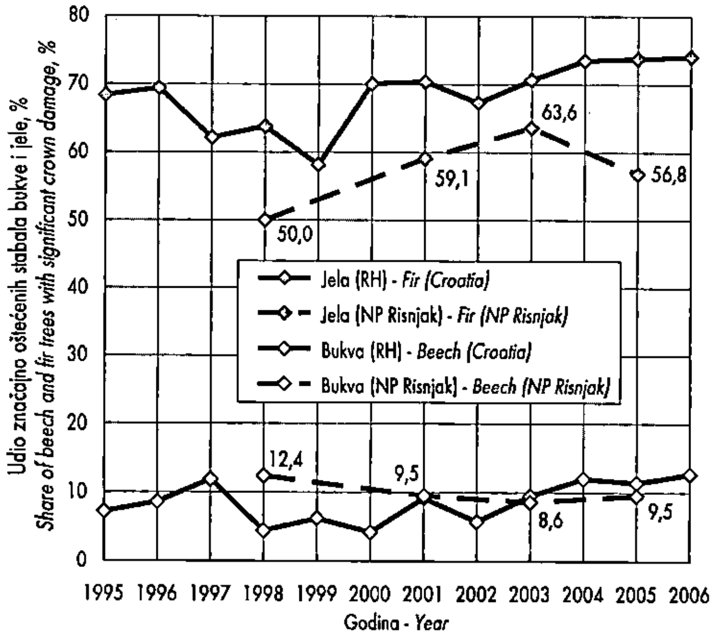

Figure 8: Comparison of fir and beech crown damage in managed forests and forests of Risnjak National Park

Slika 8. Usporedba značajne oštećenosti krošanja jele i bukve u NP Risnjak i gospodarskim šumama

that beech manifests very similar values of significant crown damage as those in commercial forests.

CONCLUSIONS
ZAKLJUČCI

The basic prerequisite for a normal, balanced and stable uneven-aged stand, as well as the condition of its sustainability, is constant natural regeneration. In terms of sustainability of the studied selection stand, the results of this research may briefly be summarized in two main conclusions: the problematic condition of fir and the aggressive onset of beech.

Namely, the proportion of significantly damaged fir trees in the experimental plot ranged from 50.0 % in 1998 to 63.6 % in 2003. The uneven-aged structure has been disturbed and consists of an excessive number of old and over-mature fir trees which have reached their physical maturity. The absence of fir from the thinnest degrees of diameter distribution suggests the absence of increment over the several past decades. The proportion of fir among the young plants in the experimental plot constantly dropped from 23.4 % in 1998 to 8.5 % in 2007. Not one fir exceeded a height of 30 cm throughout decades of monitoring.

On the other hand, the aggressiveness of beech is evident in the increased share of young beech regeneration from 16.1 % in 1998 to as much as 58.3 % in 2007. Beech crowns (alone or overlapping with fir) cover 73.9 % of the experimental plot area. The share of significantly damaged beech trees in the experimental plot did not exceed 13 % (the highest percentage of 12.4 % occurred in 1998). Fir in the thinnest degrees of the diameter distribution is being replaced with young beech trees.

The results obtained during decade-long monitoring of the structure and process of natural regeneration of beech and fir stands in Risnjak National Park do not guarantee the sustainability of the forest ecosystem, which was the basic reason for giving this area the status of a national park. The justifiability of the concept of passive protection should be re-examined in this case. There is a possibility that in the long run, such a concept of protection will harm rather than protect forest ecosystems of national parks. In order to obtain a scientifically based platform for making decisions on the future of forests in protected areas, a monitoring methodology should constantly be improved by establishing a network of permanent experimental plots in all the protected forested areas in Croatia. In no case should modern information models be neglected; on the contrary, full use should be made of their capability of presenting newly acquired knowledge in a qualitative manner.

Past insights and experience of a large number of forestry scientists, to which we contribute with our research, allows us to conclude that foresters have the knowledge, the ability but also the commitment to help forest ecosystems in protected areas to permanently fulfill their intended role. The forestry profession should definitely become more involved, particularly in those protected areas whose basic phenomenon and/or the most distinct feature are forest ecosystems. In such cases, treatment of forests should foster the preservation and naturalness of forest ecosystems in concrete sites.

REFERENCES
LITERATURA

Bončina, A., F. Gašperšić, J. Diaci, 2003: Long-term changes in tree species composition in the Dinaric mountain forests of Slovenia. For. Chron. 79: 227–232.

Cestar, D., V. Hren, Z. Kovačević, J. Martinović, Z. Pelcer, K. Bezak, A. Krznar, V. Lindić, B. Vrbek, V. Krejči, 1982: Prirodni šumski rezervat Medveđak. Rad. Šumar. inst. 50: 1–76.

Cestar, D., V. Hren, Z. Kovačević, J. Martinović, Z. Pelcer, K. Bezak, V. Krejči, A. Krznar, V. Lindić, J. Medvedović, B. Vrbek, 1983: Prirodni šumski rezervat Čorkova uvala-Čudinka. Rad. Šumar. inst. 53: 1–44.

Cestar, D., V. Hren, Z. Kovačević, J. Martinović, Z. Pelcer, K. Bezak, V. Krejči, A. Krznar, V. Lindić, J. Medvedović, B. Vrbek, 1984: Prirodni šumski rezervat Kik-Visibaba. Rad. Šumar. inst. 58: 1–40.

Cestar, D., V. Hren, Z. Kovačević, J. Martinović, Z. Pelcer, K. Bezak, V. Krejči, A. Krznar, V. Lindić, J. Medvedović, B. Vrbek, 1984: Prirodni šumski rezervat Rječica-Javornik. Rad. Šumar. inst. 58: 41–76.

Cestar, D., V. Hren, Z. Kovačević, J. Martinović, Z. Pelcer, 1986: Uputstva za izradu karte ekološko-gospodarskih tipova gorskog područja (I) SR Hrvatske. Rad. Šumar. inst. Izvanredno izdanje 4: 1–125.

Čavlović, J., 2000: Novi program gospodarenja za g.j. Belevine. Šumar. list 124 (7-8): 450–457.

Diaci, J., D. Roženbergar, U. Kolar, R. Pisek, T. Nagel, D. Hladnik, 2006: Methodologies for monitoring forest development in strict forest reserves. In: Z. Maunaga (ed.), Gazdovanje šumskim ekosistemima nacionalnih parkova i drugih zaštićenih područja, Šumarski fakultet u Banja Luci, Banja Luka, 25–33.

Dobrowolska, D., 1998: Structure of silver fir (*Abies alba* Mill.) natural regeneration in žJata' reserve in Poland. For. Ecol. Manage. 110: 237–247.

Dubravac, T., V. Novotny, 1992: Metodologija tematskog područja uzgajanje šuma - rast i prirast (primijenjena u multidisciplinarnom projektu ekološko ekonomske valencije tipova šuma). Rad. Šumar. inst., 27 (2): 157–166.

Dubravac, T., V. Krejči, B. Vrbek, 2004: Stanje strukture i mogućnost prirodne obnove čistih bukovih sastojina u šumskom rezervatu žMedvjeđak'. Plitvički bilten 6: 179 – 200.

Dubravac, T., D. Vuletić, B. Vrbek, 2005: Natural reforestation and future of beech and fir forests in the Risnjak NP. Period. biol. 107 (1): 73–79.

Dubravac, T., 2005: Primjena digitalizacije krošanja i metode vizualizacije u izučavanju strukture sastojina. Rad. Šumar. inst. 40 (1): 53–72.

Dubravac, T., M. Benko, J. Čavlović, 2005: The structure of uneven-aged stands in non-economic forests of national park Risnjak in Croatia. Ekologia-Bratislava 24 (4): 385– 396.

Dubravac, T., J. Čavlović, V. Roth, B. Vrbek, V. Novotny, S. Dekanić, 2007: The structure and possibility of natural regeneration in managed and non-managed beech and fir forests in Croatia. Period. biol, 109 (1): 21–27.

Dubravac, T., S. Dekanić, V. Roth, 2007: Effects of stand structure on regeneration dynamics of mixed uneven-aged forest. In: P. Newton (ed.), Complex Stand Structures and Associated Dynamics: Measurement Indices and Modelling Approaches, Ontario Forest Research Institute, Sault Ste. Marie, 100–101.

Hayakawa, Y. S., T. Oguchi, J. Komatsubara, K. Ito, K. Hori, Y. Nishiaki, 2007: Rapid on-site topographic mapping with a handheld laser ranger finder for a geoarcheological survey in Syria. Geographical Research, 45 (1): 95–104.

Horvat, I., 1953a: Obrazloženje prijedloga za proglašenje Risnjaka narodnim parkom. Glasnik Biološke sekcije Hrvatskoga prirodoslovnog društva, Zagreb 1950-52, Ser. II/B, T. 4-6.

Hren, V., 1972: Ramino korito. Šum. list 96 (9-10), 315-324.

Janeš, D., 2006: Uređivanje i gospodarenje prebornim sastojinama bukve i jele u gospodarskoj jedinici Markuševačka Gora. Magistarski rad, Zagreb.

Klepac, D., 1961: Novi sistem uređivanja prebornih šuma. Poljoprivredno šumarska komora SR Hrvatske, Zagreb, str. 46.

Klepac, D., 1984: Principi uređivanja šuma Nacionalnog Parka "Plitvička jezera". Šum. list 108 (7-8): 319–335.

Klepac, D., 1994: Ekološko uređivanje šuma u Nacionalnom Parku "Plitvička jezera". Znanstveno savjetovanje Plitvička jezera nacionalno dobro Hrvatske, svjetska baština, Zagreb, 69–80.

Korpel, Š., 1996: Razvoj i struktura bukovo-jelovih prašuma i njihova primjena kod gospodarenja prebornom šumom. Šum. list 120 (3-4): 203–208.

Krejči, V., T. Dubravac, 2001: Mogućnost obnove šuma Nacionalnih parkova. Rad. Šumar. inst. 36 (2): 113–122.

Kušan, V., Z. Kalafadžić, R. Pernar, Z. Horvatić, 1994: Procjena oštećenosti šuma u Nacionalnom parku „Risnjak" fotointerpretacijom infracrvenih kolornih aerosnimki. U: A. Frković (ur.), 40 godina nacionalnog parka „Risnjak" 1953.-1993. Javno poduzeće Uprava Nacionalnog parka „Risnjak", 27–31.

Matić, S., M. Oršanić, I. Anić, 1996: Neke karakteristike i problemi prebornih šuma obične jele (*Abies alba* Mill.) u Hrvatskoj. Šum. list 120 (3-4): 91–99.

Matić, S., I. Anić, M. Oršanić, 2001: Uzgojni postupci u prebornim šumama, In: S. Matić (ed.), Obična jela (*Abies alba* Mill.) u Hrvatskoj. Akademija šumarskih znanosti, Zagreb, 407–471.

Matić, S., 2006: Natural management as an important factor of forest protection and survival. In: J. Diaci (ed.), International scientific conference: Nature based forestry in Central Europe-Alternatives to Industrial Forestry and Strict Preservation, Tudia forestalia Slovenica, Ljubljana, 19–25.

Mazur, M., 1989: Structure and dynamics of silver fir (*Abies alba* Mill.) in forest communities of the Świetokrzyski National Park: II Population dynamics. Acta. Soc. Bot. Pol. 58: 409–422.

Poštenjak, K., M. Gradečki, 1994: Stojbinske prilike šuma NP "Risnjak". In: A. Frković (ed.), 40 godina nacionalnog parka "Risnjak" 1953.-1993. Javno poduzeće Uprava Nacionalnog parka "Risnjak", 34–46.

Potočić, N., I. Seletković, 2006: Oštećenost šuma u Hrvatskoj 2006. godine, Šumarski institut, Jastrebarsko, str. 29.

Prpić, B., 1972: Neke značajke prašume Čorkova uvala. Šum. list 96 (9-10): 325–333.

Redford, K. H., J. G. Robinson, W. M. Adams, 2006: Parks as Shibboleths. Conservation Biology 20: 1–2.

Runkle, J. R., 1981: Gap regeneration in some old-growth forests of the eastern United States. Ecology 62: 1041–1051.

Šafar, J., 1954: Problem njege mladog naraštaja u jelovim šumama. Šum. list 78 (11-12): 561–570.

Šafar, J., 1963: Uzgajanje šuma. Savez šumarskih društava Hrvatske, Zagreb, 598 str.

Vrbek, B., M. Gašparac, 1992: Novi nalazi imisije teških metala u Nacionalnom parku "Risnjak". Rad. Šumar. inst. 27 (1): 65–75.

Vukelić, J., 1985: Doprinos fotointerpretacijske analize vegetacijskom istraživanju šumskih zajednica NP Risnjak. Glas. šum. pokuse 23: 95–140.

*** Program za zaštitu, očuvanje i održavanje NP „Risnjak" 2001.

**** Šumskogospodarska osnova 2006. – 2015. „Hrvatske šume" d.o.o. Zagreb, 2006, str. 566.

UTJECAJ STRUKTURE SASTOJINE NA DINAMIKU RAZVOJA MLADOGA NARAŠTAJA U BUKOVO-JELOVIM ŠUMAMA NACIONALNOG PARKA "RISNJAK"

SAŽETAK

U radu se iznose rezultati istraživanja stanja strukture, regeneracijskih procesa, značajki mladoga naraštaja, uvjeta njegova razvoja i opstanka, oštećenosti krošanja bukve i jele, kao i mogućnost primjene novih načina praćenja razvoja sastojina metodama trodimenzionalne vizualizacije horizontalne i vertikalne strukture sastojine. Rezultati se temelje na desetogodišnjem istraživanju (1998.-2007.) na stalnoj pokusnoj plohi u šumi bukve i jele (*Omphalodo-Fagetum* Marinček et al. 1992) unutar NP "Risnjak".

Rezultati izmjera strukture sastojine ukazuju na narušenost preborne strukture. Distribucija broja stabala ukazuje na izostanak jele u najtanjim debljinskim stupnjevima te manjak srednje debelih stabala, što potvrđuje izostanak priliva jele iz prirodnog pomlađivanja unazad više desetljeća. Taj prostor popunjava zastarčena, nekvalitetna bukva, što upućuje na izmjenu vrsta. Prevelika zastrtost tla krošnjama, izostanak stepeničastog oblika sklopa, nagomilana drvna masa na starim, fiziološki oslabljenim stablima, također ukazuju na izostanak preborne strukture. Navedeno se odrazilo na brojnost, kvalitetu i preživljenje mladog naraštaja, a rezultati ukazuju na upitnost očekivanog normalnog procesa prirodne obnove.

Zaštićeni šumski ekosustavi poradi svoje uloge, stabilnosti i potrajnosti zahtijevaju aktivniji način zaštite u smislu pomaganja pozitivnih prirodnih procesa. Rezultati ovoga istraživanja kao i dosadašnje spoznaje mnogih šumarskih znanstvenika daju nam za pravo zaključiti kako šumari poradi svoje bogate tradicije imaju znanja, mogućnosti te obvezu pomoći zaštićenim šumskim ekosustavima da trajno obavljaju namijenjenu im ulogu.

Ključne riječi: Nacionalni park, struktura preborne sastojine, prirodna obnova, jela, bukva

UDK: 630*228.6

Original scientific paper
Izvorni znanstveni članak

THE ESTABLISHMENT AND PRESERVATION OF A BALANCED STRUCTURE OF BEECH-FIR STANDS

MOGUĆNOSTI USPOSTAVE I OČUVANJA URAVNOTEŽENE STRUKTURE JELOVO-BUKOVIH SASTOJINA

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Received – *Prispjelo*: 15. 10. 2007. Accepted – *Prihvaćeno*: 8. 1. 2008.

Beech-fir forest management in Croatia is currently faced with problems of irregularly structured stands. This is manifested in a considerable proportion of mature trees of large dimensions, poor increment, the non-existence of vertical structure and the absence of satisfactory and permanent natural stand regeneration. The characteristics of such structures show similarity with virgin forests in their terminal stage. On the assumption that a balanced selection structure may only be achieved with intensive and systematic management, the goal is to highlight the relationship between management and stand structure "development". Based on the conducted and published research dealing with concrete forest sites of fir and beech, the following elements of planning the management and structure of irregularly structured fir-beech stands are discussed:

1. The disappearance of a selection structure and the accumulation of the growing stock of large trees with diameters over 70 cm during the past 50-year period resulting from prescribed and applied low-intensity cutting operations;
2. The applicability of the prescribed cut form (based on the difference in the growing stock before and after the selection cut and the rate of curent annual volume increment), which is questionable in conditions of excessive growing stocks and low rates of current annual volume increment;
3. The transition time, recruitment and structure of regeneration as an indicator of the currently disrupted stand structure;
4. Predictions of planned intensity and structure of selection cuts, recruitment (stand regeneration) and "development of stand structure during future cutting cycles, which indicate the need for cuts of higher intensity

(over 25%) in the initial cutting cycle and gradual improvement of the disrupted selection structure; and

5. The results that indicate the negative effect of basal area of fir and beech trees with diameters exceeding 50 cm on natural fir regeneration, as well as the occurrence of natural young growth of regenerated fir (developmental stage of young growth) 5 years after the selection cut of stronger intensity (24%).

Key words: silver fir, common beech, disturbed selection structure, selection cutting intensity, increment.

INTRODUCTION AND PROBLEM
UVOD I PROBLEM

The characteristics of a single-storied structure of the majority of stands in Croatian beech-fir forests, which show similarity with virgin forests in their terminal stage (Korpel 1996), may point to insufficiently intensive planning and management with selection forests. However, the predominance of mature trees of large dimensions, the absence of vertical structure, poor increment, tree dieback and the absence of satisfactory and permanent natural stand regeneration are the consequence of management failures, unfavourable climatic impacts and pollution (Matić et al. 1996), but also of different approaches to forest management through history caused by complex interactions of social, economic and ownership attitudes towards the forest (Božić 2001, Božić 2003, Kalafadžić et al. 1989, Kušan et al. 1994).

In terms of the importance of selection management for Central European forestry (Shütz 1989, 2001, O'Hara 2002), problems of fir dieback, tree species conversion, changed structure and absence of natural regeneration (Čavlović 2000, Korpel 1996, Bončina et al. 2002) pose special challenge to forest planning and management.

Intensive planning and management is based on prescribing annual yields as the necessary framework for the application of silvicultural treatments and appropriate scheduling of selection cut with regard to spatial and structural stand features. According to the ŠGOP (2006) data, the growing stock of fir in the amount of 28.13 million m^3 increased by 1.91 % in 1996. However, the 10-year felling volume (1996 – 2005), which was only 64.2 % of volume increment, shows an extensive approach to planning. The increment volume of 77.1 % indicates the need for more intensive management, which was limited by a regulation (20 % maximal deviation). Partly in connection with these data, the fir growing stock of 27.8 million m^3 increased by only 1.76 % in 2006. To meet the need for more intensive management, the felling volume of 106.0% of volume increment has been planned for the 2006 – 2015 cutting cycle.

Assuming that in conditions in which cutting is lower than the increment, management has all the features of a virgin forest and that the percentage of increment as a direct indicator of a disturbed structure cannot be used as the key element for planning the prescribed yield, this paper aims to confirm these assumptions by comparing the structural elements of sample forests and research conducted on the relationship between the elements of management planning and stand structures.

MATERIAL AND METHODS
MATERIJALI I METODE

In order to compare and define the indicators of a disturbed structure and the elements of management planning (felling as the necessary framework for the application of management procedures), a mixed theoretical model of fir and beech was used in the second site class for fir. The mixture ratio was 80 and 20% of the total growing stock (399 m³/ha). Two forests (management classes) of fir and beech in the sites corresponding to the second site class for fir were taken as examples of a preserved selection structure on the one hand and a disturbed selection structure on the other.

The management class *Uneven-aged forests of fir, spruce and beech II* within the management unit of Bunarić (Management plan for MU Bunarić 2003) consists of 17 stands covering an area of 994.15 ha. The average growing stock per ha is 412 m³, of which fir and spruce account for 72% and beech and other broadleaves for 28%. The distribution of growing stock per diameter classes (thin, medium large, large tree) is almost theoretical (42 % of the growing stock of large trees). The current annual volume increment is 11.24 m³/ha, which corresponds to the annual increment percentage of 2.73 %. Over the past periods, management has been characterized by intensive selection cutting organized and performed by wood-industrial companies.

Stands showing a disturbed selection structure are situated within the management unit Belevine (*Uneven-aged seed forests of fir II*) over a total area of 266.24 ha (18 stands). Of the total growing stock of 476 m³/ha, fir and spruce participate with 78 % and beech and other broadleaves with 22 %. The share of the growing stock of large trees of 74 % in relation to the total theoretical growing stock indicates a disturbed stand structure. The stands increment by only 1.67 % or 7.97 m³/ha annually. Starting from 1870, management was characterized by the formation of pure coniferous stands of even-aged structure during the 70-year period. In the last 50 years, management with the group selection cut method has been applied (Čavlović 2000).

The following elements of the theoretical structure and annual cut were obtained from the mixed theoretical model; the participation of the growing stock of large trees (>50 cm), current volume increment, the percentage of current volume increment, the average transition time of stands (forest), recruitment, volume and the structure of selection cutting. These elements were juxtaposed with the sample (investigated) forests.

The ratio between the growing stock of large trees and the total theoretical growing stock, and the percentage of annual current increment at the level of individual stands were taken as indicators of a disturbed selection structure. An interaction was investigated between the percentage of volume increment and the participation of growing stock of large trees, and the volume increment and the structure of growing stock within groups of stands in the sample forests.

The applicability of the prescribed cut form (Eq. 1) (based on the difference in the growing stock before and after the selection cut and the rate of curent annual volume increment) was investigated on the example of the representative stands.

$$E = M \times \left(1 - \frac{1}{1{,}0p^{l}}\right) \times f \tag{1}$$

where M – growing stock of the stand immediately before the cut; p – annual percentage of the current volume increment; l - cutting cycle; f – relationship between the actual and the theoretical growing stock of the stand.

Interactions of elements of a disturbed structure, stand regeneration, cutting structure and intensity, as well as predictions relating to the establishment of a theoretical stand structure were analyzed and discussed on the basis of some published research results.

RESULTS AND DISCUSSION
REZULTATI S RASPRAVOM

The survey and comparison of basic structural elements (Table 1) relating to growing stock distribution per diameter classes, current volume increment and increment percentage, average transition time and recruitment show the extent to which the average structure of fir-beech stands in the MU Bunarić is close to the theoretical one. On the other hand, deviation of the growing stock and its distribution per diameter class from the theoretical structure, the low increment percentage and the high average transition time indicate a disturbed structure of the stands in the MU Belevine. This results in poor stand regeneration, which is indicated by the recruitment of only 4 trees per year per ha.

Sustaining a permanently balanced structure is based on permanent stand regeneration, or the felling of mature trees, which, according to Table 1, amounts to about 50 % of the growing stock of large trees. Can this relationship also be valid in conditions of a disturbed structure as long as the cutting volume plan is within the maximal allowed cutting intensity?

The percentage of the current volume increment can in this context be taken as a direct indicator of the stand's condition, which is caused by its structure. Figure 2 shows the dependence of the percentage of annual current increment on the participation of growing stock of large trees at the level of particular stands for the two forests under study. Disaggregate in the percentages of annual increments of the two groups of stands (forests) coincides with the level of 2 % annual percentage of

Table 1. Comparison of structural elements of the studied fir-beech forests and mixed theoretical model
Tablica 1. Usporedba osnovnih elemenata strukture istraživanih bukovo-jelovih šuma i mješovite normale

			Normal model	MU Bunarić	MU Belevine
Growing stock (m^3ha^{-1}) *Drvna zaliha*		10 - 30 cm	87.0	84.0	50.5
		31 - 50 cm	181.1	159.0	130.5
		> 50 cm	131.1	169.0	295.2
		Total	399.2	412.0	476.2
$V_{>50}/V_N$			0.328	0.423	0.739
Current annual increment *Godišnji tečajni prirast*		$m^3\ ha^{-1}$	11.80	11.24	7.97
		%	2.96	2.73	1.67
Transition time *Vrijeme prijelaza*		year	10.30	10.50	16.00
Recruitment *Priliv*		trees $yr.^{-1}$	14.70	14	4
10-yr. cut *10. god. sječa*	Total / *Ukupno*	m^3	118.0		
	Mature cut / *Zrela stabla*	m^3	66.6		

current increment and indicates considerable differences between the two forests, as well as deviations from the theoretical selection structure. Lower increment percentages of the stands in Belevine in the range of equal rate of large tree growing stock (45 – 65 %) point to generally poorer conditions of increment in the forest of Belevine (stunted trees). It may be concluded that a 2-percent annual decrease in the increment is a direct indicator of a disturbed stand structure.

The negative correlation of the dependence of annual current increment percentage on the participation of growing stock of large trees is clearly visible, which is more distinct within the forest with a preserved stand structure.

The percentage of the annual current increment is an element which is directly used in practice in the formula for planning the prescribed cut (Eq. 1) at the selection stand level. Figure 2 shows a comparison between the representative stands of two sample forests.

According to the basic structural indicators (growing stock, proportion of large tree volume, increment) the stand within the MU Bunarić is very close to the hypothetical selection structure (Figure 2a). By maintaining the current level of regeneration and volume increment, an optimal number of medium large trees may be achieved relatively rapidly. The prescribed cut, which is at the level of normal cutting intensity of 25 %, will be sufficient to achieve this goal.

On the other hand, according to Figure 2b, the structure of the stand in the MU Belevine may be declared significantly disturbed and far from a hypothetical selection structure. With considerable growing stock and proportion of mature volume (92 % of the normal volume), and the percentage of annual increment of only 1.54 %, the prescribed cut was calculated according to the Formula 1 that is identical to the first stand and that is at the level of the normal prescribed cut. Although the prescribe cut form contains the relationship between the actual and the theoretical

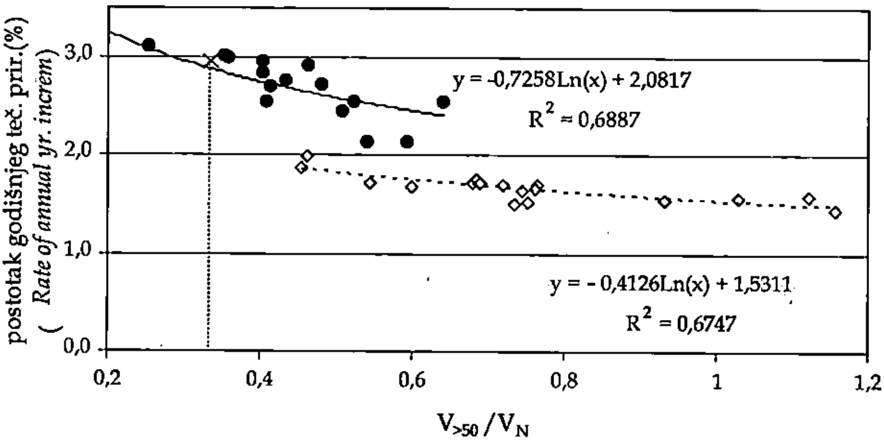


Figure 1: Rate of annual current volume increment and large tree volume proportion dependency. Ringlet and solid line – m.u. Bunaric. Rhombs and broken line – m.u. Belevine.Crosses and broken vertical line – the theoretical model.

Slika 1. Ovisnost postotka godišnjeg tečajnog prirasta i udjela drvne zalihe debelog drva. Kružići i puna linija-gj Bunarić. Kvadratići i crtkana linija-gj Belevine. Křižić i crtkana uspravna linija-normala.

growing stock (growing stock exceeds the normal one by 36 %), due to low increment percentage the 10-year cutting intensity is only 19 %.

The ten-year normal prescribed cut of 112 m³ per ha is sufficient to maintain a balanced selection structure. On the other hand, this prescribed cut in the stands with a disturbed structure does not guarantee more intensive stand regeneration, tree increment and the establishment of the selection structure. For this reason, the application of this prescribed cut form is questionable when the relationship between the structural elements in the stand are disturbed (Čavlović et al., 2006b).

The application of the theoretical rate of cutting as a method of determining the prescribed cut is more appropriate in this case. Starting from the normal annual increment percentage of 2.96 % (Table 1), the prescribed cut of 172 m³ per ha would be adequate for the 10-year cutting intensity of 29.6%, which is an increment of as much as 216 %. As it is certain that the entire or almost entire prescribed cut would relate to mature tree felling, or the regeneration of the stand in compartment 2 of the MU Belevine, over 40 % of the mature volume would be affected by cutting. This corresponds to the relations within a balanced selection structure (Table 1).

According to Čavlović et al. (2006b), the prescribed and accomplished 10-year cut in the management unit Belevine in the period 1950 – 2000 was about 17 % and reached the increment level of 114 %. However, the proportion of mature tree growing stock in relation to the total growing stock (total normal growing stock) constantly grew from 44 (52) to 61 (70) %, while stand regeneration was increasingly poor. This confirms the conclusion that intensities below 20 % (the application of the formula of volume difference before and after cutting based on the concrete percentage of annual current increment) are not suitable when structural relation-

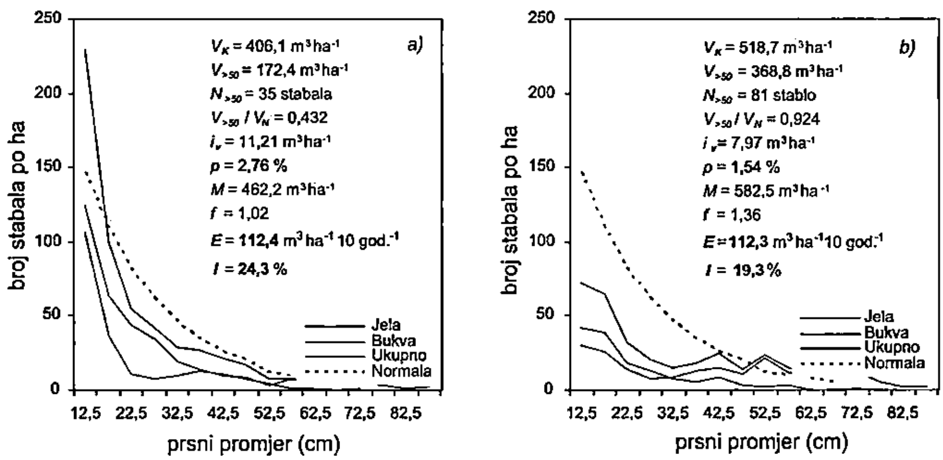


Figure 2: Diameter-class structure endprescribing cut elements for the two representative stands. a) sub-compartment 49a, m.u. Bunaric. b) compartment 2, m.u. Belevine.

Slika 2. Prikaz debljinske strukture i elemenata određivanja sječivog prihoda za dvije reprezentativne sastojine. a) odsjek 49a, gj Bunarić. b) odjel 2, gj Belevine.

ships within a stand are disturbed. Božić (1999) and Klepac (1997) also point to the trend of growing proportions of large tree volume in selection forests of Gorski Kotar.

High transition times expressed with a low increment percentage and excessive loss of transition time within a diameter class indicate a disturbed structure in terms of different conditions of fir tree growth (Čavlović et al. 2006b). In such conditions, a large number of fir trees with poor increment (stunted trees) are found in all diameter classes. Improving and balancing the conditions of fir tree increment, which is mutually dependent on regeneration and the normal selection structure, is one of the requirements to be fulfilled by future intensive approach to management.

The poor condition and structure of fir regeneration correlates directly with the proportion of large trees. Correlation analysis of the impacts of basal area of a particular part of fir and beech stand on the occurrence of the seedlings, saplings and poles of fir and beech confirmed positive correlation between the basal area of thin trees of both fir and beech on the occurrence of saplings and poles. On the other hand, the statistically considerable negative impact was confirmed of the basal area of large fir and beech trees on the occurrence of their saplings and poles. The negative impact of the basal area of large beech trees on the occurrence of the young growth, saplings and poles of fir was particularly distinct (Čavlović et al., 2006b). Such results indicate the necessity of applying cutting treatments in a particular part of a stand so as to encourage and maintain stand regeneration.

Figures 3 and 4 show predictions of fir-beech stands with a disturbed structure on the basis of a continued dynamic model system (CDMS) of the selection stand (Čavlović 1999) based on the assumptions of cause-consequence effect between cutting the mature growing stock and intensifying regeneration and increment.

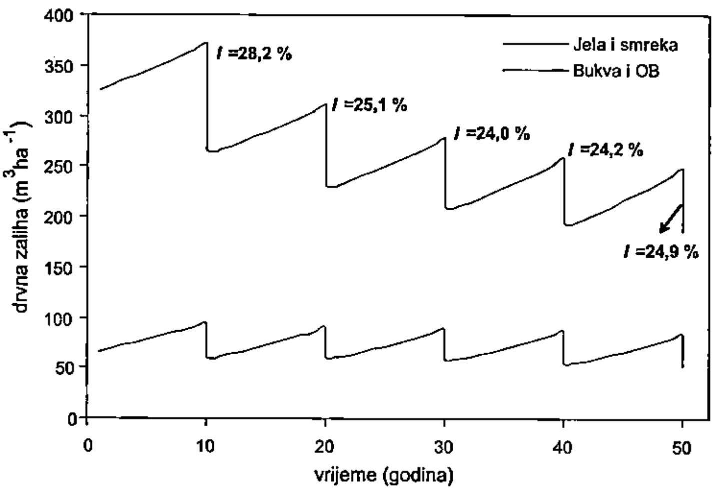


Figure 3: Prediction of growing stock development in the Belevine research site for the next 5 cutting cycles. I means 10-year cutting intensity. (according to Čavlović et al. 2006a)

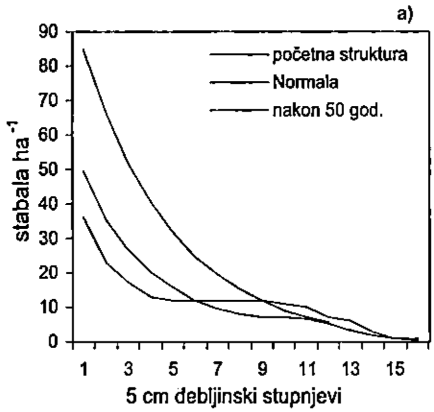
Slika 3. Projekcija drvne zalihe (m^3 ha^{-1}) prosječne sastojine u gj Belevine tijekom budućih 5 ophodnjica. I je intenzitet 10-godišnje sječe. (prema Čavlović i dr. 2006a)

The prediction of trends in the growing stock (Figure 3) shows considerable decrease in the fir growing stock, especially during the first two cutting cycles. At the end of the first cutting cycle, double increment should be cut with a cutting intensity of 28 %. This coincides with the prescribed cut determined by the method of theoretical rate of cutting on the example of compartment 2 in the MU Belevine. A decrease in the fir growing stock during the first two cutting cycles is based on cutting large-dimension trees and establishing favourable conditions for more intensive regeneration and tree incrementing. However, even after this, the cutting intensities do not fall below 24 %. At the end of the fifth cutting cycle, the total growing stock should be reduced to the bottom critical level of 280 m^3 ha^{-1}, after which a gradual increase in the growing stock might be expected.

Such a cutting scenario is expected to have a positive impact on the development of a stand's diameter structure. However, a shift in approaching the diameter stand structure to the hypothetical one over the 50-year period still seems insufficient (Figure 4).

According to research by Čavlović et al. (2006b), positive impacts were observed of higher intensity cutting (24 %) in relation to the previous ones ranging around 17 %. The structure of stand regeneration 5 years after cutting in relation to the structure of regeneration before cutting is given in Table 2.

A multiple increase in the number of plants/ young trees is evident for all the three developmental stages. The number of germinants is significant as it represents the potential for the developmental stage of small seedlings. The most important is an increase in the number of small seedlings, which is 15 times higher for the fir



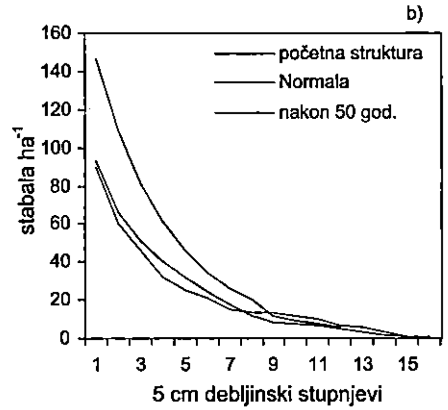


Figure 4: Observed and predicted development of diameter distribution of Belevine research forest at the end of the 50-year period in relation to the hypothetical structure: a) Silver fi and b) Total. (according to Čavlović et al. 2006a)

Slika 4. Početna i projektirana debljinska struktura na kraju 50-godišnjeg razdoblja prosječne sastojine gj Belevine u odnosu na normalnu strukturu: a) Jela i smreka i b) Ukupno. (prema Čavlović i dr. 2006a)

compared to the situation immediately before cutting. This is a direct indication of positive impacts of the 24 % cutting intensity and distinct stand regeneration.

Table 2. Review of young tree structure according to classes and tree species just before cutting and 5 years after cutting. (according to Čavlović et al. 2006b)

Tablica 2. Prikaz strukture obnove prema klasama i vrsti drveća neposredno prije sječe i 5 godina nakon sječe. (prema Čavlović i dr. 2006b)

Tree species *Vrsta drveća*	Young tree classes (number of plants/trees per ha) *Klase mladog naraštaja (broj biljaka/stabalaca po ha)*					
	Germinants *Ponik*		Small seedlings (≤ 0,3 m tall) *Pomladak (≤ 0,3 m visine)*		Tall seedlings(>0,3 ≤ 1,3 m tall) *Pomladak (>0,3 ≤ 1,3 m visine)*	
	1999.	2005.	1999.	2005.	1999.	2005.
Silver fir / *Jela*	1872	8609	317	4956	2	651
Beech / *Bukva*	0	579	136	2948	0	1076
Total / *Ukupno*	1872	9188	452	7903	2	1727

CONCLUSION
ZAKLJUČAK

Lack of intensive planning in the management with beech-fir forest, which is based on the prescribed cut as a sufficient and necessary framework for the application of regeneration and tending treatments, leads to a disturbed stand structure and processes similar to those in a virgin forest (accumulation of growing stock, cutting/mortality lower than the increment, falling quantities and qualities of increment, degradation of increment, delay stand regeneration). Permanent maintenance of a theoretical selection structure based on cutting the normal increment is a prerequisite for systematic and consistent forest planning and management. This requirement is even more important and complex in re-establishing the already disturbed stand structure. A low percentage of the annual current volume increment is a good indicator of disturbed relations in the stand structure and the intensity of planning and management in beech-fir forests, but is inadequate as an element for determining the prescribed cut, which leads to low intensities of selection cutting (less than 19 %). To plan the quantity and structure of the prescribed cut, it is more advisable to start from the relationship between the elements of the theoretical structure, theoretical increment percentage (rate of cutting), and even the maximal allowed intensity of selection cutting. This will provide a good basis for intensive management with beech-fir stands.

REFERENCES
LITERATURA

Bončina, A., J. Diaci, L. Cenčič, 2002: Comparison of the two main types of selection forests in Slovenia: distribution, site conditions, stand structure, regeneration and management. Forestry, 75: 365-373.

Božić, M., 1999: Modeli uređivanja jelovih šuma Gorskog kotara - Magistarski rad. Šumarski fakultet Zagreb, Zagreb, p. 140.

Božić, M., 2001: Management models applied to fir forests in Gorski Kotar. Glas. šum. pokuse, 38: 89-135.

Božić, M., 2003: Utjecaj stanišnih i sastojinskih elemenata na prirast obične jele (*Abies alba* Mill.) u jelovim sastojinama na kršu u Hrvatskoj – Disertacija. Šumarski fakultet Zagreb, Zagreb, p. 190.

Čavlović, J., 1999: A diameter-class model of an uneven-aged forest stand as a support to uneven-aged forest management. U: A. Amaro, M. Tome (ur.). Scientific book "Empirical and process based models for forest tree and stand growth simulation", Edições Salamandra, Lisboa, 313-326.

Čavlović, J., 2000: Novi program gospodarenja za g.j. Belevine (2000-2009.) – zaustavljanje nepovoljnih trendova i iniciranje povoljnih procesa u "razvoju" preborne šume? Šum. List, 124(7-8): 450-457.

Čavlović, J., M. Božić, A. Bončina, 2006 a: Stand structure of uneven-aged fir-beech forest with an irregular diameter structure: modelling the development of the Belevine forest, Croatia. European Journal of Forest Research, 125: 325-333.

Čavlović, J., M. Božić, K. Teslak, M. Vedriš, 2006 b: Struktura prirodne obnove preborne sastojine u uvjetima povećanja intenziteta preborne sječe. Glasnik za šumske pokuse, Posebno izdanje 5: 433-442.

Kalafadžić, Z., V. Kušan, Z. Horvatić, R. Fintić, B. Hrašovec, 1989: Određivanje stupnja oštećenosti šuma bukve i jele zajednice općina Rijeka interpretacijom ICK aerosnimki. Studija za Zavod za prostorno planiranje i zaštitu čovjekove okoline. Zajednice općina Rijeka, Rijeka, str. 90.

Klepac, D., 1997: Iz šumarske povijesti Gorskog kotara u sadašnjosti. Zagreb, str. 236.

Korpel, S., 1996: Razvoj i struktura bukovo-jelovih prašuma i njihova primjena kod gospodarenja prebornom šumom. Šum. List, 120 (3-4): 203-208.

Kušan, V., Z. Kalafadžić, R. Pernar, Z. Horvatić, 1994: Procjena oštećenosti šuma u Nacionalnom parku Risnjak fotointerpretacijom infracrvenih kolornih aerosnimki. Zbornik radova - 40 godina Nacionalnog parka Risnjak, Crni lug, 27-32.

Matić, S., M. Oršanić, I. Anić, 1996: Neke karakteristike i problemi prebornih šuma obične jele (*Abies alba* Mill.) u Hrvatskoj. Šum. List, 120 (3-4): 91-100.

O'Hara, K.L., 2002: The historical development of uneven-aged silviculture in North America. Forestry, 4: 339-346.

PG, 2003: Program gospodarenja za g. j. Bunarić 2003-2012.

Schütz, J-P., 1989: Der Plenterbetieb. Fachbereich Waldbau. ETH Zürich.

Schütz, J-P., 2001: Der Plenterwald und weitere Formen strukturierter und gemischter Wälder. Parey, Berlin.

ŠGOP, 2006: Šumskogospodarska osnova područja za područje Republike Hrvatske 2006-2015.

MOGUĆNOSTI USPOSTAVE I OČUVANJA URAVNOTEŽENE STRUKTURE JELOVO-BUKOVIH SASTOJINA

SAŽETAK

Gospodarenja bukovo-jelovim šumama u Hrvatskoj je danas suočeno dijelom sa sastojinama nepravilne strukture, koja se očituje u značajnoj zastupljenosti zrelih stabala velikih dimenzija, slabom prirastu, nepostojanju vertikalne strukture i u izostanku zadovoljavajuće i stalne prirodne obnove sastojina. Obilježja takvih struktura upućuju na sličnost s prašumom u njenoj terminalnoj fazi. Uz pretpostavku da se jedino intenzivnim i sustavnim gospodarenjem može trajno podržavati uravnotežena preborna struktura, cilj je istaknuti postojanje veze između gospodarenja (propis i izvršenje intenziteta i strukture prebornih sječa) i „razvoja" strukture sastojine. Na temelju provedenih i objavljenih istraživanja na konkretnim šumskim objektima jele i bukve, razmatraju se sljedeći elementi planiranja gospodarenja i strukture jelovo-bukovih sastojina nepravilne strukture:

1. Nestajanje preborne strukture i gomilanje drvne zalihe krupnog drva promjera iznad 70 cm tijekom prošlog 50-godišnjeg razdoblja kao posljedica propisanih i izvršenih sječa niskih intenziteta;
2. Primjenjivost obrasca razlike drvne zalihe prije i poslije preborne sječe temeljenog na postotku godišnjeg tečajno volumnog prirasta za planiranje etata, koja se pokazuje upitnom u uvjetima velikih drvnih zaliha i malog postotka godišnjeg volumnog prirasta;
3. Vrijeme prijelaza, priliv i struktura obnove kao pokazatelji postojeće narušene strukture sastojina; predikcija planiranog intenziteta i strukture prebornih sječa, priliva (obnove sastojine) i „razvoja" strukture sastojine tijekom budućih ophodnjica, koja u međuovisnom dinamičkom sustavu ukazuje na potrebu za sječama jačih intenziteta (preko 25 %) u prvim ophodnjicama i na polagano popravljanje narušene preborne strukture;
4. Rezultati koji ukazuju na negativan utjecaj temeljnice stabala jele i bukve većih od 50 cm promjera na prirodnu obnovu jele, kao i rezultati pozitivnog reagiranja preborne sastojine prirodnom obnovom jele (razvojni stadij podmladka) 5 godina nakon preborne sječe jačeg intenziteta (24 %).

Ključne riječi: jela, obična bukva, narušena preborna struktura, intenzitet preborne sječe, prirast.

UDK: 630*228.81+655

Review article
Pregledni članak

VIRGIN FOREST OF ČORKOVA UVALA IN THE LIGHT OF PROVIDING NON-WOOD FOREST FUNCTIONS

PRAŠUMA ČORKOVA UVALA U SVJETLU PRUŽANJA OPĆEKORISNIH FUNKCIJA ŠUME

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Received – *Prispjelo*: 15. 10. 2007. Accepted – *Prihvaćeno*: 3. 3. 2008.

The best known Croatian beech-fir virgin forest of Čorkova Uvala in the Plitvice Lakes National Park is the first virgin forest in Croatia to be scientifically explored. The decisive role in the shaping of the structure of this forest is played by soil depth and relief. Depending on karst phenomena, shallow brown soil on limestone (calcocambisol) and deep lessivated soil (luvisol) alternate in a mosaic-like pattern. The diversity of pedomicrosites has resulted in varied conditions for the growth of silver fir (*Abies alba* Mill.), common beech (*Fagus sylvatica* L.) and common spruce (Picea *abies* Karst.). This is responsible for the formation of an uneven-aged or selection structure of the virgin forest in the initial, optimal and ageing stage, which discriminates this virgin forest from other virgin beech-fir forests in Europe.

Research into the virgin forest development has shown that non-wood forest functions, especially those related to environmental protection, are not fulfilled in several of its developmental stages. It was found that, in comparison with a natural managed forest, a virgin forest does not produce non-wood functions as well as the former. Old growth stands should be preserved in principal forest ecosystems of Croatia to serve as sites for forestry and other research, while other forestland should be adequately managed according to natural principles to ensure optimal commercial and non wood functions.

Key words: virgin forest, nature-based forest management, non-wood forest functions, Čorkova Uvala, Plitvice Lakes National Park

INTRODUCTION
UVOD

The virgin forest of Čorkova Uvala in the Plitvice Lakes National Park is a part of the former spacious virgin forest complex of beech and fir that covered large areas in the mountainous part of the Croatian Dinaric mountain chain. The Croatian Dinarides are characterized by a typical karst relief that abounds in landforms such as sinkholes, dolines, cracks, stone blocks, crevices and fissures. The geological bedrock is made up of limestones with dolomite interbeds from the Upper Cretaceous. The bedrock is formed from vertically or laterally positioned plates (Prpić, 1972).

According to Seletković (201), the climate of beech-fir forests in Lika and Gorski Kotar is temperate warm-rainy and partially snowy-boreal. As indicated by some estimates, the average annual precipitation in Čorkova Uvala amounts to about 1,600 mm, while the mean annual air temperature is about 7° C. The dominant soil type is brown soil on limestone (calcocambisol) of varying depths (depending on area stoniness), which offers an array of conditions for the growth of forest trees. More shallow soils, melanosol on limestone and dolomite (calcomelanosol) have been identified in higher areas, while cracks and sinkholes contain deep lessivated soils (luvisol). Compared to other soils in the area, luvisol ensures much more favourable growth conditions to forest trees. Stone areas, especially plate-like layers with sporadic very shallow brown soil on limestone or melanosol on limestone provide exceptionally unfavourable conditions for the growth of forest trees (Figures 1 and 2). The virgin forest of Čorkova Uvala extends over 80 ha. Figure 1 shows a sample plot of 1 ha established in 1957. The proportion of stone area in this plot was 19%.

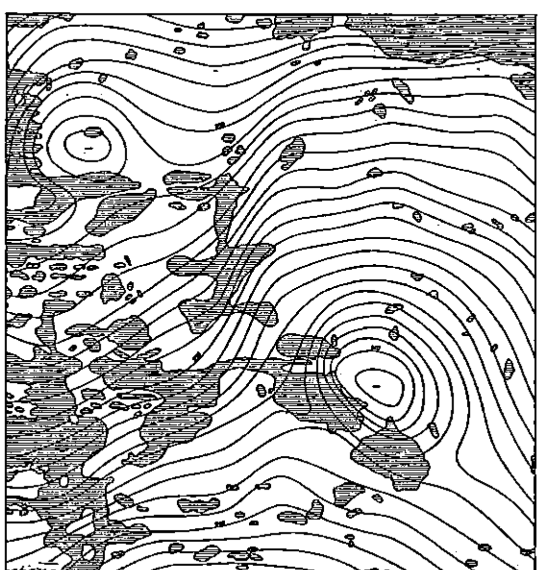

Figure 1: Contours and stoniness of the sample plot in the Čorkova Uvala virgin forest in Plitvice Lakes National Park

Slika 1. Prikaz slojnica i kamenitosti pokusne plohe u prašumi Čorkova uvala u Nacionalnom parku Plitvička jezera

In such places trees of silver fir, common beech and common spruce manifested much shower growth. Čorkova Uvala is situated at an altitude ranging from 860 to 1028 m. The exposition is eastern and north-eastern, and the slope is from 5 to 37 degrees.

A virgin forest is basically characterized by natural features. In other words, this is a forest in which growth and development evolves under the impact of natural biotic and abiotic factors. This results in the diversity of species, developmental stages and vitality. Viewed spatially and structurally, a virgin forest manifests several developmental stages. These are the initial (regeneration), the optimal, the terminal (ageing stage and decomposition stage) and the selection stage. In beech–fir virgin forests the life cycle that embraces all these developmental stages lasts for about 500 years. In the past 250 years the forestry profession has intensively drawn upon the insights gained by forestry, biological, technical and economic sciences. These insights also reflect the situation in a virgin forest, particularly the regeneration stage and the optimal stage. The development of a natural managed forest depends on biological and ecological relationships in the forest ecosystem, which are more or less under the impact of man. In contrast, in a virgin forest these relationships evolve without any human influence.

What discriminates Croatian beech-fir virgin forests from other European beech-fir virgin forests is the karst bedrock. The exceptional diversity of the parent material, as well as the diversity of soil types and depths, has resulted in varying diameter and height increments of virgin forest trees growing in different microsites. An uneven-aged structure of the forest stand, scientifically called the selection structure, has been observed in almost all developmental stages of the virgin forest, i.e. the initial, the optimal and the terminal stage. This is best illustrated by the number of trees per diameter class, which has the characteristic of the Liocourt curve.

In order to determine the impact of microsites on tree growth in the Čorkova Uvala virgin forest, we selected silver firs with breast diameters of about 40 cm from two microsite types. The first microsite type is in the stony part of the area, while the second microsite type has deeper soil. The annual rings from each sample type were analyzed for the period from 1960 to 1975. The annual rings from stony microsites were 2.4 times narrower than those from microsites with deeper soil (Prpić et al., 2001). Consequently, the impact of microsites on tree growth should be further investigated. Significant differences in diameters and heights of young trees growing in different microsites indicate a typical selection structure (Liocourt curve) in all developmental stages of the virgin forest, except that of regeneration. Similar results were also found in the virgin forest of Devčića Tavani in Northern Velebit (Prpić, 1972, 1979, Prpić and Seletković, 1996, Prpić et al., 1994, Prpić et al., 2001, Mayer et al., 1980, Kramarić and Iuculano, 1989). This was particularly confirmed by research of Mayer et al., and Kramarić and Iuculano, which encompassed a larger area of the virgin forest of Čorkova uvala (Prpić et al., 2001).

According to Anić (1965), the Čorkova Uvala virgin forest was in the late initial stage, or according to Korpel (1995), it was in the stage of intensive growth and the beginning of the optimal stage. Its growing stock amounted to 761 m^3/ha, but rose to

924 m³/ha in the following 30 years (1957 – 1987), which shows that the old growth stand in the sample plot entered the ageing stage (terminal stage).The tree mixture composition consisted of 56% of silver firs, 34% of common beeches and 10% of common spruces. Silver fir had the average volume of 5 m³, common spruce of 4 m³ and common beech of 1 m³. The number of common beeches declined in the mentioned period by 50% and that of silver firs and common spruces by 20%. Increased increment is mainly due to the common beech, which occurred in the virgin forest in the second generation since its life cycle is twice as short as that of silver fir.

Prebježić (2007) provided spatial presentation of the virgin forest as it was in 1957, including tree positions, crown projections, tree heights, positions of dead standing and fallen trees, and area stoniness. According to research based on the microsite method which involved emission pollution, the virgin forest of Čorkova Uvala was then not significantly contaminated with toxic gas emissions and acid rains, unlike the forests in the Plitvice area in the northern exposition (Glavač et al., 1985).

Figure 2 shows the area of the first sample plot of 1 ha, in which Academician Milan Anić launched his research in 1957 (Prebježić, 2007). According to Anić (1965) and Rauš (Prpić, 1979), the virgin forest belongs to the Dinaric beech-fir forest *Omphalodo-Fagetum* Marinček et al. 1992.

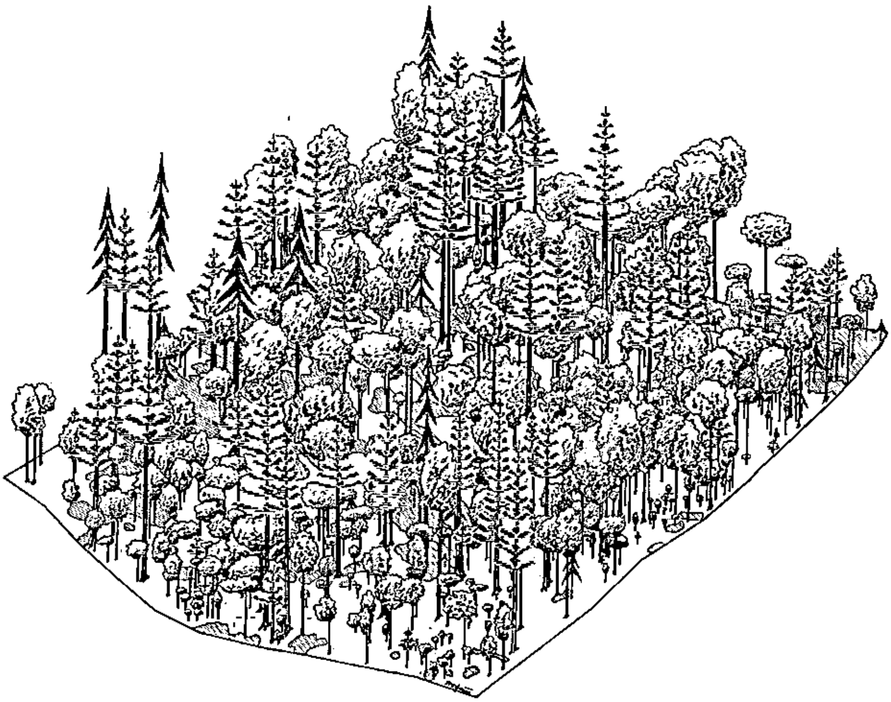

Figure 2: 3D view of the sample plot in Čorkova Uvala
Slika 2. Trodimenzionalni prikaz pokusne plohe u prašumi Čorkova uvala

WHICH NON-WOOD FOREST FUNCTIONS DOES A VIRGIN FOREST PROVIDE?
KOJE OPĆEKORISNE FUNKCIJE ŠUMA PRUŽA PRAŠUMA?

Non-wood functions or forest services are indirect benefits that managed forests offer to the environment. They are closely related to the raw material forest service, which represents direct benefit. Non-wood forest functions are particularly important in the ecological and social sense due to their impact on more immediate or remote surroundings. Non-wood forest functions drew increased attention when damage to forests, incurred by modern technical civilization, began to come to light (degradation, forest destruction and decline). This damage was primarily caused by harmful gases (sulphur dioxide and nitrogen compounds) produced by industrial and traffic emissions. Forests grew increasingly contaminated by harmful gas emissions (dry and wet depositions), especially in the northern hemisphere where industry is highly developed. In some European countries forests were so badly contaminated that they virtually perished (Germany, Czech Republic).

Forests damaged to such an extent ceased to produce wood material. Aquatic and Aeolian soil erosion set in, water springs dried out, high water waves and floods grew in frequency, and the formerly unimaginable climatic extremes occurred. This was a clear indication that beneficial forest functions in the environment were no longer present. The second half of the twentieth century saw growing interest in the importance of non-wood forest functions (Prpić, 1992). In the initial estimates their value was within the value of timber; however, in the 1990s this value increased thirty-fold and showed further rising tendency (Sabadi et al., 2000). More recently, the high value of non-wood forest functions is attributed to the impact of forests on atmospheric carbon dioxide sequestration in the process of photosynthesis and mitigation of greenhouse effects.

Non-wood forest functions are divided into ecological (protective), social and combined (social-ecophysiological) (Prpić, 2003). Ecological functions embrace the hydrological function which balances water relations in the surroundings, the water-protective function which ensures potable water from ground courses and forest springs, the anti-erosion function which refers to the role of forests in preventing erosions, the climatic function which reduces wind severity and mitigates climatic extremes (in winter, temperature in the forest is several degrees higher and in summer several degrees lower than in an out-of-forest area), and finally the anti-emission function, expressed by the capacity of tree crowns to retain large quantities of harmful substances from the atmosphere (dry depositions and acid rains).

Social functions include aesthetic, recreational, health and tourist roles of a forest. Social-ecophysiological forest functions embrace genetic, biological-diverse, natural-protective and physiological functions. The genetic function refers to genofund conservation, the biological-diverse function protects the wealth of the forest's living world, the nature-protective role relates to different categories of forest protection, and the physiological function refers to enriching the atmosphere with oxygen and sequestering carbon dioxide in the process of photosynthesis.

In some developmental stages of a virgin forest (e.g. ageing and decomposition), some non-wood forest functions are reduced or are completely absent. In the developmental stage of decomposition, the death of trees and the occurrence of gaps lead to the decline of all forest functions, including the anti-erosion, climatic and anti-emission function, and, to a smaller extent, the hydrological and water protective function. A decrease in the photosynthetic impact in the developmental stage of ageing and decomposition leads to a decrease in the physiological functions of oxygen release and carbon sequestration. In a virgin forest in the developmental stage of regeneration and decomposition, carbon sequestration and oxygen release is of lower intensity in relation to a natural managed forest, where there are no ageing and decomposition stages and the regeneration stage is much shorter than in a virgin forest.

The function of preserving biological diversity of forests on the example of a virgin forest is prescribed by the FSC forest certification (Criterion 6.3) and a by-law. In a nature-based managed forest, where there are no dead trees to provide the ecological niche for a part of the living world, an agreed number of such trees must be preserved.

According to Mayer et al. (1980), the developmental stages of ageing, decomposition and regeneration in a virgin forest, in which the number of non-wood forest functions is reduced, last for about 300 years. This is a very long period in the 500-year-long life of a beech-fir virgin forest.

DISCUSSION AND CONCLUSIONS
RASPRAVA I ZAKLJUČCI

Modern forest management in Croatia is based on natural laws and processes occurring in a virgin forest. It encompasses natural regeneration, selection and competition, as well as the use of optimal site conditions. This is how a natural and stable forest stand is formed and maintained. Such a high-quality stand is capable of optimal fulfillment of non-wood forest functions. However, nature protection in the continental region is increasingly focused on natural forests. Owing to adequate forest management, these forests have for over two centuries served to protect nature and provide other non-wood forest functions. The intention is to convert these forests into secondary virgin forests by introducing different protection categories, such as national parks, nature parks and others, as well as implementing protection over about 5% of forested areas (about 1900,000 ha).according to the forest certification regulation. This will represent significant loss of some non-wood forest functions and complete loss of the raw material forest function. According to some recent findings, the most important non-wood forest functions are diminished or lost during about 60% of a virgin forest's life.

The problem of partial or complete loss of non-wood functions of a beech and fir virgin forest should be scientifically investigated so as to ensure the stability of forests in protected areas and guarantee maximal provision of non-wood forest functions. This refers primarily to carbon sinks in different developmental stages (regeneration, ageing and decomposition), in which photosynthetic effects are much smaller or completely absent. Depending on the relief, erosion and surface runoff in the developmental stage of decomposition and regeneration become more intensive, which in turn increases water waves and causes more frequent torrents and floods.

In a forest managed on close-to-nature principles there are no virgin forest stages of ageing or decomposition. Biologically, such a forest is less diverse due to the absence of old and dead trees that otherwise provide an ecological niche for a part of the forest's living world. However, this problem is currently solved by retaining a certain number of dead trees in a stand throughout the forest' life.

In order to monitor natural processes and relationships in virgin forests, it is necessary to preserve secondary virgin forests in the most important Croatian forest ecosystems. It is also necessary to apply silvicultural treatments in all other forests (managed and protected) with the goal of permanently maintaining the stability of forest ecosystems so that they could provide optimal non-wood and commercial functions. We believe that it is reasonable to utilize timber of high quality and simultaneously preserve and protect the nature and the environment.

Forests managed according to natural principles provide general nature protection and ensure other non-wood forest functions. By adhering to well known forestry principles which the forestry science has established in the course of studying virgin ecosystems, all benefits currently required from a forest ecosystem will be achieved. A stable and well tended forest ensures optimal non-wood forest functions (Prpić, 2001).

REFERENCES
LITERATURA

Anić, M., 1965: Prašuma Čorkova uvala (rukopis).

Anić, I., S. Mikac, M. Oršanić, D. Drvodelić, 2006: Comparative analyses of structure in old-growth and managed silver fir and beech stands in Croatian Dinaric Karst, Perodicum Biologorum.

Glavač, M., H. Koenies, B. Prpić, 1985: Zur Imissionsbelastung der industriefernen Buchen und Buchentannenwaelder in den Dinarischen Gebirgen Norwestjugoslavniens. Verhandlungen der Gesellschaft fuer Oekologie, Gratz (Goettingen 87), Band XV: 237-247.

Korpel, Š., 1995: Die Urwaeder der Westkarpaten,Stuttgart, Yena, New York.

Korpel, Š., 1996: Razvoj i struktura bukovo-jelovih prašuma i njihova primjena kod gospodarenja prebornom šumom, Šum. list, CXX (3-4): 203-209.

Kramarić, Ž., T. Iuculano, 1989: O strukturi i normalitetu šuma bukve i jele (*Abieti-Fagetum illyricum* Horv. 1938) na primjeru prašume Čorkova uvala, Šum. list, XXX: 581-589.

Matić. S., B. Prpić, Đ. Rauš, A. Vranković, 1979: Rezervati šumske vegetacije Prašnik i Muški Bunar, Ur. Đ. Rauš, Zavod za istraživanja u šumarstvu Šumarskoga fakulteta Sveučilišta u Zagrebu i Šumsko gospodarstvo "Josip Kozarac" Nova Gradiška: 131.

Matić, S., B. Prpić, I. Anić, M. Oršanić, 2003: Bukove prašume, Obična bukva u Hrvatskoj, Ur. S. Matić, Akademija šumarskih znanosti, Zagreb: 414-441.

Mayer, H., M. Neumann, H. G. Sommer , 1980: Bestandesaufbau und Verjuengugsdynamnik unter dem Einfluss natuerlicher Wilddichten im kroatischen Urwaldreservat Čorkova uvala/Plitvicer Seen, Schweizerischen Zeitschrift fuer Forstwesen, 131 (1): 45-70.

Prebježić, P., 2007: Grafički prikaz strukturnih odnosa u sastojini prašume bukve i jele *(Abieti-Fagetum illyricum*, Horv. 1938) "Čorkova uvala" na području Nacionalnog parka Plitvička jezera, Šum. list 131 (7-8): 345-352.

Prpić, B., 1972: Neke značajke prašume Čorkova uvala, Šum. list, 96 (9-10): 325-333.

Prpić, B., 1979: Struktura i funkcioniranje prašume bukve i jele (*Abieti – Fagetum illyricum,* Horv. 1938) u Dinaridima SR Hrvatske, Drugi kongres ekologa Jugoslavije, Ur. Đ. Rauš, Savez društava ekologa Jugoslavije, Zagreb: 899-924.

Prpić, B., 1992: O vrijednosti općekorisnih funkcija šume. Šumarski list, 6-8: 301-312.

Prpić, B., Z. Seletković, J. Vukelić, 1994: Der Urwald Čorkova Uvala ein Model fuer den multifunktionalen Buchen-Tannen Planterwald. 7. IUFRO Tannensymposium, Altensteig – Meinz (ed. W. Eder): 250-255.

Prpić, B., Z. Seletković, 1996: Istraživanja u hrvatskim prašumama i korištenje rezultata u postupku s prirodnom šumom, Unapređenje proizvodnje biomase šumskih ekosustava, Ur. B. Mayer Šumarski fakultet Sveučilišta u Zagrebu i Šumarski institut Jastrebarsko: 97-104.

Prpić, B., S. Matić, J. Vukelić, Z. Seletković, 2001: Bukovo-jelove prašume hrvatskih Dinarita. Obična jela u Hrvatskoj, Ur. B. Prpić, Akademija šumarskih znanosti, Zagreb:479-500.

Prpić, B., 2003: Općekorisna uloga bukovih šuma. Obična bukva u Hrvatskoj, Ur. S. Matić, Akademija šumarskih znanosti, Zagreb: 213-227.

Sabadi, R., B. Prpić, H. Jakovac, 2001: Ukupna vrijednost jelovih šuma u Hrvatskoj. Obična jela u Hrvatskoj, Ur. B. Prpić, Akademija šumarskih znanosti Zagreb: 792-826.

Seletković, Z., 2001: Klima i hidrološke prilike u dinarskim jelovim šumama u Hrvatskoj. Obična jela (*Abies alba* Mill.) u Hrvatskoj. Ur. B. Prpić, Akademija šumarskih znanosti, Zagreb, str. 133-146.

PRAŠUMA ČORKOVA UVALA U SVJETLU PRUŽANJA OPĆEKORISNIH FUNKCIJA ŠUME

SAŽETAK

Najpoznatija hrvatska prašuma bukve i jele (*Omphalodo-Fagetum* /Marinček i dr. 1992/) u području Nacionalnoga parka Plitvička jezera prva je u Hrvatskoj znanstveno istražena. Presudnu ulogu u oblikovanju strukture te prašume ima dubina tla i reljef. U toj se prašumi, ovisno o krškim fenomenima mozaično izmjenjuju plitko smeđe tlo na vapnencu (kalkokambisol) i duboko lesivirano tlo (luvisol). Raznolikost pedomikrostaništa uvjetovala je različite uvjete uspijevanja stabala obične jele (*Abies alba* Mill), obične bukve (*Fagus sylvatica* L.) i obične smereke (*Picea abies* Karst.). Tako je oblikovana raznodobna, odnosno preborna struktura prašume u inicijalnoj, optimalnoj i fazi starenja, po čemu se ova prašuma razlikuju od ostalih bukovo-jelovih prašuma Europe. Proučavajući razvoj prašume utvrdili smo kako više njezinih razvojnih faza ne ispunjava u potpunosti općekorisne funkcije šume i to posebno neke vrlo značajne za zaštitu okoliša. Prema dosadašnjim spoznajama može se sa velikom sigurnošću tvrditi kako prašuma u svome dugom životnom vijeku obavlja u znatno manjoj mjeri općekorisne funkcije od prirodne gospodarske šume. U glavnim šumskim ekosustavima u Hrvatskoj potrebno je očuvati prašumske sastojine za potrebe šumarskih i drugih istraživanja, dok se sa ostalim šumskih površinama treba pravilno gospodariti prema prirodnim principima i s ciljem osiguranja optimalnih gospodarskih i općekorisnih funkcija šuma.

Ključne riječi: prašuma, prirodno gospodarenje šumom, općekorisne funkcije šuma, Čorkova uvala, Nacionalni Park Plitvička jezera

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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 Physiographic soil characteristics in the narrow-leaved ash (*Fraxinus angustifolia* Vahl) floodplain forest - the three studied sites in Upper Posavina in Croatia

Phase of ash forest	Soil	Horizon	Depth	Particle size distribution				Bulk density	Porosity	Water capacity	Air capacity	pH[a]	C org.
				Coarse sand	Fine sand	Silt	Clay						
			(cm)	(%)				g cm^{-3}	(vol %)				g kg^{-1}
Initial phase	Gleysol	A/G	0-7	0	17.5	40.6	41.9	0.83	64.4	58.7	5.7	5.69	89.4
		Grso	8-25	1	9.8	32.1	57.1	1.15	52.9	52.0	0.9	6.20	21.0
		Gr	26-55	0	9.9	27.6	62.5	1.19	52.4	51.5	0.9	6.75	36.6
		Grso	56-75	1	7.4	25.7	65.9	1.22	51.2	48.4	2.8	7.13	9.6
		Gr	76-100	1	6.4	20.6	72.0	1.37	45.2	43.2	2.0	7.23	6.9
		Gr	101-120	0.9	12.4	14.3	72.4	1.24	50.4	47.5	2.9	7.59	3.9
Optimal phase	Gleysol	Aa	0-14	0	13.1	46.3	40.6	0.99	56.4	50.1	6.3	5.67	42,0
		Gr	15-40	0	25.1	21.9	53.0	1.19	51.3	49.7	1.6	6.56	19.5
		Grso	41-83	1.7	21.3	18.6	58.4	1.34	45.1	41.4	3.7	7.42	9.3
		Gr	84-120	0	10.4	32.4	57.2	1.47	39.8	38.3	1.5	7.47	11.4
Terminal phase	Gleysol	Aoh	0-11	1.3	28.5	47.2	23.0	1.00	58.0	49.0	9.0	6.88	66.6
		Gso	12-50	1.9	20.6	42.5	35.0	1.39	45.8	41.2	4.6	7.49	62.1
		Gso	51-100	1	36.2	28.5	34.3	1.45	44.9	35.6	9.3	7.80	6.0

a - pH measured in water suspension

Slike

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.

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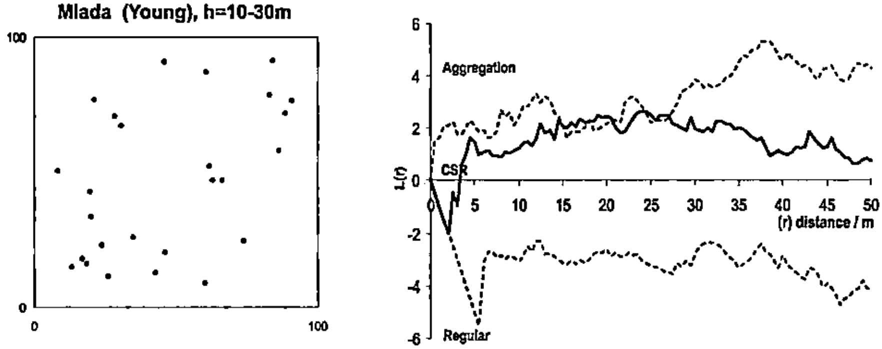

Slika 1. Horizontalna projekcija stabala na pokusnoj plohi lijevo, rezultati PP analize desno

Rasprava

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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.

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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:

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Šumarski fakultet Sveučilišta u Zagrebu
P.O.B. 422
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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);
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- All margins 2.5 cm;
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- 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.

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

Authors' titles and addresses – Written after the summary. 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

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

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

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.

Results

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).

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 Physiographic soil characteristics in the narrow-leaved ash (*Fraxinus angustifolia* Vahl) flood-plain forest - the three studied sites in Upper Posavina in Croatia

Phase of ash forest	Soil	Horizon	Depth	Particle size distribution				Bulk density	Porosity	Water capacity	Air capacity	pH[a]	C org.
				Coarse sand	Fine sand	Silt	Clay						
			(cm)	(%)				g cm^{-3}	(vol %)				g kg^{-1}
Initial phase	Gleysol	A/G	0-7	0	17.5	40.6	41.9	0.83	64.4	58.7	5.7	5.69	89.4
		Grso	8-25	1	9.8	32.1	57.1	1.15	52.9	52.0	0.9	6.20	21.0
		Gr	26-55	0	9.9	27.6	62.5	1.19	52.4	51.5	0.9	6.75	36.6
		Grso	56-75	1	7.4	25.7	65.9	1.22	51.2	48.4	2.8	7.13	9.6
		Gr	76-100	1	6.4	20.6	72.0	1.37	45.2	43.2	2.0	7.23	6.9
		Gr	101-120	0.9	12.4	14.3	72.4	1.24	50.4	47.5	2.9	7.59	3.9
Optimal phase	Gleysol	Aa	0-14	0	13.1	46.3	40.6	0.99	56.4	50.1	6.3	5.67	42,0
		Gr	15-40	0	25.1	21.9	53.0	1.19	51.3	49.7	1.6	6.56	19.5
		Grso	41-83	1.7	21.3	18.6	58.4	1.34	45.1	41.4	3.7	7.42	9.3
		Gr	84-120	0	10.4	32.4	57.2	1.47	39.8	38.3	1.5	7.47	11.4
Terminal phase	Gleysol	Aoh	0-11	1.3	28.5	47.2	23.0	1.00	58.0	49.0	9.0	6.88	66.6
		Gso	12-50	1.9	20.6	42.5	35.0	1.39	45.8	41.2	4.6	7.49	62.1
		Gso	51-100	1	36.2	28.5	34.3	1.45	44.9	35.6	9.3	7.80	6.0

a - pH measured in water suspension

Figures

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.

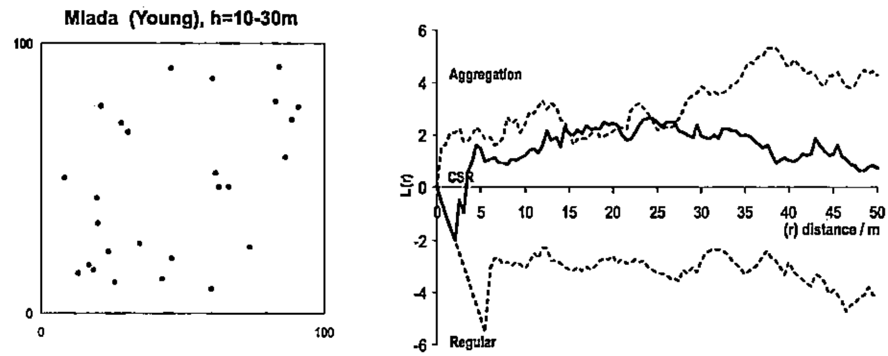

Fig.1 Horizontal projection of trees on test site on the left, results of PP analysis on the right.

Discussion

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

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

Acknowledgements

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.

Literature

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).

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Title

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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.

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GLAS. ŠUM. POKUSE · Vol. 42 Str. 1–96 Zagreb, 2007–08.

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ISSN 0352-3861
9 770352 386008