Natural regeneration of silver fir (Abies alba Mill.) along the edge of the Zagreb - Rijeka motorway

Anić, Igor; Perković, Marko; Mikac, Stjepan

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

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

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

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

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Abstract

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

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

Sažetak

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

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

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

INTRODUCTION
UVOD

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

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

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

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

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

RESEARCH AREA
PODRUČJE ISTRAŽIVANJA

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

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

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

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

RESEARCH METHODS
METODE ISTRAŽIVANJA

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

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

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

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

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

RESEARCH RESULTS AND DISCUSSION
REZULTATI ISTRAŽIVANJA I RASPRAVA

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

An ideal selection structure of a stand consists of trees of different dimensions whose distribution across a surface unit mirrors the characteristic selection tree distribution, where a normal amount of wood supply is distributed in such a way as to ensure the maximal increment, optimal natural regeneration, and ecosystem stability (Matić et al. 2001). Such a structure of selection stands in the Croatian Dinaric range is defined by normal models (Klepac 1997, 1962, 1961). According to the Management Plan (2000 – 2009), the investigated stand has the volume of 399.53 m³/ha, of which 5% is accumulated on trees with dbh up to 30 cm, 39% on medium thick trees with dbh between 31 – 50 cm, and the rest of 56% is accumulated on trees with dbh over 51 cm. The stand composition is dominated by silver fir which participates with 77.30%, followed by beech with 21.47%, common spruce with 1.13% and other species accounting for 0.10%. It is interesting to note that there are no silver firs among thin trees with dbh up to 30 cm. In this class the dominant species is common beech. The majority of silver firs are mature trees with dhb over 50 cm. Stand density is 0.62 and the annual current volume increment is 6.04 m³/ha. What follows is the description of the stand: "An uneven-aged fir stand in the stage of thick and medium thick trees. Beech occurs individually or in smaller groups and is in the stage of medium thick trees. In parts with less dense canopy there are small groups of young beech growth and some sporadic groups of young growth and saplings of fir. The fir's health status is poor." The management guidelines state the following: "the prescribed yield for the fir should relate only to dying and dead trees, while the difference up to the full yield should be realized by cutting mature and mechanically damaged trees in parts in which they interfere with the young generation. In terms of beech, only some individual beeches that are damaged should be cut down. In parts with fully canopied mature trees felling should be applied in order to open up groups where regeneration will be initiated".

Regular and salvage felling of snags in the period 2000 – 2009 included a total of 205 m³/ha, of which fir accounted for 94%. Thus, the cutting amount exceeded the planned prescribed yield in the stand with reduced density. These data relate to the average picture of the stand as a whole.

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

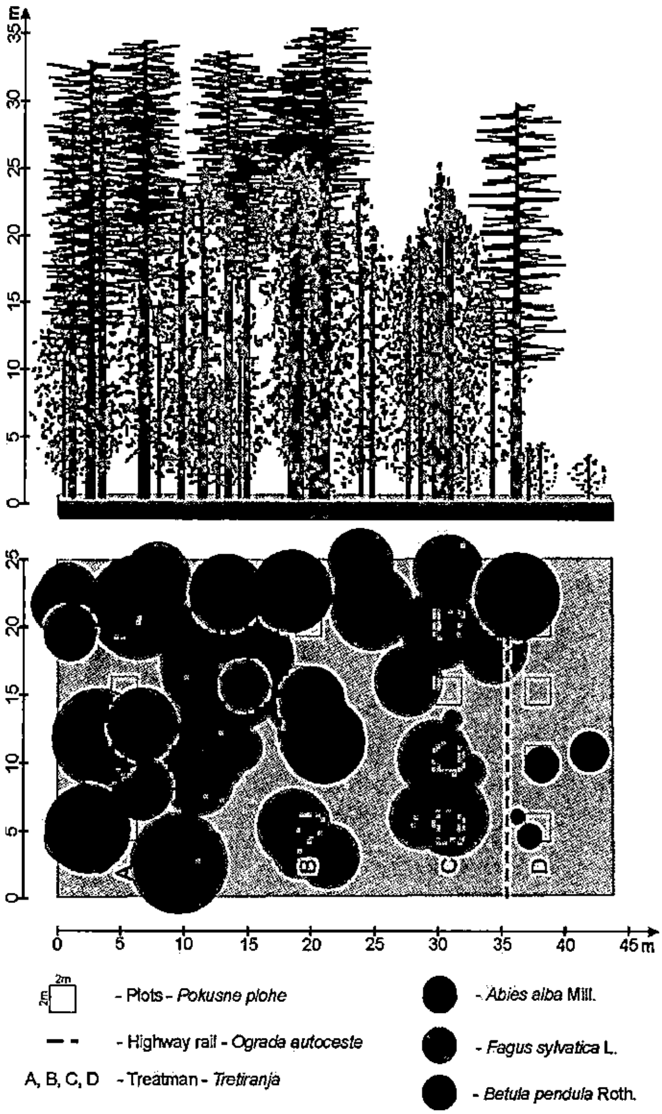

Figure 1 Stand profile and horizontal crown projection in the zones A – D of the forest edge.
***Slika 1** Profil sastojine i horizontalna projekcija krošanja u zonama A – D rubnog šumskog pojasa.*

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

The structure of the young growth
Struktura mladog naraštaja

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

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

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

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

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

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

Analysis of the young growth
Analiza pomlatka

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

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

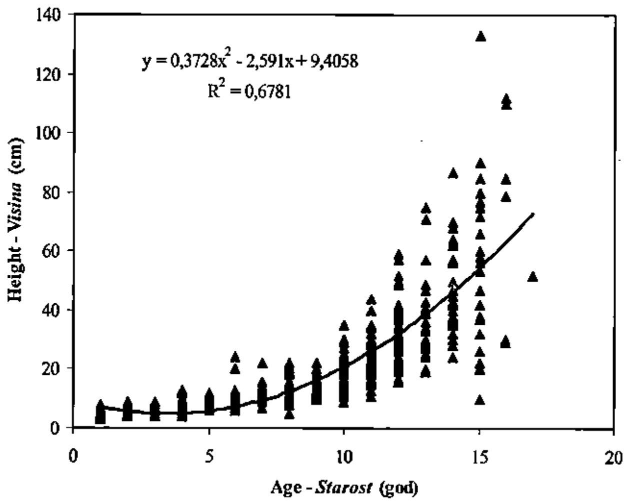

Figure 2 Age to height ratio of the young growth of silver fir.
Slika 2 Odnos između dobi i visine pomlatka obične jele.

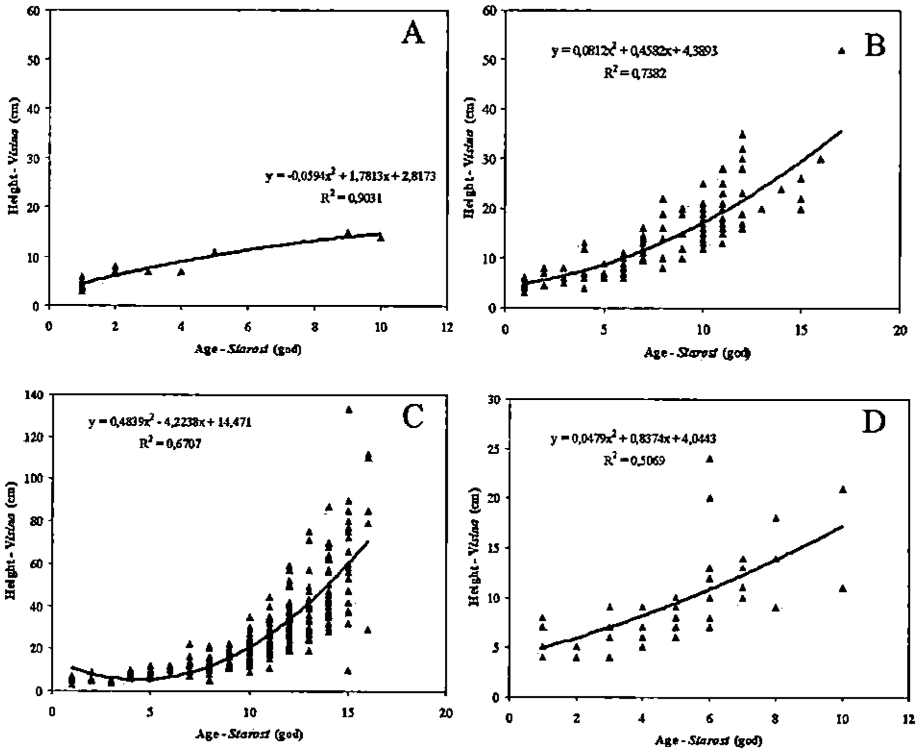

Figure 3 Age to height ratio of the young growth per treatment.
Slika 3 Odnos između starosti i visine pomlatka po tretiranjima.

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

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

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

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

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

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

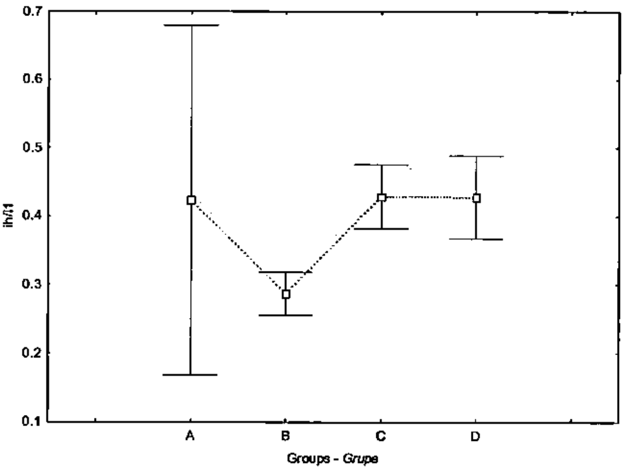

Figure 4. Ratio between the terminal and lateral shoot of the young growth of silver fir.
***Slika 4.** Omjer terminalnog i lateralnog izbojka pomlatka obične jele.*

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

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

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

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

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

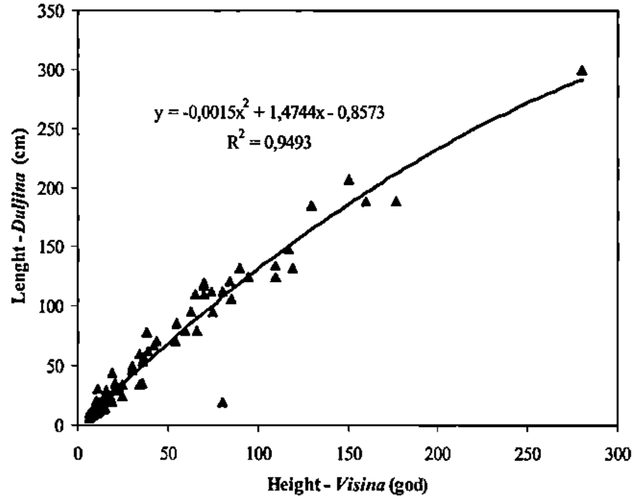

Figure 5 Ratio between the length and height of the young growth of common beech.
Slika 5. Odnos između duljine i visine pomlatka obične bukve.

CONCLUSIONS
ZAKLJUČCI

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

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

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

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