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# MICROCLIMATE AND NATURAL REGENERATION OF FOREST GAPS AS A CONSEQUENCE OF SILVER FIR (*Abies alba* Mill.) DIEBACK

## MIKROKLIMA I PRIRODNO POMLAĐIVANJE ŠUMSKIH PROGALA NASTALIH ODUMIRANJEM STABALA OBIČNE JELE (*Abies alba* Mill.)

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**Summary**

Salvage cutting is a frequent operation to remedy the dieback of silver fir trees (*Abies alba* Mill.), which results in reduced stand canopy density and formation of forest gaps. This study was conducted in the beech-fir forest range of mountainous Croatia. The aim of the study was to determine microclimate conditions and natural regeneration in large and small forest gaps. Microclimate elements were measured and the density of plants from natural regeneration determined within forest gaps, in forest gap edge areas, and in control plots. Soil temperatures were significantly affected by changes in forest gap sizes with respect to the values of air temperatures, and were highest within the gaps as compared to gap edge areas and control forest stands. Microclimate had a significant affect on the number of small seedlings of silver fir and common beech in the large forest gaps, while this was not the case for the small forest gaps.

**KEY WORDS:** dieback, salvage cutting, silver fir, forest gap, microclimate, natural regeneration

## INTRODUCTION
## UVOD

Decline and dieback of trees is a major ecological issue in forestry and causes significant management issues, such as reduction of the growing stock, lack of natural regeneration, weed cover of habitats, etc. The occurrence of silver fir (*Abies alba* Mill.) dieback was first observed and recorded in its natural habitat regions (Larsen 1986, Thomas et al. 2002, Oliva and Colinas 2007, Tikvić et al. 2008, Ficko et al. 2011). Silver fir dieback is significant from a silvicultural standpoint, as it is the key symptom of the lack of natural regeneration (Matić et al. 1996). Silver fir (*Abies alba* Mill.)

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is the most significant economic conifer species in the Republic of Croatia, accounting for a share of 9.4% of the growing stock of Croatian forests (Meštrović 2001). Silver fir is the most damaged conifer tree species in Croatia, with 64% trees exhibiting loss of over 25% needles (Potočić et al. 2017). Dieback of silver fir in Croatia, especially in the Dinarides area, is a result of the complex and variable activity of abiotic and biotic factors. Dieback can be individual, in smaller groups, or may occur in complete stands over a forest area (Anić et al. 2002).

Forest gaps can be formed naturally by wind breakage, ice breakage, dieback due to interspecies competition or due to abiotic or biotic factors. Gaps can also be created artificially, by human activities such as silvicultural practices (Muscolo et al. 2007, Albanesi et al. 2008).

By Croatian law (Anon 2006), the cutting of dead and damaged trees is mandatory and is carried out each year from July to September. By salvage cutting dead or damaged trees, larger or smaller forest gaps are formed in the stand canopy density. Gaps in the stand, which are the result of disappearance of trees, create conditions different from those in the neighbouring canopy-covered stand (Hubbell and Foster 1986, Muscolo et al. 2007), and this affects regeneration (Brown 1993). The removal of trees result in a change of the microclimate (Aussenac 2000, Ritter et al. 2005, Vilhar et al. 2005, Muscolo et al. 2007, Albanesi et al. 2008). Microclimate conditions have an important role for the processes in the forest ecosystem. It is important for development of plants, seed germination, growth and reproduction, for fauna and for the implementation of the main ecosystem processes, such as photosynthesis and the nutrient cycle (Gray et al. 2002, Ritter 2005, Arx et al. 2012).

The microclimate of forest gaps, formed naturally or as a result of silvicultural practices, can strongly affect forest regeneration and the diversity of habitat conditions compared to those within the forest stand (Albanesi et al. 2008, Latif et al. 2010). Temporal and spatial variations of microclimate conditions in and around forest gaps have rarely been investigated in managed or natural fir forests with varying climates and species compositions (Vilhar et al. 2005, Muscolo et al. 2007, Rozenberger at al. 2007, Albanesi et al. 2008, Muscolo et al. 2010). To date, no such investigations have been carried out in managed fir forests in Croatia, while Rozenberger et al. (2007) carried out an investigation in Croatian beech-fir old growth forests. Considering the significance of fir forests for the Croatian forestry, there is a need to better understand the causes of threat to these ecosystems, and to determine measures for their rehabilitation. The high sensitivity of fir and beech-fir forests, and the occurrence of tree dieback and decline of entire stands, was the motive for conducting this study in the Gorski Kotar region of Croatia. The objective of this study was to describe microclimate conditions in and around a large and small forest gap in beech-fir forests, to compare the microclimate conditions of large and small forest gaps and determine the status of natural regeneration and determine the relationship of microclimatic elements in terms of the number and species of plants in natural regeneration.

## MATERIALS AND METHODS
## MATERIJAL I METODE

### Study area – *Područje istraživanja*

The study was carried out in the mountainous Gorski Kotar region of Croatia, on the area of the Management Unit Kobiljak - Bitoraj in Forest Office Fužine, which is dominated by Dinaric beech-fir forest stands. According to the Köppen classification, Gorski Kotar is classified as having a Cfsbx climate type. This is a moderately warm rainy climate, without a dry season. The average annual air temperature for the study area is 7.2°C, with an average precipitation of approximately 2000 mm (Seletković 2001). The parent material is comprised of limestones, dolomites and sandstones of varying age, and the most common soils are calcomelanosol, brown and epimerized soil, rendzina, district brown soil and podzolic soil. The relief of the study area is highly irregular and diversified. It is interrupted by convex slopes, ditches, dales and rocks (Pernar 2001). The study investigated stands of decreased vitality and stability. Due to dieback of silver fir trees, the percentage share of common beech trees increased in the growing stock of these forests. The average dieback intensity in the research area for the period 1995–2007 was 18.3 $m^3$ $ha^{-1}$, with a range from 0.2 and 113.0 $m^3$ $ha^{-1}$ (Ugarković et al. 2011).

### Forest gaps and control plots – *Šumski otvori i kontrolne plohe*

Three large gaps and three small gaps in the beech and fir association (*Omphalodo – Fagetum* Marinček et al. 1993), and three 50 x 50 m control plots in the Kobiljak-Bitoraj Management Unit (Fužine Forest Office) were investigated. A forest gap is a ´hole´ in the forest through all levels down to an average height of 2 m above ground level (Runkle 1982). These forest gaps were created by the dieback of silver fir (*Abies alba* Mill.) trees following salvage cutting three years previously, and had an elliptical shape. Forest gaps were three years old. The large gap was surrounded by 59% fir trees and 41% beech trees. The percentage share of trees surrounding the small gap was 54% fir, 38% beech and 1% spruce.

The control plots were located in the forest stand in the vicinity of forest gaps, in the same habitat conditions (soil, geological substrate or parent material relief). The gap area was defined by the vertical projection of the crowns of can-

**Table 1** Basic data on the studied forest gaps
Tablica 1. Osnovni podaci o istraživanim šumskim progalama

| Gap characteristics *Karakteristike progala* | Large forest gaps (LFG) *Velika progala* | Small forest gaps (SFG) *Mala progala* |
|---|---|---|
| Gap area ($m^2$) *Površina progale* | 800–937 | 220–300 |
| Gap edge area ($m^2$) *Površina rubnog dijela progale* | 380–405 | 320–372 |
| Height of surrounding trees (m) *Visine okolnih stabala* | 36–38 | 31–33 |
| D / H ratio *D / H odnos* | 0.6–0.7 | 0.4–0.5 |
| Exposition *Ekspozicija* | SW | SW |
| Slope (°) *Nagib* | 9–11 | 9–10 |
| Altitude (m) *Nadmorska visina* | 700–750 | 720–760 |

opy trees bordering the gaps. The expanded gap is the forest gap plus the area extending to the bases of the canopy trees surrounding the gap (Runkle 1982). The forest gap edge was determined by vertical crown projection of edge trees surrounding the gap (Rozenbergar et al. 2007). The gap edge area is the area from the edge of the crowns towards the gap to the tree trunks surrounding the gap, i.e. the area towards the gap covered by the crowns of the edge trees. The basic data on the investigated forest gaps are shown in Table 1.

The soil type of the forest gaps and control plots was calcocambisol, and the geological substrate or parent material was Jurassic limestone. The canopy density of control plots was incomplete. The growing stock of control plots ranged from 283 to 293 $m^3$ $ha^{-1}$, with a share of 45 to 62% common beech, 31 to 44% silver fir, 6% sycamore maple, 3% spruce and from 1 to 2% other broadleaf species. The surface area of forest gaps was calculated by the ellipse formula (Runkle 1982) and corrected with the use of GPS and GIS tools.

### Measurement of microclimate elements – *Mjerenje mikroklimatskih elemenata*

Microclimate elements were measured in one large and one small forest gap and in the control plots. Within each forest gap, the gap centre and the gap directions towards the cardinal points were determined according to the Runkle

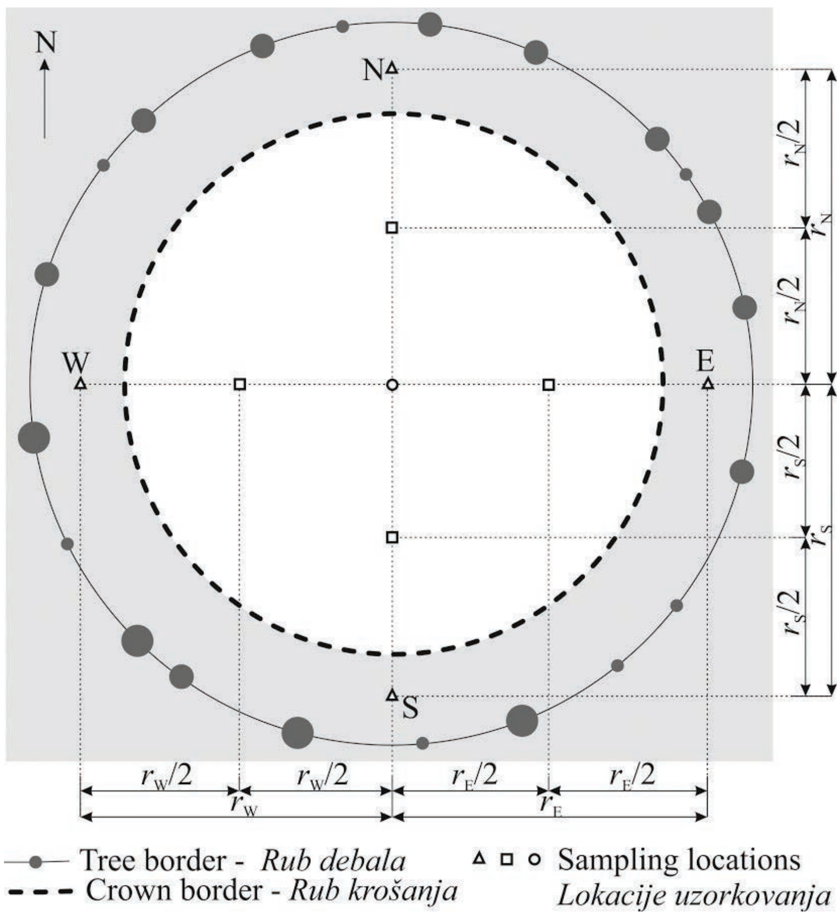


**Figure 1** Scheme of the design experiment
Slika 1. Skica plana pokusa

method (1982). Microclimate elements air temperature (°C) and relative air humidity (%) were measured at the centre point of the forest gap. Microclimate elements soil temperature (°C) and volumetric water content (%) were measured in the centre of the forest gap, at the midpoint to the forest gap edge in the cardinal point directions, and in the gap edge area. The same microclimate elements were measured in control plots (canopy-covered stands) at three positions. At sites where the microclimate elements were measured, the number of small seedlings was counted on 1.5x1.5 m plots, in order to determine the relationship between microclimate and the density of small seedlings of the forest tree species. A total of 24 plots were laid out in the large gap, small gap and in the control plots. Air temperature and relative air humidity were measured at 1.5 m from the ground. Soil temperature and volumetric soil water content were measured at a depth of 10 cm. Measurements of forest soil microclimate were carried out in undisturbed soil using the microclimate stations "Rotronic" and "Spectrum" once per hour during 2007 and 2008 years. Calibration of microclimate stations and sensors was performed by the Meteorological and Hydrological Service of the Republic of Croatia. According to official reports of the Meteorological and Hydrological Service of the Republic of Croatia, the years 2007 and 2008 were extremely hot compared to the 30-year reference period, though the overall annual temperature percentiles and precipitation percentiles for these two years were with the normal range. Summer 2007 was extremely hot and very dry, and the autumn was cold with common precipitation characteristics. Winter 2007/8 was warm and dry, while spring 2008 was warm with common precipitation characteristics, while summer 2008 was extremely hot and dry. Figure 1 shows the experimental design in the forest gaps.

Spatial interpolation implies the prediction of values of the primary variable at points within the same range as the input points (Burrough and McDonnell 1998). In this study, ESRI ArcGIS 9.3 Desktop was used for data visualization and interpolation. Spatial interpolation of variables measured in the field (e.g. temperature, volumetric water content) was performed using default regularized Spline function (Spatial Analyst extension, Interpolation toolset). This tool interpolates a raster surface from points using a two-dimensional minimum curvature spline technique resulting with smooth surface passes exactly through the input points. The predicted values are very close to the values being interpolated and errors are relatively small. However, accuracy of all spatial interpolation methods mostly depends on sampling (size, distribution, density etc.), nature and quality of the collected data.

**Table 2** Microclimate properties of large and small forest gaps and control forest stands
Tablica 2. Mikroklimatske karakteristike velike i male šumske progale te šumske sastojine

| Microclimate elements<br>*Mikroklimatski elementi* | Large forest gaps (LFG)<br>*Velika progala* | | |
|---|---|---|---|
| | Gap area<br>*Progala* | Gap edge area<br>*Rub progale* | Forest stand<br>*Šumska sastojina* |
| Air temperature (°C)<br>*Temperature zraka* | 8.98 ± 7.84 | – | 8.80 ± 7.73 |
| Air humidity (%)<br>*Vlaga zraka* | 77.28 ± 18.40 | – | 77.08 ± 18.31 |
| Soil temperature (°C)<br>*Temperatura tla* | 9.14 ± 6.22[a] | 9.04 ± 5.59[a] | 8.48 ± 4.74[b] |
| Soil VWC (%)<br>*Volumetrijska vlaga tla* | 13.29 ± 5.40[a] | 14.02 ± 4.73[b] | 14.48 ± 5.74[c] |
| | Small forest gaps (SFG)<br>*Mala progala* | | |
| Air temperature (°C)<br>*Temperature zraka* | 9.00 ± 7.74 | – | 8.97 ± 7.61 |
| Air humidity (%)<br>*Vlaga zraka* | 79.45 ± 18.69[a] | – | 78.55 ± 18.09[b] |
| Soil temperature (°C)<br>*Temperatura tla* | 8.68 ± 5.29[a] | 8.33 ± 4.24[b] | 8.32 ± 4.74[b] |
| Soil VWC (%)<br>*Volumetrijska vlaga tla* | 16.00 ± 4.93[a] | 13.49 ± 3.74[b] | 15.38 ± 6.69[c] |

Table values are presented as mean ± standard deviation
Vrijednosti u tablici su prikazane kao prosjek ± standardna devijacija

[a,b,c] Values marked with a different superscript within a row differ significantly ($p < 0.05$)
[a,b,c] Vrijednosti unutar reda označene različitim slovom, značajno se razlikuju ($p < 0,05$)

Abbreviations: LFG, large forest gap; SFG, small forest gap; VWC, volumetric water content
Kratice: LFG, velika progala; SFG, mala progala, VWC, volumetrijska vlaga tla

### Natural regeneration of plants – *Prirodno pomlađivanje biljaka*

Natural regeneration of plants which were germinated after making salvage cutting was determined at three large and three small forest gaps and in the control plots. Each forest gap was covered with a net, 5 x 5 m. The initial point of the net was the gap centre. At the intersections of this net, test plots of 1.5 x 1.5 m were installed. A total of 35 test plots were installed in the three large gaps and 31 plots in the edge areas of the large gaps, and a total of 17 test plots were installed in the small gaps and 13 plots in the edge areas of the small gaps. A total of 243 test plots (1.5 x 1.5 m) were installed in the control plots (forest stands). In each test plot, plants were counted and the species recorded. Plants were divided into one group of small seedlings which is up to three years of age or to a height of 20 cm (Prpić and Seletković 2001, Rozenbergar et al. 2007).

### Data processing – *Obrada podataka*

All microclimate data were processed using the HW3 and SpecWare 9 professional programs. Statistical processing of microclimate data, and density of plant regeneration in the forest gaps, in the gap edge areas and the control plots was carried out by the analysis of variance (Repeated measures ANOVA, One-way ANOVA, *post hoc* Fisher LSD test). The Pearson correlation coefficient was used to determine the relationship between individual microclimate elements measured and the relationship of microclimate elements and the density of small seedlings. The statistical programs Statistica 7.1. (StatSoft Inc. 2003) was used for statistical data processing.

## RESULTS
## REZULTATI

In the observed period, the mean air temperature was 8.98°C in the large forest gap, and 8.80°C in the control plots. The difference in the mean value of relative air humidity was 0.2%. No statistically significant differences were determined for air temperature or relative air humidity between the large forest gap and the control forest stand. Considerable differences were determined in soil temperatures in the control forest compared to the large forest gap and its edge areas. The mean value of the soil temperature was 8.48°C in the control forest, and 9.14°C in the large forest gap. Significant differences were also determined in volumetric soil water content between the control forest, large forest gap and its edge areas. The mean value of volumetric soil water content was 14.48% in the control forest, and 13.29% in the forest gap (Table 2). The mean air temperature did not differ significantly between the small forest gap and control forest stand. A significantly higher value of relative air humidity was determined in the small gap (79.45%) compared to the forest stand (78.55%). Significant differences were also determined between soil temperatures in the forest stand and in the gap edge area as compared to the mean soil temperature in the small forest gap. The highest soil temperature (8.68°C) was recorded in the forest gap. No significant difference was found between soil temperatures in the forest stand and forest gap edge area. Significant differences were found in the volumetric soil water content between all sites. The mean value was 13.49% in the forest gap edge area, and 16.0% in the forest gap (Table 2).

As shown in Table 3, the mean air temperature did not significantly differ between the small and large forest gaps. Relative air humidity was 79.45% in the small forest gap, which was considerably higher than in the large forest gap (77.28%). Soil temperature was significantly higher in the large gap area and its edge area compared to the small forest gap. Volumetric soil water content was 16.0% in the small gap, which was significantly higher than in the large gap (13.29%). Volumetric soil water content in the gap edge area of the large forest gap was significantly higher and amounted to 14.02%. Daily average values of soil temperature and volumetric water content over a two years period

**Table 3** Microclimate properties of large and small forest gaps area and gap edge areas

Tablica 3. Mikroklimatske karakteristike velike i male šumske progale te ruba progala

| Microclimate elements *Mikroklimatski elementi* | Positions in forest gaps *Položaj u šumskoj progali* – Gap area *Progala* | |
|---|---|---|
| | LFG | SFG |
| Air temperature (°C) *Temperature zraka* | 8.98 ± 7.84 | 9.00 ± 7.74 |
| Air humidity (%) *Vlaga zraka* | $77.28^a$ ± 18.40 | $79.45^b$ ± 18.69 |
| Soil temperature (°C) *Temperature tla* | $9.14^a$ ± 6.22 | $8.68^b$ ± 5.29 |
| Soil VWC (%) *Volumetrijska vlaga tla* | $13.29^a$ ± 5.40 | $16.00^b$ ± 4.93 |
| **Microclimate elements** *Mikroklimatski elementi* | **Gap edge area** *Rub progale* | |
| | LFG | SFG |
| Soil temperature (°C) *Temperature tla* | $9.04^a$ ± 5.59 | $8.33^b$ ± 4.24 |
| Soil VWC (%) *Volumetrijska vlaga tla* | $14.02^a$ ± 4.73 | $13.49^b$ ± 3.74 |

Table values are presented as mean ± standard deviation
Vrijednosti u tablici su prikazane kao prosjek ± standardna devijacija

$^{a,b}$Values marked with a different superscript within a row differ significantly ($p < 0.05$)
$^{a,b}$Vrijednosti unutar reda označene različitim slovom značajno se razlikuju ($p < 0,05$)

Abbreviations: LFG, large forest gap; SFG, small forest gap; VWC, volumetric water content
Kratice: LFG, velika progala; SFG, mala progala, VWC, volumetrijska vlaga tla

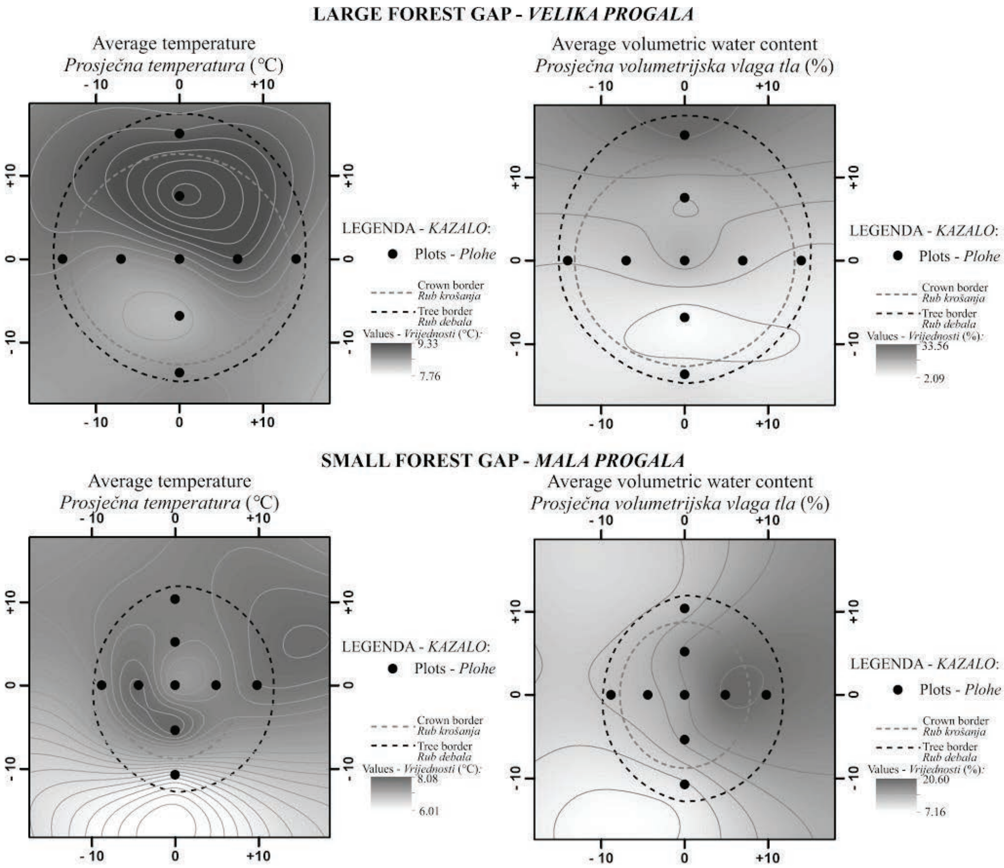


**Figure 2** Spatial interpolations of yearly average values of soil temperature and volumetric water content in large (LFG) and small forest gaps (SFG)
Slika 2. Prostorna razdioba prosječnih godišnjih vrijednosti temperature tla i volumetrijske vlage tla u velikoj (LFG) i maloj (SFG) šumskoj progali

**Table 4** Density of small seedlings (N $m^{-2}$) of forest tree species in forest gaps, forest gap edge areas, and control forest stands
Tablica 4. Brojnost pomlatka (N/$m^2$) šumskih vrsta drveća u šumskim progalama, na rubovima šumskih progala i u šumskim sastojinama

| Seedling status *Status pomlatka* | Position *Pozicija* | Large forest gaps (LFG) – *Velika progala* | | |
|---|---|---|---|---|
| | | Tree species – *Vrste drveća* | | |
| | | Silver fir *Obična jela* | Common beech *Obična bukva* | Sycamore maple *Gorski javor* |
| Small seedlings *Mlađi pomladak* | Gap area *Progala* | 1.71 ± 0.52 | 0.33 ± 0.09 | 2.09 ± 0.83 |
| | Gap edge area *Rub progale* | 3.40 ± 1.22$^{a}$ | 0.21 ± 0.05$^{b}$ | 2.74 ± 0.81$^{a}$ |
| | Forest stand *Sastojina* | 2.11 ± 0.90$^{a}$ | 0.25 ± 0.05$^{b}$ | 3.21 ± 1.10$^{a}$ |
| | | Small forest gaps (SFG) *Mala progala* | | |
| Small seedlings *Mlađi pomladak* | Gap area *Progala* | 0.60 ± 0.17 | 0.10 ± 0.05 | 0.53 ± 0.14 |
| | Gap edge area *Rub progale* | 0.80 ± 0.20$^{a}$ | 0.23 ± 0.10$^{b}$ | 0.67 ± 0.17$^{a}$ |
| | Forest stand *Sastojina* | 1.21 ± 0.70$^{a}$ | 0.25 ± 0.15$^{b}$ | 0.61 ± 0.20$^{b}$ |

Table values are presented as mean ± standard deviation
Vrijednosti u tablici prikazane su kao prosjek ± standardna devijacija

$^{a,b,c}$ Values marked with a different superscript within a row differ significantly ($p < 0.05$)
$^{a,b,c}$ Vrijednosti unutar reda označene različitim slovom, značajno se razlikuju ($p < 0,05$)

Abbreviations: LFG, large forest gap; SFG, small forest gap
Kratice: LFG, velika progala; SFG, mala progala

**Table 5** Density of seedlings (N $m^{-2}$) in large forest gaps (LFG) and small forest gaps (SFG) and their gap edge areas
Tablica 5. Brojnost pomlatka (N/$m^2$) u velikim (LFG) i malim šumskim progalama (SFG) te na njihovim rubovima

| Seedling status *Status pomlatka* | Tree species *Vrste drveća* | Gap area *Progala* LFG | SFG |
|---|---|---|---|
| Small seedlings *Mlađi pomladak* | Silver fir *Obična jela* | 1.71 ± 0.52 | 0.60 ± 0.17 |
| | Beech *Obična bukva* | 0.33 ± 0.09 | 0.10 ± 0.05 |
| | Maple *Gorski javor* | $2.09^a$ ± 0.83 | $0.53^b$ ± 0.14 |
| **Seedling status** *Status pomlatka* | **Tree species** *Vrste drveća* | **Gap edge area** *Rub progale* LFG | **SFG** |
| Small seedlings *Mlađi pomladak* | Silver fir *Obična jela* | $3.40^a$ ± 1.22 | $0.80^b$ ± 0.20 |
| | Beech *Obična bukva* | 0.21 ± 0.05 | 0.23 ± 0.10 |
| | Maple *Gorski javor* | $2.74^a$ ± 0.81 | $0.67^b$ ± 0.17 |

Table values are presented as mean ± standard deviation
Vrijednosti u tablici prikazane su kao prosjek ± standardna devijacija
[a,b]Values marked with a different superscript within a row differ significantly ($p < 0.05$)
[a,b]Vrijednosti unutar reda označene različitim slovom, značajno se razlikuju ($p < 0,05$)

were interpolated from logged data for both gaps. Raster maps showing spatial change of variables are shown in Figure 2.

Among small seedlings, sycamore maple was the most common species in the forest stands with an abundance of 3.20 $m^{-2}$, while silver fir prevailed in the gap edge areas with an abundance of 3.40 $m^{-2}$. In the large forest gaps, no significant differences were found in the number of small seedlings of silver fir, common beech and sycamore maple (Table 4).

With regard to the density of small seedlings, silver fir density was highest in the forest and in the small forest gap edge areas. Its density was 1.21 $m^{-2}$ in the control forest stands, 0.80 $m^{-2}$ in the small gap edge areas, and 0.60 $m^{-2}$ in the small forest gaps. No significant differences were found in the density of different forest tree species in the area of the small forest gaps area (Table 4).

A significantly larger number of small seedlings of silver fir were found in the large forest gap edge areas (3.40 $m^{-2}$) than in the small forest gap edge areas (0.80 $m^{-2}$). The number of small seedlings of silver fir was 1.71 $m^{-2}$ within the large forest gaps, and 0.60 $m^{-2}$ within the small gaps. A significantly higher number of small sycamore maple seedlings was found in the large forest gaps than in the small forest gaps (Table 5).

According to Table 6, the correlation of the density of silver fir and common beech plants in the large gap was statistically significant and negative (r= -0.29). The correlation of the density of silver fir plants and air temperature and relative air humidity was significant and negative, while the correlations of the density of common beech plants with the same microclimatic elements was significant and positive. The correlation of the density of broadleaf species (common beech and sycamore maple) was significant and positive (r=0.46).

In the small gap the correlation of air temperature and soil temperature was r = 0.95 for the large gap and r = 0.69 for the small gap. The correlations were significant, positive and strong. The correlation of air temperature and soil volumetric water content was significant, negative and strong, i.e., r = 0.96 for the large gap and r = 0.50 for the small gap. The

**Table 6** Pearson's correlation of microclimate elements and small seedling density in the large forest gap
Tablica 6. Pearsonova korelacija mikroklimatskih elemenata i mlađeg pomlatka u velikoj šumskoj progali

| | Fr | Cb | Sy | At | Ah | St | SVWC |
|---|---|---|---|---|---|---|---|
| Fr | 1.00 | | | | | | |
| Cb | –0.29* | 1.00 | | | | | |
| Sy | –0.11 | 0.46* | 1.00 | | | | |
| At | –0.17* | 0.31* | 0.07 | 1.00 | | | |
| Ah | –0.15* | 0.21* | –0.07 | –0.99* | 1.00 | | |
| St | –0.10 | 0.18* | –0.07 | 0.95* | 0.25* | 1.00 | |
| SVWC | 0.05 | –0.01 | –0.02 | –0.36* | –0.23* | –0.96* | 1.00 |

* significant at $p < 0.05$
* signifikantno na razini $p < 0,05$

Abbreviations: Fr, silver fir; Cb, common beech; Sy, sycamore maple; At, air temperature; Ah, air humidity; St, soil temperature; SVWC, soil volumetric water content
Kratice: Fr, obična jela; Cb obična bukva; Sy gorski javor; At temperature zraka; Ah relativna vlaga zraka; St temperature tla; SVWC volumetrijska vlaga tla

**Table 7** Pearson's correlation of microclimate elements and small seedling density in the small forest gap
Tablica 7. Pearsonova korelacija mikroklimatskih elemenata i mlađeg pomlatka u maloj šumskoj progali

| | Fr | Cb | Sy | At | Ah | St | SVWC |
|---|---|---|---|---|---|---|---|
| Fr | 1.00 | | | | | | |
| Cb | –0.14* | 1.00 | | | | | |
| Sy | –0.29* | –0.05 | 1.00 | | | | |
| At | –0.03 | 0.18 | 0.01 | 1.00 | | | |
| Ah | –0.03 | 0.18 | –0.01 | –0.94* | 1.00 | | |
| St | –0.02 | 0.18 | 0.05 | 0.69* | 0.22* | 1.00 | |
| SVWC | 0.08 | –0.16 | 0.02 | –0.22* | –0.21* | –0.50* | 1.00 |

* significant at $p < 0.05$
* signifikantno na razini $p < 0,05$

Abbreviations: Fr, silver fir; Cb, common beech; Sy, sycamore maple; At, air temperature; Ah, air humidity; St, soil temperature; SVWC, soil volumetric water content
Kratice: Fr, obična jela; Cb obična bukva; Sy gorski javor; At temperature zraka; Ah relativna vlaga zraka; St temperature tla; SVWC volumetrijska vlaga tla

correlation of air temperature and soil volumetric water content was significant, negative and weak, i.e., r = -0.36 for the large gap and r = -0.22 for the small gap (Table 6 and 7).

## DISCUSSION
## RASPRAVA

The microclimate in the resulting forest gaps depends on the macroclimate of the area in which they are located, gap size or surface area, gap shape, gap direction, condition of natural regeneration in the gap and on the ratio between gap width and average height of the surrounding trees. In the present study, no significant differences were observed in the mean air temperature between the forest gaps and control forest stands, or between the large and small forest gaps. These results are in agreement with Muscolo et al. (2007), who did not find significant differences in air temperatures between gaps of different size, or between gaps and control plots. In this study, increasing forest gap area had no significant effect on air temperature, though it did result in a significant increase of soil temperature, while the air humidity and volumetric soil water content decreased. Muscolo et al. (2007) found that large gaps had higher values of soil temperature and photosynthetic active radiation, and lower soil moisture than small gaps. These results are comparable to the results presented here for soil temperature and soil moisture. Solar radiation is filtered by the forest cover through the tree layers to the forest soil, allowing the forest soil to absorb only a small percentage of energy. With the formation of forest gaps, the protective layer of trees is lost and higher quantities of solar energy reach the soil surface, changing the soil temperature regime in the newly formed gap (Ashton 1991). This alters the forest soil microclimate. Forest succession and undergrowth can also affect temperature. Soil temperature also depends on the number of plants from natural regeneration. If regeneration is good, i.e. if the density of juvenile plants is high, differences in soil temperature are lower as the soil is protected by the crowns of the young plants. Although regeneration was more pronounced in the large forest gap edge area than within the large gap, the number of plants was very small and insufficient from the silviculture standpoint, and hence had no major effect on equating the values of soil temperature among positions in the forest gap. Regeneration was also more pronounced in the small forest gap edge area than within the small gap, and the D/H ratio likely contributed to moderate variation in soil temperature in the small gap edge area in comparison with the control forest stand.

In artificially created gaps, the soil moisture in the gap was found to be higher than soil moisture in the forest stand, with a significant difference between the small gap and forest stand (Albanesi et al. 2008). This was also confirmed by Cutini et al. (2004) in the gaps of silver fir stands in the Central Apennines (Italy). In the present study, soil moisture differed significantly in all positions of the large and small forest gaps. Furthermore, soil moisture also differed significantly between the large and small gaps. The results for the values of soil water content in the forest gaps in the present study corroborate those of Muscolo et al. (2007) and Albenesi et al. (2008) for artificial forest gaps. The reduced soil moisture levels in the large gap compared to the small gap can be explained by the extremely hot and dry years, size of the gap and by large shadows of edge trees in the small forest gap. A significantly lower value of soil moisture in the small gap edge area compared to the large gap edge area can be explained by the large surface of the horizontal projection of edge tree crowns in the small gap and the consequential high amount of interception. High air temperatures had a significant effect on the amount of evaporation and transpiration in forest gaps and thus on soil moisture.

The forest regeneration process is one of the basic issues in natural silviculture and forest ecology, particularly in applied ecology. In the forest gaps of the present study, silver fir as the main forest tree species was poorly regenerated. Apart from the poor regeneration in gaps created by tree dieback, poor regeneration was also observed in the gaps of old-growth beech-fir forests (Rozenbergar et al. 2007). According to Albanesi et al. (2008) regeneration in artificially created forest gaps was more pronounced than regeneration in gaps formed by the dieback of silver fir trees. The shape and dimensions of artificially created gaps are determined by forestry experts, while the dimensions and shapes of gaps formed by tree dieback depend on the degree of tree degradation and intensity of dieback. The area of artificially created gaps is smaller than the area of gaps formed by tree dieback. According to Schugart (1984) and Mazur (1989), silver fir can cover only a part of the gap.

With respect to silver fir regeneration in forest gaps, a microlocation with a high level of direct light is less favourable (Rozenbergar et al. 2007). In the present study, the best sites for silver fir regeneration were the forest gap edge areas and forest stands (control plots). As the canopy density of forest stands is incomplete due to tree dieback, the necessary conditions are provided for the appearance of silver fir seedlings. According to the present study, regeneration of common beech is more pronounced within the gaps. The density of sycamore maple was highest in gap edge areas, while its density was the same in the control forest stand and in the gaps. Regardless of gap size, a larger number of silver fir plants were found in the class of small seedlings, while a larger number of common beech plants were found in the class of larger seedling and saplings.

In the present study, there were no significant differences in the number of silver fir plants between the large and small forest gaps. A significantly larger number of silver fir plants were found in the large forest gap edge areas as opposed to the edge areas of small forest gaps. In the large gap edge areas and within those gaps, a significantly larger number of sycamore maple plants were found than in the small forest gap and its edge areas (Table 5).

One of the possible outcomes of competition is that the population of one competitor is increased, while the population of the other is decreased or eliminated. Analogous to this, in the large and small gaps, a significant and negative correlation was found between the number of young seedlings of silver fir and common beech. Dobrowolska (1998) stated that the reason for the poor regeneration of silver fir is the competition of plants for nutrients. Young silver fir plants appear in forest gaps while there is a lack of older plants. One of the causes of high mortality of silver fir plants lies in the changing microclimate and microbiological conditions, and competition between tree species.

Microclimate, in particular air temperature, relative air humidity and soil temperature, has a significant affect on the number of young seedlings of silver fir and common beech. Common beech requires higher air and soil temperatures than silver fir and does not tolerate excessively dry soil (Seletković et al. 2003). In terms of its ecological requirements, silver fir is a species with a narrow ecological valence (Prpić et al. 2001). Given the ecological requirements of these two species, and the correlations outlined in Table 6, silver fir prefers lower air and soil temperatures, while common beech, as a species with a broader ecological valence, is found at sites with higher soil and air temperatures. For that reason, there was a higher density of silver fir seedlings around the gap edges, and a higher density of common beech seedlings within the gaps. Since common beech and sycamore maple are more successful in regenerating the gaps, forest gaps are habitats where the change of tree species occurs.

## CONCLUSIONS
## ZAKLJUČCI

Silver fir dieback and salvage cutting of these stands create larger or smaller gaps in beech-fir forests. The creation of forest gaps causes changes in certain microclimatic elements and changes in the abundance of seedlings of various species. Forest gap size does not significantly affect air temperatures. Changes in forest gap size significantly affected soil temperature changes and soil volumetric water content. Favourable microclimate conditions were found in the small forest gap compared to the large forest gap. The density of silver fir plants in large and small forest gaps was insufficient for the species influx into higher layers of the stand. At the edge of the large and small forest gaps, the number of small seedlings of silver fir was significantly higher than that of broadleaf species. Microclimate had a significant influence on the number of small seedlings of silver fir and beech in the large gap. The results of this study could be applied in developing better silvicultural plans for the rehabilitation of forest gaps.

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## Sažetak

Zbog intenzivnog odumiranja stabala obične jele (*Abies alba* Mill.) učestale su sanitarne sječe te dolazi do prekidanja sastojinskog sklopa i stvaranja šumskih progala. Istraživanje je obavljeno u bukovo – jelovim šumama na području Gorskog Kotara. Cilj istraživanja bio je utvrditi promjene mikroklimatskih uvjeta i prirodno pomlađivanje u velikim i malim šumskim progalama. U središtu i na rubovima šumskih progala, te u pripadajućim kontrolnim plohama mjereni su mikroklimatski elementi, kao i brojnost biljaka iz prirodnog pomlađenja. Temperature tla su značajnije reagirale na promjene veličine šumskih progala u odnosu na vrijednosti temperature zraka i bile su najveće u progalama u usporedbi s rubom progala i kontrolnim šumskim sastojinama. Broj biljaka obične jele u velikim i malim šumskim progalama je nedovoljan za uraštanje ove vrste u više slojeve sastojine. Brojnost biljaka starijeg pomlatka na rubovima velikih i malih progala te u sredini progala je bila značajno veća za listopadne vrste u odnosu na običnu jelu. Kod biljaka starijeg pomlatka nismo utvrdili značajne razlike u brojnosti biljaka između malih i velikih šumskih progala. Mikroklima je imala značajan utjecaj na broj biljaka mlađeg pomlatka obične jele i bukve u velikoj šumskoj progali, dok za malu šumsku progalu to nije bio slučaj.


**KLJUČNE RIJEČI:** odumiranje stabala, obična jela (*Abies alba* Mill.), progala, mikroklima, prirodno pomlađivanje