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MICROCLIMATE DIFFERENCES IN THE DEGRADATION STAGES OF HOLM OAK (*Quercus ilex* L.) FORESTS

MIKROKLIMATSKE RAZLIČITOSTI DEGRADACIJSKIH STADIJA ŠUMA HRASTA CRNIKE (*Quercus ilex* L.)

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Summary

Maquis and garrigue are the most common degradation stages of Holm oak forests in Croatia. Disorganized and uncontrolled cutting degrades forests and changes their microclimates. Measurements were conducted in a Holm oak forest in the maquis and garrigue degradation stages, and in an Aleppo pine forest with Holm oak. The highest variations of microclimate elements were measured in the degradation stages of Holm oak. The average air and soil temperatures, precipitation, and potential evapotranspiration were highest in the garrigue stage and lowest in the maquis stage. The average volumetric soil water content was highest in the maquis stage (14.28%) and lowest in the garrigue stage (9.46%). The dry season water deficit was highest in the garrigue stage (-73.95 mm) and lowest in the maquis (-60.38 mm). Microclimate conditions in the garrigue degradation stage are less favorable for the growth and development of Holm oak than in high forest stands. The average values of microclimate elements in the Aleppo pine forest stand with Holm oak were within the average range of the microclimate elements of garrigue and maquis.

KEY WORDS: Forest microclimate; forest structure; Holm oak; degradation stages; Aleppo pine

INTRODUCTION
UVOD

In the Mediterranean region, forests have been exposed to intensive anthropogenic impacts for centuries. Examples of such impacts include uncontrolled cutting, grazing, removal of the litter layer, burning and clearing for expansion of agricultural lands, change of use of forests and forest lands for the purpose of developing infrastructure, tourism, raising of vineyards and olive groves, etc. Such long-term processes, in combination with fires, specific climatic conditions, and erosive soils, has gradually led to the general degradation of the Mediterranean forest ecosystems (Topić and Butorac 2011, Matić et al. 2011). Drought additionally supports a negative anthropogenic influence on these forests. High evaporative losses from forest cover could supply the critical moisture needed to trigger water condensation in ascending air masses as well as promoting rainfall (Millán et al. 1997).

The most important factor limiting the distribution, growth, and development of trees in the Mediterranean ecosystem is the lack of water during summer (Di Castri 1981, Ogaya & Penuelas 2006).

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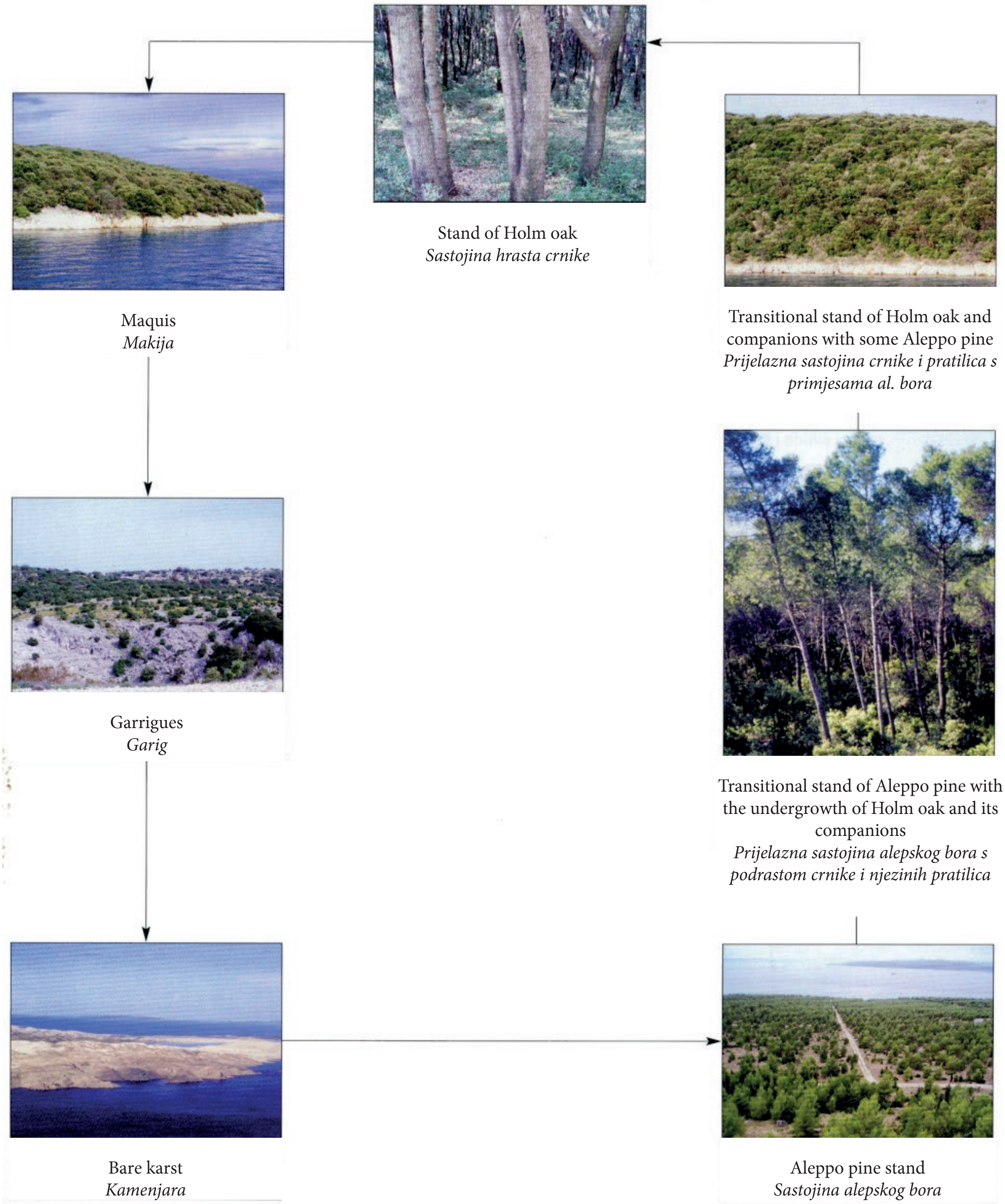

Figure 1. Forest regression (left) and progression assisted by silvicultural treatments (right) in the Mediterranean (Matić et al. 2011).
Slika 1. Shema regresije (lijevo) i progresije šuma potpomognute šumskouzgojnim postupcima (desno) u eumediteranu (Matić i dr. 2011)

Holm oak is a widely distributed Mediterranean oak species found in moderate to dry habitats (Archibold 1995). This is a very important species for the regeneration of deforested areas and abandoned agricultural areas in the Mediterranean (Rodà et al. 1999, Rey Benayas and Camacho-Cruz 2004). Holm oak is relatively difficult to raise on such terrains, and has a low survival rate and slow growth rate in comparison to other species involved in the forestation of these habitats, such as *Pinus* spp. (Baeza et al. 1991, Vallejo and Alloza 1999, Navarro Cerrillo et al. 2001). Stands of Holm oak (*Quercus ilex* L.) degrade to the maquis and garrigue stages, and the final result of the degradation process is bare karst or rocky vegetation (Figure 1) (Matić et al. 2011). In the Croatian part of the Mediterranean, the high silvicultural forms and coppice of Holm oak forests cover 29,000 ha. The degradation stages cover 120,000 ha as maquis and 23,437 ha as garrigue (Čavlović 2010).

Afforestation by Aleppo pine improves habitat characteristics, especially soil conditions. The main role of pine culture is ameliorative: protecting the soil, creating favorable microclimate conditions, improving physical and chemical soil characteristics, and returning the autochthonous broadleaved vegetation and economic value (Španjol et al. 2006). Maestre et al. (2003) reported higher soil organic carbon and total nitrogen at a depth of 0–20 cm under pine plantation 30 years after planting. Caravaca et al. (2002) found higher aggregate stability at a depth of 0–15 cm under pines 6 years after planting.

While the ultimate mechanism by which Holm oak is degraded appears to be anthropogenic disturbance, the proximate mechanisms are less well-understood. One hypothesis is that, once enough canopy trees are removed or damaged, the understory microclimate becomes inhospitable to the Holm oak understory species. Cutting or thinning forests results in alterations to microclimate conditions (Aussenac 2000). According to Aussenac (2000), it is necessary to study the interactions between forest stands and the microclimate, especially in climatic areas characterized by large water deficits such as those common in the Mediterranean, to improve the understanding of the ecology of forest species, and in particular, their reactions to water deficits under natural conditions. There has been some research into the microclimates below sparse and dense forest canopies, mostly in the subalpine and temperate climate zones (Aussenac 2000, Morecroft et al. 1998, Latif and Blackburn 2010, Arx von et al. 2013, Ugarković et al. 2018). However, there is a lack of research on the subcanopy climate in the degradation stages of forest ecosystems. An analysis of the microclimate data of forest ecosystems could allow for better understanding of the ecological conditions in forest habitats. The forest microclimate is crucial for the growth and survival of tree seedlings and understory vegetation. The microclimate conditions in the degradation stages of a forest ecosystem have not been thoroughly studied. Moreno et al. (2007) outlined the positive effects of trees on the microclimate, physical properties of soil, and soil water dynamics. Modifications to the microclimate with evolving forest cover through different stages should be considered when studying the survival and growth of young natural regeneration or in relation to afforestation operations.

The objectives of this study were to determine the microclimate differences in degradation stages of Holm oak forests and stands of Aleppo pine with Holm oak. Future additional work will be done on the growth of regeneration and understory plants.

MATERIALS AND METHODS
MATERIJALI I METODE

The study was conducted within the area of Mljet National Park on the island of Mljet, Croatia. The park covers an area of 5480 ha and is situated on the Northwestern part of the island. The geological substrate is carbonate and silicaceous rock and their various forms. Limestone is the most common of the carbonate rocks. The most common soil types are calcocambisol and lithosol, with a lesser share of rendzine on limestone and dolomite. The mean annual air temperature is 16.4 °C, and the mean annual precipitation is 770 mm (Seletković et al. 2011). The vegetation of Mljet is composed of 5 forest communities: *Junipero phoeniceae–Pinetum halepensis* Trinajstić 1988, an Aleppo pine forest with Phoenician juniper; *Querco ilici–Pinetum halepensis* Loisel 1971, an Aleppo pine forest with Holm oak; *Myrto–Quercetum ilicis* (Horvatić 1963) Trinajstić 1985, a Holm oak forest with myrtle; *Fraxino orni–Quercetum ilicis* Horvatić (1956) 1958, a Holm oak forest with manna ash; and *Fraxino orni–Quercetum cocciferae* Horvatić 1957, a Kermes oak forest with manna ash.

Experimental plots were situated in the same soil type and with the same relief characteristics. Relief characteristics were measured by Suunto Tandem 360 PC/360R DG and Garmin GPS64 devices. The study was conducted in 2 forest communities: *Querco ilici–Pinetum halepensis* and *Myrto–Quercetum ilicis*. Measurements were performed in the high silvicultural forms of Holm oak and Aleppo pine forests and at the degradation stages of maquis and garrigue. Observers measured the diameter at breast height (DBH) with Haglof tree calipers (cm) for every tree from 2 cm DBH and the height (m) of dominant and co-dominant trees in experimental plots by digital Vertex IV to calculate the main structural elements, as follows: number of trees (N), basal area (G), and wood volume (V). On the basis of the measured heights and parameters of the Schumaher–Hallove function of trees, the local tariff for each tree type was calculated. For the green olive tree (*Phillyrea latifolia* L.), Laurustinus (*Viburnum tinus* L.), strawberry tree (*Arbutus undeo* L.), tree heath (*Erica arborea* L.), and Cade juniper (*Juniperus oxycedrus* L.), we used Holm oak parameters for the Schumacher–Hall function. For experimental plots in the garrigue degradation stage, structural elements were not measured; instead, only the heights of the stand were measured.

Table 1. Characteristics of the experimental plots. Abbreviations: Qi-Mc, Holm oak with myrtle; Ph-Qi, Aleppo pine with Holm oak; Nsum, total number of trees; Gsum, basal area (m^{-2} ha); Vsum, wood volume (m^{-3} ha).
Tablica 1. Karakteristike pokusnih ploha. Skraćenice: Qi-Mc, Šuma hrasta crnike s mirtom; Ph-Qi, Šuma alepskog bora s hrastom crnikom; Nsum, ukupni broj stabala; Gsum, temeljnica (m^2/ha); Vsum, drvni volumen (m^3/ha)

Characteristic *Karakteristika*	Type of forest stand *Tip šumske sastojine*			
	Garrigue *Garig*	Maquis *Makija*	Holm oak *Hrast crnika*	Aleppo pine–Holm oak *Alepski bor-Hrast crnika*
Surface area (ha) *Površina (ha)*	0.25	0.25	0.25	0.25
Phytocenosis *Biljna zajednica*	Qi-Mc	Qi-Mc	Qi-Mc	Ph-Qi
Stage Stadij	Degradation *Degradirano*	Degradation *Degradirano*	No degradation *Nije degradirano*	No degradation *Nije degradirano*
Elevation (m) *Nadmorska visina*	90-100	100-110	100-115	80-90
Slope (%) *Nagib*	10-12	9-10	11-14	12-14
Exposure *Ekspozicija*	West–southwest *jug-jugozapad*			
Soil type *Tip tla*	Brunisol on limestone and dolomite *Smeđe tlo na vapnencu i dolomitu*			
Rock content (%) *Kamenitost*	60-70	50-60	50-60	50-60
Cover (%) *Pokrovnost*	40-50	100-100	90-90	90-90
Age (years) *Starost (godine)*	-	-	65-60	65-70
Stand height (m) *Visina sastojine (m)*	1.5-2	4-3.5	15-16	17-16
Nsum (N/ha)	-	7400-12800	1626-1550	1364-1470
Gsum (m^2/ha)	-	39.1-48.4	42.3-43.1	33.7-43.9
Vsum (m^3/ha)	-	138.4-175.4	230.7-233.2	252.7-314.4
*Species composition (%) *Omjer smjese (%)*				
Arbutus unedo	-	23-4	0-0	0-0
Erica verticlillata	-	0-18	0-0	0-0
Laurus nobilis	-	6-1	0-0	0-0
Quercus ilex	-	61-53	99-99	3-3
Phillyrea angustifolia	-	8-20	0.5-0.5	1-1
Pinus halepensis	-	0-0	0-0	96-96
Pistacia terebinthus	-	0-0	0-0	0-0
Viburnum tinus	-	2-4	0.5-0.5	0-0

*Species composition expressed in (%) in relation to the overall wood volume of the stand
*Omjer smjese po vrstama je iskazan u (%) u odnosu na ukupni drvni volumen sastojine

Microclimate stations were set up on 12 experimental plots (3 for each forest stand type), and each plot was 60 × 60 m in size. In each experimental plot, 3 Rotronic (HygroLog) and Spectrum (WD 2000) meteorological stations were positioned in subplots (20 × 60 m), corresponding to the low, medium, and large basal areas, to observe within-stand variation (Porté et al. 2004). The air temperature (°C), relative air humidity (%), and precipitation (mm) were measured at 1.5 m from the soil. The soil temperature (°C) and soil volumetric water content (%) were measured at a depth of 10 cm. Volumetric soil moisture was measured using an ECHO-25 probe. Calibration of microclimate stations and sensors was carried out by the Meteorological and Hydrological Service of the Republic of Croatia. Minor technical problems resulted in incomplete series (20% of data missing). In cases where data were missing for all replicates at one site and hour, that time was eliminated for all other sites. This prevented a hot or cold spell from biasing one site while another had missing data (Potter et al. 2001).

The microclimate study was conducted in the period from January 2012 to December 2014, with measurements performed one day per week at hourly intervals, always on the same day of the week. Precipitation was measured using an automatic rain gauge over the entire period and values are presented as the total monthly value. Potential evapotranspiration (PET) was calculated using the Blaney and Criddle method (Šimunić 2016). The dry season water deficit (DSWD) is expressed in mm and can be calculated as DSWD = p – PET, where p is the amount of monthly rainfall (mm) and PET (mm) is the monthly potential evapotranspiration (Dufour – Dror and Ertas 2004). The dry season water deficit (mm), potential evapotranspiration (mm), and precipitation were calculated on a monthly level.

Ranges were calculated as differences between the maximum and minimum values. The measured microclimatic elements are expressed as average weekly values. The main effects of the differences and ranges of microclimatic elements among type of forest stands (experimental plots) were determined using Repeated measures ANOVA. We used the following factors: forest type/degradation stage × season. There were 4 types of forest stand/degradation stage (garrigue, maquis, Holm oak forest, Aleppo pine with Holm oak forest) and 4 seasons (spring, summer, autumn, winter). Levene's test for homogeneity of variances was not significant. The mean comparison test (Fisher's least significant difference (LSD), α = 5% tolerance level) was used to test climate element differences between stands. All data were processed using the HW3, SpecWare 9.0 and Statistica 7.1 software packages (StatSoft 2003).

RESULTS
REZULTATI

The absolute maximum air temperature (40.1 °C), soil temperature (28.9 °C), and volumetric soil moisture (82.8%) were measured in the garrigue degradation stage. The absolute maximum value of relative air humidity (100%) was measured in the maquis and Holm oak forest with myrtle. In all stand types, the absolute minimum volumetric soil moisture was 0%. The highest amount of potential evapotranspiration was in the garrigue degradation stage (139.48 mm), and the lowest was in the maquis (46.85 mm). The absolute highest water deficit was also in the garrigue (-129.61 mm), and the lowest was in the Holm oak forest (-124.95 mm). The highest absolute annual range of preci-

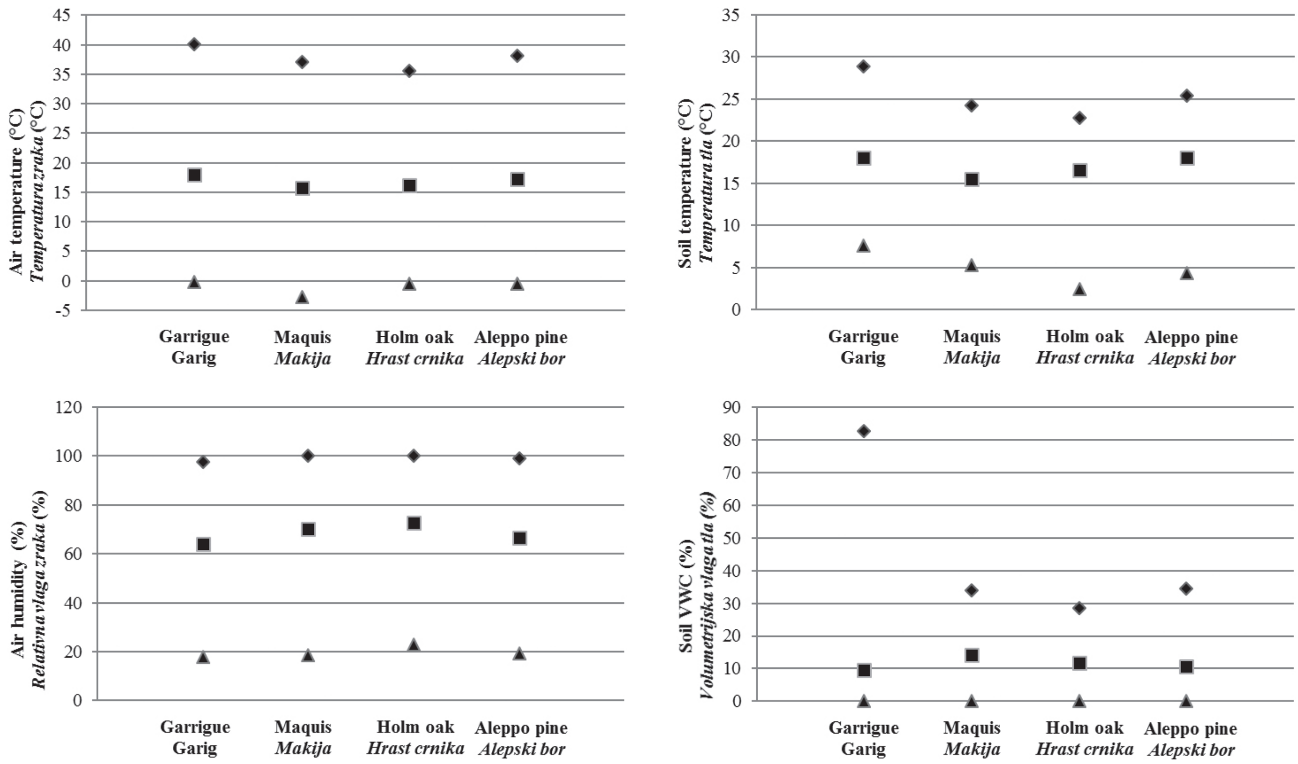

Figure 2. Annual ranges of measured microclimatic elements (♦ max, ■ mean, ▲ min)
(Data present values of all weather stations per type of forest stand)

Slika 2. Godišnje kolebanje mjerenih mikroklimatskih elemenata
(Podaci predstavljaju vrijednosti svih meteoroloških postaja po tipu šumske sastojine)

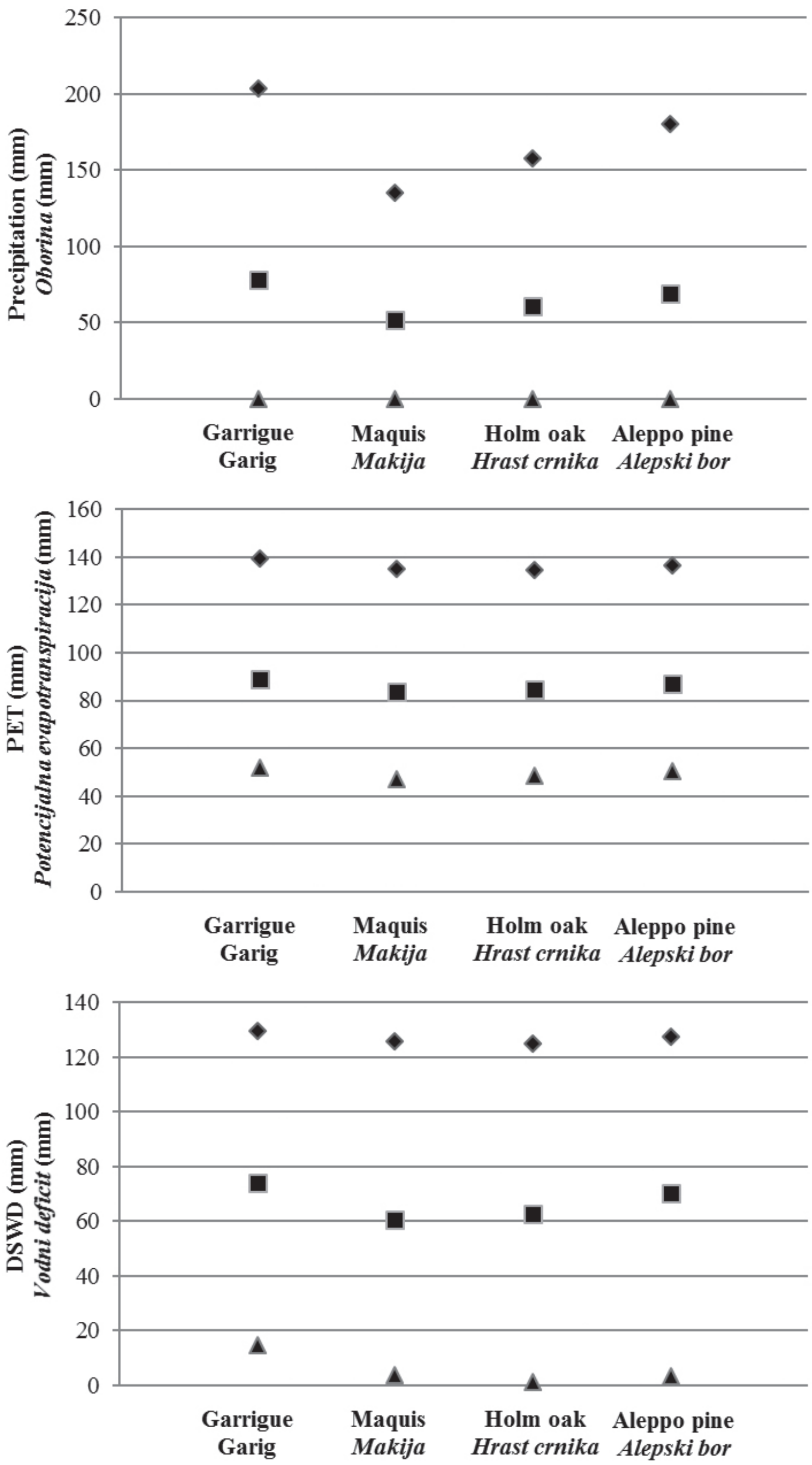

Figure 3. Annual ranges of measured microclimatic elements (♦ max, ■ mean, ▲ min).
(Data present values of all weather stations per type of forest stand)

Slika 3. Godišnje kolebanje mjerenih mikroklimatskih elemenata
(Podaci predstavljaju vrijednosti svih meteoroloških postaja po tipu šumske sastojine)

pitation (203.40 mm) was found in the garrigue degradation stage and greatest dry season water deficit (-124.27 mm) was found in the Aleppo pine forest stand, while for potential evapotranspiration the highest range was in maquis (88.10 mm) (Figure 2, 3).

The lowest annual range of air temperature (36.07 °C), relative air humidity (77.25%), and volumetric soil moisture (28.60%) were found in the stands of Holm oak with myrtle. In the maquis degradation stage, the annual range of soil temperature was the lowest (19.0 °C). The air and soil tem-

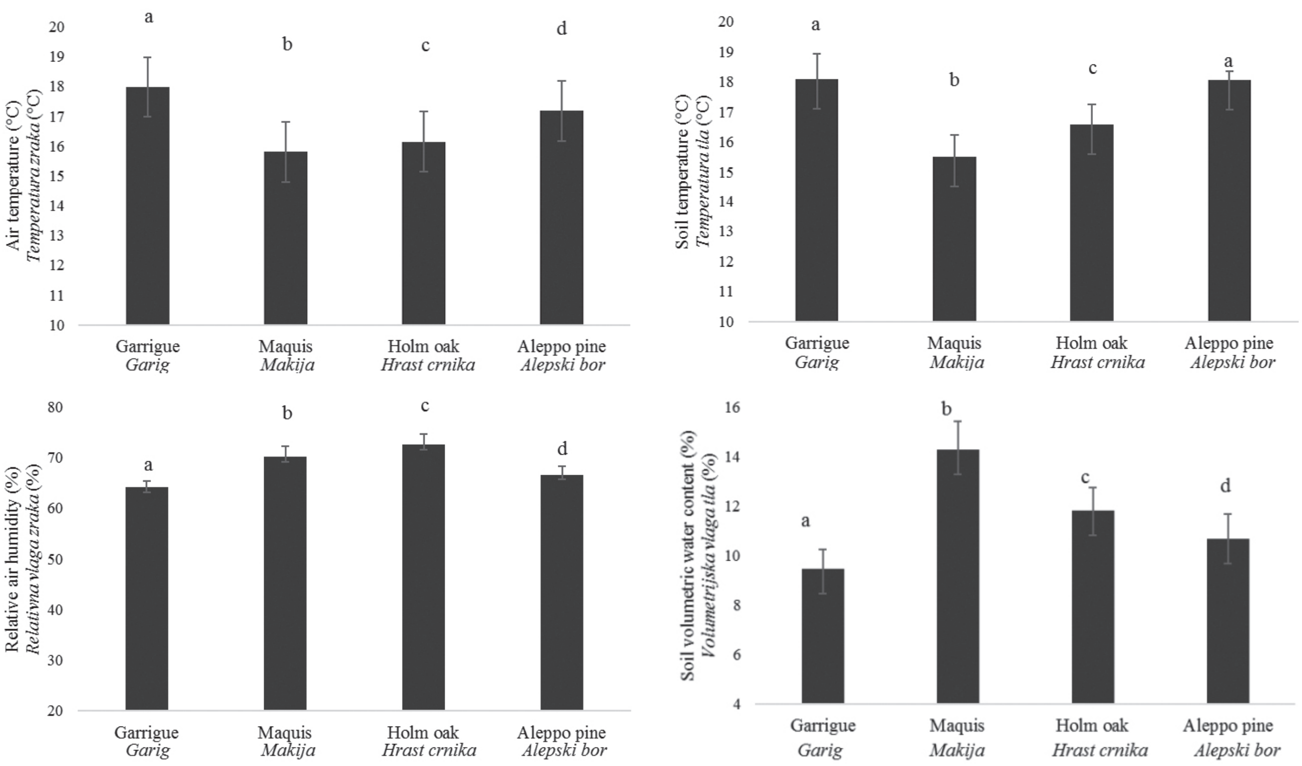

Figure 4. Comparison of the mean values of air and soil temperatures, air humidity, and volumetric soil moisture. ([a,b,c,d] Values marked with different letters differ significantly, $p < 0.05$, bars represent mean values and standard errors)

Slika 4. Usporedba prosječnih vrijednosti temperatura zraka i tla, relativne vlage zraka i volumetrijske vlage tla ([a,b,c,d] Vrijednosti označene različitim slovom značajno se razlikuju, p < 0,05, stupci predstavljaju prosječne vrijednosti i standarne pogreške)

perature ranges were lower in Holm oak forest stand than in garrigue and Aleppo pine forest stands. In the garrigue degradation stages, range of annual air temperature was 40.25 °C, higher than other types of forest stands. The range of soil temperature in garrigue was 21.30 °C. The highest annual range of relative air humidity (81.31%) was in the maquis. The lowest annual range of relative air humidity was in Holm oak forest (77.25 %). The annual range of volumetric soil moisture was highest in garrigue, 82.80% (Figure 2, 3).

The highest mean air temperature (17.98 °C, $p < 0.0000$, MS = 0.08, df = 150.00) and soil temperature (18.09 °C, $p < 0.0000$, MS = 1.16, df = 147.00) were measured in the garrigue. The lowest mean air temperature (15.81 °C) and soil temperature (15.52 °C) were in maquis (Figure 4).

The highest mean relative air humidity was measured in the Holm oak forest (72.59%), and the highest mean volumetric soil moisture was measured in maquis (14.28%). The air temperature ($p < 0.0000$, MS = 0.08, df = 150.00), relative air humidity ($p = 0.0000$, MS = 9.52, df = 150.00), soil temperature ($p = 0.0000$, MS = 1.16, df = 147.00), volumetric soil moisture ($p < 0.0000$, MS = 5.21, df = 147.00), precipitation ($p = 0.0000$, MS = 66.22, df = 60.00), potential evapotranspiration ($p < 0.0000$, MS = 0.44, df = 60.00), and dry season water deficit ($p = 0.0001$, MS = 24.08, df = 42.00) differed significantly between the degradation stages of garrigue and maquis (Figures 3 and 4). We found significant difference between the mean air temperatures in the Holm oak forest versus the maquis stage ($p < 0.0000$, MS = 0.08, df = 150.00). The mean values of soil temperature ($p = 0.0000$, MS = 5.21, df = 147.00), relative air humidity ($p = 0.0000$, MS = 9.52, df = 150.00), precipitation ($p = 0.0000$, MS = 66.29, df = 60.00), and potential evapotranspiration ($p = 0.0001$, MS = 0.44, df = 60.00) were higher in the stands of Holm oak in comparison to in the maquis degradation stage. Significant differences were found between the stands of Holm oak and Aleppo pine in the values of air temperature ($p < 0.0042$, MS = 0.08, df = 150.00), relative air humidity ($p = 0.0000$, MS = 9.52, df = 150.00), soil temperature ($p < 0.0001$, MS = 1.16, df = 147.00), volumetric soil moisture ($p < 0.0121$, MS = 5.21, df = 147.00), precipitation ($p < 0.0004$, MS = 66.29, df = 60.00), potential evapotranspiration ($p < 0.0000$, MS = 0.44, df = 60.00), and dry season water deficit ($p < 0.0004$, MS = 24.08, df = 42.00). The highest average precipitation (77.93 mm, $p < 0.0000$, MS = 66.29, df = 60.00) and potential evapotranspiration (89.15 mm, $p < 0.0000$, MS = 0.44, df = 60.00) were in the garrigue degradation stage. The lowest average precipitation (51.95 mm, $p < 0.0000$) and potential evapotranspiration (83.79 mm, $p < 0.0000$) were in the maquis stage. The mean dry season (summer) water deficit was highest in the garrigue

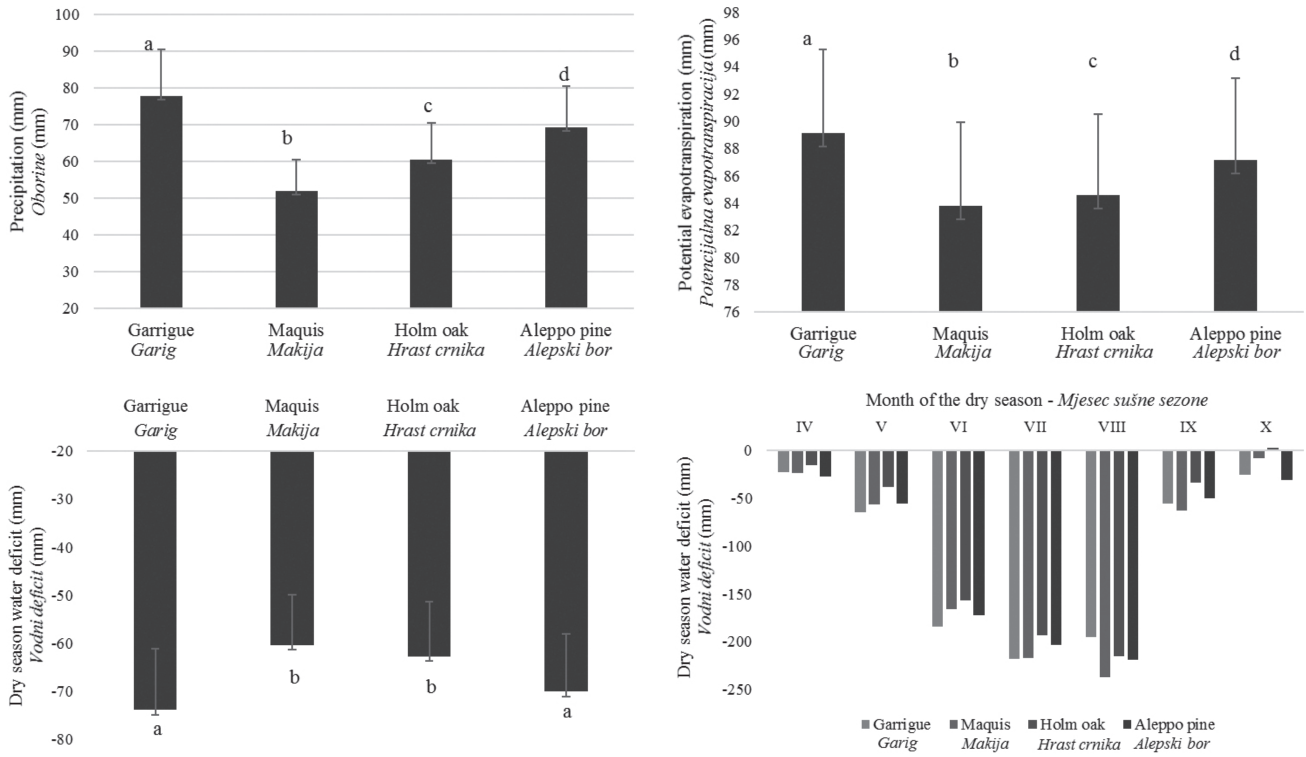

Figure 5. Comparison of mean values of precipitation, potential evapotranspiration, and dry season water deficit. ([a,b,c,d] Values marked with different letters differ significantly, $p < 0.05$, bars represent mean values and standard errors)

Slika 5. Usporedba prosječnih vrijednosti oborine, potencijalne evapotranspiracije i vodnog deficita u sušnom periodu ([a,b,c,d] Vrijednosti označene različitim slovom značajno se razlikuju, $p < 0{,}05$, stupci predstavljaju prosječne vrijednosti i standarne pogreške)

stage (-73.95 mm, $p < 0.0000$, MS = 24.08, df = 42.00) and lowest in the maquis (-60.38 mm). We found no significant difference in dry season water deficit between Holm oak forest and maquis ($p < 0.4400$, MS = 24.08, df = 42.00). No significant differences were found in mean dry season water deficits between garrigue (-73.95 mm) and Aleppo pine forest stand (-70.09 mm, MS = 24.08, df = 42.00, $p = 0.5038$). The dry season water deficit started in April and ended in October (Figure 4). For all analyzed degradation stages and types of forest stand, the lowest average water deficit was in April, from -15.48 to -26.99 mm, and the highest was in July, from -193.40 to -218.27 (Figure 5).

Table 2. Results from two-factor repeated measures ANOVA testing for the effects of type of forest stand and season on microclimate variables
Tablica 2. Rezultati analize varijance ponovljenih mjerenja (ANOVA) za dva faktora, tip šumske sastojine i godišnje doba, za mikroklimatske elemente

Microclimate Variables *Mikroklimatske varijable*	Stand type *Tip sastojine*		Seasons *Godišnje doba*		Stand type x seasons *Sastojina x God. doba*	
	F	p	F	p	F	p
Air. temp. *Temp. zraka*	656.01	0.0000	41.80	0.0000	8.54	0.0000
Soil temp. *Temp. tla*	72.98	0.0000	56.41	0.0000	35.41	0.0000
Air humidity *Vlaga zraka*	85.56	0.0000	23.07	0.0000	15.32	0.0000
VSM	44.65	0.0000	47.07	0.0000	3.69	0.0000
Precipitation *Oborine*	45.29	0.0000	2.49	0.0000	2.49	0.0000
PET	328.42	0.0000	26.92	0.0000	3.37	0.0000
DSWD	4.65	0.0067	1.77	0.1984	0.17	0.9952

VSM – volumetric soil moisture, volumetrijska vlaga tla; PET – potential evapotranspiration, potencijalna evapotranspiracija; DSWS – dry season water deficit, vodni deficit u sušnom periodu

According to the results presented in Table 2, the difference between two analysed factors and the interaction of factors stand type x seasons was statistically significant for all microclimate variables, except dry season water deficit. Differences were established between dry season water deficit and forest stand type and seasons ($p < 0.0000$), while no differences were found in the interaction of those two factors (p=0.9952).

The differences in values of dry season water deficit between Holm oak forests and maquis were not statistically significant. Between garrigue and maquis, there was a statistically significant difference in the dry season water deficit in spring (p=0.0329), summer (p=0.0046) and autumn (p=0.0256). In the comparison between Aleppo pine forest stand and maquis, there was a higher value of dry season water deficit during summer (p=0.0138), while no differences were detected for spring (p=0.0577) or autumn (p=0.0731). There were also no statistically significant differences for dry season water deficit by season between the garrigue and Aleppo pine forest stand (p=0.6369).

DISCUSSION
RASPRAVA

The largest amplitudes for most of the analyzed climatic elements were found in the garrigue degradation stage. This is explained by the structure of this degradation stage, in which plant cover is from 40 to 50% and the crown cover is significantly interrupted. The development of forest from the garrigue stage to Holm oak forest contributes to significant reductions in air and soil temperature ranges. Lower ranges of air and soil temperatures were found in Holm oak forests due the full tree canopy, subcanopy tree layer, and well-developed shrub layer.

Minimal air temperatures were lowest in maquis, meaning that the maquis degradation stage could be a less favorable breeding form for the germination of Holm oak seeds in comparison to the high silvicultural form of Holm oak forests with myrtle. According to Larcher (1969) Holm oak is most sensitive in the germination phase. A temperature drop of -2 to -3 °C is sufficient to cause damage to young plants. According to Potter et al. (2001), the buds and leaves of Holm oak are sensitive at a minimum air temperature of -5 °C. The minimum air temperature on the island of Mljet can drop to -5.2 °C (Seletković et al. 2011).

When maquis is considered as less favourable breeding form for Holm oak seedling growth and development, light as an ecological factor should be considered. High density and small amount of relative light intensity in maquis form (Oršanić et al. 2011) also has s greater impact on young plants.

According to Aussenac (2000) and Ugarković et al. (2017), soil temperature is affected by stand structure and plant abundance. In general, forest cover buffers the daily and seasonal temperature differences compared to open ground and notably clear-felled areas. Soil temperature is affected by the nature and density of cover. Soils under forest cover are warmer in the winter and colder in the summer than clear-felled areas (Aussenac 2000).

The highest maximum and average air and soil temperatures were measured in garrigue due to forest gaps indicating higher light intensity. Larger openings appear in the canopy and the stand is unable to modify the climatic elements. The lowest average air and soil temperatures were recorded in the maquis stage and probably resulted from the climate-moderating influence of dense vegetation. Large numbers of plants per unit area in this degradation stage and high plant cover moderate the influence of solar radiation. Differences in air and soil temperature, relative air humidity, volumetric soil moisture, precipitation and potential evapotranspiration between Holm oak forest stand and maquis were significant, but not for dry season water deficit. Maquis is the first degradation stage and certain ecological conditions are less favorable for Holm oak than in a forest with a high silvicultural form. According to the climatic element values, stands of Aleppo pine are more arid than stands of Holm oak and the maquis degradation stage. Reforestation with Aleppo pine as the stage before Holm oak forests, i.e., as a progression toward the return of climatogenic vegetation, improves the microclimate conditions needed for the return of Holm oak.

Air humidity is higher within forests than outside them due to poor internal mixing of internal and external air, and because higher quantities of water move from the soil depths to the air due to plant metabolism (Penzar and Penzar 2000). For that reason, the mean value of relative air humidity was highest in the Holm oak forest with myrtle in which there are tree, subcanopy tree, and shrub layers.

Previous studies have indicated that forest cover has little (Aussenac 2000, Morecroft et al. 1998, Gehlhausen et al. 2000, Meyer et al. 2001) or no (Valigura and Messina 1994) effect on the relative air humidity. In the present study, a significantly lower average air humidity was found in stages with interrupted forest cover (garrigue) and in the Aleppo pine forest stand. Generally, forest cover and tree species composition influence air humidity in Mediterranean forest ecosystems.

The maximum value of volumetric soil moisture was highest in the garrigue stage. Considering the low plant cover in this degradation stage, there is less interception (Nakamura *et al.,* 2017) and much more precipitation falls on the ground in a shorter period of time. Due to the low plant cover and low interception, we hypothesize that there is greater surface runoff, though additional research is needed to test this hypothesis.

According to Martín et al. (2014), large amounts of precipitation, soil moisture, and relative air humidity had significant and positive influences on tree growth, while high temperatures, evapotranspiration, and solar radiation had significant negative effects. Accordingly, the microclimate conditions in the garrigue degradation stage are less favorable for the growth and development of forest tree species such as Holm oak than in the maquis stage and in high silvicultural form stands. In wetter areas where annual precipitation exceeds 700 mm, soil moisture is always higher under tree crowns than outside tree crowns (Joffre and Rambal 1993). Here, average soil moisture was also found to be significantly lower in garrigue than maquis and high silvicultural forest forms as expected, due to the complete canopies in the maquis stage and high silviculture forest form as opposed to the discontinuous canopy in the garrigue. This sparse canopy and lower interception of precipitation also gave the highest soil moisture range and maximum value in garrigue.

The relative air humidity is known to have ecological significance for the supply of surface soil layers through condensation (Oršanić et al. 2011). Limited moisture will often determine the abundance of Holm oak seedlings for successful regeneration in Mediterranean areas (Oliet and Jacobs 2007). Though many factors can influence acorn production, the summer water status of plants is likely the predominant factor affecting seed growth and acorn production (Carevic et al. 2010). According to the results presented here, the best conditions for volumetric soil moisture and dry season water deficit are found in the Holm oak forest stands and the maquis degradation stage. Despite being a degradation stage, maquis is favourable for the growth of Holm oak, given the values of the dry season water deficit with regard to the ecological water requirements of Holm oak.

Under the current conditions of changing a macroclimate, microclimate conditions are also altered. According to Nunes et al. and Sardans and Peñuelas (Nunes et al. 2017, Sardans and Peñuelas 2004), longer and more frequent periods of drought can be expected in the near future in the Mediterranean forest ecosystems. By the end of the 21st century, precipitation is expected to decline in the Mediterranean as a result of climate change (Limousin et al. 2008) which will certainly have a strong impact on the negative water balance in the soil during the summer months.

Changes in the amount of available water in the soil may be a key factor in tree survival and ecosystem productivity, particularly in semiarid regions (Moreno and Cubera 2008). Due to climate change, the Mediterranean region is becoming drier, and reduced growth can be expected, which will benefit drought-tolerant species such as *Phillyrea latifolia*, while wetter (more mesophilic) species such as Holm oak will be lost. Holm oak has lower growth rates and higher mortality in drought conditions in comparison to the less susceptible *Phillyrea latifolia* and *Arbutus unedo* (Ogaya et al. 2003), and has a lower ecological amplitude for soil moisture and drought than the *Erica arborea* and *Myrtus communis* species which appear in the garrigue stage.

Considering the ecological requirements of Holm oak, it is not recommended for spaces to be filled in the garrigue degradation stage. Openings in garrigues should be reforested with species that have broader ecological amplitudes for soil conditions, particularly soil moisture, such as Aleppo pine, maritime pine, Turkish pine, and manna ash. Under pine stands, the soil gradually takes on properties that allow for the appearance of species that make up the composition of the Holm oak forest. This is a long-term process that could take 60 to 80 years or more, depending on the habitat conditions (Matić et al. 2011).

The values of all analysed microclimate elements in the Aleppo pine forest stand were more favourable than in the garrigue, with the exception of dry season water deficit. For that reason, the share of Holm oak in Aleppo pine stands is very low, at just a few percent, and Holm oak is almost absent in garrigues (Table 1). There are opposing opinions on Aleppo pine as a pioneer and amelioration tree species. Some claim that it improves the habitat for the return of Holm oak (Španjol et al. 2006), while others suggest that these improvements are unsuccessful (Maestre and Cortina 2004). It is our conclusion that Aleppo pine improves the microclimate conditions for Holm oak, though this is a long-term process.

An understanding of how ecological factors function and the reaction of ecosystem parts to those factors is essential to support the natural functioning of managed forest ecosystems. By associating microclimatic factors with the numerous morphological and biological properties of Holm oak (e.g., germination, height growth, mortality, etc.), this allows us to obtain a better understanding of the functioning of these complex forest ecosystems.

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SAŽETAK

Hrast crnika (*Quercus ilex* L.) je temeljna autohtona šumska vrsta eumediteranskog područja Hrvatske. Hrast crnika pridolazi u svim uzgojnim oblicima i degradacijskim stadijima, a makije i garizi su najčešći degradacijski stadiji crnikovih šuma. Nekontroliranim sječama sastojina sjemenjača i njihovim prevođenjem u degradacijske stadije, mijenjamo mikroklimu određene sastojine. Mikroklimatska istraživanja obavljena su na području otoka Mljeta. Mjerenja su obavljena u šumi hrasta crnike, u degradacijskim stadijima makija i garig te u šumi alepskog bora s hrastom crnikom. Tijekom dvije godine mjerena je temperatura zraka (°C), temperatura tla (°C), oborine (mm), relativna vlaga zraka (%) te volumetrijska vlaga tla (%). Potencijalna evapotranspiracija je izračunata prema metodi Blanea i Criddle. Vodni deficit tijekom sušnog perioda izračunat je kao razlika mjesečne količine oborine (mm) i potencijalne evapotranspiracije (mm). Najveća kolebanja mikroklimatskih elemenata su izmjerena u degradacijskim stadijima hrasta crnike. Najveća apsolutna maksimalna temperatura zraka izmjerena je u stadiju garig, a najveća minimalna u stadiju makije.

Prosječne vrijednosti temperatura zraka i tla, oborine i potencijalne evapotranspiracije su bile najveće u stadiju gariga, a najmanje u stadiju makije. Prosječna vrijednost relativne vlage zraka je imala najveću vrijednost u visokoj šumi hrasta crnike. Prosječna volumetrijska vlaga tla je bila najveća u makiji (14,28 %), a najmanja u stadiju gariga (9,46 %). Vodni deficit u sušnom peridou bio je najveći u stadiju gariga (-73,95 mm), a najmanji u stadiju makije (-60,38 mm). Mikroklimatske prilike u degradacijskom stadiju gariga su nepovoljne za rast i razvoj hrasta crnike u odnosu na mikroklimatske prilike u sastojini visokog uzgojnog oblika. Prosječne vrijednosti mikroklimatskih elemenata u sastojini alepskog bora s hrastom crnikom bile su između prosječnih vrijednosti mikroklimatskih elemenata sastojine gariga i makije. Analiza ovih podataka mikroklime služi boljem poznavanju ekoloških prilika šumskih staništa.

KLJUČNE RIJEČI: mikroklima šume, struktura šume, hrast crnika, degradacijski stadiji, alepski bor