PERIODICUM BIOLOGORUM
VOL. 111, No 4, 505–514, 2009

UDC 57:61
CODEN PDBIAD
ISSN 0031-5362

Original scientific paper

Regeneration of burned stands of pubescent oak (*Quercus pubescens* Willd.) and holm oak (*Quercus ilex* L.) in the Zadar area

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Key words: succession, forest fire, climatozonal vegetation, karst.

Received July 17, 2009.

Abstract

Background and Purpose: *Pubescent oak (*Quercus pubescens *Willd.) and holm oak (*Quercus ilex *L.) are climatozonal species in the area of Zadar, where the communities formed by these two species have an ecological-protective role. The aim of this research is to address the problem of the disturbed stability of these stands and the possibility of their post-fire regeneration.*

Materials and Methods: *Research was undertaken in burned and unburned areas of the Zadar Forest Office. This included pubescent oak coppices, scrub, thickets, maquis and garrigue. The relevés were made according to the plant sociology method (Braun-Blanquet 1964, Dierschke 1994). Pedological research involved taking composite samples of the humus-accumulative horizon. Chemical soil analyses were performed according to the standard methods.*

Results: *The number of pubescent oak individuals was about 2.5 times higher in burned areas compared to unburned ones. This was in contrast to holm oak, which showed poorer occurrence in burned areas in relation to unburned ones. The average number of all trees and shrubs in degraded forms of pubescent oak was 11.567 per hectare, whereas in degraded forms of holm oak forest this number was more than twice as high and amounted to 2.550 individuals per hectare.*

Conclusions: *Forest fires are an important cause of soil degradation. Burned areas are subject to erosion, the disappearance of or a decrease in soil biological activity, and extreme ecological effects. In order to mitigate the problem, certain prescribed post-fire recovery methods should be urgently applied.*

INTRODUCTION

Regeneration of vegetation is an exceptionally important natural process in areas frequently struck by forest fires. One such area is the sub-Mediterranean and eu-Mediterranean vegetation zone, which includes the Zadar area. The effect of forest fires on vegetation is linked with their intensity and frequency at a given site. Intensive and frequent fires weaken the sprouting vigour of vegetation, impoverish the soil and increase the risk of erosion. Vegetation regeneration in the Mediterranean climate is a particular problem *(1)*. Dry periods lasting for up to three months, combined with a shortage of humidity in the soil, impede the growth of young plants. Later, the main climatozonal species, the holm oak and the pubescent oak, are prevented from development by faster-growing and more aggressive species. This problem is more distinct in the eu-Mediterranean vegetation zone. One of the objectives of silvicultural activities in Mediterranean forests is to preserve the vegetation and curb devastation. However, the transition, i.e. the already exceptionally slow process of progressive succession, is additionally delayed by forest fires. This paper deals with the status of holm oak and pubescent oak stands and discusses the possibility of regeneration in the study area. Regeneration is aimed at directing the development of a stand from degraded forms (maquis, garrigue, scrub and thicket) towards a coppice forest. One of the reasons is favouring less flammable forested ecosystems over grassland and shrubland *(2)*. The decisive role in the regeneration process is played by the condition of vegetation after a forest fire. The degree of vegetation damage also dictates recovery activities. Recovery treatments have a primarily ecological role *(3)*. The commercial role of a stand is not the most important factor despite the fact that regeneration costs (planting, sowing or resurrection felling) are considered limiting factors in post-fire regeneration activities.

MATERIALS AND METHODS

Geographically, the most important parts of Zadar County are the low-lying Ravni Kotari and the Zadar-Biograd coastal area. The numerous islands of the Zadar-Biograd archipelago are situated off the coast (11 larger islands and over 200 islets). Karst uplands and the plateaus of Bukovica and Zagora are situated between the Velebit and Dinara mountains and the low-lying Ravni Kotari. The Velebit massif clearly separates the Zadar area from Lika and the continental part of Croatia. Zadar is the largest town and the most important centre. Historically known as Idassa and Jadera, it is one of the oldest towns on the Adriatic coast *(5)*.

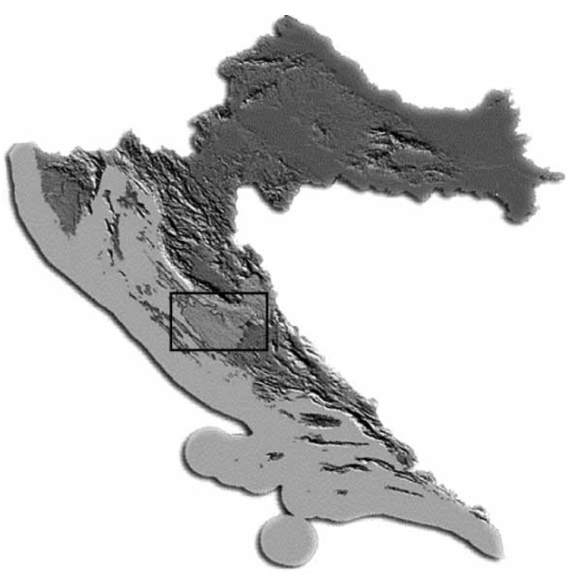

Figure 1. *Geographical position of the Zadar area (3).*

Vegetation features

According to Trinajstić *(6),* Zadar County is part of the Mediterranean region, i.e. the Mediterranean littoral vegetation belt. Its coastal part belongs to the eu-Mediterranean vegetation zone, while the part closer to Velebit belongs to the sub-Mediterranean vegetation zone. The contact belt of the eu-Mediterranean and sub-Mediterranean zones extends in a relatively wide area from the Zadar coast towards Nin and Bokanjačko Blato, where it turns into pubescent oak stands along the Miljašić ditch. Forests of holm oak and pubescent oak in the Zadar area usually occur in different degradation forms.

Phytocoenological research indicates the following forest phytocoenoses in the Zadar area:

Class:	*Quercetea ilicis* Br.-Bl. 1947
Order:	*Quercetalia ilicis* Br.-Bl. (1931) 1936
Alliance:	*Oleo-ceratonion* Br.-Bl. 1936
Ass:	*Querco ilicis-pinetum halepensis* Loisel 1971
Alliance:	*Quercion ilicis* Br.-Bl. (1931) 1936
Ass:	*Fraxino orni-Quercetum ilicis* H-ić 1956/1958
Class:	*Querco-fagetea* Br.-Bl. Et Vlieger 1937
Order:	*Quercetalia pubescentis* Br.-Bl (1931) 1932
Alliance:	*Ostryo-Carpinion orientalis* Ht. (1954) 1958
Ass:	*Querco-Carpinetum orientalis* H-ić 1939
Subass:	*Phillyrea media*
Class:	*Brachypodio-chrysopogonetea*
Order:	*Scorzonero-chrysopogonetalia*
Alliance:	*Chrysopogoni-satureion*
Ass:	*Stipo-salvietum officinalis* H-ić (1956) 1958
Ass:	*Koelerio-festucetum illyricae* Trinajstić 1992
Ass:	*Rhamno-paliuretum* Trinajstić 1996
Subass:	*Juniperus oxycedrus*
Alliance:	*Scorzonerion-villosae*
Ass:	*Danthonio-scorzoneretum* Ht et H-ić (1956) 1958
Class:	*Brachypodio-chrysopogonetea*
Order:	*Cymbopogo-brachypodietalia*
Alliance:	*Cymbopogo-brachypodion ramosi* H-ić
Class:	*Thlaspietea rotundifolii*
Order:	*Thlaspietalia rotundifolii*
Alliance:	*Peltarion alliaceae*
Ass:	*Drypetum jacquinianae* H–ić 1934

Vegetation relevés were made in each plot depending on the homogeneity of the stands in the plots over an area of 2 × 2 to 20 × 20 m (4 to 400 m^2) using the plant sociology methodology *(7, 8)*. Plant nomenclature was carried out according to Nikolić *(9, 10, 11)*.

Climatic features

According to Koppen's classification, the climate of the wider Zadar area is classified as the Csa climate type. This is the basic climate type of Mediterranean coasts, and is marked by mild and rainy winters (the mean monthly air temperature of the coldest month is between –3 °C and 18°C) and dry and hot summers (the mean monthly air temperature of the warmest month exceeds 22 °C), with at least three times more precipitation in the rainiest winter month than in the driest month. Rainfall in the driest month is less than 40 mm.

Pedological features

The main geological structure of the area consists of limestone, created during its geological evolution from the Cretaceous to the Holocene.

As part of the pedological research, composite samples of the humus-accumulative horizon formed from 5 individual samples were taken along the diagonals of the sample plot. After the samples had been dried and fragmented into small pieces, the soil was chemically analysed according to the standard methods:

1 soil reaction in water suspension and M-KCl was determined poteniometrically on a HACH EC 30 pH-meter (HRN ISO 10390:2005);

2 total carbonates were determined using the Scheibler method by means of a calcimeter (HRN ISO 10693:2004);

3 the humus content was determined following the Tjurin method (the bichromatic method);

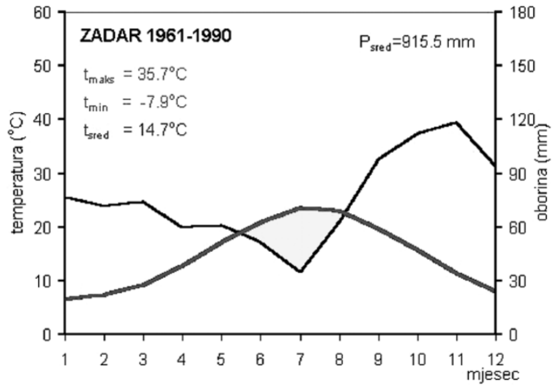

Figure 2. *Climatodiagram for the Zadar.*

4 The total nitrogen content was determined by means of the Leco CNS 2000 elementary analyser (HRN ISO13878:2004);

5 The content of physiologically active phosphorus and potassium was determined with the A1 method. The phosphorus content was read from a PE Lambda 1A UV/VIS spectrophotometer. The potassium content was read directly from the filtrates on the Eppendorf flame photometer.

According to the Forest Management Plan *(12),* the following soil types are present in the Zadar area:

terra rosa – typical, shallow or medium deep;

brown soil on limestone (calcocambisol) – typical, shallow, medium deep;

rendzina on marl and marly soft limestone – shallow;

TABLE 1

Survey of sample plots (according to sample mark and status, management class and plot position).

Sample plot mark	Management class	Management unit	Compartment/ subcompartment	Sample status	Sample plot coordinates	
1P	Coppice of pubescent oak	Škabrnja	37 a	Burned 1994	5534235	4878405
1K	Coppice of pubescent oak	Škabrnja	35 a	Unburned plot	5533998	4878872
2P	Coppice of pubescent oak	Nin-Kožino	19	Burned 1998	5519883	4894249
2K	Coppice of pubescent oak	Nin-Kožino	18	Unburned plot	5519810	4894374
3P	Coppice of pubescent oak	Lovinac	Private	Burned 2003	5529898	4899882
3K	Coppice of pubescent oak	Lovinac	Private	Unburned plot	5529855	4899888
4P	Šcrub	Musapstan	9a	Burned 2003	5521552	4890297
4K	Šcrub	Musapstan	9a	Unburned plot	5521735	4890446
5P	Thicket	Ražanac Vrsi	38	Burned 2000	5523445	4899311
5K	Thicket	Ražanac Vrsi	37	Unburned plot	5523474	4899299
6P	Maquis	Vrana	Non-managed	Burned 2003	5545005	4865716
6K	Maquis	Vrana	Non-managed	Unburned plot	5544979	4865742
7P	Garrigue	Vrana	Non-managed	Burned 1998	5545422	4866075
7K	Garrigue	Vrana	Non-managed	Unburned plot	5545475	4866025
8P	Garrigue	Vrana	Non-managed	Burned 2004	5544288	4867058
8K	Garrigue	Vrana	Non-managed	Unburned plot	5544462	4866816

TABLE 2

Phytocoenological releves.

Fraxinus ornus L.	Quercus cerris L.	Quercus pubescens Willd.	Arbutus unedo L.	Asparagus acutifolius L.	Carpinus orientalis Mill.	Cistus incanus L.	Cistus salvifolius L.	Cistus villosus L.	Clematis flammula L.	Coronilla emeroides Boiss. et. Spr.	Crataegus monogyna Jacq.	Erica arborea L.	Fraxinus ornus L.	Juniperus oxycedrus L.	Lonicera implexa Aiton	Ostrya carpinifolia Scop.	Osyris alba L.	Paliurus spina-christi Mill.	Phillyrea media L.	Pistacia lentiscus L.	Pistacia terebinthus L.	Pyrus amygdaliformis Vill.	Quercus cerris L.	Quercus ilex L.	Quercus pubescens Willd.	Rhamnus alaternus L.	Rhamnus intermedia Steud. et. Hohst.	Rhamnus rupestris Scop.	Rubus dalmaticus Tratt.	Ruscus aculeatus L.	Smilax aspera L.	Aira caryophyllea L.	Anthoxanthum odoratum L.	Anthyllis rubicunda Wender. ex Steud	Arrhenatherum elatius (L.) J. et K.	Presl	Asparagus acutifolius L.	Asparagus officinalis L.	Asphodelus albus Mill.	Avena pratensis L.	Betonica serotina Host	Bidens tripartita L.	Brachypodium pinnatum (L.) P. Beauv.	Bromus erectus Huds.	Campanula rapunculus L.	Carex caryophyllea Latourr.	Carex flacca Schreb.
	TREE LAYER			SHRUB LAYER																												GROUND VEGETATION LAYER															
1P	–	–-	2b	–	–	2a	–	–	–	–	–	+	–	–	2a	–	–	–	–	–	–	–	–	2m	–	–	–	–	–	–	–	–	+	–	–	–	–	–	+	2m	–	–	1	+	r	1	2m
1K	–	–	4	–	–	2a	–	–	–	–	–	–	–	+	2a	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	–	1
2P	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	3	–	–	+	–	–	–	–	–	–	–	+
2K	–	–	4	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2a	–	–	–	–	–	2a	–	–	–	–	–	–	–	+	–	4	–	–	–	–	–	–	–	–	–	–	–
3P	–	–	+	–	1	–	–	–	–	1	–	–	2m	+	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	2a	–	–	–	–	–	–	–	–	–	–	–	–	5	–	–	–	2m
3K	2b	3	2a	–	–	–	–	–	–	–	–	–	2b	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2m	–	–	–	–	–	–	–	–	–	2m	–	+	–	–	–	–
4P	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2a	–	1	–	–	–	3	–	–	–	–	–	–	–	–	–	4	–	–	+	–	–	–	–	–	–	–	–
4K	–	–	–	–	–	–	–	1	–	–	–	–	–	–	2b	–	+	–	2a	2a	–	–	–	–	–	4	–	–	–	–	–	–	–	–	+	2b	–	–	r	–	–	+	–	–	–	–	–
5P	–	–	–	–	+	–	–	–	2a	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	2a	–	–	–	+	–	–	–	–	–	2b	–	–	r	–	–	–	–	1	–	–	–
5K	–	–	–	–	+	–	–	–	–	–	+	–	–	–	3	–	–	2b	–	–	–	–	–	–	–	3	–	–	–	–	–	+	–	–	–	2a	–	–	–	–	–	–	–	1	–	–	–
6P	–	–	–	2a	–	–	–	–	5	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	3	–	–	–	+	–	–	+	–	–	–	–	+	–	–	–	–	–	2m	1	–	–	–
6K	–	–	–	2a	–	–	1	–	–	–	–	–	–	–	1	–	–	–	–	1	+	–	–	–	4	–	2a	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
7P	–	–	–	–	–	–	–	–	2m	–	–	–	–	–	–	+	–	–	–	1	2m	–	–	–	2a	–	–	–	–	–	+	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
7K	–	–	–	2a	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	3	2a	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
8P	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	2a	2a	–	r	–	2m	–	–	2m	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	2m	–	–	–
8K	–	–	–	–	–	–	–	–	3	–	–	–	–	–	2a	–	–	–	–	–	1	–	–	–	2b	–	–	+	–	–	–	1	–	–	–	–	–	+	–	–	–	–	2m	–	–	–	–

TABLE 2

Phytocoenological releves.

	Carex nitida Host	Centaurea angustifolia L.	Cclematis flammula L.	Cclematis viticella L.	Cconvolvulus elegantissimus Mill.	Ddianthus integer Vis.	Ddianthus sylvester Wulf.	Ddorycnium herbaceum Vill.	Ddorycnium hirsutum (L.) Ser.	Eeryngium amethystinum L.	Eeuphorbia spinosa L.	Ffilipendula vulgaris Moench	Ffraxinus ornus L.	Ggalium lucidum All.	Ggeranium nodosum L.	Hhelianthemum nitidum Clem.
GROUND VEGETATION LAYER																
1P	2M	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
1K	–	–	+	–	–	–	+	–	–	+	–	–	+	–	–	–
2P	–	–	+	–	–	–	+	2M	–	–	+	–	–	–	1	–
2K	–	–	+	+	–	–	–	+	–	–	+	–	–	–	–	–
3P	–	1	–	–	–	–	–	–	–	–	–	2M	–	–	–	–
3K	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–
4P	–	–	–	+	–	–	–	1	2M	–	–	+	–	–	+	+
4K	–	–	–	–	–	+	–	1	1	+	1	–	–	–	1	+
5P	–	–	–	–	–	–	–	2M	–	–	2A	–	–	+	–	–
5K	–	–	–	–	–	–	–	1	–	–	2A	–	–	+	–	–
6P	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
6K	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
7P	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	2A
7K	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
8P	–	–	–	–	+	–	–	–	–	–	–	–	–	2M	–	2M
8K	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	2M

	Hhelichrysum italicum (Roth.) Mill. corr. Guss.	Hieracium bauhinii Schult.	Hieracium pilosella L.	Hippocrepis comosa L.	Knautia purpurea (Vill.) borbás	Koeleria splendens C.Presl.	Linum tommasinii Rchb.	Lotus corniculatus L.	Marrubium incanum Desr.	Micromeria juliana (L.) Benth. ex Rchb.	Onosma javorkae Simonk.	Ornithogalum gussonei Ten.	Plantago holosteum Scop.	Polygala comosa Schkuhr	Quercus pubescens Willd.
GROUND VEGETATION LAYER															
1P	–	1	1	–	–	2M	–	1	–	–	–	–	1	–	–
1K	–	–	–	+	–	–	–	1	–	–	–	–	+	–	1
2P	–	+	–	–	–	–	+	–	–	–	–	–	–	–	–
2K	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–
3P	–	–	–	2M	1	–	–	–	–	–	–	1	–	–	–
3K	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
4P	–	–	–	1	+	–	–	1	–	–	–	–	–	–	–
4K	–	+	–	+	+	–	–	–	–	–	–	–	–	1	–
5P	–	–	–	2M	–	–	–	–	+	–	–	–	–	+	–
5K	–	–	–	2M	–	–	–	–	–	–	–	–	–	+	–
6P	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6K	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
7P	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–
7K	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
8P	2M	–	–	–	–	–	–	–	–	2M	–	–	–	–	–
8K	–	–	–	–	–	–	1	–	–	–	–	–	–	2M	–

	Reichardia picroides (L.) Roth.	Salvia officinalis L.	Schoenus nigricans L.	Sesleria autumnalis (Scop.) F.W. Schultz.	Silene viridiflora L.	Silene vulgaris (Mch.) Garcke	Stipa pennata L.	Tamus communis L.	Tanacetum cinerariifolium (Vis.) Schultz-bip.	Teucrium polium L.	Thesium divaricatum Jan	Thymus pulegioideS L.	Trifolium angustifolium L.	Trifolium campestre Schreb.	Viola hirta L.
GROUND VEGETATION LAYER															
1P	–	–	–	1	–	–	–	–	–	–	–	+	R	+	–
1K	–	–	–	2M	–	+	–	–	–	–	+	–	–	–	–
2P	–	–	–	–	2M	–	–	–	–	–	–	–	–	–	–
2K	–	–	–	2A	1	+	–	–	–	–	–	–	–	–	–
3P	–	–	1	–	–	–	–	–	+	–	–	–	–	–	2M
3K	–	–	–	–	–	–	–	R	–	–	–	–	–	–	2M
4P	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–
4K	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–
5P	1	–	–	–	–	+	1	–	–	–	–	–	–	–	–
5K	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–
6P	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
6K	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
7P	–	3	–	2M	–	–	–	–	–	2M	–	–	–	–	–
7K	–	+	–	+	–	–	–	–	–	+	–	–	–	–	–
8P	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
8K	–	3	–	2M	–	–	–	–	2M	1	–	–	–	–	–

lithosol on limestone;

colluvium – carbonate, medium skeletal;

mollic leptosol on limestone (calcimelanosol);

syrosem (regosol) – silicate-carbonate, shallow, medium or strongly skeletal.

RESEARCH RESULTS

Research was carried out in the area of Zadar Forest Office. Sample plots were set up in burned and unburned areas. Coppices of pubescent oak, scrub, thicket, maquis and garrigue were investigated. An overview of the sample plots by mark, management class, management unit, compartment/sub-compartment, sample status and sample plot co-ordinates is given in Table 1. The occurrence of the species expressed by their number in a sample plot was registered. In addition, mechanical and chemical soil content was also pedologically investigated in the sample plots, and the development of climatozonal vegetation was monitored.

The sample plots were of varying dimensions ranging from 2 × 2 to 20 × 20 m (4 to 400 m^2) depending on stand homogeneity.

According to Table 3, pubescent oak (*Quercus pubescens*) occurs in all the sample plots, except for sample plot 3K. The reason may be that the area in which the plot was established is privately owned and that pubescent oak may have been intentionally removed from the area. Another reason may be that there is a well-developed shrub layer, which may have limited the necessary light available to pubescent oak.

It should also be stressed that the number of pubescent oak individuals is about 2.5 times higher in the plots established in burned areas than in the plots established in unburned areas.

As far as the abundance of a particular species in sample plots set up in the scrub is concerned, an interesting result was obtained in the sample plot established in a burned area (Table 4). This plot (4P) is completely dominated by pubescent oak, unlike the control plot in which some accompanying species were also recorded (*Phillyrea media* L., *Paliurus spina- christi* Mill., *Juniperus oxycedrus* L.), of which the dominant species was *Phillyrea media*. A similar situation was also observed in the thicket in sample plots 5P and 5K. These two degraded stages showed a smaller number of pubescent oak trees in burned areas in relation to unburned ones, which is not the case with pubescent oak coppices.

As for the degraded stages of holm oak (*Quercus ilex*), in all studied sample plots this tree species occurs with its accompaniments. There were fewer holm oaks in maquis and garrigue in burned areas than in unburned ones. In the control plots set up in garrigue, there was a smaller number of accompanying species, as opposed to the control plots in maquis, where the situation was the reverse.

According to Figures 3 and 4, the average number of trees and shrubs in the degraded forms of pubescent oak is 11.567, while in the degraded forms of holm oak forest the number is twice as high and amounts to 27.550 trees. The same results were obtained for minimal and maximal values. In the degraded forms of pubescent oak, the minimal value is 1.500, while for holm oak it is 16,800. The maximal value in the degraded forms of pubescent oak is 22.075, and for holm oak it is 56.400.

Overview of some indicators of pedophysiographic features. The results of pedological analyses show that differences in nitrogen percentages in the main (burned) plots and control plots are relatively large. In almost all burned (main) plots, the nitrogen percentage decreases in relation to the control plot.

TABLE 3

Number of trees and shrubs of autochthonous vegetation in burned and unburned plots in pubescent oak coppices (Quercus pubescens).

Coppice of pubescent oak						
Sample plot	1P	1K	2P	2K	3P	3K
			Number/ha			
Species						
Q. pubescens	13175	5050	16250	6500	5544	
Q. cerris		225				
F. ornus		225				2112
C. orientalis	5525	4650				
P. latifolia		50	875	525		
P. spina christi	425	75		100		
J. oxycedrus	2950	3600		150		88
E. arborea					11572	8360
R. aculeatus						4224
Σ	22075	13875	17125	7275	17116	14784

P = burned plot; K = control plot

TABLE 4

Number of trees and shrubs of autochthonous vegetation in burned and unburned plots in scrub, thicket, maquis and garrigues.

	SCRUB		THICKET		MAQUIS		GARRIGUE			
Sample plot	4P	4K	5P	5K	6P	6K	7P	7K	8P	8K
	Number/ha									
Species										
Q. pubescens	3375	4550	1475	2925						
Q. ilex					5775	9200	7200	14300	1350	5100
F. ornus							25			
C. orientalis										
P. latifolia		6300		25	4975	8000	11400	4100	7225	2100
P. spina christi		875		125					4250	
J. oxycedrus		325	25	3425		3200		2100		7300
E. arborea										
R. aculeatus										
A. unedo					4775	11200		500		
V. tinus					4650	24800				
P. lentiscus					4325		1750	4000	9200	2300
A. acutifolius							200			
Σ	3375	12050	1500	6500	24500	56400	20575	25000	22025	16800

DISCUSSION AND CONCLUSIONS

The problems of post-fire vegetation regeneration are numerous and diverse. These problems are common to many countries in which climatic conditions are conducive to the occurrence of open fires *(13, 14)*. The basic problem is the destabilisation of ecological systems *(15)*, followed by the loss of biological diversity *(16)*. Desertification is also attributed to the effect of forest fires *(17)*. In the past decade, Mediterranean countries have been faced with very important social and economic difficulties caused by severe post-fire changes in the landscape. 186 fires had burned 4.455.71 ha in the degraded stages of holm oak and pubescent oak in the study area.

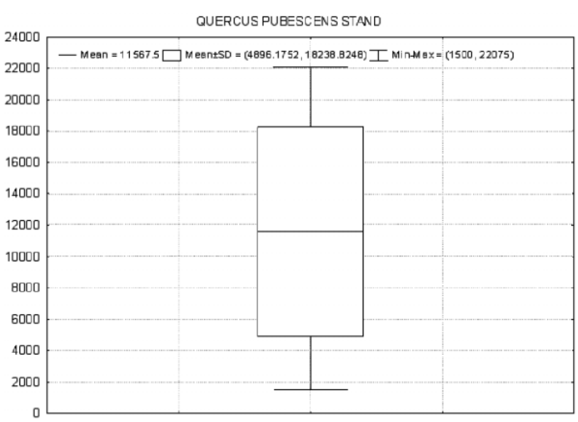

Figure 3. *Degraded forms of pubescent oak stands.*

Indicator species in stands of autochthonous broadleaves include the following: in the coppice of pubescent oak, the A layer in the majority of the plots contains *Fraxinus ornus* L., *Quercus cerris* L. and *Quercus pubescens* Willd. The B layer contains *Carpinus orientalis* Mill., *Juniperus oxycedrus* L., *Quercus cerris* L., *Quercus pubescens* Willd. and *Erica arborea* L.

The B layer in the scrub includes *Phillyrea media* L. and *Quercus pubescens* Willd. The B layer in the thicket contains *Osyris alba* L. and *Quercus pubescens* Willd.

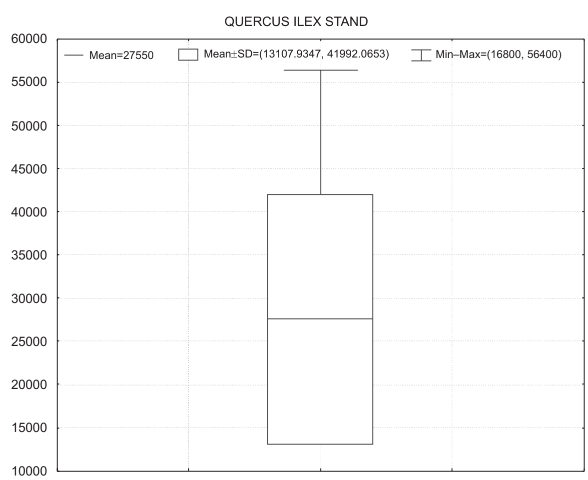

Figure 4. *Degraded forms of holm oak stands.*

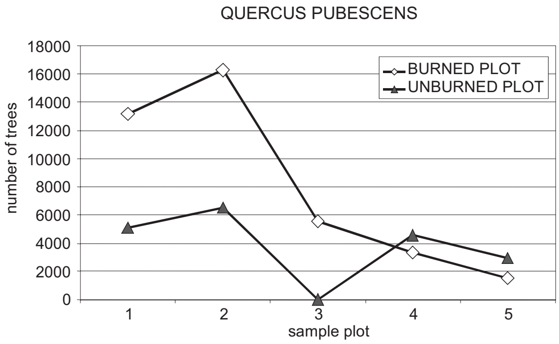

Figure 5. *Number of pubescent oak trees in sample plots.*

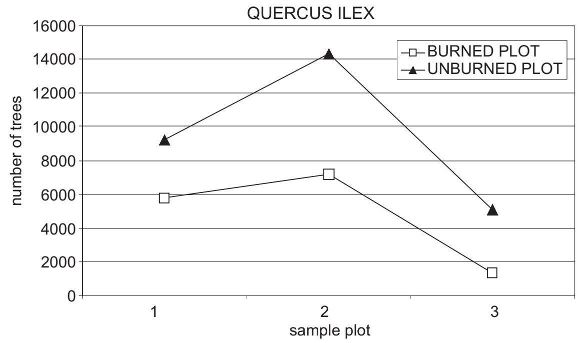

Figure 6. *Number of holm oak trees in sample plots.*

The A layer in the maquis includes *Quercus ilex* L., and the B layer contains *Arbutus unedo* L., *Cistus villosus* L., *Pistacia lentiscus* L. and, naturally, *Quercus ilex* L.

Indicator species for the garrigue are *Cistus villosus* L., *Phillyrea media* L., *Pistacia lentiscus* L. and *Quercus ilex* L. in the B layer.

If a holm oak forest is struck by a fire, a large number of sprouts from dormant buds can be expected, since holm oak is a species that shows rapid post-fire expansion by sprouts *(18, 19, 20)*. However, natural regeneration with seed is absent *(21)*. Kovačević *(22),* in his study of the maquis in Trsteno Arboretum after a fire, found that the fire did not disturb the basic floral structure of maquis either in quality or quantity. Our research confirmed the return of pubescent oak and holm oak in burned areas. Dubravac *et al. (23)* confirm these results in their research on the island of Korčula five years after a fire. The reasons for different post-fire recovery patterns (Figures 3, 4) may be attributed to different microclimatic conditions. Poorer regeneration of holm oak can be explained by its occurrence on the boundary of the distribution range. At the same time, the climatic conditions are more favourable for pubescent oak, so there is higher probability of its better regeneration. However, the results should be taken with caution and should serve as guidelines for further and more comprehensive research on a large number of sample plots.

The soil-forest fire relationship can be viewed in two ways: before fire and after fire. Soil is one of the ecological factors that define the type of vegetation in an area. Soils react differently to the harmful impacts of a fire. In terms of fire damage risks, the most represented soils in the Croatian Mediterranean area can be classified into four categories. A very high risk of damage by forest fire is manifested by regosols, rendzinas on flysch and sands, rankers, and mollic leptosols on limestone blocks. A high risk of soil damage is exhibited by mollic leptosol on

TABLE 5

Overview of some indicators of pedophysiographic features.

Sample plot	$CaCO_3$ g kg^{-1}	pH (H_2O)	pH(KCl)	P_2O_5 mg kg^{-1}	K_2O mg kg^{-1}	Org C g kg^{-1}	Total N g kg^{-1}	C:N
1P	–	6,83	5,91	66,0	339,0	35,3	2,0	18
1K	–	6,85	5,47	48,4	311,0	26,5	1,6	17
2P	–	6,48	5,72	58,3	374,4	37,2	2,4	15
2K	7	7	6,36	112,2	759,2	40,4	5,4	7
3P	29	7,31	7,12	39,6	312,0	38,6	1,8	21
3K	66	7,72	7,09	94,6	342,2	52,8	3,1	17
4P	–	6,87	5,78	62,7	530,4	39,7	2,6	15
4K	–	6,96	6,04	68,3	426,4	36,9	2,4	15
5P	17	7,5	6,62	114,4	634,4	40,0	3,3	12
5K	17	7,4	6,76	116,6	676,0	47,9	3,8	13
6P	4	7,35	6,68	80,3	540,8	62,2	4,4	14
6K	4	7,1	6,54	126,5	665,6	44,4	5,3	8
7P	21	7,42	6,79	129,8	266,2	84,2	6,6	13
7K	24	7,41	6,91	88,0	540,8	56,2	9,3	6
8P	4	7,19	6,61	66,0	322,4	61,5	5,0	12
8K	17	7,27	6,71	116,6	572,0	119,1	9,9	12

limestone, medium deep and deep rendzina on dolomite, and colluvial skeletal soils. A medium risk of soil damage is shown by lessivated soils on limestone and eutric brown soil on lake sediments. The lowest risk of soil damage is attributed to typical terra rosa, typical calcocambisol, and brown and red mollic leptosol on limestone *(24)*.

With regard to the C:N ratio, Martinović *(24)* mentions that a decrease in nitrogen concentrations and an increase in hydrolysing nitrogen after a fire result in more intensive nitrogen mineralisation in burned areas and indicate stronger future leaching from the soil. This process leads to the significant narrowing of the C: N ratio in the soil.

The results of chemical analyses are shown in Table 5. The nitrogen value in several sample plots is slightly higher in burned plots than the nitrogen value in the control plot, e.g. in burned plot 1P N = 2.0 (g kg^{-1}), while in control plot 1K N = 1.6 (g kg^{-1}). According to Martinović *(24),* a forest fire worsens humus quality. The author points out that the humus content in burned areas decreases by 11–30% over a period of 10–13 years.

To sum up, fire affects the soil nitrogen regime by gradually decreasing the total nitrogen content in burned plots in relation to the control plot. It should be pointed out that the majority of Mediterranean countries conduct long-term research on the effects of fires on soil, vegetation and on all the changes that fires cause in an ecosystem in general. Thus Iglesias *(25)* confirms that surface soil acidity shows a significant increase 10 months after a fire, and that the concentration of organic carbon in burned areas is higher than in unburned ones.

We should also mention the relationship between physical and chemical soil properties in the studied sample plots regarding silvicultural forms in which a fire has occurred. Sample plot 1P in the pubescent oak coppice is taken as an example. The following results were obtained: pH (H_2O) = 6.83; pH (1M KCl) = 5.91; P_2O_5 mg/100g soil = 6.60; K_2O mg/100g soil = 33.90; N = 0.20%; humus = 6.08%; C = 3.53 %; C/N ratio = 17.65. The following results were obtained in control plot 12K: pH (H2O) = 6.85; pH (1M KCl) = 5.47; P_2O_5 mg/100g soil = 4.84; K_2O mg/100g soil = 31.10; N = 0.16%; humus = 4.45%; C = 2.65%; C/N ratio = 16.56.

In their study of the microbiological and pedological post-fire component, Arianoutson-Farggitaki and Margaris *(26)* found that 3–4 months after a fire the activity of microbiological decomposers was almost identical to that before the fire. They conclude that fires are not catastrophic events but common changes in Mediterranean-type ecosystems. Fire affected the soil nitrification and respiration process during the two years of the experiment. To confirm that fires act as triggers for post-fire vegetation growth, especially in Mediterranean garrigue, burned pure plots were compared with unburned cleared plots. A post-fire increase in shrub density and species expansion was found. Lloret and Vila *(27)* found that grasses and Kermes oak (*Quercus coccifera* L.) were slightly less represented.

Research in this paper has shown that fires degrade forest soil to a certain extent, which is manifested by an interruption of ameliorative processes. Burned areas rapidly face a critical condition due to being subjected to erosion, the disappearance of or a decrease in the soil's biological activity and exposure to extreme ecological effects. For this reason, burned areas should urgently be treated with appropriate and prescribed recovery methods. Devastation and degradation should be halted, since these are karst Mediterranean ecological systems. One of the main goals is to establish a regeneration process with the principal species of climatozonal vegetation (pubescent oak and holm oak).

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