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UDK 630*228+521+561+(4-015) (Quercus ilex L.)

VEGETATION SUCCESSION ON PERMANENT PLOTS IN HOLM-OAK (*Quercus ilex* L.) FORESTS IN CROATIA

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The aim of this research was to compare the forest structure of the permanent plots of holm-oak forests in Croatia. These plots are included in the UNESCO program "Man and Biosphere" (MAB). The plots have an area of 1 ha and are situated along the Adriatic coast: on the island of Rab (sampled in 1983 and 1993), the island of Mljet (sampled in 1981 and 1995) and on the island of Brijuni (sampled in 1988). These five samples cover different development stages; i.e. differently aged holm-oak stands. The sampling comprised the measurement of diameter at breast height (DBH) for holm oaks and for other woody species on the plot. A regression model was constructed to describe changes in DBH distributions over time. Model testing suggests high model reliability and the possibility to estimate unknown forest age. Holm oak has unimodal DBH distributions in all development stages (excluding maquis), while other woody species have decreasing DBH distributions in all stages, which illustrates the dominance of the holm oak.

Key words: forest structure, general linear model, macquis, woody species density

INTRODUCTION

The Republic of Croatia established one hundred permanent "Man and Biosphere" (MAB) plots (UNESCO programme) in the period between 1977 and 1990. MAB plots are squares measuring 100 by 100 m (1 ha). The net of these permanently protected areas covers all areas protected by law within the Republic of Croatia (National Parks, nature reserves, etc.), as well as other important natural areas, aimed at the main terrestrial and aquatic ecosystem types (Ilijanić & Meštrov 1975, Rauš 1984, 1995, Rauš et al. 1994). The research conducted on these plots is directed at monitoring the changes in abiotic and biotic factors and the changes in the structure of each ecosystem. Each plot has been included in the registry and permanently outlined in the field. Research methods used to study these plots are in line with the mentioned UNESCO programme.

The Mediterranean vegetation in the Republic of Croatia comprises thermophilic evergreen and deciduous forests of the Adriatic region divided into two separate zones: 1) Mediterranean littoral zone and 2) Mediterranean mountainous zone (Trinajstić 1986 and Rauš et al. 1992). Among the forests of the Mediterranean littoral zone, the most represented phytocoenosis (forest type) is *Fraxino orni - Quercetum ilicis* H-ić 1956, 1958 in which holm oak (*Quercus ilex*) is the dominant species. Holm oak is also one of the most important tree species in the Mediterranean and is consequently the object of frequent research (see, for example Lieth, 1992).

The data analysed in this work was collected on the permanent plots that are within the previously mentioned phytocoenosis. The basic aim of this research was to analyse changes in the diameter at breast height (DBH) distributions for all woody species over time. The specific aim of the research was the construction and testing of the model which estimates DBH distributions of holm oak for a given age, or the age of a holm-oak forest for a given DBH distribution, both on the assumption of undisturbed even-aged stands.

MATERIAL AND METHODS

Three permanent plots with known DBH distributions, i.e. number of stems in 2 cm wide diameter classes for the holm oak and other woody species, were examined in this study.

The first plot is situated on the western part of Rab island in the northern Adriatic (Fig. 1). This part of the island (the Kalifrant peninsula) has the best forest cover and contains one of the most preserved holm-oak forests in the Mediterranean (Španjol, 1995). The climate of the island is between Mediterranean and inland climate types (Seletković & Katušin 1992). This is illustrated by the climatic data recorded at the meteorological station Rab (see Fig. 2). The plot is situated on a flat terrain without topoclimatic influence. The soil type of the plot is cambisol over limestone. The plot has been established within the area that was clear-felled in 1945. Since then, there have been no treatments or any other humanly-caused disturbances. Measurements of DBH were undertaken in 1983 and 1993.

The second plot is situated on the western part of the island Mljet in the southern Adriatic (Fig. 1). This is one of the most forested islands in the Adriatic (Matić 1995, Trinajstić 1995). The climate of the island is typically Mediterranean (see Penzar & Penzar 1995) which is illustrated by the data recorded at the nearby meteorological station Goveđari (see Fig. 2). The climate of the plot is somewhat colder and more humid due to the northern exposure of the terrain. The soil type

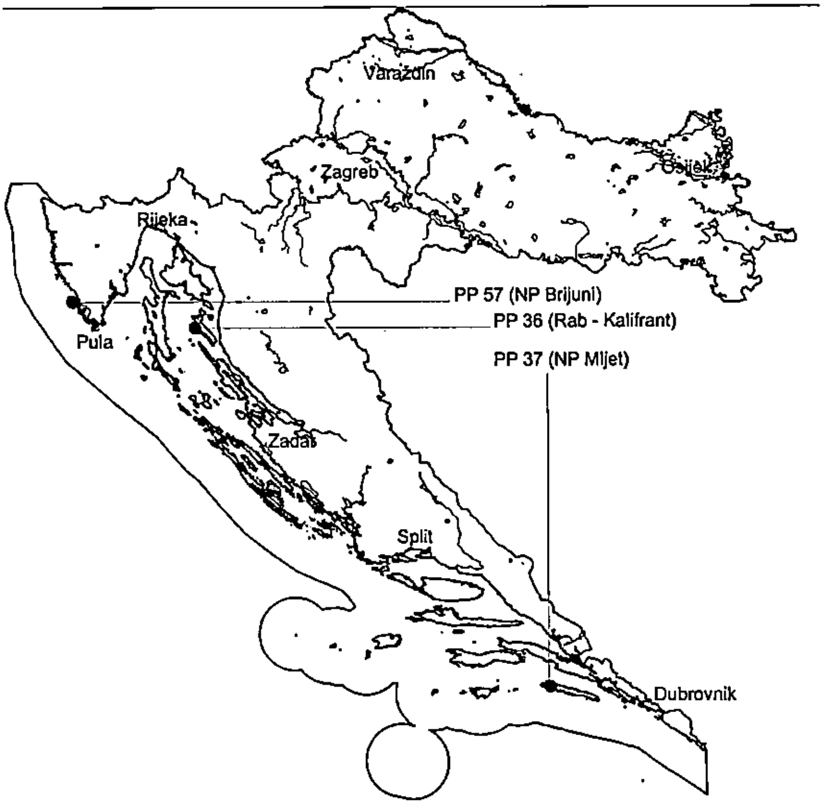

Fig. 1. Location of holm-oak permanent plots in the Republic of Croatia.

on the plot is cambisol over dolomite. The plot has been established within the area disturbed by wildfire in 1917. Since then, there have been no treatments or any other humanly-caused disturbance. Measurements of DBH were undertaken in 1981 and 1995.

The third plot is situated on the island Veli Brijun which belongs to the Brijuni archipelago in the northern Adriatic (Fig. 1). The plot climate can be illustrated (Fig. 2) by an estimation based on the macroclimatic model presented in Antonić et al. (in print). The plot is situated on flat terrain and is not influenced topoclimatically. The soil type on the plot is a mosaic of terra rossa and cambisol over limestone. The plot has been established in the old growth holm-oak forest of unknown age. Over the last hundred years there have been no treatments or any other humanly-caused disturbances in this forest. Measurements of DBH were undertaken in the year 1987 only.

In total, five samples of DBH distributions were available for this research. These five samples cover different development stages, from maquis (Rab plot in

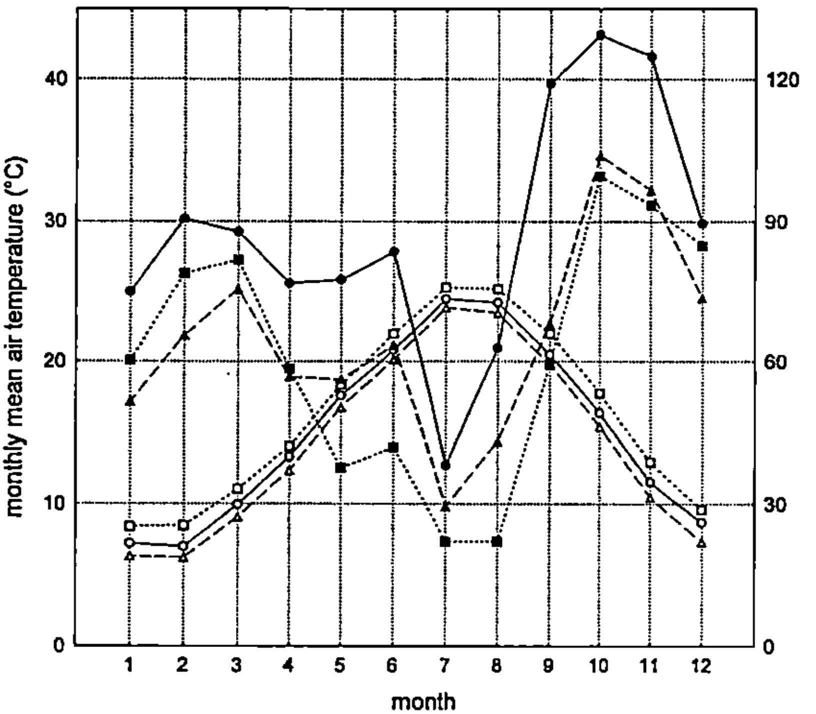

Fig. 2. Monthly mean air temperature (open symbols) and monthly precipitation (full symbols), both averaged for the period of 1981-1992, for the meteorological station Rab (circles), for the meteorological station Goveđari on the island Mljet (squares) and the model estimation for the island Veli Brijun (triangles).

1983) to the old holm-oak forest (Brijuni plot), including differently-aged forests (Rab plot in 1993 and Mljet plot in both years).

Data from DBH distributions of holm oak, recorded on the Rab plot in the years 1983 and 1993 and on the Mljet plot in the years 1981 and 1995, were used for the construction of the regression model. The model estimates the number of stems for each diameter class as a function of the forest age. The following expression was used:

$$Y = a\,DBH^{\,b}\,e^{-c\,DBH} \qquad 1)$$

where Y is the number of stems per ha, DBH is diameter at breast height in cm, and a, b, c are parameters. With the aim of using a general linear modelling procedure (Ott, 1993) which enables model optimisation and estimation of parameter errors, expression 1) was linearised using logarithmic transformation to the form:

$$\ln Y = \ln a + b \ln DBH - c\,DBH \qquad 2)$$

and parameters were expressed as a function of forest age in years:

$$\ln a = k_0 + k_1 t + k_2 t^2 \qquad 3)$$

$$b = k_3 + k_4 t + k_5 t^2 \qquad 4)$$

$$c = k_6 + k_7 t + k_8 t^2 \qquad 5)$$

where t is the forest age in years and k_i is empirical parameter obtained by the general linear modelling ($i = 0, 1, 2, ..., 8$). The full, nine-parameter model arising from expressions 2) to 5) was optimised using the backward stepwise procedure (Ott, 1993). The significance of the predictive power of the regressors was tested using the t-test (Ott, 1993). Data recorded on the Brijuni plot were used for model testing, and for the estimation of the forest age of this plot. This was done by non-linear regression using expressions 1), 3), 4) and 5), where Y was the number of stems of holm oak on this plot, k_i was the constant (respective parameter yielded by the general linear model described above) and t was estimated as an empirical parameter.

The distributions of the number of stems of the other woody species were compared only qualitatively, because the small number of plots did not provide a data sample sufficient for the building of similar species-specific models as for the holm oak, or for the use of more exact numerical methods for the comparison of species composition on different plots (e.g. following Legendre & Legendre, 1998).

RESULTS AND DISCUSSION

All observed distributions of the number of stems of holm oak are presented in Fig. 3. The optimised regression model and related statistics are presented in Table 1. The level of explained variability is very high (Table 1, Fig. 4 and 5). The testing of the model on the independent sample of the Brijuni plot suggests high model reliability (Fig. 6). The application of the model on the data from the Brijuni plot also enables the estimation of primarily unknown forest age (104 years in the year 1987).

These results suggest that the presented model could probably be widely applied in the prediction of the development of holm-oak maquis or forests as well as for the estimation of the age of the holm-oak forest. At this moment, the model is applicable only on undisturbed even-aged stands which belong to the *Fraxino orni - Quercetum ilicis* forest type. These constraints could probably be overcome using the larger sample, covering other holm-oak forest types and appropriate independent variables which describe the influence of forest management. This will be the object of future research.

DBH distributions for other woody species are shown in Table 2. These distributions are mostly decreasing in all development stages, while holm oak has uni-

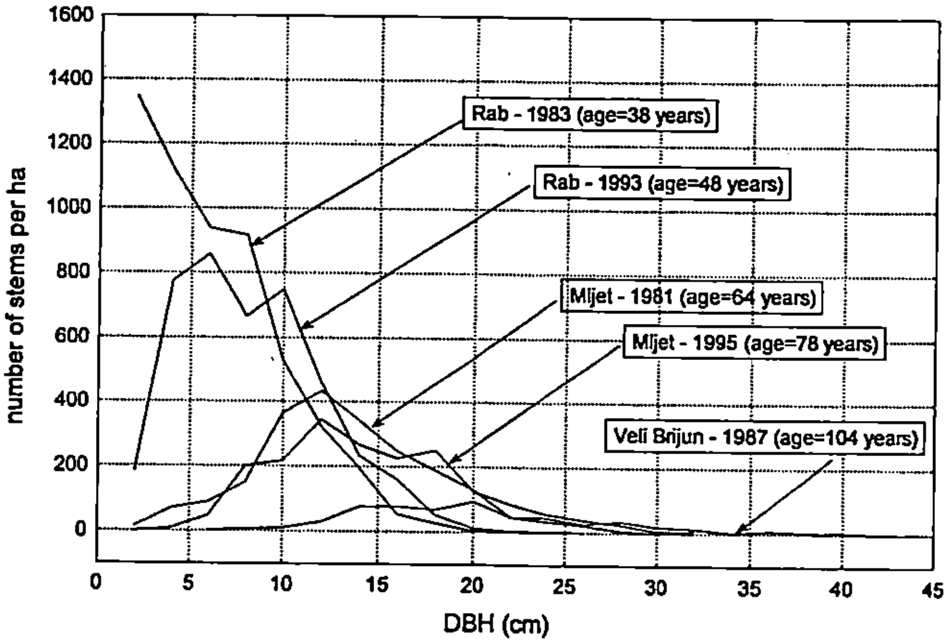

Fig. 3: Diameter at breast height (DBH) distributions of holm oak recorded for different plots and ages.

modal DBH distributions in all stages (excluding maquis) which illustrates the dominance of holm oak in these forests. It is obvious and expected that the total number of stems of all species decrease from maquis (Rab plot in year 1983), through the young forest (Rab plot in 1993) to the mature forest (Mljet plots in 1981

Table 1. Regression model for estimating logarithm of a number of stems per ha for holm oak (*Quercus ilex*). General linear model follows expressions 2) to 5). Regression coefficient is R=0.979. Ratio between regression mean square and residual mean square is F=176.44, with respective probability of p(F)=0.000. The t-value and respective p-value were used to test the hypothesis that the respective empirical parameter (k_i) is equal to zero. Model was optimised using backward stepwise method and parameters of insignificant regressors were omitted.

parameter	value	st. error	t	p(t)
k_0	9.766383	0.74083	13.18	0.000
k_2	-0.002539	0.00022	-11.47	0.000
k_3	1.446154	0.57153	2.53	0.000
k_5	0.000940	0.00015	6.07	0.000
k_6	0.987612	0.09676	10.21	0.000
k_7	-0.012664	0.00252	-5.03	0.000
k_8	0.000089	0.00002	3.98	0.000

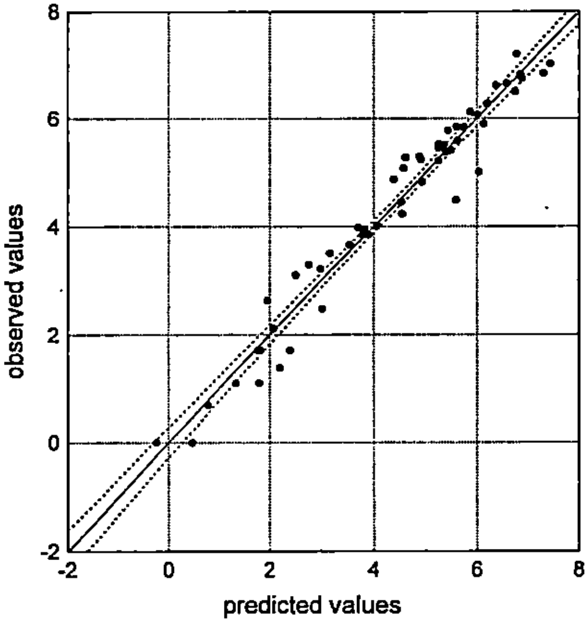

Fig. 4. Logarithm of the number of holm-oak stems: relation between predicted and observed values. Further explanation in the text.

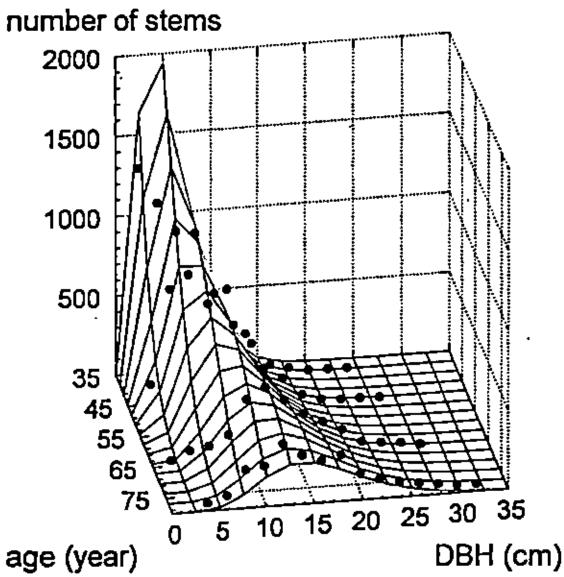

Fig. 5. Relation between the number of holm-oak stems, diameter at breast height (DBH) and stand age. Points represent observed values at the Rab plot (1983 and 1993) and the Mljet plot (1981 and 1985) fitted by the regression surface.

Table 2: Diameter at breast height (DBH) distributions of the other woody species on the studied plots. (*) for Brijuni plot data relate to *Phillyrea latifolia* (*Phillyrea media* is not present).

	Phillyrea media*					Viburnum tinus					Arbutus unedo					Fraxinus ornus				
DBH (cm)	RAB (1983)	RAB (1993)	MLJET (1981)	MLJET (1995)	BRIJUNI (1987)	RAB (1983)	RAB (1993)	MLJET (1981)	MLJET (1995)	BRIJUNI (1987)	RAB (1983)	RAB (1993)	MLJET (1981)	MLJET (1995)	BRIJUNI (1987)	RAB (1983)	RAB (1993)	MLJET (1981)	MLJET (1995)	BRIJUNI (1987)
2	1901	947	33	28		5895	2223	50	28		858	313	3			537	203			
4	668	696	86	44	106	565	645	156	17	49	424	491	14		8	128	161		3	74
6	119	109	22	14	71	28	25	106		21	320	301	3	3	40	39	95			53
8	13	11		6	35	8	3	14		3	89	132	6		54	18	39			45
10	1	2		6	28	2	3			1	15	33	3		59	2	19			33
12					19		1				1	2	3		50	1	1			23
14					14										38		1			26
16					8										41					19
18					4										23					13
20					3										24					5
22					1										8					3
24															5					
26															5					
28																				5

	Erica arborea					Pistacia lentiscus					other woody species					total				
DBH (cm)	RAB (1983)	RAB (1993)	MLJET (1981)	MLJET (1995)	BRIJUNI (1987)	RAB (1983)	RAB (1993)	MLJET (1981)	MLJET (1995)	BRIJUNI (1987)	RAB (1983)	RAB (1993)	MLJET (1981)	MLJET (1995)	BRIJUNI (1987)	RAB (1983)	RAB (1993)	MLJET (1981)	MLJET (1995)	BRIJUNI (1987)
2	1776	786				18	7				7					10992	4479	86	56	
4	544	652			9	12	5			4	4	1			376	2345	2651	256	64	626
6	107	105			1					4		10			226	613	645	131	17	416
8	10	24										1			159	138	210	19	6	296
10	3	6													123	23	63	3	6	244
12															46	2	4	3		138
14												1			36		2			114
16															11					79
18																				40
20																				32
22																				12
24																				5
26																				5
28																				5

and 1995). For the holm oak, this is the consequence of intra-species competition. For other species, this illustrates the impact of the closed holm-oak canopies which strongly reduce the light available for the understorey in mature forests in relation to the maquis. Contrary to this trend, the old forest of the Brijuni plot has a large density of other woody species (see Table 2). This plot has evident gaps in the holm-oak canopies, but it is not clear if this is the consequence of forest age or some locally specific unknown environmental influence.

The basic constraint of this research was the limited number of comparable plots representing undisturbed holm-oak forests, because they are relatively rare, due to strong and diverse human pressure. This fact additionally extends the scientific value of the permanently preserved plots in the Mediterranean area and points to the need for international collaboration.

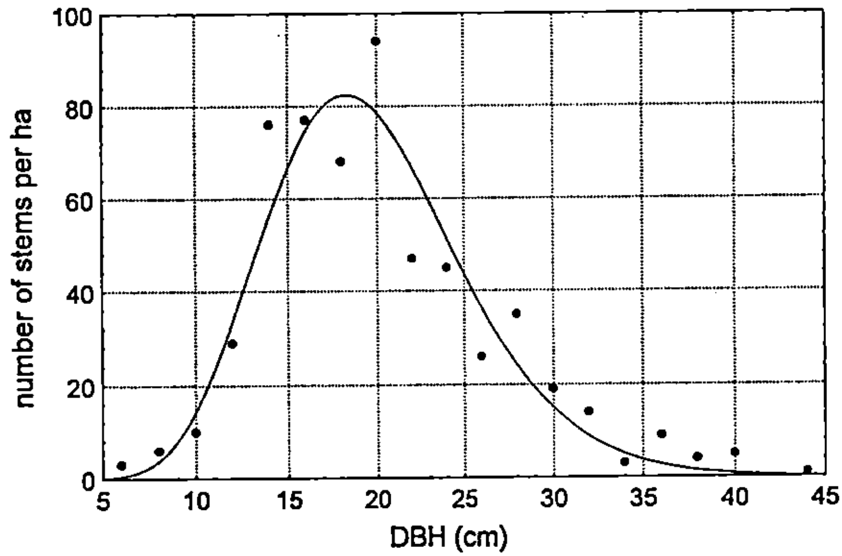

Fig. 6. Number of stems per ha for different diameter classes for the Brijuni plot. Points – observed data, line – predicted by the model based on data from the Rab plot and the Mljet plot.

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SUKCESIJA VEGETACIJE NA TRAJNIM PLOHAMA U ŠUMI HRASTA CRNIKE (*Quercus ilex* L.) U HRVATSKOJ

Cilj je ovog istraživanja bila usporedba sastojinaske strukture na trajnim plohama u sastojinama hrasta crnike u Hrvatskoj. Te plohe pripadaju UNESCO-ovu programu "Čovjek i biosfera" (MAB). Plohe imaju površinu od 1 ha i nalaze se uzduž jadranske obale: na otoku Rabu (uzorkovane 1983. i 1993), na otoku Mljetu (uzorkovane 1981. i 1995) i na Brijunima (uzorkovane 1988). Tih pet uzoraka pokriva različite razvojne stadije, odnosno sastojine hrasta crnike različite dobi. Uzorkovanje je obuhvatilo mjerenje prsnoga promjera jedinki hrasta crnike i drugih drvenastih vrsta na plohi. Izrađen je regresijski model koji opisuje promjenu distribucije prsnoga promjera kroz vrijeme. Testiranje modela upućuje na njegovu visoku pouzdanost, kao i na mogućnost procjene dobi sastojine kada ona nije poznata. Hrast crnika ima unimodalnu distribuciju prsnih promjera u svim razvojnim stadijima (isključujući makiju), dok druge drvenaste vrste imaju padajuće distribucije prsnih promjera u svim stadijima, što pokazuje dimnansnost hrasta crnike.

Ključne riječi: šumska struktura, generalni linearni model, makija, gustoća drvenastih vrsta