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UDK 630*560+181 (Quercus robur L., Q. petraea Liebl., Q. pubescens Willd., Q. ilex L.)

GROWTH OF OLD OAK TREES IN CROATIA: THE PRELIMINARY RESULTS OF THE *TGECC* PROGRAMME

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This paper presents part of the long-term research programme žTree Growth and Environmental Change in Croatia' (TGECC). This programme includes the development of the dendrochronological database for all dominant tree species and the use of the analytical methods for the correlation of tree growth with environmental change. The methods used in this programme, from sampling in the field to data analysis, are presented. The method for detecting environmental change using tree growth is introduced and tested on 135 pedunculate oak trees from the Repaš forest, where groundwater level change was recognised in previous research. The growth of old individuals of four oak species (*Quercus robur* L., *Quercus petraea* Liebl., *Quercus pubescens* Willd. and *Quercus ilex* L.) is presented and interpreted in the paper. Some of these are among the oldest individuals within these species in Croatia (e.g. holm oak from the island Rab with an estimated age of 436 years, a pubescent oak from the island Krk with an estimated age of 318 years and several pedunculate oaks from the forest Repaš, Prekodravlje, with estimated ages between 240 and 300 years).

Keywords: environmental change, growth function, tree age, tree core

INTRODUCTION

In 1999, OIKON Ltd. established a long-term research programme entitled 'Tree Growth and Environmental Change in Croatia' (TGECC). This is a self-financed research programme (OIKON Ltd. is a commercial consultancy company), from which the company expects to gain knowledge and expertise required for Environment Impact Assessments (EIA projects) and forest silviculture and management tasks in Croatia. The programme encompasses: 1) the development of a dendrochronological database covering all dominant tree species in the forests of Croatia, 2) modelling of the relation between tree growth and environmental variables (e.g. Chang and Aguilar, 1985, Friend and Hafley, 1989 or Devall et al., 1991, Antonić et al., in press, see also Antonić et al., poster abstract in the same volume) and 3) detecting *apriori* unknown environmental changes using tree growth as a retroactive monitoring variable.

Within the programme, special attention is given to old trees. Old trees have a large number of rings representing long-term records that correspond to the past states of the environment and they usually contain undisturbed (by human-induced environmental change) growth data in their young years. A dendrochronological database is filled with records which are: 1) collected especially for the TGECC programme (targeting old individuals) or 2) collected for applied dendroecological research (see, for example, Antonić et al., 1999a, 1999b and Antonić et al., in press). By the end of January 2000, the database had 366 processed tree cores with 26,485 rings.

Outside the general presentation of the TGECC programme, the special aims of this paper are: 1) the introduction of the method for detecting environmental change by growth analysis of differently aged trees growing in the same environment and 2) the presentation of growth of some old individuals belonging to four major oak species present in Croatia: pedunculate oak (*Quercus robur* L.), sessile oak (*Quercus petraea* Liebl.), pubescent oak (*Quercus pubescens* Willd.) and holm oak (*Quercus ilex* L.).

MATERIAL AND METHODS

The data used in this work were separated into two datasets. The first dataset comprises growth data from 135 pedunculate oak individuals from the Repaš forest (Fig. 1), with a known site age from 84 to 104 years (obtained from forest management documentation). These data were collected for the purpose of modelling a groundwater regime acceptable for the survival of the forest after the building of the žNovo Virje' hydro-electric power plant (Antonić et al., 1999a and Antonić et al., in press). This dataset was used in this work for the testing of the method for detecting environmental change. Selected trees belong to the same forest type (even-aged forest of pedunculate oak and common hornbeam, *Carpino betuli – Quercetum roboris* Rauš 1971). The second dataset comprises growth data from old oak individuals (see Fig. 1, Fig. 2 and Table 1), including four pedunculate oaks sampled in the Repaš forest, four sessile oaks sampled at Mt. Medvednica near the city of Zagreb, one pubescent oak from Krk island (near the city of Baška) and two from Rab island (on the Kalifrant peninsula), and finally three holm oaks from Rab island (on the Kalifrant peninsula).

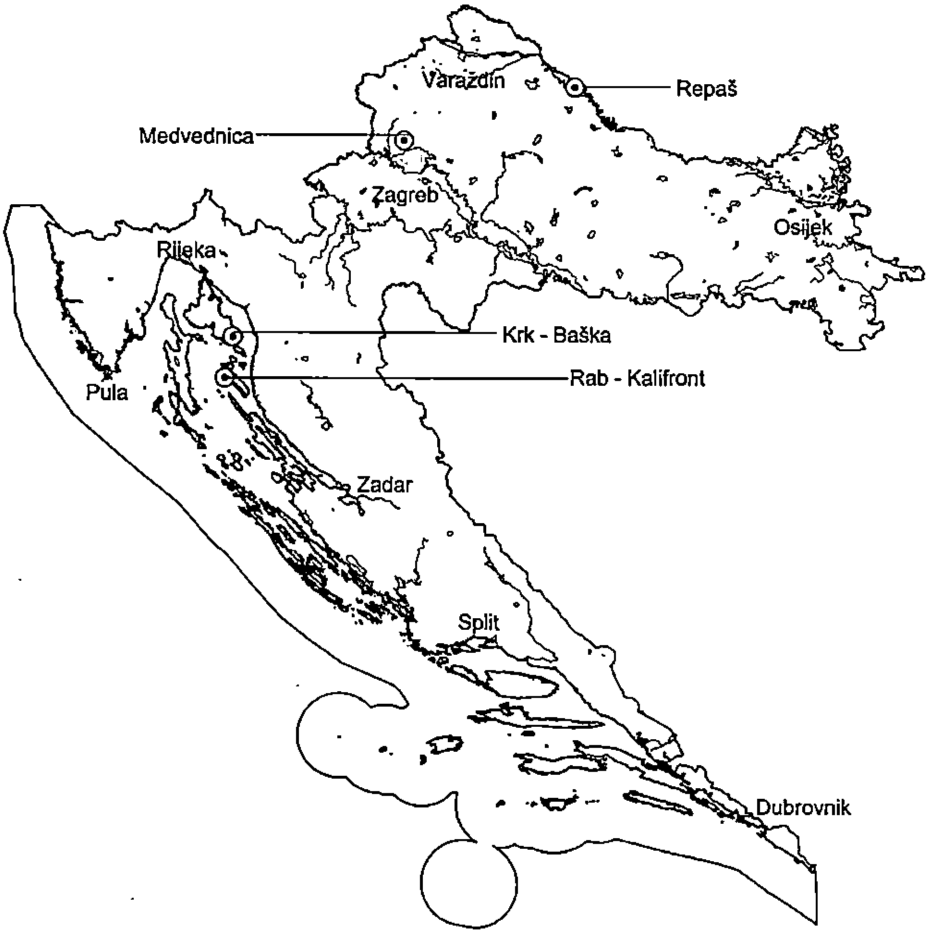
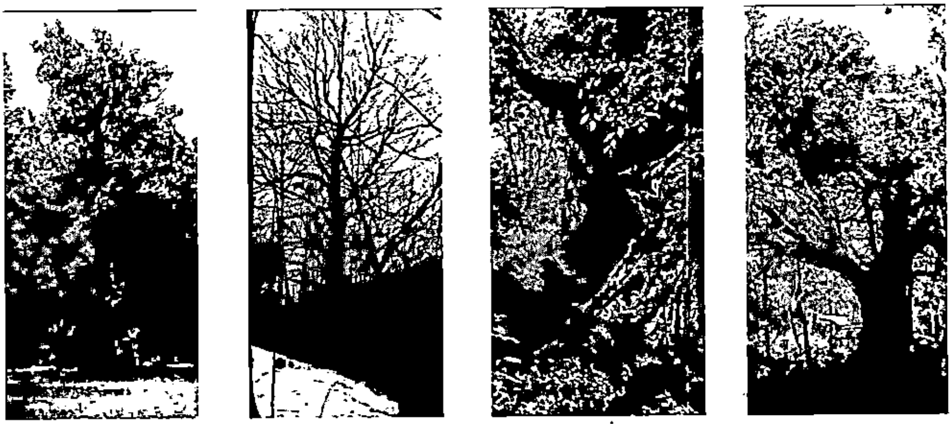


Fig. 1. Locations of the dendrochronological samples examined in this paper in the Republic of Croatia

Dendrochronological data acquisition for the TGECC programme could be separated into three phases: field sampling, sample preparation and measurement and data transformation. Dendrochronological samples are sampled with a motorised Pressler drill capable of taking long tree cores (up to 50 cm). The cores of such length enable the centre of all trees up to 1 m in diameter to be reached, covering very long tree ring time series without tree felling. The holes left in the trees are filled with self-expanding foam with fungicide and insecticide additives. Following sampling, tree cores are transported and stored in a refrigerated environment to prevent drying and changes in dimensions. Prior to measurement, the cores are glued to special holders and polished. Prepared samples are then digitised by high resolution scanning (600 to 800 dpi, 24 bit colour) on a scanner calibrated espe-



a) b) c) d)

Fig. 2. Examples of the old oak trees examined in this paper: a) *Quercus robur* (T331), b) *Quercus petraea* (T369), c) *Quercus pubescens* (T339) and d) *Quercus ilex* (T358). Tree codes correspond to Table 1.

cially for this purpose. These scans (see Fig. 3) are used for permanent storage of source data, which enables repeatable measurements. Tree ring measurement is undertaken with special dendrochronological software which can magnify samples up to 64 times and record data on ring width and ring angle (for ring width correction). These measurements are then transformed and corrected for eccentricity. For the purpose of this paper, tree ring widths were recalculated on the diameters

Table 1. Description data about old oak trees presented in this paper. DBHOB is diameter at breast height over bark. Forest types are as follows: A-pedunculate oak and common hornbeam forest, B-sessile oak and European beech forest, C-pubescent oak and hop hornbeam forest and D-holm oak and flowering ash forest.

code	species	DBHOB (cm)	height (m)	age (years)	source of age estimation	locality	altitude (m)	aspect	forest type
T331	*Quercus robur*	148.1	39.9	300	growth function	Repaš	116	flat	A
T332	*Quercus robur*	115.3	34.7	238	growth function	Repaš	116	flat	A
T333	*Quercus robur*	161.4	32.3	189	growth function	Repaš	116	flat	A
T335	*Quercus robur*	147.6	36.0	240	growth function	Repaš	116	flat	A
T366	*Quercus petrea*	64.8	16.5	109	ring count	Medvednica	590	W	B
T367	*Quercus petrea*	52.6	13.2	132	ring count	Medvednica	520	W	B
T368	*Quercus petrea*	65.4	14.5	128	ring count	Medvednica	530	flat	B
T369	*Quercus petrea*	76.8	17.1	126	growth function	Medvednica	540	flat	B
T339	*Quercus pubescens*	125.7	_	318	growth function	Krk	175	E	C
T361	*Quercus pubescens*	50.0	14.0	115	ring count	Rab	36	N	D
T364	*Quercus pubescens*	71.5	13.0	100	ring count	Rab	30	S	D
T358	*Quercus ilex*	95.8	8.0	436	growth function	Rab	50	NW	D
T360	*Quercus ilex*	50.0	9.5	110	growth function	Rab	38	SE	D
T365	*Quercus ilex*	67.5	13.0	102	growth function	Rab	26	S	D

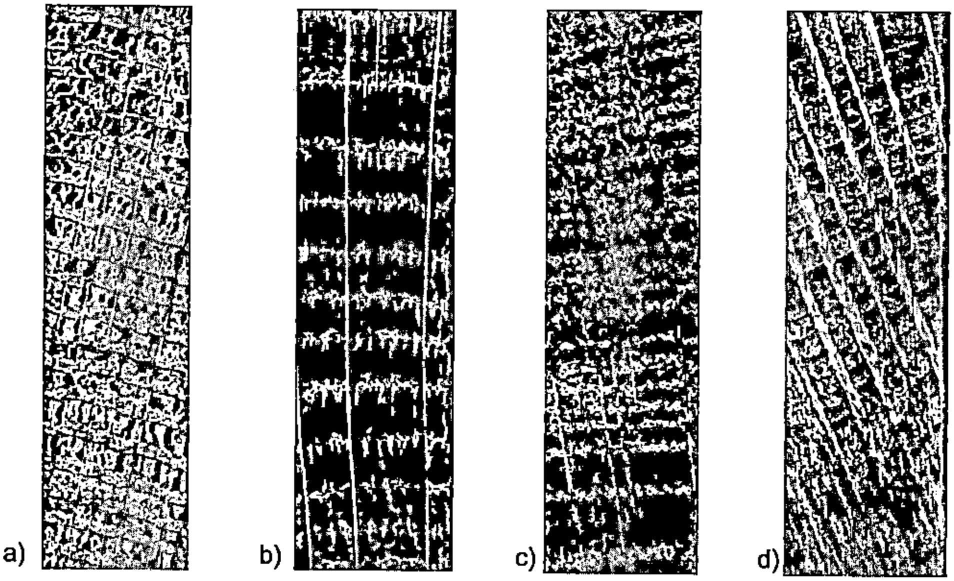


Fig. 3. Examples of the polished and scanned cores of old oak trees examined in this paper: a) *Quercus robur* (T331), b) *Quercus petraea* (T366), c) *Quercus pubescens* (T361) and d) *Quercus ilex* (T360). Tree codes correspond to Table 1.

over breast height under bark (DBHUB) for respective year, which was chosen as a growth variable.

The method of detecting environmental change is based on the testing of the hypothesis that the parameters of the growth function should change over time. The following expression was used to describe changes in the DBHUB over time:

$$\mathrm{DBHUB} = a\, e^{-b/T} \qquad 1)$$

where T is respective age and a and b are empirical parameters. The expression 1) is called Terezaki's function (Pranjić and Lukić, 1997). This function is linearised by logarithmic transformation into the form:

$$\ln \mathrm{DBHUB} = \ln a - b(1/T) \qquad 2)$$

and parameters are expressed as a function of calendar year (t):

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

$$b = k_2 + k_3 t \qquad 4)$$

This transformation enables the use of a general linear modelling procedure (Ott, 1993) to test the significance of the contribution of the particular linear terms (regressors) using t-test (Ott, 1993). The hypothesis is that in a stable environment, parameters of regressors that contain the calendar year (k_1 and k_3) cannot be significantly different from zero, which means that parameters of the growth function (a and b) are constant over time. In contrast, the significance of the parameter k_1 indicates the significant change in growth magnitude over time and the significance of parameter k_3 indicates the significant change in the growth function shape. It is important to emphasise that the method is meaningful only if differently aged individuals are included in the analysis, otherwise age (T) and calendar year (t) are linearly dependent. The other conditions for using the method are: 1) ages of selected trees have to be known, 2) relatively old trees should be included, and 3) included trees should reside on the same forest type.

In order to compare growth of the old oak trees, their age was estimated directly (by ring counting) for the individuals drilled to the tree centre and indirectly, by fitting and extrapolation of the growth function for other individuals. In both cases, the age of the breast height was neglected. In the second case the following function was used:

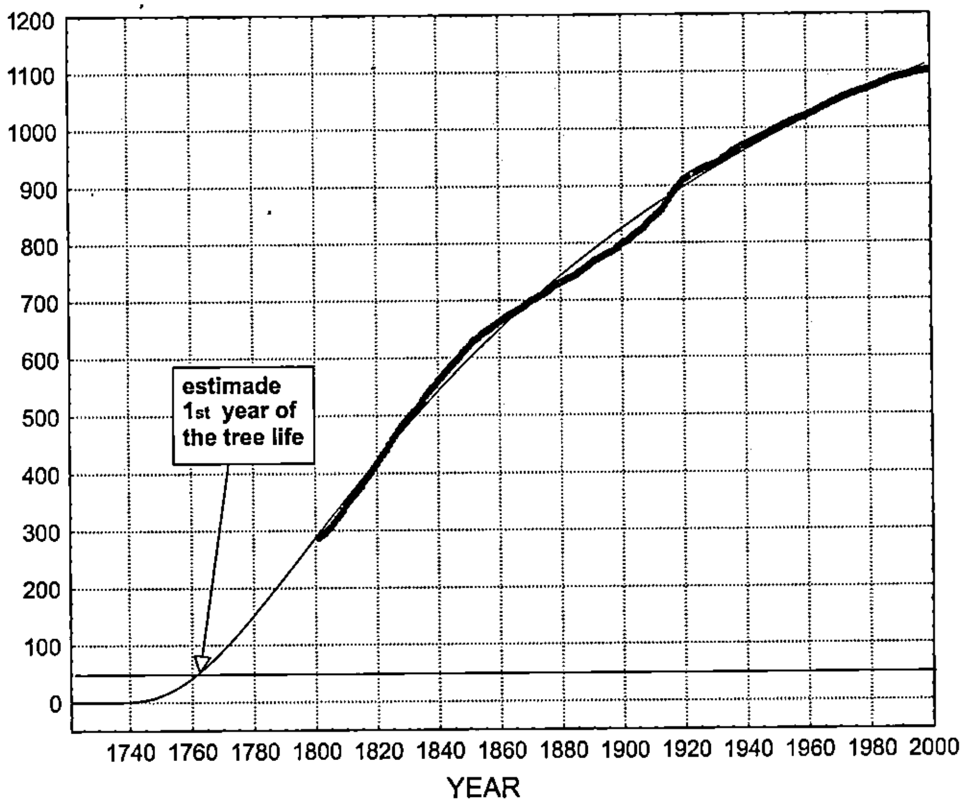


Fig. 4. Example of estimation of the tree age using extrapolation of the growth function. DBHUB is diameter over breast height under bark. Bold line represents real growth of the pedunculate oak T332 (see Table 1) and thin line represents fit by growth function. Further explanation is in the text.

$$DBHUB = a\ e^{-b/(t-c)} \qquad 5)$$

where t is calendar year and a, b and c are empirical parameters. The expression 5) is basically the same as expression 1), only the age (T) is expressed as the difference between the calendar year (t) and the empirical parameter (c) which represents the estimate of the first year of the tree's life. However, it was found that the use of the parameter c yields unrealistic results and the year in which DBHUB was equal to 5 cm was used instead (see Fig. 4).

RESULTS AND DISCUSSION

Results of the general linear model application on the above-mentioned 135 pedunculate oaks from the Repaš forest are shown in Table 2. The yielded growth model is site-specific and cannot be used generally. All regressors have a significant contribution to the regression. This suggests that the parameters of the growth function change over time, which indicates the change in the environment. Fig. 5 (upper left) shows two hypothetical growth lines with the calendar year set to constant (an assumption of two different but stable environments), arising from expressions 1) to 5) and the parameters from Table 2. These hypothetical growth lines have different shapes; the growth line for the later calendar year being steeper and with the inflexion point happening later. The hypothetical growth line which relates to the year 1995 mostly corresponds to the standard diameter growth function for pedunculate oak on first site quality described by Špiranec (1975). All these results could be interpreted as an increase in site productivity for the trees included in the analysis.

The yielded results were expected, because the Repaš forest has been exposed to the lowering of the mean groundwater table, due to the changes in the riverbed morphology of the nearby River Drava during the last century (Biondić & Vidaković-Šutić, 1998, Antonić et al., 1999, Antonić et al., in press). Pedunculate oak is a typical flood-plain species which is very sensitive to changes in groundwater levels (see, for example, Prpić et al., 1994). When the mean groundwater levels are high, this species grows more slowly than under lower mean groundwater levels, as long

Table 2. Regression model for estimating logarithm of DBHUB for pedunculate oak (*Quercus robur*) in Repaš. General linear model follows expressions 2) to 4). Regression coefficient is R=0.8405. Ratio between regression mean square and residual mean square is F=7954.7, with respective probability of p(F)=0.000. The t-value and respective p-value were used to test the hypothesis that respective empirical parameter (k_i) is equal to zero.

parameter	value	st. error	t	p(t)
k_0	-28.08179	0.44312	-63.37	0.000
k_1	0.017525	0.00022	77.98	0.000
k_2	-1108.608	33.2150	-33.38	0.000
k_3	0.588142	0.01744	33.72	0.000

as deep roots are permanently submerged in the groundwater (Prpić et al., 1987). If this condition is not met, pedunculate oak suffers dieback, which has been evident in the Repaš forest during the last decade (according to forest management documentation).

The presented method yields interpretable results; i.e. tree growth could be used as an indicator of environmental changes. The question for future research is how these results could influence forest management, regarding the use of standard yield functions constructed under the assumption of an unchanging environment (e.g. Špiranec, 1975). To answer this question, the application of the method to other tree species and to other environments is required, e.g. on the European silver fir (*Abies alba* Mill.) in the Gorski Kotar region, where forests are endangered by aeropollution and acid rains (see, for example, Prpić, 1987).

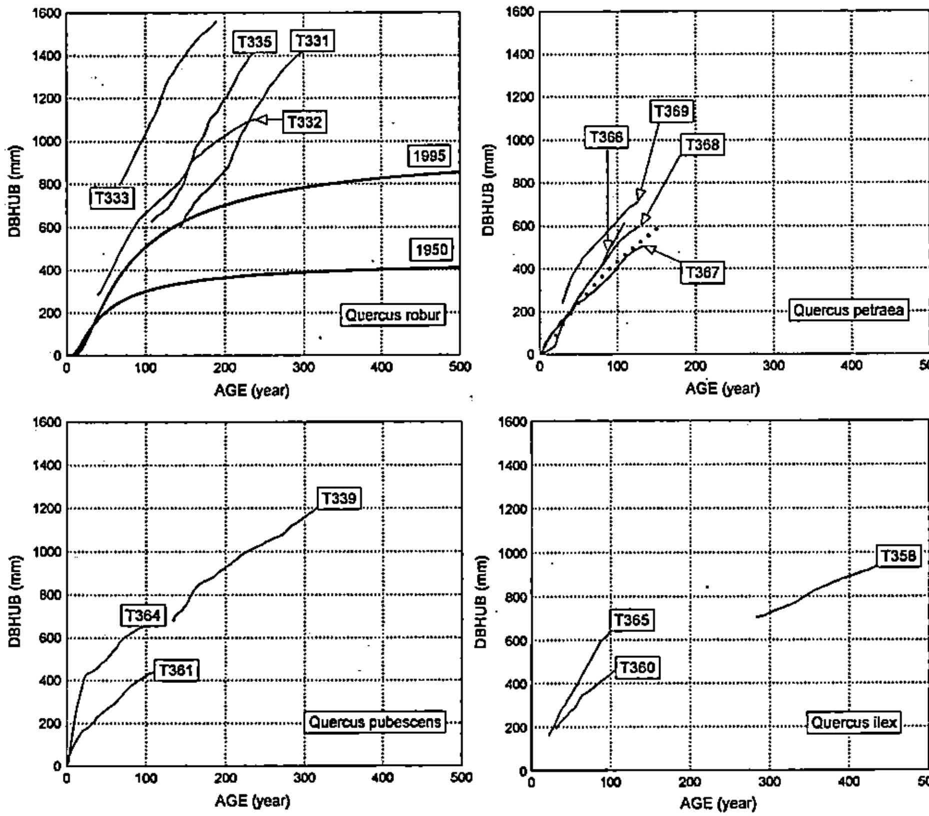


Fig. 5. Obtained growth lines for fourteen old oak individuals from four species. Tree codes correspond to Table 1. Tree ages were estimated by ring counting for the individuals drilled to the tree centre and by fitting and extrapolation of the growth function for other individuals. Bold lines on upper left graph represent hypothetical growth lines with assumption of two different but stable environments (see further explanation in the text). Bold dots on the upper right graph represent standard diameter growth function for sessile oak on the first site quality (Špiranec, 1975).

Comparing the growth of the old pedunculate oaks and the hypothetical pedunculate oak growth described above (Fig. 5, upper left), it is noticeable that the growth of old oaks has a significantly larger magnitude. It is the consequence of the dominant position of these trees in relation to the neighbours, probably for at least one century, because these individuals are the remaining elements of the natural, undisturbed flood-plain forests, which are very rare in Croatia and Europe.

The growth of four individuals of sessile oak mostly corresponds (see Fig. 5, upper right) to the standard diameter growth function for this species on first site quality (Špiranec, 1975). From the view of the presented results for pedunculate oak in the Repaš forest, constant environmental conditions could be assumed. To prove this hypothesis, the use of a larger sample is required.

Interpretation of the growth of the sampled pubescent and holm oaks from the view of theoretical growth is not possible due to the lack of standard diameter growth functions for these species. Nevertheless, despite the negligible sample size, a possible theoretical growth for these two species could be recognised (Fig. 5, lower left and right).

Some of the sampled oaks are among the oldest individuals within the respective species in Croatia, with an age of several centuries (compare Table 1). The *TGECC* programme started recently, and it is reásonable to expect that more old individuals will be identified and processed in the future, filling the *TGECC* database and enabling a wider analysis of the relation between tree growth and the environment in Croatia.

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RAST STARIH HRASTOVIH STABALA U HRVATSKOJ: PRELIMINARNI REZULTATI PROGRAMA *TGECC*

U radu se predstavlja dio dugoročnoga istraživačkog programa "Rast drveća i okolišne promjene u Hrvatskoj (TGECC)". Program obuhvaća razvoj dendrokronološke baze podataka za sve dominantne vrste drveća, te povezivanje rasta drveća i promjena u okolišu analitičkim metodama. Predstavljene su metode koje se u programu primjenjuju, od uzorkovanja na terenu do obrade podataka. Prikazana je metoda otkrivanja okolišnih promjena pomoću podataka o rastu stabala, koja je testirana na 135 stabala hrasta lužnjaka iz šume Repaš, gdje su iz prijašnjih istraživanja poznate promjene razine podzemne vode. Rast starih primjeraka četiriju vrsta hrasta (*Quercus robur* L., *Quercus petraea* Liebl., *Quercus pubescens* Willd. and *Quercus ilex* L.) prikazan je i interpretiran u radu. Neki su hrastovi među najstarijim jedinkama unutar tih vrsta u Hrvatskoj (npr. crnika s Raba s procijenjenom starošću od 436 godina, medunac s Krka procijenjen na 318 godina, te lužnjaci iz Repaša između 240 i 300 godina).

Ključne riječi: funkcija rasta, izvrtak stabla, okolišne promjene, starost stabla