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MORTALITY AND CROWN CONDITIONS ON *Quercus robur* L. PERMANENT PLOTS - A 20-YEAR OVERVIEW

MORTALITETA IN OSUTOST KROŠENJ DOBA (*Quercus robur* L.) NA TRAJNIH PLOSKVAH – 20-LETNI PREGLED

Matjaž ČATER[1]

(1) Slovenian Forestry Institute, Večna pot 2, 1000 Ljubljana, SLOVENIA, matjaz.cater@gozdis.si

ABSTRACT

Pedunculate oak (*Quercus robur* L.) forests in Slovenia are experiencing widespread mortality. Changes in lowlands are reflected in decline of complete forest complexes, high mortality, uneven stand structure and associated forest regeneration problems. Prediction of the present-tree response in disturbed forest ecosystems may significantly contribute to better guideline policies for the silvicultural and forest management practice in the changing environment in both stressed and stabile forest ecosystems.

Data from annual crown condition surveys in the 1995-2014 period from four permanent plots have been compared with parameters from hemispherical photo analysis and hydrometeorological data. Good agreement has been confirmed between crown defoliation and total openness; all parameters from the hemispherical photo analysis, which were corrected for winter period values, also indicated a better agreement. Mortality rate and crown defoliation correlated well with extreme drought events. Pattern of agreement among compared parameters was different for the Krakovski gozd and Dobrava plots on one hand and Cigonca and Hraščica plots on the other hand. Mortality is influenced by the average air temperatures much more than by precipitation and groundwater table oscillations.

Key words: pedunculate oak, crown conditions, mortality, drought, lowland forests, climate

IZVLEČEK

V dobovih sestojih Slovenije ugotavljamo povečano mortaliteto. Spremembe v nižinskih delih se kažejo kot upad vitalnosti celotnih gozdnih kompleksov, povečanje smrtnosti, porušeno razmerje razvojnih faz in težave, povezane z naravno obnovo. Napovedi sedanjega odziva dreves lahko v prihodnje prispevajo pomembne informacije za nadaljnje gospodarjenje in gojenje tako v poškodovanih kot ohranjenih dobravah.

Podatke vsakoletnega popisa stanja krošenj na štirih stalnih vzorčnih ploskvah smo vzporejali s podatki analize hemisfere krošenj in hidrometeorološkimi podatki. Potrdili smo dobro ujemanje med osutostjo in odprtostjo krošenj (hemisferna analiza). Parametri, od katerih smo odšteli zimske vrednosti in jih vzporejali z osutostjo, so pokazali boljše ujemanje od osnovnih. Potrdili smo korelacijo med smrtnostjo in osutostjo krošenj ter ekstremnimi sušnimi razmerami. Vzorci ujemanja so se med sabo razlikovali za Krakovski gozd in Dobravo na eni strani ter Cigonco in Hraščico. Povezava med smrtnostjo in povprečno temperature zraka je bila večja od povezave s podtalnico in padavinami.

Key words: dob, stanje krošenj, osutost, smrtnost, suša, nižinski gozdovi, klima

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1 INTRODUCTION

1 UVOD

Pedunculate oak (*Quercus robur* L.), one of the important and key tree species of European forests, is naturally widely distributed in the different climatic areas. It covers the widest area of all European oaks (Trinajstić 1996); in humid Atlantic region it coincides well with sessile oak (*Q. petraea* (Matt.) Liebl.), while in Scandinavian and the East-European region it reaches even further (Krahl-Urban 1959, Leibundgut 1991). In the areas located east and south-east of the Alps and where under the influence of the Mediterranean and Pannonian regions, it is a distinctive heliophyte, well distributed in humid valleys and floodplains on deep clayed or sandy soils with sufficient groundwater level, where occasional floods are no rarity (Trinajstić 1996). In Slovenia, oaks grow on 55 per cent of forested area; with pedunculate and sessile oaks, bitter (*Q. cerris* L.) and downy oaks (*Q. pubescens* Wild.) are also found in lowlands and on the edges of the colline zone, where forest cover is smaller and human population density higher than in the rest of forested areas.

European oak forests represent important ecosystems as sources of high-quality wood and, since they grow in lowlands, also very important wildlife habitats and biodiversity hot spots. Pedunculate oak forests in particular are experiencing widespread mortality in Europe, which have resulted in uneven age-class proportions and have reduced seedling regeneration, and sustainability concerns. Oak mortality has occurred repeatedly during the past three centuries and became more pronounced in recent decades in Europe (Thomas et al. 2002) and North America (Allen et al. 2010). Although the cause of mortality is currently unknown, it has been associated with changes in water availability (Hämmerli and Stadler 1989, Levanič 1993, Cochard et al. 1996, Triboulot et al. 1996, Tyree and Cochard 1996, Čater 2003, Čater and Batič 2006), weather extremes and forest management choices (Harapin and Androić 1996). Many studies have also explained periodic oak decline as a consequence of climate extremes and pathogens (Führer 1992) or by the occurrence of *Phytophthora* fungi, although the primary pathogenicity remains unknown (Jung et al. 2000). Extinction of lowland forests is therefore characterised not only by economic loss, but also by degradation and loss of rich oak-growing sites.

Lowland oak forests in Slovenia are exposed to temperate climate, but they encounter periods of severe drought, which are known to be involved in forest decline processes (Čater 2003), as well as limiting forest primary productivity and tree growth. Except for floodplain characteristics, they are the most artificially changed forests in Slovenia as well as in lowlands of other European countries. Originally, their natural range coincided with that of the nowadays most intensely managed agricultural land (Wraber 1951, Čater and Batič 2006). Larger complexes of pedunculate oak are now restricted to small areas and found only in moist sites less suited for agriculture. Significant correlation has been confirmed between groundwater table and pre-dawn water potential (Čater et al. 1999), lower groundwater, precipitation and higher defoliation of pedunculate oaks (Čater 2003) and also between groundwater table, water potential and stomatal conductance in different light categories of planted and naturally regenerated oak saplings (Čater and Batič 2006). Short term ability of adult pedunculate oaks to osmotically compensate water stress has been confirmed during drought stress (Čater 2011a), but their condition is not improving according to their radial growth and status of crown transparency (Levanič et al. 2011).

Changes in lowlands are reflected in decline of complete forest complexes, high mortality and uneven stand structure that are associated with problems in natural regeneration of pedunculate oak. The main aim of our research was to overview the last 20-year period status of the lowland pedunculate oaks and to predict their ecological perspective. Study and prediction of the present-tree response in disturbed forest ecosystems would contribute to guideline policies for the silviculture and forest management practice in in both stressed and stabile forest ecosystems.

Our goal of the research was to compare long-term crown conditions with parameters obtained from analysis of hemispherical photos (1) and to parallel crown conditions with evidenced mortality and groundwater table over the 20-year period on all studied plots (2).

2 MATERIAL AND METHODS

2 METODE

2.1 Research plots

2.1 Raziskovalne ploskve

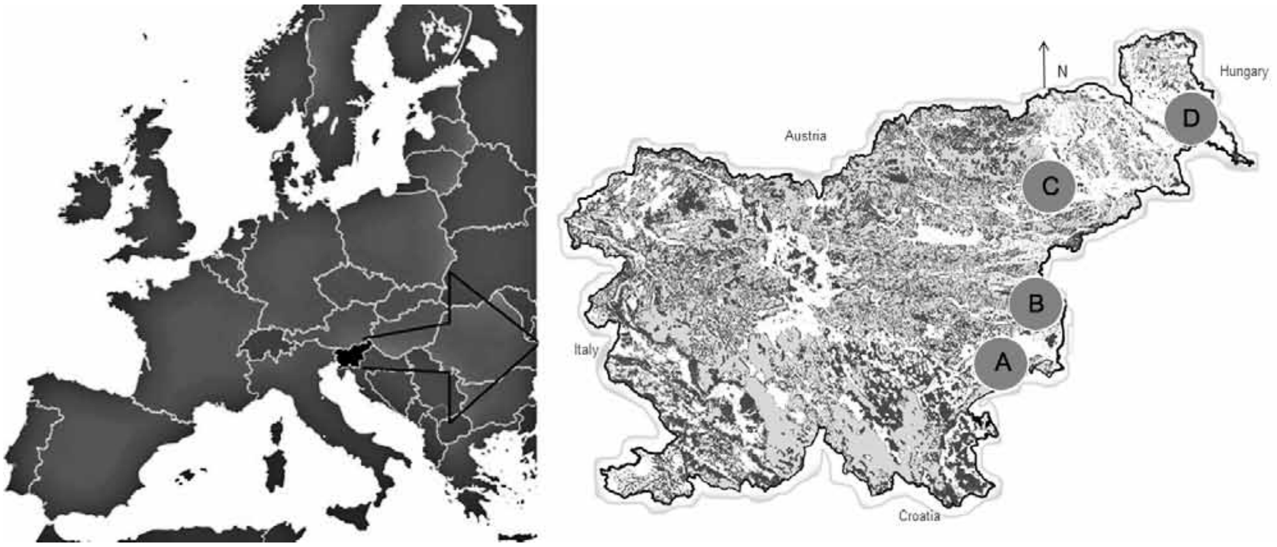
Surveys included four permanent plots: Krakovski gozd (A), Dobrava near Brežice (B), Cigonca near Slovenska Bistrica (C) and Hraščica near Beltinci (D) with their main characteristics presented in Fig 1. All plots included more than 100 years old stands on homogenous sites with more than 50% of pedunculate oak in the dominant (mature) layer, with canopy closure higher than 0.7 and average stand density of 250-300 trees/ha. Each research permanent plot, rectangular in shape, is divided into 25 subplots. All pedunculate oaks were numbered and all trees with breast height diameter (dbh) over 10 cm marked and evidenced.

2.2 Crown condition assessment

2.2 Ugotavljanje stanja krošenj

The crown condition survey was performed every year during the first week of August on same adult trees on permanent plots to give an estimate of current state of pedunculate oaks in Slovenia. The main indicator was evaluated at first by the ocular estimate of the missing proportion to virtual and same healthy tree of the same social status and site conditions as the estimated one (IPCC 2007) to the accuracy of 5%. Ocular surveys started in 1995 and finished in 2014 and were performed by the same person (author) during this period.

During the 2005-2014 period, the hemispherical photos, all taken from the same height and spot, supported ocular estimates; 25 photos were made every year for each permanent plot over a systematic grid on every hectare plot. Colour digital hemispherical photographs were taken during windless weather and standard overcast sky conditions 150 cm above the forest floor when the solar disk was completely obscured. The camera was levelled and the fish-eye lens oriented toward magnetic north prior to each shot. Photographs were taken with a digital Nikon Coolpix



Plot / *Ploskev*	Altitude / *Nadmorska višina* (m)	Soil / *Tla*	Annual avg. air T / *Povprečna letna T* (^{0}C)	Annual precipitation / *Letna količina padavin* (mm)
A (Krakovski gozd)	154	Gleysols on Pleistocene clay and loam *Oglejena tla na pleistocenski ilovici*	10.9	1138
B (Dobrava)	176	Gleysols on uncalcareous alluvial sediments *Oglejena tla na nekarbonatnih aluvialnih/ napla-vljenih sedimentih*	11.0	990
C (Cigonca)	265	Gleysols on Pleistocene clay and loam *Oglejena tla na pleistocenski ilovici*	10.7	1061
D (Hraščica)	163	Eutric cambisols on gravel *Evtrična rjava tla na produ*	10.6	792

Fig. 1: Location and characteristics of the permanent plots (Čater 2003)i

Slika 1: Lokacija in značilnosti trajnih raziskovalnih ploskev (Čater 2003)

995 with fine photo quality, calibrated fish-eye lens and analysed with WinScanopy software (2003 pro-d).

Exposure fitting was done to above canopy conditions prior to shooting on every plot as indicated by Macfarlane et al. (2000) and Zhang et al. (2005) without noteworthy blooming effects (Leblanc et al. 2005). In the process of hemispherical photograph analysis, the ''standard overcast sky'' (SOC) model was applied for diffuse light distribution. For the calculation within the vegetation period, the sun's position was specified every 10 min. The solar constant was defined as 1.370 W/m2, 0.6 was set for atmospheric transmissivity and 0.15 for the proportion of diffuse radiation compared to the calculated direct potential radiation. An automatic thresholding method based on the same colour scheme was applied for the discrimination between sky and canopy elements in all digital photographs, as thresholding of the photographs is crucial and may significantly affect the calculated parameters (Ishida 2004). The analysis was carried out for 120 degree angle of hemisphere, as it proved to be the best explaining angle (Čater et al. 2011). Several parameters from the photo analysis were used for further comparisons:

- Canopy openness - (percent open sky) share of open sky unobstructed by the vegetation compared to real canopy above lens,
- Indirect Site Factor (ISF%) - share of diffuse light below the canopy compared to the share of diffuse light in the open (above the canopy), and
- Leaf Area Index (Licor LAI 2000 generalised linear method corrected with clumping indexes of the sky grid's zenith rings).

Results from the high growing season were corrected for the results obtained during the winter period to assess crown condition without area produced by trunks and branches (Čater 2011b) (Fig. 2).

Crown conditions parameters obtained from the hemispherical photo analysis were compared with ocular estimates and tree mortality rate in regard to the total tree number of a hectare plot for every year and studied plot. Trees were considered dead if the crown transparency did not improve from the 100% assimilation area loss during the two consecutive observation years. Only dead trees were removed from the plots.

Data from surveys were compared with average monthly temperature and precipitation from the closest meteorological stations Kostanjevica ob Krki (plot

Fig. 2: Hemispherical image of summer (left) and winter (right) stand conditions. Corrected area = area measured in summer - area measured in winter.

Slika 2: Posnetek hemisfere krošenj v poletnem (levo) in zimskem (desno) obdobju. Korigirane vrednosti = poletne vrednosti – zimske vrednosti

A), Bizeljsko (plot B), Slovenske Konjice (plot C) and Murska Sobota (plot D) (Slovenian public information, ARSO-met) and groundwater levels from the closest measurement stations (Uhan 2014).

2.3 Data analysis
2.3 Obdelava podatkov

Parameters from the hemispherical photo analysis and ocular estimates were compared for the same 2005-2014 period. Regression coefficients were provided for every parameter and comparison. Data analysis and correlation between measured variables were analyzed with the Statistica data analysis software system (2011), obtaining the significance of correlation coefficient (P) and the determination coefficient of the linear regression (R^2).

3 RESULTS
3 REZULTATI
3.1 Temperature and precipitation
3.1 Temperature in padavine

On average, most precipitation fell on plot A (1137mm), followed by plot C (1061mm), plot B (990mm) and plot D (792mm); during the same pe-

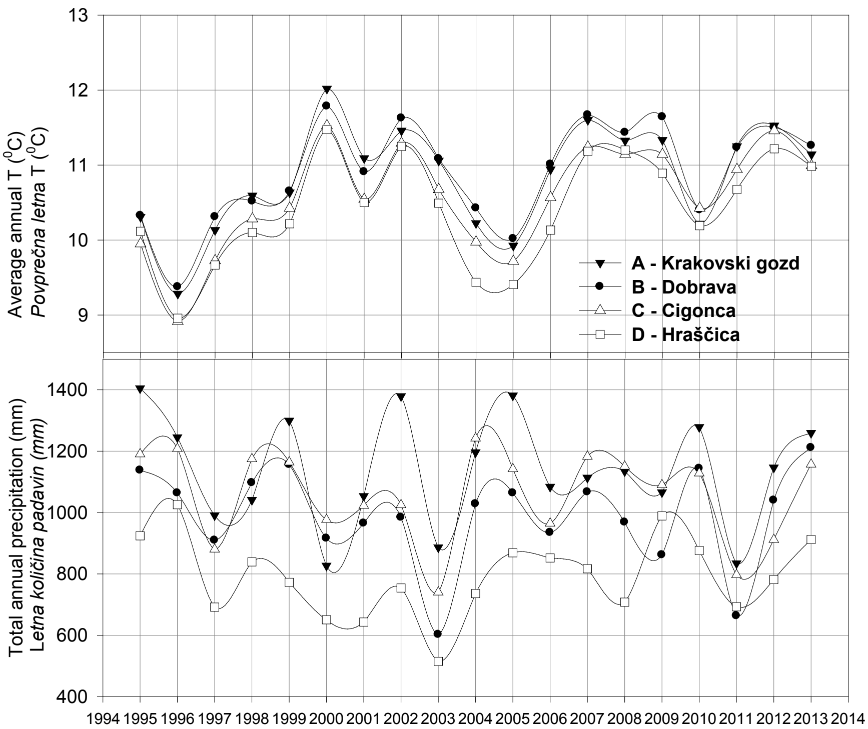


Fig. 3: Average annual air temperature and total annual precipitation on research plots (1995-2013)

Slika 3: Srednje letne temperature zraka in skupna količina padavin na raziskovalnih ploskvah (1995-2013)

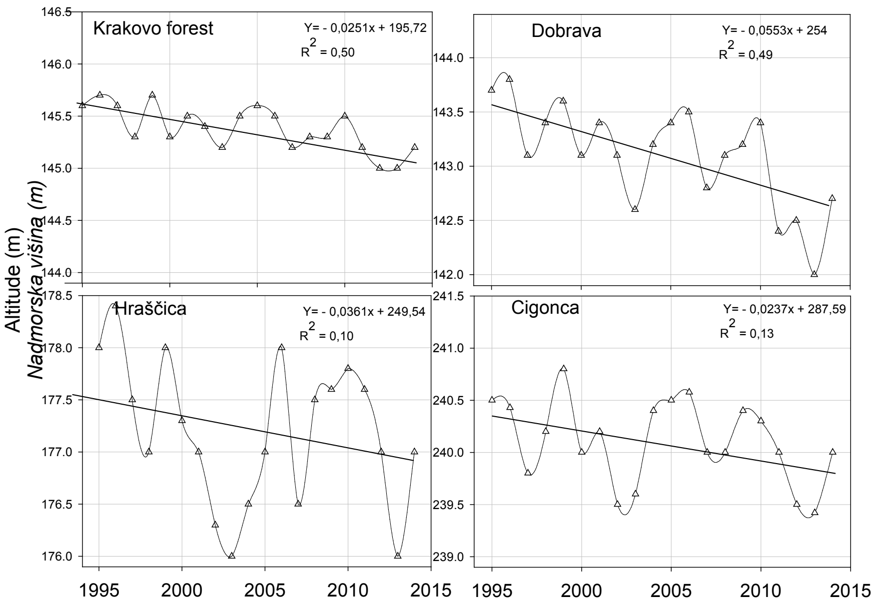


Fig. 4: Dynamics of groundwater table for the observed forest complex - the mean annual value for the closest measuring station is provided.

Slika 4: Dinamika ravni podtalnice za najbližje merilne postaje trajnih raziskovalnih ploskev

riod, average air temperature had less oscillations (Fig. 3).

3.2 Groundwater
3.2 Podtalnica

Annual average values for the groundwater table during the 20-year observation period from the closest hydrological stations (Uhan 2014) are presented on the same amplitude range (Y-axis, 2.5m) to better illustrate the dynamics and the observed trend (Fig. 4). On all measuring stations, significant decline of average values with pronounced amplitude variation could be evidenced.

3.3 Crown defoliation vs. hemispherical photo analysis
3.3 Primerjava osutosti krošenj in parametrov analize hemisfere krošenj

For the 2005-2014 period, comparisons between ocular assessment and hemispherical photo analysis parameters (tot. openness, ISF and LAI) were made for all plots. Correlation coefficients are presented for the regular and corrected data, where parameters obtained during the high growing season were corrected for the ones during the winter period (Table 1).

Best agreement was achieved in all cases with total openness and ISF - relation between canopy and sky region above the measured point and share between indirect light at the point of measurement and above canopy, respectively, while LAI parameters indicated lower values, as they are derived - calculated and changed by the algorithm during the evaluation process.

3.4 Crown defoliation
3.4 Osutost krošenj

Ocular assessment showed increased crown defoliation since 1995 (Čater 2003), which coincided well with extreme weather events such as drought in 2000, 2003 and 2013. With increasing defoliation, progres-

Table 1: Correlation coefficients (R^2) for the agreement between average ocular estimate and parameters from hemispherical analysis. Corrected values are bold, regular ones are shaded.

Preglednica 1: Korelacijski koeficienti (R^2) med povprečno okularno oceno osutosti in parametri hemisfernih fotografij. Korigirane vrednosti so poudarjene, nekorigirane senčene.

Plot/ *Ploskev* Parameter/ *parameter*	A (Krakovski gozd)		B (Dobrava)		C (Cigonca)		D (Hraščica)		Total	
	Corrected		Corrected		Corrected		Corrected		Corrected	
Tot. openness	**0.84**	0,79	**0,85**	0,65	**0,80**	0,64	**0,81**	0,72	**0,78**	0,67
ISF (%)	**0,68**	0,57	**0,55**	0,51	**0,53**	0,52	**0,55**	0,54	**0,54**	0,51
LAI (lin)	**0,50**	0,40	**0,48**	0,41	**0,43**	0,39	**0,44**	0,42	**0,43**	0,39
LAI (log)	**0,47**	0,34	**0,49**	0,35	**0,40**	0,38	**0,39**	0,41	**0,38**	0,34

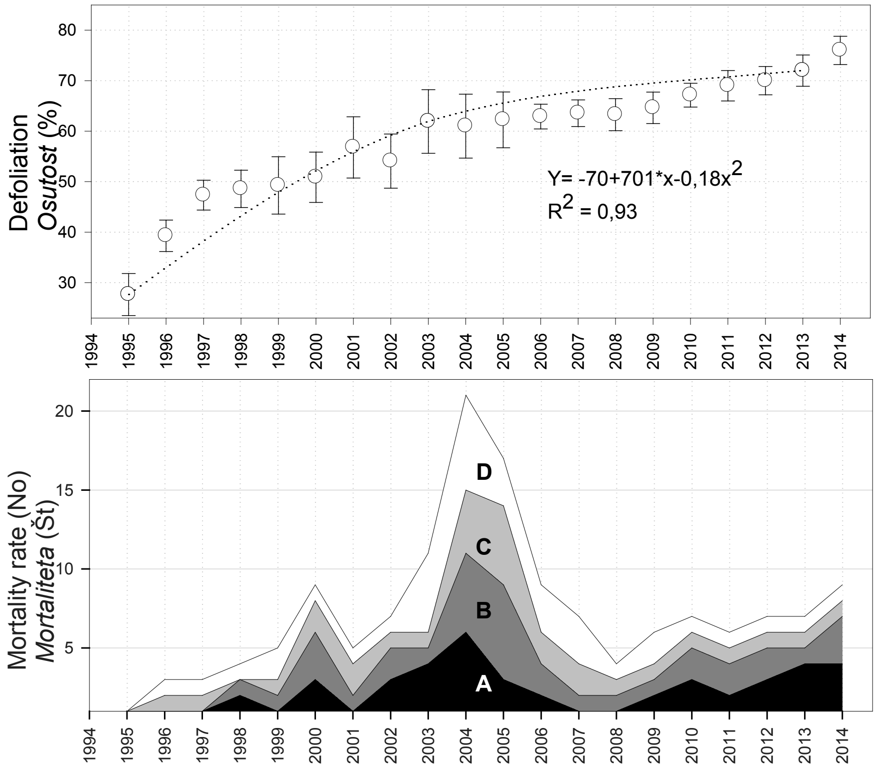


Fig 5: The average crown defoliation on all pedunculate oak plots (1995-2014, n=192 adult trees, 48 per plot) with standard deviation (above) and annual mortality rate (No/ha, below)

Slika 5: Povprečna osutost na vseh dobovih ploskvah (obdobje 1995-2014, n=192 odraslih dreves, 48 na vsaki ploskvi) s st. napako (zgoraj) in letna smrtnost (št/ha) (spodaj)

sive decrease in dispersion after 2005 of individual values was also evidenced, indicating that oaks are gradually losing the individual response (Fig 5).

The steepest increase in crown defoliation was noted between 1995 and 1998. From 1999 to 2010, the conditions on all plots were comparable, with crown defoliation increasing towards 70% and significant oscillations in years with drought. The only recovery in the 19-year period was noted from 2001-2004 for less than 5%.

3.5 Mortality, groundwater and climate

3.5 Smrtnost, podtalnica in klima

Min-max range of groundwater table significantly correlated with mortality. Well evidenced are also drops below the critical value in extreme droughts in 2003 and 2013. The total mortality rate corresponded well with defoliation (R^2=0.71; p≤0.000) on all plots (Fig 6). Highest agreement between defoliation and mortality was established on plot A-Krakovski gozd (R^2=0.77), C-Cigonca (R^2=0.74), D-Hraščica (R^2=0.67), and lowest on plot B-Dobrava (R^2=0.62).

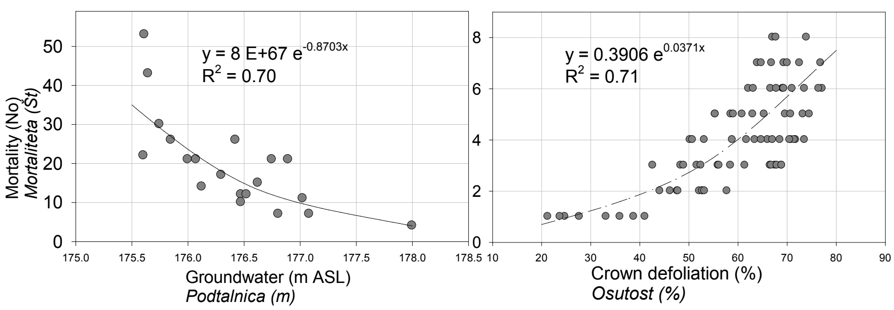


Fig. 6: Comparison between mortality (cumulative value in observed period) and average groundwater (left) on all plots and between annual mortality and crown defoliation (right) (1995 - 2014)

Slika 6: Primerjava med mortaliteto in ravnjo podtalnice (levo) in mortaliteto ter osutostjo (desno) (1995 - 2014)

Table 2: Correlation coefficients (R^2) between groundwater vs. total precipitation and average air temperatures in different periods (1995-2013). Values higher than (R2=0.50) are highlighted.

Preglednica 1: Korelacijski koeficienti (R^2) med podtalnico ter padavinami in povprečno temperature zraka v različnih obdobjih leta (1995-2013). Poudarjene so vrednosti, večje od 0,5.

Plot/ Ploskev	Total annual precipitation *Letna količina padavin* (mm)	Average annual air temperature *Povprečna T zraka* (⁰C)	Total precipitation (May-August) *Količina padavin (maj-avgust)* (mm)	Average air temperature (May-August) *Povprečna T zraka (maj-avgust)* (⁰C)	Precipitation in June *Količina padavin v juniju* (mm)	Average air temperature in June *Povprečna T zraka (junij)* (⁰C)
A (Krakovski gozd)	0.29	**0.62**	0.29	0.46	0.31	0.07
B (Dobrava)	0.29	**0.53**	0.33	0.43	0.29	0.08
C (Cigonca)	0.23	0.23	0.21	0.43	0.27	0.21
D (Hraščica)	0.24	0.20	0.23	**0.53**	0.30	0.30

During the observed period, 393 adult oaks died; highest mortality rate was noted for plot D-Hraščica (148), B-Dobrava (111), C-Cigonca (84), and lowest for A-Krakovski gozd (50). Groundwater table correlated better with average annual air temperature than average annual precipitation and did not change significantly when compared to the May-August period or to individual months. Values for June as the most influential month (Levanič 2014) are also presented (Table 2).

Table 3: Correlation coefficients (R^2) between annual mortality vs. total precipitation and average air temperatures in different periods (1995-2013). Values higher than R2=50 are highlighted.

Preglednica 3: Korelacijski koeficienti (R^2) med letno mortaliteto ter padavinami in povprečno temperature zraka v različnih obdobjih leta (1995-2013). Poudarjene so vrednosti, večje od 0,5.

Plot *Ploskev*	Total annual precipitation *Letna količina padavin* (mm)	Average annual air temperature *Povprečna T zraka* (⁰C)	Total precipitation (May-August) *Količina padavin (maj-avgust)* (mm)	Average air temperature *Povprečna T zraka (maj-avgust)* (⁰C)
A (Krakovski gozd)	0.05	0.31	0.07	0.31
B (Dobrava)	0.11	0.37	0.12	0.44
C (Cigonca)	0.25	**0.50**	0.25	**0.51**
D (Hraščica)	0.12	**0.60**	0.04	**0.64**

Comparison between temperature and precipitation vs. mortality rate highlighted only significant relation with temperatures (Table 3).

4 DISCUSSION

4 RAZPRAVA

Consequences of oak stand degradation, causing massive oak dieback in the eighties, could be seen today. Uneven distribution of precipitation, extreme temperatures and water pollution have disturbed the natural balance at the end of the 19th century (Manojlović 1926), (Donaubauer 1995). Several theories have attempted to explain the oak decline as the combined effect of several factors (Führer 1992, Rösel and Reuther 1995) and some have indicated possible causes in parts of Europe (Hämmerli and Stadler 1989, Hartmann et al. 1989, Näveke and Meyer 1990, Harapin and Androić 1996).

The destabilized status has been worsened by unsuitable silvicultural and technical measures and changed environmental conditions (Rösel and Reuther 1995). In depth studies concerning oaks have been performed to explain dysfunctions induced by water stress (Cochard et al. 1996, Triboulot et al. 1996, Tyree and Cochard 1996).

Favourable light conditions constitute basic environmental conditions for most of the life's processes in terrestrial ecosystems. Tight connection exists between tree canopies, stand structure and available light below crown canopies (Comeau and Heineman 2003), which results in different survival and adaptation strategies of plants to changed light conditions.

In our study, a significant agreement was confirmed between ocular crown assessment and parameters obtained from the hemispherical photo analysis during the 2005-2014 period - best between crown conditions and total openness, smaller with LAI. Agreement was better if parameters were corrected for winter values.

Highest mortality rate was observed on the easternmost located plot with highest groundwater table oscillations and smallest amount of precipitation.

Different response was also noted for plots from the southern part of the country (A-Krakovski gozd and B-Dobrava), showing similar correlation between groundwater and average annual air temperature (Table 3) from C-Cigonca and D-Hraščica between mortality and average annual air temperature (Table 4). Not only the drop but also oscillations in the groundwater proved to be the most correlating parameter with mortality, which was highest on plot D -Hraščica and lowest on plot A-Krakovski gozd. Increased defoliation, reduced radial growth and reduced individual response indicate questionable perspective and weaker adaptation ability of adult oaks, as the defoliation variability becomes narrower through years (Fig.7). Similar conclusions are reported for Croatian lowland oak forests by Matić (2009). Drop in groundwater table during last decade, combined with weather extremes, resulted in large-scale dieback of mature and senescent stands in 40% of all present pedunculate oak forests, causing changes in stand density and structure (Čavlović et al. 2009).

As some authors report connection between lower mortality in trees with wider crowns and larger breast diameter (Marcu 1987, Harapin and Androić 1996), no relation between dbh and mortality was confirmed in our study (data not shown). Although a large leaf area should be an advantage in periods of sufficient water availability, it could also predispose trees to severe water stress when water availability declines, because of higher transpirational demand (McDowell et al. 2006).

According to our former research, many ecological processes proved to be significantly connected with the groundwater table level and consequently with water availability in general. In connection with regeneration, the water stress was caused by decrease of groundwater table below critical threshold point in different light categories (Čater and Batič 2006), while adult trees also managed to compensate short term water stress during summer periods by increasing osmotic component in the sap (Čater 2011b). Adaptation was better in stands with smaller tree density, where thinning has been performed recently, prior to water stress (Čater 2011a, b). Oaks that have experienced worse growth and environmental conditions in the past (and found a way to adapt to it) have better stress and survival strategies than the ones with continuously favourable site conditions (Levanič et al. 2011).

It is our belief that the amplitude and frequency of extreme events increases, and that already weakened trees are becoming more and more susceptible to negative effects of environmental stressors. Physiologically weakened adult trees have no more available adaptation plasticity, so at first sight moderate drought increases its lethal effect.

2 CONCLUSIONS
5 ZAKLJUČKI

Lowland oak forests are threatened mainly by the conversion of forests into agricultural land, where relatively small remaining forest patches are affected by the rapidly changing environmental factors. Increasing mortality rate is gradually induced by reduced water availability - the altered groundwater table since the late 1980's, accompanied by the precipitation redistribution, which adult oak trees are no longer able to compensate and adapt, and loss of individual response. In the future, pedunculate oak trees may exhibit greater rates of mortality, particularly on sites of prior fast growth, if the predictions of increased drought severity and frequency are accurate.

6 ACKNOWLEDGEMENT
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6 LITERATURE
6 VIRI

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