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Climate and relief properties influence crown condition of common beech (*Fagus sylvatica* L.) on the Medvednica massif

IVAN SELETKOVIĆ[1]
NENAD POTOČIĆ[1]
DAMIR UGARKOVIĆ[2]
ANAMARIJA JAZBEC[2]
RENATA PERNAR[2]
ANTE SELETKOVIĆ[2]
MIROSLAV BENKO[1]

[1] Croatian Forest Research Institute
Cvjetno naselje 41
10450 Jastrebarsko, Croatia

[2] Faculty of Forestry
University of Zagreb
Svetošimunska 25
10000 Zagreb, Croatia

Correspondence:
Nenad Potočić
Croatian Forest Research Institute
Cvjetno naselje 41
10450 Jastrebarsko, Croatia
E-mail: nenadp@sumins.hr

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Abstract

Background and Purpose: *Common beech is a dominant broadleaved tree species in European forests, and also on the Medvednica massif. Since climate is a decisive factor in the development of a certain type of vegetation, it might have an equally important role in its survival. The influence of relief properties on the crown condition of common beech (Fagus sylvatica L.) can also be significant, since beech stands on Medvednica vary in their elevation and exposition.*

Materials and Methods: *Twelve common beech research plots, with complete defoliation data sets in the period 2004–2006 were chosen to represent the variety of environmental conditions present on the Medvednica massif in the western Pannonian region of Croatia. Climate parameters used in the model included annual precipitation (AP), precipitation in the vegetation period (VP), mean annual air temperature (AT), and mean air temperature in the vegetation period (VT). The elevation (EL) of the experimental plots and data from the meteorological station of Puntijarka were used to obtain an estimate of the AT, VT, AP and VP on each research plot.*

Results: *The share of moderately to severely damaged trees (crown defoliation over 25%) was highest in 2004, an expected result of the 2003 drought. This value was significantly higher than in the following two years. The determining climate parameter explaining the changes in defoliation was VP, and the most decisive relief parameter was EL. Defoliation was higher with low VP and higher EL. D was higher predominantly on southern expositions.*

Conclusions: *Climate and relief properties were found to significantly influence the crown condition of beech trees. Although there is a significant positive trend of temperature change on Medvednica, in the period 2004–2006 precipitation in the vegetation period had the dominant effect on the crown condition.*

INTRODUCTION

Vegetation responds to climate change directly and indirectly. Direct effects include responses to temperature; indirect effects occur primarily as soil-mediated phenomena, such as the influence of precipitation on soil moisture regimes *(1)*. Meteorological conditions are regarded as critical in the process of forest decline, as they govern the water relations, especially in situations of disturbed water absorption and transport in trees *(2, 3, 4)*.

In this study we used the crown condition, expressed as the percentage of defoliation, as a measure of common beech vitality. Tree vitality can be defined as the ability of a tree to assimilate, to survive stress, to react to changing conditions, and to reproduce *(5)*. Brang, P. (Ed.), 1998. Sanasilva-Bericht 1997. Zustand und Gefährdung des Schweizer Waldes – eine Zwischenbilanz nach 15 Jahren Waldschadenforschung. Berichte, Eidg. Forschungsanstalt für Wald, Schnee und Landschaft 345, 102 pp (in German, with English abstract). It has been questioned whether defoliation is a valid indicator of tree vitality *(6, 7)*, Kandler, O., 1988. Epidemiologische Bewertung der Waldschadenserhebungen 1983 bis 1987 in der Bundesrepublik Deutschland (in German). *Allg. Forst- Jagdtztg.* **159**, pp. 179–194. View Record in Scopus | Cited By in Scopus (2)6,7666, since it does not reflect early stages of crown recovery *(8)*. Besides, trees with little foliage are known to survive on extreme sites for many years, while trees with dense foliage can suddenly die *(9)*. Crown defoliation is a non-specific symptom of tree vitality widely used in forest practice *(10)*. The results of Dobbertin and Brang *(9)* demonstrate that tree defoliation assessed in 5% steps is a useful parameter to predict year-to-year tree mortality. Crown defoliation is a product of the tree crown status from the past several years of growth, which can be misleading if used as a stress indicator when assessing current vitality *(10)*.

Common beech (*Fagus sylvatica* L.) is a dominant broadleaved tree species in European forests, and also on the Medvednica massif. The crown condition of beech in Croatia is significantly better (the share of moderately to severely damaged trees in 2006 was 12.7%) than the European average of 27.0% *(11),* but on Medvednica it is far worse, with 54.2% of moderately to severely damaged trees *(12)*.

Although common beech is a tree species adapted to various ecological conditions, it grows best in areas marked by moderately warm summers and high quantities of precipitation *(13)*. Beech finds its optimum in areas with a mean annual air temperature between 7 and 10 °C and a mean temperature in the vegetation period from 14 to 17 °C. The distribution range of beech in the western Pannonian part of Croatia receives between 806 and 1255 mm of precipitation, 55% of which in the vegetation period *(14)*.

Some authors hypothesise that the expansion of beech in Central Europe in the Holocene was triggered by a climatic change towards wetter and cooler conditions *(15)*. Therefore, it is safe to assume that climatic factors, especially temperature and precipitation, will have an equally important role in the survival of beech in the future. Previous research results *(16)* suggest that the crown condition of beech on Velebit is strongly influenced by the mean annual air temperature.

The analysis of meteorological data from the meteorological station Grič (Zagreb, Croatia) shows that in Croatia a change in the temperature and precipitation regime is already present *(17)*. In Croatia, the seven warmest years in the period 1880–2000 occurred in the decade 1990–2000. Drought was present in Croatia in 2000 and again in 2003 *(18, 19)*.

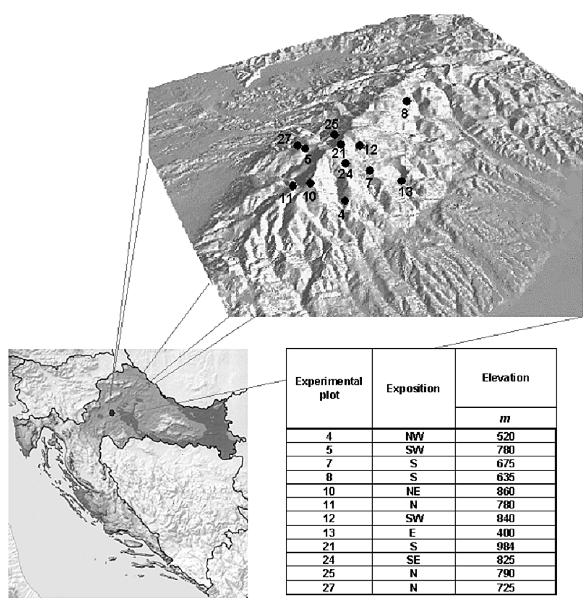
Climate change is perhaps the most critical factor facing the current generation of land managers who are concerned about the future condition of natural and managed ecosystems (20).

It is often stressed that stands at higher elevations are more exposed to stress and more intensive dieback than stands at lower elevations *(21, 22)*. Lorenz *et al. (23)* state that the crown condition is significantly linked to elevation, especially in mountainous regions, and exposition can also have a significant influence on defoliation. Although common beech in Croatia has a wide vertical distribution, there is also a growing share of moderately to severely damaged trees as the elevation rises *(24)*. Since the plots on Medvednica vary in their elevation and exposition, the influence of relief properties on the vitality of beech was also considered in this research.

MATERIALS AND METHODS

Research area and crown condition assessments

Medvednica is a massif stretching for 42 kilometres in a northeast – southwest direction. It is located in the western Pannonian region of Croatia, with the highest peak of 1,033 m above sea level (Figure1). Twelve common beech permanent forest research plots, with complete defoliation data sets in the period 2004–2006, were chosen according to their exposition and altitude to best represent the variety of environmental conditions present in the beech distribution area on Medvednica.



Experimental plot	Exposition	Elevation m
4	NW	520
5	SW	780
7	S	675
8	S	635
10	NE	860
11	N	780
12	SW	840
13	E	400
21	S	984
24	SE	825
25	N	790
27	N	725

Figure 1. *Locations of research plots on digital terrain model of Medvednica and main relief properties of plots.*

Crown condition data as a percentage of defoliation of 182 beech trees was assessed annually according to the ICP Forests Manual *(25)*. Each plot had a complete defoliation data set for the period 2004–2006 and assessments on all plots in all years were performed by the same team of two observers. We used the share of trees with defoliation over 25% (moderately to severely damaged trees) as a measure of beech vitality.

Climate properties in the research area

The western part of the Pannonian area of Croatia is encompassed by the climate type Cfwbx" according to Koeppen's classification. Precipitation occurs uniformly throughout the year. The smallest amount falls in the winter, while precipitation maximums occur in spring and late summer. AT is 6.8 °C, and AP is 1247 mm *(14)*. Climate properties on Medvednica are given using a climate diagram following the design of Walter and Lieth *(26)* and made using the KlimaSoft 2.1 software *(27)* (Figure 2).

To determine the direction of change in the temperature and precipitation regime on Medvednica, we used precipitation and temperature data from the State Meteorological and Hydrological Service, the meteorological station of Puntijarka (988 m a.s.l.) for the period 1980–2006 instead of the longer data time series from the meteorological station of Grič, located in Zagreb city centre. Meteorological stations on mountain tops differ in several respects from stations at lower altitudes. Many of the low-lying stations are located close to or even within cities and can therefore be affected by changes in urbanisation *(28)*. In contrast, the mountain stations are presumably sufficiently far away from towns not to be influenced by the effects of urbanisation *(29)*.

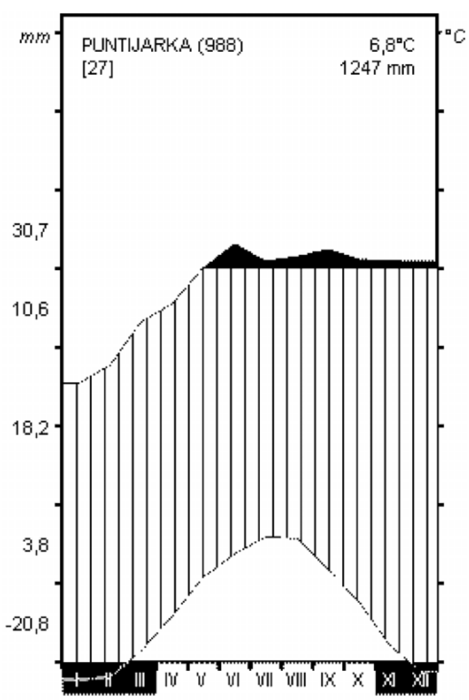


Figure 2. *The climate diagram of meteorological station Puntijarka (Medvednica) for the period 1980–2006.*

TABLE 1

Linear trends of air temperature values and their significance for the period 1980 – 2006, meteorological station Puntijarka. AT – mean annual air temperature, VT – mean air temperature in the vegetation period.

Air temperature element	Linear trend	t	p
AT	y = 0,0457x + 6,1517	2,4911	0,0200*
VT	y = 0,0481x + 11,808	2,35519	0,0270*

*p<0.05, x = year

The linear trends of the mean annual air temperature and annual precipitation values were calculated by simple regressions, and their significance tested by the Student's t-test (Table 1).

Regression models of the theoretical change of the mean annual air temperature (AT, °C) and annual precipitation (AP, mm) with the change in elevation (EL, m) *(30, 31)* were used to obtain an estimate of the AT and AP on the research plots. The model functions used for extrapolation were:

Y=11.1 – 0.005 z (z = elevation, m a.s.l.)
for temperature *(30)* and

Y= 1.33 z + 876.6 (z = elevation, m a.s.l.)
for precipitation *(31)*.

The climate properties of 2004, 2005, and 2006 were obtained by the percentile method *(32)*.

Statistical and spatial analyses

Descriptive statistics were calculated for tree crown defoliation (D, %), AP, precipitation in the vegetation period (VP, mm), AT and mean air temperature in the vegetation period (VT, °C) of the observed years. Type I error (α) of 0.05 was considered statistically significant.

Multiple regression analysis was used to determine which of the analysed variables were significant in explaining the variability of defoliation. Since AT, VT and AP can be obtained through a linear combination of EL, exposition (EX) and VP, their influence could not be assessed in the same model. To determine the influence of EX (nominal variable) on D, we used a stepwise selection procedure for multiple regression analysis *(33)*, where northwest exposition was used as the baseline, because defoliation in NW expositions was the lowest in all years.

The difference between the share of moderately to severely defoliated trees for the observed years was tested using the repeated measures analysis of variance (ANOVA) test. In the case of a significant difference between the years, we used the Tukey HSD multiple comparisons post hoc test to determine which of the years were causing the difference *(34)*. All statistical analyses were conducted using the SAS 8.0 statistical package (regression) *(35)* and STATISTICA 7.1. (ANOVA). Graphs were produced using the STATISTICA 7.1 program *(36)*.

The digital terrain model (DTM) for the area of the Medvednica massif (Figure 1) was developed using the program ArcGIS-Scene/INFO-TIN (Triangular Irregular Network) modules, on the basis of digital data for the contours from the topographic map.

RESULTS AND DISCUSSION

The linear trends show the direction of the changes of the precipitation and air temperature regime on Medvednica: AT and VT have a significant positive trend in the period 1980–2006 (Table 1). The trends of precipitation (Table 2) are also positive but non-significant. In the Northern Hemisphere's mid and high latitudes, the precipitation trends are consistent with climate model simulations that predict an increase in precipitation due to human-induced warming *(37)*. Most models show an increase in precipitation for Europe as a whole as a consequence of a higher content of water vapor in the atmosphere *(1)*.

In the years of the crown condition assessment, the climate varied: from an average 2004, to a very rainy 2005 and a very warm 2006 (Table 3). The year 2003, preceding the crown condition assessments, was, as in the major part of Europe, extremely dry (Figure 3).

From a comparison of Figure 4 with the changes in climate properties in the years 2004–2006 (Table 3), it is possible to see the general effect of AT and AP on D. In

TABLE 2

Linear trends of precipitation values (mm) and their significance for the time period 1980 – 2006, meteorological station Puntijarka. AP – annual precipitation, VP – precipitation in the vegetation period.

Precipitation element	Linear trend	t	p
AP	y = 0,2867x + 1243,1	0,0527	0,9583
VP	y = 0,396x + 674,35	0,0749	0,9408

$p<0.05$, x = year

TABLE 3

Values of annual precipitation and temperature percentiles for the meteo station Puntijarka.

Year	Precipitation, in percentiles*	Temperature, in percentiles*
2003	0 – extremely dry	98 – extremely warm
2004	66 – normal	63 – normal
2005	96 – very rainy	31 – normal
2006	36 – normal	93 – very warm

* according to State meteorological and hydrological service Review 2004 –2007

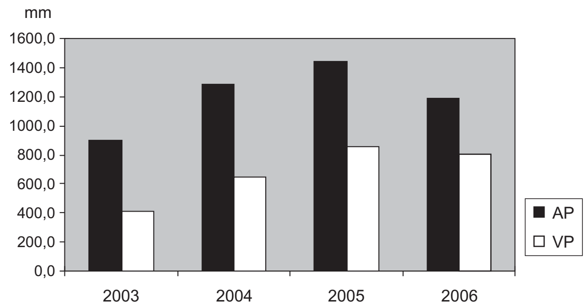


Figure 3. *AP and VP for the period 2000–2006, meteorological station Puntijarka.*

the period 2004–2006, the lowest moderate to severe damage percentage of beech trees on Medvednica occurred in 2005 (48.10%), which was a rainy year (Table 3). In the year before and the year after, the values were higher; in 2004 the share of moderately to severely damaged beech trees was the highest in the studied period (Table 4) despite average climate conditions. The high value of defoliation in 2004 was probably due to the lag effect of the severe drought in 2003 (Table 3). Stribley and Ashmore *(38)* consider the causes of beech decline in vitality to be uncertain, but they deem it likely that drought years are important. The lag effect of drought is often considered as the cause of severe defoliation and even dieback of forest trees. Drobyshev, Linderson and Sonesson *(39)* suggest that drought could act as a triggering factor predisposing trees to growth declines and subsequent mortality and that the effect of drought manifests itself as a growth depression followed, with some time lag, by death. Climatic variables of the year preceding the year of crown assessment accounted for 79% of the variation in current defoliation in the research by Neirynck and Roskams *(40)*. Siedling *(41)*, in his assessment of German ICP Forests Level I data, reports that beech responded – mainly with a delay of one year – with some foliar loss in areas where there was a surplus of temperature after the generally hot and dry summer of 2003. As a part of climate change monitoring in Great Britain, it

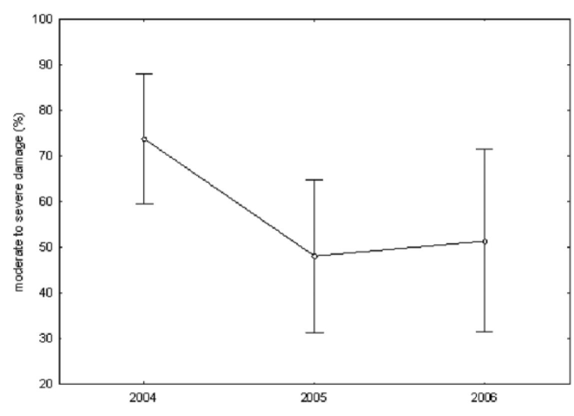


Figure 4. *The share of moderately to severely damaged beech trees (over 25 % defoliation) for the years 2004 – 2006 (vertical bars denote 0,95 confidence intervals).*

TABLE 4

Results of repeated measures ANOVA for moderate to severe damage of beech tree crowns.

	df	MS	F	p	Tukey post hoc
			Between subject		
error	8	1162.52			
			Within subject		
Year	2	1751.6	10.62	0.0012	(2004)(2005, 2006)*
error	16	165			

was concluded that the high percentages of beech trees were poorly foliated (over 25% crown density reduction) following previous dry summers. Besides this, many of the symptoms observed indicated drought damage which may have resulted from root death in the previous year. An examination of the relationships between climatic variables and annual crown density records for five species in Britain revealed a particularly strong negative correlation between the percentage of beech trees with over 25% crown density reduction and average rainfall in the previous July in England and Wales *(42)*. In addition, summer rainfall of the preceding year is the most significant predictor of total leaf number in beech forests *(43)*. Therefore, crown defoliation is a product of the tree crown status from the past several years of growth, which can be misleading if used as a stress indicator when assessing current vitality *(10)*. Our results show that the degree of defoliation can be linked to the climate properties in the current year, as well as in the previous years.

Unlike the defoliation of beech trees in Croatia in the same period, which was more or less stable – 2004: 12.0%, 2005: 11.4%, 2006: 12.7% of trees with defoliation >25% *(44, 45, 46)*, on Medvednica the differences in defoliation between the years were quite distinctive. We assume this to be the effect of the differences in annual climate properties that are better expressed on a smaller, climatically more homogenous area, i.e. the annual differences in defoliation are not masked by crown condition data from other, climatically different areas. On the issue of large-scale monitoring, Siedling *(41)* states that »results do not always match the drought stress hypothesis, however, this is not to be expected considering the heterogeneous site, stand and climatic conditions«.

Climate and relief properties were found to influence the crown condition status of beech trees on Medvednica. The determinant parameters for D were EL, EX and VP. Using multiple regression, EL and VP were significant in all three years: D is higher with the rise in EL, and vice versa with VP. We did not see any significant influence of temperature on D, although the linear trend of AT and VT in the period 1980–2006 (Table 1) was significantly positive. This is to be expected since the temperature influences defoliation indirectly, through a rise in evapotranspiration (i.e. drought). According to Kirigin *(47)*, excessive transpiration requires large quantities of available water.

Conversely, the calculations of Potočić *et al. (16)* suggest the strong influence of AT, and the relatively low influence of precipitation on the crown condition of beech on Velebit mountain, although the trends of temperature and precipitation are similar – the difference between Medvednica and Velebit is that on Velebit precipitation is abundant and therefore not a limiting factor.

All the variables together explain between 14.1 and 22.6 % of the variation (Table 5). In the alpine region of Switzerland, it was found that a multitude of stress factors, such as extremely high and low temperatures, late frosts, intensive solar radiation, or long-lasting snow cover, most likely obscure the influence of the main climatic properties, such as precipitation and temperature *(48)*. In this research, these variables were not considered; due to the prevailing climate conditions on Medvednica, their significant influence cannot be expected. On the other hand, the results may also depend on other biotic and abiotic damage factors (pest gradations, soil types, wet and dry deposition, ozone, etc.).

TABLE 5

Results of multiple regression analysis for defoliation of beech trees on Medvednica as dependent variable (EL – elevation, EX – exposition, VP – precipitation in the vegetation period).

Year	Variable	Parameter estimate	Standard error	t value	p	Model R^2
2004	EL	11.4432	2.0060	5.70	<0.0001*	0.1405
	EX	–0.2625	0.3291	–0.80	0.4261	
	VP	–76.2908	13.3720	–5.71	<0.0001*	
2005	EL	19.4199	2.3536	8.25	<0.0001*	0.2258
	EX	–0.1083	0.3295	–0.33	0.7426	
	VP	–66.9581	8.1151	–8.25	<0.0001*	
2006	EL	17.2528	2.3824	7.24	<0.0001*	0.1885
	EX	–0.8292	0.3335	–2.49	0.0136*	
	VP	–50.7582	7.0065	–7.24	<0.0001*	

TABLE 6

Results of stepwise selection procedure for multiple regression analysis of EX. (S – south, SW – southwest, SE – southeast, E – east. Northwest is baseline.).

Year	Exposition	Parameter estimate	Standard error	t value	p	Model R^2
2004	S	2.9514	1.4256	2.07	0.0397*	0.0208
2005	S	6.3131	1.6870	3.74	0.0002*	0.0585
	SW	5.0292	3.4068	1.48	0.1412	
2006	SE	–4.2878	2.6443	–1.62	0.1062	0.0563
	E	5.9204	2.6440	2.24	0.0261*	
	S	3.3060	1.7868	1.85	0.0655	
	SW	5.3916	3.4423	1.57	0.1186	

*$p<0.05$

Using a stepwise selection procedure, D was higher predominantly on southern expositions (Table 6). The significant influence of EX on the crown condition of beech on Medvednica was partly expected, given the recent frequent drought episodes (in 2000 and 2003). The influence of exposition is, in effect, the influence of a certain damage factor (wind, snow, drought, etc.), intensified by a certain exposition, and depending on the geographical position, the climate type of the area and the tree species concerned. In the research of the influence of various stand and site factors on the defoliation of forest tree species in Croatia *(24),* the defoliation of pubescent oak was the highest on northeastern expositions open to prevailing strong winds; for black pine, the damage to crowns was most severe on western expositions; and for beech, the only relevant factor was elevation.

CONCLUSIONS

In contrast with data from large-scale monitoring, case studies are able to provide more data from a limited area, therefore more precisely showing the ecosystem response to a specific set of climatic factors present in a research area, and with various elevations and expositions adding to the variability of data. On the other hand, this creates a problem in interpreting data from a limited number of research plots, and care needs to be taken in making general conclusions.

Although the change of climate in the Medvednica area is most obvious from the trend of temperatures, precipitation can have the dominant role in the vitality of forest ecosystems on a shorter time-scale; precipitation in the vegetation period was the dominant climate parameter influencing the crown condition of common beech trees on Medvednica between 2004 and 2006, and elevation and exposition had an added influence.

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