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The influence of climate properties on crown condition of Common beech (*Fagus sylvatica* L.) and Silver fir (*Abies alba* Mill.) on Velebit

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Abstract

Background and Purpose: *From a variety of environmental factors that are thought to be a likely cause of dieback of forest tree species, climate properties are surely among the most important. The fact that beech and fir forests on Velebit represent the most southern large complexes of these forests in Croatia makes them especially interesting in the context of their potential reaction to the effects of climate change.*

Materials and Methods: *Eight permanent forest research plots located on Velebit, (4 x 4 km plot network) with complete crown condition data sets in the 2001-2006 period, were used for the purpose of this research. Climate data from the meteorological stations of Gospić, Baške Oštarije, Ličko Lešće, Oltari and Kosinjski Bakovac were used for the analysis of the influence of climate properties on beech and fir crown condition.*

Results: *Annual precipitation (AP), precipitation in the vegetation period (VP), mean annual air temperature (AT) and mean air temperature in the vegetation period (VT) account for 17,08% of Common beech defoliation variability. VP, AT and VT account for 25.06% of Silver fir defoliation. The most determining parameters are VT and then AT: defoliation increases with increasing VT and decreasing AT.*

Conclusions: *Low defoliation of beech and fir trees in 2002 can be related to low VT and high AT. With both species, our calculations suggest a strong influence of AT on defoliation, and relatively low influence of precipitation.*

INTRODUCTION

From a variety of environmental factors that are thought to be likely causes of dieback of forest tree species, climate properties are surely among the most important. Since climate is a decisive factor in the development of a certain type of vegetation, it is quite clear that it has an equally important role in its survival. Meteorological conditions are regarded as critical in the process of forest decline, as they govern water relations, especially in situations of disturbed water absorption and transport in trees *(1)*. Environmental stresses such as drought are supposed to be a primary, predisposing mechanism of forest decline, making forest trees more vulnerable to damages such as fungal diseases, or defoliating and wood-boring insects *(2)*. Sudden changes of air temperature can also result in damages to forest ecosystems, destruction of the assimilatory apparatus of trees and subsequent dieback of the whole ecosystem *(3)*. 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 *(4)*. The analysis of meteorological data from meteorological station Grič shows that the change in temperature and precipitation regime is already present in Croatia *(5)*.

Silver fir (*Abies alba* Mill.) is the most widely distributed coniferous species in Croatia: it participates with 9.4% in the growing stock of all Croatian forests *(6)*. Due to its major ecological and economical importance, the deteriorating health status of silver fir in recent years has been a matter of great concern. Silver fir is a species with a long history of dieback throughout Europe. The first large-scale dieback of Silver fir in Croatia was recorded in 1900 near Ogulin *(7)*. According to annual assessments of crown condition of forests *(8)* Silver fir is also the most damaged tree species in Croatia, with about 70% trees exhibiting loss of over 25% needles since year 2000.

When discussing the dieback of Siver fir, climate properties deserve a special attention. The deficit of precipitation, along with high air temperatures, lowers the vitality of fir trees because excessive transpiration requires large quantities of available water *(9)*. These conditions are unfavorable for photosynthesis, transport of nutrients and other physiological processes. Dendroecological studies have shown that severe water stress (during consecutive dry years) is an important cause of damage, especially crown deterioration, in silver fir *(10)*. Low water supply was singled out as the key factor in the dieback of fir in Jura Mountains, France *(11)*. Batič *(12)* associated heavy barkbeetle damages on fir in Lika in 1923, 1924, and 1929 with lower vitality of fir trees caused by drought. Several researchers considered the lack of moisture in the air and soil a primary cause of fir dieback in Gorski kotar *(13, 14)*.

Common beech (*Fagus sylvatica* L.) is a dominant broadleaved tree species in European forests. Its crown condition in Croatia is far better than the condition of Silver fir, with less than 12 % trees defoliated more than 25% in the 2001- 2006 period *(15)*.

The causes of beech decline in vitality are uncertain, but it is likely that drought years are important *(16)*. Conversely, the evaluation of inventory data between 1980 and 1992 in Bavarian forests revealed a high tolerance of this tree species to drought *(17)*.

Extreme climatic events like drought are thought to be important in initiating changes in forest ecosystems *(2)*, regardless of the tree species involved. The fact that beech and fir forests on Velebit represent the southernmost large complexes of these forests in Croatia makes them especially interesting in the context of their potential reaction to effects of climate change. In this paper the influence of climate properties on the crown condition of Silver fir and Common beech trees on Velebit is discussed.

MATERIALS AND METHODS

Research area and crown condition assessments

Crown condition data from eight permanent forest research plots located on 4 x 4 km plot network on Velebit, with complete crown condition data sets for the 2001–2006 period, were used for the purpose of this research (Figure 1). The data were collected in the framework of the UN/ECE International Co-operative Programme for the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). On these plots, crown condi-

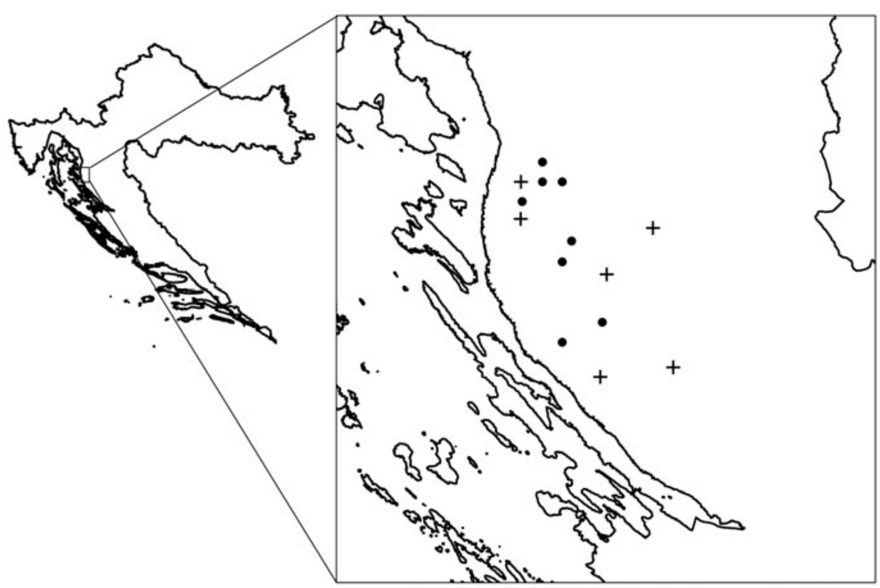

Figure 1. *Research plots (circle) and meteorological stations (+) on Velebit.*

TABLE 1

Results of repeated measures ANOVA.

	Repeated Measure Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition				
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	307147.9	1	307147.9	576.2509	0.000000
species	2413.5	1	2413.5	4.5280	0.034705
Error	95941.9	180	533.0		
year	6775.5	5	1355.1	28.5630	0.000000
year* species	4641.2	5	928.2	19.5658	0.000000
Error	42698.2	900	47.4		

tion as a percentage of defoliation of beech and fir trees was assessed annually according to the ICP Forests Manual *(18)*. Since trees with defoliation over 25% are considered to be moderately to severely damaged, the share of these trees is a good measure of the forest ecosystem vitality.

Climate data

Climate data from the meteorological stations of Gospić, Baške Oštarije, Ličko Lešće, Oltari and Kosinjski Bakovac (Figure 1) were used for the analysis of climate properties in the research area: linear trends of mean annual air temperatures and annual precipitation values were calculated by simple regressions, and their significance tested by Student's t-test.

Regression models of theoretical change of mean annual air temperature (°C) and annual precipitation (mm) with elevation *(19, 20)*, by using elevation of experimental plots and the data from the nearest meteorological station, were used to obtain estimate of the mean annual air temperature (°C) and annual precipitation (mm) on the research plots.

Statistical analyses

Descriptive statistics was done for all analyzed variables. For all analyses type I error of 5% was considered statistically significant. The differences in defoliation were tested using the repeated measure analysis of variance (ANOVA) test. Effects of species (beech – 20, fir – 100), assessment year (2001–2006) and their interaction were tested as fixed effects. Tukeye multiple comparison post hoc test was used to determine exact differences *(21)*.

The influence of variables – annual precipitation and temperature, as well as precipitation and temperature in the vegetation period, on defoliation was tested by univariate and multivariate regression. Stepwise procedure was used to determine the best model for explaining defoliation through these variables *(22)*. All statistical analyses were conducted using SAS 8.2 statistical package (regression), *(23)* and STATISTICA 7.1 (repeated measures, ANOVA) STATISTICA 7.1. *(24)*. Graphs were produced using EXCEL and STATISTICA 7.1.

RESULTS AND DISCUSSION

The data on the share of Silver fir trees with defoliation over 25% in Europe, Croatia and on Velebit research plots for the 2001-2006 period are given in Figure 2. Unlike large differences in defoliation between Croatian and European data, the differences between Velebit and Europe are smaller. The disproportion of Silver fir defoliation in Croatia and Europe is discussed elsewhere *(25)*. On Velebit plots the differences in defoliation between years are quite distinctive. We assume that this is effect of differences in annual climate properties that are better expressed on a smaller, climatically more homogenous area, e.g. annual differences in defoliation are not masked by data from other, climatically different areas.

The crown condition of beech in Croatia is significantly better than the European average, as evident from Figure 3. On Velebit, the share of Common beech trees with defoliation over 25% corresponds well with the Croatian data for the 2001-2006 period.

Figure 4 and Table 1 show different defoliation development patterns of beech and fir trees after starting at similar values in year 2001, although statistically significant differences were not established. Still, large differences in the share of trees with defoliation over 25% (Figures 2, 3), especially present in year 2005 (10% beech vs. 38.5 % fir), clearly distinguish the defoliation patterns of these two species.

The lowest mean defoliation of beech was recorded in year 2002 (14.8%), and the highest in 2003 (19.1%). The values in these two years are significantly different. After 2003, the values were decling toward 2006, when there was again a significant difference against mean defoliation in year 2003.

Similarly, the minimum fir defoliation was recorded in 2002 (12.5%) and this low value is significantly different compared to high means in the years to follow (2003 –2006), with no significant change in the crown condition between 2003 and 2004, and the maximum mean defoliation (28.1%) reached in 2005. In 2006 there was again, like in 2002, the evidence of some crown condition recovery.

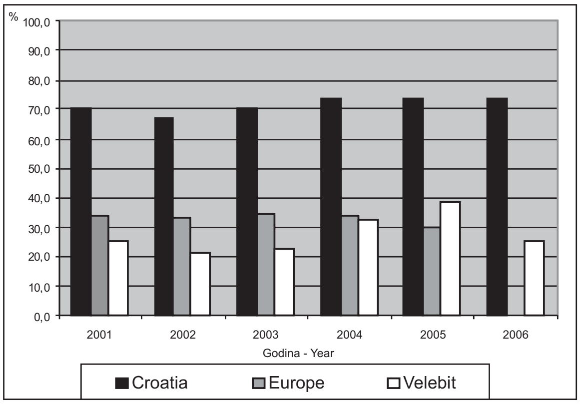

Figure 2. *Comparison of the share of Silver fir trees with defoliation over 25% in Europe, Croatia and on Velebit research plots for the 2001-2006 period.*

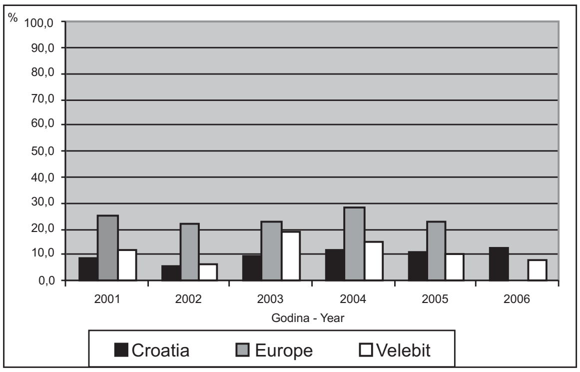

Figure 3. *Comparison of the share of Common beech trees with defoliation over 25% in Europe, Croatia and on Velebit research plots for the 2001-2006 period.*

Linear trends of air temperature (Table 2) show that the temperature in the area of research has risen. The trend is statistically significant for all meteorological stations except temperatures in the vegetation period for the meteorological station Baške Oštarije.

The equations show that precipitations were either lowering or increasing, depending on the meteorological station. The linear trend of annual precipitation is significant only for the meteorological station Oltari (Table 3).

Using the multivariate stepwise procedure, annual precipitation (AP), precipitation in the vegetation period (VP), mean annual air temperature (AT) and mean air temperature in the vegetation period (VT) account for 17.08% of common beech defoliation variability (Table 4). Univariate procedure reveals that beech defoliation was significantly influenced by AP (R^2= 0.041), AT ((R^2 = 0.114), and VT (R^2 = 0.088). Although with beech, VP was not significant in the univariate analysis, it was due to interrelations of parameters, significant in the multivariate procedure: with less VP, defoliation was higher – an expected result. Changes in beech growth were clearly related to fluctuation in water deficits between 2002 and 2005 in a Swiss study *(26)*. The recovery process depends on wet periods subsequent drought: one year is usually enough for light recovery *(27)* (compare beech defoliation in Figure 4).

All variables except AT significantly affected the defoliation of fir in a univariate procedure. The results obtained in a study by Modrzyñski *(1)* »confirm to some extent that (...) increasing temperature may accelerate defoliation«.

After stepwise procedure, VP, AT and VT accounted for 25,06% of fir defoliation. The most determining parameters are VT and then AT: defoliation increases with increasing VT and decreasing AT. VP also influences fir defoliation, but to a lesser degree.

Relatively high correlations between defoliation and drought have been found in the northern lowlands of Switzerland, indicating that drought can cause premature leaf or needle loss. In the alpine area, correlations

TABLE 2

Linear trends of air temperature and their significance.

Meteo station	Mean annual air temperature (°C)		
	Linear trend	t	p
Zavižan	y = 0.0213x+3.3698	t (34) = 2.1739	0.0367*
Gospić	y = 0.0406x+7.9932	t (35) = 4.9178	0.0000*
Baške Oštarije	y = 0.0413x+6.9886	t (24) = 3.0850	0.0050*
Ličko Lešće	y = 00466x+8.6628	t (24) = 3.2033	0.0038*
	Mean air temperature in the vegetation period (°C)		
Zavižan	y = 0.0389x+7.9211	t (34) = 3.1060	0.0038*
Gospić	y = 0.0551x+13.663	t (35) = 5.0573	0.0000*
Baške Oštarije	y = 0.0323x+12.652	t (24) = 1.7031	0.1014
Ličko Lešće	y = 0.0471x+14.605	t (24) = 2.5097	0.0192*

* significant at p= 0.05

TABLE 3

Linear trends of precipitation and their significance.

Meteo station	Annual precipitation (mm)		
	Linear trend	t	p
Zavižan	y = 2.259+1934.3	t (34) = 0.4290	0.6706
Gospić	y = –0.5985x+1372.7	t (35) = –0.1939	0.8473
Baške Oštarije	y = –0.601x+2208.7	t (24) = –0.0621	0.9509
Ličko Lešće	y = 6.35x+1043.8	t (24) = 1.3586	0.1868
Oltari	y = –25.41x+1850.3	t (14) = –2.2661	0.0398*
Kosinjski Bakovac	y = 4.2531x+1345	t (24) = 0.7516	0.4595
	Precipitation in the vegetation period (mm)		
Zavižan	y = –2.3861+919.07	t (34) = –0.6763	0.5034
Gospić	y = –0.2864+599.22	t (35) = –0.1181	0.9066
Baške Oštarije	y = –2.2618x+918.67	t (24) = –0.3239	0.7488
Ličko Lešće	y = 2.248x+469.08	t (24) = 0.6162	0.5435
Oltari	y = –7.0185x+796.2	t (14) = –0.6722	0.5123
Kosinjski Bakovac	y = 1.6926x+575.92	t (24) = 0.3931	0.6976

* significant at p= 0.05

TABLE 4

Results of univariate and multivariate (stepwise) regression. AP=annual precipitation, VP= precipitation in the vegetation period, AT= mean annual air temperature, VT= mean air temperature in the vegetation period.

	Variable	Univariate regression			Multivariate stepwise regression		
		Parameter estimate	p	R^2	Parameter estimate	p	R^2
Fagus sylvatica	AP	0.005	<0.0001	0.0412	0.008	<0.0001	0.1708
	VP	–0.001	0.357	0.0011	–0.009	<0.0001	
	AT	–1.975	<0.0001	0.1136	–2.463	0.0001	
	VT	–1.378	<0.0001	0.0881	0.879	0.1118	
Abies alba	AP	–0.010	0.0036	0.0250			0.2506
	VP	0.012	0.003	0.0260	0.052	<0.0001	
	AT	–0.436	0.771	0.0003	–18.120	<0.0001	
	VT	2.209	0.072	0.0075	20.936	<0.0001	

were rather weak; there a multitude of climatic stress factors such as extremely high and low temperatures, late frosts, intensive solar radiation, or the long lasting snow cover, most likely obscure the influence of drought on crown defoliation *(2)*.

CONCLUSIONS

Taking into account climatic data and crown condition in each assessment year, and on the basis of determined dependecies, it is possible to relate the development of defoliation, especially when a change in defoliation is large, with certain climatic parameters used in the multivariate model. Low defoliation of beech and fir trees in 2002 can be related to low VT and high AT at sufficient precipitation. In 2003, the upsurge of beech defoliation was clearly related to low VP. The recovery of common beech crown condition after 2003 cannot be related exclusively to higher AT, but it is indicative that low beech defoliation was again recorded in 2006, when AT was approximately at the level of AT in year 2002. Gradual lowering of beech defoliation in the 2004-2006 period can be clearly related to the increase in VP at the same period.

The increase in fir defoliation in 2003 was in a part the consequence of drought in the vegetation period, but the next significant increase of fir defoliation (in 2005) can

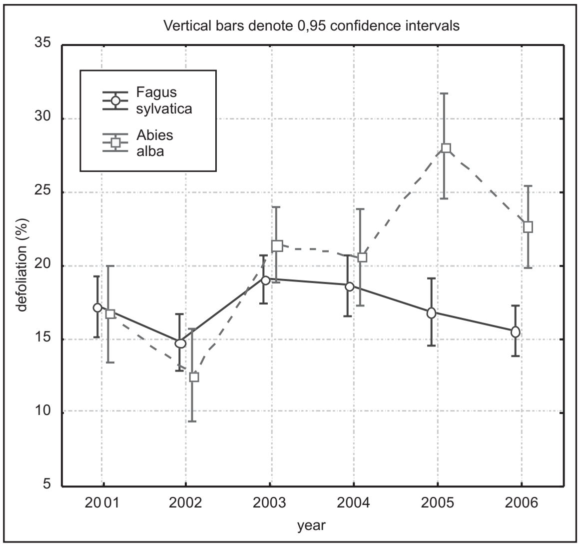

Figure 4. *Development of mean defoliation of beech and fir trees on Velebit in the 2001-2006 period.*

only be related to low AT. With both species, our calculations suggest a strong influence of AT on defoliation, and relatively low influence of precipitation.

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