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Dieback of Silver Fir (*Abies alba* Mill.) on Northern Velebit (Croatia)

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Abstract

Background and Purpose: *Silver fir is the most widely distributed and the most important commercial conifer species in Croatia; however, it is also the most endangered. The first records of its dieback in Croatia go back to the beginning of the 19th century. Dieback has since caused growing concern and has become a major problem in forestry. The phenomenon of silver fir dieback is attributed to a number of causes. The objective of this study is to present the dynamics and intensity of silver fir dieback in the last decade on northern Velebit and determine the connection between tree dieback, relief and climatic factors.*

Materials and Methods: *Data on dead silver fir trees were collected in northern Velebit (management units Begovača, Jelovac and Lom, Krasno Forest Office) at the level of the management units for the 1998-2006 period. The dynamics of tree dieback was analyzed on the basis of dead tree volume. Regression models were used to obtain data on temperature and precipitation quantity for each compartment/subcompartment. Dependence of dieback intensity on relief and climatic factors was established with correlation coefficients.*

Results: *The average annual dieback of silver fir in the 1998-2006 period ranged from 0.4 to 0.1 m^3/ha. The highest dieback index, amounting to 2.5% of the total growing stock, was recorded in the management unit Jelovac, while the lowest, reaching 1.4% of the total growing stock, was recorded in the management unit Lom. The lowest dieback of only 0.6 m^3/ha on average was detected in NW expositions, while the highest of 2.7 m^3/ha was found in eastern expositions. An increase in mean vegetational air temperatures of 1.1°C and 0.7°C was recorded in the areas of meteorological stations Gospić and Zavižan respectively, as well as a decrease in vegetational precipitation quantities of 4.2% (Gospić) and 0.4% (Zavižan).*

Conclusions: *A rising trend in the quantity of dead wood mass of silver fir (Abies alba Mill.) has been recorded in the past ten-year period. Fir dieback in the amount equaling annual increment was established. The highest dieback intensity occurred at lower altitudes and milder slopes. A statistically significant increase in air temperature values was recorded in the study area. Although precipitation quantities are reduced, they are not statistically important. Very slight to slight, but statistically significant positive correlation was found between a rising trend in temperatures and precipitation. Correlation was also found between an increase in the silver fir growing stock and dieback intensity.*

Figure 1. *Research area (Krasno Forest Office, North Velebit).*

INTRODUCTION

Silver fir (*Abies alba* Mill.) is the most endangered commercial tree species in Croatia. It participates in the growing stock of Croatian forests with 9.4% *(1)*. The phenomenon of silver fir dieback is manifested across Europe. However, differences in factors such as soil, climate and air pollution exacerbate the establishment of causes of silver fir dieback despite a large number of hypotheses treating the phenomenon *(2)*. Silver fir dieback is important from the forest-silvicultural aspect because it is linked with the absence of natural regeneration *(3, 4, 5)*.

The present condition of fir forests is characterized by a disturbed structure of differently aged trees. This has led to a number of adverse effects: very poor or completely absent natural fir regeneration, decreased or increased growing stock in relation to the normal model, ageing, physiological weakening and dieback of dominant trees, changes in the stand's micro-climate, degraded forest soils caused by excessive weeds, erosion, reduced microbiological activity, raw humus accumulation, the onset of secondary pests which accelerate dieback processes, aggressive invasion of common beech at the expense of silver fir, and others. Such a condition may be attributed to three groups of causes: inadequate silvicultural treatments, the occurrence of long, dry periods in global climate, and adverse impacts of acid rains and pollutants that contaminate the air, water and soil *(6)*. Negative impact of chemical substances in the atmosphere is constantly increasing. This factor, combined with global changes in the atmosphere which are responsible for climatic excesses, is perceived as the most important cause of silver fir dieback *(7, 8)*.

Similarly, changes in nutritional and physiological status, brought about by insufficient precipitation, are considered the main cause of dieback and decline of the Spanish fir in the Pyrenees *(9)*. Dry period as a stress factor is one of the main reasons for dieback, damage and declining health of forest ecosystems of silver fir *(10)*. According to Oszlànyi, drought, climate change and abrupt and sudden temperature oscillations are stress factors responsible for damage to forest ecosystems, the destruction of the tree's assimilation apparatus and subsequent degradation of the entire ecosystem *(11)*. Seletković *et al.* analyzed meteorological data from the Meteorological Station Zagreb – Grič to detect changes in temperature and precipitation regimes over the last 100 years in Croatia *(12)*. Matić *et al.* perceive climate change as the principal cause of decline of several tree species and of silver fir in particular. They attribute the formation of stands with different tree species ratios in the composition mix, and even with sporadic occurrences of other tree species, to the above factor *(13)*. In commercial forests, the volume of dead trees, or the volume of trees felled in sanitary cuts, is generally used to illustrate the intensity of tree dieback. It can also be used as an indicator of a stand's health status *(14)*.

Dieback intensity may be expressed as the mortality percentage (»mortality rate«) of trees calculated as the ratio between the number of dead trees and the number of living trees *(15, 16, 17, 18, 19),* or it can be expressed in absolute form (m^3, m^3/ha) *(20)*. Multiple objectives of this study were to determine the dynamics and intensity of silver fir dieback in the area of northern Velebit, establish the relationship of dead trees to relief and climatic factors, define trends in macroclimatic elements (air temperatures and precipitation quantities), and explain their correlation with the status and trends of silver fir dieback in the study area.

MATERIALS AND METHODS

Field research, conducted in the distribution range of beech-fir stands of northern Velebit, encompassed the management units of »Begovača« (1170 ha), »Jelovac« (1726 ha) and »Lom« (2775 ha) in Krasno Forest Administration. Northern Velebit is situated in the west of Croatia (Figure 1). The climate of the study area is temperate warm rainy climate, while snowy forest climate (boreal) begins at 1,200 m above the sea level and over. The mean annual air temperature ranges from 4.0 to 8.0 °C, and the mean annual precipitation quantity varies between 1600 and 2000 mm.

Data on the number and wood mass of dead silver fir trees were collected from annual field manuals of marked damaged and dead trees at the level of all compartments and subcompartments in the management unit. The data were collected for the 1998-2006 period. The wood mass of dead trees was obtained using field measurements of tree diameter and local tariffs. Mortality index was calculated in the percentage form as the ratio of dead wood mass and silver fir growing stock per surface unit (ha). The percentage of sanitary cuts was obtained on the basis of dead wood mass and total wood mass of the cut fir. The mortality index was determined on the basis of the ratio between dead wood mass and the compartment or subcompartment size.

To analyze climate and climatic conditions in the study area, data on air temperatures and precipitation quantities for climatological stations Zavižan (1,594 m a.s.l.) and Gospić (564 m a.s.l.) were used for a prolonged monitoring period.

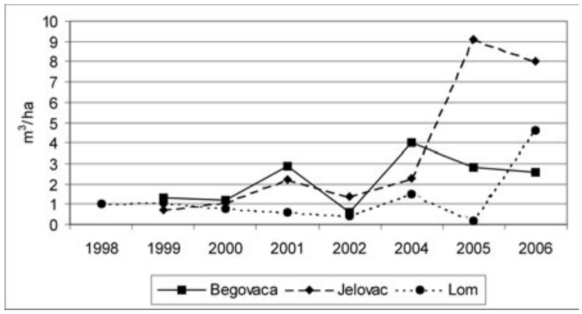

Figure 2. *Dieback intensities of silver fir (m³/ha) in the area of management units of Krasno Forest Office, northern Velebit.*

Since the meteorological stations are located at lower altitudes than the observed compartments and subcompartments, regression models were used to obtain data on temperature and precipitation quantities for each observed compartment and subcompartment on the basis of theoretical changes in mean annual air temperature (°C) and precipitation quantities (mm) in dependence to altitude *(21, 22)*.

Linear trends in annual air temperatures and precipitation quantities (simple regression) were calculated for the above meteorological stations. Their significance was tested with the Student's t-test. Annual and vegetation precipitation quantities, as well as air temperature values for the 1998-2006 period were compared with the 1970 – 1997 reference series using the t-test of independent sam-

TABLE 1

Overall absolute dieback, dieback index, and the percentage of salvage cutting in the total annual prescribed yield of silver fir in the area of Krasno Forest Office, northern Velebit.

Year	Forests management units								
	Begovaca			Jelovac			Lom		
	Absolutely dead m³	Dieback index %	Percentage of salvage cutting %	Absolutely dead m³	Dieback index %	Percentage of salvage cutting %	Absolutely dead m³	Dieback index %	Percentage of salvage cutting %
1998	–	–	–	–	–	–	584	1.2	34.1
1999	459	1.4	19.8	278	0.8	13.4	125	1.3	7.3
2000	358	0.6	15.5	372	0.6	17.9	469	0.8	27.4
2001	450	2.9	19.4	906	1.4	43.7	137	0.7	8.0
2002	144	0.5	6.2	423	0.8	20.4	70	0.4	4.1
2004	1680	3.0	72.5	187	1.5	9.0	585	1.4	34.2
2005	635	2.7	27.4	2712	8.1	130.7	7	0.1	0.4
2006	134	2.8	5.8	682	4.2	32.9	3142	5.4	183.6
AVERAGE		2.0	23.8		2.5	38.3		1.4	37.4

ples. Dry years were identified with climatograms *(23)* and the percentile method. All the data were processed in the Statistica 6.0 and Klimasoft 2.0 programmes.

RESULTS

Dieback Intensities of Silver Fir

According to results presented in Figure 1, an increase in the average annual dead wood mass was recorded for all three management units. Intensity of the increase was more pronounced after the particularly dry year of 2003, especially in the management unit Jelovac.

The lowest value of the average annual dead wood mass was 0.4 m^3/ha in 2002, and the highest 9.1 m^3/ha in 2005.

Absolute dieback of silver fir (*Abies alba* Mill.) in the study area was the most intensive after 2003. Mortality indexes also had the highest values in that period. Annual mortality indexes varied from 0.1 to 8.1%.

Average annual mortality indexes for the observed period were from 1.4 to 2.5%. Average sanitary cutting values ranged from 24 to 38%.

A correlation analysis of dead wood mass and growing stock of silver fir provided positive, slight and statistically significant correlation (R=0.24*). The most severe dieback was recorded in the third diameter class trees ($d_{1,30}$ > 50 cm), from 52 to 56% of the total dead wood mass, and the slightest in the first diameter class trees ($d_{1,30}$ 10–30 cm), i.e. only 6% of the total dead wood mass.

Dead trees in the second diameter class participated in the total dead wood mass with 37 to 40%.

On average, annual dieback intensity (m^3/ha) in the 1998-2006 period equals the values of the current annual increment (Table 2).

Dieback intensities in the management unit Jelovac were slightly higher than the increment, which will cause a long-term decrease in the growing stock of silver fir.

Dieback and Relief Factors

With regard to exposition, the lowest dieback rate was recorded in northern expositions. In NW expositions it was only 0.6 m^3/ha, but in eastern expositions it amounted to as much as 2.7 m^3/ha.

In terms of terrain slope, the highest dieback rate was recorded on mild slopes (2.7 m^3/ha) and the lowest on very steep slopes (1.0 m^3/ha). Similarly, the correlation between dead wood mass and slope was negative, very slight and statistically significant (R= -0.16*).

In relation to altitude, the most severe dieback was observed at the lowest altitudes (3.2 m^3/ha), and the lowest at the highest altitudes (0.5 m^3/ha). The correlation between dead wood mass and altitude classes was also negative, very slight and statistically significant (R=-0.19*).

TABLE 2

Average annual dieback intensity and average annual current increment of silver fir (Abies alba Mill.) for the 1998 – 2006 period in three management units of Krasno Forest Office, northern Velebit.

Management unit	Annual dieback intensity (m^3/ha)	Current annual increment (m^3/ha)
Begovača	2.2	2.3
Jelovac	3.5	3.4
Lom	1.3	2.0

TABLE 3

The relationship between silver fir dieback (m^3/ha) and relief factors in three management units of Krasno Forest Office, northern Velebit.

Relief factors			Average dieback m^3/ha	N
	Exposition	N	2.4	4
		NE	1.7	34
		NW	0.6	2
		E	2.7	20
		W	2.4	5
		S	1.9	32
		SE	2.5	12
		SW	2.4	22
		VARIOUS	2.5	94
	Slopes	Very mild < 5^0	2.6	16
		Mild 7 – 15^0	2.7	137
		Moderately steep 15 – 25^0	1.5	66
		Very steep 25 – 40^0	1.0	6
	Altitude	900-1000	3.2	3
		1000-1100	1.9	44
		1100-1200	2.8	76
		1200-1300	2.7	60
		1300-1400	1.4	34
		1400-1500	0.5	8

N- Number of compartments

Dieback and Climatic Factors

Among climatic elements, fir dieback is most firmly linked with air temperatures and precipitation quantities. For this reason, we investigated their changes during a prolonged monitoring period.

Linear trends in air temperatures (Table 4) have a positive prefix, which means that the temperature in the study area is rising. A trend in temperature increase is

TABLE 4

Linear trend in air temperatures and their significance for meteorological stations in the area of northern Velebit.

Met. station	Mean annual air temperatures (°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*
	Mean vegetational air temperatures (°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*

TABLE 5

Linear trend in precipitation and their significance for meteorological stations in the area of northern Velebit.

Met. station	Annual precipitation quantities (mm)		
	Linaer 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
	Vegetational precipitation quantities (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

statistically significant both for annual and vegetation air temperatures.

According to the Student's t-test results for mean annual and vegetation air temperatures, a statistically significant increase in mean annual air temperatures of 1.0 °C and mean vegetation air temperatures of 1.1 °C was recorded in the area of Gospić Meteorological Station for the 1998-2006 period. This increase was not statistically significant for the area of Zavižan Meteorological Station and amounted to only 0.3 °C for mean annual and 0.7 °C for mean vegetation air temperatures.

The correlation of annual and vegetation air temperatures with dieback intensity in the compartment and subcompartment was positive, very slight and statistically significant (R=0.20*).

Linear equations of trends in precipitation quantities have a negative prefix, which means that the quantity of precipitation in the study area is decreasing. Linear trends are not statistically significant. A decrease in the precipitation quantity for the 1998-2006 period in the area of Gospić Meteorological Station was 3% for mean annual precipitation quantities and 4% for mean vegetation precipitation quantities. In the said period, mean annual precipitation quantities dropped by 2.5% and mean vegetation ones by 9% in the area of Zavižan Meteorological Station.

The correlation of annual and vegetation precipitation quantities and silver fir dieback intensity was negative, moderate and statistically significant (R=-0.20*).

DISCUSSION

The average annual tree dieback per hectare in the study area has an upward trend, thus confirming the disturbed stability of these forest ecosystems in the area of northern Velebit.

The data of Krasno Forest Office show that the participation of sanitary cutting or dead wood mass of silver fir amounts to 40% of the prescribed yield for northern Velebit. With regard to the upward dieback trend in the study area, it is expected that the share of sanitary cutting in the total yield will rise.

According to Oszlànyi *(11),* the high percentage of sanitary cutting (about 60% of the annual prescribed yield) indicates disturbances in both ecological conditions and forest ecosystem stability. In terms of single years, a very high percentage of sanitary cutting in the total yield was recorded in the study area. On average, the percentage varied between 24 and 38% for the observed period.

The percentage of sanitary cutting in the total yield varied from year to year. The highest values were recorded after the very dry year 2003, amounting to 73% in the management unit Begovača, to 131% in the management unit Jelovac, and to as much as 184% in the management unit Lom. Maximum participation percentage of sanitary cutting in the total yield occurred after the exceptionally dry year 2003 *(24)*. Intensive sanitary cutting operations resulted in changes in both the age structure and composition mix of particular tree species *(17)*.

The highest dead wood mass of silver fir (m^3/ha) was found in the third diameter class. As a rule, trees in this class were older and physiologically weaker. Markalas *(16)* also recorded a significantly higher dieback rate of Greek fir in larger diameter classes, especially those with breast diameters over 72 cm. However, trees in other diameter classes also participate with significant percentages in the total volume of dead trees (from 37 to 40%).

In the area of northern Velebit, the volume of dead trees is equal to the values of annual current increment. Increment reduction, physiological weakening and dieback of dominant trees in forest ecosystems of silver fir are only some of the changes recorded by a number of forest researchers *(25)*. Intensive sanitary cutting operations result in changes in the age structure and the composition mix of particular tree species *(17)*.

Dieback and decline of Spanish fir in the Pyrenees is attributed to changes in the physiological status caused by insufficient precipitation *(9)*. Such changes are also reflected on decreased increment. Large-scale tree dieback combined with decreased increment and increased number of dry years and other stress factors leads to the reduced growing stock of a particular species in relation to the normal model, which in turn jeopardizes the functioning of the forest ecosystem of a species.

Apart from air temperature which depends on cloudiness and solar insuolation, precipitation plays the greatest role in the development of vegetation as it is the main source of humidity in the soil. Lack of precipitation and high air temperatures weaken the resistance of silver fir since increased transpiration uses up large quantities of water.

The highest values of dead tree volumes were recorded at the lowest altitudes and mild slopes. More extensive climate changes and a larger number of dry years were recorded in Gospić Meteorological Station, which is situated at lower altitude, than in Zavižan Meteorological Station situated at higher altitude. According to regression models of Gajić-Čapka *et al.* (*22*), and Zaninović *et al. (21),* lower altitudes manifest lower values of precipitation quantities and higher values of air temperatures. In the period from 1998 to 2006, there were three dry years recorded in Zavižan Meteorological Station and as many as five dry years in Gospić Meteorological Station.

The correlation of growing stock of silver fir (*Abies alba* Mill.) with dead wood mass of trees is positive, weak and statistically significant (R=0.24*), which means that an increase in the growing stock of silver fir in a subcompartment correlates positively with the quantity of dead trees.

However, the correlation of growing stock of silver fir and slope is negative and very weak (R= -0.20*), and that between growing stock and altitude is also negative, but strong (R= -0.54*). This means that with an increase in altitude and inclination, the growing stock of silver fir decreases and so does the quantity of dead trees. Correlations of relief and climatic factors with the volume of dead trees are very weak to weak, but statistically significant. Very similar correlations of relief and climatic factors were obtained by Thomas *(26),* who investigated the interaction of ecological factors and silver fir dieback in the area of Vosges in France. Thomas *et al.* (2002) investigated the correlation between crown defoliation and relief factors and also obtained weak and very weak correlations (R=0.12 for inclination and R=0.36 for altitude). The correlation of defoliation classes and climatic factors was weak (R=0.20 for temperature and R=0.29 for precipitation).

The lowest volume of dead trees was recorded in north-west exposition, while eastern and other expositions manifested the highest volume of dead trees. This was to be expected in view of the fact that southernmore sides are warmer. With an upward trend in mean annual and vegetational air temperatures, they become even more unfavorable for tree species with narrow ecological valence such as the silver fir (*Abies alba* Mill.).

An increase in the mean annual and vegetational air temperature and the occurrence of climatic excesses that characterize the ongoing climate change may cause stressful states in tree species with narrow ecological valence such as the silver fir. This refers primarily to direct ecological factors (warmth and water).

Higher mean annual and vegetational air temperatures and lower annual and vegetational precipitation quantities result in increased quantities of dead wood mass of silver fir trees. In 1988, only 60% of annual precipitation quantity and 26% of the quantity in the vegetation period was recorded in the distribution range of Greek fir (*Abies cephalonica*) in Greece in relation to the reference series of 1961 – 1987. Drought affecting Greece in 1988 caused physiological weakening of Greek fir and mass gradation of secondary pests, leading to tree dieback of catastrophic proportions across Greece in 1989. The volume of dead trees was 2.2 times higher than the annual volume increment *(16)*.

On northern Velebit the volume of dead trees of silver fir in the period under observation equaled the values of wood mass increment of silver fir.

Stanovsky *(17)* studied the impact of climatic factors on the condition of forest ecosystems in the Czech Republic. In the ten-year monitoring period (1991 – 2000), the trend in dead trees coincided with the duration of the dry period. He used a cross-correlation function to obtain a strong, statistically significant correlation between dry period duration and dead tree volume. Catastrophic decline of forest ecosystems in the area of Silesian Lowlands was caused by lack of precipitation in the vegetation period and secondary pest gradation.

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