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Crown Condition of Norway Spruce in Different Eco-climatic Regions of Lithuania: Implications for Future Climate

VIDAS STAKĖNAS, POVILAS ŽEMAITIS* AND REMIGIJUS OZOLINČIUS

Institute of Forestry, Lithuanian Research Centre for Agriculture and Forestry, Liepų str. 1, Girionys, Kaunas District, LT-53101, Lithuania
*Corresponding author: povilaszemaitis@gmail.com, phone: 8 601 99530

Abstract

A decrease in the continentality of the Lithuanian climate is expected in response to climate change. Of all tree species, Norway spruce (*Picea abies* (L.) H. Karst.) is one of the most sensitive to changes in the climate. For this reason, studies on the crown condition of Norway spruce in different eco-climatic regions can help to identify factors that could have substantial effects on the condition of forests in the future.

Data from Lithuanian regional forest monitoring (1989 – 2010) were used in this study. The crown condition of Norway spruce, the occurrence of defoliation and the proportion of healthy trees have been assessed annually for an average of 2,000 trees. Trends in the crown condition of spruce and the factors affecting spruce crown condition in three largest eco-climatic regions of Lithuania are presented in this paper as the Žemaičių Highlands, the Middle Plain and the South-East Highlands.

A significant decrease in the crown condition of Norway spruce, caused primarily by *Ips typographus* damage (1993 – 1997), was recorded in all eco-climatic regions. After the elimination of the 1993 – 1997 data (*I. typographus* damage), the crown condition of Norway spruce shown a decreasing trend over the period of analysis. Crown defoliation increased (r= 0.66, p= 0.004), and the proportion of healthy trees decreased (r= -0.49, p= 0.02) in the coarse of time. The biggest Norway spruce crown condition decrease was observed in the Žemaičių Highland region – the most maritime climate region (Δ D = 4; Δ H = -14.5).

The deterioration of spruce crown condition associated with the decrease of climate continentality may indicate that climate change is a possible factor influencing the degradation of the spruce crowns. Another potential driver for the decrease in spruce crown condition is the precipitation during the second half of the vegetation period.

Key words: Norway spruce, defoliation, eco-climatic region, ICP-Forest

Introduction

In Lithuania, the continentality of the climate increases from west to east. The annual and daily temperature amplitude become broader, the winters become colder, the duration of snow cover becomes longer and the weather becomes drier. However, climate change has decreased the continentality of the Lithuanian climate, causing decreases in the amplitude of the annual temperature and seasonal differences in precipitation. Observations indicate that this trend will continue in the 21st century (Graham et al. 2008, Rimkus et al. 2006).

Recent studies have shown that Norway spruce (*Picea abies* (L.) H. Karst.) is one of the most sensitive species to climate change, in comparison with other tree species in Northern (Kairiūkštis 2000, Schlyter et al. 2006, Jyske et al. 2010) and Central Europe (Bolli et al. 2007, Albert and Schmidt 2010, Yousefpour et al. 2010). The basis for this sensitivity is that Norway spruce is particularly sensitive to increases in temperature and/or decreases in soil water availability. Spruce has distinct western and southwestern limits that correlate well with winter temperature isotherms. According to Dahl (1990), the southwestern distribution limit of Norway spruce correlates with the -2ºC isotherm for the coldest month. The underlying physiological mechanism is still obscure, but spruce does not grow well in areas with mild winters. In plantations, it grows quite well beyond the natural limits of its distribution. Apparently, however, it does not reproduce well by natural means (Dahl, 1990). Therefore, due to its low productivity, it cannot compete with species that are growing at their ecological optimum. Therefore, the area

occupied by spruce stands shrinks from the northern taiga to the south. Dahl (1990) also notes that under the conditions of a climatic scenario with a doubling of the CO_2 level, the limit of the natural distribution of spruce moves approximately 100-500 km in a north-easterly direction. It is probable that shrinkage of spruce habitat will result from the deterioration of the condition of the spruce due to the presence of unfavourable factors and due to the inability of the spruce to compete with other species in a similar ecological niche.

Climatic conditions, especially temperature and precipitation during the growing season, influence tree condition (Webster et al. 1996, Ozolinčius et al. 1999, Modrzynski 2003, Desprez-Loustau et al. 2006). Soil humidity and precipitation are the most important factors in foliage formation during the first half of the vegetation period (Strand 1997). Artificial drought experiments have shown that drought produces a substantial increase of defoliation in Scots pine trees (Ozolinčius et al. 2009). Solberg (2004) also notes that dry and warm summer weather is a significant stress factor affecting Norway spruce condition, producing defoliation, yellowing and mortality. Higher precipitation usually serves to produce better tree condition, i.e., a decrease in defoliation (Solberg 2004, Breda et al. 2006, Seletkovic et al. 2009, Grodzki 2010). However, an increase in the amount of precipitation may cause an increase in defoliation (De Vries et al. 2003). Previous studies have shown that water deficiency not only reduces water availability but also induces fine root mortality. As a result, the time for spruce to recover from a drought is longer (Gaul et al. 2008).

The aim of this study is to highlight the differences between the condition of Norway spruce (*Picea abies* (L.) H. Karst.) in different eco-climatic regions and to identify the meteorological factors affecting spruce crown condition. The detection of significant factors would enable the prediction of spruce condition in a changing climate.

Materials and methods

K. Kaušyla (*Lietuvos TSR atlasas* 1981) defined four climatic regions in Lithuania: the Coast, the Žemaičių Highlands, the Middle Plain and the South-East Highlands (Fig. 1). The climate continentality index (CI) is different for each region: the Coast (CI – 22-24), the Žemaičių Highlands (CI – 25-27), the Middle Plain (CI – 28-30) and the South-East highlands (CI – 31-32) (Gabrilavičius and Danusevičius 2003). The Coast and the Žemaičių Highland regions were merged into a single region, the Žemaičių Highland region. Gabrilavičius and Danusevičius calculated the index of continentality with the following equation (Хромов 1974):

$$K=A - \sin\varphi/A$$

where K – index of continentality, A – average amplitude of temperature (the temperature difference between the coldest winter month and the warmest summer month), and φ – geographical latitude.

The data analysed in this study were collected under Forest Monitoring Level I as part of ICP-Forests. The tree crown condition was evaluated annually (1989 – 2010) on the permanent observation plots on the national (4×4 km) and transnational grid (16×16 km). The forest monitoring data were analysed for different Lithuanian climatic regions. The total number of spruce trees assessed annually during this period was approximately 2,000 (a total of 44,000 assessments).
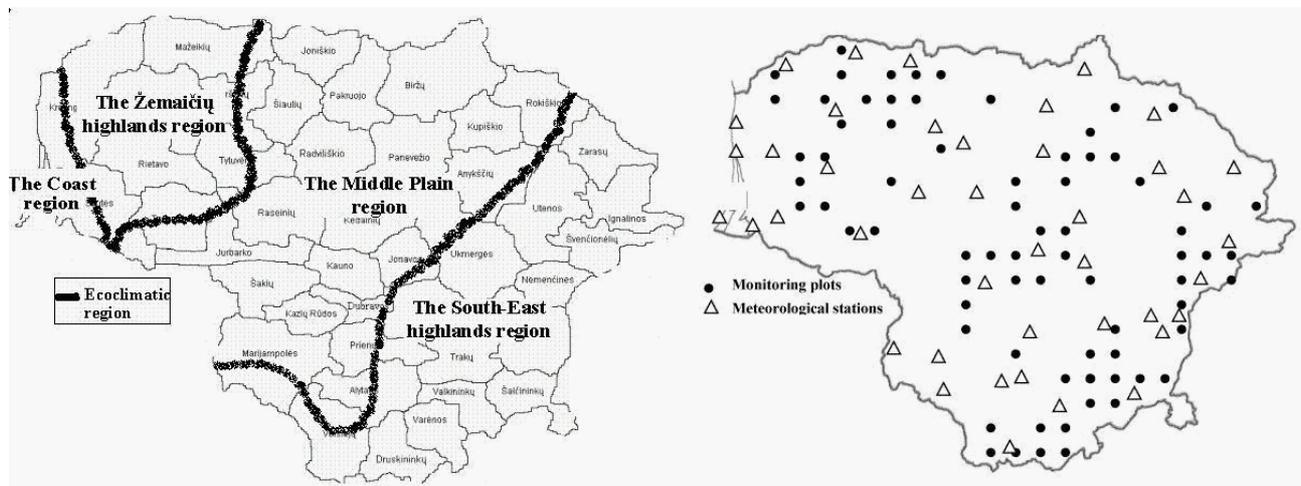
Figure 1. Eco-climatic regions in Lithuania (left map), transnational forest monitoring grid (16×16 km) and network of meteorological stations in Lithuania (right map)

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In this network, a plot consists of four subplots (Fig. 2) at a distance of 25 m to the north, west, south and east from the centre of the plot. The subplot consists of six predominant, dominant and co-dominant trees closest to the centre of the subplots. Defoliation is estimated in percentage classes. The trees with a loss of foliage up to 10% are assigned to the 0 defoliation class and are considered healthy (Eichhorn et al. 2010).
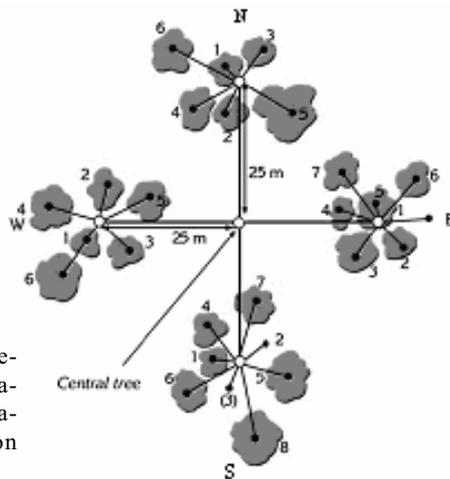
Figure 2. A schematic representation of the permanent observation plot

Meteorological data (average temperature, amount of precipitation) were obtained from a network of 35 meteorological stations situated throughout Lithuania (Lithuanian Hydrometeorological Service 2001) (Fig. 1).

Data analysis

To derive changes in Norway spruce defoliation from 1989 to 2010, a linear regression analysis (with an F-test – analysis of the variance of a regression) was performed with years as the explanatory variable and crown defoliation as the dependent variable. An analysis of variance (ANOVA with Student t-test ($\alpha = 0.05$)) was also performed to justify the separability of crown defoliation in different eco-climatic regions. The results of these analyses are shown in Figure 3.

The crown condition (defoliation and proportion of healthy trees) trend (R^2, r values) in the course of time was calculated after elimination of the years (1993 – 1997) in which *I typographus* had a very significant effect on spruce condition (Table 1). ΔD (defoliation) and ΔH (the proportion of healthy trees) were calculated from linear regression lines. To examine the direct effect of climatic factors on spruce condition, the years (1993 – 1997) with large attacks of bark beetles were eliminated. A linear regression line has an equation of the form $Y = a + bX$, where X is the explanatory variable and Y is the dependent variable. The slope of the line is b, and a is the intercept (the value of y

if $x = 0$). From this equation, we calculated the mean defoliation and the proportion of healthy trees at the beginning (1989) and the end (2010) of the period of analysis. ΔD and ΔH were calculated from the equation $\Delta = Y1 - Y2$, where $Y1$ and $Y2$ are the values of analyzing indicator linear regression trend (mean of defoliation (for ΔD) or the number of healthy trees (for ΔH)) in 1989 and 2010, respectively.

A backwards elimination multiple regression model was used to define the relationship between the meteorological factors and the spruce condition indicators (defoliation and proportion of healthy trees) in different eco-climatic regions. We used the following multiple regression model: $Y = \alpha + \beta_1 X_1 + ... + \beta_p X_p$, where Y – response; X – explanatory variable; α is the intercept; β_p are slopes (or coefficients).

The regression models include the mean annual air temperature and precipitation, the annual temperature and precipitation of individual months (e.g., January, February) and the average temperature and precipitation during the current and during the previous hydrological year. For example, the current hydrological year (X-IX months) consists of the indices for October, November, December (X-XII) of the previous year and January, February, March, April, May, June, July, August and September (I-IX) of the current year.

To determine whether the spruce crown condition indicators were correlated similarly with the meteorological factors in different eco-climatic regions, a cluster analysis (Linkage rule – Single Linkage, distance measure – Euclidean distance) was used. The calculations were performed on the linear correlation (Spearman) coefficient series obtained by analysing the relationship between climatic factors (the average temperature and precipitation for different months (periods)) and the indicators of spruce crown conditions (defoliation and proportion of number of healthy trees) in different climatic regions of Lithuania. A total of 3 series (1 series in each eco-climatic region) with 136 variables each was used in the analysis.

Results

Changes in defoliation and proportion of healthy trees

The variation in the crown defoliation of Norway spruce among different Lithuanian eco-climatic regions is shown in Fig. 3.

During the entire study period (1989 – 2010), the average difference in defoliation between the Žemaičių and South-East Highland climatic regions was 2% (t-test, $p < 0.05$).

The outbreaks of *I. typographus* in Norway spruce stands caused a remarkable deterioration of crown

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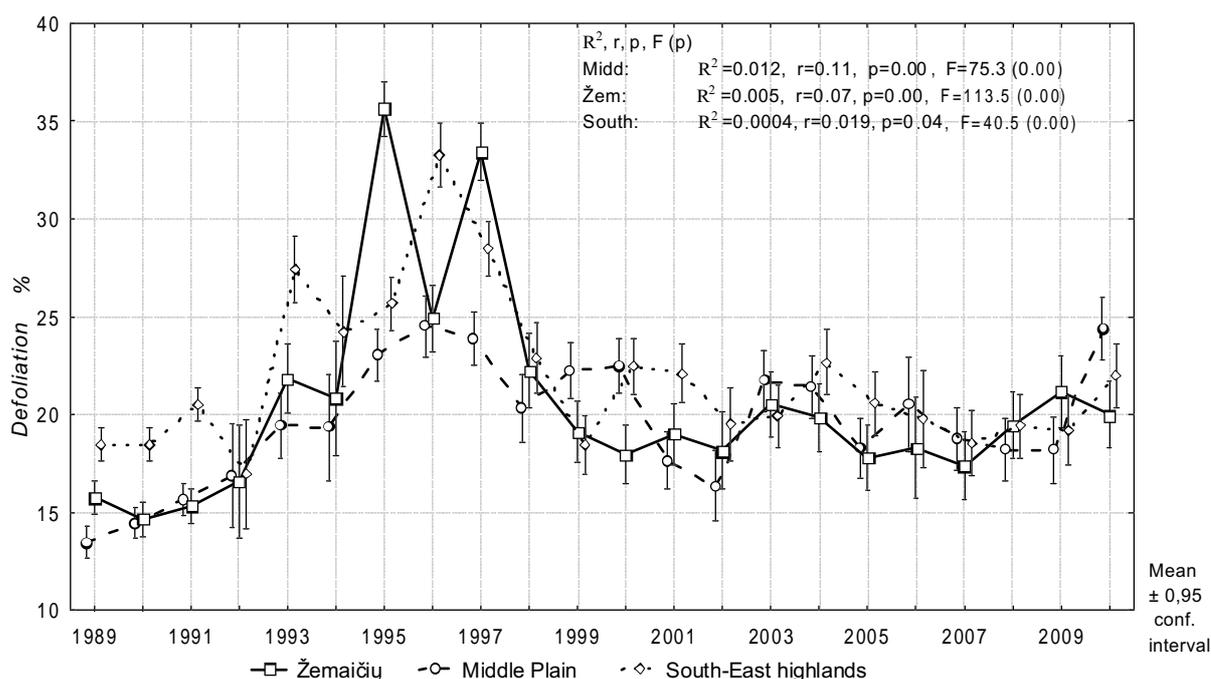
Figure 3. Mean defoliation of Norway spruce trees in different eco-climatic regions of Lithuania (1989-2010)

condition in 1993 – 1997. Compared with the beginning of the study period, defoliation nearly doubled, and the number of dead trees (tree mortality) increased approximately 250 times (13.1% of all analysed spruce trees were recorded as dead, whereas the corresponding percentage in 1989 was only 0.052%). Similar results were obtained in all climatic regions. The most recent data indicate less reliable changes in defoliation. During 1998 – 2010, the mean defoliation varied between 19 and 23%.

Over the entire period (1989 – 2010), no statistically significant trend in defoliation was found. However, after the elimination of the years 1993 – 1997, when *I. typographus* had a very significant effect on spruce condition, increasing defoliation over time was observed in all eco-climatic regions (r= 0.66, p= 0.004) (Table 1).

Significant differences in mean crown defoliation and in the mean number of healthy spruce trees in different eco-climatic regions were not found (Table

1), but the condition of the spruce tended to decrease in all regions (the r value varied between 0.22 and 0.66). The greatest changes were observed in the Žemaičių Highland eco-climatic region (ΔD= 4.0; ΔH= -14.5%). The smallest changes in tree condition were observed in the South-East highlands eco-climatic region (Δ D = 1.5; Δ H = -5.1%). However, during the study period (1989 – 2010), the trees in this area showed the poorest condition – the greatest defoliation and the smallest number of healthy trees (the differences in defoliation and number of healthy trees between this region and Žemaičių region were equal 2% and 7% respectively).

Meteorological factors and crown condition

We used backwards elimination multiple regression models to define the relationship between meteorological factors and spruce condition indicators in different eco-climatic regions (Table 2). The regression models included the average temperature and amount

Table 1. Norway spruce crown defoliation and number of healthy trees, mean changes in different eco-climatic regions (after elimination of data for 1993–1997, when I. typographus had a very significant effect on spruce condition)

Eco-climatic regions	Defoliation			Number of healthy trees (%)		
	r	Δ D	Mean ± SE	r	Δ H	Mean (%) ± SE
The Žemaičių highlands	**0.63***	4.0	18.6 ± 0.5	**- 0.65***	- 14.5	26.6 ± 2.1
The Middle Plain	**0.65***	5.1	20.3 ± 0.6	**- 0.52***	- 10.3	23.2 ± 2.2
The South-East highlands	0.27	1.5	20.2 ± 0.4	- 0.22	- 5.1	21.8 ± 1.8
All regions	**0.66***	3.8	19.8 ± 0.4	**- 0.56***	- 13.3	23.9 ± 1.9

* Significant at the 0.95 probability level; Δ D Defoliation shift (1989-2010); Δ H Shift in number of healthy trees (1989-2010)

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of precipitation during the current and during the previous hydrological year. Several variables were included in the regression equations, but certain variables were predominant: the precipitation during the current year and during the previous year over the second half of the vegetation period (months VI – VIII) and the average temperature during the current and during the previous hydrological year. The results of this analysis show that the precipitation during the second half of the vegetation period and the average temperature during the current and during the previous hydrological year were negatively correlated with spruce defoliation. The defoliation decreased with increases in the precipitation over the second half of the vegetation period and the average temperature during the current and during the previous hydrological year. The second crown condition indicator, the proportion of healthy trees, was correlated with the average temperature during the current and during the previous hydrological year. The precipitation during the second half of the vegetation period had no significant effect on the proportion of healthy trees. It is possible that

these indicators respond differently to environmental changes.

Differences among different Lithuanian climatic regions in the impact of meteorological factors on the crown condition of Norway spruce are difficult to demonstrate. A cluster analysis was used to clarify these differences (Fig. 4). Calculations were performed on several series of linear correlation coefficients (3 series by 136 variables) obtained by analysing the relationship between climatic factors (temperature and precipitation averages for different months (periods)) and spruce crown condition indicators (defoliation and the number of healthy trees) in different climatic regions of Lithuania.

The results of the cluster analysis indicate that precipitation and temperature fluctuation have a relatively similar effect on the number of healthy trees and defoliation in the Middle Plain and the Žemaičių Highlands but a relatively different effect in Southeast Lithuania (Euclidean distance = 2.5 between the Žemaičių Highlands and the Middle Plain, 3.3 between these regions and the South-East Highland region).

Table 2. Coefficients of the stepwise multiple regressions of defoliation and of the number of healthy trees as a function of meteorological factors

Type of regression	Linear regression model [a]	R^2 adj.
D (all climatic regions)	D = 26.8 − 0.65*TIV + 0.02*PVI -0.04*PVIII − 0.02*PVI-VIIIpr	0.39
H (all climatic regions)	H = 22.19 + 1.5*TX-IX + 1.77*TX-IXpr − 0.11*PIV − 1.18*TVIIpr	0.26
D (the South-East climatic region)	D = 45.8 − 0.02*PVI-VIII − 2.69*TX-IX	0.47
D (the Middle Plain climatic region)	D = 21.5 − 0.4*TI − 0.2*TXIIpr − 0.01*PVII-VIII	0.40
D (the Žemaičių highlands climatic region)	D = 17 − 0.57*TX-IXpr + 0.1*PV-VI − 0.03*PVII-VIII + 0.07*PVpr	0.63
H (the South-East climatic region)	H = 7.8 + 2.4*TX-IX+ 0.95*TIII − 0.17*PIV	0.42
H (the Middle Plain climatic region)	H = 44.4 − 1.17*TVIIpr + 0.11*PIXpr -0.09*PXpr	0.50
H (the Žemaičių highlands climatic region)	H = 18.3 + 0.98*TIIIpr +0.12*PIIIpr	0.35

[a] D, average defoliation (%); H, number of healthy trees (%); T – temperature (°C) (by month or period); P, amount of precipitation (mm) (by month or period); pr – previous hydrological year.
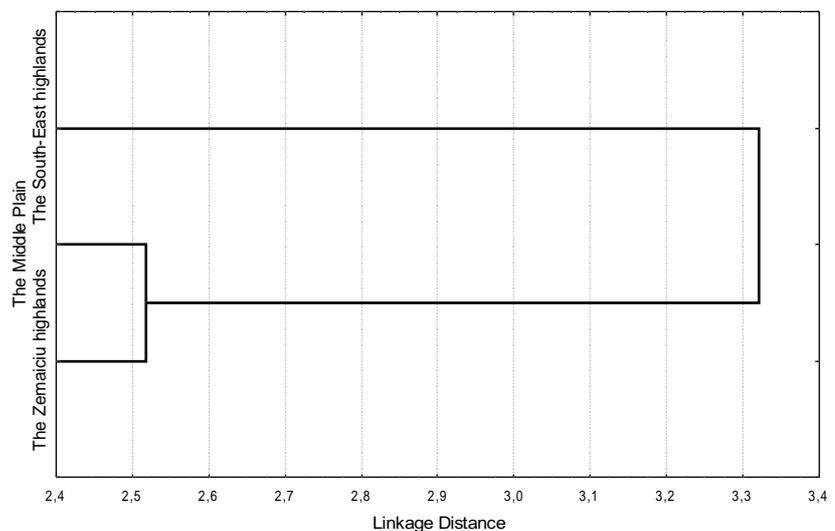
Figure 4. Defoliation and the number of healthy trees in response to climatic variability factors, compared across different climatic regions

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Discussion

The results of this study showed that the greatest negative changes in tree condition were associated with damage caused by bark beetles (*I. typographus*). This damage occurred from 1993 to 1997. The damage can be considered a tertiary effect of climatic factors because dry summers and abundant windthrow create favourable conditions for the growth of *I. typographus* populations. However, the principal purpose of the study was to examine secondary effects of climatic factors on spruce condition (the relationship between climatic factors and tree condition indicators). In our investigation, these factors were considered secondary, although factors such as frost or hail damage represent primary meteorological effects. For this reason, we eliminated the years of the bark beetle outbreak to focus on the effects of climatic factors on defoliation. We did not consider differences associated with the results within each year, such as differences in tree age, stand density and species composition, because the stands were randomly selected and a large sample size was used. This approach was based on the assumption that the samples for a given year had similar characteristics.

After the elimination of variables, the multiple regression analysis yielded reliable trends in defoliation and in the proportion of healthy trees. The results show that the deterioration of tree condition was expressed less strongly in the regions with a less strongly marked continental climate. The climate of the Žemaičių eco-climatic region is less strongly continental than the climate of the Middle Plain and South-East regions. The deterioration of Norway spruce in the regions with higher continentality may indicate that this decrease is one of the possible factors involved in the degradation of spruce condition even if it does not correspond to major differences in condition. According to previous research (Gabrilavičius and Danusevičius 2003), trees from different eco-climatic regions are adapted to specific climatic conditions. Previous observations indicate that the continentality of the Lithuanian climate is decreasing as a result of climate change (Rimkus et al. 2006). The decreasing continentality of the climate and the increase in the average annual temperature (especially in winter) can produce conditions that exceed the limits of physiological stress for spruce. Several researchers have suggested that spruce is adapted to a cold climate (Kairiūkštis 2000, Dahl 1990, Sykes et al. 1996).

Nevertheless, it is difficult to identify the causes of tree deterioration because deterioration is influenced by complex factors, including weather conditions, air quality and biotic damage. Previous research (Karazija et al. 1996) has shown that droughts in 1992 and 1994 produced a marked decrease in the groundwater level and caused losses of moisture from the shallow soil layers. As a result of these drought-induced changes, it was difficult for trees to absorb moisture reserves from the soil. For this reason, spruce declined in Lithuania and was affected by *I. typographus*. This decline also reflected the occurrence of numerous windthrow events in 1993. Even in this case, abiotic factors were ultimately the cause of the insect damage. We estimate that in 1996, compared with the beginning of the study period, defoliation was twice as high and the number of dead trees was approximately 250 times higher (13.1% of all spruce trees). The recovery of the tree condition began in 1997. Previous studies showed that the greatest decrease in crown condition and the highest tree mortality generally occur a few years after storm-caused disturbance (Schroeder 2003), although decreases in host tree resistance due to summer drought can result in prolonged mortality periods (Økland and Bjørnstad 2003, Rouault et al. 2006, Faccoli 2009). Other researchers have also identified meteorological factors as contributing (Ogle et al. 2000) or predisposing (Villalba and Veblen 1998) to tree mortality. For these reasons, meteorological factors do not completely explain the variability of the condition of Norway spruce. The regression analysis performed in this study showed that climatic factors explain only about one-half of the variability in crown condition. A few results of the regression analysis can be noted. Summer droughts act as a driver for the crown condition of spruce. Most of the regression equations obtained in this study included the amount of precipitation during the second half of the vegetation period. The reliability of the regression equation depends slightly on the climatic region. The regression equations included not small number of variables. The variables appearing in these equations were not always the same. This result indicates that the selection of variables can be random because the relationship between the factor and the response is weak.

For all these reasons, it is difficult to determine whether the crown condition of Norway spruce is similarly correlated with the fluctuations in meteorological factors in all Lithuanian eco-climatic regions. Our results suggest that in the Middle Plain and the Žemaičių eco-climatic regions, the number of healthy trees and defoliation show relatively similar responses to fluctuations in precipitation and temperature. However, the responses in these regions are different from the responses in South-East Lithuania. This result could indicate that the factors that have negative or positive effects on spruce condition are not the

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same in different regions of Lithuania. Because trees from different climatic regions are adapted to the specific climatic conditions of those regions, climatic changes do not have similar effects on tree condition in different regions. However, the reliability of the results could be influenced by the proportions of different habitats in different regions, and information on habitats was not considered in this study.

The detection of relationships between meteorological factors and the crown condition of Norway spruce is complicated, and these factors potentially interact with each other (temperature with precipitation, for example). Within the context of different effects of pollutants on forest ecosystems, their synergistic effects and their interactive effects with environmental stressors, it is very difficult to discuss the correlation of meteorological factors with tree condition (Müller-Edzards et al. 1997, Ozolinčius and Stakėnas 2001).

Conclusions

A significant decrease in Norway spruce crown condition, resulting primarily from *I. typographus* damage (1993 – 1997) was recorded in all eco-climatic regions. After the elimination of 1993 – 1997 data (*I. typographus* damage), the crown condition of Norway spruce tended to decrease over the period of analysis. Crown defoliation increased over time ($r = 0.66$, $p = 0.004$), and the proportion of healthy trees decreased ($r = -0.49$, $p = 0.02$). The greatest decrease in Norway spruce crown condition was observed in the Žemaičių Highlands region, the region with the most maritime climate ($\Delta D = 4$; $\Delta H = -14.5$).

The condition of Norway spruce was very similar in the three Lithuanian eco-climatic regions examined. However, the deterioration of crown condition associated with the spatial gradient of the decrease in the continentality of the climate may indicate that this aspect of climate change is one of the possible degradation factors for spruce. Summer drought also influences the crown condition of spruce.

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BALTIC FORESTRY

CROWN CONDITION OF NORWAY SPRUCE IN DIFFERENT /…/ REGIONS /…/   V. STAKĖNAS ET AL.

СОСТОЯНИЕ КРОН ЕЛИ ЕВРОПЕЙСКОЙ (*PICEA ABIES* (L.) H. KARST.) В РАЗНЫХ ЭКОКЛИМАТИЧЕСКИХ РЕГИОНАХ ЛИТВЫ: ВЛИЯНИЕ МЕТЕОРОЛОГИЧЕСКИХ ФАКТОРОВ

В. Стакенас, П. Жямайтис и Р. Озолинчюс

Резюме

Климатологические исследования показывают, что континентальность климата в Литве уменьшается. Ель европейская является одной из самых чувствительных к изменению климата древесных пород. Поэтому исследования состояния крон ели европейской в разных экоклиматических регионах Литвы с различной континентальностью климата может способствовать выявлению факторов, оказывающих в будущем существенное влияние на состояние лесов.

Анализировались данные регионального мониторинга лесов за период 1989-2010 г. В качестве показателей состояния крон использовались дефоляция крон и количество здоровых деревьев (в % от всех оцененных). В каждом году оценивалось состояние в среднем около 2000 елей. Изменение состояния деревьев и метеорологических параметров изучалось в 3 экоклиматических регионах Литвы - Жемайтской возвышенности, Среднелитовской низменности и Юго–восточных возвышенностей.

Существенное ухудшение состояния крон ели, в основном вызванное повреждениями *I. typographus,* установлены во всех экоклиматических регионов. Элиминирование данных за период вспышки *I. typographus* (1993-1997 г.) показали тенденцию ухудшения состояния крон елей. При этом в течение исследуемого периода дефоляция крон увеличилось ($r = 0.66$, $p = 0.004$), а количество здоровых деревьев уменьшилось ($r = -0.49$, $p = 0.02$). Наибольшее ухудшение состояния крон ели наблюдалось в районе Жемайтской возвышенности, т. е. в менее континентальнном климатическом регионе ($\Delta D = 4$; $\Delta H = -14.5$).

Предполагается, что ухудшение состояния крон елей при взаимодействии с уменьшением континентальности климата может быть возможным фактором деградации ельников. Как факторы влияния на состояние крон рассматриваются также летние засухи и количество осадков за вторую половину вегетационного периода.

Ключевые слова: Ель европейская, дефоляция, экоклиматические регионы, ICP-Forest