

REVIEW PAPER

Possible Effects of Climate Change on Forest Biodiversity, Tree Growth and Condition: Review of Research in Lithuania

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Abstract

With the rise in average temperature of 0.7-0.9°C during the last century, particularly significant in the last decades (over the last 15-30 years), winter in Lithuania has become milder, with shorter periods of snow cover and increased amounts of precipitation. Summer now has severe droughts, especially in July-August. The duration of thermal spring and autumn has increased. As a result of these changes, the climate in Lithuania is becoming less continental.

The possible effects of climate change on forest ecosystems are discussed. The research data in Lithuania (1990-2011) from scientific reports, scientific articles, diploma theses, etc. have been used.

The effects of climate change on different components and indices of forest ecosystems, such as soil chemistry and microbiology, ground vegetation, forest insects, birds, herbivorous animals, and tree diseases as well as tree phenology, growth and crown condition, have been analysed. In many cases, the effects of climate change depend on stand and site characteristics.

Key words: climate change, forest ecosystem, biodiversity, tree growth, phenology, crown condition

It is considered true that climate change can cause both negative and positive effects on forests. The negative effects are expected to be as follows: decline of forest resources (spread of diseases and disappearance of native species, including trees); forest condition decline (loss of needles or leaves); deforestation; and soil degradation (lack of organic matter, drop in water level, etc.). The positive effects could be as follows (in case of heavy rains): the recovery of trees and fewer forest fires, etc. (Tschakert 2007, Eastaugh 2008). These effects can be masked or enhanced by regional variability (Eastaugh 2008). Consequently, forest research on the possible effects of climate change on forest biodiversity, tree growth and condition in Lithuania could result in a better understanding of the global effects of climate change. In addition, forest biodiversity and tree growth and condition define forest ecosystem sustainability in general. In “The dictionary of forestry” (1998), forest ecosystem sustainability has been described as “the capacity of forests, ranging from stands to ecoregions,

to maintain their health, productivity, diversity, and overall integrity, in the long run, in the context of human activity and use”.

Nowadays forests are influenced by some global environmental changes. For example, it is considered that the main reason for an increase in the tree growth is climate warming, increasing amount of nitrogen in soils, decrease in air pollution, especially decrease in the concentrations of SO₂ (Ozolinčius 1998, Nojd and Hari 2001, Juknys et al 2002, Todaro et al. 2007, Augustaitis et al. 2010). It means that actual impact of climate change on forest ecosystems can be hidden by an influence of above mentioned factors. This is a reason that only selected data which indicate direct changes under the influence of drought, temperature or precipitation or changes in various indices of forest ecosystems which correlate with indices of climate change (temperature, precipitation, etc.) have been analysed.

Data from scientific reports, published articles, diploma theses, etc. have been used.

Climate change in Lithuania: meteorological data

Global mean temperatures have increased 0.6°C since the late nineteenth century and by 0.2-0.3°C over the past 40 years, with the most recent warming being greatest over the continents between 40° and 70° N. According to the Intergovernmental Panel on Climate Change (2007), a rise in average global temperatures of 2.0–4.5°C is likely during the next century. Climate models predict that heat waves (and, consequently, droughts) will become more common and more intense, most notably in the western USA, East Asia and central Europe (earthobservatory.nasa.gov/Drought).

The analysis of meteorological data in Lithuania corresponds to findings at the global level. It was observed that beginning with the fourth decade of the 20th century, the number of deep cyclones hitting Lithuania during cold seasons (November-March) increased, whereas the number of anticyclonic formations decreased. Moreover, the analysis of air flux direction and velocity in the middle troposphere revealed that air transport from the west and north above Lithuania has also become stronger since the middle of the 20th century (Rimkus and Bukantis 2008).

During the last century and particularly significantly in the last decades (over the last 15-30 years), a rise in the average temperature of 0.7-0.9°C was observed. Winter becomes milder (an increase in the highest rate of temperature was recorded in winter), with a shorter period of snow cover and an increased amount of precipitation. Summer developed severe droughts, especially in July-August (during the last 120 year period the decrease in the average amount of precipitation in August was 0.23 mm per year and summer droughts in July-August became more frequent); spring became longer; and autumn also became longer and warmer. The duration of thermal spring and autumn has lengthened; as a result, the climate in Lithuania is becoming less continental (Bukantis and Rimkus 2005, Galvonaitė and Valiukas 2005, *Mineralinių dirvožemių...* 2005, Galvonaitė et al. 2007, Rimkus and Bukantis 2008).

According to the latest climatic models ECHAM5 and HadCM3 using A1B, A2 and B1 greenhouse gas emission scenarios, climate change predictions for the Lithuanian territory show that air temperatures will rise in the 21st century. The strongest effect will occur during the winter season (4 8°C), with less of an effect occurring during the summer (1.5-3.5°C). Regional differences in temperature change would not be very high; only in the winter season could they change more than 2°C (Rimkus and Bukantis 2008).

The amount of precipitation will increase in winter and spring and decrease in summer and autumn. The phase of precipitation will more often be liquid because of rising air temperatures in winter. According to recent prognoses, the amount of precipitation will increase in winter (December, January and February): precipitation is expected to increase 17.3 mm during the coming five decades (*Mineralinių dirvožemių...* 2005). In July, August and at the beginning of autumn, the probability of droughts will increase drastically (Rimkus and Bukantis 2008). According to pessimistic climate scenarios, some areas in Lithuania will suffer from soil water deficiency as early as the middle of the 21st century in summer. On the other hand, projected temperature conditions indicate approximately a one-month increase in the length of the vegetation period.

Sunshine duration will increase during the 21st century. The increase will be most evident from May to September. Meanwhile, a decrease in the number of sunshine hours in the winter season (particularly in February) is expected.

Meteorologists forecast that forestry will mainly suffer from the increasing temperatures in winter and summer and from the increased frequency and magnitude of forest fires and winter storms (Rimkus and Bukantis 2008).

Climate change and forest fauna and flora

Soil and soil organisms. There is no specific research on climate change effects on forest soils in Lithuania. Nevertheless, some data from long-term investigations of forest soils could aid in the prognosis of soil property changes, especially those due to droughts and mild winters.

During drought periods, increased acidity, decreased concentrations of P₂O₅ and increased N and K₂O were observed in forest litter and in the upper horizons of soils (Vaičys et al. 1997, Armolaitis 2003). For example, in September 1999, when the amount of precipitation was only 28 mm, the acidity of mineral soil increased by 0.2-0.4 pH_{H₂O} units at depths of 10-65 cm.

Interesting data were obtained from a drought simulation experiment, which was conducted in a 60-year-old Scots pine (*Pinus sylvestris* L.) stand (*Pinetum vaccinio-myrtillosum* forest type on Arenosols). Drought was simulated by using a transparent roof construction installed below the stand canopy that remained permanent for the entire period of the experiment (Ozolinčius et al. 2008). A statistically significant increase in organic soil layer pH (by 0.29 pH_{CaCl₂} units) was found, but no significant soil pH changes were recorded in the mineral topsoil up to a 10-cm

depth. Furthermore, drought significantly increased the concentrations of mineral N compounds in the OL layer by 2.3 and 3.0 times for $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$, respectively. Nevertheless, a significant increase in mineral N, particularly in $\text{NH}_4\text{-N}$, was estimated only in the mineral topsoil (0–2 cm in depth). Non-significant reductions of organic C, mobile P_2O_5 , K_2O and exchangeable Mg^{2+} , were measured in the OL layer and mineral topsoil. Only the concentration of exchangeable Ca^{2+} significantly decreased, from 2 g kg^{-1} (in the control) to 1.3 g kg^{-1} in the Ap horizon (0–2 cm).

The artificial drought significantly increased the abundance of nitrifying and ammonifying microorganisms in the forest litter (Ozolinčius et al. 2008). Nevertheless, the increase in nitrogen accumulative microflora in the mineral topsoil was not significant, even though in the Ap layer (2–10 cm in depth), the microflora abundance significantly decreased by approximately a factor of 2 in comparison with control plots. Drought significantly reduced the abundance of denitrifying soil microorganisms. However, the denitrification observed in the control plots was higher.

The influence of extremely warm winters on the decomposition of organic matter in *Arenosols* was investigated in 2008 (the average temperature of 2008 was the highest since 1961; the lowest temperature in January was -0.5°C). It was found, that during this warm winter, the intensity of decomposition of organic matter in soils was as high as during the vegetation period (Armolaitis 2009).

Because of the high intensity of organic matter decomposition and increased leaching rates in winter, nutrition deficiency, especially N, could occur during spring. Nevertheless, climate change, and with it a related increase in the amount of forest litter (because of better foliage growth), could positively affect soil fertility (Armolaitis 2009).

Long-term research (1993–2006) in the soils of conifer forests indicates that the density of microarthropods (the majority of microarthropods are the oribatid mites, which constitute 70.2 to 81.1 %) varies yearly. Average values of microarthropods vary depending on seasonal humidity: in the dry season, changes in the microarthropod complex structure are observed – there is a decrease of *Collembola* and an increase of oribatid mites (Eitminavičiūtė and Matusėvičiūtė 2008). A decrease in the average density of microarthropods, compared with the previous 9 years (1993–2001), was recorded in the Ažvinčiai old-growth forest (Eitminavičiūtė and Matusėvičiūtė 2008).

Ground vegetation. The study of changes in the phenology and seasonal variation of projection cover of herbaceous vegetation in the 140-year-old broad-leaved forest (Kamša reserve) showed that vegetative

development depends on spring temperature: in warm springs, herb flowering starts two weeks earlier; in cold springs, two weeks later. In some cases (2006), the projection cover of herbs showed two peaks – one in spring time and the other in August (because of summer drought). In some cases (1991), the projection cover of herbs remained stable until October (Marozas and Abraitienė 2008).

Under artificial drought conditions, the cover of both mosses and vascular plants in Scots pine stands significantly decreased. In a 2-year-period, the drought significantly decreased the cover of mosses to 1%. Similar changes were observed in the cover of vascular plants. Nevertheless, the Shannon diversity index only decreased to 1.8 (it was approximately 2.5 in the control plots) (Ozolinčius et al. 2009). The diversity of epiphytic lichen species in the experimental and control plots showed some difference; however, this difference was not significant (Buožytė et al. 2008).

Studies of pine stands (*Vacciniosa* and *Vaccinio-myrttilosa* forest types) from 1970–1978 (forest phytocoenological observations) and 1994–1997 (Forest Health Monitoring plots) showed that over 20 years the total average number of species per plot did not change. However, the mean Ellenberg value (E_N index) increased significantly in the 50–80-year-old *Vacciniosa* pine stands: from 1.6 (in 1970–1978) up to 2.8 (in 1994–1997) (Ozolinčius et al., 2005). This change could be explained by the significant increase in the cover of *Rubus idaeus* L., which had a high Ellenberg's nitrogen-demand value ($n_1=6$). In addition, after the 20-year period, six new species with high Ellenberg's nitrogen-demand values ($n_1 \geq 5$) were recorded: *Brachypodium sylvaticum* (Huds.) Beauv., *Carex hirta* L., *Calamagrostis arundinacea* L., *Chamaenerion angustifolium* L., *Cirsium arvense* (L.) Scop.S.Str. and *Moehringia trinervia* (L.) Clairv. At the same time, tree canopy indices in the Scots pine stands (*Vacciniosa* and *Vaccinio-myrttilosa* forest types) essentially did not change over the 20-year period: the mean stocking level in investigated *Vacciniosa* stands increased from 0.61 (1970–1978) to 0.68 (1994–1997). This means that the increase in species with high Ellenberg's nitrogen values could not be related to changes in light conditions. More detailed investigations show that the changes in the mean weighted Ellenberg's indexes of light and continentality were negligible, while the index of temperature had an increasing trend in the *Vacciniosa* forest type (Ozolinčius et al. 2011). On the other hand, more intensive litterfall is related to climate warming and positively affects soil nutrient status (see above).

Some alien species (for example, *Lupinus polyphyllus* Lindl.) have widely spread throughout the country,

inhabiting not only forests but also the forest outskirts, roadsides and abandoned fields. Research on genetic diversity using the RAPD method revealed that these species are becoming genetically adapted to local conditions: the genetic distance between forest populations of *L. polyphyllus* was lower than that of the forest and field populations (Vyšniauskienė et al. 2011).

Insects. Climate warming can influence the feeding activity of insect-pests (it is thought that an increased amount of CO₂ in the atmosphere changes the C/N ratio in plants, which stimulates the feeding activity of some insects), the abundance and number of their generations and the spread of invasive species. On the other hand, trees weakened by droughts or mild winters are more susceptible to pests and diseases. In Lithuania, mild winters and droughts were declared as a primary reason for Norway spruce damage by (*Ips typographus*) from 1992-1994 (Karazija et al. 1996, Ozolinčius and Stakėnas 1998). Warm, dry air conditions from April-June have a positive influence on *Panolis flammea* Schiff. abundance (Valenta et al. 2003). Climate change can alter higher trophical interactions, especially those between animals and their predators, parasitoids and pathogens. There are some data indicating that climate influences the activity of ticks (*Ixodes ricinus* L.) (Ambrasienė 2007).

The first outbreaks of *Acantholyda nemoralis* were recorded in Lithuania 35 years ago, while outbreaks of *Dendrolimus pini* were recorded just 15 years ago. *Camreraria obridella* Desch. & Dim., a new pest for Lithuania, was not known 5 years ago. Warm weather in winter and spring may be favourable for the development of forest insect populations, especially for *Panolis flammea* Schiff., *Dendrolimus pini* L. and *Lymantria dispar* L. (Gedminas 2009). Recently, new aphid species (*Aphis oenotherae* and *Brachycaudus divaricatae*) were recorded in Lithuania (Rakauskas 2004).

Herbivorous animals. Climate change affects population growth, location during the non-vegetative period and feeding behaviour of forest wildlife (Belova 2008). The atypical mild weather during the non-vegetative period in recent decades provided favourable conditions for herbivorous animals' population growth. Although a close negative correlation has been ascertained between the consumption of shoots by roe deer (*Capreolus capreolus* L.) and moose (*Alces alces* L.) and mean air temperature during the non-vegetative period, the area of damaged stands increased (Belova 2008).

Climate warming models predict less influence of moose on the main tree species. Herbivorous animals are able to adapt to climate changes through changes in their habitats and in the consumption of woody plants (Belova 2008).

Birds. On the other hand, climate warming induced an earlier arrival of birds, increased populations of southern bird species and decreased populations of northern ones (Žalakevičius and Žalakevičiūtė 2001, Žalakevičius 2005).

The possible changes in rare bird species populations were assessed according to special criteria suggested by H. Q. P. Crick (2004). Twenty-nine rare bird species listed in the Lithuanian Red Data Book were assessed. It was found that climate change could influence 18 forest bird species. Climate change can negatively affect 9 species: *Accipiter gentilis*, *Aquila clanga*, *Milvus migrans*, *Falco columbarius*, *Tetrao tetrix*, *Tetrao urogallus*, *Coracias garrulus*, *Picoides tridactylus* and *Picus viridis* (Brazaitis 2009).

Climate change and stand species composition

Over the long-term, increased temperatures and droughts would lead to a shift in the natural species composition toward more drought tolerant species (Lasch et al. 2002, Mueller et al. 2005, IPCC 2007, etc.). Some native species in Lithuania could be treated as very susceptible to climate change. Many investigators forecast a decrease in the proportion of Norway spruce in stand species composition. Analysing the geographical range of forest species composition across the gradient from north to south, it is evident that the proportion of Norway spruce drops very drastically with increased average air temperature and decreased precipitation – approximately 30-40 % in boreal forests and less than 2% in steppe (*Atmosferos taršai...* 1999).

Using long-term data on temperature and palynologic analysis, curves of tree species distribution in Lithuania during the boreal and Atlantic periods have been drawn. It was found that a temperature increase of 2 °C over the course of approximately 2000 years has doubled the number of oaks, alders and limes, while birches 'reduced by more than half' (Kairiukstis et al. 1990).

From 1989-1991, European Ash (*Fraxinus excelsior* L.) was one of the healthiest tree species. At that time (1990), trees without signs of defoliation (defoliation class 0) comprised 60.7%. A decline in ash condition became clear afterwards (Ozolinčius and Stakėnas 1999). Ash mortality did not depend on the stand geographical position, age or species composition, although some intensification of mortality was noted in 20-40-year-old stands and slight increases in mortality were observed in relation to the increasing quantity of ash trees in the stand composition (Juodvalkis and Vasiliauskas 2002). Although it is recognised that *Armillaria mellea* (Juod-

valkis and Vasiliauskas 2002) plays the main role in the ash decline process, the scientific community has discussed other possible reasons for ash decline. One hypothesis was that ozone is a predisposing factor and another hypothesis was that a new, unknown disease had arisen (Ozolinčius 2002). Now it is agreed that the severely poor condition of ash stands may be related to climate change and the fungal pathogen, *Chalara fraxinea*, which was identified in Poland a few years ago (Kowalski 2006). The investigation on 24 European populations in 3 Lithuanian progeny trials shows that health condition and survival rate of foreign populations of ash trees was worse than these of the Lithuanian ones. Among the Lithuanian populations, in terms of growth characteristics, resistance, survival and proportion of healthy individuals were those originating from Ignalina, Pakruojis, Šakiai and Kėdainiai districts (Pliūra et al. 2011).

In most cases, alien species have a reproductive advantage over indigenous species. A good example is Red Oak (*Quercus rubra* L.). Red oak was introduced into Lithuanian forests in 1875. Now, it spreads rapidly and is very aggressive - the number of grass vegetation species in red oak stands is significantly less (by more than 10 species) in comparison with stands of native English oak (*Quercus robur* L.) (Straigyte 2008). Climate change also provides favourable conditions for the distribution of woody invasive species such as Box elder (*Acer negundo* L.), mostly spread on riversides (Straigyte and Valentinaitė 2011), Black locust (*Robinia pseudoacacia* L.) and Wild Black cherry (*Padus serotina* (Ehrh.) Borkh.).

Tree phenology and growth

Phenology. Climate change affects tree phenology. An advance of spring (according to tree phenology) and lengthened growing season were recorded in the USA and in many European countries (Bradley et al. 1999, Menzel 2000).

In Lithuania, bud swelling of the Common oak (*Quercus robur* L.) and Norway spruce (*Picea abies* (L.) Karst.) during the period of 1997-2005 was recorded 11-13 days earlier in comparison with the 1974-1996 period (Karpavičius and Žeimavičius 2008). The beginning of bud swelling phenophase advanced on average from 1 (oak) to 14 days (ash) in 1956-2008 (Šimatonytė and Žeimavičius 2009). Shift of bud burst dates of lime trees (*Tilia cordata* L.) during the period 1956-2010 consisted of 13.5 days, and shift in timing of leaf unfolding - 9.7 (Juknys et al. 2011). The investigations of Silver birch (*Betula pendula* L.) indicate that advanced budburst compares with the same phenological phase 30-40 years ago (Ozolinčius and Bareika

2008). In recent years, the vegetation period of silver birch has started earlier in spring, while in autumn it ended later; thus, it has become longer by 14-16 days (Bareika and Ozolinčius 2008). Growing season of lime trees has been extended by 22.6 days during 1956-2010 period (Juknys et al. 2011).

The data analysis reveals that the average annual growing season has lengthened by 0.38 days per year (Romanovskaja and Bakšiene 2011). Similar data were obtained in Latvia: within the study period of 1971-2000, the beginning of the growing season advanced by 5.4 days per decade and the length of the growing season increased by 3.7 days per decade, mainly due to an earlier onset of the spring phase (Kalvane et al. 2011). The length of vegetation period of deciduous tree species depends mostly on warming in late winter-spring (February-April) (Šimatonytė and Žeimavičius 2009).

By using long-term data, it has been shown that air temperature evokes the beginning of flowering in many woody plants, especially early flowering ones (*Coryllus avellana* L., *Alnus incana* Moench) (Romanovskaja and Bakšiene 2004, 2009, 2010, Veriankaitė et al. 2010). The long-term research data (1961-2010) show that the first flowering dates of European hazel (*Coryllus avellana* L.) occurred earlier by 0.43 days per year (Romanovskaja and Bakšiene 2011). Due to climate warming during the last decade, Apple tree (*Malus domestica* Borkh.) starts flowering 4-5 days earlier than the longtime average (Romanovskaja and Bakšiene 2009). April strongly influences the annual changes in the dates of the beginning of Apple tree flowering: the correlation coefficient between the mean monthly air temperature and dates of the beginning of apple tree flowering is -0.48 - (-0.80) (Romanovskaja and Bakšiene 2009). Plants that start flowering in early spring, when air temperature exceeds 0°C, are particularly sensitive to temperature changes (Romanovskaja and Bakšiene 2011).

The strong correlation between the flowering phenology of some species was revealed. The beginning of the European bird cherry (*Padus avium* Mill.) flowering is suitable for forecasting the date of the beginning of the apple tree flowering (Romanovskaja and Bakšiene 2009).

On the other hand, phenological effects depend on tree species, growth site (soil fertility, etc.) and geographic region. For example, on temporarily overmoistured sites, spring (swelling of catkins, flowering, swelling of vegetative buds, bud burst and unfurling) and summer-autumn (maturation of seeds, yellowing and fall of leaves) phenological phases of silver birch begin by 1-5 days later than on sites with normal humidity (Bareika and Ozolinčius 2008).

Data from the Lithuanian regional forest monitoring from 1989-2010 (3000-4000 trees have been observed each year) and tree fruiting assessments in 16 seed orchards show that number (score) of Scots pine fruit had a tendency to increase over the past 20 years (Ozolinčius et al. 2011).

Tree increment. Increasing in growth trend was observed in European forests during the last few decades. However, in the North, close to the Arctic Circle, both negative and positive growth trends have been measured (Mielikainen and Sennov 1996, Makinen et al. 2001). Barber et al. (2000) found that over the past 90 years the growth of white spruce (*Picea glauca* (Moench) Voss) has decreased with rising temperatures in Alaska. In northern altitude forests, reduction of the radial increment was characteristic since 1950, later (since 1980) – increase (Linderholm et al. 2002). It is considered that the main reasons for forest increment changes are warming climate, increasing amount of nitrogen in soils and increasing concentrations CO₂ in the atmosphere (Nojd and Hari 2001, Todaro et al. 2007), as well as decreasing in air pollution (Ozolinčius 1998, Juknys et al. 2002).

Data from European Intensive Monitoring Plots over a five-year period have been used to examine the influence of environmental factors on tree increment. Temperatures above the long term mean in the growing season correlated with higher relative growth for Norway Spruce (*Picea abies* (L.) Karst.), Scots Pine (*Pinus sylvestris* L.) and Common Beech (*Fagus sylvatica* L.). A temperature deviation of 0.1°C accounted for an increase of 2 to 4 % in growth; however, drought may offset the effects of increased temperature, at least for pine and spruce, at sites with low water availability (Dobbertin and Solberg 2007, after 'The condition of forests in Europe' 2007).

In Lithuania, tree radial increment is preconditioned by air temperature and precipitation during the vegetation period as well as by winter and spring temperatures. The effects of air temperature and precipitation during the vegetation period depend on forest habitat humidity: an increase in the mean temperature and decrease in precipitation promotes tree growth on moist and marshy forest habitats, while a precipitation surplus becomes a growth-limiting factor. An increase in the mean temperature has a more significant influence on habitats of normal humidity than an increase in precipitation (Stravinskienė 2002). The results of dendrochronological research on Scots pine trees in the northern part of the Baltic coastal zone have demonstrated that cold winters and summer droughts were the main factors of the narrow tree ring formation during the period 1816-2002 (Vitas 2004). V. Stravinskienė (2002) indicated that winter temperatures down

to -30 °C have no impact on tree radial increment; however, in the years with very cold winters (1909, 1928, 1940-1942, 1953, 1979) followed by cold springs and cool summers, tree increment decreased up to 40% in comparison with years with normal seasonal temperatures.

Investigations of Scots pine growth in city forests and parks show that possible changes in pace of the radial increment will be influenced by warming climate and air pollution. If recent climate prognosis will be true, the pace of the radial increment in the coming 30 years due to climate change will be up to + 0.004 mm per year, and due to increased air pollution (after the end of Ignalina nuclear power plant exploitation) – up to - 0.006 mm per year (Šimatonytė 2010).

Over the last 50 years (1952-2002), in Lithuania, the response of English oak to the mean air temperature of a hydrological year (from October to September of the coming year) and to the mean monthly air temperatures of February, March, April and August was more positive than in the XVIII-XIX centuries. It shows that the response of oak to climate warming is more positive (Ruseckas 2006). No significant decrease in the radial oak increment was recorded during the last few decades; however, at the same time, significant fluctuations in temperatures, especially during the cold period, were the main factors influencing oak radial increment in Lithuania (Grigaliūnas 1997).

Lithuanian data have confirmed that periods of minimal growth (dendrochronological indexes) are becoming more frequent (Bitvinskis and Vitas 1999). The analysis of signature years in tree-ring chronology of European larch (*Larix decidua* Mill.) shows that the formation of narrow rings is linked with hot/dry summers and of wide rings to warm winters and springs (Vitas and Žeimavičius 2010).

Severe droughts have a strong influence on late-wood of Norway spruce (Karpavičius 1999, Vitas 2001).

Comparison of the growth in height of pines of the same age from 1989-2008 and from 1954-1973 in raised bog habitat (Dubrava Small Strict Reserve) showed that over the last 20 years an increase (1.95 times) in the growth height of young pines was observed. Reliable ($r = 0.33-0.38$) correlation between the average annual periodic temperatures (duration of the period 1-3 years) and the radial increment of growing pines has been determined (Ruseckas 2008).

L. Kairiūkštis and J. Vencloviėnė (2000) have analysed four chronologies of 133-867 years in duration for oak, spruce and Siberian larch (*Larix sibirica* Ledeb.) and singled out distinct group cycles of the radial increment: 21-24, 36-45, 92-93, 174-178 and 697 years. It has been found that the last ecoclimatic minimum for tree growth was around the year 1500 (so-called

short glacial period) and the next minimum is expected around the year 2150.

At the same time, long-term continuous warming could cause negative effects - the transfer of Scots pine southward causes a decrease in wood yield (Danusevičius 2008).

Climate change and tree condition (crown defoliation, tree damage and mortality)

Analysing long-term data on tree condition, no significant correlation was found between average meteorological factors during the growing season and average defoliation, but it was statistically significant ($r = -0.65$) between the proportion of healthy trees (defoliation 0-10%) and the average temperature of the growing season (Ozolinčius et al. 2005). The data suggest that the greater the amount of precipitation, the greater the number of healthy pine trees ($r = 0.77$). Analysis of sanitary condition of birch indicates that tree condition in temporarily overmoistured forest sites ("L" hydrotop) is better than on sites of normal humidity ("N" hydrotop), and crown defoliation, amount of dead branches in the crown, number of damaged trees in the stand correlate with average summer temperature ($r = -0.36$, $p < 0.05$) (Bagdžiūnaitė and Treigienė 2010).

Negative correlation was established between precipitation during May-August and crown defoliation of pine trees. The effect of temperature on crown condition changed from positive in November, December and mid-summer (July), when higher temperatures resulted in better pine crown condition, to negative in early spring and June (Augustaitis et al. 2007).

Air concentrations of SO_2 , and SO_4^{2-} and NH_4^+ deposition, as well as spring and summer precipitation and mean winter temperature were shown to be the key factors affecting Scots pine (*Pinus sylvestris* L.) defoliation (Augustaitis et al. 2007). Meteorological parameters determine approximately 40% of mean defoliation variability in pine stands and climate warming (annual temperature increase) could lead to an increase in crown defoliation (Augustaitis 2005, Augustaitis et al. 2007).

If air concentrations of the considered pollutants and acid deposition remain stable in the future, the changing climate should mitigate the negative effect of air pollutants and acid deposition and result in better pine stand condition (Augustaitis et al. 2007, Augustaitis 2008). Only extreme conditions like heat and drought over the vegetation period could change this assumption (Augustaitis 2008).

A significant correlation was recorded between hydrothermal coefficient of Selianinov (HTC) ($\text{HTC} > 1.5$ – over-wet climatic conditions; $\text{HTC} < 0.6$ – drought) and the number of healthy (defoliation 0-10%)

pine trees – $r = 0.74$ (Ozolinčius and Stakėnas 2001). In the experimental plots with simulated soil drought (roof experiment), the mean crown defoliation of pine trees gradually increased. In the year following the removal of the roof, the recovery process began and defoliation decreased (Ozolinčius et al. 2008).

In most cases, correlations between climate change indices and crown defoliation are weak and mathematically unreliable. Only in some cases is it possible to state a reliable correlation (e.g., the higher the mean annual air temperature, the worse the condition of spruce stands). However, strong winds and droughts have a significantly great influence on stand condition. Data from long-term tree observations on experimental and forest monitoring plots have shown that due to strong wind and drought the tree mortality rate can increase by up to 10 times (Ozolinčius et al. 2005). These effects depend on species, stand and site characteristics. For example, in Lithuania, spruce stands are the most sensitive to wind damage, especially stands that are mixed, 50-60 years old, with relatively low stocking level (less than 0,7), on fertile (sod-gleyic or Gleyic Cambisols, sod-carbonate and gley - trophotop „d“) and overmoistured („U“ ir „L“ hydrotops) soils (Mikšys 1998a, b).

Tropospheric (ground level) ozone is considered to be one of the most important phytotoxic air pollutants related to heat and solar radiation. An increase in the ozone concentration ($0.9 \mu\text{g}/\text{m}^3$ per year) was established in Lithuania (Girgzdiene and Girgzdys 2001). A strong correlation was found between ozone exposure (AOT 40 index) and tree condition indexes (average defoliation and proportion of healthy trees). The forest monitoring data suggest that deciduous species, especially ash, are more sensitive to ozone (Ozolinčius et al. 2005).

A survey carried out on exposed sample plots situated throughout Lithuania (network 52x52 km) showed ozone-induced leaf injuries on Red raspberry (*Rubus ideaus* L.), Grey alder (*Alnus incana* L.), Goat willow (*Salix caprea* L.) and Glossy buckthorn (*Frangula alnus* Miller.). More visible injuries were found in the eastern part of Lithuania where higher episodic ozone concentrations were recorded during summer (Ozolinčius and Serafinavičiute 2003). An ozone fumigation experiment under controlled environmental conditions in climatic chambers revealed that the foliage of deciduous trees, including ash, was more sensitive to ozone than conifers (Serafinavičiūtė and Stakėnas 2006).

Conclusions

With the rise in average temperature of 0.7-0.9°C during the last century, winter in Lithuania became mild-

er, with shorter periods of snow cover and increased precipitation. Summer droughts became more severe, especially in July-August. The duration of thermal spring and autumn has lengthened. As a result, the climate in Lithuania is becoming less continental.

Research on forest soils indicates a possible increase in the amount of organic matter. Nevertheless, the influence of extremely warm winters on organic matter decomposition was defined. On the other hand, increased acidity and decreased concentrations of some nutrients were found in forest litter and in the upper horizons of soils during drought periods. Drought can significantly change the abundance of nitrifying and ammonifying microorganisms as well as the structure of the microarthropod complex (a decrease in *Collembola* and an increase in oribatid mites).

Climate change affects the seasonal development of ground vegetation. In warm springs, the flowering of herbs starts two weeks earlier. In years with summer droughts, the projection cover of herbs shows two peaks – one in spring and other in August; in some cases, the annual projection cover of herbs can stay stable until October. Under artificial drought conditions, the cover of both mosses and vascular plants in Scots pine stands significantly decreases, except of the species of epiphytic lichens. The Shannon diversity index indicated less decrease.

Over the long-term, changes in ground vegetation structure occur; in pine stands (*Vacciniosa* forest types) new species with high Ellenberg's nitrogen-demand values were recorded. The changes of mean weighted Ellenberg's indexes of light and continentality were negligible, while the index of temperature showed an increasing trend.

Climate change provides favourable conditions for the distribution of woody alien species. Some alien herbaceous species are becoming genetically adapted to local conditions.

Some native tree species in Lithuania could be treated as very susceptible to climate change. Many investigators forecast a decrease in the proportion of Norway spruce and common ash in stand species composition.

Recently, more frequent insect outbreaks as well as new insect species were recorded. Mild winters and droughts were declared as a primary reason for tree damage by some insects. The atypical mild weather during the non-vegetative period in recent decades provided favourable conditions for herbivorous animals' population growth. Although a close negative correlation has been ascertained between the consumption of shoots and mean air temperature during the non-vegetative period, the area of damaged stands increased. Climate warming induced an earlier arrival

of birds and an increase in the populations of southern bird species, whereas northern species decreased. Climate change can negatively affect some bird species listed in the Lithuanian Red Data Book.

Climate change evokes the beginning of leaf unfolding and flowering of many woody plants, particularly of early flowering species (*Coryllus avellana* L., *Alnus incana* Moench). Plants that start flowering in early spring, when air temperatures exceed 0°C, are particularly sensitive to temperature changes. The data revealed that the average annual growing season has lengthened. Number (score) of Scots pine fruit had a tendency to increase over the past 20 years.

A comparison of tree growth in bog habitat showed an increase in height growth over the last 20 years. Dendrochronological data on mineral soils confirmed that periods of minimal growth are becoming more frequent. Nevertheless, there is no detailed research on tree growth changes for different species under various site conditions.

In most cases, correlations between climate change indices and crown defoliation are weak and mathematically unreliable. However, the extreme synoptic situations – strong winds and droughts – have a great and significant influence on stand condition.

Climate change can have an effect on the relation between air pollutants and tree condition. It is assumed that climate change should mitigate the negative effect of air pollutants and result in better stand condition for some species (for example, pine). Only under extreme conditions, like heat and drought over the vegetation period, could change this assumption. Tropospheric (ground level) ozone is considered to be a secondary pollutant increasingly affecting deciduous tree condition.

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