SPECIFICITY OF RESPONSE REACTION OF NORWAY SPRUCE TO GLOBAL CLIMATE CHANGE

Solveiga Luguza, **Imants Liepa**, **Raivis Baltmanis**
Latvia University of Agriculture
solveiga.luguza@llu.lv

Abstract
This research deals with tendencies of growth of Norway spruce *Picea abies* (L.) Karst. during last 50 years (1960 – 2010) in eastern part of Latvia emphasizing trendal specificity of active periods during the first (t1: 1960-1985) and the second (t2: 1986-2010) time interval. There have been 150 superior stand trees bored in six mixed pine-spruce *Pinus sylvestris* L. – *Picea abies* (L.) H.Karst. stands. An active period of factor's impact is the time span when some meteorological factor (decade average, minimal or maximal temperature and sum of decade precipitation) influences an increase of annual ring width significantly. Comparing average temperatures from two weather stations included in this research the difference between interval t1 and t2 is approximately 1 °C. Active periods of temperature impact on growth of Norway spruce in eastern part of Latvia during last decades have changed not only their location but also an impact direction from positive to negative. Minimal and maximal decade temperatures are those mostly determinating the radial growth of Norway spruce in the eastern part of Latvia. Interval t2 is quite rich in active periods both from minimal and maximal decade temperature. Research results prove hypothesis about trendal shift of meteorological factors' impact active periods due to climate change. An increase in decade precipitation level in winter caused annual ring growth positively both in the interval t1 as well as in t2.
Key words: Norway spruce, tree-ring width, decade, active periods, trendal shift.

Introduction

There are only two economically important conifer species growing naturally in Latvia – Scots pine *Pinus sylvestris* L. (forms 35% of all forest stands) and Norway spruce *Picea abies* (L.) H.Karst. (18%) (Valsts meža dienesta..., 2012).

Almost half of all stands of Norway spruce form the first age group – young forest stands (1-40 years) (Meža nozare..., 2012) what means today's decisions in the field of forest risk management are extremely important for growing of qualitative future forest.

Norway spruce is a tree species with wide occurrence in Europe. Because of being far from the borders of the species distribution area, Norway spruce stands in Latvia are provided with optimal growing conditions (Zviedris, 1960). Unfortunately spruce stands have suffered a lot especially in last decades – in severe storms and from expansion of forest pests afterwards (Luguza et al., 2012c).

Ecological factors in forest are in close interconnection in addition, these relations are sophisticated and their impact on growing conditions is complex. If one of factor changes its direction or impact intensity of influence others vary too. A decrease of the light intensity causes changes in temperature and moisture level in the forest stand which impacts activity of microorganisms in the forest soil in its turn. That leads to the verity that process of separating and exploring of some factors' proportion of impact is quite a difficult task and can be done only partly (Zviedris, 1960). However in many cases partial replaceability of factors is the only one feasible solution in open air forest stand where there are no possibilities of regulation of temperature regime or amount of precipitation.

The aim of this research is to describe tendencies of growth of Norway spruce *Picea abies* (L.) H.Karst. during the last 50 years (1960 – 2010) in the eastern part of Latvia accentuating trendal specificity of active periods during the first (t1: 1960-1985) and the second (t2: 1986-2010) time interval.

Materials and Methods

During the late autumn of 2012 six tentative sample plots within area of 0.12 ha (30 × 40 m) each have been established for data collection in mixed pine-spruce stands in the eastern part of Latvia – three sample plots near Alūksne (further in text – A2, A4, A6) and other three sample plots near Kalsnava (K2, K4, K6) with conformable weather-stations Alūksne (57°26'22.48" N, 27°02'07.36" E) and Zīlāni (56°31'11.94" N, 25°55'06.45" E), respectively (Figure 1). There are 150 cores from Norway spruce bored.

Research period from the year 1960 to 2010 is divided in two parts: the first one is called t1 and stands for 1960-1985, but the other 1986-2010 is t2. A location of active periods is examined for each period separately and it is followed by trendal shift analysis of them. Average annual temperature in the last quarter of the century has increased significantly - for about 1 °C (Table 1).

Either total precipitation shows increase from 53 mm (Zīlāni) to 81 mm (Alūksne) during last decades.

Decade average temperature in the course of the year keeps the tendency from interval t1 (1960 – 1985)

Figure 1. Location of the sample plots (○) and weather-stations (▲) used in research.

Table 1

Average annual temperature and precipitation sum in t1 (1960-1985) and t2 (1986-2010) intervals in Alūksne and Zīlāni weather-stations

Alūksne weather-station				Zīlāni weather-station			
average annual temperature (T_{avg}), °C		annual precipitation sum (Prec), mm		average annual temperature (T_{avg}), °C		annual precipitation sum (Prec), mm	
t1	t2	t1	t2	t1	t2	t1	t2
4.4 ± 0.17	5.4 ± 0.17	685 ± 19.8	766 ± 21.5	5.3 ± 0.24	6.2 ± 0.18	642 ± 17.8	695 ± 17.5

to interval t2 (1986 – 2010), but it solely shows an increase in the last decades (Figure 2). The tendency is that both in Alūksne weather-station data and Zīlāni weather-station data is similar. According to the decade sum of precipitation there were slight differences between both weather-station average sums in t1 – sharp decline in Alūksne appeared in the third decade of May, but even more sharper one appeared in VI1 in Zīlāni. The second decade of August in Alūksne was remarkably dry especially compared to the same period of the year in Zīlāni. The total tendency in t2 points out more similar distribution of precipitation sum between both analysed periods.

In each of six sample plots 25 trees have been bored at the height of 1.3 m using 4.3 mm increment borer choosing the direction of boring randomly, whereas driller's back is turned to the imaginary centre of the sample plot. Trees were chosen unintentionally; however, reminding spruces of different diameter groups to be present.

According to the methodology given by J.H. Speer (2010), after boring process the cores in the laboratory where air dried, and afterwards mounted on specially made wooden core mounts. Then, they were sanded to make borders of the tree-rings as visible as possible.

Visual cross-dating was performed analysing graphs of tree-ring widths. Measuring of tree-ring widths were completed using 0.01 mm units on LINTAB - 4 measuring table with stereomicroscope supplemented by Instrumenta Mechanik Labor GmbH program T-Tools Pro that provides accumulating and first stage data processing. The main part of data analysis was carried out using the computer tool APAR (Tool for Analysing of Active Periods) – specially programmed for calculating of active periods using the most informative indicator of tree growth – tree-ring width (Liepa, 1996) and data of meteorological observations (decade average, minimal, maximal temperatures and decade sum of precipitation). This tool is one of European Regional Development Funds project, a contract number: 2010/0208/2DP/2.1.1.0/10/APIA/VIAA/146) outcomes and will be free to access.

State Ltd. 'Latvian Environment, Geology and Meteorology Centre' (http://www.meteo.lv/meteorologija-datu-pieejamiba/?nid=462) provided us with meteorological data.

It is presumed that significant increase of growing ring ends with the last decade of September. Respectively, values of meteorological factors

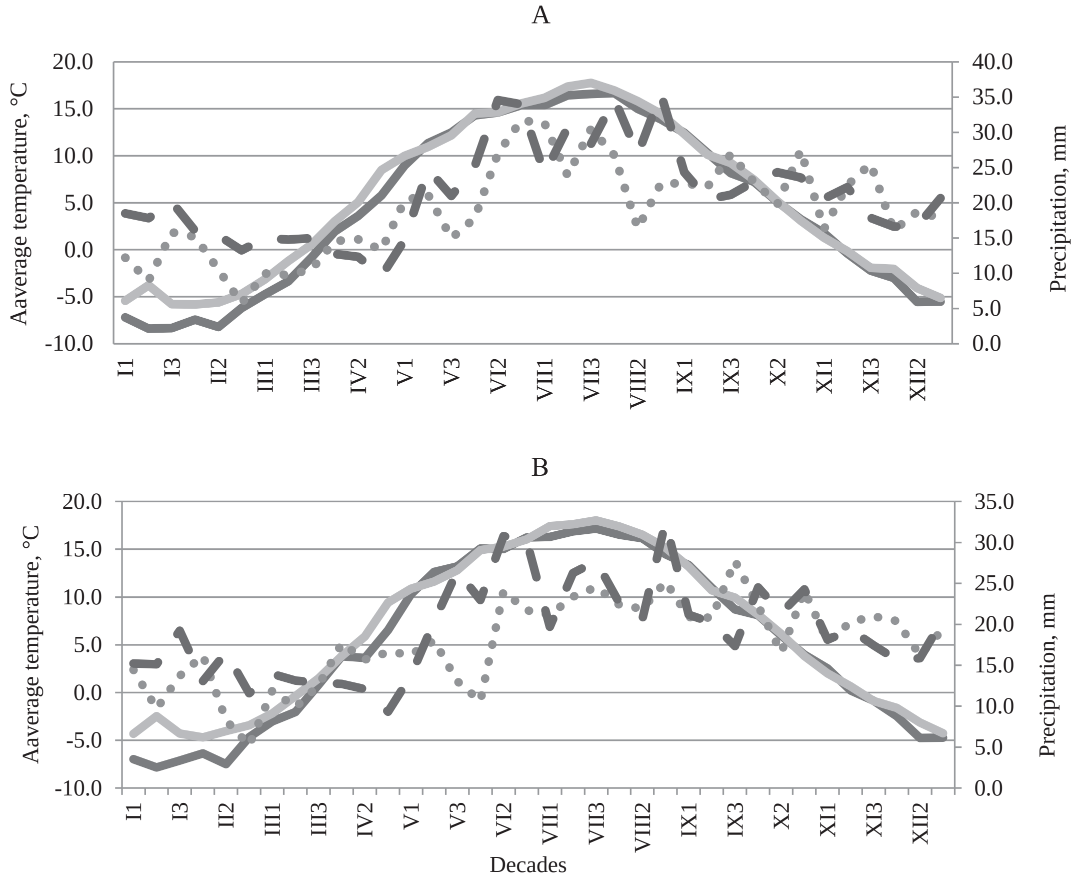

Figure 2. Average air temperature of decades and amount of precipitation in Alūksne weather-station (A) and Zīlāni weather-station (B) for time intervals t1 and t2;
- T_{avg} (1960-1985), - T_{avg} (1986-2010), – Prec (1960-1985), Prec (1986-2010).

Table 2

List of sample plots and main characteristic features of them

Sample plot	Latitude	Longitude	Sample plots stand formula	Forest site type
A2	57.2699981	27.4024936	7P145 3E100 + B70	*Myrtillosa turf. mel.*
A4	57.2704235	27.3970734	6P145 4E63	*Vacciniosa turf. mel.*
A6	57.3145361	27.4238901	8P80 2E60 + B80	*Myrtillosa turf. mel.*
K2	56.6856664	25.9364619	7P3E78 + EB90	*Hylocomiosa*
K4	56.6850923	25.9352405	6P4E90 + EB100	*Hylocomiosa*
K6	56.6912865	25.8923651	6E3P1B101	*Vacciniosa mel.*

P – *Pinus sylvestris* L., E – *Picea abies* (L.) H.Karst., B – *Betula sp.* L.; in stand formula 7P145 3E100 + B70, 7P145 – 70% of stand tree volume form 145 years old Scots pine and 30% of volume is 100 years old Norway spruce, average age of *Betula sp.* is 70 years but tree volume does not exceed 5% of total.

observed in October – December are referred to the next growing season annual ring.

For identification of time slices of the year when risk probability of several meteorological factors is significantly high, active periods determined by temperature (decade average, minimal and maximal) and precipitation (decade sum) (active periods - further in the text) are calculated using correlation analysis sticking to the theoretical basis given by I. Liepa (Лиепа, 1980).

Results and Discussion

European Environment Agency (EEA) notifies that years from 2002 to 2011 have been the warmest decade registered in Europe ever when average temperature exceeded 1.3 °C the one in the preindustrial period (McGlade, 2012). Comparing average temperatures from two weather stations used in this research, the difference between periods 1960 – 1985 and 1986 – 2010 is approximately 1 °C (Table 1). Meteorological factor's impact active periods on Norway spruce growth in the eastern part of Latvia during last decades have changed not only their location, but also the impact direction from positive to negative ($p<0.05$) (Table 3).

Researching Norway spruce in NE Lithuania A. Vitas (2011) has summarised different results obtained in Siberia, Finland and has come to new cognitions in the field of describing of tree growth rate in Lithuania. All of them point out June as time of culmination of growth.

According to the research results in NE Lithuania growth maximum of Norway spruce occurs in June as well as it is for Scots pine (Vitas, 2011). Spring and early summer (April, May, June) is a period of the year when growth rate increases, but the end of summer (July, August) is a time when growth trend has an opposite direction (Vitas, 2011). Trees meet the requirements in definite climatic factors during the growing season quite variably. That is the reason why insufficiency, optimum or oversaturation of the exact factor in one decade impacts the tree growth positively or negatively, but it can be even without any significance in other period of time (Luguza et al., 2012 a, b).

Minimal and maximal decade temperatures are those mostly determining the tree radial growth increase. This is especially well illustrated by Alūksne

Table 3

Summary of temperature impact active periods ($p<0.05$) on Norway spruce in the eastern part of Latvia

Sample plot	Average temperature				Minimal temperature				Maximal temperature			
	t1		t2		t1		t2		t1		t2	
	+	-	+	-	+	-	+	-	+	-	+	-
A2	XII_2 I_3 VII_3	×	III_3	×	XI_3 I_2	VI_2	×	X_3 IX_2	IV_1	VI_2	×	×
A4	XII_2 VI_2 VII_3	V_3	III_3	×	XII_3 III_3 IV_1	VI_2	×	XI_2 III_3 V_3 IX_3	III_3 IV_1	×	×	XI_3 VII_2 VIII_2
A6	×	XII_2 I_1 I_2 I_3	×	×	VI_2	×	×	VII_2 VII_3 VIII_1	II_2	×	×	VII_2 VII_3 VIII_1
Average in Alūksne locality	XII_2 VII_3	×	III_3	X_3	XI_3 III_3 IV_1	VI_2	×	III_3 VII_2 IX_2 IX_3	IV_1	VI_2	×	VII_2 VIII_2 IX_2
K2	×	×	×	XII_1 XII_3 VIII_2 IX_3	I_2	×	VII_1	XI_3 XII_2 XII_3 I_1 VIII_2	XI3 V3	II3 VI2	×	XII1 I1 I2 IX3
K4	×	II3	×	VII2	X1 X3	II3	II3	×	V3	II3 VI2 VII3	×	V3 VII2
K6	II2 VII1	×	×	×	II2 IV2	×	III3	×	II3 VI2 VII1	XI3 V3	X2	VII2
Average in Kalsnava locality	×	×	V2	XII1 IX1 IX3	XII3	×	×	XI3 XII1 XII2	V3	II3	×	VII2

Roman numerals indicate month but Arabic numerals – decade, e.g. XII_2 – the second decade of December; × - temperature impact active periods were not observed ($p<0.05$).

sample plots which are all stands on drained peatlands - *Myrtillosa turf. mel.* and *Vacciniosa turf. mel.*

M. Rybníček et al. (2010) exploring Norway spruce in the Czech Republic (it should be added – in elevation from about 400 - 800 m a.s.l.) found significant correlation between average monthly temperatures in October of the previous year and in May of current year and radial increment. In Latvia, a substantial research in the field of exploring of Norway spruce active periods (using data from 1937 - 1969) was carried out in the end of 1970ties by I. Liepa (Лиепа, 1980). Results showed that average temperature had one positive active period in April. According to the results of this research, there are only some sample plots where decade minimal temperatures show positive significant impact on tree radial increase (A4, Alūksne region and K6) in addition that appears in interval t1 only. This proves the hypothesis about trendal shift of active periods due to climate change: 1937 – 1969 – significant, 1960 – 1985 – episodical and 1986 – 2010 – not significant impact. For every forest much more favourable situatio is when there is a potentially small amount of active periods i.e. trees meet the requirements in existing climatic factors optimally. However as Table 3 shows, the interval t2 is quite rich in active periods: starting from the 3rd decade of October to the 3rd decade of December from the previous year when an impact is both from minimal and maximal temperatures as well as summer decades – from the 2nd decade of July to the 1st decade of August.

The length of vegetation period plays an important role in tree growth irrefutably in general (Fischer and Neuwirth, 2013). Research results in NE Lithuania show that the length of the growing period for individual trees in the forest stand varies because of differences in the beginning and the ending points in spring and autumn. Genetic features of various tree species determine that growing season of Norway spruce is 4 - 5 days longer comparing to Scots pine. Duration of the growing period of spruce draws out 0.3 days per annum for the last 30 years (Vitas, 2011). What is more, several climate change models show that till the end of the 21st century temperature in Europe will rise for 2.5 – 4 °C compared to average in the period of 1961 – 1990 (McGlade, 2012). Thus, it is assumed that active periods found now might have another trendal shift.

Reaction of various tree species to different meteorological factors is temporally diverse. For

Table 4

Summary of precipitation impact active periods (p<0.05) on Norway spruce in the eastern part of Latvia

Sample plot	Sum of decade precipitation, mm			
	t1		t2	
	+	-	+	-
A2	I_2	×	II_1 III_2 V_2 VI_1	×
A4	I_3	×	×	XI_3 XII_1
A6	II_2	×	III_3	XII_1
Average in Alūksne locality	I_2 IV_1	×	II_1 V_2 VI_1	XII_1
K2	I_3 III_1	XI_2 II_3	×	×
K4	I_3 III_1	XI_2 II_3	IV_3	×
K6	×	XII_3 I_3 III_1	×	X_2
Average in Kalsnava locality	III_1	×	XI_2	×

Roman numerals indicate month but Arabic numerals – decade, e.g. XII_2 – the second decade of December; × - precipitation impact active periods were not observed (p<0.05).

example researching Douglas-fir *Pseudotsuga menziesii* var. *glauca* J.H. Bassman et al. (2002) proves that low temperature in May and summer months (June, July, August) impacts tree-growth negatively. Here should be added that for forest stands growing in temperate zone air temperature plays more important role than precipitation. Amount of precipitation in May and June of the current growing season is the factor of vital concernment to both spruce and pine (Dzenis and Elferts, 2012). In the year 1996 H.P. Kahle and H. Spiecker where already dealt with the problem of different reaction of young, middle-age and old trees of Norway spruce to exact level of precipitation. Research results in Europe what are summarized by R. Ozolinčius (2012) show calculation of the effect of increased growing season temperature above the long term mean. If growing conditions in the forest stand are optimal, water balance is stable, a positive effect of heightened temperature appears in 2 - 4% increase of tree growth on 0.1 °C of positive air temperature variation. Quite often microclimate in particular stand is untypical that leads to discrepancy with research results of other authors and different conclusions between stands and even individual trees (Indriksons, 2009; Ozolinčius, 2012).

In most cases not the total amount but temporal distribution of precipitation can be a risk for the tree growth, e.g. its diminution in growing season in complex with its increase in winter can cause real hazard to coniferous (Augustaitis, 2011).

For Douglas-fir, the level of precipitation is a particularly important factor in June when decrease of it induces diminishing of tree growth significantly (Bassman et al., 2002).

An increase of decade precipitation level in winter caused tree-ring growth positively both in the interval t1 as well as in t2 (Table 4). A trendal shift of active periods appears in almost all sample plots. In 1960 – 1985 positive active periods were from the 2nd decade of January till the 1st decade of March but 1986 – 2010 came with significant correlation between annual ring width and sum of decade precipitation from the 1st decade of February till the 3rd decade of March.

Fall-out in the end of previous year plays a significant role in the growth of Norway spruce in the eastern part of Latvia – that was actually both in t1 and in t2.

Conclusions

1. Meteorological factor's impact active periods on Norway spruce growth in the eastern part of Latvia during last decades have changed not only their location, but also an impact direction from positive to negative.
2. Minimal and maximal decade temperatures are those mostly determining the radial growth of Norway spruce in the eastern part of Latvia.
3. Decade minimal temperature active periods have largely changed their direction of impact from positive to negative and they are located in the end of previous year (the 3rd decade of October, the 2nd and 3rd decades of November, all decades of December) and in summer months (starting from the 2nd decade of July to the 1st decade of August).
4. An increase in decade precipitation level in winter caused tree-ring growth positively both in the interval 1960 - 1985 as well as in the interval 1986 - 2010.
5. The sum of decade precipitation in the end of previous year plays a significant role in the growth of Norway spruce in the eastern part of Latvia – that was actually both in the interval 1960 - 1985 as well as in the interval 1986 - 2010.

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