Possible Signs of Growth Decline of Pedunculate Oak in Latvia during 1980–2009 in Tree-ring Width and Vessel Size

ROBERTS MATISONS*, DIDZIS ELFERTS AND GUNTIS BRŪMELIS
University of Latvia, Faculty of Biology
Riga, Kronvalda blvd.4, LV1010, Latvia
**Corresponding author, e-mail: robism@inbox.lv*

Matisons, R., Elferts, D. and Brūmelis, G. 2013. Possible Signs of Growth Decline of Pedunculate Oak in Latvia during 1980–2009 in Tree-ring Width and Vessel Size. *Baltic Forestry* 19(1): 137–142.

Abstract

Decreased growth of pedunculate oak (*Quercus robur* L.) during the 20th century has been documented in Europe and is considered as one of the symptoms of oak decline. However, there is insufficient information on wood formation of oak in Latvia (Baltic countries). Tree-ring width is a commonly used proxy for evaluation of growth, but other wood proxies, such as earlywood vessel size, can provide additional information on mechanisms affecting growth. In this study, we investigated changes in tree-ring width and cross-section area of earlywood vessels for the periods of 1899–2009. Since the 1980s, abrupt changes in wood formation were observed, particularly in the more continental eastern Latvia. Tree-ring width showed significant decrease, while lumen cross-section area of earlywood vessels significantly increased in the eastern part of Latvia. These changes might have been triggered by an extremely cold December in 1978.

Key words: earlywood vessel, tree-ring width, growth changes, climatic extreme, *Quercus robur*

Introduction

Decline of pedunculate oak has been observed since the second part of the 20th century in many regions of Europe (Wazny et al. 1990, Brasier 1996, Führer 1998, Thomas et al. 2002, Drobyshev et al. 2007a, Helama et al. 2009, Sonesson and Drobyshev 2010). Symptoms of oak decline are decreased vitality with loss of crown and decrease of tree-ring width (TRW) (Drobyshev et al. 2007a, Helama et al. 2009, Sonesson and Drobyshev 2010, Anderson et al. 2011). The cause of the decline is not completely understood, but is considered to be an effect of a complex of environmental factors. Pest activity, such as *Phytophthora sp.* fungus, is considered as one of the reasons (Brasier 1996, Jung et al. 2000), along with climate change. It has been shown that decline can be triggered by climatic extremes, such as drought or extremely low temperature, which can weaken oak, making it susceptible to pests (Sonesson and Drobyshev 2010, Anderson et al. 2011).

The decline of oak on its northern distribution limit has been shown to be a continuous process, and decreased TRW can last for up to several decades (Helama et al. 2009, Anderson et al. 2011). Declining and dying oaks in Finland were observed to grow slower also before visual symptoms of decline appeared (Helama et al. 2009). Oak is a light demanding species (Jones 1959), and thus the effect of competition might facilitate decrease of vitality. However, during recent decades in Southern Sweden growth improvement also has been observed (Sonesson and Drobyshev 2010).

TRW has been often used to study decline of oaks (Wazny et al. 1990, Thomas et al. 2002, Helama et al. 2009, Sonesson and Drobyshev 2010). Earlywood vessel size is another proxy that could be used, as it has been shown to contain strong environmental signals (Garcia-Gonzalez and Eckstein 2003, Tardif and Conciatori 2006, Campelo et al. 2010, Fonti et al. 2010, Matisons et al. 2012). Vessel size in oak also can be related with physiological vigour of tree (Fonti et al. 2009). The symptoms of the decline might be expected to be reflected in high and low frequency variation of vessel size, as earlywood vessels are the main water conducting elements in oak (Tyree and Ewers 1991, Granier et al. 1994, Tyree and Zimmermann 2002). Previous work has indicated that major changes in wood formation of oak might have occurred since the 1980s (Matisons and Brūmelis 2012). The aim of the study was to determine if decreased growth below that expected from the age-related decline had occurred in Latvia during the last few decades, using both tree-ring width and earlywood vessel size as proxies.

Materials and methods

Material and data

Study area, sampling, sample treatment and proxy measurement procedures are described in Matisons et al. (2012); the same material was used in this study. Mean time-series of tree-ring width (TRW, ±0.01 mm) and mean earlywood vessel lumen area of tree-ring (VLA, ± 100 μn^2) for stands was obtained for 40 sites located across Latvia (Figure 1). The stands were oak-dominated on clayey soils; details about sites are shown in Table 1. The study area is located in the hemiboreal forest zone. According to data from Latvian Environment, Geology and Meteorology Centre (LEGMC) mean yearly temperature is 5 ºC and mean annual precipitation ranges from 550–850 mm.

Table 1. Location (WGS 84 coordinates), soil moisture, relief, age (mean age of five oldest cored trees), and species composition of studied sites (stands) and number of cored trees

Code	Coordinates	Soil moisture	Relief	Stand age	Mixed stands	Number of cored trees
			Western region			
ANC	21º56'5E, 57º34'23N	Dry	Flat	215	Yes	10
CCE	22º34'18E, 56º39'1N	Dry	Flat	176	Yes	10
DOB	23º17'24E, 56º36'9N	Dry	Slight slope	184	Yes	10
DOB1	23º13'10E, 56º35'34N	Dry	Slight slope	192	Yes	18
DRB	21º17'42E, 56º35'0N	Dry	Flat	212	Yes	10
DUN1	22º20'52E, 57º29'47N	Dry	Flat	157	No	10
DZC	23º2'17E, 57º7'5N	Dry	Flat	227	Yes	10
GVZ	21º19'5E, 56º31'26N	Moist	Flat	230	Yes	10
ICV	24º8'56E, 56º34'9N	Dry	Flat	148	No	10
JBRsa	23º23'57E, 56º43'0N	Dry	Flat	237	No	8
JBRsl	23º25'22E, 56º44'51N	Moist	Flat	176	Yes	7
JEL	23º45'0E, 56º37'4N	Dry	Flat	225	Yes	18
KUL	22º2'6E, 56º55'26N	Dry	Flat	118	Yes	11
MZN	24º1'58E, 56º26'47N	Dry	Flat	223	Yes	10
PIL	21º41'53E, 57º12'5N	Dry	Flat	197	Yes	12
SKR	21º59'7E, 56º34'58N	Dry	Slight slope	173	Yes	10
TBR	21º34'23E, 56º45'32N	Dry	Flat	167	Yes	12
UGL	21º58'31E, 57º14'35N	Dry	Flat	223	Yes	14
			Eastern region			
AGL	26º54'5E, 56º12'41N	Dry	Flat	206	No	10
ALK	26º57'37E, 57º22'54N	Dry	Slight slope	115	Yes	10
BAR	26º38'59E, 56º42'30N	Moist	Flat	165	Yes	12
BIK	26º17'51E, 56º55'19N	Dry	Flat	160	Yes	10
BZN	26º3'41E, 56º50'11N	Dry	Flat	118	Yes	23
CES	25º13'24E, 57º17'30N	Dry	Slight slope	252	Yes	10
DKL	25º4'35E, 57º37'28N	Dry	Flat	186	Yes	10
ELK	25º36'45E, 56º13'19N	Dry	Flat	118	Yes	11
EZR	27º36'28E, 56º11'15N	Dry	Flat	202	No	10
JEK	25º57'16E, 56º28'17N	Dry	Slope	180	Yes	10
LMBsa	24º55'26E, 57º30'52N	Dry	Flat	184	Yes	10
LMBsl	25º2'11E, 57º30'33N	Moist	Flat	220	Yes	10
LOB	25º12'42E, 56º44'12N	Dry	Flat	193	Yes	16
LZA	27º57'22E, 56º30'23N	Dry	Flat	167	Yes	5
RDA	26º10'57E, 55º53'11N	Dry	Slight slope	180	Yes	14
RUJ	25º23'40E, 57º52'26N	Moist	Flat	114	No	10
SIG	24º48'2E, 57º9'5N	Dry	Slope	219	Yes	12
SKV	25º2'33E, 56º39'38N	Dry	Flat	117	No	10
STP	24º56'45E, 57º22'21N	Dry	Slight slope	180	No	10
STR	25º43'19E, 57º37'44N	Dry	Slight slope	176	Yes	10
VDL	25º46'31E, 56º16'21N	Dry	Flat	173	Yes	10
VLK	26º4'18E, 57º42'21N	Dry	Slight slope	149	Yes	7

Data analysis

As suggested by Matisons et al. (2012) data was divided in two groups: western (18 sites) and eastern (22 sites) regions of Latvia (Figure 1, broken line) as wood formation and its relation with climatic factors differs between western and eastern parts of Latvia due to differences in continentality. The border line (Figure 1) generally coincides with changes of continentality (LEGMC). Quality of measurements was checked and interseries correlation, mean sensitivity and autocorrelation was calculated with COFECHA (Grissino-Mayer 2001). Gleichläufigkeit and Gini coefficients were calculated between site time-series using the program R (R Development Core Team 2009) with library dplR (Bunn 2008). For determination of changes in wood formation in the later part of the 20th century, mean time-series of both TRW and VLA for sites were standardized and Euclidian distance matrices were produced. Based on Euclidean distances chronological clustering using the "coniss" method was applied. Significance of clustering was assessed by the "broken stick" method. The analysis was conducted using the program R (R Development Core Team 2009) using libraries "rioja" (Juggins 2009). Mean time-series of TRW and VLA were calculated for eastern and western regions of Latvia based on time-series of sites, which were calculated from mean time series of trees.

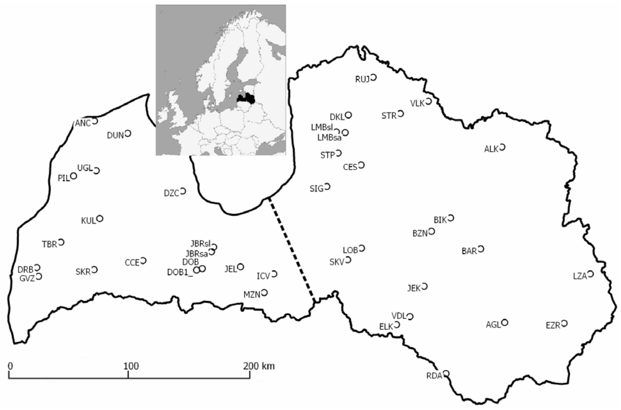

Figure 1. Location of sampling sites (sampled stands)

Results

Mean site time-series for sites (Figure 2) showed distinct changes of TRW and VLA since the 1980's. TRW showed decrease resulting in lower amplitude of site time-series, while VLA showed increase and increasing spread between site time-series. Chronological clustering, conducted for regional subsets of data, showed that five and eight clusters for TRW and three and four clusters for VLA were significant in the west-

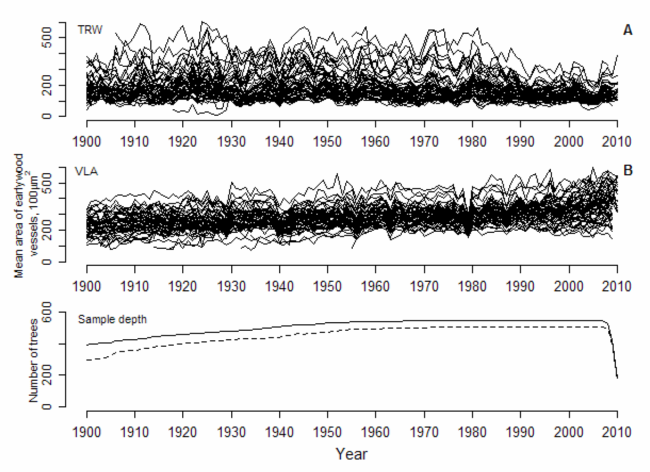

Figure 2. Mean time-series for each stand of TRW (A), VLA (B) and their sample depth (replication)

ern and eastern regions, respectively. Different patterns of clustering of TRW and VLA were observed in western and eastern regions of Latvia (Figure 3). For both tree-ring proxies in the eastern region an explicit cluster, which consisted of the last 30 years, was distinguished in the first level of division. In the western region a cluster consisting of the first 30 years of the analysed period was observed, but explicit clustering for the last 30 years was not evident. Thus, chronological clustering showed that the visually apparent decrease of TRW and increase of VLA since the 1980s formed a significantly different pattern (trend) than the preceding years of the chronology (mean time-series) of the eastern region (Figure 4). Although VLA was higher in the eastern than in the western region since 1950, extremely low values of VLA occurred in 1979, which is about at the time trends for TRW and VLA changed. Although TRW did not show extreme values in 1979–1980, a decrease was observed a few years later.

Statistics of mean regional time-series of TRW and VLA suggested that wood formation have changed during recent decades in both regions of Latvia (Table 2). For the period 1980–2009, the agreement (interseries correlation) and mean sensitivity of time-series were lower than in the preceding 30-year period, particularly for VLA in the western region. During this period VLA also showed slightly lower GLK in both regions. Autocorrelation was higher for both proxies in the most recent period, particularly for VLA, which increased from AC = 0.13 and 0.10 to 0.36 and 0.59, in western and eastern regions of Latvia, respectively.

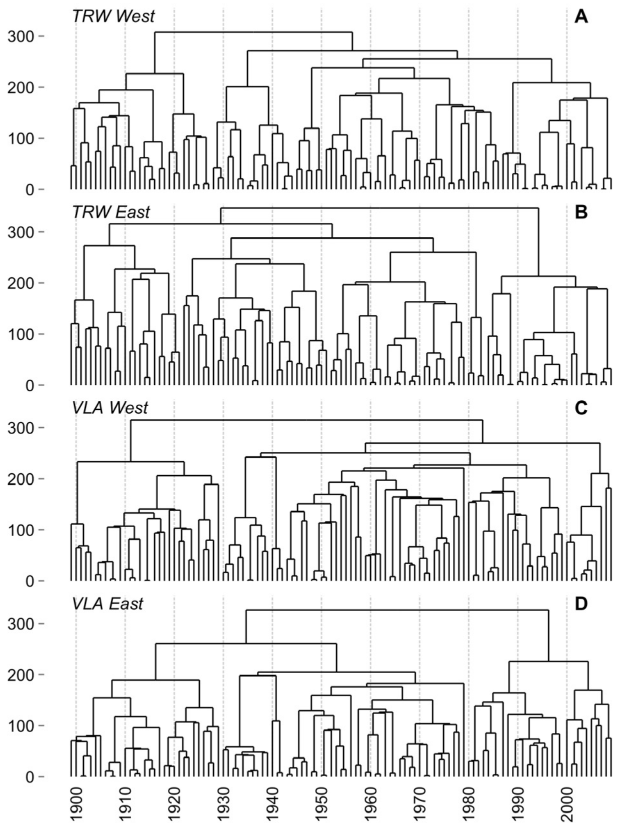

Figure 3. Chronological clustering of TRW (A – western region and B – eastern region) and VLA (C – western region and D – eastern region) mean site time-series for the period 1899-2009

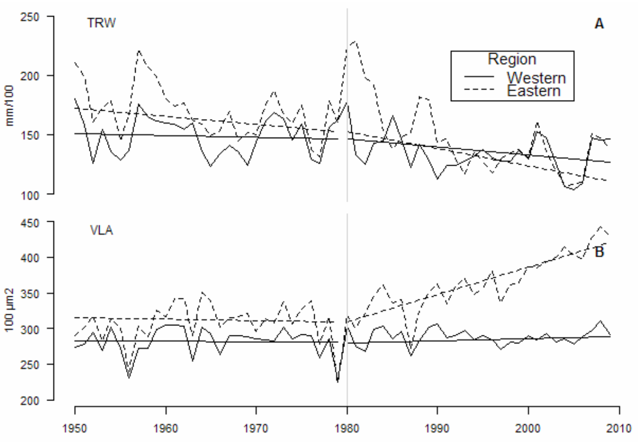

Figure 4. Mean regional time-series of TRW (A) and VLA (B) for eastern and western regions of Latvia for the period 1950-2009 and linear trend lines for periods of 1950-1979 and 1980-2009

Discussion and conclusion

Shifts in trends of TRW and VLA occurred at about 1980 in the more continental eastern region of Latvia (Figures 3, 4). Long-term changes of oak growth have been shown to occur after extreme events (Helama et al. 2009, Sonesson and Drobyshev 2010). Similarly, shifts of wood formation after 1980 (Figure 4) might have been triggered by a rapid drop of temperature in winter of 1978/1979. According to data from the LEGMC, in 1978, a rapid change of temperature from a warm November (5 °C above the 100 year mean) was followed by extreme cold in late December (16 °C below the 100 year mean), when temperature in the eastern regions reached -43.2 °C. Such a sudden drop of temperature in autumn can damage oaks that are not sufficiently hardened (Morin et al. 2007). VLA, which contains less autocorrelation than TRW (Table 2, Garcia-Gonzalez and Eckstein 2003), reacted immediately, showing an increase already after 1980 (Figure 4). The decrease of TRW started about 1980–1982, but it was not abrupt, likely due to higher autocorrelation (Pallardy 2008, Speer 2010). The trends of TRW and VLA in western Latvia did not change during the last 30 years, likely due to milder climate; trends in wood formation during 1900–1930 were likely caused by ageing.

Table 2. Statistics of TRW and VLA time-series for western and eastern regions of Latvia for the periods 1950-1979 and 1980-2009

	TRW western region	TRW eastern region	VLA western region	VLA eastern region
	1950–1979			
Mean value	148.75	169.95	281.61	307.86
Standard deviation	16.44	21.92	19.84	28.42
Autocorrelation	0.49	0.46	0.13	0.10
Mean Gleichläufigkeit (GLK) between sites	0.62	0.64	0.63	0.74
Gini coefficient	0.47	0.43	0.30	0.26
Mean interseries correlation	0.59	0.59	0.72	0.85
Mean sensitivity	0.11	0.12	0.06	0.10
	1980–2009			
Mean	134.02	147.42	288.19	364.21
Standard deviation	16.43	31.53	11.43	39.56
Autocorrelation	0.54	0.70	0.36	0.59
Mean Gleichläufigkeit (GLK) between sites	0.62	0.64	0.57	0.64
Gini coefficient	0.49	0.44	0.31	0.26
Mean interseries correlation	0.51	0.60	0.36	0.66
Mean sensitivity	0.08	0.08	0.04	0.05

As earlywood vessel size in Latvia is limited by temperature in the dormant season and spring (Matisons and Brūmelis 2012, Matisons et al. 2012), the increase (change of trend) of VLA during 1980–2009 (Figure 4) might be facilitated by accelerating warming of climate in recent decades (IPCC 2007, Lizuma et al. 2007). Earlywood vessels in oak function only in the year of their formation (Tyree and Ewers 1991, Tyree and Cochard 1996) and conduct most of the water (sap) (Granier et al. 1994). Thus, conditions affecting vessel size can determine water transport during the growing season. Larger vessels are more susceptible to embolism (Sperry 1995), which causes physiological water deficit and impedes growth (Garcia-Gonzalez and Eckstein 2003, Pallardy 2008) thus explaining the observed decrease of TRW (Figure 4). This is also supported by positive relationship between TRW and August precipitation (Matisons et al. 2012). Increasing variability of precipitation in summer (Briede and Lizuma 2007, Avotniece et al. 2010) may also facilitate water deficit. Additionally, the necessary amount of water transport can be gained by different combinations of vessel number and size (Tyree and Zimmermann 2002). However in narrow tree-rings there might be lack of space to for more numerous smaller vessels to form, and thus larger vessels are formed to sustain the needed amount of water transport, as confirmed by negative relationship between TRW and VLA (Tardif and Conciatori 2006). Larger vessels are susceptible to embolism, which can cause a decrease of TRW and trigger formation of larger vessels in the next year, resulting in a negative feedback loop. This also might explain the observed increased autocorrelation and decreased sensitivity of VLA during 1980–2009. An alternative explanation of changes in wood formation might be related with pest activity and competition within stands.

Differences in autocorrelation, interseries correlation and sensitivity of time-series (Table 2) suggest that climate extremes in 1978 affected wood formation also in western region of Latvia, however, the effect was weaker. Dependence of growth on stored reserves is higher in suppressed trees (Pallardy 2008), which can explain the increase of autocorrelation in time-series of TRW. Decreased sensitivity of TRW (Table 2) can be explained by reduced growth when latewood with is low (Zhang 1997). As habitat characteristics influences variation of TRW (Matisons and Brūmelis 2012), a decrease of agreement between TRW series (Table 2, interseries correlation) and spread of VLA series during 1980–2009 (Figure 2) might suggest increasing influence of local factors on growth.

Decreased growth and loss of sensitivity of TRW time-series are symptoms of oak decline (Wazny et al. 1990, Thomas et al. 2002, Helama et al. 2009), but the studied oaks were visually healthy and there was no obvious reduction of crowns or defoliation, contraindicating oak decline. In Southern Sweden, where the lifespan of oak growing in forest is considered to be 150–200 years, dying oaks show depressed growth several decades before death (Drobyshev et al. 2007b, Drobyshev and Niklasson 2010). In this respect, the mortality rate of older oaks (~200 years) in Latvia might increase as a result of the suppressed growth. However considering that changes in wood formation were likely consequences of a climatic extreme, decreasing frequency of cold events (Avotniece et al. 2010) might be beneficial for oak in the future. The observed slight increase of TRW in 2009–2010 (Figure 2) might also suggest improvement of growth, as recently observed in southern Sweden (Sonesson and Drobyshev 2010).

Acknowledgements

The work was funded by the European Social Fund (ESF) project "Support for Doctoral Studies at the University of Latvia" Nr.2009/0138/1DP/1.1.2.1.2/09/IPIA/ VIAA/004 and "Support for Doctoral Studies at University of Latvia – 2" Nr.2011/0054/1DP/1.1.2.1.2/11/IPIA/VIAA/002. Also appreciation is given to the Latvian State Forest Service for inventory data and Latvian Environment, Geology and Meteorology Centre for climatic data. Agita Treimane and Sandra Ikauniece kindly provided some of the samples and thanks are extended to colleagues for help during sampling. Comments of two anonymous reviewers helped to improve manuscript.

References

Anderson, M., Milberg, P. and Bergman, K.O. 2011. Low pre-death growth rates of oak (*Quercus robur* L.)—Is oak death a long-term process induced by dry years? *Annals of Forest Science* 68: 159–168.

Avotniece, Z., Rodinov, V., Lizuma, L., Briede, A. and Kļaviņš, M. 2010. Trends in frequency of extreme climate events in Latvia. *Baltica* 23: 135–148.

Brasier, C.M. 1996. *Phytophthora cinnamomi* and oak decline in southern Europe. Environmental constraints including climate change. *Annals of Forest Science* 53: 347–358.

Briede, A. and Lizuma, L. 2007. Long-term variability of precipitation in the territory of Latvia. In: M. Kļaviņš (Editor), Climate Change in Latvia. Riga, Latvia, p. 35–45.

Bunn, A. 2008. A dendrochronology program library in R (dplR). Dendrochronologia 26: 115–124.

Campelo, F., Nabais, C., Gutierrez, E., Freitas, H. and Garcia-Gonzalez, I. 2010. Vessel features of *Quercus ilex* L. growing under Mediterranean climate have a better climatic signal than tree-ring width. *Trees* 24: 463–470.

Drobyshev, I. and Niklasson, M. 2010. How old are the largest Swedish oaks? A dendrochronological analysis. *Ecological Bulletins* 53: 155–163.

Drobyshev, I., Anderson, S. and Sonesson, K. 2007a. Crown condition dynamics of oak in southern Sweden 1988–1999. *Environmental Monitoring and Assessment* 134: 199-210.

Drobyshev, I., Linderson, H. and Sonesson, K. 2007b. Temporal mortality pattern of pedunculate oaks in Southern Sweden. *Dendrochronologia* 24: 97–108.

Fonti, P., von Arx, G., Garcia-Gonzalez, I., Eilmann, B., Sass-Klaassen, U., Gärtner, H. and Eckstein, D. 2010. Studying global change through investigation of the plastic responses of xylem anatomy in tree rings. *New Phytologist* 185: 42–53.

Fonti, P., Treydte, K., Osenstetter, S., Frank, D. and Esper, J. 2009. Frequency-dependent signals in multi-centennial oak vessel data. *Palaeogeography, Palaeoclimatology, Palaeoecology* 275: 92–99.

Friedrichs, D.A., Büntgen, U., Frank, D.C., Esper, J., Neuwirth, B. and Löffler, J. 2008. Complex climate controls on 20th century oak growth in Central-West Germany. *Tree Physiology* 29: 39–51.

Führer, E. 1998. Oak decline in Central Europe: a synopsis of hypotheses. In: M.L. McManus and A.M. Liebhold (Editors), Proceedings: Population Dynamics, Impacts, and Integrated Management of Forest Defoliating Insects. USDA Forest Service General Technical Report NE-247, p. 7–24.

Garcia-Gonzalez, I. and Eckstein, D. 2003. Climatic signal of earlywood vessels of oak on a maritime site. *Tree Physiology* 23: 497–504.

Garcia-Gonzalez, I. and Fonti, P. 2006. Selecting earlywood vessels to maximize their environmental signal. *Tree Physiology* 26: 1289–1296.

Granier, A., Anfodillo, T., Sabatti, M., Cochard, H., Dreyer, E., Tomasi, M., Valentini, R. and Breda, N. 1994. Axial and radial water flow in the trunks of oak trees: a quantitative and qualitative analysis. *Tree Physiology* 14: 1383–1396.

Grissino-Mayer, H.D. 2001. Evaluating crossdating accuracy: a manual and tutorial for the computer program COFECHA. *Tree-Ring Research* 57: 205–221.

Helama, S., Läänelaid, A., Raisio, J. and Tuomenvirta, H. 2009. Oak decline in Helsinki portrayed by tree-rings, climate and soil data. *Plant and Soil* 319: 136–74.

IPCC 2007. Observations: Atmospheric Surface and Climate Change. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, H.L. Miller (Editors), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge, p. 235–346.

Jones, E.W. 1959. Biological flora of the British Isles: *Quercus* L. *Journal of Ecology* 47: 169–222.

Juggins, S. 2009. rioja: Analysis of Quaternary Science Data, R package version 0.5-6. http://cran.r-project.org/package=rioja.

Jung, T., Blaschke, H. and Oßwald, W. 2000. Involvement of soilborne *Phytophthora* species in Central European oak decline and the effect of site factors on the disease. *Plant Pathology* 49: 706–718.

Lizuma, L., Kļaviņš, M., Briede, A. and Rodinovs, V. 2007. Long-term changes of air temperature in Latvia. In: M. Kļaviņš (Editor), Climate Change in Latvia. Riga, Latvia, p. 11–20.

Matisons, R., Elferts, D. and Brūmelis, G. 2012. Changes in climatic signals of English oak tree-ring width and cross-section area of earlywood vessels in Latvia during period 1900–2009. *Forest Ecology and Management* 279: 34–44.

Matisons, R. and Brūmelis, G. 2012. Influence of climate on tree-ring and earlywood vessel formation in *Quercus robur* in Latvia. *Trees* 26: 1251–1266.

Morin, X., Ameglio, T., Ahas, R., Kurz-Besson, C., Lanta, V., Lebourgeois, F., Miglietta, F. and Chuine, I. 2007. Variation in cold hardiness and carbohydrate concentration from dormancy induction to bud burst among provenances of three European oak species. *Tree Physiology* 27: 817–825.

Pallardy, S.G. 2008. Physiology of woody plants. Elsevier, Burlington, 454 pp.

Pilcher, J.R. and Gray, B. 1982. The relationships between oak tree growth and climate in Britain. *Journal of Ecology* 70: 297–304.

R Development Core Team 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Sokal, R.R. and Rohlf, F.J. 1995. Biometry, 3rd edition. Freeman and Company, New York, 887 pp.

Sonesson, K and Drobyshev, I. 2010. Recent advances on oak decline in Southern Sweden. *Ecological Bulletins* 53: 197–207.

Speer, J.H. 2010. Fundamentals of Tree-ring Research. The University of Arizona Press, Tucson, 368 pp.

Sperry, J.S. 1995. Limitation on stem water transport and their consequences. In: B. Gartner (Editor), Plant stem: Physiology and functional morphology. Netherlands, p. 105–122.

Tardif, J. and Conciatori, F. 2006. Influence of climate on tree rings and vessel features in red oak and white oak growing near their northern distribution limit, southwestern Quebec, Canada. *Canadian Journal of Forest Research* 36: 2317–2330.

Thomas, F.M., Blank, R. and Hartman, G. 2002. Abiotic and biotic factors and their interactions as causes of oak decline in Central Europe. *Forest Pathology* 32: 277–307.

Tyree, M.T. and Cochard, H. 1996. Summer and winter embolism in oak: impact of water relations. *Annals of Forest Science* 53: 173–180.

Tyree, M.T. and Ewers, F.W. 1991. The hydraulic architecture of trees and other woody plants. *New Phytologist* 119: 345–60.

Tyree, M.T. and Zimmermann, M.H. 2002. Xylem structure and ascent of sap. Springer, Berlin, 304 pp.

Wazny, T., Siwecki, R. and Liese, W. 1990. Dendrochronological investigations on the oak decline of the Krotoszny Plateau, Poland. In: R. Siwecki and W. Liese (Editors) Oak decline in Europe: Proceedings of an International Symposium, Kornik, Poland, May 15–18, 1990. Polish Academy of science, Poznan, p. 233–239.

Zhang, S.Y. 1997. Variations and correlations of various ring width and ring density features in European oak: implications in dendroclimatology. *Wood Science and Technology* 31: 63-72.

Received 16 October 2012
Accepted 07 June 2013

ФОРМИРОВАНИЕ ДРЕВЕСИНЫ ДУБА ОБЫКНОВЕННОГО В ЛАТВИИ С 1980 ПО 2009

Р. Матисонс, Д. Елфертс и Г. Брумельис

Резюме

Сокращение прироста (спад) дуба, широко исследован в Европе, однако информация недостаточна в странах Балтии (Латвия). Ширина годичных колец широко используются для анализа прироста, но другие измерения древесины, такие, как площадь сосудов ранней древесины, могут предоставить дополнительную информацию о механизмах ограничения роста. Мы изучали изменения ширины годичных колец и площади сосудов ранней древесины в периоде с 1899 по 2009. Изменения в формировании древесины дуба были обнаружены, в частности, в континентальной, восточной части Латвии. Ширина годичного кольца значительно уменьшилась, в то время как площадь сосудов ранней древесины увеличилась в восточной части Латвии. Эти изменения, вероятно, были вызваны экстремальными погодными условиями: крайне холодным декабрем в 1978 году.

Ключевые слова: сосуды ранней древесины, ширина годичных колец, крайности погоды, *Quercus robur* L.