Latvia University of Agriculture

RESEARCH FOR RURAL DEVELOPMENT 2013

Annual 19th International Scientific Conference Proceedings

Volume 2

Jelgava 2013

Research for Rural Development 2013
Volume 2
Annual 19th International Scientific Conference Proceedings
Jelgava, LLU, 2013
228 pages
ISSN 1691-4031

The ethic statements of the conference „Research for Rural Development 2013" are based on COPE's Best Practice Guidelines:
http://www2.llu.lv/research_conf/proceedings.htm
Approved and indexed:The Proceedings of previous Annual International Scientific Conferences "Research for Rural Development" published by Latvia University of Agriculture since 1994 and has been approved and indexed in to databases: AGRIS; CAB ABSTRACTS; CABI full text; EBSCO Academic Search Complete; Thomson Reuters Web of Science; Elsevier SCOPUS.

Online: http://www2.llu.lv/research_conf/proceedings.htm
Editorial office: Latvia University of Agriculture, Lielā ielā 2, Jelgava, LV -3001, Latvia
Phone and fax: + 371 630 05607; e-mail: Ausma.Markevica@llu.lv

Printed and bound in „Drukātava"

Supported by:

FOREWORD

The four independent reviewers estimated each paper and recommended 68 articles for publishing at the proceedings consisted of 2 volumes, which started life as presentations at the Annual 19th International Scientific Conference "Research for Rural Development 2013" held at the Latvia University of Agriculture, in Jelgava, on 15 to 17 May 2013.

In the retrospect of four months later, we can count the Conference as a great success. The theme – Research for Rural Development - attracted participation more than 150 researchers with very different backgrounds. There were 114 presentations from different universities of Lithuania, Netherland, Poland, Thailand, Kazakhstan, Iran, Nepal and Latvia.

Thank you for your participation! I'm sure that you have learned from the presentations and discussions during the conference and you can use the outcomes in the future.

The cross disciplinary proceedings of the Annual 19th International Scientific Conference "Research for Rural Development 2013" (2 volume since 2010) are intended for academics, students and professionals. The subjects covered by those issues are crop production, animal breeding, agricultural engineering, agrarian and regional economics, food sciences, veterinary medicine, forestry, wood processing, water management, environmental engineering, landscape architecture, information and communication technologies. The proceedings will be useful for researchers in educational sciences, too. The papers are grouped according to the sessions in which they have been presented.

Finally, I wish to thank Organizing and Scientific Committee and the sponsors for their great support to the conference and proceedings.

On behalf of the Organizing Committee
of Annual 19th International Scientific Conference
"Research for Rural Development 2013"

Ausma Markevica
Latvia University of Agriculture

CONTENTS

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

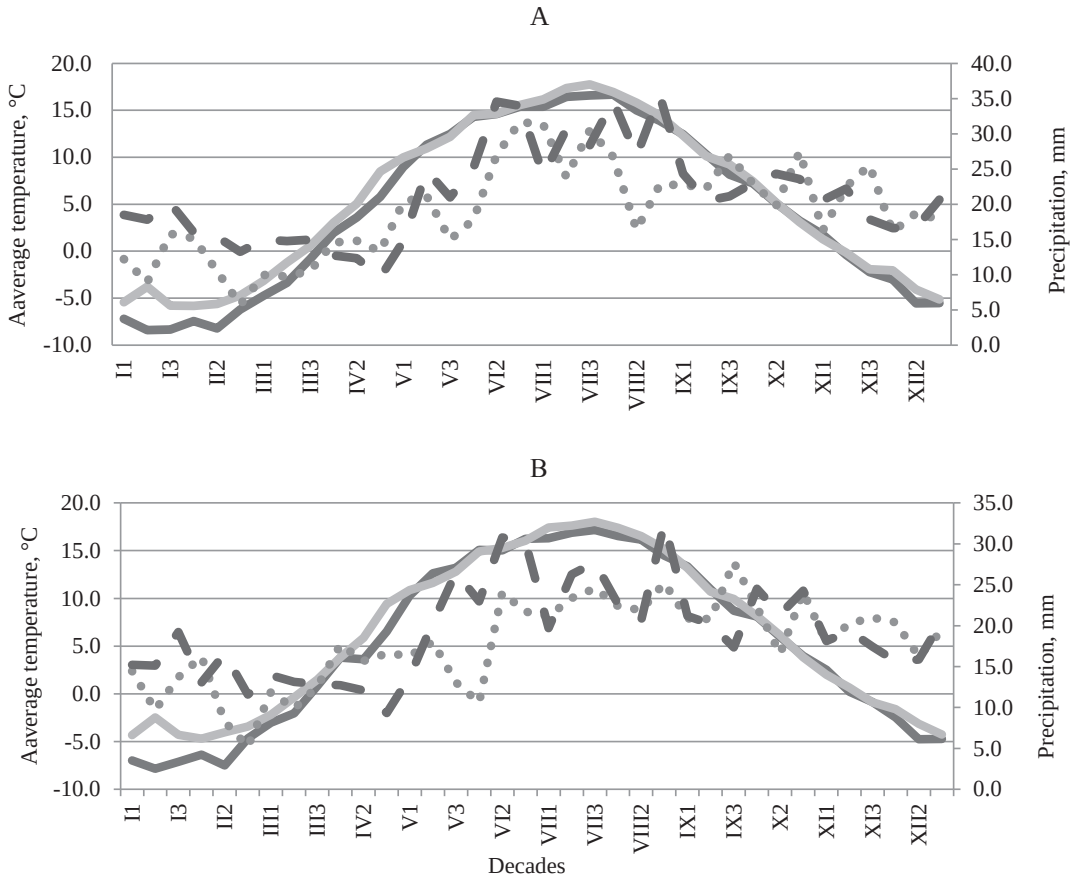


Figure 2. Average air temperature of decades and amount of precipitation in Alūksne weather-station (A) and Zīlāni weather-station (B) for time intervals t1 and t2;
— - T_{avg} (1960-1985), — - T_{avg} (1986-2010), ●●● – Prec (1960-1985), — — — Prec (1986-2010).

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.

Acknowledgements

This research was partly funded by the **European Regional Development Funds project** 'The support system of planning and decision making for the sustainable forest management' (State Education Development Agency, Latvia University of Agriculture, contract number: 2010/0208/2DP/2.1.1.0/10/APIA/VIAA/146). Authors express their gratitude for the technical support to colleagues of the Department of Silviculture.

References

1. Augustaitis A. (2011) Impact of Meteorological Parameters on Response of Pine Crown Condition to Acid Deposition at Aukštaitija National Park. *Baltic Forestry*, 17(2), pp. 205-214.
2. Bassman J.H., Edwards G.E., Robberecht R. (2002) Long-termexposure to enhanced UV-B radiation is not detrimental to growth and photosynthesis in Douglas-fir, *New Phytologist*, 154, pp. 107-120.
3. Dzenis J., Elferts D. (2012) First steps in climate reconstruction from tree-rings of coniferous tree species in Latvia. In: Vitas A. (ed) Materials of the 2nd International Conference of the Baltic States Dendrochronologist; Kaunas, Group of Dendroclimatology and Radiometrics, *Baltdendro 2012*, Lithuania, pp. 6-7. Available at: www.dendrochronology-lt.com/baltdendro2012-mq.pdf, 11 February 2013.
4. Fischer S., Neuwirth B. (2013) Vulnerability of Trees to Climate Events in Temperate Forests of West Germany, *ISRN Forestry*, 2013, Article ID 201360, 15 p. Available at: http://dx.doi.org/10.1155/2013/201360, 2 March 2013.

5. Indriksons A. (2009) *Cycle of Biogenous Elements in Drained Forests*. Resume of the PhD Paper For the Scientific Degree of Dr.silv., LLU, Jelgava, 64 p.
6. Kahle H.P., Spiecker H. (1996) Adaptability of Radial Growth of Norway Spruce to Climate Variations: Results of a Site-Specific Dendroecological Study in High Elevations of the Black Forest (Germany). *Radiocarbon*, (38), pp. 785-801.
7. Liepa I. (1996) *Pieauguma mācība* (*Forest increment science*). LLU, Jelgava, 123 lpp. (in Latvian).
8. Luguza S., Liepa I. (2012a) Structure of the impact of maximal temperature on radial growth of Scots pine (*Pinus sylvestris* L.). In: Collection of Abstracts. *7th International Scientific Conference 'Students on their Way to Science'*, Latvia University of Agriculture, Faculty of Social Sciences, Faculty of Engineering, Forest Faculty, Jelgava, p. 90.
9. Luguza S., Liepa I., Cirse K. (2012b) Role of tree growth active periods in dendroecological research. In: Abstracts and Programme. *Joint International Conference 'Biological Reaction Of Forest To Climate Change and Air Pollution'*, Aleksandras Stulginskis University, Kaunas, p. 99.
10. Luguza S., Miezīte O., Liepa I., Indriksons A., Ruba J. (2012c) Temperature Impact on Distribution of Entomological Damage in Norway Spruce *Picea abies* (L.) Karst. Young Forest Stands. *Mežzinātne*, 25(58)', Special Issue of Abstracts of International Conferences Organized by LVMI SILAVA, SNS, IUFRO, COST, Salaspils, pp. 90-92.
11. McGlade J. (2010) Europe's Environment Agency sets out 2010 report. Available at: http://www.europarl.europa.eu/news/lv/headlines/content/20101129STO02048/html/Eiropas-Vides-a%C4%A3ent%C5%ABras-zi%C5%86ojums-n%C4%81kotne-ir-za%C4%BCa, 25 February 2013.
12. Meža nozare 20 Latvijas neatkarības gados (Forest sector in 20 years of independence). (2012) ZM Meža departaments Available at: http://www.zm.gov.lv/doc_upl/Meza_nozare_20_LV.pdf, 12 March 2013. (in Latvian).
13. Ozolinčius R. (2012) Possible Effects of Climate Change on Forest Biodiversity, Tree Growth and Condition: Review of Research in Lithuania. *Baltic Forestry*, 18(1), pp. 156-167.
14. Rybníček M., Čermák P., Žid T., Kolář T. (2010) Radial growth and health condition of Norway spruce *(Picea abies* (L.) Karst.) stands in relation to climate (Silesian Beskids, Czech Republic)**.** *Geochronometria*, 36(1), pp. 9-16.
15. Speer J.H. (2010) *Fundamentals of tree-ring research*. The University of Arizona Press, Tucson 360 p.
16. Valsts meža dienesta 2011. gada publiskais pārskats (The State Forest Service (SFS) public report 2011) (2012) Valsts meža dienests Available at: http://www.vmd.gov.lv/doc_upl/VMD_PUBLISKAIS_PARSKATS_2011.pdf, 12 March 2013. (in Latvian).
17. Vitas A. (2011) Seasonal Growth Variation of Pine, Spruce, and Birch Recorded by Band Dendrometers in NE Lithuania. *Baltic Forestry*, 17(2), pp. 197-204.
18. Zviedris A. (1960) *Egle un egļu mežs Latvijas PSR* (*Spruce and spruce forest in Latvia USSR*). Latvijas PSR Zinātņu akadēmijas izdevniecība, Rīga, 240 lpp. (in Latvian).
19. Лиепа И.Я. (1980) *Динамика древесных запасов: Прогнозирование и екология* (*Stand volume dynamics. Forecasting and ecology*). Зинатне, Рига, 170 с. (in Russian).

REVIEW ABOUT INVESTIGATIONS OF *SALIX SPP.* IN EUROPE

Irēna Pučka[1], Dagnija Lazdiņa[2]
[1]Latvia University of Agriculture
[2]Latvian State Forest Research Institute "Silava"
irena.pucka@du.lv

Abstract
Willow species are nowadays extensively studied. Species are being investigated to evaluate their use and role in various sectors of national economy. The use of willows in short rotation coppice (SRC) for biomass and energy production has a priority in the European Union policy. There are many countries that have grants and financial aid system for so-called 'green energy' production. Willow species also have other economically and ecologically important features: resistance to contaminants, strong root system, high tannin contents, decorative, etc. Willow SRC systems are used for phytoremediation and in wastewater purification, in combination with biomass production. There are several countries of Eastern Europe researching adequacy of the willow SRC for the farmland contaminated by radionuclides segregated from the Chernobyl nuclear power plant disaster. Willows are used for quarry restoration, water sludge treatment, erosion control etc, but the most important field at the moment is the biomass production.
Key words: *Salix*, willows, biomass, ecological restoration, phytoremediation.

Introduction

Introduction and General Characteristics of Willows (Salix spp.)

The geographical distribution of *Salix spp*. includes all continents except Antarctica and Australia. Plants are adapted to a wide range of climatic and soil conditions (Kuzovkina and Quigley, 2005), and ecological demands of willows to light are high (Саутин и др., 1986; Milovanović et al., 2011). The most suitable soils for willows are the soils rich in nutrients. Some willow species can grow successfully on the soils poor in plant nutrients, dry or peat soils with shallow drainage, which also includes areas not suitable for traditional agriculture (Саутин и др., 1986; Техника, 2012). Willows grow quickly on locations with water-logged soils and prefer neutral soil reaction (Milovanović et al., 2011).

Investigations of fast-growing wood species (willows, poplars, aspens etc.) are a significant area in many countries around the world – Sweden, England, Ireland, Poland, Estonia, Denmark, the USA, Canada et al. (Weih and Nordh, 2005; Mola-Yudego, 2010; Mola-Yudego and González-Olabarria, 2010). Assessing the potential of willow biomass crops in a wide range of countries and economic sectors can highlight fields where willow cultivation can really be economically important.

The ability to outgrow the sprouting willow shoots after harvesting of aboveground biomass, makes it suitable for phytoremediation purposes of contaminated soils (extract heavy metals Cd, Zn and reduce organic pollution). Stands of willows reduce unfavourable effects of wind erosion and prevent soil erosion and have been traditionally used in protective structures (windbreaks, shelters and living walls) because the stands create a strong root system (Kuzovkina and Quigley, 2005; Smart et al., 2005; Kundas et al., 2008; Dimitriou et al., 2009; Pajevic et al., 2009; Milovanović et al., 2011; Родькин, 2011).

Some willow species are evaluated as decorative and are used for landscaping (Саутин и др., 1986; Anonymous, 2011a). Pioneer species can become established on the newly created, vacated, degraded or contaminated soils - for example - gravel pits, quarries, waste sites, roadsides etc. (Kuzovkina and Quigley, 2005; Milovanović et al., 2011). All the components of willow crop (branches, leaves, bark, roots) can be used for practical purposes. Accordingly, complex use of willows does not produce waste (Веселов, 2011). Willow wood is used as the raw material for cellulose, synthetic fibre and in other production processes. Willows have the potential for future economic activity in different fields, so the aim of study is to select and analyze appropriate information about willows related research fields and activities in Europe. The main tasks are to review scientific literature; analyse and interpret assessed factual material and evaluate the qualitative or quantitative indicators of willow plantations.

Materials and Methods

The following paper was developed through a review of essential scientific literature and other information sources, available at the time of writing. These information sources provided information on general characteristics of *Salix*, agricultural requirements, ways of use, economic benefits. This paper focuses on the literature review about the use and the role of willows in different sectors of national economy of the European countries.

Results and Discussion

This section include information about the potential use of willows and willow SRC, and discuss

the expected positive or negative impact of willow cultivation based on the existing literature.

Biomass production of willows

Willow has become one of the most promising fast growing crop of agroforestry and abandonet agricultural land management (Pospelova and Kouzmich, 2006). That can make a contribution to sustainable development - increase employment in rural areas, provide additional incomes for farmers, boost export etc. (Gasol et al., 2008). The highest economic efficiency of willows is measured by the biofuel production (Техника, 2012).

Renewable energy including biomass makes up a great proportion of total energy supplies in many countries across the world. The use of biomass for energy production has a significant role in the European Union policy. The EU legislation determines a mitigation of climate change, reduction of the greenhouse gas emissions of the fossil fuel combustion and providing security of energy sector (Gasol et al., 2008; Mosiej et al., 2012). Proportion of renewable energy in the Europe is expected to increase by at least 20 % by 2020. Due to this, several countries have a target to increase overall share of energy from renewable sources consumption: Spain – 20%, Lithuania, France, Estonia, Slovenia, Romania – 23-25%, Denmark, Portual, Austria – 30-34%, Finland-38%, Latvia – 40%, Sweeden – 49% (Directive 2009/28/EC.., 2009), Ukraine – 11% (Anonymous, 2012), Belarus – 25% (Копиця и др., 2009).

The high price of traditional energy sources (oil, gas), growing demand for energy and higher ecological requirements regarding generation of thermal and electrical energy are the factors that lead to increasing interest in the production of renewable energy(Anonymous, 2011a). The price of energy from willows is aproximetly three times cheaper than from natural gas (Техника, 2012). Willows are among the most widely planted bioenergy crops in Europe (Anonymous, 2004; Faaij, 2006; Mola-Yudego, 2010). In many EU counties the area of land dedicated to willow SRC has increased in recent years, based on planting grant applications. The United Kingdom government provide financial support for the willow plantation establishment. Since 2009 the establishment of plantations is a supported activity also in Latvia and Poland. Sweden has several support mechanisms to farmers and currently is a leader in willow plantation establishment (LVMI "Silava", 2006). Thanks to the Swedish experience, the willow is now one of the most planted commercial energy crops in Europe (Mola-Yudego, 2011) for heat and power production in the willows SRC plantations (Berndes et al., 2003; Mola-Yudego and Aronsson, 2008; Mola-Yudego, 2011). Biomass from SRC has been identified as one of the most energy efficient carbon reduction technologies (Volk et al., 2004; Styles and Jones, 2007). Stands of willow SRC can sequestrate more than 20 tons of CO_2 per hectare per year (Техника, 2012).

The potential for energy forest plantations, including willow plantations, in the European countries is large: for example, in Poland 1.5-2.1 million ha of agricultural land are suitable for plantation establishment. The land suitability for willow and other energy plant cultivation (% of available agricultural lands) has been estimated to be 19% in Estonia, 7.5% in Latvia and 20.6% in Lithuania (Fischer et al., 2005; Mosiej et al., 2012). The largest willow plantations in the EU are located in Sweden (more than 19 000 ha), smaller - in Poland (about 6000 ha), Italy and the United Kingdom (about 3 000 ha) and other European countries (Wright, 2006; Mola-Yudego and González-Olabarria, 2010; Anonymous, 2011a). Further increase of SRC plantations in the EU is expected, especially in the areas near biomass power plants (Dimitriou et al., 2009). *Salix viminalis* (called energy willow) plantations in Ukraine can produce 10 tonnes dry matter per hectare per year (Agrarnik, 2011), in Poland and Sweeden 10-12 tonnes **(**Рагулина, 2007), in Latvia – 6-12 tonnes in fertilized plantations (Lazdiņa et al., 2007).

Ukraine is one of the most energy inefficient countries in Europe (Техника, 2012), although the country has a huge potential for 'green energy' sector development and enlargement of renewable energy sources. Biomass from the plantations of fast-growing species (including willow plantations) is classified as one of the most appropriate form of renewable energy. Despite the favourable climatic conditions and great number of spare lands for industrial plantings in Ukraine, energy plants currently are not sufficiently widespread (Фучило и Сбитная, 2011). Only the company 'SALIX energy' is engaged in willow cultivation and solid biofuel production. In 2012, the area of willow plantations for energy estimated at 280 ha, with plans to increase planted area by about 2000 ha (Anonymous, 2011a; Техника, 2012). According to the Energy Strategy of Ukraine for the period till 2030, it is planned to improve the energy efficiency. Therefore, investments in agro-energetic fields are topical for the state (Anonymous, 2011a). Willow plantations in Ukraine are divided into two groups (depending on the intended purpose): 1) with a narrow specialization – to get raw materials (wickers, furniture wood, bark and others), 2) complex use of all the willow components (Саутин и др., 1986). There are currently no mechanisms for the support of willows growing in Ukraine. Producers of biofuel may get only income tax relief (Anonymous, 2011a).

Belarus shows a high interest in developing more secure and sustainable energy sector (Pospelova and

Kouzmich, 2006). Agroforestry offers a potential way to get biomass for energy production. It is expected that the area under willow plantations will increase (Копиця и др., 2009).

There is little information available about the real extent of willow ecosystems – natural willow stands - in the Russian Federation, which has one of the world's largest areas of natural willow stands (Tsarev, 2005). The willow biomass production has several preconditions - potential biomass production on abandoned agricultural lands, wetlands, river floodplains etc. However, the state needs financial aid (grants, subsidies, etc.) for development of the industry (Рагулина, 2007). Russian leaders have shown an interest in renewable energy sector development by reaching a target of 4.5% of all electricity generation from renewable sources (not including large-scale hydropower plants) by 2020 (Anonymous, 2011b).

Willows for phytoremediation and ecosystem restoration

Willows can be used to improve water quality and to protect or restore riparian ecosystems (Smart et al., 2005), in quarry and degraded soils - quarries, slopes, eroded areas, abandoned pastures restoration in combination with the biomass energy production (Quinn et al., 2004; Алиев и Гаунов, 2007).

In Ukraine, investigations by local scientists show that use of willows in coniferous and broad-leaved forest areas improve soil conditions. *Salix* can be used in projects to restore degraded lands and lands unsuitable for agriculture, to reduce negative impact of some environmental factors (Фучило и Сбитная, 2011). Willow plantations cause positive impact on the local biodiversity (Техника, 2012).

Water quality deterioration was observed in many water bodies of Belarus. Plantations of fast-growing trees have proved to be effective and relatively cheap measure to improve water quality. Willow plantations can be used for agricultural wastewater treatment (Родькин, 2011). Some researchers have been conducted on the ability of willow to dispose of manure and mud runoff from leaching fields and treatment plants. A significant part of lands in Belarus is contaminated, flooded or drained. To restore soil fertility of these territories, willow plantations can be established. Annual natural leaf defoliation ensures the circulation of nutrients and increases the humus content in the soil (Milovanović et al., 2011; Родькин, 2011). High drainage role of the willow species are evaluated positively in Russia, but there is a risk that willows could occlude drainage system with roots (Рагулина, 2007).

Willows have an important role in combating desertification and in the forest landscape restoration (Smart et al., 2005; Bõrjesson and Berndes, 2006). Willow vegetation filters for partial wastewater and sewage sludge treatment were studied in Sweden (Dimitriou and Aronsson, 2005). The advantage of the SRC willow species is a possibility to remove N, P and several heavy metals from agricultural land. Cleaning of drainage water from agricultural land using a willow plantation now is becoming more and more popular in Sweden. P was accumulated in leaves and branches of willows. Similar experiments conducted in other countries are indicative that willows are suitable also for other purposes: municipal and rain water treatment, utilization of nutrients, insurance of zero water runoff from the area (Родькин, 2011).

Experiments in Russia show that completely untreated sewage waters (from animal farms etc.) can be successfully used in plantation fertilization (Рагулина, 2007). Willows enrich the soil with minerals and microelements and serves as a natural filter for groundwater remediation (Техника, 2012).

There has been a study conducted in Latvia with regard to the willow waste water sludge treatment systems (Lazdiņa, 2009).

Land reclamation

Willows might be useful for purification of soils from radionuclides (Родькин, 2011; Kundas et al., 2008). After the Chernobyl accident (1986), more than 4300 km^2 of radioactively contaminated land in Ukraine, Belarus and Russia was excluded from agricultural use. Cultivation of non-food industrial crops may be an alternative land use option for these territories (Van der Perk et al., 2004). Willow SRC has many advantages for contaminated soil and can grow on a wide variety of soils (Raslavičius, 2012). The willow does not accumulate a lot of radionuclides in comparison with grass and cereals and can be used as wood for bioenergy purposes (Kundas et al., 2008). Investigations in Serbia were conducted to establish the ability of the willows to purify polluted areas. The aim was to evaluate the standards of appropriate timber for biodiesel production (Borišev, 2009; Pajevic et al., 2009). In these experiments low concentration levels of heavy metals (Cd, Ni, Pb) were determined in the willow leaves. This suggests that willow plantations could be established on and biomass with relatively low Cd, Pb, Ni concentrations could be obtained from the areas contaminated with heavy metals.

Heavy metal accumulation in soils of Belarus is characteristic mainly to urban areas, along road sides, railways, near dumps and large animal farms. Short rotation willow plantations are appropriate phytotechnology for these territories, because species are highly productive and are resistant to pollution. This biomass can be used to generate biofuels. This study was initiated to evaluate accumulation of heavy metals in willow biomass, depending on the dose of potassium K fertilizer. The optimal dose of potassium fertilizer controls the cesium-137 accumulation in

willow biomass. Willows are able to grow on soils with low zinc and copper content (for example, degraded peatlands). These elements are playing an important role in providing plant viability (Родькин и Пронько, 2010) and no additional fertilizer was needed. A successful implementation of appropriate technologies can promote willow cultivation (Kundas et al., 2008b). Targeted plantation establishment means: species selection, agro technology related solutions, preparation of planting material etc. technologies (Саутин и др., 1986).

Bioengineering

Most studies suggest that SRC willow entails positive effects on biodiversity (Rowe et al., 2009; Dauber et al., 2010). In Ukraine willow plantations are used as protective structures against wind and water erosion, for fixation of coasts, slopes, sands, for nutrient utilization and as snow retention systems (Фучило и Сбитная, 2011; Техника, 2012). The potential of willow plantations in Belarus was estimated for marginal soils, degraded areas restoration. Perennial trees have well-developed deep-penetrating root systems, therefore, can be effectively used to track carbon, water and nutrient (Родькин, 2011).

Russian explorer Афонин (2006) considers that inclusion of willows in continuous or fragmented forest plantations will increase biodiversity and resistance. Heterogeneous willow plantations are suitable for biomass, industrial raw material production, for protective or decorative plantations, for land recultivation or low productivity forest plantation reconstruction (Веселов, 2011).

Other uses of willows

Wood from short rotation willow plantations can be used in the production of cellulose pulp, cardboard and paper. Chips can be used in the production of chipboards for furniture (Stolarski et al., 2011). Lignocellulosic biomass is positively considered as a raw material for the production of second generation liquid fuels (Guidi et al., 2009). Willows provide different wood products (pulp, paper, boards, plywood, packing crates, pallets and furniture), non-wood products (fodder, fuelwood) and services as protection of soil and water, crops, shelter, shade, livestock and dwellings (Tsarev, 2005; Саутин и др., 1986).

In Ukraine and Belarus willows are used as a cheap and renewable raw material for different sectors of economy – for wickerwork (hampers, furnitures etc.), production of medicine, pulp, paper and tannin. Ropes, footwear are produced from living bark. In areas with low forest cover willows are used for housing and ancillary construction (Саутин и др., 1986; Фучило и Сбитная, 2011). Some decorative and splendid willow species are used for landscaping (Родькин, 2011; Фучило и Сбитная, 2011).

Energetic willows in Russia are also used as an ecologically clean raw material for pellet and wood chip production (Техника, 2012). Willows are ranked in an important position in the list of natural healing substances. Some studies have confirmed anti-inflammatory, anaesthetic and antifebrile properties of willow bark extract. Salicylic acid can be obtained from the bark of willow trees (Коптина, 2010). Willow switches are widely used for wickerwork

Table 1

Complex use of willows in different Eastern and Western Europe countries

	Ways of use								
	I	II	III	IV	V	VI	VII	VIII	References
Russia	+	+	+	+	+		+	+	Tsarev, 2005; Афонин, 2006; Алиев и Гаунов, 2007; Рагулина, 2007; Романов и др., 2008; Коптина, 2010
Belarus	+	+	+	+	+	+	+	+	Саутин и др., 1986; Kundas et al., 2008; Родькин и Пронько, 2010; Mosiej et al., 2012; Raslavičius, 2012
Ukraine	+	+	+	+	+	+	+	+	Anonymous, 2004; Фучило и Сбитная, 2011; Техника, 2012
Latvia	+	+	+	+	+		+		Evarts-Bunders, 2005; Lazdiņa, 2009; Mola-Yudego, 2010
Other European countries	+	+	+	+	+		+	+	Van der Peak et al., 2004; Borišev, 2009; Guidi et al., 2009; Pajevic et al., 2009; Stolarski et al., 2011; Mosiej et al., 2012

I – Biomass and energy production; II – Ecosystem restoration; III – Phytoremediation and land reclamation; IV – Bioengineering; V – Landscaping; VI – Housing and ancillary constructions; VII – Wickerworks; VIII – Other use (medicine, cosmetics and cellulose production, salicil acid production, livestock feed etc.)

(Романов и др., 2008). For example, *Salix alba* has a relatively high compressive and breaking strength. The boards for exterior walls, ceiling and partition decoration, farm auxiliary buildings can be made from *S.alba*. Subtle branches are now most widely used for basketry (Веселов, 2011).

The summary of investigations about complex use of willows is presented in Table 1.

Conclusions

1. Willow, as a renewable source of energy and a way of soil bioremediation, is becoming popular and offers benefits for social and environmental sectors in many countries.
2. Proportion of renewable energy in Europe is expected to increase by at least 20% by 2020, also through fast growing tree species use for biomass and energy production.
3. The potential for energy forest plantations in European countries is relatively high - from 7.5% to 20.6% of available agricultural lands.
4. The contribution of willows into energy balance of the European countries will be significant in the future, using biomass as renewable energy source.
5. West European and Scandinavian countries have used willows mainly for phytoremediation and energy purposes. While in some East European countries willow plantations for energy purposes are in initial stages of development.
6. Well-managed willow plantation can yield about 12 tonnes of dry matter per hectare per year.
7. Some countries have used willows as a raw material for chemical processing and for wickerwork.
8. Willows for housing and ancillary constructions are mainly used in Belarus and Ukraine.
9. Willow cultivation also includes potential environmental impacts: field works, raw material extraction (fuels, minerals), additional substances into the environment (fertilizers, pesticides etc.). These effects should be taken into account to make a general assessment of SRC willow.
10. Willow industry is greatly affected by national policies and grant system.
11. The most important impediments for faster development of the willow sector are: a long pay-back period from investing in the willow as an energy crop, yield risks associated with climate variability, high technologies variety.

References

1. Anonymous (2004) *A strategy for non-food crops and uses: creating value from renewable materials*, Department for Environment, Food and Rural Affairs, London, 47 p.
2. Anonymous (2011a) Энергетическая верба – экологическое биотопливо XXI века (Energetic willow – ecological fuel of the 21st Century). *Аграрник*, 21, 6-7c. (in Russian).
3. Anonymous (2011b) Renewable Energy Policy in Russia: Waking the Green Giant. International Finance Corporation, Washington, 72 p.
4. Anonymous (2012) Energy Community Ministerial Council adopts Renewable Energy 2020 targets. Available at:http://www.energy-community.org/portal/page/portal/ENC_HOME/NEWS/News_Details?p_new_id=6342, 15 June 2013.
5. Berndes G., Hoogwijk M., Van den Broek R. (2003) The contribution of biomass in the future global energy supply: a review of 17 studies. *Biomass Bioenergy*, 25, pp. 1-28.
6. Borišev M. (2009) Phytoextraction of Cd, Ni, and Pb Using Four Willow Clones (*Salix spp*.). *Polish Journal of Environmental Studies,* 18 (4), pp. 553-561.
7. Bõrjesson P., Berndes G. (2006) The prospects for willow plantations for wastewater treatment in Sweden. *Biomass and Bioenergy*, 30, pp. 428-438.
8. Dauber J., Jones M.B., Stout J.C. (2010) The impact of biomass crop cultivation on temperate biodiversity. *GCB Bioenergy*,2, pp. 289-309.
9. Dimitriou I., Aronsson P. (2005) Willows for energy and phytoremediation in Sweden. *Unasylva*, 221(56), pp. 46-50.
10. Dimitriou I., Baum C., Baum S., Busch G., Schulz U., Köhn J., Lamersdorf N., Leinweber P., Aronsson P., Weih M., Berndes G., Bolte A. (2009) The impact of Short Rotation Coppice (SRC) cultivation on the environment. *Landbauforschung – vTI Agriculture and Forestry Research*, 59(3), pp. 159-162.
11. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official journal of the European Union*. 47 p.
12. Evarts-Bunders P. (2005) *Vītolu (Salix L.) ģints Latvijā* (Willow (*Salix* L.) species in Latvia). DU BRIPI, Daugavpils, 100 lpp. (in Latvian).
13. Faaij A.P.C. (2006) Bio-energy in Europe: changing technology choices. *Energy Policy*, 34, pp. 322-342.

14. Fischer G., Prieler S., van Velthuizen H. (2005) Biomass potentials of miscanthus, willow and poplar: results and policy implications for Eastern Europe, Northern and Central Asia. *Biomass and Bioenergy,* 28, pp. 119-132.
15. Gasol C.M., Martinez S., Rigola M., Rieradevall J., Assumpico A., Carrasco J., Ciria P., Gabarrell X. (2008) Feasibility assessment of poplar bioenergy systems in the southern Europe. *Renewable and Sustainable Energy Review*, 13, pp. 801-812.
16. Guidi W., Tozzini C., Bonari E. (2009) Estimation of chemical traits in poplar short rotation coppice at stand level. *Biomass Bioenergy*, 33, pp. 1703-1709.
17. Kundas S., Rodzkin A., Pozniak S., Romanovsky C. (2008) Assessment of the environmental benefit of fastgrowing Willow cultivated for biomass supplying. *Protection*, 8, pp. 1-8.
18. Kuzovkina Y.A., Quigley M.F. (2005) Willows beyond wetlands: uses of *Salix* L. species for environmental projects. *Water, Air, and Soil Pollution*, 162, pp. 183-204.
19. Lazdiņa D. (2009) Notekūdeņu dūņu izmantošanas iespējas kārklu plantācijās (Using of wastewater sewage sludge in short rotation willow coppice). *Summary of Promotion Thesis*, Jelgava, LLU, 57 lpp**.** (in Latvian).
20. Lazdiņa D., Lazdiņš A., Kariņš Z., Kāposts V. (2007) Effect of sewage sludge fertilization in short-rotation willow plantations. *Journal of environmental engineering and landscape management,* 15, pp. 105-111.
21. LVMI „Silava" (2006) Īscirtmeta enerģētiskās koksnes plantāciju produktivitātes paaugstināšanas iespējas (Improvement of productivity for energetic short-rotation plantations). Pārskats par projekta izpildi. Salaspils. 84 lpp. (in Latvian).
22. Milovanović J., Babović N., Dordevic A., Spasic S., Marišova E., Končekova L., Kotrla M., Tothova M. (2011) *External and internal factors influencing the growth and biomass production of short rotation woods genus Salix and perennial grass Miscanthus.* Faculty of Applied Ecology FUTURA Singidunum University, Belgrade, 178 p.
23. Mola-Yudego B. (2010) Regional potential yields of short rotation willow plantations on agricultural land in Northern Europe. *Silva Fennica,* 44(1), pp. 63-76.
24. Mola-Yudego B. (2011) Trends and productivity improvements from commercial willow plantations in Sweden during the period 1986-2000. *Biomass and bioenergy*, 35, pp. 446-453.
25. Mola-Yudego B., Aronsson P. (2008) Yield models for commercial willow biomass plantations in Sweden. *Biomass and Bioenergy*, 32(9), pp. 829-837.
26. Mola-Yudego B., González-Olabarria J. (2010) Mapping the expansion and distribution of willow plantations for bioenergy in Sweden: lessons to be learned about the spread of energy crops. *Biomass and Bioenergy*, 34(4), pp. 442-448.
27. Mosiej J., Karczmarczyk A., Wyporska K., Rodzkin A. (2012) Biomass Production in Energy Forests. Short Rotation Plantations. *Forests and Energy*, 3 (17), pp. 196-202.
28. Pajevic S., Borisev M., Nicolic N., Krstic B. (2009) Phytoremediation capacity of poplar (Populus spp.) and willow (*Salix spp*.) clones in relation to photosynthesis. *Archives of biological sciences*, Belgrade, 61(2), pp. 239-247.
29. Pospelova T., Kouzmich V. (2006) Renewable energy projects in the Republic of Belarus. In: Presentation at UNESCO-ROSTE meeting on e-learning in renewable energy in Eastern and South Eastern European countries, Arab states, Australia, Indonesia and China, Venice, 14 p.
30. Quinn J., Stephens W., Brierley E., Harris J., Howsam P. (2004) Quarry Restoration for Sustainable Biomass Energy Production. *Final Report Institute of Water & Environment,* Cranfield University**.** 178 p.
31. Raslavičius L. (2012) Renewable energy sector in Belarus: A review**.** *Renewable and Sustainable Energy Reviews*, 16, pp. 5399-5413.
32. Rowe R.L., Street N.R., Taylor G. (2009) Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable and Sustainable Energy Reviews*, 13, pp. 271-290.
33. Smart L.B., Volk T.A., Lin J., Kopp R.F., Phillips I.S., Cameron K.D., White E.H., Abrahamson L.P. (2005) Genetic improvement of shrub willow (*Salix spp*.) crops for bioenergy and environmental applications in the United States. *Unasylva*, 221(56), pp. 51-55.
34. Stolarski M.J., Szczukowski S., Tworkowski J., Wróblewskab H., Krzyzaniaka M. (2011) Short rotation willow coppice biomass as an industrial and energy feedstock. *Industrial Crops and Products*, 33, pp. 217-223.
35. Styles D., Jones M. (2007) Energy crops in Ireland: Quantifying the potential life-cycle greenhouse gas reductions of energy-crop electricity. *Biomass and Bioenergy,* 31(11-12), pp. 759-772.

36. Tsarev A.P. (2005) Natural poplar and willow ecosystems on a grand scale: the Russian Federation. *Unasylva,* 213(55), pp. 10-11.
37. Van der Perk M., Burema J., Vandenhove H., Goor F., Timofeyev S. (2004) Spatial assessment of the economic feasibility of short rotation coppice on radioactively contaminated land in Belarus, Ukraine, and Russia. II. Monte Carlo analysis. *Journal of Environmental Management*, 72, pp. 233-240.
38. Volk T.A., Verwijst T., Tharakan P.J., Abrahamson L.P., White E.H. (2004) Growing fuel: a sustainability assessment of willow biomass crops. *Frontiers in Ecology and the Environment*, 2(8), pp. 411-418.
39. Weih M., Nordh N.E. (2005) Determination of biomass production in hybrid willows and prediction of field performance from pot studies. *Tree Physiology*, 25, pp. 1197-1206.
40. Wright L. (2006) Worldwide commercial development of bioenergy with a focus on energy crop-based projects. *Biomass and Bioenergy*, 30, pp. 706-714.
41. Алиев И.Н., Гаунов Ю.М. (2007) Естественное лесовосстановление техногенных земель в степной зоне Кабардино-Балкарии (Forest regeneration in the technogenic steppe soils of the Kabardino-Balkar). *Лесное хозяйство и зеленое строительство в Западной Сибири*, Материалы III-го международного интернет-семинара, Томск, ТГУ, 3-8 с. (in Russian).
42. Афонин А.А. (2006) Изменчивость ив Брянского лесного массива и перспективы их селекции на устойчивость и продуктивность (Variability of willows in the Bryansk forests and prospects for their selection in regard to resistance and productivity). Диссертация, 410 с. (in Russian).
43. Веселов А. (2011) Эффективное использование ивы (Effective use of willows) 'Садовод', 34 Available at: http://www.sadovod.spb.ru/TextShablon.php?LinkPage=330, 10 January 2013. (in Russian).
44. Копиця В.Н., Родькин О.И., Шкутник О.А. (2009) Вредители промышленных энергетических плантаций Быстрорастущей ивы в условиях Республики Беларусь (Pests of energy plantations of industrial quick-growing willows in the Republic of Belarus). *Экологический вестник*, 1(7), 29-35 с. (in Russian).
45. Коптина А.В. (2010) Получение биопродуктов из коры ивы Salix acutifolia (Obtaining bioproducts from the *Salix acutifolia* bark). Автореферат. Диссертации на соискание ученой степени кандидата технических наук, Щёлково, 149 с. (in Russian).
46. Рагулина Р.И. (2007) *Биоэнергетический потенциал калининградской области* (Bioenergy in Kaliningrad: potential of the region). Автореферат**,** Московский государственный университет имени М.В. Ломоносова, Калининград, 24 с. (in Russian).
47. Родькин О.И. (2011) *Производство возобновляемого биотоплива в аграрных ландшафтах: экологические и технологические аспекты*. (Production of renewable biofuel in agricultural landscape: the ecological and technological aspects). МГЭУ им. А.Д. Сахарова, Минск, 212 с. (in Russian).
48. Родькин О.И., Пронько С.К. (2009) Моделирование накопления 137Cs в биомассе быстрорастущей ивы для оценки перспективности использования земель в агроэкосистемах в зависимости от уровня их загрязнения радионуклидами (Modeling of cesium-137 accumulation in the willow biomass for assesment of land use perspectives in agro-ecosystems depending on their level of contamination). *Экологический вестник,* 3/4(9/10), 25-31 с. (in Russian).
49. Родькин О.И., Пронько С.К. (2010) Экологические аспекты производства древесины Быстрорастущей ивы (*Salix viminalis*) на загрязненных тяжелыми металлами землях (Environmental aspects of the production of fast growing willow (*Salix viminalis*) wood on areas polluted with heavy metals). *Экологический вестник,* 3(13), 41-46 с. (in Russian).
50. Романов Е.М., Мухортов Д.И., Нуреева Т.В., Трегубов Д.А. (2008) Создание и эксплуатация плантаций с коротким циклом производства (на примере плантаций ивы на лозу) (Establishment and operation of short rotation coppice plantations (example of the willow plantations). Сборник научно-технической информации по лесному хозяйству, *Лесохозяйственная информация*, 3-4 с. (in Russian).
51. Саутин В.И., Райко П.Н., Воробьев В.Н. (1986) *Выращивание и комплексное использование ивы* (Cultivation and complex use of willows). 'Ураджай', Минск, 57 с. (in Russian).
52. Техника (2012) Энергетическая верба-экологически чистое биотопливо 21 века (Energetic willow – ecological fuel of the 21st Century). *Novinka agrotehniki*, 1, 26-28 с. (in Russian).
53. Фучило Я.Д., Сбитная М.В. (2011) Ивы естественной дендрофлоры Украины (Willows of natural dendroflora of Ukraine). Рациональное использование ресурсного потенциала регионов России и сопредельных государств: Сборник научных статей. 'Курсив', Брянск, 175-180 с. Available at: http://afonin-59-bio.narod.ru/mvl/mvl_abstracts.htm, 8 December 2012. (in Russian).

THE INFLUENCE OF THE GROWING SEASON ON THE SPECTRAL REFLECTANCE PROPERTIES OF FOREST TREE SPECIES

Gediminas Masaitis, **Gintautas Mozgeris**
Aleksandras Stulginskis University, Lithuania
gediminas.masaitis@stud.asu.lt

Abstract
The aim of current study was to investigate the spectral separability trends of different tree species due to varying foliage spectral reflectance properties during the growing season. Five tree species prevailing in Lithuania were chosen for the study: Aspen (*Populus Tremula* L.), Black Alder (*Alnus Glutinosa* (L.) Gaertn.), Norway Spruce (*Picea Abies* L.), Scots Pine (*Pinus Sylvestris* L.) and Silver Birch (*Betula Pendula* Roth). The hyperspectral reflectance data was collected under laboratory conditions scanning the foliage samples from two healthy middle aged stands.
Hyperspectral scanning was implemented using Themis Vision Systems LLC VNIR 400H hyperspectral imaging camera in 400-1000 nm range. Principal component analysis and the Jeffries-Matusita distance measure were applied for the analysis of hyperspectral data. The wavelengths providing the best separability between tree species were determined. They were discovered to vary during the growing season: in late spring – early summer the most informative wavelengths were concentrated in blue and near infrared spectral zones, in summer they shifted towards green and red zones, and in autumn they moved further to longer waves - the red and near infrared - spectral zones.
The investigated tree species were determined to be spectrally separable during the whole growing season, but the particular periods were revealed to contribute for improved spectral separability between certain tree species. The separability between coniferous species was best in September, while deciduous species were best separable when the samples were collected in August.
Key words: hyperspectral reflectance, growing season, coniferous trees, deciduous trees.

Introduction

The future of forest inventory lies in much wider usage of remotely sensed data. The hyperspectral imagery, a relatively new technology in remote sensing, is expected to serve as a new solution in forest inventory for a remote identification of tree species. The advent of a new generation of hyperspectral sensors capable to collect high spectral resolution reflectance data, such as the VNIR400H used in this study, encourages expecting the improvement in remote forest tree species classification (Masaitis and Mozgeris, 2012).

Nevertheless, numerous previous studies (Cochrane, 2000; Im and Jensen, 2008; Price, 1994) underlined difficulties in the separability of plants based only on their spectral response. The spectral properties of vegetation are determined by quite a small number of independent variables: the concentration of chlorophyll a, chlorophyll b and the carotenoids in visible wavelengths (400–700nm) (Tucker and Garrett, 1977) and the number and configuration of the air spaces that form the internal leaf structure reflectance in the near infrared wavelengths (700–1300 nm) (Danson, 1995). In summary, the reflectance of vegetation from different species is highly correlated due to their similar chemical composition (Portigal et al., 1997).

Moreover, while modern hyperspectral sensors record spectral signals at very small steps (less than 1 nm), the neighbouring wavebands have a high degree of correlation, resulting in informational redundancy (Thenkabail et al., 2004). This creates challenges of treatment of high-dimensional inter-correlated data (Varshney and Arora, 2004).

Previous studies (Castro-Esau et al., 2004; Kalacska et al., 2007) proved that seasonal spectral variation is a limiting factor to the ability to accurately classify forest species using unsupervised or automated classification techniques. Therefore a better understanding of seasonal spectral variation is needed for the refinement of existing classification techniques or the development of the new ones.

Many studies have been dealing with hyperspectral data at a single plant level (Asner, 1998; Castro-Esau et al., 2004; Kalacska et al., 2007; Manevski et al., 2011; Vaiphasa et al., 2005; Zhang et al., 2006). The results indicated the field or laboratory taken hyperspectral measurements can significantly contribute to the discrimination of plants on species level. But the temporal variation in leaf level spectral signatures was investigated only in several studies so far (Burkholder, 2010; Castro-Esau et al., 2004; Cipar et al., 2008; Dillen et al., 2012; Hesketh and Sánchez-Azofeifa, 2012).

This study is aimed to investigate the spectral separability trends of different tree species regarding the varying foliage reflectance properties during the growing season. Five tree species were selected for the research: Aspen (*Populus Tremula* L.), in pictures and tables referred to as ‘AS’, Black Alder (*Alnus Glutinosa* (L.) Gaertn.), in pictures and tables referred to as ‘BA’, Norway Spruce (*Picea Abies* L.),

in pictures and tables referred to as 'NS', Scots Pine (*Pinus Sylvestris* L.), in pictures and tables referred to as 'SP' and Silver Birch (*Betula Pendula* Roth), in pictures and tables referred to as 'BI'. These species are most common and commercially important forest tree species in Lithuania. Aspen stands make up 3.8%, Black Alder – 6.9%, Birch – 22.3%, Norway Spruce – 20.8%, and Scots Pine – 35.1% of total forest area (State Forest Service, 2012).

The aim of current study was to investigate the spectral separability trends of different tree species due to varying foliage spectral reflectance properties during the growing season.

The objectives are as follows:

1. To determine the wavebands which provide the best spectral separability of investigated species accounting for the growing season.
2. To determine the optimal season enabling the best spectral separability of investigated tree species.

Materials and Methods

The samples of Birch, Norway Spruce and Scots Pine were collected in 50 years old mixed Scots Pine – Birch - Norway Spruce stand grown on dry sandy soil. The samples of Aspen and Black Alder were collected in 40 years old Black Alder – Birch - Aspen stand grown on drained peat soil. Stands were located in Eastern Lithuania, Vilnius district, the area of Arvydai forest district of Nemenčinė State Forest Enterprise, Block No 551, compartment No 1 and Block No 968, compartment No 4. Five best growing (dominant tree in the stand, no foliar loss or other visible symptoms of tree stress or disease) trees in the stands were randomly selected for taking samples for each tree species. The samples were collected from the middle-upper part of the crown of each tree. The folding ladder and basic climbing equipment as well as telescopic cutter were used for samples collection. Four sample branches were cut from the northern – eastern – southern - western sides of the crown of each tree. Totally, 20 samples were obtained from each tree species, i.e. 100 samples in total during one mission.

Eight sample acquisition missions and hyperspectral scanning sessions were performed in total during the whole growing season, the year 2012. The acquisition dates were May 31, June 7, June 14, July 3, July 19, August 12, September 9 and September 22. Cut samples were moistened and immediately packed into plastic bags. The bags were labelled, put into portable cooler bags and transported to the laboratory for immediate spectral measurements.

Sample leaves and needles were harvested only from current year's sprouts of deciduous and coniferous tree species. Each hyperspectral scanning session of the collected samples was conducted as per Masaitis et al. (2013). The produced hyperspectral images were cropped to 1000×1000 pixels. A total of 100 reflectance curves were constructed (20 for each species). Each reflectance curve was treated as a series of numbers (reflectance coefficients) and was used for statistical analyses.

The distribution of the spectral responses at every spectral band was tested for normality using the Shapiro-Wilk test ($\alpha = 0.05$) and the homogeneity of the variance was checked using Levene's test ($\alpha = 0.05$). The spectral data at every spectral band ($p>\alpha$) and for all investigated species were homoscedastic and normally distributed.

Principal component analysis (PCA) was employed to reduce the dimensionality and redundancy inherent in hyperspectral data. PCA reduces the data to a set of orthogonal eigenvectors, which maximize variation and greatly reduce autocorrelation (Wold, 1966). The non-linear iterative partial least squares (NIPALS) algorithm was employed in calculations (Wold, 1966; Wold et al., 1987). In this study, principal component analysis was used to compute the contribution of the reflectance coming from each wavelength to the principal components. Wavebands were treated as independent variables. The reflection data of all 100 samples (20 for each tree species) were analysed. The data were pre-processed using unit variance scaling and mean-centering procedures. Component loadings were computed for each waveband for the latent variables (principal components (PCs) or factors). Component loadings represented the relative grade to which each variable (waveband) explained the relationship between the component and sampled tree species. If the component covers a significant portion of the overall data variance that is related to the differentiation of tree species, then the wavebands with highest loadings on that component are well-suited for tree species differentiation. Thus, the wavebands with the highest absolute values of component loadings were selected as most important ones that can optimally discriminate the tree species and provide the best separability among them.

Spectral responses in selected optimal wavebands were then used to form the matrixes containing values of spectral responses for 20 samples for every tree species. Those matrixes were used to calculate the spectral separability between tree species employing the calculation of Jeffries-Matusita (JM) distances. The JM distance is a measure of the average distance between the two class density functions (Richards, 1999). This measure indicates whether any two tree species are spectrally separable.

For normally distributed classes JM is calculated as:

$$J_{ij} = 2(1 - e^{-B}), \quad (1)$$

in which:

$$B = 1/8\ (m_i - m_j)^T \{(C_i + C_j) / 2\}^{-1} (m_i - m_j) + 1/2 \ln \{(|C_i + C_j) / 2|) / (|\sqrt{|C_i|}\ \sqrt{|C_j|})\}, \quad (2)$$

where: i and j are the spectral responses of two tree species being compared; C is the covariance matrix of the spectral response; m is the mean vector of the spectral response; ln is the natural logarithm function; T is the transposition function; and |C| is the determinant of C.

The JM distance is asymptotic to the value of 2.0 for increasing class separability (Richards, 1999). The JM distance was calculated for every pair of investigated tree species for every sample acquisition day.

Results and Discussion

The PCA has been used as a technique for optimal band selection in many studies (De Backer et al., 2005; Hesketh and Sánchez-Azofeifa, 2012; Kalacska et al., 2007; Koonsanit et al., 2012; Song et al., 2011; Torbick and Becker, 2009) and proved to be a reliable technique among unsupervised band selection methods (Bajcsy and Groves, 2004). It is also used in our study, as it is based on generic information evaluation approach and is computationally efficient.

The PCA indicated that the first five PCs in each resulting transformation were retained such that more than 99% of the variation in the initial spectral data of every sample acquisition day was represented. Thus, the 5 wavebands with the highest absolute values of component loadings to PC1, PC2, PC3, PC4 and PC5 were selected as optimal ones that can discriminate the tree species and provide the best separability between them (Table 1). The blue and near infrared portions of the spectra were the most important ones in tree species discrimination in the beginning of the growing season (May - June), when the just burst leaves of the deciduous species were dominating in the crown and only initial stages of the sprouts development were present in coniferous species. Since July, however, when the rush growth of the sprouts is over and leaves/needles become senescent, the optimal bands shifted to the green - red portion of the spectra, and, as the growing season started turning to its end (in September), the red and near infrared portion of the spectra started to dominate among the most important wavebands.

The selection of only 5 optimal wavebands was performed in order to reduce the redundant spectral responses in a hyperspectral data sets and also considering the principle of JM distance calculation. The JM distance measure applied in our study is a parametric method based on covariance matrixes calculation. Calculation of the JM distance using all 955 bands was not possible because of the singularity problem of matrix inversion (the number of 20 spectral samples per one tree species was not sufficient for such calculation). However, many previous studies have proven a smaller set of selected bands could generate even more accurate results than the whole set of spectral bands (De Backer et al., 2005; Gong et al., 1997; Krahwinkler and Rossmann, 2010; Vaiphasa et al., 2005).

The power of the spectral separability among tree species according to their leaf/needle reflectance during the growing season was estimated by JM distances. Values of JM distance (calculated by Eq. 1) range from 0.0 to 2.0 and indicate how well the selected

Table 1

Optimal wavelengths for tree species spectral separation during the growing season

Date	Wavelengths, nm*
05-31	400.1 ^{B}; 404.6 ^{B}; 739.9 ^{R}; 957.1 ^{NIR}; 987.3 ^{NIR}
06-07	401.8 ^{B}; 416.0 ^{B}; 510.1 ^{G}; 952.7 ^{NIR}; 1000.1 ^{NIR}
06-14	400.1 ^{B}; 418.8 ^{B}; 737.4 ^{R}; 980.2 ^{NIR}; 985.3 ^{NIR}
07-03	400.1 ^{B}; 682.5 ^{R}; 708.7 ^{R}; 742.5 ^{R}; 998.8 ^{NIR}
07-19	400.1 ^{B}; 517.5 ^{G}; 683.1 ^{R}; 694.6 ^{R}; 725.9 ^{R}
08-12	406.9 ^{B}; 557.8 ^{G}; 692.1 ^{R}; 723.3 ^{R}; 735.4 ^{R}
09-09	417.1 ^{B}; 512.0 ^{G}; 731.0 ^{R}; 792.7 ^{NIR}; 988.5 ^{NIR}
09-22	417.1 ^{B}; 683.1 ^{R}; 695.9 ^{R}; 715.0 ^{R}; 731.6 ^{NIR}

* superscripts after the wavelength indicate the portion of the spectra, B – blue (400-495 nm), G – green (495 – 590 nm), R – red (590 – 750 nm), NIR – near infrared (750 – 1000 nm)

pairs of investigated objects are statistically separable. Values greater than 1.9 indicate that the pairs have excellent separability. Values less than 1.0 indicate low separability (Richards, 1999). Many authors have reported JM distance as appropriate separability measure for feature selection (Mutanga et al., 2007; Psomas et al., 2005; Thomas et al., 1987; Vaiphasa et al., 2005). The presence of exponential factor in the JM calculation (Eq. 1) provides an exponentially decreasing weight to increasing separations between spectral classes. If plotted as a function of distance between class means it shows a saturating behaviour which is highly desirable in separability measures (Richards, 1999). Therefore, this method was selected for our study, too. Furthermore, it is easily interpretable and comparable to the results of other studies possible.

Some peculiarities of spectral separability depending on growing seasons were identified (Table 2, Figure 1). The early stages of trees sprouts development offer good separation ability between deciduous and coniferous though the results of the measures on May 31 need to be treated with caution, because on that date the deciduous had all leaves unfolded and coniferous only showed first needles. Analogously, the spectral data acquired in late September, when the leaves of deciduous species started changing their colour, resulted in good separability between coniferous and deciduous.

Overall, since mid-July, spectral responses of Scots Pine showed good separability from the deciduous species. Spectral responses of foliage of Norway Spruce indicated poorer spectral separability from leaves of deciduous trees than the ones of Scots Pine. The spectral separability between Norway Spruce and deciduous trees decreased along with the development of Norway Spruce needles till early-July then, after mid-July, started to increase. The spectral separability among Scots Pine and deciduous trees, on the contrary, revealed general increasing trend through the whole growing season. The values of JM distance for spectral separability among deciduous species (Aspen, Black Alder, and Birch) were relatively low and the best performance of separability was detected in mid-August. The JM indices for investigated coniferous species (Norway Spruce and Scots Pine) proved these species to be best spectrally separable in early September, while the worst separability was detected in early July.

Only few studies questioning the importance of the seasonal effect on spectral reflectance of tree crowns or leaves were conducted so far (Burkholder, 2010; Castro-Esau et al., 2004; Cipar et al., 2008; Dillen et al., 2012; Hesketh and Sánchez-Azofeifa, 2012; Key et al., 2001; Murakami, 2004). None of them was focused on the tree species that were investigated in our study. Anyway, majority of authors stress the effect of season on the accuracy of classification or the degree of spectral separability of forest tree species (Burkholder, 2010; Castro-Esau et al., 2004; Hesketh and Sánchez-Azofeifa, 2012; Key et al., 2001; Murakami, 2004).

As this study was dealing with some methodological aspects on processing of *in situ* acquired hyperspectral data and was aimed to reveal general trends of spectral reflectance development regarding the growing season, to ensure the maximum data objectivity, the sites for sample collection were limited to the area as compact and homogeneous as possible. That resulted in selection of two healthy and well grown stands

Table 2

Jeffries-Matusita distances for investigated tree species

Tree species to be separated	Date of samples acquisition							
	05-31	06-07	06-14	07-03	07-19	08-12	09-09	09-22
AS - BI	1.0253	1.0565	1.1024	1.1677	1.0887	1.2258	1.0969	1.2157
BA - AS	1.0833	1.0460	1.0513	1.1135	1.0513	1.0833	1.0177	1.0223
BA - BI	1.0330	1.0253	1.0025	1.0050	1.0177	1.1618	1.0075	1.0137
BA - NS	1.7600	1.5331	1.4565	1.4279	1.5388	1.4228	1.4279	1.7964
NS - AS	1.9348	1.7264	1.4698	1.6712	1.5445	1.5275	1.4434	1.4331
NS - BI	1.7246	1.4997	1.4434	1.4101	1.4672	1.5024	1.5417	1.8717
SP - AS	1.2306	1.3600	1.6736	1.7289	1.9887	1.9866	1.9955	1.8209
SP - BA	1.0942	1.1303	1.6653	1.6523	1.9689	1.8220	1.8570	1.8483
SP - BI	1.0969	1.1417	1.2586	1.2092	1.6282	1.5219	1.6161	1.9479
SP - NS	1.6405	1.5177	1.6040	1.1360	1.2461	1.3002	1.9640	1.6074

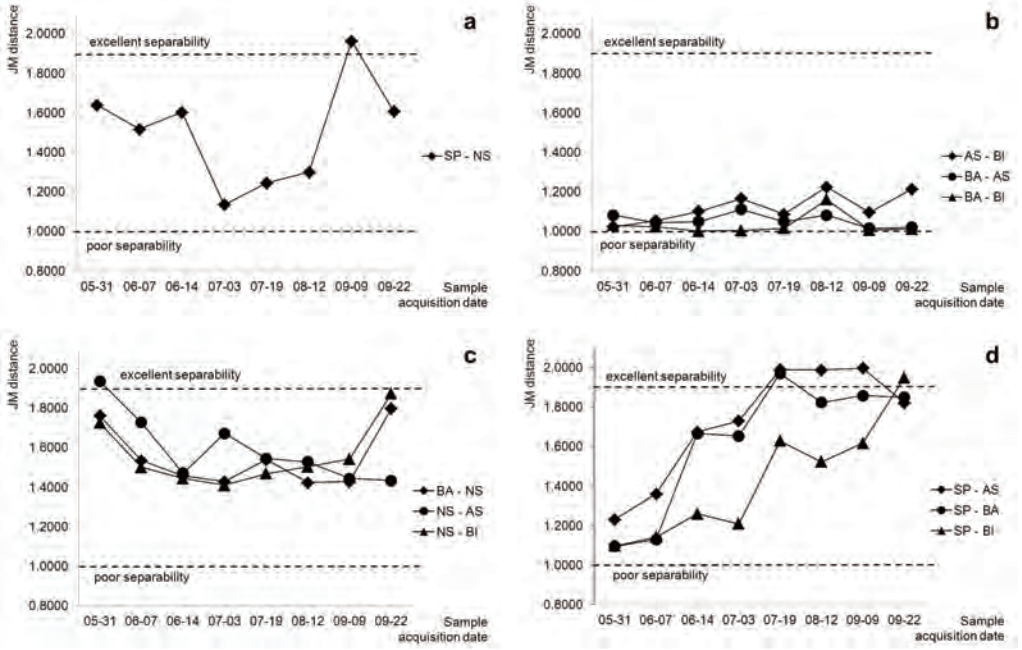


Figure 1. The JM distances between Scots Pine and Norway Spruce (a), between deciduous (b), between Norway Spruce and deciduous (c), and between Scots Pine and deciduous (d).

of similar age which were as spatially proximal as possible. For the same purpose only current year's foliage was collected from the coniferous trees. These conditions of the study should be considered in the treatment of the results.

Conclusions

1. The wavebands which resulted in the best spectral separability among Aspen, Black Alder, Birch, Norway Spruce and Scots Pine varied during the growing season: in late spring – early summer the most informative wavelengths were concentrated in blue and near infrared spectral zones, in summer they shifted towards green and red zones, and in autumn they moved further to longer waves - the red and near infrared spectral zones.
2. The spectral separability between the investigated tree species was discovered to vary depending on the growing season. For coniferous species (Scots Pine and Norway Spruce) it was relatively highest in September, while the deciduous species (Aspen, Black Alder, and Birch) were best separable from each other in August. Scots Pine was found to be better spectrally separable from deciduous than Norway Spruce.
3. This study proved that certain periods of the growing season are important to the intensity of spectral separability of investigated tree species. Overall, the investigated tree species were determined to be spectrally separable during the whole growing season, but particular periods of the growing season were revealed to contribute for improved spectral separability between certain tree species. Thus, correctly chosen spectral data acquisition date would increase the possibility for successful spectral discrimination of desired tree species.

Acknowledgments

The study was carried out within the framework of the national project No VP1-3.1-ŠMM-08-K-01-025 entitled "Specific, genetic diversity and sustainable development of Scots Pine forest to mitigate the negative effects of increased human pressure and climate change" supported by the EU Social Fund.

References

1. Asner G. (1998) Biophysical and biochemical sources of variability in canopy reflectance. *Remote Sensing of Environment*, 64, pp. 234-253.
2. Bajcsy P., Groves P. (2004) Methodology for hyperspectral band selection. *Photogrammetric Engineering and Remote Sensing journal*, 7, pp. 793-802.

3. Burkholder A. (2010) *Seasonal trends in separability of leaf reflectance spectra for Ailanthus altissima and four other tree species, Thesis (Ph.D.)*, West Virginia University, Morgantown, USA, 38 p.
4. Castro-Esau K.L., Sanchez-Azofeifa G.A., Caelli T. (2004) Discrimination of lianas and trees with leaf-level hyperspectral data. *Remote Sensing of Environment,* 90, pp. 353-372.
5. Cipar J., Cooley T., Lockwood R. (2008) Summer to autumn changes in vegetation spectral indices of deciduous trees. In: Gao W. and Wang H. (eds) Remote Sensing and Modeling of Ecosystems for Sustainability V. *Proceedings of the Society of Photo-Optical Instrumentation Engineers(SPIE), Vol. 7083,* San Diego, USA, pp. 8306-8316.
6. Cochrane M.A. (2000) Using vegetation reflectance variability for species level classification of hyperspectral data. *International Journal of Remote Sensing*, 21 (10), pp. 2075-2087.
7. Danson F.M. (1995) Developments in the remote sensing of forest canopy structure. *Advances in Environmental Remote Sensing*, Wiley, New York, USA, 123 p.
8. De Backer S., Kempeneers P., Debruyn W., Scheunders P. (2005) Band selection for hyperspectral remote sensing. *IEEE Geoscience and Remote Sensing Letters*, 2, pp. 319-323.
9. Dillen S.Y., De Beeck M.O., Hufkens K., Buonanduci M., Phillips N.G. (2012) Seasonal patterns of foliar reflectance in relation to photosynthetic capacity and color index in two co-occurring tree species, *Quercus Rubra* and *Betula Papyrifera*. *Agricultural and Forest Meteorology*, 160, pp. 60-68.
10. Gong P., Pu R., Yu B. (1997) Conifer species recognition: an exploratory analysis of in situ hyperspectral data. *Remote Sensing of Environment*, 2, pp. 189-200.
11. Hesketh M., Sánchez-Azofeifa G.A. (2012) The effect of seasonal spectral variation on species classification in the Panamanian tropical forest. *Remote Sensing of Environment*, 118, pp. 73-82.
12. Im J., Jensen R. (2008) Hyperspectral Remote Sensing of Vegetation. *Geography Compass*, 2/6, pp. 1943-1961.
13. Kalacska M., Bohlman S., Sanchez-Azofeifa G.A., Castro-Esau K., Caelli T. (2007) Hyperspectral discrimination of tropical dry forest lianas and trees: Comparative data reduction approaches at the leaf and canopy levels. *Remote Sensing of Environment*, 109, pp. 406-415.
14. Key T., Warner T.A., McGraw J.B., Fajvan M.A. (2001) A comparison of multispectral and multitemporal information in high spatial resolution imagery for classification of individual tree species in a temperate hardwood forest. *Remote Sensing of Environment,* 1, pp. 100-112.
15. Koonsanit K., Jaruskulchai C., Eiumnoh A. (2012) Band selection for dimension reduction in hyperspectral image using integrated information gain and principal components analysis technique. *International Journal of Machine Learning and Computing*, 3, pp. 248-251.
16. Krahwinkler P., Rossmann J. (2010) Tree Species Classification Based on the Analysis of Hyperspectral Remote Sensing Data. In: Reuter R. (ed) Remote Sensing for Science, Education, and Natural and Cultural Heritage. *Proceedings of the 30th EARSeL symposium*, University of Oldenburg, Oldenburg, Germany, pp. 321-328.
17. Manevski K., Manakos I., Petropoulos G.P., Kalaitzidis Ch. (2011) Discrimination of common Mediterranean plant species using field spectroradiometry. *International Journal of Applied Earth Observation and Geoinformation,* 13, pp. 922-933.
18. Masaitis G., Mozgeris G. (2012) Some peculiarities of laboratory measured hyperspectral reflectance characteristics of Scots Pine and Norway Spruce needles. In: Latvia University of Agriculture (eds) Research for Rural Development 2012. *Proceedings of the 18th Annual International Scientific Conference, Vol 2*, Latvia University of Agriculture, Jelgava, Latvia, pp. 25-32.
19. Masaitis G., Mozgeris G., Augustaitis A. (2013) Spectral reflectance properties of healthy and stressed coniferous trees. *iForest*, 6, pp. 30-36.
20. Murakami T. (2004) Seasonal variation in classification accuracy of forest-cover types examined by a single band or band combinations. *Journal of Forest Research*, 3, pp. 211-215.
21. Mutanga O., Ismail R., Ahmed F., Kumar L. (2007) Using insitu hyperspectral remote sensing to discriminate pest attacked pine forests in South Africa. In: Asian Conference on Remote Sensing 2007. *Proceedings of 28th Asian Conference on Remote Sensing,* Curran Associates, Kuala Lumpur, Malaysia, pp. 2089-2095.
22. Portigal F., Holasek R., Mooradian G., Owensby P., Dicksion M., Fene M., Elliot M., Hall E., Driggett D. (1997) Vegetation classification using red-edge 1-st derivative and green peak statistical moment indices with the Advanced Airborne Hyperspectral Imaging System (AAHIS). In: *Proceedings of the 3rd International Airborne Remote Sensing Conference and Exhibition: development, integration, applications and operations, Vol. 2*, ERIM International, Ann Arbor, USA, pp. 789-797.

23. Price J.C. (1994) How unique are spectral signatures? *Remote Sensing of Environment*, 49, pp. 181-186.
24. Psomas A., Zimmermann N.E., Kneubühler M., Kellenberger T., Itten K. (2005) Seasonal variability in spectral reflectance for discriminating grasslands along a dry-mesic gradient in Switzerland. In: Zagajewski B., Sobczak M., Wrzesień M., (eds) New quality in environmental studies. *Proceedings of 4th EARSeL Workshop on Imaging Spectroscopy*, Warsaw, Poland, pp. 655-666.
25. Richards J.A. (1999) *Remote sensing digital image analysis*, Springer-Verlag, Berlin, Germany, p. 240.
26. Song S., Gong W., Zhu B., Huang X. (2011) Wavelength selection and spectral discrimination for Paddy Rice with laboratory measurements of hyperspectral leaf reflectance. *ISPRS Journal of Photogrammetry and Remote Sensing*, 66, pp. 672-682.
27. State Forest Service (2012) *Lithuanian statistical yearbook of forestry*, Lututė, Kaunas, Lithuania, 184 p.
28. Thenkabail P.S., Enclona E.A., Ashton M.S., Van Der Meer B. (2004) Accuracy assessments of hyperspectral waveband performance for vegetation analysis applications. *Remote Sensing of Environment*, 91, pp. 354-376.
29. Thomas I.L., Ching N.P., Benning V.M., D'Aguanno J.A. (1987) A review of multi-channel indices of class separability. *International Journal of Remote Sensing*, 3, pp. 331-350.
30. Torbick N., Becker B. (2009) Evaluating principal components analysis for identifying optimal bands using wetland hyperspectral measurements from the Great Lakes, USA. *Remote Sensing*, 1, pp. 408-417.
31. Tucker C.J., Garrett M.W. (1977) Leaf optical system modeled as a stochastic process. *Applied Optics* 16, pp. 1151-1157.
32. Vaiphasa Ch., Ongsomwang S., Vaiphasa T., Skidmore A.K. (2005) Tropical mangrove species discrimination using hyperspectral data: A laboratory study. *Estuarine, Coastal and Shelf Science,* 65, pp. 371-379.
33. Varshney P., Arora M. (2004) *Advanced Image Processing Techniques for Remotely Sensed Hyperspectral Data*. Springer Press, Berlin, Germany, 322 p.
34. Wold H. (1966) Estimation of principal components and related models by iterative least squares. In: Krishnaiah P. R. (ed) *Multivariate Analysis*, Academic Press, New York, USA, pp. 391-420.
35. Wold S., Esbensen K., Geladi P. (1987) Principal component analysis. C*hemometrics and Intelligent Laboratory Systems*, 2, pp. 37-52.
36. Zhang J., Rivard B., Sánchez-Azofeifa A., Castro-Esau K. (2006) Intra- and inter-class spectral variability of tropical tree species at La Selva Costa Rica: implications for species identification using HYDICE imagery. *Remote Sensing of Environment*, 105, pp. 129-141.

ABIOTIC RISKS OF MANAGING YOUNG FOREST STANDS OF NORWAY SPRUCE (*PICEA ABIES* (L.) KARST.)

Jelena Ruba, **Olga Miezite**, **Raivis Baltmanis**, **Solveiga Luguza**
Latvia University of Agriculture
jelena.ruba@llu.lv

Abstract
According to the forecast, in future the number of storms in Latvia is going to increase. The wind and the snow are risk factors influencing damages of forests; the least tolerant species against wind damages is *Picea abies* (L.) Karst. It is impossible to avoid the damages caused by weather conditions – windbreaks, windthrows, snowbreaks, snow crushes and snowthrows in forests, since they reoccur in certain periods of time. The aim of the research was to analyze the impact of abiotic risk factors on the management of young *Picea abies* (L.) Karst. stands. Young stands of Norway spruce were researched in all regions of Latvia in 2011 and 2012. These stands were up to 40 years old. In total, 75 stands were measured and surveyed, and 257 sample plots were arranged, where the following damages were identified: frost damages, snow crushes, snowbreaks, snowthrows, windfall and windthrows. The sample plot method was used. The intensity of damages is higher on drained soils. The linear correlation between occurrence and intensity of impact damages caused by abiotic factors was significant ($r = 0.988 > r_{0.05} = 0.253$). There is no significant ($p = 0.686 > \alpha = 0.05$) difference between the intensity of impact damages caused by abiotic risk factors in the stands with regular and irregular shapes of forest compartments. Irregular form forest plots have formed naturally, occurrence of abiotic factors there is 7.5% but the factor intensity – 6.7% and that is higher than in regular forest plots where abovementioned parameters reach 4.7% and 2.9%.
Key words: occurrence, intensity, snowbreaks, snow crushes, windbreaks.

Introduction

Forest ecosystem is under impact of both biotic and abiotic factors. The effect of inanimate nature factors has increased. It is indicated by the data collected during the last few years. For example, in year 2011 most of the damage was caused by abiotic factors – 21.3% (Annual Report of the State Forest Service, 2011). Increasingly often it is forecast that winds will become stronger and the number of storms will increase in the territory of Latvia in future (Donis, 2010b). Wind and snow are risk factors which cause more and more damage to the forest. In windfalls the trees are mostly broken directly under the crown level. That is why, the most vulnerable are lanky trees and the ones with a dense wood structure and different damage. We consider it a normal phenomenon when individual windthown trees speed up the ecological succession process. Because of the flat root system, the less resistant tree species to wind damage is Norway spruce (Picea abies) which grows on mineral soil wetlands (The State Forest Service (SFS) Preparation of digital forest map, 2007). In the forest site types on drained soils proportion of broken trees is four times less than proportion of windthrown trees (Donis, 2006). After windfalls there is a possibility of formation of new growing conditions and substrates (Bambe, 2008).

In winter, in Norway spruce forest stands, snow accumulates on tree crowns more than in other forest stands. Due to the conical shape of the tree crown with steep or pendulous branches, the load of the snow on the crowns is evened (Zālītis, 2006). Trees can be windthrown because of the heaviness of snow. It is called a snowbreak. Snowbreaks usually happen in thinned and too dense forest stands, and also in places where the groundwater level is high. Especially endangered are unthinned young forest stands with a lot of diseased, depressed trees, and trees with asymmetric crowns and tilted stems. It is not possible to avoid windfalls, windbreaks, snowbreaks, snow crushes and snowfalls because they appear after certain periods of time. That can bring great losses to the forest owners. The losses can be reduced by forehanded thinning. Often there is a need of clear cutting in forest stands after snowbreaks and windbreaks. That is because of the cracks in tree stems which appear after breaking. Because of this, it is not possible to use stems as an industrial timber and usually they are sold for pulpwood, firewood and chips.

In Latvia severe storms have been recorded in 1795, 1872, 1876, 1967, 1969, 1998, 2000 (Rinkus, 1999), in 2001 (Bambe, 2008), in years 2005 and 2010 (www.vmd.gov.lv/?sadala=359). One of the last severe storms raged in Latvian forests in 2001. Throughout that year large forest areas were toppled both in private and state forest in Zemgale and Latgale. 1022.6 hectares of stands were recognized as dead because of windfalls and windbreaks that comprised 53% of all dead forest stands. Different damage was done to groups of trees as well as to individual trees in the forest stands. Severely damaged forest stands, where density of healthy trees is under the value of critical cross-section area, must be clear cut to avoid fast reproduction of European spruce bark beetle (*Ips typographus* L.*)* and spreading of fungi *Ophiostoma*

Syd. and P. Syd. which reduce the wood quality (Rinkus, 1999; Luksa and Teders, 2001).

Relatively recently – on January 8-9, 2005 severe storm raged in the northern regions of Europe; it reached Latgale as well. As the evaluation of forest stands' extent showed, 19 thousand hectares of forest stands had been destroyed in windfalls and snowbreaks between year 1991 and 2010, so we can conclude that this particular storm had caused the most severe damage to the forest sector. Because of the storm in 2005, a lot of trees were tilted permanently, tree crowns were broken partly or completely. Norway spruce (*Picea abies*) unmixed stands and Scots pine (*Pinus sylvestris*) young forest stands, seasoning and post-mature stands were those that suffered the most. Because of the above-mentioned, the aim of this research is to analyze the risk factors - windfalls, windbreaks, snowfalls, snowbreaks and snow crushes - in the management of Norway spruce young forest stands.

The objectives are:

1) to carry out the analysis of occurrence and intensity of abiotic risk factors of young forest stands in different regions of Latvia;
2) to give assessment of correlation between the sanitary conditions and the location of forest plots in forest area.

Materials and Methods

The research examines up to 40 year old Norway spruce (*Picea abies*) young forest stands, surveyed in the years 2011 and 2012. The empiric material was collected in the year 2011 in 34 stands, in four regions of Latvia. All together 125 temporary sample plots were created in 14 unmixed stands and 20 mixed stands where abiotic damages were detected in 11 Norway spruce (*Picea abies*) stands that had been injured by various factors – frost, snow and wind. Stands for the research were selected randomly. The following damages were detected: wind-broken and wind-thrown trees, snow-crushed, snow-broken and snow-fallen trees (damage by frost – frost crack, windbreak - a fence, line of trees, etc, serving as a protection from the wind by breaking its force, windthrow - the uprooting of trees by wind (Harper Collins, 2013), snow crush - of the snow bent trees (Dolacis, 1998), snowbreak - the breaking of trees by snow, snowfall – an amount of snow that falls in a

Table 1

Characterization of Norway spruce (*Picea abies*) young forests stands damaged by abiotic factors used in research

Research objects	Coordinates (XY)	Stand* composition	Forest site type	$D_{av.}$*, cm	H_{av}*, m	Number of trees per hectare	Spatial shape
34 young forest stands surveyed in 2011, with 11 different kinds of abiotic damages observed in them							
Jelgava 21/14	484807.9; 6287541.3	$5E4B1M_7$	*Myrtillosa mel.*	1.9	2.0	4100	regular
Skede 8/35 (2)	425715.8; 6347181.0	$10E_{32}$	*Oxalidosa*	13.3	15.7	2350	not regular
Jelgava 32/10	484863.4; 6286320.2	$9E1P_{33}$	*Myrtillosa mel.*	14.4	16.0	5800	not regular
Viesite 1/4	580207.1; 6253710.3	$7E2B1A_8$	*Oxalidosa*	2.7	3.6	5530	not regular
Skede 9/14	424443.2; 6346511.6	$6E3B1Ba_5$	*Oxalidosa*	2.0	2.8	3240	not regular
Kalsnava 102/3	615019.4; 6285982.0	$6B4E_{20}$	*Myrtillosa turf. mel.*	5.1	6.0	6850	not regular
Viesite 143/27	585145.5; 6246343.0	$10E_{38}$	*Myrtillosa mel.*	15.4	13.7	1210	regular
Kalsnava 153/1	614652.5; 6284536.1	$10E_{35}$	*Myrtillosa mel.*	16.6	16.9	1150	regular
Dagda 128/4	708813.1; 6233142.0	$10E_{14}$	*Hylocomiosa*	9.9	11.5	3060	not regular
Kalsnava 21/5	616433.1; 6358080.9	$6E2P2B_{19}$	*Oxalidosa turf. mel.*	0.9	6.0	2600	regular
Kalsnava 133/10	615013.6; 6284537.4	$6E4P_{36}$	*Hylocomiosa*	14.8	13.5	960	regular
41 young stands surveyed in 2012, with 1 kind of abiotic damage observed in them							
Jelgava 32/15	484276.9; 6286130.9	$10E_{38}$	*Hylocomiosa*	15.0	15.0	2320	not regular

* $D_{av.}$ – average tree diameter, $H_{av.}$ – average tree height, E – *Picea abies*, B – *Alnus incana*, M – *Alnus glutinosa*, P – *Pinus sylvestris*, B – *Betula* sp., number – stand structure and age.

Table 2

Sample plot radius, area and coefficient (k) for estimation of number of trees

No.	Average tree height, m	Sample plot radius, m	Square sample plot size, m	Sample plot area, m^2	Coefficient (k) to estimate number of trees	Min number of sample plots per ha	Measured sample area, $m^2\ ha^{-1}$
1.	≤ 12.0	3.99	10.0 × 5.0	50	200	4	0.02
2.	12.0 ≤	7.98	-	200	50	2	0.04

Table 3

Damage degrees of abiotic factors

Damage evaluation	Damage degree
Trees without indications of weakening or growth disturbances	0
Economically insignificant damages or faults (few broken branches, small stem damages)	1
Economically significant damages (trees with one or more small stem damages that do not exceed half of the stem diameter, etc.)	2
Highly damaged (damages of the central shoot of tree, its premature die-back; withered, broken top; stem of a tree is bent and cannot take a vertical position; tree with one or more stem damages where scars exceed half of stem diameter; visible resin galls on all length of tree stem)	3
Trees died in the current year (needles and leafs are yellow and brown)	4
Dead trees	5

single storm or in a particular period of time (Merriam – Webster, 2013). Characterization of Norway spruce (*Picea abies*) young forests stands damaged by abiotic factors is presented in Table 1. No damage was observed in pure Norway spruce (*Picea abies*) stands in *Hylocomiosa* and *Oxalidosa* site types if they were surrounded by at least two young forest and seasoning stands as well as in mixed spruce-birch young forest stands in *Oxalidosa* forest site type. By calculating the coefficient of tree slenderness, which is the proportion of average tree height and diameter (H : D), the stability of the young stands of spruce in snowbreaks is found (Skudra and Dreimanis, 1993).

However, in the year 2012 the empirical data were collected in 132 temporary sample plots in 41 stands based on the components of the stands where 15 were pure stands and 26 mixed stands. The number of sample plots depends on area of forest plots (Table 2). Most of them were round sample plots, only in stands with high density square sample plots were used and stationed on diagonals or transects in identical distances on a systematic basis, covering all area of the stand. The ruling indicator for choosing the type of sample plots was the average tree height of the stand. With the average tree height of up to 12 m a 50 m^2 sample plots were created with a circle radius of 3.99 m, but in stands with average tree height H ≥ 12.0 m a sample plot of 200 m^2 with a 7.98 m radius was created (Table 2).

In each of the temporary sample plots trees were counted, diameter at breast height (DBH) was measured (with a precision of 1 mm). To measure DBH at 1.3 m height from the root flare the following instruments were used: electric sliding calliper or simple calliper. Heights for 20 – 30 trees were measured using VERTEX measuring instrument with a precision of 0.1 m. The coordinates of each young growth were determined with a GPS device LKS-92 by transforming geographic coordinates into XY system (The State Forest Service (SFS) Preparation of digital forest map, 2007). Damages of abiotic factors were divided into six damage degrees (Table 3).

To calculate these indicators, it is necessary to estimate the number of trees per hectare, using the following formula (1):

$$N = \frac{Np \times 10000}{L} \quad (1)$$

where N – number of trees per hectare after sample plot inventory data, pieces ha^{-1};
Np – number of trees in the sample plot, pieces;
L – area of sample plot, m^2.

Damage occurrence proportion was estimated using formula (2):

$$P = \frac{n \times 100}{N} \quad (2)$$

where P – damage occurrence proportion, %;
n – number of damaged trees, pieces ha^{-1};
N – total number of measured trees, pieces ha^{-1}.

Damage intensity was estimated using formula (3):

$$R = \frac{\sum n_i b_i \times 100}{N \times k} \quad (3)$$

where R – damage intensity, %;
n_i – number of damaged trees, pieces ha^{-1};
b_i – degree of damage;
N – total number of measured trees, pieces ha^{-1};
k – highest degree of damages (points).

To find out how young stands of Norway spruce are influenced by stands next to them, the location in woodland was defined. Forest plot forms (regular and irregular) were found with the help of the State Forest Service geographical information system (GIS) maps ArcGIS 9.1, 9.2 and 9.3 (The State Forest Service (SFS) Preparation of digital forest map, 2007). Correlation and regression analyses were used for finding out the relevance between the occurance and intensity of damages.

Results and Discussion

Periodical changes in the weather cause snowbreaks, snowfalls, windbreaks and windfalls, that in the forests of Latvia often lead to damages for individual trees as well whole stands. The forests may suffer from insect and fungal attacks, because the sanitary conditions deteriorate after the damage. The analysis of the collected data in the forests of Jelgava, Skede, Viesite, Kalsnava and Dagda areas showed that Norway spruce is often damaged by snowbreaks and snow crushes (79%). The windbreaks are also commonly met in Latvian forests and the occurrence is 19% (in Figure 1 – Figure 3) summary data from Table 1 have been used).

Norway spruce is a tree species which is resistant to frost. Small majority of damage was observed in pure Norway spruce stands, while damage occurrence and intensity of impact was higher in mixed stands. The results of this research showed that frost damage is found just in one of the 75 measured and surveyed young forest stands in Jelgava forest region and occurrence of damages reaches 2%, while in other regions frost damage was not detected. Young forest Norway spruce stands were most severely affected by the snow crushes, snowbreaks and snowfalls in Kalsnava and Dagda regions; while tree damage in Viesīte was significantly smaller, where several types of abiotic risk factors were observed: snow crushes, snowbreaks, windthrows and windbreaks. In Skede region frost and snow crush damages were found in insignificant amount (Figure 1).

All young forest stands were divided in several height groups (up to 5 m; 5.1 – 10; 10.1 m and more) to determine which of them have suffered the most by abiotic factors. Tree damage occurrence in the first group varies from 4.9 – 7.2% and intensity – 2.0 – 6.0%, in the second - occurrence 19.7 – 53.9% and intensity 2.9 – 6.0%, while in the third group respectively -

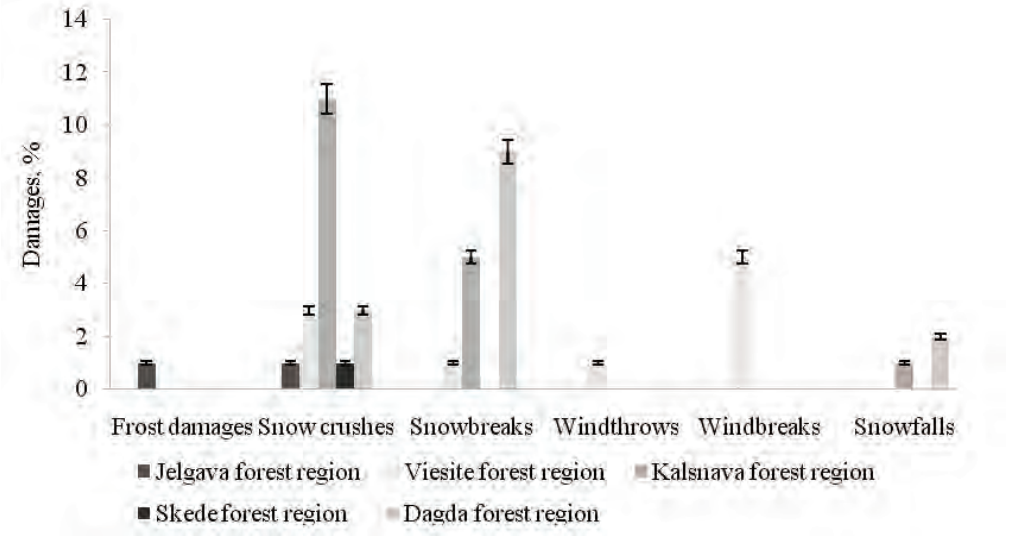


Figure 1. Distribution of abiotic risk factors in different regions of Latvia.

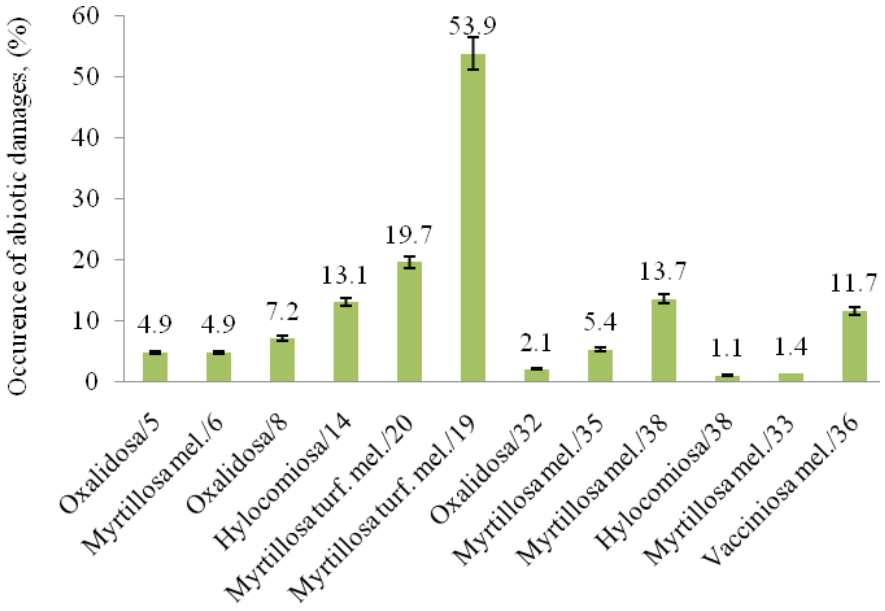


Figure 2. Correlation between forest site type and stand age and the occurrence of abiotic factors.

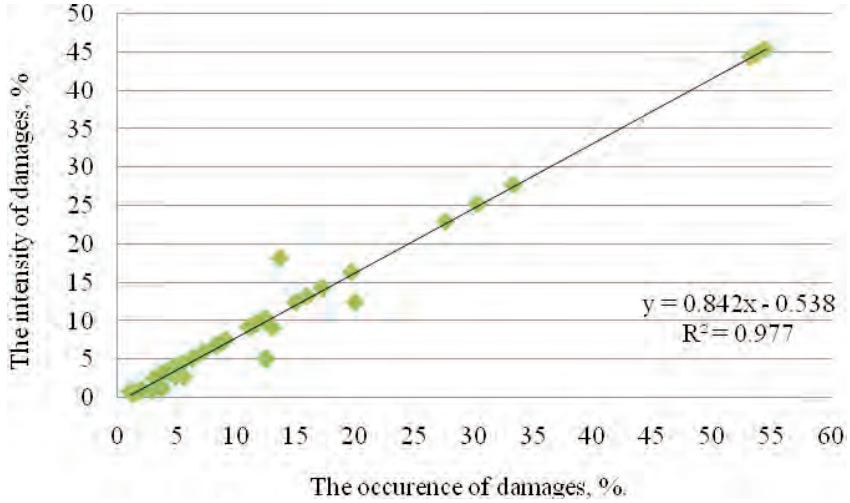


Figure 3. Correlation between abiotic factors occurrence and intensity of damage in spruce young forest stands ($r_{fact} = 0.988 > r_{crit} = 0.253$).

1.1– 13.7% and 0.9 – 18.3%. The most significant damages of snow crush were found in 19-year-old spruce young stands on *Oxalidosa turf. mel*. drained soil with an average height 6.0 m, insignificant – in *Oxalidosa* and *Hylocomiosa* with tree ages ranges 5 – 36 years and with average tree height 11.5 – 16.9 m. Other authors have mentioned previously that in drained forest site types there are more abiotic risks of damages than in other types of forests (Donis, 2006). Looking for the relation between the stand average tree height groups and occurrence of abiotic risks damages analysis of variance showed that there is no significant difference between the stand average tree height groups ($p = 0.522 > \alpha = 0.05$), also there are no significant differences between different regions - Jelgava, Viesite, Skede, Dagda and Kalsnava ($p = 0.535 > \alpha = 0.05$) (Figure 2).

Research of correlation between the occurrence and intensity of the damage of abiotic factors correlation analysis shows significant linear correlation: $r = 0.988 > r_{0.05} = 0.253$ (Figure 3).

After assessing the location of young forest stands in the woodland and objects around them, the research results have shown that the most significant damage is observed in Kalsnava - 21/5. This stand is growing on *Oxalidosa turf. mel.* drained soils and has

a regular form but there is a block ride in the north side (Table 1) while on the other three sides it is surrounded by the middle forest Scots pine stand and two seasoning forest stands. The occurrence of abiotic damages reaches even 53.9% and density 44.9%. J. Donis (2006) concluded that damage intensity in young forest stands depends on a proximal stand structure and infrastructure objects. It means that the forest plot location in the woodland is a significant risk factor for abiotic factor damage intensity that is indicated in our research as well.

After investigation of the location of other forest stands in their woodlands, it was concluded that in stands Kalsnava 102/3, Viesite 143/27 and Kalsnava 133/10 parameters of damage occurrence and intensity differ and are higher than in other young forest stands. Intensity of snowcrushes and snowbreaks in Kalsnava 102/3 reach 16.4%. It should be added that this object is surrounded by birch seasoning stands. After comparing damage between separate sample plots, it was found that there was no significant damage in the first and third ones but in those laid at the very roadside intensity of damage reached 10.4 and 4.0%. The same regularity refers to the young forest stands Dagda 128/4, Viesite 1/4 and Skede 9/14 where more tree damage was observed and it was more intensive in sample plots laid near block rides and forest roads. High ratio of occurrence and intensity could be explained by the fact, that these stands belong to the risk group – unstable stands endangered by snowbreaks and snow crushes with coefficient of slenderness 90 – 120. This means that young forest stands with high density impacts stability against abiotic factors.

After examining the location of woodland and surrounding stands in the research object Viesite 143/27, we may conclude the following – the forest plot is regular, quadrangular; the intensity of windfalls and windbreaks is quite high – 18.3%. Situation can be explained with block roads laying on two sides and being surrounded by two seasoning forest stands. Young forest stand Kalsnava 133/10 shows a quite high ratio of snowfalls and snowbreaks – 9.7%. The occurrence of damage and level of damage intensity in the first and second sample plot is 11.1% and 9.3% respectively and is evaluated as high, but in the third no damage was observed. It could be explained with the shape of the forest plot that was narrow and outstretched along the block road.

After assessing the abiotic risk factors, it is possible to conclude that the periodic damage caused by them is the reason for destruction of huge amount of trees. Wind damage is the cause for uninterrupted economic losses for forest management in several European countries (Zeng et al., 2004; Уланова, 2006). Situation with windfalls is similar because it is not possible to avoid them in almost all types of boreal forests (Ulanova, 2000). For example, research results in Finland show, that wind is the main abiotic factor which causes material losses even more than snow does (Heinonen et al., 2011). Our research deals with the wind impact because it is the second most important factor after the snow damage (19%). Young forest stands and middle forest are those mostly affected by snowbreaks and snowfalls as well as snow crushes which are the reasons for forming of cracks in tree stems or staying bended so the possibility of growing qualitative timber is lost (Ņesterovs, 1954).

To minimize and manage the abiotic risks, it is essential to create the strategy for dealing with natural disasters; there is a need for strict management plan and careful attention, paid to spatial planning (Ткаченко, 1955; Slodicak and Novak, 2006; Donis, 2010a; Panayotov, 2011). Irregular form forest plots have formed naturally, occurrence of abiotic factors there is 7.5% but factor intensity – 6.7% and that is higher than in regular forest plots where abovementioned parameters reach 4.7% and 2.9%. Difference of intensity of abiotic damage factors between regular and irregular forest plots is not significant ($p = 0.686 > \alpha = 0.05$).

Conclusions

1. One of the most important abiotic factors, which is found in all forest districts represented in this research and causes significant impact to Norway spruce young forest stands, is the snow crush.
2. Block rides, roads, amelioration system ditches, water bodies, clear-cut areas and location of the stand in woodland play significant role as factors of the intensity of abiotic damage risk.
3. The most significant damage is observed in those young forest stands of Norway spruce which are located beside the block rides and are surrounded by at least two seasoning stands or middle-forest. In these stands the level of damage occurrence reaches 53.9% and intensity of damage – 44.9%.
4. Shape (regular or irregular) of the forest plot is not a significant abiotic risk factor ($p = 0.686 > \alpha = 0.05$).

Acknowledgments

This research is financed through the European Regional Development Fund project: "Decision support system for sustainable forest management" (No. 2010/0208/2DP/2. 1.1.0/10/APIA/VIAA/146).

References

1. Bambe B. (2008) Veģetācijas dinamika 2005. gada janvāra vētras postītos mežos (Dynamic of vegetation in forests suffered in forest storm in January 2005). *Ģeogrāfija. Ģeoloģija. Vides zinātne: Referātu tēzes*. Latvijas Universitāte, Rīga, 292. lpp. (in Latvian).
2. Valsts meža dienests (2011) Valsts meža dienesta 2011. gada publiskais pārskats (Annual Report of the State Forest Service 2011). Available at: http://www.vmd.gov.lv/doc_upl/vmd_publiskais_parskats_2011.pdf, 15 January 2013. (in Latvian).
3. Harper Collins (2013) Definition of windthrow, windbreak, windfall. The Collins English Dictionary. Available at: www.collinsdictionary.com/dictionary, 14 March 2012.
4. Merriam – Webster (2013) Definition of snowfall, snowbreak. An Enciclopedia Britannika Company Merriam_Webster. Available at: www.merriam-webster.com/dictionary, 14 March 2012.
5. Dolacis J. (1998) *Mežtehnikas, mežsaimniecības un kokrūpniecības terminu vārdnīca* (Dictionary of forestry, the forest industry and the wood processing). Pimais izdevums, Antera, Rīga. 6512 lpp. (in Latvian).
6. Donis J. (2006) *Ekstrēmu vēju ātrumu ietekmes uz kokaudzes noturību novērtējums, lēmuma pieņemšanas atbalsta sistēmas izstrāde* (Evaluation of extreme wind speed impact on steadiness of forest stand, elaboration of the support system of decision making). Zemkopības Ministrijas Meža Attīstības fonda pasūtītais pētījums, LVMI Silava, Salaspils, 64 lpp. (in Latvian).
7. Donis J. (2010a) Klimata izmaiņu radītie meža audzēšanas riski un to mazināšanas iespējas: vējš un uguns (Climate change caused risks on forest growing and facilities of minimization of them: wind and fire). Available at: www.zm.gov.lv/doc_upl/J_Donis_1_dala.pdf, 26 November 2012. (in Latvian).
8. Donis J. (2010b) Klimata izmaiņu radītie meža audzēšanas riski un to samazināšanas iespējas. In: Jansons Ā. (eds) *Meža apsaimniekošana klimata izmaiņu kontekstā* (Climate change caused risks on forest growing and facilities of minimization of them. Forest management in context of climate change). LVMI Silava, Salaspils, 18-20. lpp. (in Latvian).
9. Heinonen T., Pukkala T., Ikonen V.-P., Peltola H., Gregow H., Venäläinen A. (2011) Consideration of strong winds, their directional distribution and snow loading in wind risk assessment related to landscape level forest planning. *Forest Ecology and Management,* 261, pp. 710-719.
10. Luksa M., Teders M. (2001) Vējgāzes Latvijā un Igaunijā (Windfalls in Latvia and Estonia). *Baltijas Koks,* 12 (20), 20.-21. lpp. (in Latvian).
11. Ņesterovs V. (1954) *Vispārīgā mežkopība* (Common silviculture). Latvijas valsts izdevniecība, Rīga, 610 lpp. (in Latvian).
12. Panayotov M., Kulakowski D., Laranjeiro Dos Santos L., Bebi P. (2011) Wind disturbances shape old Norway spruce – dominated forest in Bulgaria. *Forest Ecology and Management,* 262, pp. 470-481.
13. Rinkus E. (1999) 1998. gada snieglauzēs bojāto audžu sanitārā stāvokļa rezultāti (Results in sanitary conditions in year 1998 snowbreak damaged forest stands). *Meža dzīve,* 2, 14-15. lpp. (in Latvian).
14. Rūba J. (2012) *Parastās egles (Picea abies (L.) Karst.) jaunaudžu sanitārais stāvoklis Zemgales, Kurzemes un Vidzemes reģionā* (Sanitary condition of young Norway spruce *Picea abies* (L.) Karst. stands in Zemgale, Kurzeme and Vidzeme regions). Maģistra darbs. LLU, Jelgava, 61 lpp. (in Latvian).
15. Skudra P., Dreimanis A. (1993) *Mežsaimniecības pamati* (Fundamentals of forestry). Zvaigzne, Rīga, 262. lpp. (in Latvian).
16. Slodicak M., Novak J. (2006) Silvicultural measures to increase the mechanical stability of pure secondary Norway spruce stands before conversion. *Forest Ecology and Management,* 224, pp. 252-257.
17. Ulanova N.G. (2000) The effects of windthrow on forests at different spatial scales: a review. *Forest Ecology and Management,* 135, pp. 155-167.
18. Valsts meža dienests (2007) Meža digitālā karte (Preparation of digital forest map). Available at: karte.vmd.gov.lv:7777/vmdgis/main.jsp, 26 February 2013. (in Latvian).
19. Zālītis P. (2006) *Mežkopības priekšnosacījumi* (Preconditions of silviculture). LVMI Silava, Salaspils, 219 lpp. (in Latvian).
20. Zeng H., Peltola H., Talkkari A., Venäläinen A., Strandman H., Kellomäki S., Wang K. (2004) Influence of clear-cutting on the risk of wind damage at forest edges. *Forest Ecology and Management,* 203, pp. 77-88.
21. Ткаченко М.Е. (1955) *Общее лесоведение* (Common siviculture). Издание 2, Гослесбумиздат, Москва: - Ленинград, 597 с. (in Russian).
22. Уланова Н.Г. (2006) *Восстановительная динамика растительности сплошных вырубок и массовых ветровалов в ельниках Южной тайги* (Dynamic of vegetation regeneration after clear-cuttings and massive windfalls in Southern taiga). Диссертация доктора биологических наук, Моск. гос. ун-т им. М.В. Ломоносова, Москва, 424 с. (in Russian).

TREE SPECIES IDENTIFICATION USING LIDAR AND OPTICAL IMAGERY

Gints Priedītis, **Ingus Šmits**, **Salvis Daģis**, **Dagnis Dubrovskis**
Latvia University of Agriculture
Gints.Prieditis@llu.lv

Abstract
Tree species identification is important for a variety of natural resource management and monitoring activities especially in forest inventory. The objective of research is to identify tree species using digital aerial photography and LIDAR data in Latvian forest conditions. The study outlines a number of tree species identification posibilities: the ability to identify conifers and deciduous trees; the ability to identify pine and spruce; the ability to identify birch, aspen and black alder. The study site is a forest in the middle part of Latvia at Jelgava district (56º39' N, 23º47' E). Aerial photography camera (ADS 40) and laser scanner (ALS 50 II) were used to capture the data. LIDAR resolution is 9 points m^{-2} (500 m altitude). The image data is RGB, NIR and PAN spectrum with 20 cm pixel resolution. During the study a modified region growing algorithm was developed to determine tree canopy and tree species identification using threshold segmentation, Fourier transform, frequency filtering and reverse Fourier transform. Tree species classification of coniferous and deciduous trees is possible in 82% of the cases, the first storey of the trees can be classified correctly in 96% of the cases, but the second storey of the trees only in 49% of the cases. Spruce identification is possible in 81.1% of the cases, for first storey trees in 89.6% of the cases and for the second storey trees in 72.9% of cases. Deciduous tree correct classification is possible in 63% of the cases, birch 75%, black alder 60% and aspen only in 41% of the cases.
Key words: Forest inventory, laser scanning, aerial photography, data fusion.

Introduction

Tree species recognition is economically and socially important task of forest inventory. Traditionally recognition of tree species is conducted by a labor-intensive inventory on the field. However, these methods are costly, time-consuming and not applicable to large areas. Since remotely sensed data became applied in forestry, there have been numerous studies to classify tree species at different forest types (Wen et al., 2008; Korpela et al., 2009; Waser et al., 2010). Many researchers using different data sets have been studying spectral patterns that allow obtaining tree species characterizing data from the high-resolution aerial photography (Andersen et al., 2006; Heinzel et al., 2008). The spectral characteristics of tree species were studied at various scales from a single tree (Heinzel et al., 2008; Kim et al., 2008; Vastaranta et al., 2011) to a stand level (Thomas et al., 2006).

The most commonly used datasets in forest inventory based on remote sensing are RGB (Red, Green, and Blue) and NIR (Near Infrared) spectrum. Different studies have described tree species identification ((Heinzel et al., 2008; Kim et al., 2008) and tree location accurate determination (Hyyppä et al., 2008) using such data structure. Mainly required information is obtained from near-infrared captured image intensity, because it describes tree species specificity the best. Most researchers recognize that the range of intensity values cannot be precisely defined corresponding to individual species (Rossmann et al., 2007; Heinzel et al., 2008).There is a very large number of factors that may cause the value of the infrared spectral differences (Vaughn et al., 2012), for example, the exact time when a picture is taken, the weather conditions at the time the image was captured, the flight direction, exposure settings etc. Despite these problems, various studies have shown that using infrared spectrum it is possible to classify coniferous and deciduous trees successfully (Korpela, 2004; Leppänen et al., 2008).

Finnish researcher I. Korpela points out that, in order to raise tree species identification accuracy high resolution areal images are required (Korpela et al., 2009). The study also shows that in automatic tree species identification main source of error is a low-resolution aerial images (Korpela, 2004; Korpela et al., 2009).

Very promising results are obtained with a multispectral and hyperspectral imaging (Holmgren et al., 2008; Dinuls et al., 2011) where hundreds of spectral bands enabled a finer discrimination of spectral properties and have been applied to identify tree species. Factor analysis methods that reduce the high range of data and process only the part which is characterized by tree species are frequently used (Kim et al., 2008; Waser et al., 2010). The main disadvantages of such equipment use are relatively high cost and the quality of the data acquired. Numerous studies have shown that, despite the large number of spectra, spectral measurements tend to be the same for different species (Kim et al., 2008; Wen et al., 2008; Waser et al., 2010). However, R. Dinuls has conducted research in Latvia forests on species classification capabilities using a multispectral camera, he has been able to classify correctly five economically most important tree species with 97% accuracy (Dinuls et al., 2011). It should be noted

that the study was conducted under ideal conditions, but in real practice a number of obstructive factors will influence the classification process and correct classification rate will be lower.

In S. Hatmi study eCognition program was used for automatic tree species identification from multispectral remote sensing data with 2 m spatial resolution. In result the species composition of forest area was determined with 78% accuracy (Hatami, 2012). This paper shows that the tree canopy compartment boundaries and species composition can be determined automatically using specialized software.

Practically for all researchers so far it has been difficult to determine the species in mixed forest stands. Automated identification of species with the individual tree method is still problematic, even in cases with the access to different types of data (Vauhkonen et al., 2008) is available.

Although coniferous and deciduous species can be distinguished using spectral properties, they have their own 3-dimensional crown structures which cannot be detected via passively sensed imagery data (Kim, 2007). Airborne laser scanning (LIght Detection And Ranging, or LIDAR) is one of the active optical remote sensing technologies that can provide highly accurate measurements of both the forest canopy and the ground surface. It provides data that makes it possible to isolate individual trees and using information about 3dimensional crown structures identifies species. However, the use of digital aerial photography and LIDAR data has limitations to distinguish tree species due to the lack of high spectral resolution or large number of spectral bands, or laser scanner parameter settings.

Data processing methods at different conditions work differently, mainly due to forest density, represented tree species and forest diversity, as well as LIDAR and digital aerial cameras technology specifics. Numbers of different methods are used to identify tree species using airborne LIDAR and digital aerial cameras. All of them can be divided into classification, clustering or segmentation approaches which can be subdivided in more details. Frequently used methods are nearest neighbor classification; image segmentation; threshold value segmentation; watersheds segmentation and segmenting of region extensions.

The objective of the research is to identify tree species using digital aerial photography and LIDAR data in Latvian forest conditions. The study outlines a number of tree species recognition variants: the ability to identify conifers and deciduous trees; the ability to identify pine and spruce; the ability to identify birch, aspen and black alder.

Materials and Methods

The study site is a forest in the middle part of Latvia at Jelgava district (56º39’ N, 23º47’ E). Represented species are Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) H.Karst), silver birch (*Betula péndula* Roth), black alder (*Alnus glutinos* L.), and European aspen (*Populus trémula* L.). The area consists of mixed coniferous and deciduous forest with different age, high density, complex structure, various components, composition and soil conditions.

Remote sensing data were obtained using a specialized aircraft Pilatus PC-6, which is equipped with a digital aerial photography camera (ADS 40) and laser scanner (ALS 50 II). A LIDAR digital terrain models (DTM) were estimated from leaf-on data having 9 points m^{-2} at 500 m altitude. Flight was done on 19 May, 2010. The image data is RGB (Red, Green, and Blue*)*, NIR (Near Infrared*)* and PAN (Panchromatic) spectrum with 20 cm pixel resolution.

Tree species accuracy was tested in 350 sample plots (0.045 ha). Only those trees which were recognized with the remote sensing methods were tested.

Differentially corrected Global Positioning System measurements were used to determine the position of each plot center. The accuracy of the positioning was approximately 1 meter. Tree locations within a plot were measured using a center as the origin and then tree azimuth and distance to the center were determined.

To determine tree canopy, an image segmentation was done. The aim is to find all the pixels that belong to the same tree. The method is based on a single tree segmentation using local maxima as tree tops, and a local minimum of the tree crown boundaries. Before the tree segmentation process, in order to improve the results obtained, it is necessary to perform data filtering, which reduces the shadow effect on the segmentation results. The filter, which was applied in the image preparation phase is modeled using band interaction parameters, the mathematical expression is as follows:

$$b'_1 = \frac{b_1}{\sqrt{b_1^2 + b_2^2 + b_3^2}} \quad (1)$$

where, b1, b2, b3 - a range of image intensity values; b’1 - is the image intensity spectrum of the filtered values.

During the study, a modified region growing algorithm was developed (shown in Figure 1). Algorithm starts with a tree center pixel detection process using a local peak detection method with

Fourier transformation. Fourier transform was performed to each image from the previously prepared data sets. After this process, the texture of image was obtained (noise and disturbance that in further processing may be falsely considered as local maxima were filtered). From each found tree center region extension is performed, which will compete with the neighboring regions, until the end of one of the conditions: no more free pixels; the radius of the region exceeds the maximum; none of the surrounding pixels color intensity values fit in 3 standard deviations area from the segment of the internal pixel color intensity values has been reached.

The result of this process is images with foliar segments (shown in Figure 1). For further use of the data, collected segments were converted to a GIS polygon and put into the database. After transformation data were filtered, allowing to get rid of segments with error.

Within the study species identification possibilities were analyzed using near-infrared and RGB aerial photographies, as well as the LIDAR data. During the

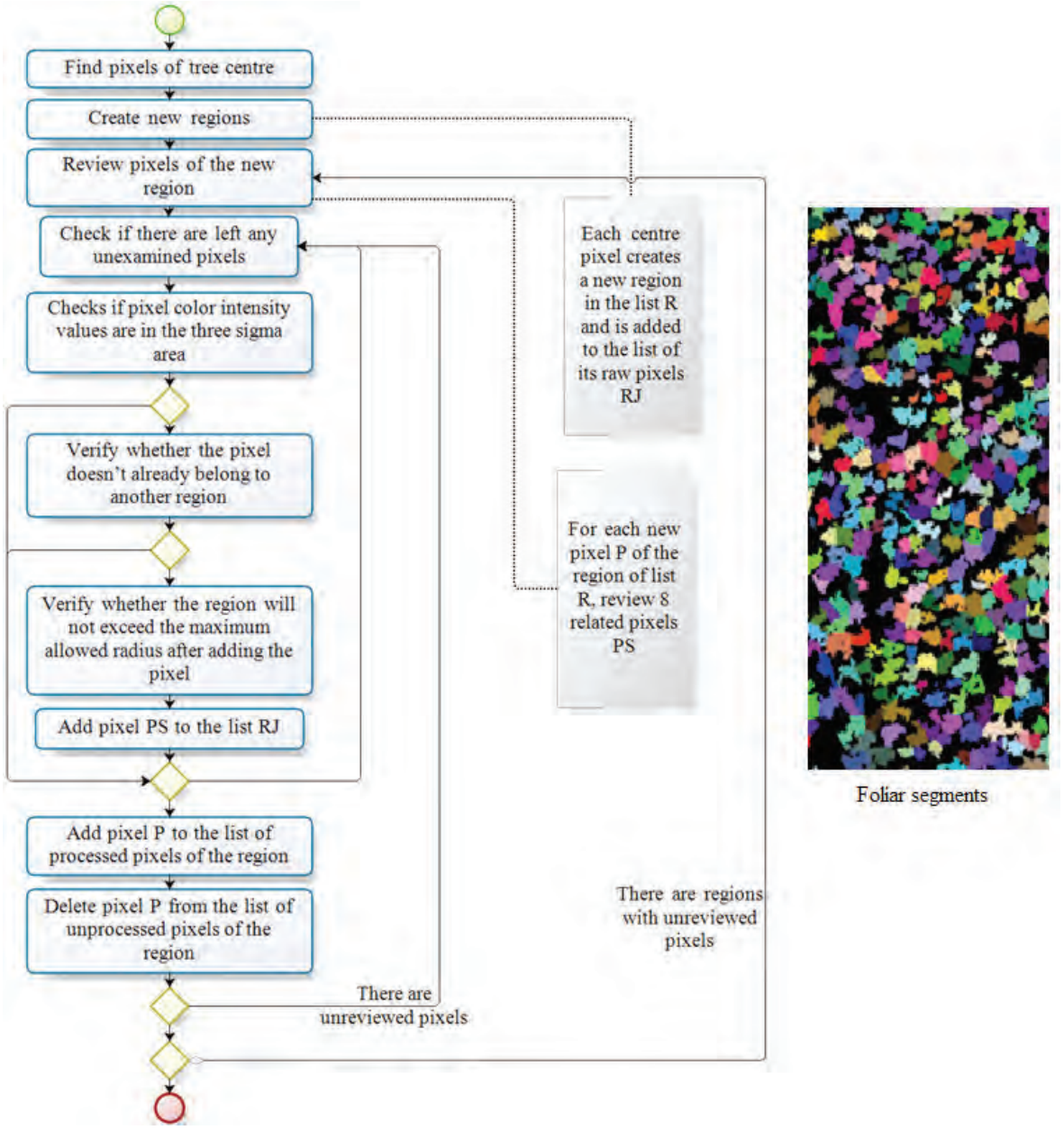


Figure 1. Region growing algorithm to determine tree canopy.

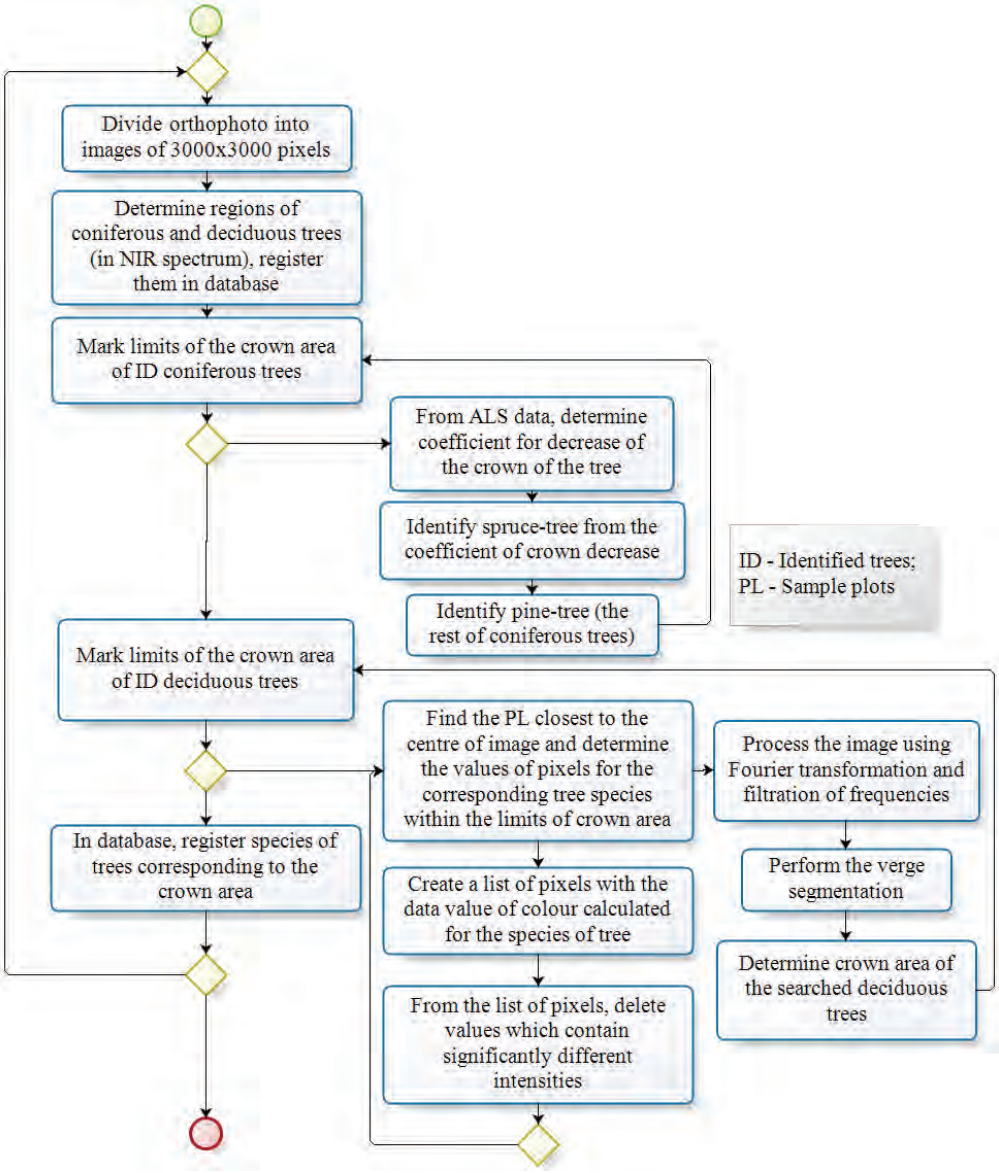


Figure 2. Tree species identification algorithm.

study species identification algorithm was developed (shown in Figure 2.).

Firstly it is necessary to define crown area segments and its boundaries. Then using NIR image coniferous and deciduous regions are defined according to the pixel values in the tree crown segment. Such a distribution of the two groups is simple, because within the image is the observed differences in the intensity of these two groups of species.

To divide coniferous trees in species level LIDAR data were used. All points owned by each tree were found and used to identify the species from tree crown slope factor. Following linear equation was applied to calculate tree crown slope factor:

$$y = mx + b \quad (2)$$

where, y – crown's top slope, degrees; m – slope factor; b – coefficient (in this case, zero).

Tree center point to the other points is considered as the zero point. Slope coefficient describes the height and cross-plane displacement ratio changes, following ratio was used:

$$m = \frac{Y1-Y2}{X1-X2} \quad (3)$$

where, Y – plane elevation changes, m; X – plane displacement changes, m.

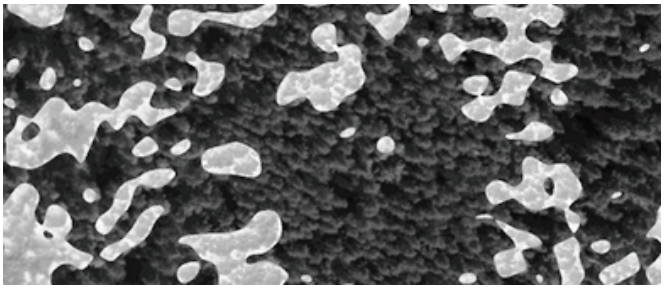


Figure 3. Threshold segmentation resulting image.

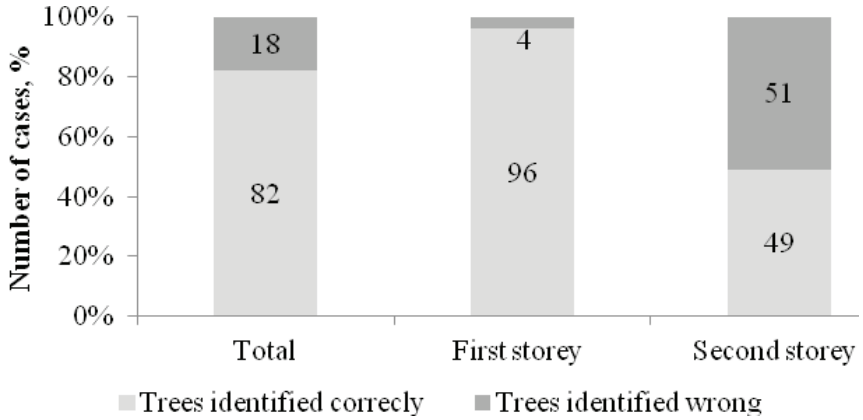


Figure 4. Results of tree classification of coniferous and deciduous trees.

Using a crown slope factor, it is possible to identify spruce, because spruce tops are more pointed than other tree species. This approach has been used for determined tree species spruce, but other conifers were automatically classified as pine.

In species identification within deciduous trees as the output material RGB image was used. The image size is important; too large image can make different color intensity for the same species, thus increasing the possibility of an error. The user is required to mark the sample pixels according to searched species. Output data are taken from the nearest plot against the image center. The resulting sample pixel list is checked and cleared of pixels with very different intensity values, for example, shadow affected and treetop highlighted pixels. Fulfilling all the necessary adjustments the image processing process starts whereby Fourier transform and frequency filtering allows to get rid of the noise. Threshold segmentation is performed to resulting image. The result is a binary (two-color) image (Figure 3.), which represents searched species (segments of the white areas). The threshold value is selected from prepared list of minimum color intensity.

This approach of segmentation allows defining regions with different intensities. In data processing it is necessary to point sample pixels manually according to required species, and this is a big disadvantage for this method.

Results and Discussion

Tree species classification of coniferous and deciduous trees is possible in 82% of the cases, the first storey of the trees can be classified correctly in 96% of the cases, but the second storey of the trees only in 49% of cases. Results of tree classification of coniferous and deciduous trees are shown in Figure 4.

A satisfactory precision level for identification of tree species of coniferous and deciduous trees is 95%, but it can be very difficult to be achieved, especially in mixed stands (Korpela et al., 2009).

The results of the crown slope factor for spruce and pine species level is shown in Figure 5, but crown slope factor for forest storey level (only spruce) in Figure 6. In both figures distribution range of slope factor is shown using amplitude. In this case, attention has been highlighted on the absolute values in order to understand better the properties of spruce crown slope factor. The age class range for pine and spruce is twenty years.

It is possible to recognize tree species using crown shape comparison method from LIDAR data using crown slope factor. Analysis of slope factor values

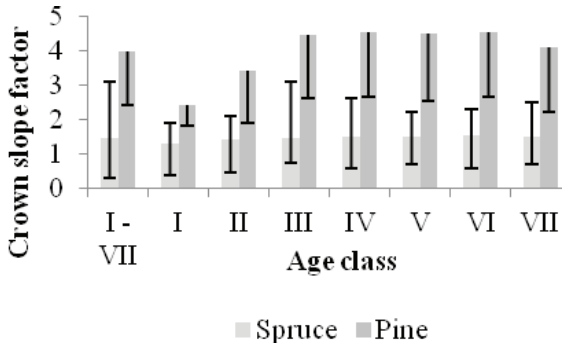


Figure 5. Results of the crown slope factor for spruce and pine species level.

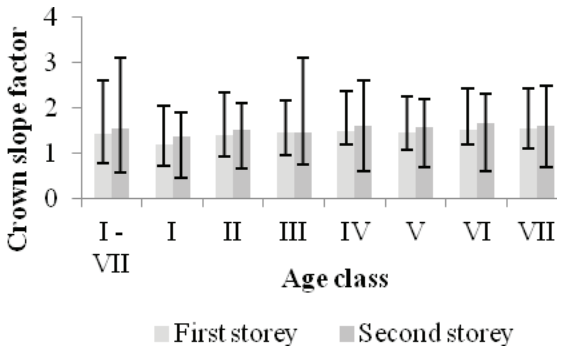


Figure 6. Results of spruce crown slope factor for forest storey level.

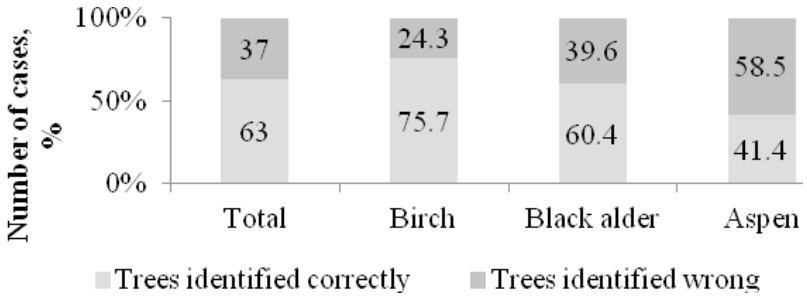


Figure 7. Results of deciduous tree classification.

shows that estimated coefficient at spruce level in 82% is not greater than 1.65; as a result, all trees that are less are considered to be spruce. When discussed young and middle-age stands, the larger range of errors are found. Identified tree species detection results show that method can give correct results in 81.1% of the cases, for the first storey trees in 89.6% of the cases and for the second storey trees in 72.9% of cases. Most trees which are not classified correctly are with small crown dimensions and are located under the dominant tree canopy.

Results of deciduous tree classification are shown in Figure 7. Deciduous tree species classification is possible in 63% of the cases, birch 75%, black alder 60% and aspen only in 41% of cases.

In literature using a similar approach the tree species identification results show variable results. The use of digital aerial photography and LIDAR data has limitations to distinguish tree species due to the lack of high spectral resolution or large number of spectral bands, or laser scanner parameter settings. In many works, the authors mention that the forest type and the dominant species are the main factors that affect tree species identification possibilities (Korpela et al., 2009; Waser et al., 2010). Almost all scientists up until now had problems to identify tree species in a mixed stands using both LIDAR data, as well as digital data of aero photographies. To improve tree species identification level is to perform aero photographing in spring when the forest is less dense and deciduous leafage is with high contrast that can be useful in tree species identification process. Also, either tree crown shape analysis from LIDAR data or multispectral data analysis can be used for better species recognition.

Conclusions

1. Out of all identified trees, classification of coniferous and deciduous tree is possible in 82% of the cases. The first storey trees can be classified correctly in 96% of cases but the second storey trees only in 49% of cases.
2. Deciduous species identification of the available data structure is complicated. Creation of an automated algorithm, during the course of the study that would be able to successfully perform classification of deciduous trees failed, which means that other data collection sources of remote sensing must be searched in order to be able to provide a more diverse information on the research object and to expand possibilities of RGB and CIR data structures.
3. Classification algorithm of deciduous trees showed weak results. Classification of deciduous trees at the level of species works satisfactory with

the dominant trees of the first storey. Results of the classification of species performed during the course of the study shows that 63% of deciduous trees were classified correctly. The species of silver birch was classified correctly in 75%, black alder in 60% but aspen only in 41% of the cases.

4. Other remote sensing data sources need to be used and that could provide more comprehensive information and complete RGB and CIR data structures opportunities.
5. The identification results of identified tree species of the stands for spruce shows that method applied can reach a correct result in 81.1% of the cases, for the first storey trees in 89.6%, but for the second storey trees in 72.9% of the cases.
6. Latvian forest conditions are difficult for single tree remote sensing methods mainly of mixed deciduous and coniferous spaces with high level of the second storey trees in one stand. Mostly trees are close together with high density and homogeneous crown. In most cases, the trees that are identified incorrectly are with small crown dimensions and are growing in the second storey of the stand. One of the error sources are the trees that are not being identified, but with their canopy are creating errors.

References

1. Andersen H.E., McGaughey R.J., Reutebuch S.E., Schreuder G., Agee J. (2006) The Use of Height - Resolution Remotly Sensed Data in Estimating Crown Fire Behavior Variables: Final Report JFSP Project 01-1-4-07. Available at: http://forsys.cfr.washington.edu/JFSP06/FINAL_REPORT_Proj_01_1_4_07.pdf, 16 January 2009.
2. Dinuls R., Lorencs A., Mednieks I. (2011) Performance Comparison of Methods for Tree Species Classification in Multispectral Images. *Electronics and Electrical Engineering*, 111, pp. 119-122.
3. Hatami F. (2012) *Carbon Estimation of Individual Trees Using High Laser Density Data of Airborne LiDAR*: Master's thesis. University of Twente. Enschede (Netherlands), pp. 64.
4. Heinzel J.N., Weinacker H., Koch B. (2008) Full automatic detection of tree species based on delineated single tree crowns - a data fusion approach for airborne laser scanning data and aerial photographs. In: *SilviLaser 2008 conference Proceedings*. Edinburgh (UK), pp. 76-85.
5. Holmgren J., Persson A., Söderman U. (2008) Species identification of individual trees by combining high resolution LiDAR data with multi□spectral images. *International Journal of Remote Sensing*, 29, pp. 1537-1552.
6. Hyyppä J., Hyyppä H., Leckie D., Gougeon F., Yu X., Maltamo M. (2008) Review of methods of small-footprint airborne laser scanning for extracting forest inventory data in boreal forests. *International Journal of Remote Sensing: 3D Remote Sensing in Forestry*, 29, pp. 1339-1366.
7. Kim S., Schreuder G., McGaughey R., Andersen H.E. (2008) Individual tree species identification using LiDAR intensity data. In: *ASPRS 2008 Annual Conference Proceedings*. Oregon: American Society for Photogrammetry and Remote Sensing, pp. 12.
8. Kim S. (2007) *Individual tree species identification using LIDAR- derived crown structures and intensity data*: dissertation. University of Washington, pp. 137.
9. Korpela I., Tokola T., Ørka H.O., Koskinen M. (2009) Small-Footprint Discrete-Return LiDAR in Tree Species Recognition. In: *ISPRS Hannover Workshop 2009 High-Resolution Earth Imaging for Geospatial Information*, pp. 6.
10. Korpela I. (2004) *Individual Tree Measurements by Means of Digital Aerial Photogrammetry*: Academic dissertation. University of Helsinki, pp. 94.
11. Leppänen V.J., Tokola T., Maltamo M., Mehtätalo L., Pusa T., Mustonen J. (2008) Automatic Delineation of Forest Stands from LiDAR Data. In: *GEOBIA 2008 - Pixels, Objects, Intelligence. GEOgraphic Object Based Image Analysis for the 21st Century*. Vol. 38 – Part 4/C1, pp. 6.
12. Rossmann J., Schluse M., Bücken A., Krahwinkler P. (2007) Using Airborne Laser-Scanner-Data in Forestry Management: a Novel Approach to Single Tree Delineation. In: ISPRS Workshop on Laser Scanning 2007 and SilviLaser 2007: conference proceedings. Vol. 36, Part 3/W52, pp. 350-354.
13. Thomas V., Treitz P., McCaughey J.H., Morrison I. (2006) Mapping stand-level forest biophysical variables for a mixedwood boreal forest using lidar: an examination of scanning density. *Canadian Journal of Forest Research*, 36, pp. 34-47.
14. Vastaranta M., Holopainen M., Yu X., Haapanen R., Melkas T., Hyyppä J., Hyyppä H. (2011) Individual Tree Detection and Area – Based Approach in Retrieval of Forest Inventory Characteristics from Low – Pulse Airborne Laser Scanning Data. *The Photogrammetric Journal of Finland*, 22, pp. 1-13.

15. Vaughn N.R., Moskal L.M., Turnblom E.C. (2012) Tree Species Detection Accuracies Using Discrete Point Lidar and Airborne Waveform Lidar. *Remote Sensing*, 4, pp. 377-403.
16. Vauhkonen J., Tokola T., Leppänen V. (2008) Applied 3D texture features in ALS-based tree species segmentation. Available at: http://homepages.ucalgary.ca/~gjhay/geobia/Proceedings/Sessions/Session12/6724_Tokola_Proc.pdf, 16 January 2009.
17. Waser L.T., Baltsavias E., Ginzler C., Küchler M. (2010) Semiautomatic classification of tree species by means of multi-temporal airborne digital sensor data ADS40. In: *ISPRS Technical Commission VII Symposium*. Vol. 38 - Part 7B, pp. 633-638.
18. Wen Z., Baoxin H., Linhai J., Woods M., Courville P. (2008) Automatic Forest Species Classification using Combined LIDAR Data and Optical Imagery. In: *Geoscience and Remote Sensing Symposium*, pp. 134-137.

THEORETICAL EVALUATION OF WOOD FOR BIOENERGY RESOURCES IN PRE-COMMERCIAL THINNING IN LATVIA

Andis Lazdiņš, **Santa Kalēja**, **Kristaps Gruduls**, **Andis Bārdulis**
Latvian State Forest Research Institute "Silava"
andis.lazdins@silava.lv

Abstract
The study represents results of theoretical evaluation of forest biomass available for solid biofuel production in pre-commercial thinning in Latvia. The study is based on the National forest inventory (NFI) data; calculations are done for each NFI plot separately. The calculation is done in three steps – selection of the NFI sample plots, which fulfils criteria for the pre-commercial thinning, development of the diameter distribution table, setting the criteria of the thinning intensity, calculation of extractable biomass. Thinning from below (removal of the smallest trees) is considered in calculation. Two types of biomass are accounted – full tree (aboveground biomass) and stem-wood (stem biomass). The study demonstrates that pre-commercial thinning could become an important source of forest biomass in Latvia (15400 GWh of primary energy according to current situation in forests); however, dimensions of trees and harvesting conditions might be challenging for production. The most of the potential biofuel resources are located in stands with average tree higher than 8 m; therefore, it is reasonably to develop and introduce technologies applicable for production of partially delimbed trees.
Key words: pre-commercial thinning, solid biofuel, resource assessment.

Introduction

Up to 40 years old coniferous, ash and oak stands, up to 10 years old grey alder as well as up to 20 years old stands of other deciduous species are considered young stands (Latvijas Republikas Saeima, 2000). Pre-commercial thinning is done to improve stand structure and secure growth of tree species and populations, which are more adopted to a particular place, to increase productivity of the forest stand and increase value of remaining trees in future. Properly done pre-commercial thinning secures that target trees reach commercially valuable dimensions 10...20 years earlier (Bisenieks, 2005). Pre-commercial thinning in Latvia is usually done with bush-saws before trees reach 6 m height, in pine stands – even sooner. Restrictions for thinning intensity are set by the Regulations of Cabinet of Ministers No. 935 (Ministru Kabinets, 2012). No solid biofuel has been collected in pre-commercial thinning in Latvia up to now, in spite of the fact that this is one of the most important potential sources of high quality solid biofuel in forest operations.

Recent studies on the solid biofuel production in pre-commercial thinning in Latvia are concentrated on increase of productivity and selection of stand for more efficient extraction; however, knowledge about resources and accounting methods are poorly developed (Lazdiņš and Thor, 2009). Due to the fact that there were no alternative solutions, motor-manual pre-cmmercial thinning was also out of the scope of researchers during last decades. Recent studies by the LSFRI Silava about productivity of the motor-manual thinning shows that average productivity varies between 0.14 and 0.03 ha hour^{-1} (7...33 hours ha^{-1}), depending on initial number of trees in the stand, if the average tree height is 6...7 m (Zimelis et al., 2012). This means that mechanized extraction of biomass for energy can be feasible in delayed pre-commercial thinning in forest stands with larger trees, where motor manual operations are loosing their efficiency.

Modern harvesting machines can be used in pre-commercial thinning to produce traditional roundwood assortments as well as forest biofuel from small size stems and tops of trees. Extraction technologies applicable in the pre-commercial thinning can be organized into 4 groups: harvesters or harvarders with accumulating felling heads, combined extraction and comminution machines and motor-manual operations. Combined machines have practical meaning in short rotation plantations, because in normal forest stands relief, dead wood, stumps and other obstacles are considerably hampering productivity (Skogforsk, 2011).

Importance of the resource assessment in the light of productivity of harvesting machinery and adaptation of harvesting methods is highlighted, for instance, in Sweden, where young stands with average tree height less than 12 m covers 12.3% of the forest area and stands with average tree height between 12 and 15 m – 18.4% of the forest area. The first group of stands can contribute to bioenergy production with 149 mill. tons of wood (50 dry tons ha^{-1}); the second group of stands can contribute with 258 mill. tons of wood (62 dry tons ha^{-1}). Studies in Sweden approves that biofuel production in pre-commercial thinning is not feasible, if breast height diameter of average tree in a stand is below 8 cm. For smaller trees the new „Boom corridors" technology and new type of accumulating felling head is invented, securing by 16% higher productivity in comparison to

traditional methods (Bergström, 2009; Bergström et al., 2010).

The aim of the study is to estimate potential solid biofuel resources in pre-commercial thinning following to legal and technical restrictions of the forest management.

Materials and Methods

Theoretical assessment of the solid biofuel resources in pre-commercial thinning is done based on the results of the first round (2004...2008) of the National forest inventory (NFI). All sample plots and their compartments, which correspond to the land use categories forest or afforested land are used in calculation. The NFI data utilized in calculation are land use category, area of the plot or its compartment (in recalculation to forest area 1 m^2 = 0.69 ha), stand type, stand age, soil (organic or mineral), dominant tree species, number of trees in the dominant stand, diameter and height of average tree, basal area and growing stock of the dominant stand. Additional parameters calculated on the base of the NFI data are volume of average tree, minimal number of trees in respect to height of average tree and dominant tree species according to national legislation (a correction of + 10% was applied in calculation). Open street map data (Geofabrik GmbH and OpenStreetMap Contributors, 2013) was used to determine average distance between centre of the particular NFI plot and the nearest road. The State forest register database was used to identify those NFI sample plots, which overlaps with forest compartments, where forest management is restricted by law. The areas, where forest thinning is forbidden, were excluded from the calculation of resources.

The NFI plots and sectors suitable for solid biofuel production in pre-commercial thinning were selected by separation of areas on poor soils (*Cladinoso-callunosa, Callunoso-sphagnosa, Callunosa mel.* and *Callunosa turf. mel.*) as well as in stand types, where pre-commercial thinning is not a common forestry practice (*Sphagnosa, Caricoso-phragmitosa, Dryopterioso-caricosa* and *Filipendulosa*). Remaining plots were split into 2 groups – on wet and organic soils (suitable for extraction on frozen soil) and on dry or drained mineral soils (can be extracted at any time). Then the plots and compartments with average tree height of 4...12 m were selected for further evaluation – selection of areas, where basal area (number of trees) would be above minimal allowed value after extraction of 20% of trees (cleaning of 4 m wide strip-roads). For species, which do not have legal requirements for minimal basal area, the values of birch are used in calculation (Ministru Kabinets, 2012).

Due to lack of reliable biomass expansion factors for small trees in forest lands, biomass expansion factors elaborated in afforested lands were used in the resource assessment (Lazdins, 2011). Stem and aboveground biomass of trees is estimated using equation 1, species specific coefficients are provided in Table 1. Biomass calculations are done according to the dominant tree species.

$$Y_i = b_0 * x_i^{b_1}, \text{where}$$

Y_i – *biomass* (*stem or above ground biomass, kg*);
x_i – *factorial value* (*diameter at breast height, cm*);
b_0; b_1 – *coefficients*.

(1)

Growing volume is calculated by multiplying stem biomass and relative wood density (Table 2). For other species that are mentioned in Table 2 density of birch was applied.

Extractable biomass is calculated in two steps. At the first step, the number and biomass of trees extractable on strip-roads was estimated, assuming that strip-roads cover 20% of stands; at the second step, the number and biomass of trees to be harvested in the remaining stand to reach minimum basal area were estimated. Stem volume extractable on strip-roads was calculated using proportion – 20% of growing stock, stem biomass was calculated according to relative

Table 1

Coefficients for calculation of biomass of trees (Lazdiņš et al., 2011)

Species	Stem biomass		Above ground biomass	
	b_0	b_1	b_0	b_1
Aspen	0.17	1.78	0.27	1.61
Birch	0.17	1.95	0.29	1.76
Grey alder	0.16	1.77	0.2	1.78
Spruce	0.36	1.37	1.16	1.21
Black alder	0.1	2.27	0.12	2.24
Pine	0.14	1.88	0.23	1.91

wood density (Table 2), above ground biomass was calculated using biomass expansion factors (Table 3). Average tree volume on strip-roads was calculated using equation 2, number of extractable trees – equation 3.

$$v = \frac{V}{n}, where$$

$$v - stem\ volume\ of\ average\ tree, m^3,$$
$$V - given\ growing\ stock, m^3 ha^{-1},$$
$$n - given\ number\ of\ trees\ per\ ha^{-1}. \quad (2)$$

$$n_1 = \frac{V * 20}{v}, where$$

$$n_1 - number\ of\ extractable\ trees\ per\ ha^{-1}. \quad (3)$$

Table 2

Relative wood density (Penman, 2003)

No.	Species	Relative wood density, tons m^{-3}
1.	Aspen	0.35
2.	Grey alder	0.45
3.	Birch	0.5
4.	Spruce	0.4
5.	Black alder	0.45
6.	Ash	0.58
7.	Oak	0.58
8.	Pine	0.42

Table 3

Biomass expansion factors (Penman, 2003)

No.	Species	Biomass expansion factors (stem to above ground biomass)
1.	Coniferous species	1.35
2.	Deciduous species	1.30

Estimation of biomass of extractable trees in the remaining stand starts with calculation of diameter distribution of the stand using *Beta* distribution equation (Arlinger, 1997). The general Beta function is provided in equation 4.

$$B_{(m,n)} = \int X^{m-1} * (1 - X)^{n-1} * d * x \quad m, n > 0 \quad (4)$$

Minimal diameter of trees $a = 0.4 \bullet d$, maximal diameter b = $1.7 \bullet d$, where d is diameter of average tree in the plot. The equation is approved in stands with average diameter of trees in the range of 6...60 cm (Arlinger, 1997); therefore, there is a risk that estimation of the solid biofuel resources in this study may have high level of uncertainty.

Coefficient m for pine, birch and other species is calculated by equation 5, for spruce – with equation 6. Coefficient n is calculated by equation 7 for all species.

$$m = 0.5 + 0.1 * (d - 6) \quad (5)$$

$$m = 0.3 + 0.08 * (d - 6) \quad (6)$$

$$n = m * \left(\frac{b - a}{d - a} - 1\right) \quad (7)$$

Number of trees in each diameter class is calculated using equation 8. Distribution of trees is calculated within the range of 2...30 cm with 1 cm step. It the sum of trees in distribution differed from actual number of trees, remaining trees were added or removed equally from all presented diameter classes.

$n = (x - a)^{m-1} * (b - x)^{n-1}$, where
$x - diameter\ of\ tree\ (cm)$ (8)

Extractable trees were accounted in smaller diameter classes until the number of trees to be removed is reached. Respectively, all trees in larger diameter classes are set for retaining until the sum of trees in a particular diameter class reaches the minimal number of trees calculated earlier; the rest of trees in remaining diameter classes are marked for extraction. The last stage of calculation is estimation of average diameter of extractable trees and above ground and stem biomass using equation 1, stem volume by multiplying of stem biomass and relative wood density, calculation of total extractable biomass and stem volume (in strip-roads and a stand), number of extractable trees and average volume, and other characteristics of extractable trees.

The intermediate results (extractable above-ground biomass per ha^{-1}) were filtered to select outliers (values exceeding range of 3 standard deviations), which were replaced with average values except outliers (extractable above-ground biomass, stem biomass and stem volume per ha^{-1}) for particular tree species.

Results and Discussion

According to the study results, extraction of biofuel in pre-commercial thinning is possible in 161 kha area (4.5% of the forest area in Latvia and about 20% of the forest stands, which fits the height criteria for pre-commercial thinning). Total extractable aboveground biomass is 2962 ktons (15400 GWh of primary energy), stem biomass – 2231 ktons, stem-wood – 4.9 mill. m^3. Average extractable aboveground

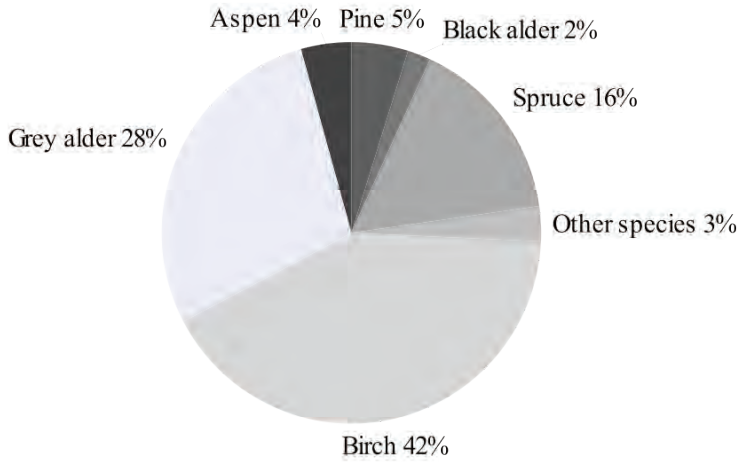


Figure 1. Distribution of stem biomass available for biofuel production in pre-commercial thinning.

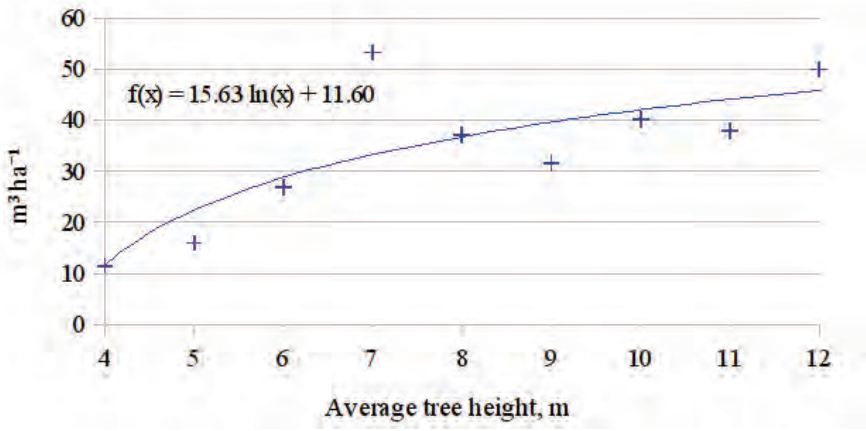


Figure 2. Average extractable stock depending on height of average tree.

biomass is 25 tons ha^{-1}, stem biomass – 19 tons ha^{-1}, stem volume – 41 m^3 ha^{-1}. Stem volume of average extractable tree is 0.01 m^3; this includes trees with diameter of less than 4 cm, which are not used for biofuel production, respectively actual stem volume of average tree is larger. Average age of stand suitable for biofuel production is 18 years.

The most of the resources are concentrated in birch dominant areas (42%, Figure 1), coniferous contributes to 21% of the resources, which means that potential deliveries of biomass to pellet factories using mainly coniferous wood is limited (462 ktons of stem-wood).

If selecting only stands with average breast height diameter of at least 8 cm, the biofuel extraction in pre-commercial thinning can be done in 53 kha (33% of the potentially accessible areas), including 13 kha accessible only in winter. Total extractable aboveground biomass in these areas is 1065 ktons, extractable stemwood – 2.4 mill. m^3 (49% of stem-wood accessible in pre-commercial thinning according to this study), stem volume of average extractable tree is 0.03 m^3.

Extractable stock of stem-wood varies from 12 m^3 ha^{-1} in areas with average tree height of 4 m to 50 m^3 ha^{-1} in areas with average tree height of 12 m (Figure 2). The largest average extractable stock is in birch stands (66 m^3 ha^{-1}). Average estimated intensity of thinning is 41% of the growing stock.

Stem volume of average extractable tree follows to exponential regression determined by the initial height of average tree (Figure 3). The stem volume of average extractable tree is 15 times bigger in areas, where height of average tree is 12 m in comparison to areas with 4 m long trees and 6 times larger in comparison to areas with 6 m long trees. This means that delaying of pre-commercial thinning is important factor to increase feasibility of the biofuel extraction.

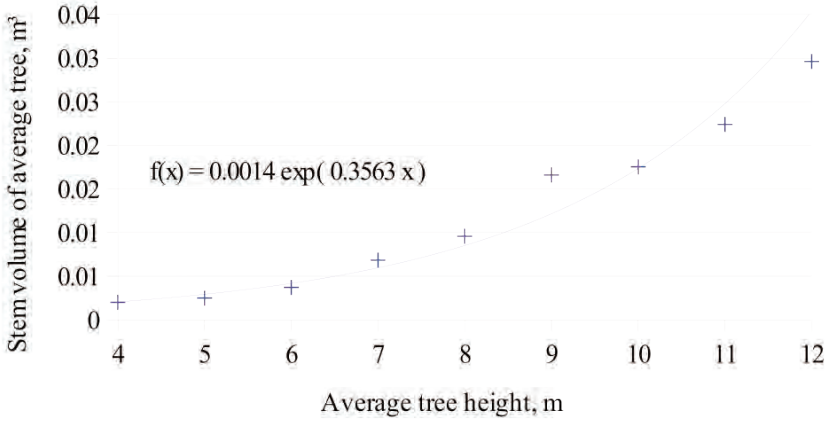


Figure 3. Average extractable stock depending on height of average tree.

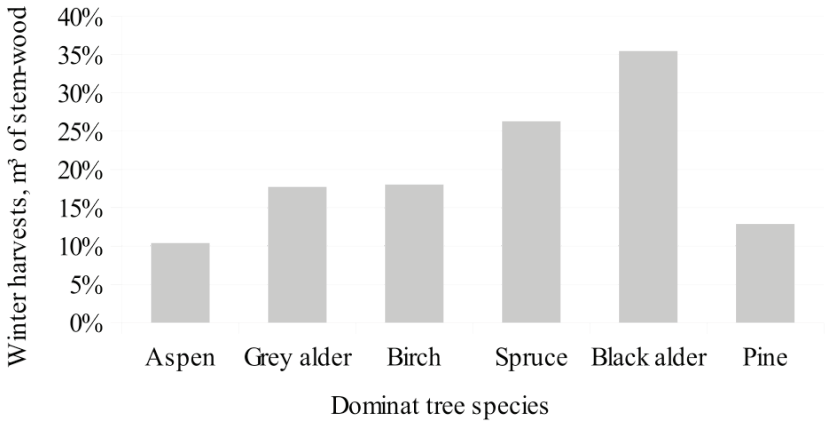


Figure 4. Proportion of solid biofuel to be extracted in winter time.

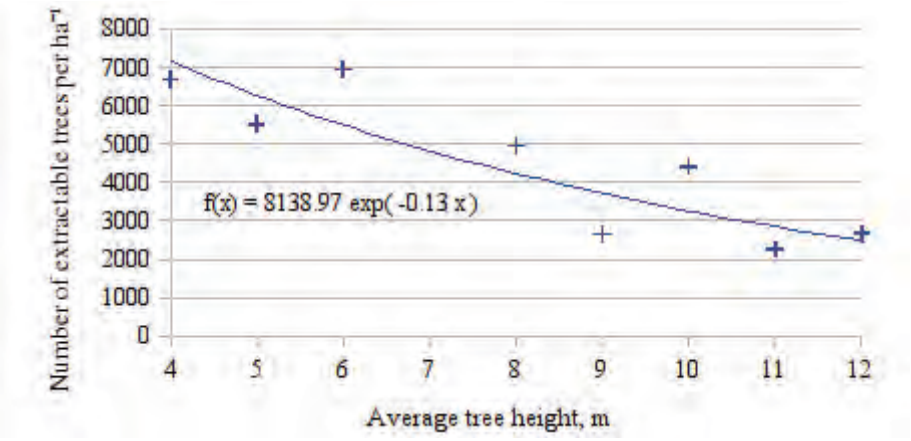


Figure 5. Average number of extractable trees depending from height of average tree.

The average proportion of solid biofuel, that can be extracted in winter time only is 19%; the highest (35%) this proportion is areas, where black alder is dominating, the smallest (respectively, 10% and 13%) in aspen and pine dominant areas (Figure 4).

The average number of extractable trees varies from 7 thousand to 2 thousand per ha; it has a tendency to decrease with the increase of height of average tree (Figure 5). The average distance from the centres of the NFI plots to the nearest to the road is 279 m; there

is no linear correlation between height of average tree in the area and distance to the road; which means that all resources are equally accessible. However, the distance to average road and actual forwarding distance is not calibrated in Latvia, therefore, the actual distance to the road might be longer.

Conclusions

1. Extraction of biofuel in pre-commercial thinning is possible in 161 kha area. Total extractable aboveground biomass is 2962 ktons, stem-wood – 4.9 mill. m^3, including 21% of resources located in coniferous dominant stands. Considering that the calculation includes biomass of trees being thinner than 4 cm, the results of the study can slightly overestimate the biofuel resources.
2. Biomass expansion factors as well as the coefficients used in calculation of the diameter distribution of trees are not evaluated in young stands; therefore, the resource assessment in this study should be considered as preliminary and further improvements are necessary, especially elaboration of equation for calculation the diameter distribution of trees.
3. Economically efficient biofuel extraction (according to Swedish assumptions) can be done in Latvia in 53 kha with total extractable aboveground biomass of about 1065 ktons (36% of the total potential in pre-commercial thinning).
4. The delaying of pre-commercial thinning is an important factor to increase feasibility of the biofuel extraction, because the stem volume of extractable trees is 6 times bigger in areas where an average tree is 12 m in comparison to areas with 6 m long trees; therefore, silvicultural studies should be concentrated on evaluation of delayed thinning to find synergies between forest management and biofuel production.
5. Accessibility of the biofuel seems not to be a problem (only 19% of biofuel can be extracted only in winter time); however, average harvesting conditions may be much worse than in the study, because they are determined by the worst place in a stand and not the average conditions.

Acknowledgements

The study is done within the scope of the National forest competence center project "Methods and technologies to increase forest value" (L-KC-11-0004). The methodology is elaborated within the scope of the Central Baltic INTERREG IV A Programme 2007-2013 project "The Development of the Bioenergy and Industrial Charcoal" (No. cb46).

References

1. Arlinger J. (1997) SkogForsk Yield - a program for calculations of possible levels of saw logs, pulp wood and forest fuel removals - User's Guide, version 2.0. Uppsala, Skogforsk, 28 p.
2. Bergström D. (2009) Techniques and systems for boom-corridor thinning in young dense forests. Available at: http://pub.epsilon.slu.se/2154/, 1 February 2013.
3. Bergström D., Bergsten U., Nordfjell T. (2010) Comparison of boom-corridor thinning and thinning from below harvesting methods in young dense Scots pine stands. Available at: http://www.doria.fi/handle/10024/73313, 1 February 2013.
4. Bisenieks J. (2005) Sastāva kopšana (Pre-commercial thinning). In: Meža enciklopēdija J. Broks, Rīga, Zelta grauds, 1. sēj. 281. lpp. (in Latvian).
5. Geofabrik GmbH and OpenStreetMap Contributors (2013) Download OpenStreetMap data for this region: Latvia. OpenStreetMap Data Extracts 2013. Available at: http://download.geofabrik.de/europe/latvia.html, 1 February 2013.
6. Latvijas Republikas Saeima (2000) Meža likums (Forest law). Available at: http://www.likumi.lv/doc.php?id=2825, 1 February 2013. (in Latvian).
7. Lazdins A. (2011) Preconditions for efficient management of naturally afforested farmlands. Summary of the Doctoral thesis for the scientific degree Dr. in Forest Ecology and Silviculture. Available at: http://agris.fao.org/agris-search/search/display.do?f=2011%2FLV%2FLv1113.xml%3BLV2011000523, 1 February 2013.
8. Lazdiņš A., Lazdiņa D., Liepiņš K. (2011) Above-ground biomass equations for the most common tree species growing on abandoned farmlands. Proceedings of Rural Development 2011, The fifth international scientific conference, Aleksandras Stulginskis University, Kaunas, pp. 64-68.
9. Lazdiņš A., Thor M. (2009) Bioenergy from pre-commercial thinning, forest infrastructure and undergrowth – resources, productivity and costs. In: Annual 15th International Scientific Conference Proceedings, Latvia University of Agriculture, Jelgava, pp. 147-154.
10. Latvijas Republikas Ministru Kabinets (2012) Ministru Kabineta noteikumi Nr. 935 par koku ciršanu mežā (Regulations of Cabinet of Ministers No. 935 about tree cutting in forest). Available at: http://www.likumi.lv/doc.php?id=253760, 1 February 2013. (in Latvian).

11. Penman J. ed. (2003) Good Practice Guidancefor Land Use, Land-Use Change and Forestry, 2108, 11, Institute for Global Environmental Strategies (IGES), Kamiyamaguchi, Hayama, Kanagawa, Japan, 594 p.
12. Skogforsk (2011) Efficient forest fuel supply systems Composite report from a four year R&D programme 2007-2010, Skogforsk, Uppsala Science Park, S-751 83 Uppsala, 116 p.
13. Zimelis A., Lazdiņa D., Lazdāns V. (2012) Pārskats par jaunaudžu kopšanas un agrotehniskās kopšanas darbu ražīguma un pašizmaksas izpēti (Report on studies on productivity and prime costs of tending and pre-commercial thinning of young stands). LVMI Silava, Salaspils, 54 lpp. (in Latvian).

CHARACTERISTICS OF WOOD CHIPS FROM LOGGING RESIDUES AND QUALITY INFLUENCING FACTORS

Kristaps Gruduls, **Arta Bārdule**, **Toms Zālītis**, **Andis Lazdiņš**
Latvian State Forest Research Institute "Silava"
kristaps.gruduls@silava.lv

Abstract
The aim of this paper is to characterize and ascertain quality influencing factors of wood chips produced from forest residues in clear-cuts. The quality of food fuels varies according to the harvesting season, site characteristics and silvacultural treatment. For this study 89 piles of logging residues from clear-cuts located in Western part of Latvia were used. Piles were stored in different parts of clear-cut according to its direction against nearby stand. Piles of logging residues were pre dried and then chipped. A period of chipping and sample acquisition was from February to May of the year 2012. Results show that chips from forest residues can be successfully used for medium scale boilers. Chips with lower carbon content, calorific value, relative moisture and bulk density of wet chips can be produced in May. Location of the pile in centre and SE part of the clear cuts can decrease resulting ash content in wood chips.
Key words: wood chips, quality.

Introduction

During the last years logging residues from clear-cuts are considered an important resource for renewable energy production. In the year 2007, Finland produced 21.9 PJ of energy from wood chips obtained in forests, and it is estimated that by the year 2015 this number will be increased from 51 to 71 PJ per year (Heinimö and Alakangas, 2009). It is calculated that in Ireland 150 000 - 200 000 t of forest residues may be available for harvesting (Hoyne and Thomas, 2001), but data obtained in Latvia show that after clear-cuts approximately 20 to 30% of biomass from above ground tree volume is left in area and 2.5 milj. m^3 is usable as fuel resource. (Lazdans, 2006) According to FAO Forestry paper 93, approximately 33% from the total tree volume is usable as wood fuel straight from the forest (The potential use of wood residues for energy generation, 1990).

Available wood residue volumes from forest that could be used for energy production is imposing, but the quality of food fuels varies according to harvesting season, site characteristics and silvacultural treatment. Bulk density, moisture content, size and shape of wood fuels are important for wood fuel handling, storing and transporting (Picchio et al., 2012), but calorific value can be seen as essential quality indicator for any fuels (Spinellia et al., 2011).

Storage of forest residues in small piles in cutting area can result in loss of needles and improve nutrition recycle to forest ecosystem (Nurmi, 1999) and decrease ash content due to needle loss (Jirjis and Lehtikangas, 1991). Study by Lehtikangas and Jirjis (1993) show that moisture content in softwood forest residues stored for 7 months in covered piles reduced to 26%, but in uncovered 37% from initial 55%, but after 11 months of storage moisture content rose to 29% in covered and 51% in uncovered piles. Liaqat (2011) in his study observed that piles placed in a slope and under the shade of trees showed higher moisture and ash content than those who were located in a plain site. Increment in ash content could be explained by higher amount of contamination and led to lower calorific value.

The aim of the study was to determine quality of wood chips produced from harvesting residues in final felling, depending from storage time, location of piles and presence of coverage.

Materials and Methods

Data material for this study was obtained in the beginning of the year 2012 from February till May from 89 piles of logging residues located in clear-cuts during comminution process. All piles were located in the western part of Latvia in forests managed by joint-stock company 'Latvijas valsts meži'.

Before chipping operation piles were pre-dried. 8 piles were covered but 81 were not. The shortest drying period for some was 17 days but the longest – 4 years (in reality they consisted of mixed – fresh and

Table 1

Nummber of piles by storage time

Storage time, months	No information	1 to 12	13 to 24	25 to 36	37 to 48
Number of piles	12	55	15	3	4

Table 2

Summary of chip particle size characteristics (n=88), %

Particle size	Minimum	Maximum	Mean	Std. Error
0-3.15 mm	0.0	51.5	18.1	1.2
3.15-16 mm	22.4	78.5	44.5	1.3
16-45 mm	4.9	68.6	32.1	1.6
45-63 mm	0.0	12.1	3.5	0.3
> 63 mm	0.0	7.0	1.8	0.2

Table 3

Summary of chip quality characteristics

Indicator	Unit	Minimum	Maximum	Mean	Std. Error	n
Abs. Moisture	%	17.6	203.3	97.8	5.2	87
Relative moisture	%	20.6	73.1	49.2	1.5	88
Density (wet)	$kg \cdot L^{-1}$	0.242	0.531	0.382	0.008	82
Density (dry)	$kg \cdot L^{-1}$	0.128	0.267	0.189	0.003	81
Carbon content	$g \cdot kg^{-1}$	450	567	520	3	84
Ash content	%	1.5	23.3	7.9	0.7	84
Calorific value	$kWh \cdot kg^{-1}$	4.36	5.49	5.04	0.03	84

stored material). Piles were divided into groups by 2 factors. One of them was the month of chipping to determine the impact of time on quality of wood chips and the other one was by the location of pile in area to determine the impact of forest wall on characteristics of wood chips. Particle size distribution of wood chips was determined using a sieve set made from stainless steel according to ISO 3310-2, aperture sizes: 3.15 mm, 16.0 mm, 45.0 mm and 63.0 mm.

Total moisture content in wood chips was determined according to LVS CEN/TS 14774, density of wood chips was determined using Archimedes density measurement kit of Precisa XB 220A balance according to LVS CEN/TS 15150. Ash content was determined by calculation from the mass of residue remaining after the sample is heated in air under rigidly controlled conditions of time, sample weight and equipment specifications to a controlled temperature of 550 ± 10 °C according to LVS CEN/TS 14775. Total carbon content was determined using elementary analysis according to LVS ISO 10694. Calorific values were estimated according to LVS CEN/TS 14918 standard.

Results and Discussion

On average 76.6% of wood chips produced from logging residues and used for this study are in size from 3.15 to 45 mm, but only 5.3% of total amount of chips is larger than 45 mm. According to Kofman (2005) wood chips with such particle size distribution can be successfully used for medium size boilers (0.250...1MW) and on average only 44.5% (3.15...16 mm) of wood chips produced from forest residues can be used in small size boilers (< 250 kW), because they acquire nominal particle sizes from 8 to 15 mm. As shown in Table 2, in some cases such particle size can contain up to 78.5% from the total volume of separate piles.

Average absolute moisture (Table 3) for analysed samples was from 17.6 to 203.3% on average 97.8%, but relative moisture ranged from 20.6% - 73.1%, on

Table 4

Pearson correlation values between density and moisture of wood chips from logging residues

Value	Density (wet)	Density (dry)
Abs. Moisture	0.726	-0.648
Relative moisture	0.705	-0.655

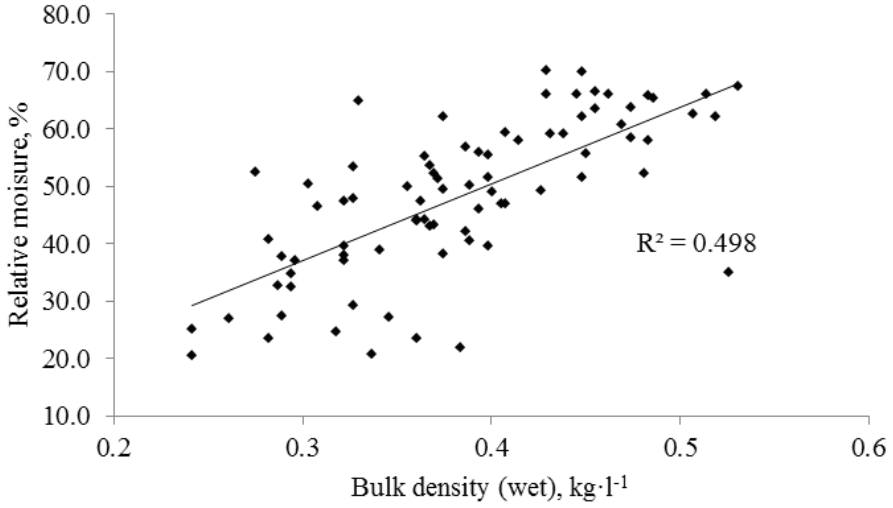


Figure 1. Correlation between bulk density of wet chips and relative moisture.

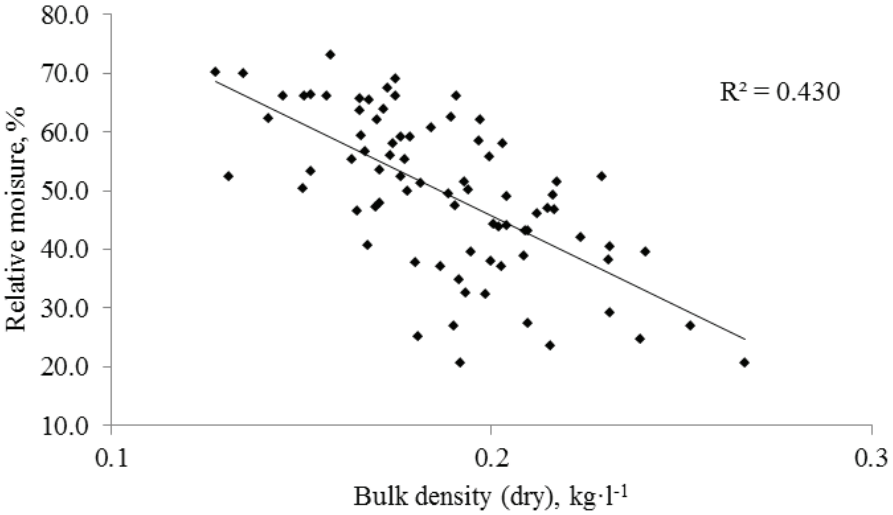


Figure 2. Correlation between bulk density of dry chips and relative moisture.

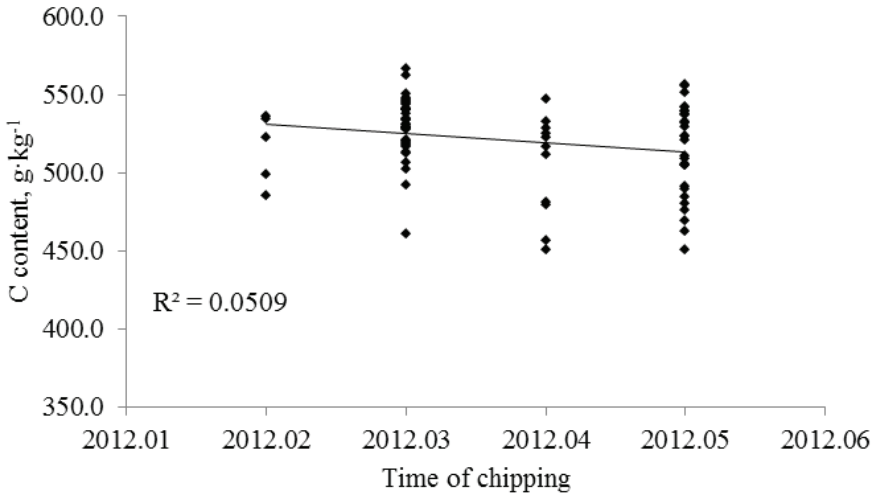


Figure 3. Correlation between sample preparation month and carbon content in chips ($p = 0.04 < 0.05$).

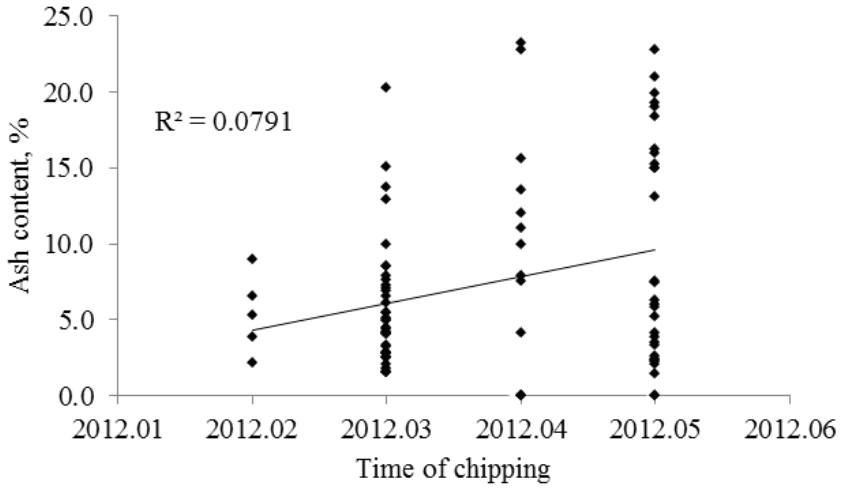


Figure 4. Correlation between sample preparation month and ash content in chips (p= 0.001 < 0.01).

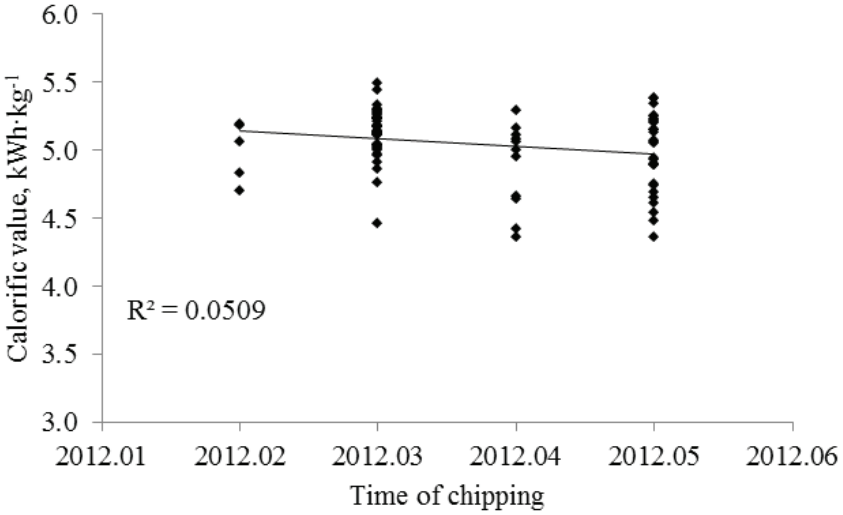


Figure 5. Correlation between sample preparation month and calorific value of chips (p= 0.04 < 0.05).

average is 49.2% confirming results obtained by the study of Lehtikangas and Jirjis (1993) that average moisture of wood chips produced from stored forest residues is approximately 50%.

Bulk density of wet chips ranged from 0.242 to 0.531 kg·L^{-1}, on average 0.382 kg·L^{-1}, but dry bulk density ranged from 0.128 – 0.267 kg·L^{-1}, on average 0.189 kg·L^{-1}. When compared, wet and dry bulk density show significant correlation at 1% significance level with absolute and relative moisture (Table 4, Figure 1 and 2) in all 4 pairs (p = 0 < 0.01).

Carbon content in wood chips varies between 458 and 567 g·kg^{-1}, but ash content in chips varies between 1.5 and 23.3%, both show significant correlations at 5% level with time of comminution (Figure 3 and 4). The highest content of ash was found in wood chips highly polluted with soil particles and consisting of mixed material stored for up to 3 years.

As shown in Figure 4, the ash content in chips increases with time of comminution (more ash in chips produced in May). This could be explained by higher amount of contaminants in chips after melting of snow. The calorific value (Figure 5) of chips decreases by the same period and could be effected by needle loss and higher contamination as mentioned by Liaqat (2011) and found in this study.

Figures 6 and 7 demonstrate that relative moisture and density of chips is smaller in samples produced in May than for those that are produced in February. This could be explained by drying of wood, which is approved also in other studies (Francescato et al., 2008). Smaller moisture content in wood is associated with higher evaporation rate of logging residues in this time.

Location of the pile in clear-cut has no significant impact on ash content from burned forest residues

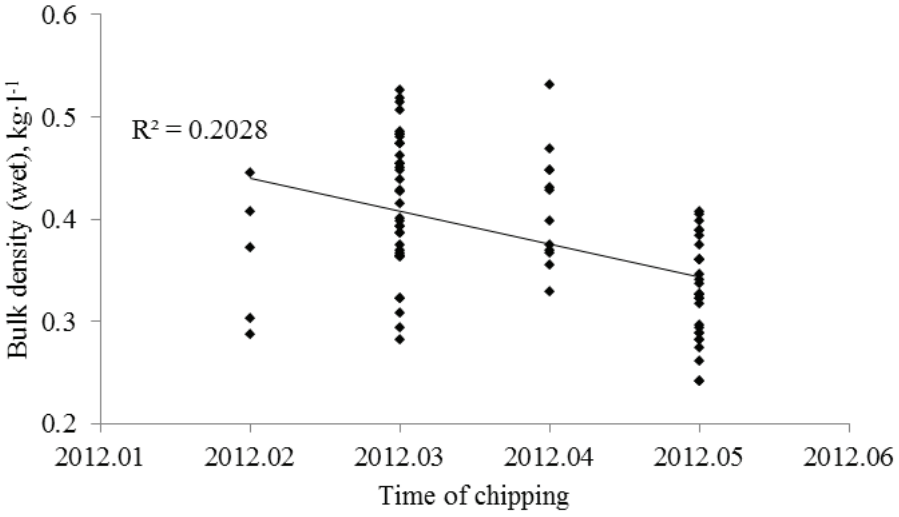


Figure 6. Correlation between comminution date and density of wet chips (p= 0.00 < 0.01).

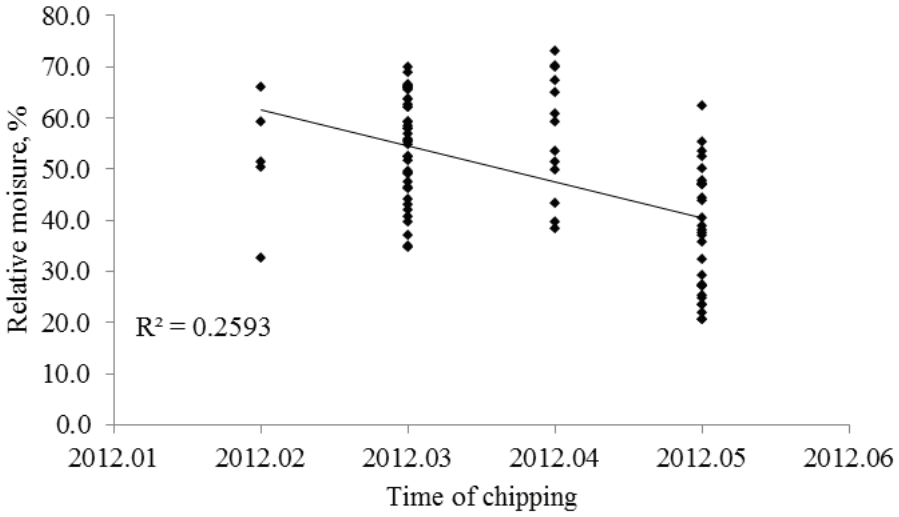


Figure 7. Correlation between comminution date and relative moisture of wet chips (p= 0.00 < 0.01).

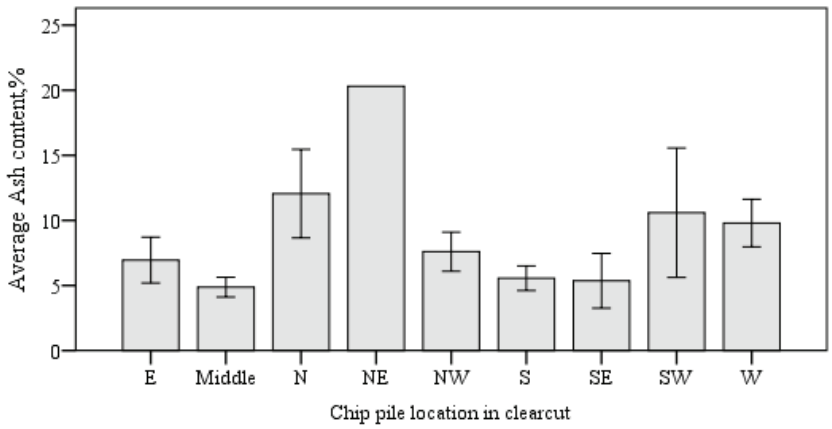


Figure 8. Pile location impact on ash content in chips (± 1Standart error).

($r = -0.17$, $r_{0.01;84}=0.28$, n=84). Smaller ash content is found in chips from piles that are stored in the middle of the clear cut area (Figure 8) and at the SE of the forest wall. There was only one pile located at the NE of the forest wall, thus leaving the values for this location questionable.

Absolute and relative moisture is slightly higher for covered piles with similar drying period durations, but still the difference of absolute ($p = 0.2 > 0.01$) and relative ($p = 0.4 > 0.01$) moisture is not significant between covered and uncovered piles. Higher content of moisture in covered piles could be explained by the fact, that tarpaulin was used as coverage material which prevents air circulation (Liaqat, 2011). Absence of significant difference in moisture content in covered and uncovered piles could be explained by the fact that piles were formed over longer period of time, thus consisting of mixed – fresh and stored material.

Conclusions

1. On average 76.6% of wood chips produced from logging residues and used for this study are in size from 3.15 to 45 mm and can be used for medium size boilers (0.25...1 MW), and 44.5% of wood chips produced from forest residues can be used in small size boilers (< 250 kW)
2. Calorific value of wood chips from forest residues varies from 4.36 to 5.49 $kWh \cdot kg^{-1}$, on average 5.04 $kWh \cdot kg^{-1}$ and carbon content from 450...567 $g \cdot kg^{-1}$, on average 520 $g \cdot kg^{-1}$.
3. Time of wood chip production is important factor for wood chip quality because during the period from February to May carbon content, calorific value, relative moisture and bulk density of wet chips decrease, whereas ash content increases.
4. Location of the pile in the centre and SE part of the clear cuts can decrease resulting ash content in wood chips.

Acknowledgements

The study is done within the scope of the Central Baltic INTERREG IV A Programme 2007-2013 project "The Development of the Bioenergy and Industrial Charcoal" (No. cb46).

References

1. Francescato V., Antonini E., Bergomi L.Z., Metschina C., Schnedl C., Krajnc N., Koscik K., Gradziuk P., Nocentini G., Stranieri S. (2008) *Wood Fuels Handbook*. AIEL - Italian Aghforestry Energy Association, Legnaro, Italy, 79 p.
2. Heinimö J., Alakangas E. (2009) *Market of biomass fuels in Finland. IEA Bioenergy Task 40 and EUBIONET III - Country report of Finland 2009. Research report 3.* Lappeenranta University of Technology. Faculty of Technology, 35 p.
3. Hoyne S., Thomas A. (2001) *Forest residues: Harvesting, storage and fuel value*. COFORD, Ireland, 26 p.
4. Jirjis R., Lehtikangas P. (1991) Storage of forest residues in covered windrows. In: Suadicani K. (eds). Research Report No. 10. *Proceedings from joint-meeting IEA/BEA activity 4 and 5. Activity 4: Wood preparation, storage and drying. Activity 5: Measurement and evaluation of wood fuel.*, Danish Forest and Landscape Research Institute, Frederiksberg, Denmark, pp. 46-53.
5. Kofman P.D. (2005) Quality of woodchip fuel. Available at: http://www.seai.ie/Grants/Renewable_Heat_Deployment_Programme/About_Renewable_Heating/Wood_Chip_and_Wood_Pellet_Boilers/Quality_Wood_Chip_Fuel.pdf, 1 March 2013.
6. Lazdans V. (2006) *Enerģētiskās koksnes resursu vērtējums, to sagatavošanas tehnoloģijas un izmaksas, veicot kopšanas cirtes 20-40 gadus vecās mežaudzēs. Projekta atsakite* (Assessment of Energy wood resources, its preparation technology and costs of 20-40 years old thinning stands. Project report). Salaspils, 71 lpp. (in Latvian).
7. Lehtikangas P., Jirjis R. (1993) *Valtlagring av avverkningsresler frân barrlrad under varierande omstandigheier. Rapport No. 235.* (*Storage of softwood logging residues in windrows under variable conditions. Report No. 235*). Sveriges Lantbruksuniversitet, Institute for Virkeslara, Uppsala, 45 p. (in Swedish).
8. Liaqat F. (2011) *Effects of storage and geographical location on fuel quality of Norway spruce forest residues*. Second cycle, A2E. Uppsala: SLU, Dept. of Energy and Technology, 45 p.
9. Nurmi J. (1999) The storage of logging residue for fuel. *Biomass and Bioenergy*, 17-1, pp. 41-47.
10. Picchio R., Spina R., Sirna A., Monaco A.L., Civitarese V., Giudice A.D., Suardi A., Pari L. (2012) Characterization of Woodchips for Energy from Forestry and Agroforestry Production. *Energies*, 5(10), pp. 3803-3816.
11. Spinelli R., Nati C., Sozzi L., Magagiiotti N., Picchi G. (2011) Physical characterization of commercial woodchips on the Italian energy market. *Fuel*, 90, pp. 2198-2202.
12. The potential use of wood residues for energy generation (1990) In FAO Forestry paper 93. Rome. Available at: http://www.fao.org/docrep/T0269E/t0269e08.htm, 1 March 2013.

COMPARISON OF DIFFERENT ELECTRONIC DEVICES FOR DETECTING *HETEROBASIDION* ROOT ROT

Kristaps Gruduls[1,2], Jānis Donis[2], Tālis Gaitnieks[2]
[1]Latvia University of Agriculture
[2]Latvian State Forest Research Institute "Silava"
kristaps.gruduls@silava.lv

Abstract
Root rot caused by *Heterobasidion* spp. is one of the most important pathogens in Norway spruce (*Picea abies* (L.) Karst.) stands in Latvia. It is estimated that in Latvia on average 22.9% of Norway spruce stumps are infected with *Heterobasidion* spp. The aim of this study was to compare four different electronic devices for *Heterobasidion* root rot detection in Norway spruce. In the autumn of 2009, in a sample plot located in the forests of Kalsnava district 27 trees were used to compare the possibility of instruments to detect root rot. The results show that IML-RESI F400 accuracy for detecting root rot in Norway spruce is high and the instrument is usable for detecting root rot, but additional accumulators are needed for large sample plots. Rotfinder's accuracy for detecting root rot varies from probe to probe taken from one tree. Conditiometer AS-1 and Arbo-Sonic decay detector show slightly higher average values for infected trees, but the difference for both instruments between healthy and decayed trees is not significant, thus leaving the usage of instruments questionable.
Key words: Electronic devices, Root rot, *Heterobasidion*, *Picea abies*.

Introduction

Root rot caused by *Heterobasidion* spp. is one of the most important pathogens in Norway spruce (*Picea abies* (L.) Karst.) stands in Latvia. It is estimated that in Latvia on average 22.9% (Gaitnieks et al., 2007) of Norway spruce stumps are infected with *Heterobasidion* spp.

In order to prepare long term management and, if possible, recovery scenarios for infected stands it is important to identify rot in its early stage. In the world several methods are available for instrumental root rot detection. Greig (1998) in his paper mentions 12 instruments that can be used for rot detection, but Catena (2003) divides them in five categories. The oldest method mentioned is the percussion of the trunk with a hammer for interpretation of the produced sound pattern. This method is described as quick and very cost-effective, but the results depend on the operator's experience. Sampling tree tissue with Pressler auger, visual assessment and, if needed, measuring samples for fractural resistance with fractometer is mentioned as a second most common method (Matthec and Breloer, 1994).

In the third category instruments which are used to insert probes in the tissue of the tree e. g., portable compression meter (Barrett et al., 1987), decay detecting drill (Seaby, 1990) and resistograph are included. The fourth category is associated with devices which use sound or ultrasound, including arbosonic decay detector and Sylvatest (Nicolotti and Miglietta, 1998). The last category contains instruments that use radioisotopes for rot detection (Catena, 2003), such as radar systems (Hruska et al., 1999)

In Latvia a study using digital root rot detection instruments was realized in 2004,- resistometer 'Conditiometer AS-1' was tested for its ability to detect root rot. The authors of this study conluded that the electrical resistance of wood is influenced by ambient temperature and tree diameter (Gaitnieks et al., 2004).

The aim of this study is to compare four different electronic devices for *Heterobasidion* root rot detection in Norway spruce.

Materials and Methods

The material for this study was obtained in the autumn of 2009 from a stand managed by 'State Forest Service Forest Research Station'. The stand is located in the Eastern part of Latvia, Kalsnava district with a total area of 5.4 ha and the sample plot area 0.84 ha (70×120 m).

Table 1

Instrument description

Instrument	Parameter	Unit of measurement
IML-RESI F400	Relative wood resistance	%
Conditiometer AS-1	Electrical resistance	kΩ
Rotfinder	Electrical resistance	Decay Class
Arbo-Sonic decay detector	Propagation time of ultrasound	μsec

For this study 27 trees (12 without root rot and 15 without root rot) were chosen from the previous studies to compare the root rot detection ability of different electronic instruments shown in Table 1. Instruments were tested in 65 years old Norway spruce (80%) and Silver birch (*Betula pendula* Roth.) (20%) mixed stand in *Oxalidosa turf. mel.* forest type.

In selected trees *Heterobasidion* spp. was detected in laboratory by examining bore cores for the presence of conidiophores (Swedjemark, 1995) earlier that year. After this study all 27 trees were cut down and inspected once more for *Heterobasidion* spp. presence. Information about *Heterobasidion* spp. presence was used to evaluate the possibility of instruments to detect root rot.

At the beginning of the study diameters at the base of the stump and breast (1.3 m from the base of the stump) height were measured with a calliper. The first instrument tested was IML-RESI F400. Before each measurement strips of waxed paper were fixed on the measurement recording device. For each tree two holes (one at the stump height, another at the breast height of the tree) were drilled and the instrument automatically fixated the relative resistance graph of timber on waxed paper strips. Later in the laboratory the paper strips were examined to detect root rot cavities and the depth at which the rot occurs was recorded into MS Excel worksheet. Results were then compared with the previously obtained results.

Measurements with Rotfinder started with an input of the current tree diameter at the breast height to the instrument before each measurement. Two probes from each tree were obtained. Rotfinder has a scale from 0 to 10. 0 means that the sample tree has no rot, but 1 to 10 means that there is a possibility that the tree is infected with rot-causing fungi. Measurement results were recorded into MS Excel worksheet and the accuracy of the instrument for each probe calculated as a relative value of correctly detected measurements from all measured trees for each probe.

Measurements of electrical resistance of wood at the breast height of the sample trees were conducted using Conditiometer AS-1. The probe was stuck in the bark as deep as possible and, while slowly pulling the probe out, lower values of the reading were recorded. The average electrical resistance (in kΩ) was calculated from four readings from each tree. The data were analysed using the regression analyses and analysis of variance.

Measurements of ultrasound propagation time at stump height were conducted using Arbo-Sonic decay detector. Before each measurement, two bark plugs on opposite sides of the trees (4.5 cm in diameter) were removed to expose xylem at the breast height. Transducers (transmitter and receiver) were pressed simultaneously against the xylem on opposing points of each tree to generate the ultrasound wave across each diameter and ultrasound propagation time readings (time per unit of distance - μsec) were recorded. Regression analysis was used to detect correlation between the diamaeter at breast height and the propagation time of ultrasound. Analysis of variance was used to further analyze propagation time in relation to tree diameter at stem height.

Results and Discussion

A correlation of decrease of average electrical resistance of wood with increase of tree diameter was detected in the analysis of results obtained with Conditiometer AS-1. It was also clarified that the average resistance (Figure 1) for infected trees (12.6 ± 0.7 kΩ) is slightly higher than for not infected (11.8 ± 0.6 kΩ), still, the difference between average resistance of infected and not infected trees is not significant (p=0.39>0.05). Similar results were obtained by Gaitnieks et al. in 2004.

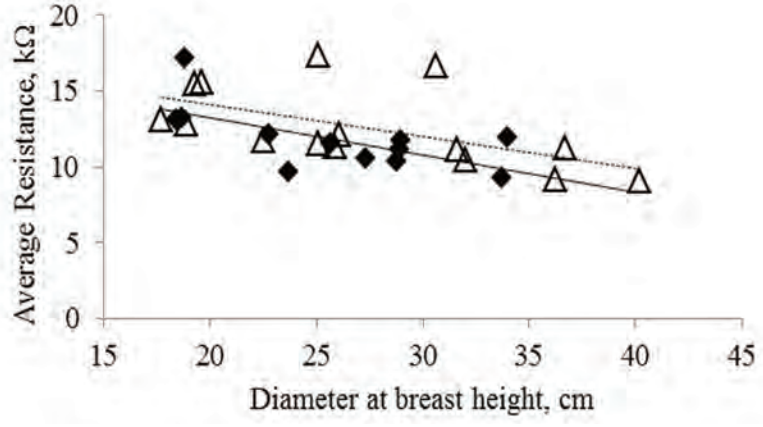


Figure 1. Correlation between the tree diameter and wood electrical resistance of trees (Conditiometer AS-1). (♦ - Not infected, Δ - Infected, —— - Not infected (R^2=0.412), ····· - Infected (R^2=0.324))

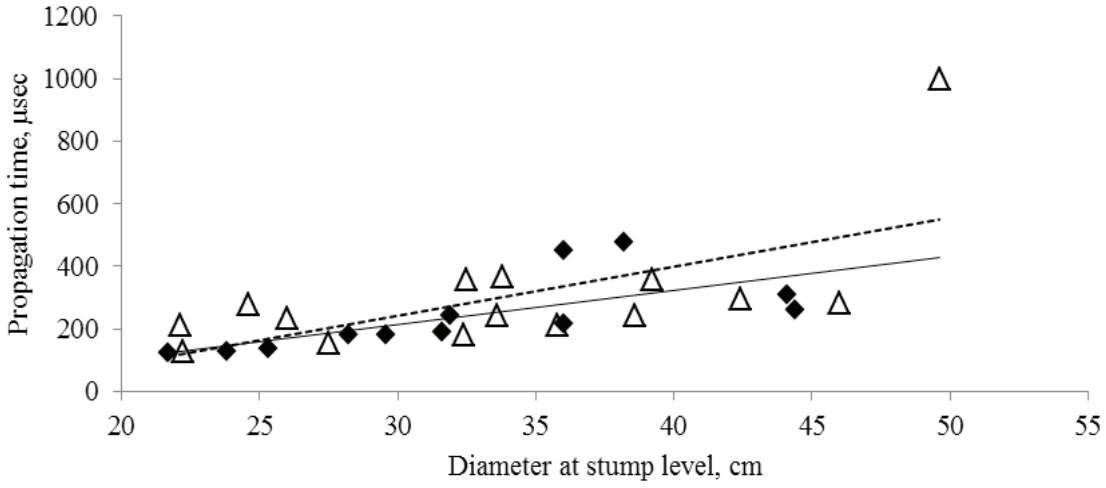


Figure 2. Correlation between the tree diameter and sound propagation time through wood (Arbo-Sonic Decay Detector).
(♦ - Not infected, Δ - Infected, —— - Not infected (R^2=0.462), ····· - Infected (R^2=0.407)

Table 2

Summary of results for Rotfinder (n=27)

Group	1. probe	2. probe
Correctly detected not infected trees	12 (45%)	12 (45%)
Correctly detected infected trees	6 (22%)	7 (26%)
Uncorectly detected infected trees	9 (33%)	8 (30%)

Results obtained with Arbo-Sonic decay detector indicate that the average ultrasound propagation time through wood (µsec) is in positive correlation with the increase of diameter of examined trees (Figure 2). The average propagation time for infected trees was determined to be (301 ± 53 µsec), higher than for not infected ones (241 ± 34 µsec), yet again, the difference between average propagation time of infected and not infected trees is not significant (p=0.37>0.05). The aAccuracy of Conditiometer AS-1 and Arbo-Sonic decay detector could be influenced by high moisture in the stand, characteristic for *Oxalidosa turf. mel.* forest type.

Data obtained by using Rotfinder show that in both probes not infected trees were identified correctly (Table 2). Some variation between repeated measurements exists. In the first measurement round 67% of cases from all measurements (not infected + infected) results were correct, in the second measurement round 70% were correct. Results of this study show lower accuracy levels of instrument than that obtained by Romeralo (2010) whose study's accuracy levels ranged from 75.8% to 87.2%. To increase the accuracy of the instrument it could be reccomended to increase the number of probes taken from each tree.

Data obtained from IML-RESI F400 resistance meter show that in all 24 measurement pairs measurements were 100% correct. It should be mentioned that after 48 measurements both accumulators of the instrument included in the set went empty leaving 3 trees unmeasured, thus showing that optimal number of measurements for one accumulator load is in range from 20 to 25 and, to obtain more data from sample plots, more charged accumulators are needed.

In order to evaluate the influence of different factors (moisture, ambient temperature, age, stand composition) on labor-intensity and accuracy level of root rot detection instruments in Norway spruce stands, other forest types and age groups will be tested.

Conclusions

1. Rotfinder accuracy in this study from the first probes was 67%, but from the second 70%, thus suggesting that by increasing number of probes taken, accuracy could improve.
2. Conditiometer AS-1 and Arbo-Sonic Decay Detector show slightly higher average values for infected trees, but the difference for both instruments between groups is not significant, thus leaving the usage of instruments questionable.

3. The accuracy of IML-RESI F400 for detecting root rot in Norway spruce is 100% and it can be useful for detecting root rot.We suggest the purchase of additional batteries for large sample plots.

Acknowledgements

Research was supported by JSC 'Latvia's State Forests' and Forest Industry Competence Centre (project No. L-KC-11-0004) project 'Methods and technologies for increase of the forest capital value', research direction 'Investigation of the factors limiting the spread of root rot'.

References

1. Barrett D.K., Seaby D.A., Gourlay I.D. (1987) Portable 'Compression Strength Meter: a tool for the detection and quantification of decay in trees. *Agricultural Journal*, 11, pp. 313-322.
2. Catena A. (2003) Thermography reveals hidden tree decay. *Arboricultural Journal: The International Journal of Urban Forestry*, 27, pp. 27-42.
3. Gaitnieks T., Arhipova N., Donis J., Stenlid J., Vasaitis R. (2007) Butt rot incidence and related losses in Latvian Picea abies (L.) Karst stands. In: Garbelotto M. and Gonthier P. (eds) Root and Butt Rots of Forest Trees. Proceedings of the 12 th IUFRO International Conference on Root and Butt Rots, The University of California, Berkeley, California, Medford, Oregon, USA, pp. 177-179.
4. Gaitnieks T., Šica L., Indriksons A., Grantiņa L. (2004) Root-rot detection in Norway spruce stands using pulsed electronic tool. In: Manka M. and Lakomy P. (eds) Root and Butt Rots of Forest Trees. Proceedings of the 11 th IUFRO International Conference on Root and Butt Rots, Poznan and Białowieża, Poland, pp. 379-385.
5. Greig B.J. (1998) Field Recognition and Diagnosis of *Heterobasidion annosum.* In: Woodward S., Stenlid J., Karjalainen R., Hüttermann A. (eds) *Heterobasidion annosum: biology, ecology, impact and control*, CAB International, Wallingford, UK, pp. 35-42.
6. Hruska J., Cermak J., Sustek S. (1999) Mapping tree root systems with ground-penetrating radar. *Tree Physiology*, 19, pp. 125-130.
7. Mattheck C., Breloer H. (1994) Field guide for visual tree assessment (VTA). *Arboricultural Journal: The International Journal of Urban Forestry*, 18, pp. 1-23.
8. Nicolotti G., Miglietta P. (1998) Using High-Technology Instruments to Assess Defects in Trees. *Journal of Arboriculture*, 24 (6), pp. 297-302.
9. Romeralo C. (2010) *Reliability of Rotfinder instrument for detecting decay in standing trees*. Second cycle, A1E. Uppsala: SLU, Department of Forest Mycology and Pathology, 59 p.
10. Seaby D.A. (1990) Recent advances in the detection of wood decay. *Research for practical arboriculture.* Forestry Commission Bulletin, 97, pp. 168-176.
11. Swedjemark G. (1995) *Heterobasidion annosum root rot in Picea abies: variability in aggressiveness and resistance*, PhD thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden, 42 pp.

COMPARISON OF PRODUCTIVITY OF CBI AND MCR-500 STUMP LIFTING BUCKETS IN LATVIA

Agris Zimelis[1,2], Andis Lazdiņš[2], Ziedonis Sarmulis[1]
[1]Latvia University of Agriculture
[2]Latvian State Forest Research Institute "Silava"
agris.zimelis@silava.lv; andis.lazdins@silava.lv; ziedonis.sarmulis@llu.lv

Abstract
The stump lifting trials were implemented in 5 forest compartments of the JSC 'Latvia state forest' Vidusdaugava, Rietumvidzeme, Zemgale and Ziemeļkurzeme forestries in autumn, 2012. Total extracted area was 3.5 ha, excluding constrol. Two stump extraction buckets were compared in these trials – CBI (made in Canada) and MCR-500 (made in Latvia). The scope of the study was to estimate if the prototype of the MCR-500 can compete with stump lifting buckets having positive feedback from industry. Considering that the CBI head cannot prepare soil, this operation was not done by the MCR-500 either. In total 1796 stumps were marked and their main parameters were taken in all trial areas. Extracted biomass was estimated theoretically using biomass expansion factors elaborated in Nordic countries. Allegro CX field computers with SDI software were used in time studies to obtain information about productivity and distribution of productive time in a work cycle. The study demonstrated that productivity of stump extraction with both stump lifting buckets did not differ significantly in 6 cases out of total 10 comparisons.
Key words: stump extraction, time study, biomass dry matter, productivity.

Introduction

First scientific studies about stump use for biofuel and impact of stump extraction on forest regeneration in Latvia dated back in late 19th century (Bode, 1840). After Latvia gained sovereignty in the 20th century, the issue about energy independence was outstanding; thus, forest owners returned to stump extraction and solution of the forest regeneration problems. Like nowadays, opposite opinions were declared at that time, for example, O. Ceichner believed that stump harvesting is facilitating leaching of nutrients and erosion of soil. He did not recommend to perform stump extraction in state forests (Ceichners, 1929). At the same time, he and other researchers agreed that stump extraction is facilitating natural regeneration of pine stands and does not affect trees of the next generation (Vasiļevskis, 2007) in any harmful way. K. Lange was one of the most active advocates of stump extraction. He believed that leaving of stumps in clear-felling areas for decaying is wrong (Lange, 1925). Before the World War Two, a production of firewood from stumps reached 730 thousand m^3 annually. In 1939, the Forest Administration recommended to utilize all clear-felling areas for stump extraction. At that time the most conventional method for stump extraction was blasting or mechanical extraction using special devices. Average productivity of stump extraction was 2...2.5 stacked m^3 or 1.6...2 m^3 per day (Vasiļevskis, 2007).

After retrieval of independence stump biomass for long a time was out of the field of interests of forest practitioners, because cheaper resources of woody biomass (firewood, residues from sawmills and harvesting) were available; however, with an increase in demand and rise of firewood cost, extraction of stumps were resumed (Lazdiņš, 2006). In cooperation with the Forest Research Institute of Sweden Skogforsk studies of productivity of mechanized stump extraction in clear-felling areas were implemented in 2006. A caterpillar excavator with a specialized stump lifting bucket was used in these studies. Average productivity of stump extraction was 10.4 m^3 per hour; respectively, it was 40 times higher than 60 years ago (Lazdiņš and Thor, 2009); however, these studies did not solve issues related to the forest regeneration. According to research data, stump extraction improves soil structure, lowers density and improves aeration of soil, thus creating favourable conditions for development of new trees. Removal of rotten coniferous stumps from clear-felling areas decreases the risk of getting infected with root rot for trees of the next generation (Vasaitis et al., 2008).

According to theoretical studies, the annual potential of stump biomass in Latvia is 1607 thousand tons, including 985 thousand tons that are available by applying currently used technologies. With the amount of harvesting remaining on average 10 million m^3 per year the same as current clear-felling proportion, stump extraction each year can be performed in 35.8 ha area. The average stump wood resources are 26.7 dry tons ha^{-1} (Adamovičs et al., 2009).

During analysis of the stump biofuel production technology, it was found out that the most effective solution to decrease costs is soil preparation during stump extraction and implementation of two-stage stump crushing – first into large pieces (diameter approx. 20 cm) at a log yard, at the same time shaking off most of excessive soil, and then into ordinary chips at a customer side. For the second stage crushers with electric engines are more preferable (Zimelis et al., 2012).

Research goal: to compare the productivity of a stump lifting bucket MCR-500 and CBI produced bucket.

The main tasks:

1. Measure stumps and estimate stump biomass stock in the experimental areas.
2. Perform time studies of stump extraction processes.
3. Compare productivity of both stump lifting devices.

Materials and Methods

Five experimental plots (Table 1) were established in the JSC company 'Latvijas Valsts Meži' Rietumvidzeme, Ziemeļkurzeme, Zemgale and Vidusdaugava Forestry in clear-felling areas (former spruce dominant forest stands of the same age and density) considerably affected by root rot. Sample plots were established in areas, where root rot was found in at least 50% of stumps. The idea behind establishment of the trials in diseased spruce stands was to have sample plots, where distribution of root rot after stump extraction can be compared with traditional forest regeneration. About half of all stands were left for traditional forest regeneration practices. Area of each extracted sample plot was at least 0.5 ha, excluding 10 m wide buffer zone.

The CBI bucket was mounted on a caterpillar excavator Komatsu PC210LC and the MCR-500 – on New Holland E215B excavator.

Mass of both excavators is about 23 tons, engine output - 110 kW, boom length without excessive load is 8 m, width of drive chains 60 cm, hydraulic motor produces pressure of at least 37 MPa at high flow hydraulic lines, maximum hydraulic oil feed is at least 200 L min^{-1}. The excavators can reach 6 km h^{-1} speed, while its actual speed outside felling area is 2.3 km h^{-1}. Width of excavators with standard drive chains is 2.6 m. As for New Holland excavator, only one hydraulic line provided maximum pressure;therefore, the stump splitting knife could be used only on partial capacity (at 20 MPa pressure). Due to this limitation, the excavator could not split larger stumps.

According to the working method, a stump extractor had to lift all stumps with a diameter of more than 10 cm and less than 50 cm. If a diameter of stump was larger than 50 cm, the operator had to decide whether it is more preferable to lift it or leave it. Taking into account previous experience with spruce stump extraction, the operator was advised to lift all spruce stumps (apart from too large in diameter) and leave only larger pine stumps. This restriction does not apply to places with high groundwater level, where pines usually have a shallow root system. There was no previous experience with extraction of birch and aspen, so the working method was perfected over time; thus, larger birch stumps were left, but all aspen stumps were extracted disregarding their diameter. The operator was advised to leave all black alder, linden and other stumps of broad-leaved tree species. Also, stumps within 4 m distance from ecological trees were not extracted. The operator was directed to extract stumps from all strip-roads, considering that forwarding of stumps biomass will be done in winter time.

All stumps with a diameter above 10 cm were marked at the felling-area before extraction. Soil preparation was not performed at extracted areas with a stump lifting device. This was planned for the spring time using a forest trencher.

Measurements were made from the topsoil till the top of the stump surface in 2 repetitions. Bottom of the stump is thought to be the horizontal soil layer, which is a hard cover and cannot be deformed easily. If there are mosses, lichens, snow or branches on the topsoil, those are to be removed until the top of the soil is visible and touchable.

Allegro CX field computers with SDI software were used in time studies.

For calculating stump biomass, breast height diameter ($D_{1,3}$) is used; therefore, stump measurement data at first are recalculated to breast height diameter. For spruce, which is the dominant tree species in all trial objects, 1st equation is used, for pine – 2nd equation, for birch – 3rd equation. For other species equations of spruce are used. Prior to this study, these equations were used in the JSC 'Latvia state forest' study on solid biofuel production from stumps at final felling (Thor et al., 2008).

Table 1

Identified research objects

Object ID	Area, ha	Sampling plot marking	Stump lifting head	Stand type
65-03-07-410-58-34	1.7	Nītaure	MRC-500	Dm (*Hylocomiosa*)
82-04-07-714-188-9	2	Stende	CBI	Vr (*Oxalidosa*)
82-05-07-712-437-8	3.4	Dursupe	CBI	Dm (*Hylocomiosa*)
83-05-07-603-326-7	1.4	Jaunpils	CBI	Vr (*Oxalidosa*)
80-29-07-501-360-9	3	Ogre	MRC-500	Dm (*Hylocomiosa*)

$$D_{1.3} = 0.7 + 0.74 \times D_0 \text{ ; where} \quad (1)$$

$D_{1.3}$ – diameter at 1.3 meter height, cm;
D_0 – average stump diameter, cm.

$$D_{1.3} = -1.89 + 0.87 \times D_0 \text{ ; where} \quad (2)$$

$D_{1.3}$ – diameter at 1.3 meter height, cm;
D_0 – average stump diameter, cm.

$$D_{1.3} = -6.7 + 0.916 \times D_0 + \frac{50.5}{D_0} \text{ ; where} \quad (3)$$

$D_{1.3}$ – diameter at 1.3 meter height, cm;
D_0 – average stump diameter, cm.

Stump biomass is calculated using 4th equation for spruce, 5th – for pine (Marklund, 1988) and 6th – for birch (Repola et al., 2007). The equation for birch biomass includes also coarse roots. Spruce biomass equation is used to determine stump and root biomass for other tree species.

$$M_S = \exp\left(-3.36 + 10.67 \times \frac{D_{1.3}}{D_{1.3} + 17}\right); \text{ where} \quad (4)$$

M_S - biomass dry matter, kg.

$$M_S = \exp\left(-3.97 + 11.05 \times \frac{D_{1.3}}{D_{1.3} + 15}\right); \text{ where} \quad (5)$$

M_S - biomass dry matter, kg.

$$M_S = \exp\left(-3.68 + 11.54 \times \left(\frac{2 + 1.25 \times D_{1.3}}{2 + 1.25 \times D_{1.3} + 26} + \right.\right.$$
$$\left.\left. + 0.02 + 0.05\right)\right); \text{ where} \quad (6)$$

M_S - biomass dry matter, kg.

Biomass of coarse spruce and pine roots (diameter above 5 cm) is calculated using other equations: for spruce – 7th equation but for pine – 8th equation (Marklund, 1988).

$$M_S = \exp\left(-6.39 + 13.37 \times \frac{D_{1.3}}{D_{1.3} + 8}\right); \text{ where} \quad (7)$$

M_S - biomass dry matter, kg.

$$M_S = \exp\left(-6.34 + 13.29 \times \frac{D_{1.3}}{D_{1.3} + 9}\right); \text{ where} \quad (8)$$

M_S - biomass dry matter, kg.

Biomass of fine roots (diameter below 5 cm) is calculated separately, using 9th equation for spruce and 10th – for pine (Marklund, 1988).

$$M_S = \exp\left(-2.57 + 7.63 \times \frac{D_{1.3}}{D_{1.3} + 12}\right); \text{ where} \quad (9)$$

M_S - biomass dry matter, kg.

$$M_S = \exp\left(-3.84 + 8.88 \times \frac{D_{1.3}}{D_{1.3} + 10}\right); \text{ where} \quad (10)$$

M_S - biomass dry matter, kg.

Additional stump biomass above root collar is calculated by determination of volume as of cylinder volume (equation No. 11), and then dry substance biomass using equation No. 12 (Hakkila, 1975) is calculated.

$$V_C = \frac{\left(\frac{D_0}{100}\right)^2}{4} \times \pi \times H \text{ ; where} \quad (11)$$

V_C – stump volume, m^3;
D_0 – stump diameter, cm;
H – stump height, m.

$$M_S = V_C \times B_K \text{ ; where} \quad (12)$$

M_S – stump biomass dry matter, kg;
V_C – stump volume, m^3;
B_K – wood relative density, kg m^{-3}.
(spruce – 394 kg m^{-3}, pine – 476 kg m^{-3}, birch – 510 kg m^{-3}).

Extracted biomass constitutes of above- and below-ground parts of stump as well as coarse roots. It has to be taken into account, that such calculations of biomass can be inaccurate, as they are based on unverified equations. In addition, the diameter of stump is measured at cross-cut point that usually is above a root collar; hence, it is possible that there is a systematic error underestimating stump biomass in all calculations. However, these uncertainties have systematic characteristics and will not affect comparison of 2 stump lifting devices as far as the trial sites are similar and the same approach is used in measurements and calculations in all sites.

Data were processed using Microsoft Excel software - Data Analysis, Descriptive Statistics, F-test Two-Sample for Variances.

Results and Discussion

Stumps were measured in the autumn 2012 about 2 weeks before extraction. In total 1796 stumps were marked in all sites. Table 2 shows the summary of results of stump measurement.

Table 2

Stump measurement results

Object	Indicator	Hardwoods	Spruce	Pine
65-03-07-410-58-34	Number, pcs.	7	207	1
	Diameter (D), cm	45.7 ± 9.5	37.4 ± 0.9	24.0 ± 0.1
	Height (H), cm	32.0 ± 4.8	32.6 ± 0.8	23.0 ± 0.1
82-04-07-714-188-9	Number, pcs.	30	215	20
	Diameter (D), cm	29.7 ± 1.7	25.8 ± 0.7	29.0 ± 1.6
	Height (H), cm	31.6 ± 1.5	31.3 ± 0.6	29.1 ± 1.8
82-05-07-712-437-8	Number, pcs.	5	125	30
	Diameter (D), cm	35.8 ± 1.0	35.3 ± 1.6	40.4 ± 1.3
	Height (H), cm	35.2 ± 4.3	29.8 ± 1.0	27.5 ± 1.2
83-05-07-603-326-7	Number, pcs.	69	279	9
	Diameter (D), cm	38.6 ± 1.2	38.2 ± 0.7	40.8 ± 3.4
	Height (H), cm	24.7 ± 1.4	28.7 ± 0.7	20.0 ± 2.3
80-29-07-501-360-9	Number, pcs.	122	639	38
	Diameter (D), cm	35.9 ± 0.9	32.4 ± 0.5	37.3 ± 1.8
	Height (H), cm	27.8 ± 1.0	27.7 ± 0.5	20.0 ± 1.5
Number, pcs.		233	1465	98
Diameter (D), cm		37	34	34
Height (H), cm		30	30	24

Stumps, which were not extracted, were estimated according to the time study data by identification of those stump IDs, which did not appear in the study results. Stumps, which appeared during time studies (usually on strip-roads), were treated as average stumps in the stand. According to the time studies, 1568 stumps were extracted, including 82% of marked stumps that could be noticed and 5% extracted without markings (labels were lost).

Spruce stump diameter differences were analyzed by ANOVA single factor method. It was indicated that the differences in general were considered to be statistically significant (F = 26.20 > = 2.38 Fcrit). Comparing the experimental site in pairs by LSD

Table 3

Extracted stump total and available biomass with both technical devices

Bucket	Sample plot	Indicator	Species					All species
			other	aspen	birch	spruce	pine	
CBI	Dursupe	total biomass, kg	2149	-	284	14290	3905	20628
		accessible biomass, kg	1862	-	284	12411	3329	17887
	Jaunpils	total biomass, kg	3567	-	4376	29053	651	37648
		accessible biomass, kg	3136	-	4376	25089	556	33156
	Stende	total biomass, kg	494	-	1152	10818	1130	13594
		accessible biomass, kg	418	-	1152	9005	939	11514
	All	total biomass, kg	**6210**	**-**	**5813**	**54161**	**5686**	**71870**
		accessible biomass, kg	**5415**	**-**	**5813**	**46505**	**4823**	**62557**
MCR-500	Nītaure	total biomass, kg	858	7	753	23013	34	24665
		accessible biomass, kg	746	7	753	19874	27	21407
	Ogre	total biomass, kg	3183	3608	3612	46856	3163	60421
		accessible biomass, kg	2765	3608	3612	39971	2687	52643
	All	total biomass, kg	**4041**	**3614**	**4365**	**69869**	**3197**	**85086**
		accessible biomass, kg	**3510**	**3614**	**4365**	**59845**	**2714**	**74049**
Both devices		total biomass, kg	**10251**	**3614**	**10178**	**124030**	**8882**	**156956**
		accessible biomass, kg	**8926**	**3614**	**10178**	**106351**	**7537**	**136606**

(Least significant difference) test, the following results were obtained:

- Nītaure – Ogre: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 3.27$);
- Nītaure − Dursupe: diameter difference is not statistically significant ($t = 2.24 > t_{n;\,a} = 1.26$);
- Nītaure − Jaunpils: diameter difference is not statistically significant ($t = 2.24 > t_{n;\,a} = 1.62$);
- Nītaure − Stende: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 7.87$);
- Ogre − Dursupe: diameter difference is not statistically significant ($t = 2.24 > t_{n;\,a} = 1.37$);
- Ogre − Jaunpils: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 5.43$);
- Ogre − Stende: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 6.13$);
- Jaunpils − Dursupe: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 9.65$);
- Jaunpils − Stende: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 2.74$);
- Stende − Dursupe: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 5.96$).

According to the time study results and theoretical estimation of stump biomass, actual extracted stump biomass is 92% out of extractable biomass of marked stump. Together in all objects 137 tons of extractable stump biomass were produced, including 63 tons with the CBI bucket and 74 tons – with the MCR-500 bucket (Table 3). The most of the actually extracted biomass (78%) was spruce stumps.

Average time consumption for stump extraction converted into engine hours, excluding longer delays, is 0.42 hour ton^{-1}, but expressed as productive working time – 0.37 hour ton^{-1}. The smallest productivity has been identified in areas with high groundwater level (Ogre, Dursupe, Stende, Table 4).

Spruce stump extracting productive time differences were analyzed by ANOVA single factor method. It was indicated that the differences in general were considered to be statistically significant (F = 17.28 > = 2.38 Fcrit). Comparing the experimental site in pairs by LSD (Least significant difference) test, the following results were obtained:

- Nītaure – Ogre: diameter difference is not statistically significant ($t = 2.24 > t_{n;\,a} = 1.16$);
- Nītaure − Dursupe: diameter difference is not statistically significant ($t = 2.24 > t_{n;\,a} = 0.09$);
- Nītaure − Jaunpils: diameter difference is not statistically significant ($t = 2.24 > t_{n;\,a} = 1.61$);
- Nītaure − Stende: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 7.30$);
- Ogre − Dursupe: diameter difference is not statistically significant ($t = 2.24 > t_{n;\,a} = 0.89$);
- Ogre − Jaunpils: diameter difference is not statistically significant ($t = 2.24 > t_{n;\,a} = 0.71$);
- Ogre − Stende: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 7.07$);
- Jaunpils − Dursupe: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 6.39$);
- Jaunpils − Stende: diameter difference is not statistically significant ($t = 2.24 > t_{n;\,a} = 1.33$);
- Stende − Dursupe: diameter difference is statistically significant ($t = 2.24 < t_{n;\,a} = 6.54$).

It means that productivity of both stump lifting heads does not differ significantly in 6 cases out of total 10 comparisons.

Stump lifting buckets MCR-500 and CBI are different; during the trials MCR-500 did not use a splitting knife, so the extraction quality was worse; therefore the working method was adapted, like the use of shaking instead of dropping of stumps to get rid of soil particles. Figure 1 shows, that MCR-500 spent more time on lifting and splitting stumps (mainly because opening and closing of splitting knife took more time than for CBI); however, additional working time expenditure was retrieved by more efficient

Table 4

Summary of results of time studies

Stump lifting head	Sampling plot	Total biomass, kg	Working hours, h ton^{-1}	Productive time, h ton^{-1}	Productive time share
CBI	Dursupe	17887	0.58	0.43	94.40%
	Jaunpils	33156	0.29	0.27	96.90%
	Stende	11514	0.5	0.44	98.10%
	All plots	62557	0.43	0.37	96.70%
MCR-500	Nītaure	21407	0.37	0.34	98.20%
	Ogre	52643	0.42	0.4	95.20%
	All plots	74049	0.41	0.38	95.90%
Both devices	**All plots**	**136606**	**0.42**	**0.37**	**96.20%**

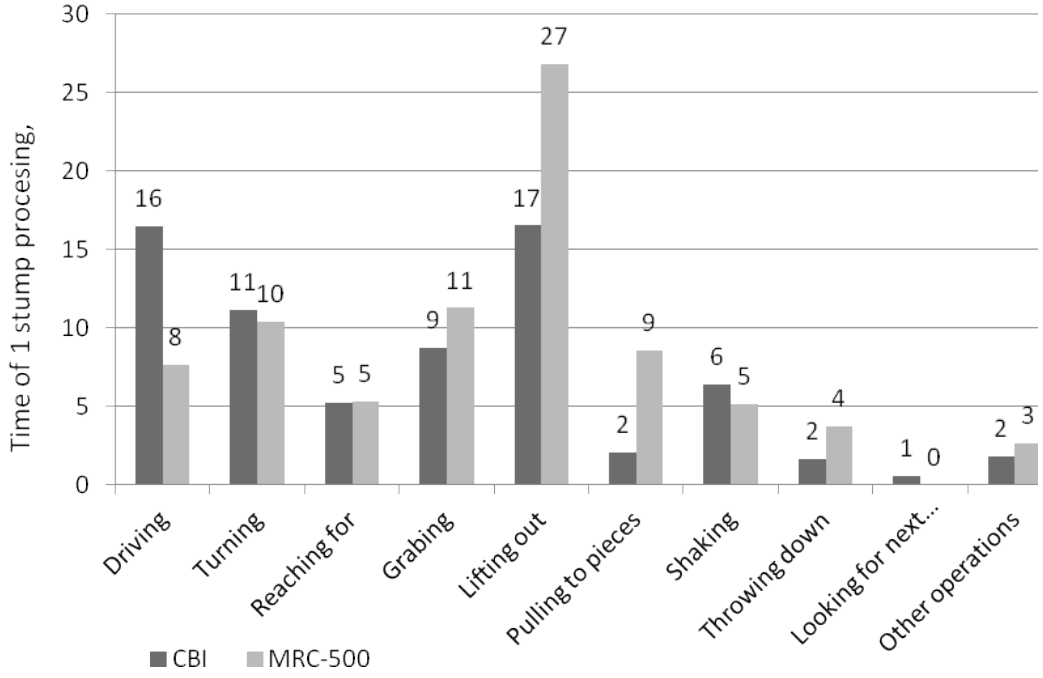


Figure 1. Comparison of structure of productive time consumption.

manoeuvring and spending less time for passages. It means that normally (ensuring necessary pressure in both hydraulic lines) MCR-500 would work faster than CBI lifting head. Probably there would be changes in productivity if other operator would be chosen. It is characteristic for harvester operators (a case of MCR-500) to use a crane more intensively to reach a tree before felling, whereas excavator operators usually operate in different manner when they drive or manoeuvre the excavator to select better position before stump extraction. In this case a more intensive use of crane was more beneficial approach according to the study results.

It has to be taken into account that allometric equations, developed in Sweden, have not been tested in Latvia, and can overestimate or underestimate amount of extracted biomass. It means that actual productivity can be different; therefore, the results can be used only to compare two stump lifting heads. Actual amount of extracted stumps could be determined after crushing of stumps, where it is possible to weigh chip trucks.

Conclusions

During stump extraction, operators noticed 87% of all stumps; as a result, the sample plot area is well extracted, and obtained data allows us to analyse productivity of both devices objectively.

1. Production time consumption analysis shows the difference between time spent on stump extraction and splitting by both head units compared in trials.
2. Performing statistical processing of productivity data of both stump lifting heads show the usefulness of further research on the use of the MCR-500.

Acknowledgements

The article is written within the scope of the European Regional Development Fund's project "Developing and testing a multifunctional prototype machine for stump harvesting and mounding" (No. 2DP/2.1.1.1.0/10/APIA/VIAA/174).

References

1. Adamovičs A., Dubrovskis V., Plūme I., Jansons Ā., Lazdiņa D., Lazdiņš A., Kārkliņš G. (2009) Biomasas izmantošanas Ilgtspējības kritēriju pielietošana un pasākumu izstrāde (Application of criteria and development of activities for sustainable biomass utilization). Valsts SIA Vides projekti, 186, 53-85. lpp. (in Latvian).
2. Bode A. (1840) *Handbuch zur Bewirtschaftung der Forsten in den deutschen Ostseeprovinzen Russlands: Ein Leitfaden für Privatforstbesitzer und Forstverwalter (Guide for the management of forests in the German Baltic provinces of Russia: A guide for private forest owners and forest managers)*. F. Lucas, 295 S. (in German).

3. Ceichners O. (1929) Celmu laušanas iespaids uz meža dabisko atjaunošanos (Effect of stump extraction on natural forest regeneration). *Mežsaimniecības rakstu krājums (Sammlung forstwirtschaftlicher Schriffen),*Vol. 7, 32-57. lpp. (in Latvian).
4. Hakkila P. (1975) Bark percentage, basic density and amount of acetone extractives in stump and root wood. *Folia forestalia,* Vol. 14, 71 p.
5. Lange K. (1925) Vēl par celmu izmantošanu (More about utilization of stumps). *Mežsaimniecības rakstu krājums (Sammlung forstwirtschaftlicher Schriffen)*, Vol. 3, 31-35. lpp. (in Latvian).
6. Lazdiņš A. (2006) Meža biomasas sagatavošana un izmantošana (Utilization of forest biomass). VSIA Vides projekti, Rīga, 54 lpp. (in Latvian).
7. Lazdiņš A., Magnus T. (2009) Bioenergy from pre-commercial thinning, forest infrastructure and undergrowth – resources, productivity and costs. In *Annual 15th International Scientific Conference Proceedings*, Latvia University of Agriculture, Jelgava, pp. 147-154.
8. Lazdiņš A., Zimelis A., Gusarevs I. (2012) Preliminary data on productivity of stump lifting head MCR-500. In: *Proceedings of the international scientific conference*, Latvia University of Agriculture, Jelgava, pp. 150-155.
9. Marklund L.G. (1988) *Biomassafunktioner för tall, gran och björk i Sverige (Biomass functions for pine, spruce and birch in Sweden)*. Sveriges lantbruksuniversitet, Institutionen för skogstaxering, 73 p. (in Swedish).
10. Repola J., Ojansuu R., Kukkola M. (2007) Biomass functions for Scots pine, Norway spruce and birch in Finland. Available at: http://www.metla.fi/julkaisut/workingpapers/2007/mwp053.htm, 14 January 2012.
11. Thor M., Nordén B., Iwarsson-Wide M., von Hofsten H., Lazdāns V., Lazdiņš A., Zimelis A. (2008) Forest energy from small-dimension stands, "infra-structure objects" and stumps (research report), SKOGFORSK, The Forestry Research Institute of Sweden, 75 p.
12. Vasaitis R., Stenlid J., Thomsen I.M., Barklund P., Dahlberg A. (2008) Stump removal to control root rot in forest stands. A literaturestudy. Silva Fennica, Vol. 42, Nr. 3, pp. 457-483.
13. Vasiļevskis A. (2007) *Latvijas valsts mežu apsaimniekošana, 1918-1940 (Management of Latvian state forests in Latvia, 1918-1940)*. Nacionālais apgāds, 430 lpp. (in Latvian).
14. Zimelis A., Lazdiņš A., Lazdāns V. (2012) *Enerģētiskās koksnes sagatavošanas tehnoloģijas kopšanas cirtēs, galvenās izmantošanas cirtēs un meža infrastruktūras objektos (Production of energy wood in pre-commercial thinning, commercial thinning, final felling and forest infrastructure)*. Atskaite par projektu LVMI Silava, Salaspils, 143 lpp. (in Latvian).

ECONOMIC VALUE OF WOOD CHIPS PREPARED FROM YOUNG STAND TENDING

Santa Kalēja[1], **Alfons Grīnfelds**[1], **Andis Lazdiņš**[2]
[1]Latvia University of Agriculture
[2]Latvian State Forest Research Institute "Silava"
kalejasanta@inbox.lv

Abstract
Small diameter wood obtained from young stand tending, with average $d_{1.3}$ > 4 cm, is suitable for the production of biofuel. So far mainly hand motorized tools have been used in young stand tending, to gather the small -diameter wood is costly and unprofitable. As the technology evolves and labor costs rise studies are carried out on how to increase the profitability of the young stand tending, by applying mechanized tending and production of biofuel from small-diameter wood. The study analyzed indicators, which directly affect the profitability of biofuel production from small-diameter wood produced by harvester tending. The biofuel production costs are analyzed using average purchase price of woodchips production service paid by JSC 'Latvijas valsts meži' (further JSC LVM). Revenue related to sales of chips is analyzed on the basis of JSC LVM average sales price for woodchips. The price of the preparation of the small-diameter wood is high and the proportions of the full cost price of wood chips make up 38%. The price of forwarding service impact on the full cost price comprises up to 25% and depends on the forwarding distance. The profitability calculation shows, that production of woodchips from the harvester tended young stands has to be regarded as unprofitable.
Key words: energy wood, small diameter wood, young stand, profitability.

Introduction

Young stand tending is very important for the forest industry. The main objective is to establish consistent, appropriate to circumstances, economically viable forest stand with the desired species composition and number of trees, by providing them with adequate growing space (Meža enciklopēdija, 2003; Lazdāns, 2006). Young stand tending is one of the basic tasks in the forest economy and so far has been associated only with expenses. Although tending can be repeated one to three times within one forest growth cycle, the frequency of tending has been reduced for economic reasons, while searching for the most optimal efficiency (Lazdāns, 2006).

As the technology evolves, it is likely that small-diameter wood from young stand tending in future could be used for biofuel production. The income from the sale of biofuel would increase the total income from the stand, but such practices are not used in Latvian. The young stand tending is done mainly by hand motorized tools. Cultivated small-diameter wood is left to decay in tend because, despite the variety of new technical solutions, the cost of harvesting and processing of small-diameter wood are high (Lazdāns, 2006; Lazdāns et al., 2008; Lazdiņš, 2012). Biofuel extraction from the young stand tending is seen as a great opportunity to increase the economic value of forests in Scandinavia and is supported at the national level through subsidies. Due to the increasing expenses of hand labor, the young stands are tended in a mechanized way. Small-diameter wood is used in production of the energy wood chips (Lazdāns, 2006; Ehring et al., 2010; Lazdiņš, 2012). In order to help the young stand tending, the Latvian private forest owners are given an opportunity to gain support from the European Agricultural Fund for Rural Development (EAFRD) activity of Rural Development Programme 2007 - 2013 'Improving the economic value of forest'. The aim is to increase the economic value of forests by tending young stands, which has an area of at least 2 hectares and the average stand height of 10 or less meters. So far 2.3 million LVL has been acquired from this activity (Lazdiņš, 2012; Rural Support Service…, 2013).

Biofuel extraction from young stand is not affected by fluctuations in logging amount (Lazdiņš, 2012). Three potentials should be considered when evaluating the possibilities to produce wood chips form small-diameter wood. The theoretical potential is built on all the theoretically and physically available small diameter wood resources, which can be used in production of energy wood chips, regardless of the technical, environmental, legal and administrative constraints. Theoretical potential is calculated from forest auditing data of a particular young stand during a specified period of time. The technical potential of biofuel is derived from theoretical potential, by taking into account technical, ecological and legal constraints. Economically based biofuel potential is based on technically available potential of biofuels, the realization of which, according to the current market situation, is economically profitable. Analysis of potential production costs and revenue from woodchips is carried out to evaluate economic profitability (Hepperle, 2010; Straube, 2010; Lazdiņš, 2012). The data are used to calculate the cost-effectiveness or economic efficiency in this analysis. Profitability or yield from the production process is

denoted by term cost-effectiveness. Results from the profitability calculation show whether the profitability is sufficient or it is necessary to increase it by improving the production process (Pelšs, 2001). The objective of this study was to analyze the profitability of wood chips produced from small-diameter wood obtained from harvester tended young stands.

Materials and Methods

Average purchase price of wood chips production service paid by JSC 'Latvijas valsts meži' (JSC LVM) are analyzed as well as the average sales value of wood chips as of February 2013. The volume of wood chips sales is analyzed for the period from 2006 to 2013. The overall cost-effectiveness formula is used to calculate the profitability of wood chips production from the energy wood obtined from young forest tending (Formula 1).

$$R = \frac{P}{A} \times 100, \quad (1)$$

where: R is turnover profitability, %; P is profit or loss, LVL bulk m^{-3}; A is turnover, LVL bulk m^{-3} (Pelšs, 2001; Ahtikoski et al., 2008).

Turnover for one bulk m^3 of produced wood chips is sales price LVL bulk m^{-3}. JSC LVM forecasted average sales price of chips in 2013, from which the full cost price of wood chips will be deducted, is used for the calculation of profit or loss (Formula 2).

$$P = C_{sale} - I_{full}, \quad (2)$$

where: C_{sale} is sales price of wood chips, LVL bulk m^{-3}; I_{full} is full cost price of wood chips, LVL bulk m^{-3} (Pelšs, 2001).

The full cost price of wood chips from young stand small diameter wood is calculated by classical model of full cost price (Formula 3):

$$I_{full} = I_{cut.} + I_{forw.} + I_{chipp.} + I_{trans.} + I_{adm.} + I_{sell.} + I_{overh.}, \quad (3)$$

where: $I_{cut.}$ is the price of the small diameter wood cutting service, LVL bulk m^{-3}; $I_{forw.}$ is the price of forwarding service, LVL bulk m^{-3}; $I_{chipp.}$ is the price of chipping service, LVL bulk m^{-3}; $I_{trans.}$ is the price of road transportation service, LVL bulk m^{-3}; $I_{adm.}$ is the administration costs, LVL bulk m^{-3}; $I_{sell.}$ is selling costs, LVL bulk m^{-3}; $I_{overh.}$ is overheads, LVL bulk m^{-3} (Pelšs, 2001; Petty and Kärhä, 2011).

The cost of small-diameter wood preparing service is affected by the chosen technical solution. The current study analyzed the preparing of small-diameter wood by harvester. The price of the forwarding service as well as the price of road transportation service depends on the distance. The general linear regression model is used to describe the relationship between the factorial sign, which in this case is the distance of forwarding or road transportation, and the resulting feature, which in both cases is the price of services (Formula 4):

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i,$$
$$i = 1 \dots N, \quad (4)$$

where: β_0 is the free member of the general group regression line; β_1 is the directional coefficient of the general group regression line; ε_i is the random error; N is the number of general group elements.

The chipping service price was taken as a constant value and, according to the average JSC LVM prices of wood chips production service for February of 2013, is 1.87 LVL bulk m^{-3}.

It is assumed that the administrative costs, which should be included in full cost price of wood chips, comprise 3% of the production cost of wood chips, but the cost of sales is 2%.

The overhead, includable in the full cost price of wood chips, could be special paper coverage for drying small diameter wood. It increase full cost price of wood chips by 0.04 LVL bulk m^{-3}

Results and Discussion

Monitoring data about wood biomass usage for energy purposes have shown that from 2005 to 2011 in Latvia we can observe an upward trend in wood chip consumption. Monitoring data also show that in 2008 Latvia experienced a little decrease in wood chip consumption, that can be explained with the onset of the economic crisis. In 2009 the consumption of wood chips returned to the level of 2007 and continued to grow (Koksnes biomasas izmantošanas…, 2012).

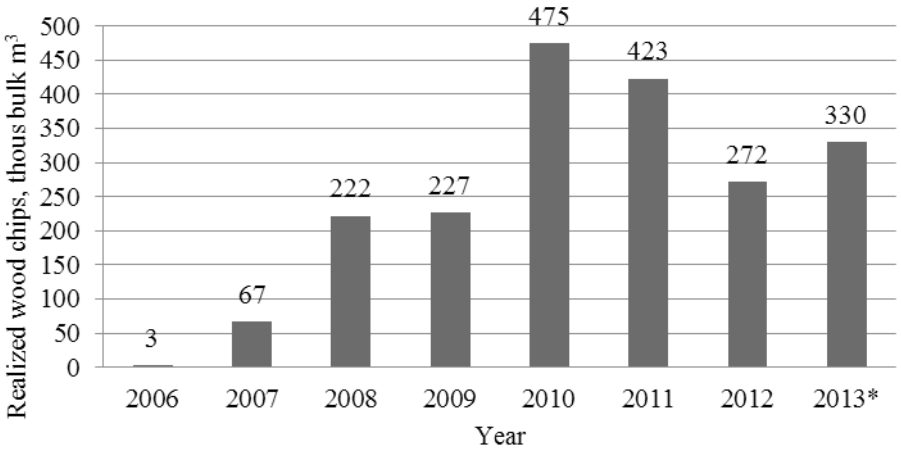
JSC LVM is one of the largest wood chip producers in this country. Analyzing JSC LVM wood chip sales (Fig. 1) it can be concluded that from 2006, when JSC LVM started to produce the wood chips, till 2010 there was a sharp rise in wood chip sales. The volume sold in 2007 increased 22 times in comparison with that of 2006. The rapid sales growth was observed in 2008, when, compared to 2007, it increased 3 times. The sales growth in 2009 was low compared to 2008, while in 2010, compared to 2009, wood chip sales increased 2 times, reaching 475 thousand bulk m^3. These sales growth trends can be explained by the increase in wood chip consumption in Latvia. The fall in consumption in 2008, associated with the onset of

economic crisis, did not affect the JSC LVM wood chip sales volume as it accounted for only 11% of total national consumption of wood chips (Koksnes biomasas izmantošanas…, 2012). The slight decline in sales happened in 2011 and this tendency continued also throughout 2012. The above situation can be explained by economic constrains associated with the implementation of the forest certification system and reorganization of the production. In the 2011 the consumption of wood chips decreased by about 4.4%. Sales of wood chips in 2012, compared to 2010, decreased 1.7 times and got closer to the amount of wood chip sales of 2009.

Sales of wood chips in 2013 will increase 1.2 times in comparison to 2012. The production of wood chips has also increased in other Baltic and Nordic countries (Koksnes biomasas izmantošanas.., 2012).

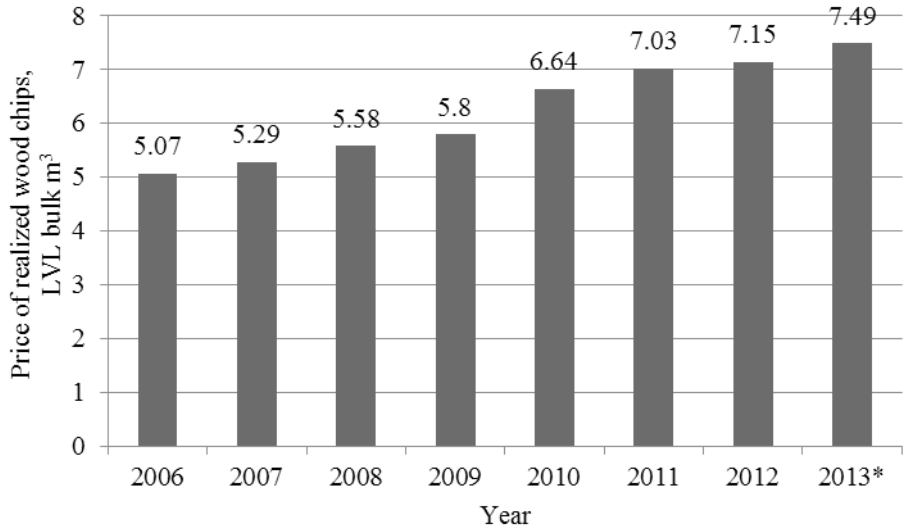
The average price at which the JSC LVM sold the wood chips has increased (Fig. 2.).

The price growth in 2007 when the JSC LVM launched the sale of wood chips was 4% compared to 2006. In 2008 compared with 2007, the sales price increased by another 5%. Such increases can be observed in 2009, when the sales price, compared to 2008, rose by 4%. In 2010, compared to 2009, the sales price of wood chips increased by 13%. This



* predicted sales volume

Figure 1. Volume of wood chips sold by JSC LVM during the years 2006 to 2013, thousand bulk m^3.



* predicted sales price

Figure 2. Price changes of realized wood chips by JSC LVM during the years 2006 to 2013, LVL bulk m^{-3}.

tendency continued in 2011, when, compared with 2010, the price rose by 6%, while in 2012, compared with 2011, by 2%. The price of wood chips increased 1.4 times or by 29% in 2012, compared to 2006, when LVM began marketing the wood chips. Increase in sales price is expected to continue in future. This is due to the growing demand for energy wood chips that is associated with the rise in consumption (Koksnes biomasas izmantošanas…, 2012).

Previous studies have confirmed that harvesting of small-diameter wood for production of wood chips should be started only if the average height of the felled small-diameter wood is from 4 to 9 meters, and the number per hectare, depending on the species, ranges from 5,000 to 6,000 units. It is possible to harvest 30 to 110 m3 small-diameter wood per hectare from young stands that meet these conditions. Young stands, from which the cultivated small-diameter wood will be used in the production of wood chips, should be at least 2 to 3 hectares, so that small-diameter wood chipping material would form at least 100 m^3 of small-diameter wood in the upper stack. When a young stand is chosen for the biofuel production, sustainability of the soil plays an essential role, in order to allow tending of young stands, forwarding of small diameter wood and construction of stowage (Lazdāns, 2006). The average diameter of trees at breast height ranges from 4 to 30 cm.

Several combinations of technology and machines can be used in the wood chip production. Traditional scheme of wood chip production begins with a small-diameter wood preparation, transportation, chipping and further transport.

When the service rates of young stand tending by the harvester are analyzed, cost of production of biofuel derived from young stands can be calculated.

Small-diameter wood cutover preparation costs range from 2.12 to 2.39 LVL bulk m^{-3} depending on the selected logging equipment (Lazdāns et al., 2008). Since so far the harvester has not been used in tending of young stands with a volume of average tree $d_{1.3} < 8$ cm, no information on pricing is available. Scientific studies show that the smaller the average diameter of the tree stands the higher the production costs of small-diameter wood. Based on this information assumption is made that the service average price for harvester used tending of young stand with an average tree $d_{1.3} < 8$ cm would exceed the average price of small-diameter wood production from young stands with an average tree $d_{1.3} > 8$ cm. The price for harvester service has been analyzed for a young stand with an average tree $d_{1.3} > 8$ cm (Fig. 3.). It appears that the forwarding price is affected not just by average volume of timber, but also by tree species.

The lowest thinning service prices are for pine (*Pinus sylvestris*) stands. They are l ower than prices for the rest of the stands by average 0.5%; consequently, it can be considered that the differences are not statistically essential (Fig. 3.). Spruce (*Picea abies*) tending prices are on average 4% higher than prices for pine stands and other stands.

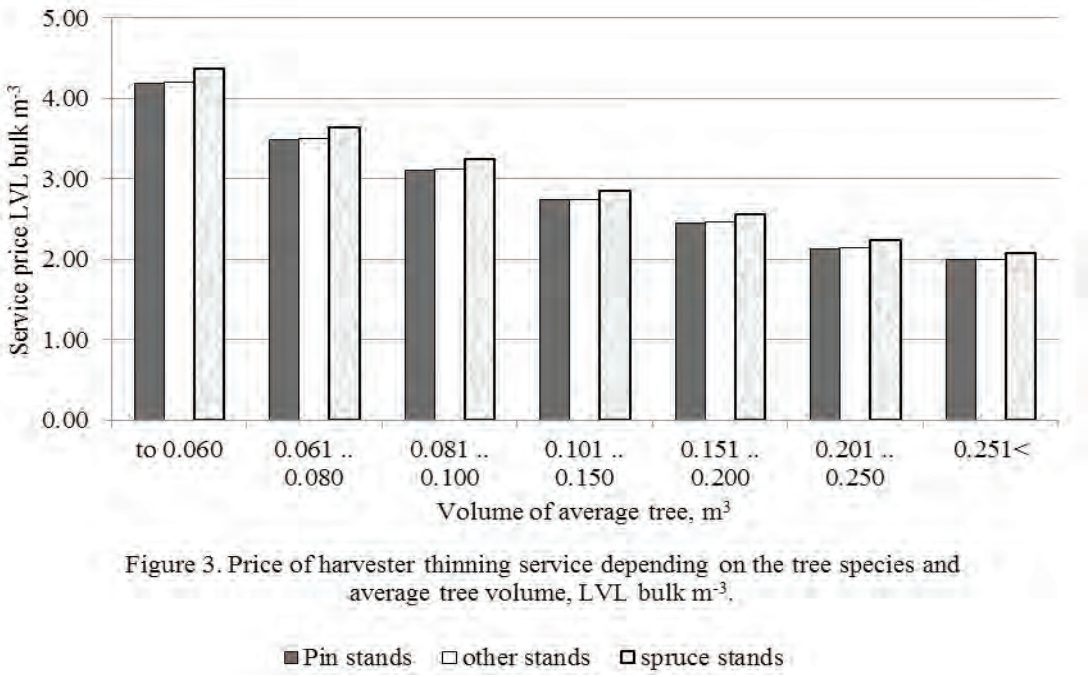


Figure 3. Price of harvester thinning service depending on the tree species and average tree volume, LVL bulk m^{-3}.

Another significant issue for analysis of wood chip production costs is the price of small-diameter wood forwarding service, depending on the distance. Small-diameter wood forwarding prices are equalized to prices of logging residues forwarding service in selective cutting (Fig. 4.).

There is a strong linear relationship between forwarding distance (l) and average price of service (c), as indicated by the coefficient of determination $R^2 = 0.9995$, i.e. if the forwarding distance increases by 100 metres, service price increases by 0.19 LVL bulk m^{-3}.

Road transportation service prices for produced wood chips also have a significant impact on the wood chip production costs. The price of service (c) increases if the transportation distance (l) increases. This correlation can be explained by a linear regression model (Fig. 5.).

Price for every 10 km increases by 0.16 LVL bulk m^{-3}, if the wood chips are transported to the final consumer in Latvia. Price for every 10 km increases by 0.19 LVL bulk m^{-3} if the wood chips are transported outside the Latvian border.

The selected manufacturing technology greatly affects efficiency of the wood chip production. Technology and tending methods are chosen by the above mentioned criteria - the soil bearing capacity, stand density and average diameter of the tree (Vilkriste, 2012).

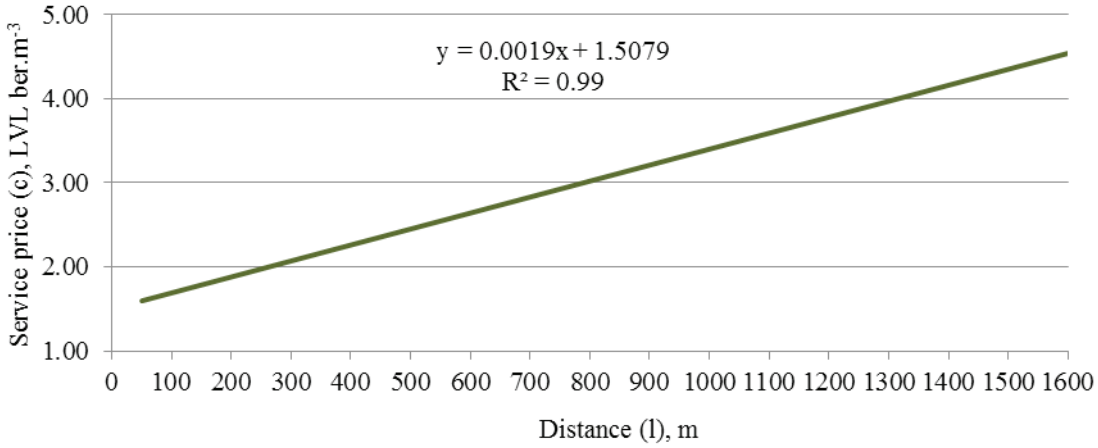


Figure 4. Price of thinning residual forwarding service depending on the forwarding distance, LVL bulk m^{-3}.

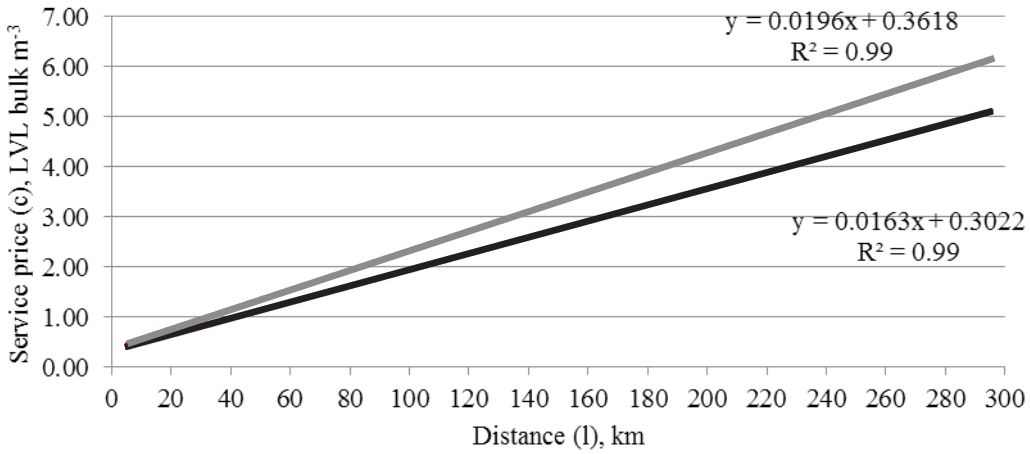


Figure 5. Price of wood chips road transportation service depending on the distance , LVL bulk m^{-3}.

Table 1

Full cost price calculation for wood chips

Indicators	Volume of average tree (to 0.060 m^3)	Full cost price structure, %	Volume of average tree (more than 0.251 m^3)	Full cost price structure, %
Price of cutting service	4.19	38.4	1.99	23.2
Price of forwarding service (601 … 700 m)	2.74	25.1	2.74	31.9
Price of chipping service	1.87	17.2	1.87	21.8
Price of road transportation (71 … 80 km)	1.54	14.1	1.54	17.9
Overheads	0.04	0.4	0.04	0.5
Cost of production	**10.38**	**95.2**	**8.18**	**95.2**
Costs of administration	0.31	2.9	0.25	2.9
Costs of sales	0.21	1.9	0.16	1.9
Full cost price	**10.90**	**100**	**8.59**	**100**

To calculate the full cost price of wood chips, two full cost price calculating models were created. In the first model it was assumed that young stand tending is carried out by harvester with the average tree volume of up to 0.060 m^3. The second model of tending stand average tree volume is greater - 0.251 m^3 (Table 1).

In calculations we used JSC LVM average service purchase price for chipping as of February 2013. Assuming that the average forwarding distance of small-diameter wood from the young stand tending for JSC LVM is within the range of 601…700 m and the average road transportation distance is from 71…80 km, in calculations we used the average price of service purchase. The estimated overheads were 0.04 LVL bulk m^{-3}.Results of the first calculation model show that the production cost of wood chips is 10.38 LVL bulk m^{-3}, while the full cost price is 10.90 LVL bulk m^{-3}. Results of the second calculation model show that the production cost of wood chips is 8.18 LVL bulk m^{-3}, so the full cost price is 8.59 LVL bulk m^{-3} respectively.

From the analysis of the full cost price and cost structure of wood chips we can conclude that in the first calculation model the biggest part of total costs comprise harvesting service costs, followed by forwarding and chipping service costs. Road transportation service costs are also relatively high. Administration and marketing costs as well as overheads account for only 5.2% of the full cost price of wood chips. Cost structure of the second calculation model differs from the first model. With the increase of average tree volume obtained from young stand, the service costs of small-diameter wood harvesting will decrease. The biggest part of costs consists of forwarding costs of small-diameter wood, followed by harvesting, chipping and road transportation service costs.

Assuming that the sales price of wood chips is 7.49 LVL bulk m^{-3}, in the first calculation model full cost price of wood chips is higher than the sales price, thus production of wood chips under certain conditions result in loss – 3.41 LVL bulk m^{-3}. The calculation results show that the profitability level of turnover is negative (- 46% bulk m^{-3}). In the second calculation model the full cost of wood chips is higher than the sales price of wood chips (loss – 1.10 LVL bulk m^{-3}). Consequently, the profitability level remains negative (- 15% bulk m^{-3}).

Production of wood chips from harvester tended young stands has to be regarded as unprofitable due to the current average price which JSC LVM pays the contractors for the production services. Possibilities to reduce the cost of production have to be explored to make more profitable production of small-diameter wood biofuel. Particular emphasis should be put on small-diameter wood preparation costs, which account for the greatest proportion of the total cost. Small-diameter wood preparation cost reductions can be achieved by boosting workers' productivity. It could be done by using the multi-operation machines in the preparation process (Lazdāns, 2006). Cost-benefit ratio of wood chip production could be increased if the market price of wood chips increased.

Conclusions

1. The prices for the preparation of small-diameter wood produced from harvester tending young stand are high and depending on average tree volume of stand represent about 24 to 38% of the full cost price of wood chips.
2. Forwarding service prices depend on forwarding distance. The price for every 100 m increases by 0.16 LVL bulk m^{-3}. It creates substantial full cost price increase in the form of wood chips.

3. Transportation prices are different, depending on the final consumer - whether it is in Latvia or abroad. The price for every 10 km increases by 0.16 LVL bulk m^{-3} in Latvia and 0.19 LVL bulk m^{-3} if the wood chips are transported outside.
4. Production of wood chips from harvester tended young stands has to be regarded as unprofitable due to the current average price which JSC LVM pays to the contractors for wood chip production services.

References

1. Ahtikoski A., Heikkilä J., Alenius V., Siren M. (2008) Economic viability of utilizing biomass energy from young stands —The case of Finland. *Biomass and Bioenergy*, 32, pp. 988-996.
2. Ehring R., Rotheneder E., Strasser C., Kristöfel C., Figl F. (2010) Wood fuel production technology and benefits derived from producing wood fuel. Available at: www.afo.eu.com/GetItem.asp?item=digistorefile, 4 February 2013.
3. Hepperle F. (2010) Prognosemodell zur Abschätzung des regionalen Waldenergieholzpotenzials auf der Grundlage forstlicher Inventur und Planungsdaten unter Berücksichtigung ökologischer, technischer und wirtschaftlicher Nuzungseinschrankungen (Forecast model for the calculation of the regional forest energy-wood potential based on forest inventory and planning data regarding technical, ecological and economical usage restrictions). Available at: http://www.freidok.uni-freiburg.de/volltexte/7902/, 4 February 2013. (in German).
4. Koksnes biomasas izmantošanas enerģijas ieguvē monitorings (Monitoring of wood biomass use for energy) (2012) Available at: http://www.e-koks.lv/files/Biomasa_projekts_2012.pdf , 4 March 2013. (in Latvian).
5. Lazdāns V. (2006) *Enerģētiskās koksnes resursu vērtējums, to sagatavošanas tehnoloģijas un izmaksas, veicot kopšanas cirtes 20 - 40 gadus vecās mežaudzēs* (Energy wood resource assessment, preparation technology and the costs of the thinning 20 - 40 old stands). Latvijas Valsts mežzinātnes institūts 'Silava', Salaspils, 70 lpp. (in Latvian).
6. Lazdāns V., Lazdiņš A., Zimelis A., Nordén B., Iwarsson – Wide M. (2008) *Forest energy from small-dimension stands, 'infra-structure objects' and stumps*, The Forestry research Institute of Sweden 'Skogforsk', Latvijas Valsts Mežzinātnes Institūts 'SILAVA', Uppsala, 44.p.
7. Lazdiņš A. (2012) *Pārskats par tehnoloģiju un tehnikas pieejamību enerģētiskās koksnes sagatavošanai un piegādei no galvenās cirtes, kopšanas cirtēm un meža infrastruktūras apauguma* (Review of technology and technical availability of energy wood production and supply from main cut, thinning and forest infrastructure overgrow). Latvijas Valsts mežzinātnes institūts 'Silava', Salaspils, 38 lpp. (in Latvian).
8. *Meža enciklopēdija* (Encyclopedia of forest) (2003) Zelta grauds, Rīga, 368 lpp. (in Latvian).
9. Pelšs A. (2001) *Vadības grāmatvedība* (Management accounting). 1. daļa, KIF 'Biznesa Komplekss', Rīga, 199 lpp. (in Latvian).
10. Petty A., Kärhä K. (2011) Effects of subsidies on the profitability of energy wood production of wood chips from early thinnings in Finland. *Forest Policy and Economics,* 13. pp. 575-581.
11. Rural Support Service information (2013) Available at: http://www.lad.gov.lv/lv/es-atbalsts/lauku-attistibas-programmas-pasakumi/122-meza-ekonomiskas-vertibas-uzlabosana/, 10 March 2013.
12. Straube C. (2010) Erfassung des Energieholzpotentials und seiner Verfügbarkeit im Wald und im Offenland mit neuen Fernerkundungsmethoden (Acquisition of the bioenergy potential and the availability in the forest and non-forest land using new remote sensing techniques). Available at: http://www.freidok.uni-freiburg.de/volltexte/7632/, 4 February 2013. (in German).
13. Vilkriste L. (2012) Enerģētiskā koksne- ieguvums īpašniekam, mežam un sabiedrībai (Energy wood-acquisition the owner, the forest and the public). Available at: http://projektwebbar.lansstyrelsen.se/wood-energy-andcleantech/SiteCollectionDocuments/Information%20Material/Wood%20Energy%20A%20Hot%20Topic%20LV.pdf, 12 January 2013. (in Latvian).

LINEAR REGRESSION ANALYSIS OF INDICES DESCRIBING LATVIAN WOOD PROCESSING INDUSTRY

Janis Krumins, **Ingus Smits**, **Salvis Dagis**, **Dagnis Dubrovskis**, **Irina Arhipova**
Latvia University of Agriculture
janis.krumins@llu.lv

Abstract
To forecast how different indices describing Latvian forest industry will develop in the future, the decision support program which is based on the research of supply chains and production processes as well as on systematic analysis of the whole industry should be developed. One of the most common types of analysis is modelling of processes. In this paper processes of forestry and wood processing in Latvia are modelled by using general approach for system modelling, and each process is described as an abstract system where only its input and output values were identified. Correlations of input and output value time series with a simple and multiple regression analysis method were analyzed. Regression analysis was created for 77 pairs of indices which theoretically could have significant correlations. Input and output factor linear regression analysis for set of processes Forestry and Wood processing shows that not always there is significant correlation between time series of chosen model factors. Some of correlations between time series of input and output data in the model of forest sector even showed controversial results. The amount of information about processes and their quantitative indicators in Latvian wood processing industry is not sufficient for development of precise simulation models. There is need to develop a list of criteria for missing information and carry out its collection process.
Key words: forest sector modelling, Latvian forest industry, linear regression analysis.

Introduction

In Latvia, timber resources have a significant economical, social and ecological value as forests cover 54% of territory and timber stocks are slightly increasing year by year. During last ten years, annual cutting volume of timber resources has been 10 to 13 million m^3 (State Forest Service, 2012). Forest industry consists of two important sectors – forestry and wood processing industry both closely working together. Together with connected sectors (transport, building, energy industries, science, etc.), forest industry employs around 14% of able-bodied population, from which most are employed in rural areas of Latvia. Total export value of goods produced by wood processing industry in 2011 and 2012 reached 1.2 billion LVL (Ministry of Agriculture ..., 2012).

To forecast how different indices describing Latvian forest industry will develop in the future, a decision support tool should be developed. This tool should be in the form of IT program where economic modelling of the Latvian wood resource utilization and further processing could be done. This kind of program should be based on the research of supply chains and production processes as well as on systematic analysis of the whole industry (Toppinen and Kuuluvainen, 2010). One of most common types of analysis is modelling of processes. Its main task is to describe general production and supply processes in sufficient degree of detailed elaboration. To fulfil this task, it is possible to use different approaches (Becker and Kahn, 2003).

Since 2012 in Latvia as a decision support tool in strategic planning for the whole forestry sector programme 'MESTRA", jointly developed by Latvia University of Agriculture and Latvian State Forest Research Institute "Silava", is used. There is no decision support tool for strategic planning of wood processing sector though.

In this paper processes concerning forestry and wood processing in Latvia are described. They are being modelled by using general approach for system modelling and each process is described as an abstract system where only its input and output values are identified (Hangos and Cameron, 2001). To study most important processes and their relationships on a conceptual level, this kind of model is used in the research. For further research of identified relationships simple and multiple regression analysis of indicators acquired from different statistical sources was used. As wood processing companies are closely linked with forestry which is the main wood supplier to wood processing industry, then looking for indicators that influence Latvian wood processing industry, indicators of the whole forest sector were observed.

Our research had two main tasks. The first task was to identify indicators that influence Latvian wood processing industry and collect their time series. The second task was to analyze correlation of collected data from at least the last ten year period and evaluate which data could be used for development of programme prototype for economic modelling of Latvian wood resource utilization and further processing.

Materials and Methods

For analysis of indicators that influence Latvian forest processing industry only those indicators

were selected which had information for at least last ten years. This minimal length of time series was necessary to get as feasible data as possible from simple and multiple linear regression analysis of the indices. Most of the collected data had time series for at least twelve years. Time series data were collected from different publicly available data bases - Central Statistical Bureau of Latvia (Central Statistical Bureau ..., 2012), Ministry of Agriculture and State Forest Service. Information was gathered in the following groups: the number of employees, area of forest land, stock volume of forest stand, area of felled forest land, volume of felled timber, area of regenerated forest land, net turnover, profit and profitability of forest sector enterprises, non-financial investments in forestry enterprises, value added, value added per employee, average gross salaries of employees, sales of manufactured products, import and export of forest industry, balance of foreign trade, prices of exported production.

Information about each group time series was collected in the most detailed level possible. For example, information about employment, net turnover, profit and profitability of forest sector enterprises, non-financial investments in forestry enterprises, value added, value added per employee and average gross salaries of employees were collected and analyzed in groups by the type of activity – forestry and logging (NACE 02), manufacture of timber products (NACE 16) and manufacture of furniture (NACE 31). In addition, information about sales of manufactured products, import and export volumes and value of forest industry was collected and analyzed by different type of production.

After all data were collected, a general model of forest industry for description of the processes and their relationships was created (Figure 1).

For construction of model the so called 'black box' principle was used which is common in modelling and analyzing different solutions of information

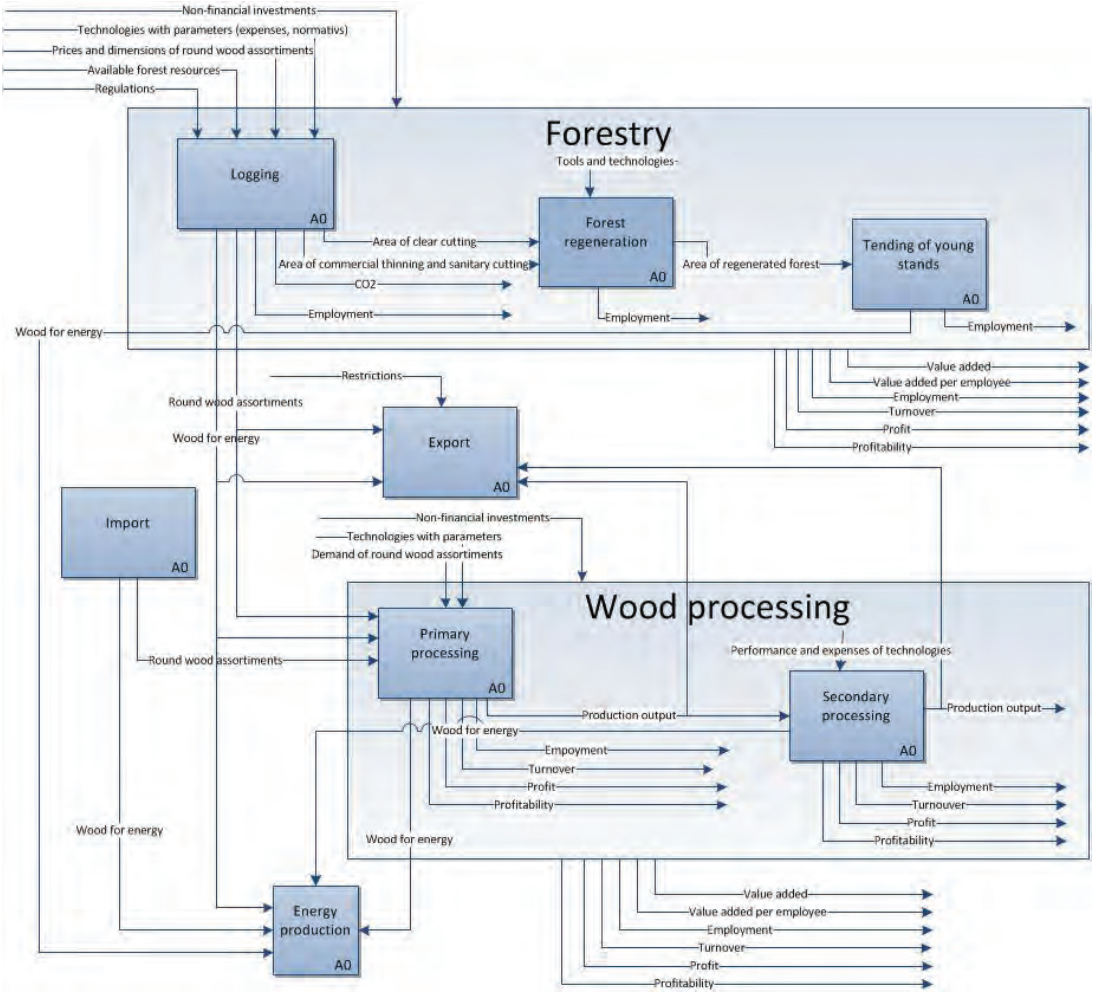


Figure 1. General model of forest industry for description of the processes and their relationships.

technologies. In this case the process is described without going in details about its structure and its ongoing activities. The main characteristic feature of the process is a set of information about input and output where output data of one process can be initial information to another process. In figure 1 eight main processes of the forest sector and their characterizing data can be seen. The processes which are included in the model are as follows: Logging, Forest regeneration, Tending of young stands, Imports, Exports, Primary wood processing, Secondary wood processing and Energy production. To simplify the initial version of the model according to the available data set, processes of wood extraction, forest regeneration, tending of young stands are viewed as a single process Forestry. Similarly also primary and secondary wood processing processes are analyzed as a single process Wood processing. The main reason for this kind of analysis is the limited set of statistical information that does not allow creating a more detailed analysis of all processes in the model.

Import and Logging can be considered as the beginning of the model (the first processes) where data of the process Import are used as information for further analysis, but relations inside the process at this stage of modelling are not covered. Consequently, as the main output information here is volume of round wood and energy wood.

Set of processes Forestry is viewed on a more detailed level. It has five general input data items, which during development process of the model are divided into more detailed information. Input and output data can be divided into several groups - economic indicators, data characterizing technological processes, regulatory information and data describing resources. In this case, the economic performance is characterized by non-financial investments in forestry enterprises and the prices of assortments from input side as well as by value added per employee, employment, turnover of forestry and logging companies, profit, profitability and value-added on output side. Information characterizing the technological processes from input side is an assortment of round wood dimensions and prices and description of technologies with parameters. The most important information that is necessary for the modelling and analysis of the process Forestry is descriptive data about the resources available, which in a given model diagram makes one common input 'available forest resources'. Within the process Forestry resource transformation takes place, and results of transformations are characterized with output information - volume of round wood assortments and energy wood.

Next block in the model is Wood processing, and it describes processing of the received round wood assortments. This block consists of two processes - Primary wood processing and Secondary wood processing. Input data set for this block consists of a compilation of information that describes the available volumes of round wood assortments, technologies with parameters and non-financial investments. In output and internal circulation of information there are indicators that describe the results of each process, as well as the overall outcome. Main shortcoming for introduction of this block into real model is the large diversity of manufactured products as well as a relatively small set of statistical information, which is available for analysis of the internal processes.

Next step was to look for pairs of input and output time series for each of the processes out of pre-collected information of indicators that influence Latvian forest processing industry that theoretically could have significant correlations. For each pair of indices simple or multiple linear regression analysis was made. Regression analysis was performed by means of SPSS software where coefficient of determination (R^2) and input factor significance were calculated as well as model of regression was found.

After the regression analysis was performed, pairs of indices whose correspondence to real data was at least 30% ($R^2>0.3$) were selected for detailed analysis and evaluation if they could be used in programme prototype for economic modelling of Latvian wood resource utilization and further processing. In this paper a detailed description of relationship between input and output factors of the model processes was performed for those pairs of indices whose R^2 was at least 0.3 in set of processes Forestry and at least 0.7 in set of processes Wood processing.

Results and Discussion

Regression analysis was performed for 77 pairs of indices which theoretically could have significant relations. However, in most of the cases correlation was unsatisfactory.

Input and output factor linear regression analysis for the set of processes Forestry shows that not always there is a significant correlation between time series of chosen model factors (Table 1).

Regression analysis shows that profit of forestry and logging enterprises is significantly dependent ($p<0.05$) on the amount of non-financial investments in enterprises of forestry and logging. Profit of forestry and logging enterprises increases for 931 LVL if amount of non-financial investments in forestry and logging enterprises increases by one thousand LVL and model correspondence to real data is 50.5% because coefficient of determination R^2 is 0.505.

Turnover of forestry and logging enterprises is significantly dependent ($p<0.01$) on the amount of non-financial investments in enterprises of forestry

Table 1

Correlation between input and output factors in set of processes Forestry

No	Input factor X_i	Output factor Y	R^2	Regression equation
1.	X_1: Amount of non-financial investments in enterprises of forestry and logging, thousand LVL*	Y: Profit of forestry and logging enterprises, million LVL	0.505	$Y= -2.009 + 0.000931 * X_1 + e_i$
2.	X_1: Amount of non-financial investments in enterprises of forestry and logging, thousand LVL**	Y: Turnover of forestry and logging enterprises, million LVL	0.617	$Y= 107.14 + 0.003937 * X_1 + e_i$
3.	X_1: Amount of non-financial investments in enterprises of forestry and logging, thousand LVL**	Y: Profitability of forestry and logging enterprises, %	0.602	$Y= -69.97 + 0.01358 * X_1 + e_i$
4.	X1: Area of final felling, ha**	Y: Area of regenerated forest land, thousand ha	0.421	$Y= 2.094 + 0.0006 * X_1 + e_i$
5.	X1: Area of reconstructive felling, ha***	Y: Employment in forestry and logging, thousands of employees	0.639	$Y=14.40358+ 0.01327 * X_1 + e_i$
6.	X1: Area of commercial thinning, ha*	Y: Employment in forestry and logging, thousands of employees	0.320	$Y=11.624+ 0.000185* X_1 + e_i$

* - factor is significant with probability P=95% (p<0.05)
** - factor is significant with probability P=99% (p<0.01)
*** - factor is significant with probability P=99.9% (p<0.001)

and logging. Turnover of forestry and logging enterprises increases to 3.9 thousand LVL if the amount of non-financial investments in forestry and logging enterprises increases by one thousand LVL and model correspondence to real data is 61.72% (R^2=0.6172).

Profitability of forestry and logging enterprises is significantly dependent (p<0.01) on the amount of non-financial investments in enterprises of forestry and logging. Profitability of forestry and logging enterprises increases by 0.014% if amount of non-financial investments in forestry and logging enterprises increases by one thousand LVL and model correspondence to real data is 60.2% (R^2=0.602).

The area of regenerated forest land is significantly dependent (p<0.01) on the area of final felling (Figure 2). The area of regenerated forest land increases for 0.6 ha if the area of final felling increases by 1 ha and model correspondence to real data is 41.12% (R^2=0.421).

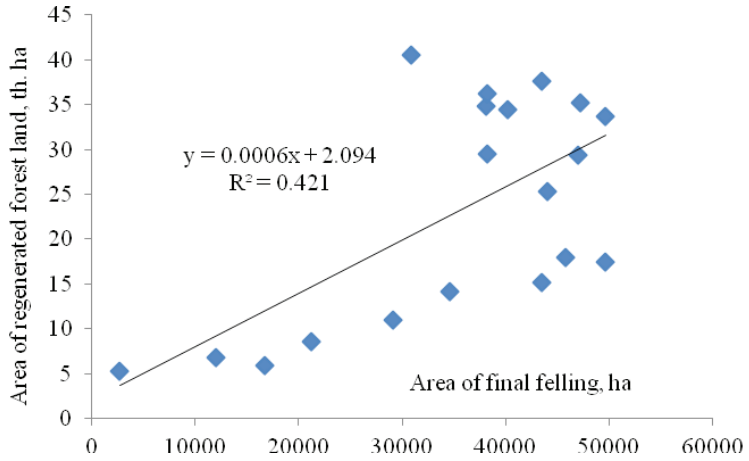


Figure 2. Correlation between area of regenerated forest land and area of final felling.

Employment in forestry and logging is significantly dependent ($p<0.001$) on the area of reconstructive felling. The number of employees in forestry and logging increases by 13.27 if the area of reconstructive felling increases by 1 ha and model correspondence to real data is 63.9% ($R^2=0.639$). This result of statistical analysis is controversial as from logical point of view the area of reconstructive felling could not have significant influence on employment as reconstructive felling in Latvia is done only in the area of a few hundred hectares annually.

Employment in forestry and logging is significantly dependent ($p<0.05$) on the area of commercial thinning. The number of employees in forestry and logging increases by 0.2 if the area of reconstructive felling increases by 1 ha and model correspondence to real data is 32% ($R^2=0.320$).

Input and output factor linear regression analysis for the set of processes Wood processing shows that not always there is a significant correlation between time series of chosen model factors (Table 2).

Value added (manufacture of timber products, manufacture of furniture) is significantly dependent on import of round wood ($p<0.1$) and type of activity ($p<0.01$) (Figure 3). The interaction effect of two factors is not significant. The

Table 2

Correlation between input and output factors in set of processes Wood processing

No	Input factor X_i	Output factor Y	R^2	Regression equation
1.	X_1: Import of round wood in forest sector, th. m^3 # X_2: Type of activity (manufacture of timber products, manufacture of furniture)** $X_1 * X_2$: Interaction effect of two factors	Y: Value added by type of activity (manufacture of timber products, manufacture of furniture), th. LVL.	0.716	Y=39863.24 + 139981.7236 (if X_2=manufacture of timber products) + 21.8288 * X_1 + 49.1889 * X_1 (if X_2=manufacture of timber products) + e_i
2.	X_1: Import of round wood, th. m^3*** X_2: Type of activity (manufacture of timber products, manufacture of furniture)* $X_1 * X_2$: Interaction effect of two factors	Y: Employment, (manufacture of timber products, manufacture of furniture), thousands of employees	0.920	Y=8.0256 + 17.9089 (if X_2=manufacture of timber products) + 0.0017 * X_1 + 0.00278 * X_1 (if X_2= manufacture of timber products) + e_i
3.	X_1: Import of round wood, th. m^3*** X_2: Type of activity (manufacture of timber products, manufacture of furniture)*** $X_1 * X_2$: Interaction effect of two factors	Y: Turnover of enterprises by type of activity (manufacture of timber products, manufacture of furniture), million LVL	0.927	Y= 80.95 + 419.0279 (if X_2=manufacture of timber products) + 0.060742 * X_1 + 0.29559 * X_1 (if X_2=manufacture of timber products) + e_i
4.	X_1: Import of firewood, th. tons X_2: Type of activity (manufacture of timber products, manufacture of furniture)*** $X_1 * X_2$: Interaction effect of two factors	Y: Employment, (manufacture of timber products, manufacture of furniture), thousands of employees	0.899	Y=9.0026 + 18.41 (if X_2=manufacture of timber products) + 0.02829 * X_1 + 0.3425 * X_1 (if X_2=manufacture of timber products) + e_i
5.	X_1: Import of firewood, th. tons X_2: Type of activity (manufacture of timber products, manufacture of furniture)*** $X_1 * X_2$: Interaction effect of two factors	Y: Turnover of enterprises by type of activity (manufacture of timber products, manufacture of furniture), million LVL	0.834	Y=99.799+ 515.618 (if X_2=manufacture of timber products) + 7.0162 * X_1 + 32.4655 * X_1 (if X_2=manufacture of timber products) + e_i
6.	X_1: Import of firewood, th. tons# X_2: Type of activity (manufacture of timber products, manufacture of furniture)** $X_1 * X_2$: Interaction effect of two factors	Y: Value added by type of activity (manufacture of timber products, manufacture of furniture), th. LVL.	0.740	Y=43398.6746+125035.7013 (if X_2 = manufacture of timber products)+3245.15*X_1+14605.476 * X_1 (if X_2=manufacture of timber products) + e_i
7.	X_1: Amount of non-financial investments in enterprises of manufacture of furniture, thousand LVL***	Y: Turnover of enterprises in manufacture of furniture, million LVL	0.794	Y= 82.7379 + 0.002707 * X_1

* - factor is significant with probability P=95% ($p<0.05$)
** - factor is significant with probability P=99% ($p<0.01$)
*** - factor is significant with probability P=99.9% ($p<0.001$)
# - factor is significant with probability P=90% ($p<0.1$)

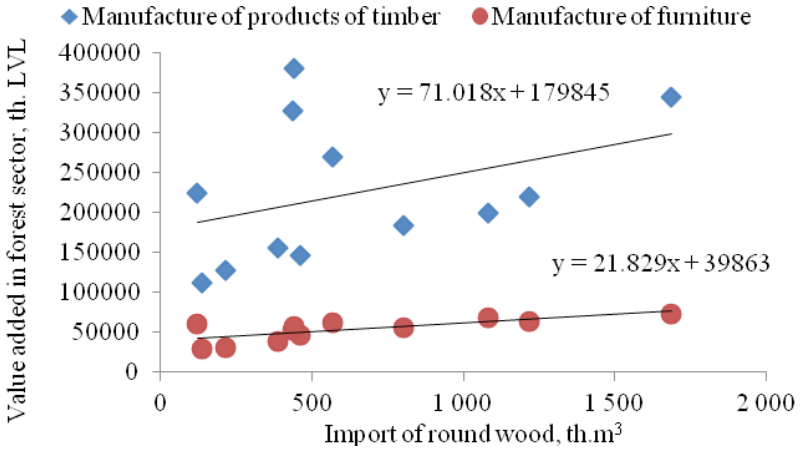


Figure 3. Correlation of value added in forest industry, import of round wood and type of activity (manufacture of timber products, manufacture of furniture).

correspondence of the model to real data was 71.6% (R^2=0.716).

General description of the model shown in Figure 3 is the following: Y = 39863.24 + 139981.72 (if X_2=manufacture of timber products) + 21.82 * X_1 + 49.19 * X_1 (if X_2= manufacture of timber products) + e_i

where

- Y is value added in forest industry (manufacture of timber products, manufacture of furniture), million LVL;
- X_1 is quantitative factor Import of round wood in forest sector, thousand m^3;
- X_2 is qualitative factor Type of activity with 2 values: manufacture of timber products, manufacture of furniture;
- e_i is random error.

When making interpretation of model direction coefficients, the model is transformed depending on the type of activity: manufacture of timber products, manufacture of furniture. As the result, following equations are obtained:

- if Type of activity is manufacture of timber products, then
  Y = 39863.24 + 139981.7236 (if X_2 = manufacture of timber products) + 21.8289* X_1 + 49.1889*X_1 (if X_2 = manufacture of timber products) + e_i or Y = 179845 + 71.018*X_1
- if Type of activity is manufacture of furniture, then
  Y = 39863.24 + 21.8289*X_1 + e_i

It means that

- if Import of round wood in forest sector (factor X_1) increases by 1000 m^3, then Value added in manufacture of timber products increases by 71.02 thousand LVL;
- if Import of round wood in forest sector (factor X_1) increases by 1000 m^3, then Value added in manufacture of furniture increases by 21.83 thousand LVL;
- taking into account that interaction effect of two factors X1 * X2 is not significant, it means that monetary increase of value added in the forest sector depending on the round wood import is not significantly different in manufacture of timber products or furniture. Graphically this means that two regression lines are almost parallel, as their increment rates are not significantly different.

Further on all other relations presented in Table 3 are described briefly.

The number of employed persons in forest sector (manufacture of timber products, manufacture of furniture) is significantly dependent on the import of round wood ($p<0.001$) and the type of activity ($p<0.05$). Interaction effect of two factors is not significant. The correspondence of the model to real data was 92.0% (R^2=0.920).

Turnover of forest sector enterprises by the type of activity (manufacture of timber products, manufacture of furniture) is significantly dependent on import of round wood ($p<0.001$), type of activity ($p<0.001$) and interaction effect of two factors ($p<0.001$). The correspondence of the model to real data was 92.7% (R^2=0.927).

The number of employed persons in forest sector (manufacture of timber products, manufacture of furniture) is significantly dependent on the type of activity ($p<0.001$), but it is not significantly dependent on the amount of imported firewood and interaction effect of two factors. The correspondence of the model to real data was 89.9% (R^2=0.899).

Turnover of enterprises by the type of activity (manufacture of timber products, manufacture of furniture) is significantly dependent on the type of activity ($p<0.001$), but it is not significantly dependent on the amount of imported firewood and interaction effect of two factors. The correspondence of the model to real data was 83.4% ($R^2=0.834$).

Value added in forest sector (manufacture of timber products, manufacture of furniture) is significantly dependent on the type of activity ($p<0.01$) and import of firewood ($p<0.1$), but it is not dependent on interaction effect of two factors. The correspondence of the model to real data was 74.0% ($R^2=0.740$).

Turnover of enterprises in the type of activity-manufacture of furniture is significantly dependent on amount of non-financial investments in enterprises of manufacture of furniture ($p<0.001$), and correspondence of the model to real data was 79.4% ($R^2=0.794$).

For development of comprehensive programme prototype for economic modelling of Latvian wood resource utilization and further processing, the forest sector model should be supplemented with information about demand of production between local and export markets, influence of used wood processing technologies on different output indices, employment dependency on volume and assortment of products manufactured.

Conclusions

1. The processes which are included in the model of Latvian forest industry are the following: Logging, Forest regeneration, Tending of young stands, Imports, Exports, Primary wood processing, Secondary wood processing and Energy production. Available data set of statistical information for detailed analysis of all processes of the model is limited. Therefore, regression analysis for most of the processes is done on a less detailed level – for set of processes Forestry and Wood processing.
2. In the model of forest industry every process is described with input and output information where output data of one process can be initial information to another process. Correlations of input and output value time series were analyzed with a simple and multiple regression analysis method.
3. Regression analysis was performed for 77 pairs of indices which theoretically could have significant relations, but in most of the cases correlation was unsatisfactory. In set of processes Forestry only for 7 correlations and in set of processes Wood processing for 12 correlations correspondence to real data was at least 30% ($R^2>0.3$).
4. Some correlations between time series of input and output data in the model of forest sector showed controversial results. For example, annual increase of area of reconstructive felling by 1ha leads to annual increase of number of employees by 13 which cannot be true.
5. From analyzed pairs of indicators, in programme prototype for economic modelling of Latvian wood resource utilization and further processing, should be used those regression equations, whose correspondence to real data is at least 70% ($R^2>0.7$).
6. The amount of information about processes and their quantitative indicators in Latvian wood processing industry is not sufficient for development of precise simulation models. There is need to develop a list of criteria for missing information and carry out its collection process.

Acknowledgements

This research was carried out within the frame of the project 'Substantiation of deciduous trees cultivation and rational utilisation, new products and technologies' in Latvia University of Agriculture (contract number: 2011. 10-4/VPP-5) and preparation of manuscript: by European Social Fund's project Support for the implementation of the Latvian Agricultural University doctoral study (contract number: 04.4-08/EF2.D2.45).

References

1. Becker J., Kahn D. (2003) The Process in Focus. In: Becker J., Kugeler M., Rosemann M. (eds.) *Process Management. A Guide for the Design of Business Processes*. Springer, Berlin, pp. 1-12.
2. Central Statistical Bureau of Latvia (2012) Statistics Database. Available at: http://csb.gov.lv/en/dati/statistics-database-30501.html, 22 October 2012.
3. Hangos K., Cameron I. (2001) *Process Modelling and Model Analysis.* Academic Press, London, 543 p.
4. Ministry of Agriculture of the Republic of Latvia (2012) Meža nozares produkcijas ārējā tirdzniecība (External trade of forest industry). Available at: http://www.zm.gov.lv/?sadala=289, 12 November 2012. (in Latvian).
5. State Forest Service (2012) Meža apsaimniekošana (Forest management). Available at: http://vmd.gov.lv/?sadala=2, 05 February 2013. (in Latvian).
6. Toppinen A., Kuuluvainen J. (2010) Forest sector modelling in Europe - the state of the art and future research directions. *Forest Policy and Economics*, 12, pp. 2-8.

INTERNAL FACTORS AFFECTING COMPETITIVENESS OF LATVIAN SMALL AND MEDIUM-SIZED FURNITURE MANUFACTURERS

Sigita Liše[1], **Jānis Mārciņš**[2]
[1]Latvia University of Agriculture
[2]Latvian Association of Wood Processing Entrepreneurs and Exporters
sigita.lise@e-koks.lv; janis.marcins@latvianwood.lv

Abstract
The furniture industry is an innovative industry that produces high added value products and its turnover is several billions of euros in Europe, and there mainly work small and medium-sized enterprises (abbreviation – SMEs). Nowadays competitiveness is an essential factor for both a country and its enterprises in the process of dealing with changing market conditions. The global market is changing and for enterprises it is too hard to position themselves and find the way how to differ from other competitors. From 2006 until 2010 a Latvian furniture market value, numbers of employees and enterprises in the sector and its share in GDP has decreased. As a result, there are the serious challenges to be met and increase their competitiveness in domestic and export markets. The author has made an in-depth research into influencing competitiveness factors of SME micro level in the furniture manufacturing industry.The study objective was to identify the key internal factors wich influence the SME of Latvian furniture manufacturers. The aim was to obtain an internal factor of competitiveness assessment of the 30 respondents by random sampling method and expert method of factor assessment. The enterprises need to constantly increase their competitiveness. The internal factors influencing the competitiveness of SMEs are connected with the products, manufacturing of products, financial situation, management and marketing activties. The competitiveness level of Latvia`s SMEs in the furniture manufacturing has been evaluated as average in 70% of cases. Only 27% of the enterprises show a good level of competitiveness.
Key words: internal factors of competitiveness, SME, furniture manufacturers.

Introduction

Today the market is constantly changing, thus making it difficult for enterprises to position themselves and find the way to differ from the competitors (Fikss, 2009). If an enterprise does not follow and respond to the changes in the external environment, there might be a situation when other competitors become stronger in satisfying customers' high level needs (Caune and Dzedonds, 2009).

There are many different definitions of the concept `competitiveness`, but all of them have common guidelines. However, the most important thing is that competitiveness is the ability to carry out one`s relative advantages. Only one question remains open – which are those advantages or disadvantages that reveal the advantages of one subject`s competitiveness over another`s. The following authors should be distinguished (Barney, 1991; Coyne, 1986; De Wit and Meyer, 1994; Henderson, 1983; Johnson and Scholes, 1993; Ketel, 1999; Peteraf, 1993; Porter, 1985; Prahalad and Hamel, 1990; Sanchez and Heene, 1997; Thompson and Strickland, 1998). Studies related to the competitiveness of enterprises are relatively few. As regards the furniture industry and its enterprises competitiveness studies, there is practically none in Latvia.In Latvia, there are many key enterprises competitiveness study authors (Caune, 2005; Fedotova, 2012; Geipele and Vanags, 2009; Judrupa and Šenfelde, 2007; Kassalis, 2010; Vasiļjeva and Gļebova, 2010).

The competitive advantages are identified with variety factors and their combinations. Competitiveness factors are divided according to different authors and vary slightly depending on the working area and country. For the competitiveness assessment the identification and selection of affecting factors is important. In the study the author choses the factors identified by Vasiļjeva and Gļebova (2010) thatanalyse the competitiveness factors of production enterprises in Latvia and are more accurate and relevant. At the same time they are sufficient covering a number of minimum factors. The identified factors are supplemented with a few important factors that are essential for the furniture industry. According to research of foreign and local scientists, the competitiveness factors can be to divided into two groups, i.e. the internal and external factors. In this paper an in-depth description and more detailed research and results of the enterprises competitiveness of internal factors are given. The external factors to compete in the segment and enterprises group are equal, but most importantl arethe competitiveness internal factors.

SMEs constitute a large part of the economy in Europe and in Latvia, and they play an important role for GDP and employment. SMEs describing elements and factors are different from the micro and large scale enterprises. SMEs are the key transition periods between a micro and large enterprise which requires more attention and makes the direct promotion to

this enterprise group. The government and each management of industry, including furniture sector, need to think about how to promote the development of SMEs and encourage new enterprises. According to the Ministry of Economics in Latvia information, there were ~ 73 771 active individual enterprises in 2010 of which 99.52% were of SME and it is by ~ 4% more than in 2009. Latvian distribution of economically active enterprises are as follows: micro enterprises are 83.94%, small enterprises are 12.94%, medium-sized enterprises are 2.64%, but large enterprises are 0.48%. SMEs are in all sectors, but the main areas are trade, services, construction and manufacturing, and one of the Latvian manufacturing industries - the furniture sector. According to the data of the Central Statistical Bureau of Latvia (2010), in Latvian forest industry there are 2832 enterprises, of which 543 are directly related to the furniture production and which is 18% less than in 2009. In Latvian furniture sector there is 81% of micro enterprises, 18% - small and medium-sized enterprises, and only 1% - large furniture enterprises. In 2010, about 5 500 employees were employed directly in the furniture sector, of which 68% were employed in SMEs. A total turnover of furniture industry was 105 million lats, of which 77% consisted of SMEs. In Latvia, the most produced is bedroom furniture (15%), wooden furniture (10%), office furniture (9%) and upholstered furniture (8%). The other types of furniture (58%) include the furniture for dining rooms, living rooms, shops, kitchens and other products. Although after the economic crises the activities in the sector declined, the last two years showed an improvement in terms of turnover and export volume. However, their contribution to the forest sector and the countries` economy has decreaded. The author has made an in-depth research into influencing competitiveness factors of SME micro level in the furniture manufacturing industry. The study objective was to identify the key internal factors wich influence the SME of Latvian furniture manufacturers. In 201,1 the study was conducted to appraise the furniture manufacturers the operational results show that they influence their competitiveness in the micro level. The study can be again done after a year to see changes in in enterprises' competitiveness level whether it will have been increased or decreased.

Materials and Methods

The competitiveness assessment is very important for the enterprise growth in the future. Usually, if there is a need to identify the important criteria of competitiveness, the customer questionnaires are used, but the author`s general task is not to identify the competitiveness criteria of furniture sector. In this case, the identification criteria which are mentioned in the literature have been used.

Based on the author`s document analysis on the enterprise competitiveness and its factors, the affecting factors of SME competitiveness on the furniture manufacturing industry were selected. The key internal factors are the following: the product competitiveness, financial condition, marketing, management and sales effectiveness as well as production competitiveness. Determining the importance of factors influencing competitiveness of SMEs, the experts` method will be used in its evaluation. In the evaluation of the importance of the factors influencing competitiveness of the enterprises, the pair – wise

Table 1

The pair-wise comparison matrix and its influenc`s weight determination algorythm by the experts

Factors	F_1	F_2	...	F_n	Determining the number of factors, F_{sk}	Importance of factor coefficients α
F_1	1	$F_{12} = \frac{1}{N}(a_1 + \cdots + a_n)$	...	$F_{1n} = \frac{1}{N}(a_1 + \cdots + a_n)$	i_1	$\alpha_1 = \frac{i_1}{I_{kop}}$
F_2	$\frac{1}{F_{12}}$	1	...	$F_{2n} = \frac{1}{N}(a_1 + \cdots + a_n)$	i_2	$\alpha_2 = \frac{i_2}{I_{kop}}$
...	...	...	...	...	...	...
F_n	$\frac{1}{F_{1n}}$	$\frac{1}{F_{2n}}$	...	1	i_n	$\alpha_n = \frac{i_n}{I_{kop}}$
				TOTAL	$I_{kop} = \sum_{n=1}^{\infty} i_n$	1.0

Table 2

Scale of factors values

Relative importance intensities of factor	Definition	Explanation
1	Equal importance	Both factors contributed equally
3	Moderate superiority over the other	Expert decision gives an insignificant superiority over the other
5	Essential or strong superiority	Expert decision gives a strong superiority over the other
7	Significant superiority	Expert decision gives a significant superiority over the other that it becomes practically significant
9	Very strong superiority	Expert decision gives a very strong significance over the other
2,4,6,8	Compromise values of relative importance intensities of factor	It is used in cases of compromise

comparison can be used, based on the method offered by the experts. The pair-wise comprasion matrix and its influence`s relative weight determination algorythm is shown in Table 1. Currently, five areas of expertise, i.e. the public administration, education and research, forest sector, economic and financial sector and organization sector of professional business are defined.

The calculation of the coefficient of importance factor used the values in the Table 2.

The important issue is the condition that the competitiveness internal factors and criteria of SME should be defined clearly, they must be measurable in time, provide the information on the current situation and comply with the changes, as well as encourage the activity. In total 4 factors and 31 criteria were identified.

After the coefficient of importance factors obtaining in the micro level has made the assessment function of competitiveness furniture manufacturing SME. Micro level of competitiveness consists of 4 affecting internal factors, which are expressed by the formula (1):

Determining of competitiveness levels for SMEs a specific rating value is used, as it is mentioned in Table 4.

The model of SMEs competitiveness represents the positive and negative aspects, its operational efficiency and the problems that decrease its growth and development. The competitiveness assessment model is approbated to 30 enterprises of SME in the furniture manufacturing sector, i.e. 28% from all SME in the Latvian furniture industry according to the information of date base "Lursoft" in 2009.

Results and Discussion

Since the first study can be used as the reference, other studies are evaluated according to the competitiveness in SME of furniture manufacturing sector. The satudy of the competitiveness of internal factors allows to construct a model with the help of which the effect of small and medium-sized furniture manufacturing competitiveness is shown in Latvia (Fig. 1).

According to the results of methodology derived, the concrete coefficient of importance factors for the SME in the furniture manufacturing industry (Table 5) are given. For further information of introduction contents the symbol of factors and criteria will be used.

The study shows that the criteria of product competitiveness are the product quality (f_{11}) with the coefficient of importance criterion 0.21. Next important criterion is a product price (f_{13}) with importance coefficient 0.20 and product assortment (f_{12}) with coefficient 0.19. Less important criteria are product assortment (f_{12}), warranty terms (f_{14}), ease of use (f_{15}) and other benefits (f_{16}). Furniture manufacturing SME

$$MU_k = \left((\alpha_1 F_1 + \alpha_2 F_2 + \alpha_3 F_3 + \alpha_4 F_4) / (\alpha_1 F_{max} + \alpha_2 F_{max} + \alpha_3 F_{max} + \alpha_4 F_{max}) \right) \text{ x } 100 \quad (1)$$

where:

MU_k – competitiveness level of SME in the furniture industry (percentage);

$\alpha_1 + \alpha_4$ – coefficient of importance factor;

$F_{1, \ldots,} F_4$ – internal factor (Table 3)

F_{max} – maximum values of factor.

Table 3

Internal factors and criteria of competitiveness of Latvian SME in the furniture manufacturing industry

Factor (its symbol)	Criterion (its symbol)
Product competitive factor (F_1)	Product quality (f_{11})
	Product assortment (f_{12})
	Price (f_{13})
	Warranty terms (f_{14})
	Ease of use (f_{15})
	Other benefits (f_{16})
Financial condition factor (F_2)	Solvency ratio (f_{21})
	Profit before tax (f_{22})
	Liquidity (f_{23})
	Turnover growth (f_{24})
	Return of equity (f_{25})
Marketing, management and sales effectiveness factor (F_3)	Market share dynamics (f_{31})
	Labor productivity (f_{32})
	Levels of management competency (f_{33})
	Control system efficiency (f_{34})
	Stock policy (f_{35})
	Discount policy (f_{36})
	Deferred payment policy (f_{37}),
	Customer loyalty (f_{38})
	Investment projects (f_{39})
	Competitive market research (f_{310})
Production competitive factor (F_4)	Availability of production resources (f_{41})
	Investment in human capital (f_{42})
	Scientific research projects (f_{43})
	New or innovative technologies (f_{44})
	Labor productivity (f_{45})
	Productions staff by educational relevance (f_{46})
	Use e of cooperation (f_{47})
	Environmental and ecological impact (f_{48})
	Infrastructure of productions (f_{49})
	Cost calculation (f_{410})

Table 4

SME competitiveness rating scale

Competitiveness assessment in micro level	Assessment limits
Very low competitiveness	Less than 10.0% of the total factor value of the reporting period
Low competitiveness	From 10.1% to 30.0% of the total factor value of the reporting period
Middle competitiveness	From 30.1% to 50.0% of the total factor value of the reporting period
Good competitiveness	From 50.1% to 70.0% of the total factor value of the reporting period
High competitiveness	From 70.1% to 90.0% of the total factor value of the reporting period
Very high competitiveness	Over 90.1% of the total factor value of the reporting period

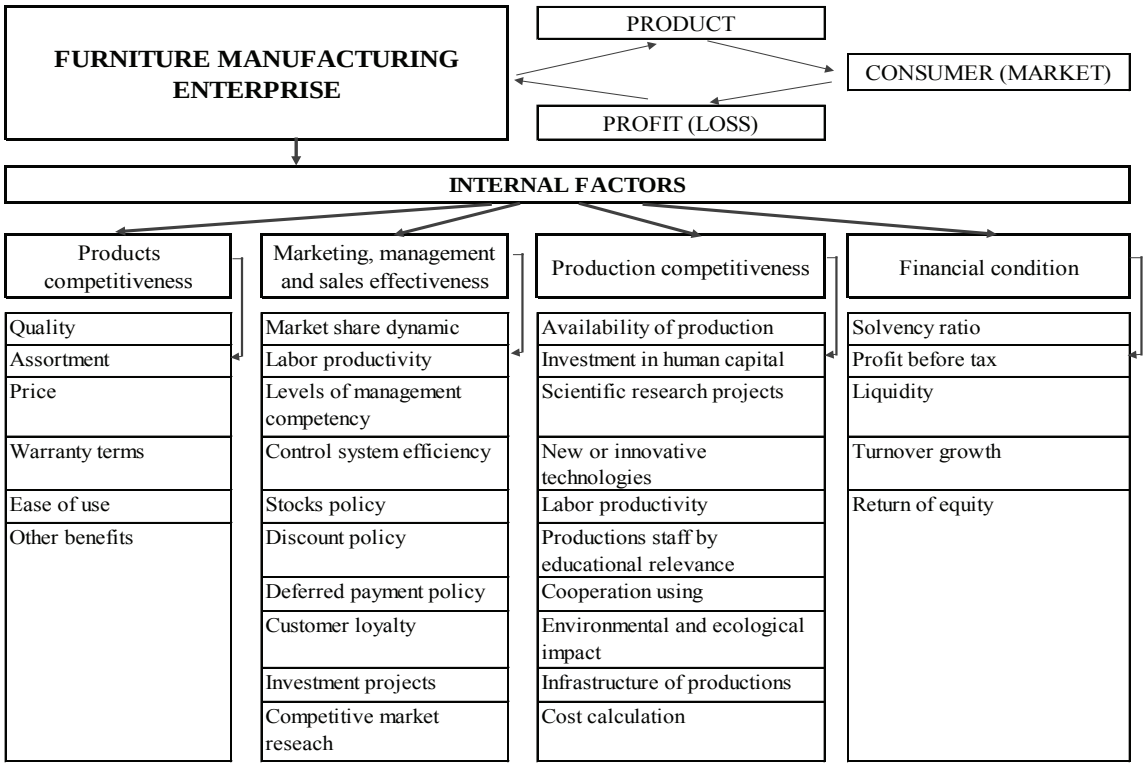


Figure 1. Model of furniture manufacturing SME competitiveness internal factors.

Table 5

Internal factors affecting competitiveness value of SME

Sign of factor	Competitiveness factors	Coefficient of importance factor
F_1	Product competitiveness	0.26
F_2	Financial condition	0.17
F_3	Marketing, management and sales effectiveness	0.24
F_4	Production competitiveness	0.22

product competitiveness factors F_1 average value from obtained respondents (30 SME) is 0.7857 ± 0.05788 with confidence level 95%, where minimum value is 0.66, but maximum value is 0.89. The results of factor F_1 show that 57% of all respondents have been able to reach value above calculated average. The value of maximum and minimum assessment has not acquired any respondents.

The factor F_2 most important criteria are the solvency ratio (f_{21}) with the coefficient of importance criterion 0.30, then the profit before tax (f_{22}), liquidity (f_{23}) and return of equity (f_{25}) with coefficient 0.20. Less important criterion is the turnover growth (f_{24}) with coefficient 0.10. The small and medium-sized furniture enterprises factor F_2 average assessment from obtained respondents is 0.4883 +/- 0.34081, where the minimum and maximum values are scale from 0 to 1 with confidence level 95%. The result of the study shows that 50% of all respondents are able to reach the financial condition over the calculated average and 17% of respondents reached the maximum values of the factor assessment and 3% - minimum values.

The most important criteria of factor F_3 are investment project (f_{39}) with coefficient of importance criterion 0.20, competitive market research (f_{310}) with coefficient 0.15, market share dynamics (f_{31}) with coefficient 0.10 and customer loyalty (f_{38}) with coefficient 0.10. Less important criteria are f_{33} with coefficient 0.09, f_{32} with coefficient 0.08, f_{34} and f_{35} with coefficient 0.07 then f_{36} and f_{37} with coefficient 0.06. Factor F_3 of 30 SME an average value from obtained respondents is 0.3992 ± 0.13735 with confidence level

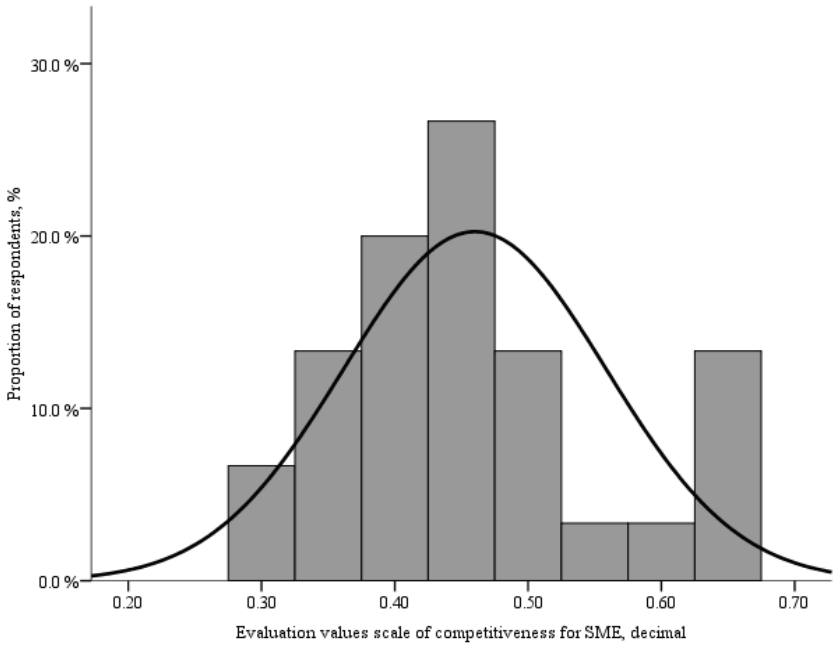


Figure 2. Internal affecting competitiveness factors evaluation values of SME.

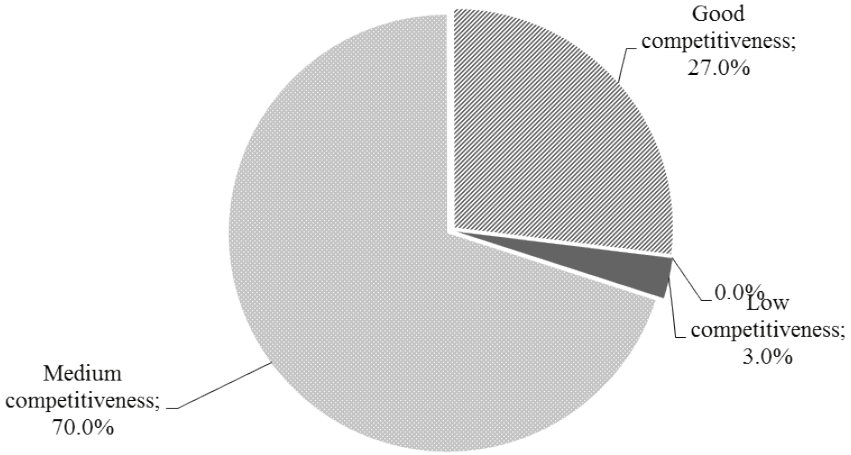


Figure 3. Furniture manufacturing SME competitiveness assessment by internal factor.

95%, where the minimum and maximum values are 0.20 and 0.76. The results of marketing, management and sales effectiveness factor show that 47% of respondents have been able to reach the value above calculated average, but maximum and minimum assessment has not acquired any respondents.

The factor of production competitiveness F_4 most important criteria are the availability of production resources (f_{41}) and cooperation using (f_{47}) with coefficient 0.16 and cost calculation (f_{410}) with coefficient 0.15. Less important criteria are f_{42}, f_{43}, f_{44}, f_{45}, f_{48}, f_{49} with coefficient 0.08 and f_{46} with coefficient 0.05. Furniture manufacturing SME competitiveness factor F_4 average value from obtained respondents (30 enterprises) are 0.3533 ± 0.19519 with confidence level 95%, where the minimum and maximum values are from 0.04 to 0.78. The total average value of internal competitiveness factor is 0.46 ± 0.09678 with confedence level 95% (Fig. 2).

The study shows that 50% of respondents consciously are able to achieve competitiveness assessment above calculated, but 40% have been able to reach good competitiveness in the micro level above the average calculated (Fig. 2).

The results show that more than two-thirds or 70% of the respondents evaluate the competitiveness

level as medium and only 27% evaluate- it as good. Conversely, a low competitiveness level is estimated by 3% of all respondents (Fig. 3)

Figure 3 depicts that no enterprises have acquired very low or high competitiveness assessment, which implies that SME competitiveness of micro level is not so weak, but its potential has been untapped. This also characterizes the decreasing statistics of furniture industry from the beginning of economic crisis in 2007 until 2011, which marked the difficult period for the Latvian furniture industry. Therefore, the furniture manufacturing SME should be strengthened by competitiveness and the key affecting factors for growth of the sector identified in the future. The competitiveness assessment method helps to identify the strengths and weaknesses of enterprises, so assessing their competitiveness regularly can be systematically analyzed. This might help to define indicators of development obstacles such as weak product competitiveness, financial condition, marketing, management and sales effectiveness, and also increase the overall competitiveness of the formation in the future. The competitiveness assessment method allows using furniture sector competitiveness benchmarking to identify the challenges for furniture manufacturing industry in time.

Conclusions

1. The internal factors are directly dependent on the enterprises activities and are able to operate on them. The main important factors for small and medium-sized furniture manufacturing enterprises are a product competitiveness (F_1), financial condition (F_2), marketing, management and sales effectiveness (F_3) and production competitiveness (F_4).
2. The results of the study show that competitiveness internal factors F_1, F_2, F_3 and F_4 average assessment values have been able to reach about half of the respondents, i.e. 57%, 50%, 47% and 50% respectively.
3. The competitiveness level of Latvia`s SMEs in the furniture manufacturing has been evaluated as average in 70% of cases and only 27% of the enterprises show a good level of competitiveness.

Acknowledgments

The paper has been supported by the European Social Fund within the project „Support for the implementation of doctoral studies at the Latvia University of Agriculture" (sub-activity 1.1.2.1.2 Support for the implementation of doctoral studies), agreement No 2009/0180/1DP/1.1.2.1.2/09/IPIA/VIAA/017.

References

1. Barney J.B. (1991) Firm resources and Sustained competitive advantage. *Journal of Management*, 17, pp. 99-120.
2. Caune J. (2005) *Konkurētspējīgās priekšrocības radīšanas, attīstīšanas un pārnešanas metodika Latvijas uzņēmumos: promocijas darba (Competitive advantage in the creation, development and transfer methodology in the Latvian companies: PhD thesis)*. Latvijas universitāte, Rīga, 188 lpp. (in Latvian).
3. Caune J., Dzedons A. (2009) *Stratēģiskā vadīšana (Strategic Management)*. 2.izd., Lidojošās zivs, Rīga, 379. lpp. (in Latvian).
4. Coyne K.P. (1986) Sustainable Competitive Advantage: What it is and what it isn't. *Business Horizons*, January, pp. 54-61.
5. De Wit B., Meyer R. (1998) *Strategy: Process, Content, Context: An International Perspective*, Thomsom Learning, Third Edition, London, UK, 957 p.
6. Fedotova K. (2012) *Konkurētspējīgas uzņēmējdarbības vadīšanas nodrošināšana koksnes produktu ražošanā Latvijā: promocijas darbs (Ensuring Competitive Entrepreneurship Management for Manufacturing Wood Products in Latvia: PhD dissertation)*. Rīgas Tehniskā universitāte, Rīga, 182 lpp. (in Latvian).
7. Fikss P. (2009) *Mārketinga ģēnijs (Marketing Genius)*. Jāņa Rozes apgāds, Rīga, 392 lpp. (in Latvian).
8. Geipele I., Vanags J. (2009) System of the assessment indicators of the competitiveness of the construction industry. *Geomatics*, Issue 5, pp. 62-75.
9. Henderson B. (1983) The Anatomy of Competition. *Journal of Marketing*, 47, pp. 7-11.
10. Johnson G., Scholes K. (1993) *Exploring corporate strategy*: *Text and Case*, Prentice-Hall International,Hertfordshire Ltd, 3rd Edition, UK, 733 p.
11. Judrupa I., Šenfelde M. (2007) The Main Factors of Regional Competitiveness and the Importance of International Indexes in Its Evaluation. *Problems of Foreign Economic Relations Development and Attraction of Foreign Investments: Regional Aspect*, Ukraina, pp. 945-950.
12. Kassalis I. (2010) Uzņēmumu konkurētspējas paaugstināšanas iespējas Latvijas tautsaimniecība (The potentional of increasing the competitiveness of companies in the economy of Latvia). *Latvijas Universitātes raksti*, 754.sēj., Ekonomikas un vadībzinātne, 9-22. lpp. (in Latvian).

13. Ketel C. (1999) *International Competition and the Efficiency of Firms*, University of London, London, 432 p.
14. Peteraf M. (1993) The cornerstones of competitive advantage: A resource-based view. *Strategic Management Journal*, 14, pp. 179-191.
15. Porter M.E. (1985) *Competitive Advantage: Creating and Sustaining Superior Performance*, Free Press, New York, USA, 570 p.
16. Prahalad C.K., Hamel G. (1990) The core competence of the corporation. *Harvard Business Review*, 68, pp. 79-91.
17. Sanchez R., Heene A. (1997) Reinventing strategic management: new theory and practice for competence-baaed competition. *European Management Journal*, 15 (3), pp. 303-317.
18. Thompson A., Strickland A.J. (1998) *Strategic Management: concepts and cases*, Irwin McGraw Hill, Boston, USA, 1049 p.
19. Vasiļjeva L., Gļebova A. (2010) Ražošanas uzņēmumu konkurētspējas nodrošināšana Latvijā (Provision of Competitiveness of Production Companies in Latvia). *RTU zinātniskie raksti*, 3.sēr., Ekonomika un uzņēmējdarbība, 8. sēj., Rīga, 51-63. lpp. (in Latvian).

RESEARCH METHODOLOGY OF CUTTING PROCESSES OF ASPEN WOOD

Andis Ābele, **Henn Tuherm**
Latvia University of Agriculture
Andis.Abele@llu.lv

Abstract
Machining of wood of soft deciduous trees is currently based on the knowledge about cutting of wood of hard deciduous and coniferous trees and has not developed a comprehensive research methodology of cutting processes. Therefore, the objective of the study is a development of methodology for longitudinal sawing with circular saw and straight milling that would be utilized with a purpose of acquiring further knowledge on wood cutting and the improvement of cutting tool designs. Sub-objective of the study is determination of duration of cutter's wear periods when using developed methodology. For the purpose of solving problems regarding cutting process of soft deciduous wood, the optimization of cutting tools and cutting modes were carried out in conditions that comply with the tendencies of the practise. The cutting process was carried out by a computer numerical control machine and the data acquisition by electronic measuring instruments. Aspen (*Populus tremula* L.) wood was used for wood samples. The methodology was developed for sawing, which complements the authors previously described methodology of the milling process investigations. Initially, only the results of periods of cutter wear and cutting velocity effects on these periods when milling process is used were obtained. It was concluded that the methodology can be used for further investigations and the critical wear period begins two times later when cutting velocity increases twice.
Key words: sawing, milling, aspen, methodology of cutting processes, optimization of wood cutting.

Introduction

Wood processing industry is more and more beginning to focus on processing wood of soft deciduous trees, such as aspen, manufacturing not only decoration boards, but also structural building elements and furniture. Considering the volume of the soft deciduous wood resources that are available and its regeneration potential, the use of these particular tree species in manufacturing wood products gives essential privileges. It reduces the mass of products and its production costs comparing to a denser wood species. Sawing and milling are two of the major mechanical wood processing techniques that are applied during the technological process of manufacturing products from any type of wood. Furthermore, from all the wood cutting processes that are based on sawing, the most popular is longitudinal cutting with circular saws. The straight milling, however, is most popular from all the milling techniques. This also means that the majority of studies regarding wood cutting processes are interrelated with these techniques of mechanical wood processing. Studies that aim to determine the right cutting modes for deal cutting and other processes are mostly carried out by processing wood of conifers or hard deciduous trees (Budakçı et al., 2011; Fotin et al., 2010; Nordström and Bergström, 2001; Simonin et al., 2009). It may be attributed to the fact that the wood of soft deciduous trees originally was considered inferior and not suitable for mechanical processing, and because of that an insufficient amount of studies has been carried out regarding this type of wood both in Latvia and abroad. Therefore, the current regularities of processing the soft deciduous wood are based on regularities that have been learned during the cutting processes of wood of coniferous and hard deciduous trees. It is because the knowledge on the regularities regarding longitudinal sawing and straight milling of soft deciduous wood is not sufficient enough to choose the cutting tools and cutting modes that would be the most appropriate for this type of wood. This creates a necessity to develop an optimal cutting tool and cutting modes prescribed exactly for the processes of cutting soft deciduous wood, as it is anticipated that the use of these species of wood will only be increasing.

A wide range of studies regarding the wood cutting process that have provided valuable long-term results, have been carried out in a number of countries, whereas only few notable studies have been carried out in the Republic of Latvia. One of them was developed during the 1970s, explaining the resistance to abrasion of cemented-carbide compositions during the process of cutting pressed birch and gray alder wood (Sleņģis et al., 2009). Another notable study that has to be mentioned is the one regarding cutting process of black alder and aspen, carried out by the Department of Wood Processing at Latvia University of Agriculture in 2008, within the framework of the State Research programme (Sleņģis et al., 2009). Changes in roughness of the surface and cutting power were determined for these types of wood by processing samples of them in different cutting velocities and feed speeds whereas changes in abrasion of cutting tool, depending on its angular parameters during the process of cutting aspen wood were described in the studies that were carried out from 2010 to 2012 (Ābele and Miončinskis, 2012). However, the studies carried out in both the Republic of Latvia and abroad regarding wood cutting process do not provide comprehensive information regarding

what impact various factors have on the process of cutting soft deciduous wood, taking into consideration the impact of both desirable and undesirable features of the respective cutting mode.

New designs of circular saws and milling cutters that would reduce or even eliminate the unwanted features of the mutual impact between wood and cutting tool would also reduce the production costs, extending the permissible operating period and increasing performance of the cutting tool. In addition to that, by reducing the kerf width, while maintaining stability of the circular saw, an opportunity to use the wood and energy resources more efficiently is given. Propositions of new circular saw and milling cutter designs could make a practical contribution not only to improvement of cutting modes and cutting tools for soft deciduous, but coniferous and hard deciduous wood as well.

The optimization of cutting modes also provides a theoretical contribution to solutions regarding wood cutting process, improving the already existing knowledge on the features of the mutual impact between wood and cutting tools, which could serve as a base for development of methodology for an analytic description of cutting process. The currently available information is not always sufficient enough, especially when processing soft deciduous wood, to develop a comprehensive theoretical structure of the cutting process. Furthermore, the traditional calculation does not take into consideration the cases, when circular saws with hard tipped teeth are used, adding that the aforesaid method is the most common nowadays for producing teeth of a saw. Ascertaining that this feature actually impacts the cutting process more comprehensive and state of the art analytic methods might be provided.

Solving complications regarding the study, it is necessary to initially determine what factors are involved in the cutting process, and which ones impact the undesirable features of the process most. Only then it is possible to develop propositions and create new cutting tool designs that would reduce the aforesaid undesirable features, providing the optimal conditions exactly for the cutting process of soft deciduous wood.

Therefore, the objective of the study is a development of methodology for longitudinal sawing and straight milling processes. That would be appropriate for further knowledge obtaining about interaction between wood and cutting tool, and for the improvement of cutting tool designs exactly for wood of soft deciduous trees. Second line objective of the study is determination of duration of cutter's wear periods when using developed methodology.

Materials and Methods

The cutting processes of circular saw and milling cutter are similar in respect to both kinematics of the cutting tools and features of the chips formation. The main difference between the two is the purpose of the cutting process. For a circular saw it is dividing wood in smaller pieces, while in straight milling it is surface levelling and roughness reduction. Therefore, the methodology of wood cutting process in relation to sawing is mainly described. Methodology of straight milling process is described in other paper of authors (Ābele and Miončinskis, 2012).

Wood cutting process is mechanized and often even automatical in most of the modern wood cutting companies. Therefore, the experiments of the wood cutting study shall be performed by using computer numerical control (CNC) machines, so a cutting process that complies with state of the art tendencies of wood cutting industry could be ensured. A multifunctional CNC machine 'Biese Rover 325', which can be set up either as a circular saw or milling cutter, has been used in this study.

A unique circular saw tipped by tungsten carbide compositions has been designed for the experimental work. It is the most common method for producing saw teeth as it improves the abrasion resistance of the saw teeth (Simonin et al., 2009). The circular saw has been produced by a cutting tool producer from Latvia – 'Nook Ltd.'. The parameters of the circular saw are indicated in Figure 1. This circular saw consists only of a two teeth that are located on the opposite circumference points of the circular saw. Therefore, it takes less time to reach the prescribed load capacity for the saw teeth comparing to standard circular saws. This is characterized by an efficient cutting distance per tooth, which is probably the most important parameter to reach a level of wear for the saw teeth that would comply with the practice conditions (Nordström, 2005). In respect to that, the length of the cutting trajectory for a single tooth is 10,000 m. Respectively, this means that the cutting distance in this study, which is equivalent to the practice conditions, should be approximately 20,000 m, knowing that the saw has two teeth.

Samples of aspen wood with a moisture content of 8…10% have been used during the experiment work of the study. For the purpose of maintaining the stiffness and resistance of the processed wood samples during the cutting process, sawing has been carried out by creating longitudinal kerfs next to each other on both wider sides of the wood sample, leaving 3 mm wide partition between the kerfs. The scheme of kerfs is illustrated in Figure 2. Taking into consideration that the distance from cutting circumference of the circular saw to the outer circumference of the pressure disc is

30 mm, height of the kerf is set to 28 mm. Therefore, an enclosed cutting process has been ensured for every kerf, which is a normal characteristic of sawing. The depth that has been set for the kerf gives a 61.5 mm long length of the cutting trajectory for every rotation of the spindle. For the length of cutting trajectory at one rotation of the spindle calculating the following equation (1) can be used:

$$l = u_z + \frac{\pi \cdot D}{360} \arccos\left(1 - \frac{2 \cdot H}{D}\right), \quad (1)$$

where l is length of cutting trajectory at one rotation of the spindle, mm; u_z is feed per tooth, mm; π is the constant (π = 3.14); D is diameter of cutting circumference, mm; H is height of the kerf (using technique of sawing) or thickness of cutting layer (using technique of milling), mm.

The optimal cutting velocity for a circular saw is 50 m s^{-1} but the feed per tooth is 1 mm (Nordström and Bergström, 2001). Therefore, the feed speed during the experiments shall be 16 m min^{-1}, which complies with normal cutting conditions in practice. For the feed speed calculating the following equation (2) can be used:

$$u = \frac{u_z \cdot n \cdot z}{1000}, \quad (2)$$

where u is feed speed, m min^{-1}; u_z is feed per tooth, mm; n is rotation frequency of shaft (dependent on cutting velocity), min^{-1}; z is number of teeth of cutting tool.

To determine the optimal cutting modes, one should not only be using the parameters that are considered to be optimal as of right now. Therefore, they shall only be used during the initial experiments;

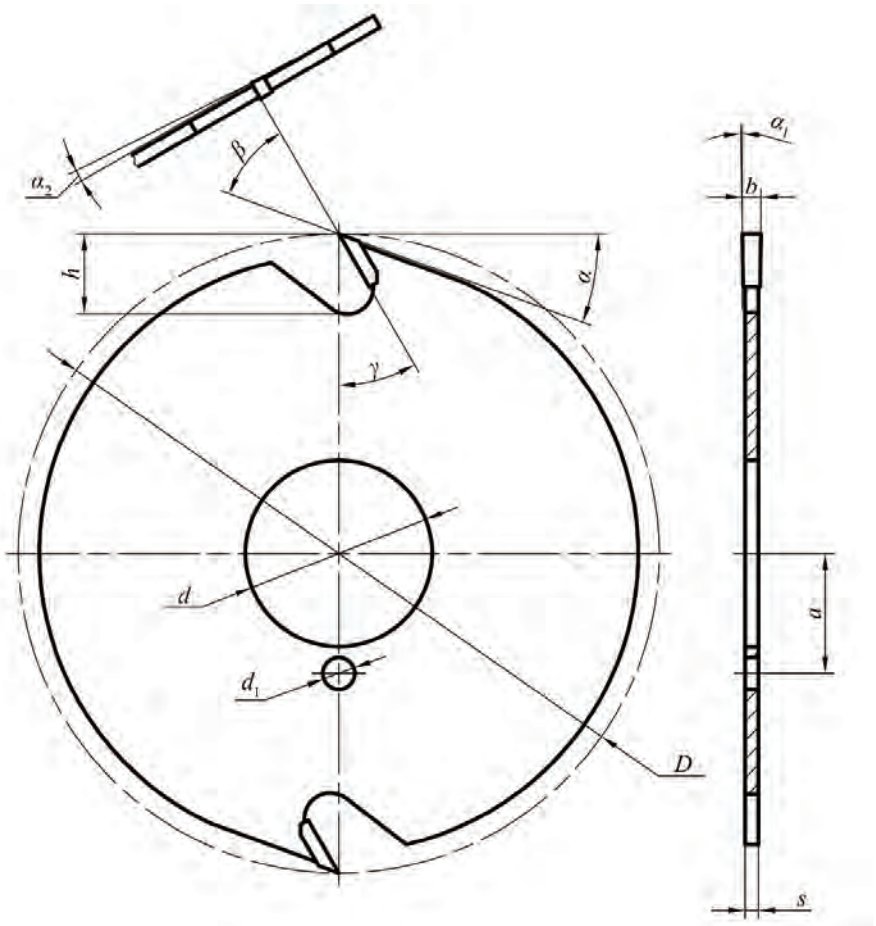


Figure 1. The parameters of the circular saw.
D - diameter of cutting circumference (D = 120 mm); d - diameter of basing bore (d = 35 mm);
d_1 - diameter of pin bore (d_1 = 6 mm); a - length between centres of bores (a = 22.9 mm);
s - saw body thickness (s = 2 mm); b - kerf width (b = 3 mm); h - tooth height (h = 15 mm);
α - clearance angle (α = 20º); β - sharpness angle (β = 40º); γ - rake angle (γ = 30º);
α_1 - radial clearance angle (α_1 = 2º); α_2 - tangential clearance angle (α_2 - 3º).

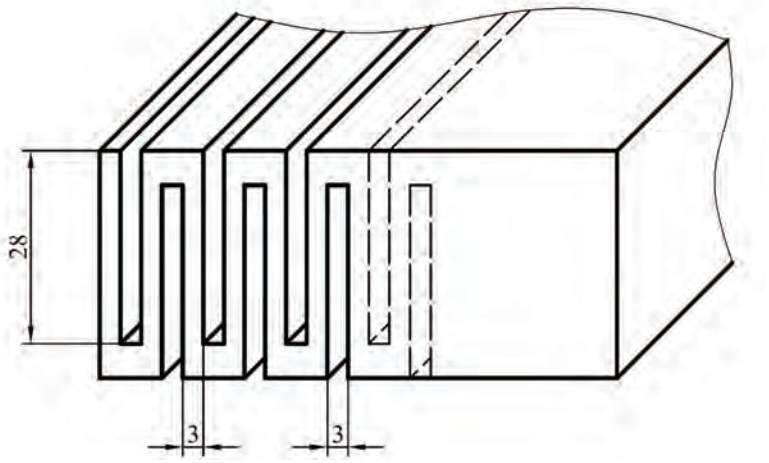


Figure 2. The scheme of kerfs.

however, it is necessary to alternate the parameters as the experimental work continues, including the values of cutting velocity and feed per tooth, which are respectively larger and smaller than 50 m·s^{-1} and 1 mm.

Electronic measuring instruments have been used in determination of the results, increasing the accuracy of the experiments. Roughness of the surface has been determined every time when a prescribed length of the cutting trajectory has been reached. To determine the right time for performing these measurements, the calculation of the breakdown of cutting trajectory has been used, previously described in other paper (Ābele and Miončinskis, 2012). A device 'Perthometer M2' by company 'Mahr' has been used for measuring the roughness of the processed wood surface. The device is applicable only for measuring roughness of a flat surface; therefore, the wood sample after sawing was cut completely to open up the inner surface of the kerfs, from which taking a roughness measurement was anticipated. This device ensures determination of four parameters that characterize roughness:

- R_a – the deviation of the arithmetical mean of the surface profile roughness from the mean of the depth of the surface profile roughness;
- R_z – the mean distance between the five highest and five lowest points of the surface profile;
- R_{max} – the maximum roughness depth of the surface profile;
- R_k – the median value of the cumulative breakdown of the surface profile roughness values (Flitney, 2007).

The cutting force and power may be determined by applying various methods. Most commonly used methods are based on the electricity consumed by the engine of the cutting tool. One of such methods is determination of changes in the electrical current that has been consumed by an electrical engine (Barcík et al., 2010). The other method though compares the power of the electrical engine before and during the cutting process, resulting in a difference that indicates the power that has been consumed (Ābele and Miončinskis, 2012). However, only electrical power can be determined by using these two above mentioned methods, thus, they do not provide direct and accurate results, knowing that the cutting process is characterized the best by the mechanical power. Therefore, a method of measuring the torque of the cutting tool's spindle has been used in this study. For this matter a measuring device that performs a constant monitoring of changes in the torque throughout the cutting process has been used. To calculate the cutting power (3) and cutting force (4), using the data from the torque measurements (Kováč and Mikleš, 2010), the following equation can be used:

$$N_{gr} = \frac{2 \cdot 1000 \cdot M \cdot v}{D}, \quad (3)$$

$$P_{gr} = \frac{N_{gr}}{v}, \quad (4)$$

where N_{gr} is cutting power, W; M is torque of shaft, N m; v is cutting velocity, m s^{-1}; D is diameter of cutting circumference, mm; P_{gr} is cutting force, N.

Rounding radius of the cutters has been determined by using the replicating method. At first, every time after a prescribed length of the cutting trajectory was reached (the same as used for measuring the roughness), a lead plate was pressed on the cutting edge of the cutter perpendicularly. Then this imprint was analyzed with a microscope, measuring the rounding radius of the cutting edge. Lead is a relatively soft substance, which easily may be deformed. Therefore, a set of three lead plates shall be used in making of the imprinting; however, only one, the middle one, shall

be used for the examination of the imprint. A digital microscope 'Keyence VHX-100 K', with up to 800 times optical magnification was used for the purpose of examining the imprint.

During the initial stage of the study regarding cutting modes of the soft deciduous wood, cutting tools shall be used with the angular and linear parameters, as well as the body structure close to the indications that have been used in common practice of wood cutting. It is essential in learning about the current situation of the wood cutting modes, meaning what the main factors are, and what impacts them most. By discovering the most significant factors that impact the cutting modes aversely, it is possible to find solutions to eliminate or at least reduce them. For this matter, propositions regarding the improvements of the cutting tool designs may be developed based on the discovered adverse features that are impacting the cutting process. Then, after the improved models of the cutting tools have been developed, the wood cutting experiments may be carried out, examining the effectiveness of the implemented improvements, and their impact on the cutting mode. Essentially, it is impossible to limit all the adverse features of the cutting process at once; therefore, the optimization of the cutting tool design and cutting modes shall be carried out gradually. Simultaneously with the examination of the technological indications of the improvements, it is necessary to carry out a cost-effectiveness analysis, determining whether the implementation of the new improved cutting tool, and, respectively, the replacement of the former one, is comprehensively beneficial in the wood processing.

Changes in the parameters of wood cutting modes are quantifiable in respect to the time and the length of the cutting trajectory (Ābele and Miončinskis, 2012; Fotin et al., 2009). Therefore, for the mathematical calculations and analysis, it is preferable to use correlation and regression analyses that also indicate the regularities among the changes of the cutting mode parameters.

Results and Discussion

The characteristic curve regarding the changes of the surface roughness from the processed wood (Figure 3) is visually similar to the one that has been discovered during the previous studies regarding the cutting process of the soft deciduous wood (Ābele, 2010). From obtained results (Figure 3) it can be concluded that initial wear period is in a range of cutting trajectory from 0 m to 8,000 m, which complies with cutting time 1.5 hours. Afterwards, the intensity of processed wooden surface roughness decreases. It shows the beginning of monotone wear period of cutter, which continuous up to reaching 95,000 m length of cutting trajectory with corresponding cutting time 16 hours. This cutter's wear period differs from reference data (Astakhov and Davim, 2008) with that there is not a gradual increase in surface roughness, but it almost does not change in the whole wear period. After a monotone cutter's wear period ends, the surface roughness R_a sharply increases again, showing the beginning of critical wear period of cutter. It means that in this case re-sharpening of the cutter should be organized after work of 16 hours.

Even though the tendency towards changes in the surface roughness in respect to the length of the cutting trajectory is very alike, when comparing this characteristic curve with previously obtained, the length of the cutting trajectory after which the

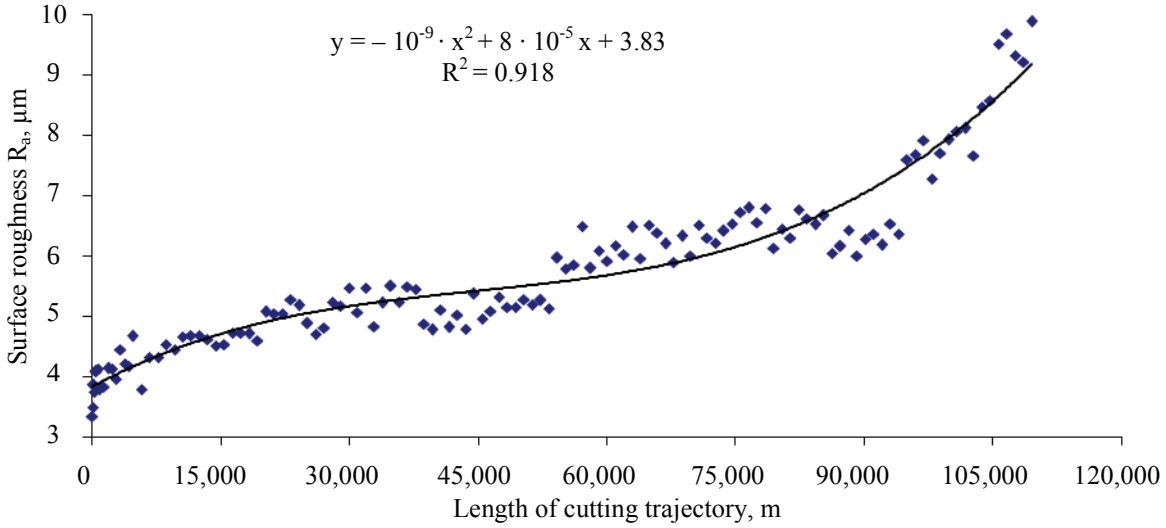


Figure 3. Changes of surface roughness R_a respect to length of cutting trajectory when milling at rake angle of 10º.

monotone and critical stage of wear initiates is different. The beginning values of the monotone wear stage differ only by 3,000 m; however, the beginning values of the critical wear stage differ almost twice, which is a very significant variance. Such contrasting results of the experiment may be explained by the difference in some specific mode parameters, such as the cutting velocity and feed speed.

The cutting velocity and feed speed values used in the 2010 study were 20.4 m s^{-1} and 2.4 m min^{-1} respectively (Ābele, 2010). However, in this study the cutting speed has been increased up to 40 m·s^{-1} for a purpose of brining it nearer to the optimal cutting velocity that is being used in straight milling machines, and feed speed increased to 4.7 m min^{-1} (according to Ābele and Miončinskis, 2012). That resulted in an unaffected value of feed per tooth (0.443 mm). The main parameter that should be taken into consideration as a result changing factor is the cutting velocity because it is impacting the wear of the cutter most (Astakov and Davim, 2008). The feed speed in this case is not as important because the feed per tooth has remained unchanged throughout both studies. Therefore, it may be assumed that when the cutting velocity has been increased from 20.4 to 40 m s^{-1}, it takes twice longer cutting trajectory to initiate the critical stage of wear for the cutter. However, it has also been ascertained by other authors that by increasing the cutting velocity, the critical wear phase of the cutter is reached sooner (Banshoya et al., 1998; Ratnasingam and Perkins, 1998). The contrasting results may be explained by the fact that the wear of the cutter in various cutting velocities has always been expressed in respect to the cutting time by other authors. Though, the feed speed, rather than the cutting velocity, is usually the factor that impacts the cutting time most; other authors have chosen to use it as a constant, while changing the cutting velocity. On the contrary, the parameters characterizing the cutter's wear are expressed in respect to the length of the cutting trajectory in this study, and the feed speed is being changed along with the cutting velocity. In addition, the cutting time, when the critical wear phase of the cutter initiates is equivalent to 16 hours for both, when milling with a cutting velocity of 20.4 m s^{-1} and 40 m s^{-1}. Therefore, the results of studies carried out by other authors should be similar, knowing that by increasing the speed, also the distance travelled in one unit of time increases. For example, if the cutting velocity increases twice and the feed speed remains the same, the cutter comes into contact with the wood twice as much in the same unit of time, chipping off twice as much wood, and as a result, it is subjected to a higher level of friction. Consequently, the length value of the cutting trajectory will be twice as long at the same cutting time as it can be observable in this study. Another study indicates that by increasing the cutting velocity, the feed per tooth decreases, and therefore also decreases the amount of wood chipped off, which all results in an increase of the cutting power because a higher cutting resistance is created (Barcík et al., 2008). Furthermore, it has been ascertained that the resistance of wood, along with the cutting power, increases more when the cutting velocity is increased from 45 to 60 m s^{-1}, comparing to the observation of velocity increase from 30 to 45 m s^{-1}. The increase in the cutting resistance might be the cause for a more intense abrasion of the cutter, when the cutting velocity is higher. However, the increase in the cutting power might not be characterizing the wear of the cutter unequivocally, but unfortunately such a possibility has not been considered. Besides, the feed per tooth and the thickness of the chippings has not reduced in the aforesaid study. The above mentioned indicates that it may not be concluded that the results acquired in this study are contradictory, comparing to those of other authors, because a difference exists in the interpretation of the results and the parameters of the cutting mode used. However, a further research is necessary to clarify the impact of the cutting velocity in respect to the wear of the cutter.

Conclusions

1. The developed methodology can be used to analyze regularities of the wood cutting processes and for further knowledge obtaining. It is appropriate both sawing with circular saws and milling with cutterheads not only wood of soft deciduous but also wood of hard deciduous and coniferous trees cutting, because the developed methodology is more universal when compared with previously used.
2. The initial wear period is in the range of cutting trajectory up to 8,000 m but the beginning of the critical wear period is observed after reaching length of the cutting trajectory 95,000 m that corresponds to the cutting time of 16 hours.
3. Cutting velocity is significantly affecting the start of the critical wear period of the cutter and in further investigations, it is necessary to evaluate influence of cutting velocity on wear of the cutter, too.

References

1. Astakhov V.P., Davim J.P. (2008) Tools (geometry and material) and tool wear. In: Davim J.P. (eds) *Machining. Fundamentals and Recent Advances*, Springer, London, pp. 29-57.

2. Ābele A. (2010) Mīksto lapkoku griešanas procesu pētījumi: diplomdarbs (Studies of cutting process of hardwoods: diploma paper). LLU Kokapstrādes katedra, Jelgava, 2010, 56 lpp. (in Latvian).
3. Ābele A., Miončinskis U. (2012) Parameter changes characterizing the wear of the cutting tool in the milling process of aspen wood. *ProLigno*, 8(3), pp. 74-88.
4. Banshoya K., Nagatomi K., Murase Y. (1998) Relationship Between Cutting-Edge Hardness and Tool Life for Alloy-Steel Bit in Machine Boring of MDF. *Bulletin of the Faculty of School Education. Hiroshima University*, 20, pp. 179-189.
5. Barcík Š., Kminiak R., Řehák T., Kvietková M. (2010) The influence of selected factors on energy requirements for plain milling of beech wood. *Journal of Forest Science*, 56(5), pp. 243-250.
6. Barcík Š., Pivolusková E., Kminiak R. (2008) Effect of technological parameters and wood properties on cutting power in plane milling of juvenile poplar wood. *Drvna industrija*, 59(3), pp. 107-112.
7. Budakçı M., İlçe A.C., Korkut D.S., Gürleyen T. (2011) Evaluating the surface roughness of heat-treated wood cut with different circular saws. *BioResources*, 6(4), pp. 4247-4258.
8. Flitney R. (2007) *Seals and Sealing Handbook. Fifth edition.* Butterworth-Heinemann, Elsevier, Oxford, 620 p.
9. Fotin A., Cismaru I., Cismaru M., Salcá E-A. (2010) Study concerning the influence of milling parameters upon the surface quality. *ProLigno*, 6(1), pp. 55-65.
10. Fotin A., Cismaru I., Salcá E-A., Cismaru M. (2009) Influence of the variable parameters of the machining regimes upon the surface quality obtained by straight milling. *ProLigno*, 5(4), pp. 53-63.
11. Kováč J., Mikleš M. (2010) Research on individual parameters for cutting power of woodcutting process by circular saws. *Journal of Forest Science*, 56(6), pp. 271-277.
12. Nordström J. (2005) On wear of wood-cutting tools: Doctoral thesis. Karlstad University, Sweden, 2005, 56 p.
13. Nordström J., Bergström J. (2001) Wear testing of saw teeth in timber cutting. *Wear*, 250(1–12), pp. 19-27.
14. Ratnasingam J., Perkins M.C. (1998) An investigation into the tool wearing characteristics of rubberwood (Hevea brasiliensis) laminated veneer lumber. *Holz als Roh- und Werkstoff*, 56(1), pp. 31-35.
15. Simonin G., Meausoone P-J., Rougie A., Triboulot P. (2009) Carbide characterization for spruce rip-sawing. *ProLigno*, 5(2), pp. 49-57.
16. Sleņģis M.E., Miončinskis U., Dekšnis A. (2009) Apses un baltalkšņa koksnes frēzēšanas procesa pētījumi (Studies of milling process of aspen and grey alder wood). In: Andersons B., Daugavietis M., Tuherm H., Viesturs U., Grīnfelds A. (eds) *Lapu koku audzēšanas un racionālas izmantošanas pamatojums, jauni produkti un tehnoloģijas. Valsts pētījumu programma, 2005 – 2009: rakstu krājums (Substantiation of deciduous trees cultivation and rational utilisation, new products and technologies. State Research Programme, 2005 – 2009: Proceedings)*. Latvijas Valsts koksnes ķīmijas institūts, SIA Tipogrāfija Pērse, Rīga, 90-94. lpp. (in Latvian).

DETERMINING THE SURFACE ENERGY COMPONENTS OF WOOD USING THE CONTACT ANGLE METHOD

Laura Laiveniece, **Andris Morozovs**
Latvia University of Agriculture
laura@infonet.lv; Andris.Morozovs@llu.lv

Abstract
The properties of the transverse section surface of the wood are crucial when using it as an adhesive in finger joints. Contact angles of three test liquids sessile drops - water, diiodomethane and ethylene glycol - with known characteristics of surface free energy were measured on wood surface with the grain orientation 45 ° against the plane. Acid–base approach was used to calculate surface free energy and its characteristics of Scots pine *(Pinus sylvestris* L.) with moisture content of 21% and Norway spruce (*Picea abies* L. Karst) with moisture content of 10% wood samples from values of the contact angle. The wetting behavior of the wood samples was examined with the contact angle method (goniometer technique) in the Laboratory of the Department of Chemistry of Latvia University of Agriculture at the beginning of 2013. The aim of this study was to verify possibility of determining the contact angle values of the wood and calculate the surface free energy and its components of wood from the obtained contact angle values using acid-base theory. At the end of this study it was concluded that the acid–base approach is a suitable method to calculate surface free energy and its characteristics of wood from the values of the contact angle. Nevertheless, indirect methods of liquid drop contact angle value estimation must be used because direct determination is not feasible on wood surfaces with open capillaries.
Key words: acid-base theory, contact angle, surface free energy, wood.

Introduction

The contact angle, also called the three phase contact angle, is the angle between the tangent to the liquid/vapour interface and the solid surface. It is a physicochemical property of multiphase system and it depends on the interfacial energies of the solid–liquid, liquid–vapour and solid–vapour interfaces (Nowak et al., 2013). At constant pressure and temperature the equilibrium contact angle is related to interfacial energies through Young's equation (Formula (1)):

$$\gamma_{lv} cos\theta = \gamma_{sv} - \gamma_{sl} \quad (1)$$

where θ is the equilibrium contact angle, γ_{lv} and γ_{sv} the surface free energies of the liquid/vapour and solid/vapour interfaces respectively and γ_{sl} the interfacial energy of the solid/liquid interface (Figure 1).

Surface and interfacial forces at a certain contact angle are in equilibrium. It is reached when cohesive forces in the liquid and adhesive forces between gas-solid surface are in equilibrium due to adhesive forces of the solid-liquid interface. Therefore the equilibrium contact angle can only be measured when the liquid is in stationary state (Gindl et al., 2001, Baldan, 2012, Nowak et al., 2013).

The measurement of the contact angles of a drop of test liquids, with known surface free energy and therefore surface free energy parameters on a given solid surface, is the usual method of obtaining the surface free energy of the solid material (Gindl et al., 2001). The principal idea of the surface free energy is that it is the excess energy associated with the presence of a surface (Baldan, 2012). The surface free energy (γ_s) of a solid is defined as the change of the total surface free energy (G) per surface area (A) at constant temperature (T), pressure (P) and moles (n) (Formula (2)):

$$\gamma_s = (\delta G / \delta A)_{T,P,n} \quad (2)$$

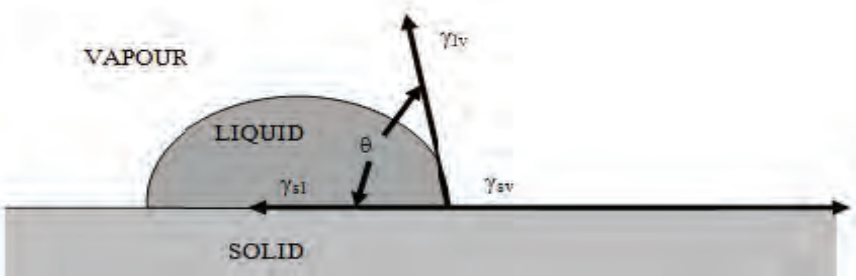


Figure 1. The interactions between the forces of cohesion and adhesion of the contact angle (Figure 1 made by author after Gindl et al., 2001, Baldan, 2012).

It is a characteristic parameter that influences surface related processes such as adsorption, wetting and adhesion (Gindl et al., 2001).

Depending on the kind of surface to be examined and the selected test liquids, several methods are available for calculation of the surface free energy of a solid. To relate components more closely to the chemical nature of the phases, the polar component could be better described in terms of acid–base interactions (Gindl et al., 2001, Baldan, 2012).

The wetting properties of natural solids are determined by molecular interactions between their surface and liquids (Fuentes et al., 2011). The fundamental adhesion between the adhesive and substrates can occur due to fact that all materials have forces of attraction between their atoms and molecules, and a direct measure of these interatomic and intermolecular forces is the surface tension. Therefore, the tension in surface layers is the result of the attraction of the bulk material for the surface layer - reducing the number of molecules in the surface region resulting in an increase in intermolecular distance. In this process work has been done, and also work to return in a normal configuration need to be done (Baldan, 2012). Molecular interactions are evaluated by means of well described advancing and receding contact angles (quasi-equilibrium parameters); then afterwards it is possible to evaluate the surface free energy components by means of theories such as Owens-Wendt, acid-base theories, geometric and harmonic mean approach and equation of state methods which are based on the theoretical Young contact angle, assuming that an equilibrium state can be reached (Gindl et al., 2001, Fuentes et al., 2011).

Contact angle values of sample surface are an important parameter in adhesion science. From the value of the contact angle or its dynamics valuable information about the surface free energy, hydrophobicity, irregularities, roughness and chemical heterogeneity of sample can be received (Mazzola et al., 2012). The interpretation of experimentally obtained data of contact angle depends on a correctly chosen wetting theory. Theories that model wetting behaviour cannot normally be applied to natural material due to the complex phenomena at their surface (Fuentes et al., 2011).

The wettability of surface depends on many factors, both physical and chemical. Surface roughness has a significant influence on the contact angle even for seemingly smooth surfaces at macroscopic scale or at nano-scale, and is important for many practical wetting and spreading processes (Chau et al., 2009). The surface of porous material affects measured values of contact angle due to differences in surface texture and absorption effects (Winfield et al., 2001). As we all know, wood is a complex material, and its wettability depends on many factors, for example, wood species, type of wood, biological attacks, grain orientation and aging of an exposed surface (Gindl et al., 2001). The direction in which wood is cut is the reason for the diversity of wood surfaces, because cell structures and directions vary along different planes and the position of measurement point whether it is in late or earlywood (Winfield et al., 2001).

Young's equation requires that the solid surface is smooth, flat, homogenous, inert, insoluble, nonreactive, non-porous, and of non-deformable quality. These conditions are referred to as an ideal surface (Chau et al., 2009). There is an interest due to the complexity of solid surfaces for which very precise measurements of surface free energy are not generally possible (Baldan, 2012). It is difficult to study the contact angle on wood surface because the problem of defining roughness is a complex one (Gindl et al., 2001). But still many authors recognize that surface free energy determination through contact angle measurement is a suitable method for determination of surface free energy of wood for practical applications (Chau et al., 2009, Wolkenhauer et al., 2009).

The aim of this study is to verify the possibility of determining the contact angle values of wood and to calculate the surface free energy and its components of wood from the obtained contact angle values by using acid-base theory.

Materials and Methods

Materials

Wood samples of non-dried Scots pine *(Pinus sylvestris* L.) with moisture content of 21% and dried in-room conditions Norway spruce (*Picea abies* L. Karst) with moisture content of 10% were used. Wood samples with surface area 50 × 100 mm and thickness of 20 mm with the annual ring orientation on surface width of sample were cut from rectangular timber with wood grains 45 ° to the plane. Samples of pine wood were stored in laboratory at room temperature and relative humidity (RH) 55%, but samples of Norway spruce were kept in desiccator at room temperature and RH 90% above water until 21% moisture content was reached.

Three test liquids were used to measure the contact angles – purified water (reverse osmosis filtered and demineralised with purifying system TKA, conductivity 0.2 μS), diiodomethane produced by ACROS organics (99 +% pure) and ethylene glycol produced by ACROS organics (99 +% extra pure). Surface tension characteristics of test liquids used in calculation by software of OCA 20 are listed in the Table 1.

Table 1

Surface free energy characteristics of test liquids by H.Y. Erbil used to measure contact angles (Erbil, 1997)

Test liquids	Surface tension, γ_L, mN m^{-1}	Dispersion component, γ_L^D, mN m^{-1}	Polar component, γ_L^P, mN m^{-1}	Acid component, γ_L^A, mN m^{-1}	Base component, γ_L^B, mN m^{-1}
Diiodomethane	50.80	50.80	2.60	0.00	0.00
Etyhlene glycol	48.00	29.00	19.00	1.92	47.00
Water	72.80	21.80	52.20	25.50	25.50

Contact angle measurement

The wetting behavior of the wood samples was characterized by the contact angle method (goniometer technique) in Laboratory of the Department of Chemistry of Latvia University of Agriculture at the beginning of 2013. The contact angles values of the sessile drop were obtained by using a DataPhysics optical contact angle measuring instrument OCA20 (Germany). First the drop of test liquid on the wood surface was recorded with video mode at the maximal speed - 25 frames per second. After that the video was analyzed frame by frame with the dynamic tracking mode and the contact angle was determined with droplet shape smoothing optimization and fitting by Laplace-Young method that is included in DataPhysics OCA20 software. The contact angle values as a function of time were approximated with the linear function and intercept values of ten 3μL drops of each liquid on four specimens were averaged, and used for the calculation of the free energy and its components with OCA20 software.

Calculation of surface free energy

The surface free energy calculations are based on the Young's equation which assumes thermodynamic equilibrium. Direct measurement of surface free energy of solids is not feasible and necessitates indirect evaluation due to chemical heterogeneity, roughness and porosity of wood (Wolkenhauer et al., 2009). However, evaluation is based on the Young's equation.

The surface free energy components of a wood were calculated from measured values of contact angles of three test liquids (one non-polar (diiodomethane) and two polar (water and ethylene glycol)) with known surface tension components. Diiodomethane was chosen as the non-polar test liquid to avoid problems due to the polarity of the wood. Knowing pure liquids surface free energy components, it is possible to determine the Lifshitz-van der Waals and the acid-base components of wood (Gérardin et al., 2007).

Acid-base theory or three liquid method is developed and modified by many authors and is the most complex one (Gindl et al., 2001). From the measured values of contact angles of different liquids with known surface tension it is possible to calculate and to determine polar or non-polar and acidic-basic components of the surface free energy of wood using the Lifshitz-van der Waals/acid-base (LW-AB) approach (Gindl et al., 2001, Baldan, 2012). The surface free energy (γ) is the sum of a Lifshitz–van der Waals component γ_i^{LW} (corresponding to γ_i^d) and a polar, or Lewis acid–base component γ_i^{AB} (corresponding to γ_i^P) (Formula (3)):

$$\gamma = \gamma_i^{LW} + \gamma_i^{AB} \tag{3}$$

The acid–base component γ_i^{AB} can be further subdivided and expressed in terms of electron-accepting and electron-donating component (Formula (4)):

$$\gamma_i^{AB} = 2\sqrt{\gamma_i^+ \gamma_i^-} \tag{4}$$

where γ_i^+ is the electron–acceptor parameter of the acid–base surface free energy component or Lewis acid parameter of surface free energy and γ_i^- is the electron–donor parameter of the acid–base surface free energy component or Lewis base parameter of surface free energy. The solid/liquid interface energies are equal to (Formulas (5) and (6)):

$$\gamma_{sl}^{LW} = \left(\sqrt{\gamma_{lv}^{LW}} - \sqrt{\gamma_{sv}^{LW}}\right)^2 \tag{5}$$

$$\gamma_{sl}^{AB} = 2\left(\sqrt{\gamma_{sv}^+ \gamma_{sv}^-} + \sqrt{\gamma_{lv}^+ \gamma_{lv}^-} - \right.$$
$$\left. - \sqrt{\gamma_{sv}^+ \gamma_{lv}^-} - \sqrt{\gamma_{sv}^- \gamma_{lv}^+}\right) \tag{6}$$

where the subscripts s, l and v denote solid, liquid and vapour phase, respectively. In combination from equations (1, 4-6) we obtain the following equation (Formula (7)):

$$(1 + \cos\theta)\gamma_{lv} = 2\left(\sqrt{\gamma_{sv}^{LW} \gamma_{lv}^{LW}} + \right.$$
$$\left. + \sqrt{\gamma_{sv}^+ \gamma_{lv}^-} + \sqrt{\gamma_{sv}^- \gamma_{lv}^+}\right) \tag{7}$$

(Gindl et al., 2001, Gérardin et al., 2007, Baldan, 2012).

In order to assess the significance of the calculated values of surface free energy we used mathematical statistics tools - standard deviation and coefficient of determination that are included in DataPhysics OCA20 software calculation.

Results and Discussion

Wood samples were cut with surface area 50 × 100 mm and 20 mm thick so that the wood tracheids are open and the grain orientation to the surface is 45 °. Selected thickness is considered to be sufficient for the contact angle values of wood not to be affected by length of tracheids. Wood grain angle to surface 45 ° was chosen for technical reasons and to avoid predominance of radial or tangential direction of fibers.

There exist little research on the penetration rate of adhesives into wood, therefore the chosen direction of the fibers to the surface is of 45 °, including the interaction of capillary and gravity forces in contact angle value determination (Fig. 2.).

Accurate measurements of contact angles on wood are influenced by the inherent roughness, porosity, and absorptive and swelling potentialities of wood surfaces. If the contact angle formed by the liquid is less than 90°, the liquid should penetrate into porous wood that results in gradual absorption of the droplet and the contact angle decreases. So the droplet may never reach equilibrium. To avoid these difficulties it is supposed that contact angle's instantaneous value depends on the surface free energy component (the surface property) and the dynamics of capillary action component (the wood bulk property). Infiltration of the droplet is linear, therefore decrease of contact angle is linear, too (Fig. 3.).

We can suppose that the quasi-equilibrium state of the contact angle component value of receding contact angle is close to equilibrium state. It could be obtained by extrapolating contact angle values to time moment 0 s when the drop touches wood surface and drop is formed in the same way as described by T. Rubina et al., 2009.

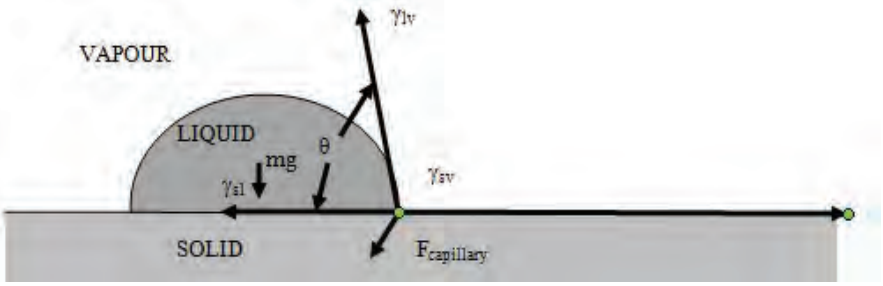


Figure 2. Expected directions of forces that affect contact angle value - γ_{lv} and γ_{sv} the surface free energies of the liquid/vapour and solid/vapour interfaces respectively, γ_{sl} the interfacial energy of the solid/liquid interface, mg the force of gravity and $F_{capillary}$ the capillary force (Figure 2 made by author after Baldan, 2012, Nowak et al., 2013).

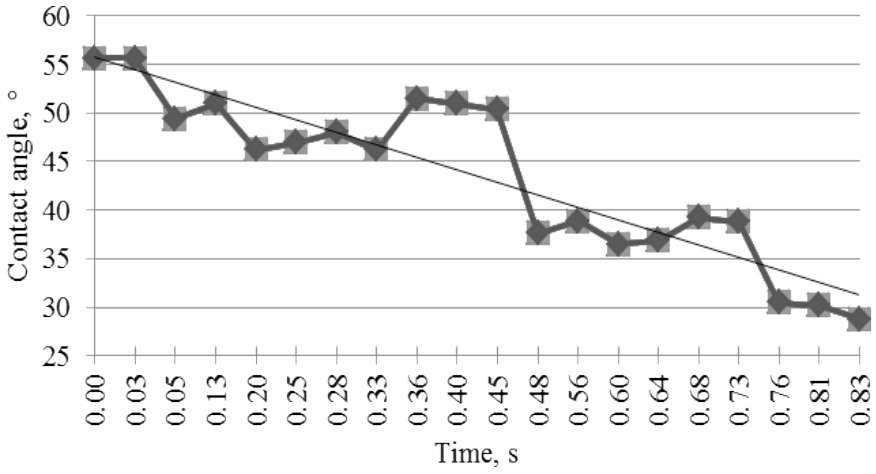


Figure 3. The 3μL of water droplet contact angle dynamics on spruce wood sample and its linear approximation.

During the contact angle measurements, it was observed that the liquids not only wetted the surface but also penetrated into the wood. Measured values of contact angle are affected by complexity of wood surface, differences in the surface texture, absorption effects and interaction of sum of forces. Unfortunately, penetration into the surface of the wood was too fast to evaluate values of contact angle without video camera and an image analysis system. The easiest way was to measure the contact angle values with water on the Scots pine sample due to slower liquid penetration and evaporation, longer lifetime of the droplet and also due to higher moisture content of the wood. The fastest penetration and evaporation and the shortest lifetime of liquid droplet happened to diidomethane on the Norway spruce sample. Measured mean values of contact angle on Scots pine and Norway spruce samples are shown in Table 2.

From the obtained values of the contact angle wecan observe that, in general, values of three test liquids are higher for Scots pine samples with moisture content of 21% and lower for Norway spruce samples with moisture content of 10%. It can be explained with higher surface energy which could be caused by adsorbed water on wood surface.

Surface properties could be affected by peculiarities of wood drying and treatment processes. Heterogeneity of the surface cause material anisotropy, or non-uniform distribution and reactivity of functional groups which are located on the surfaces. Contaminants and dust particles of homogenous surfaces can turn it into actually heterogeneous surface due to different wetting and adsorption properties of dust particles (Chau et al., 2009).

In general, determination of contact angle values from video materials is a complex and laborious process; in most cases from one liquid droplet of diidomethane we can obtain approximately 3 values of contact angle, however, from one liquid droplet of water we can obtain more than 20 values of contact angle. For further studies, to obtain unequivocal results of contact angle values, it is needed to get the mode for determination of the liquid penetration rate in wood tracheids.

The surface free energy components of wood were calculated with DataPhysics OCA20 software and acid-base approch from averaged measured values of contact angles of three test liquids with known surface tension components (Table 3).

Although Norway spruce and Scots pine are softwood, the calculated surface free energy is different due to chemical composition and moisture content. The surface free energy of Norway spruce is higher than that of the Scots pine, but the coefficient of determination is opposite which means that Scots pine values of surface free energy are with better fitting. There could be a supposition that there exists a close relation between surface energy and moisture content of wood - increase in moisture content will increase the surface energy (Zhang, Wang, 2006). In this case, more studies are necessary with different moisture content of each species to prove the above mentioned statement, because Scots pine with a higher moisture content shows lower value of surface energy if it is assumed that all softwood has the same trend.

S.E. Abed et al. (2012) discovered that cedar, pine, ash and teak wood species are bigger electron

Table 2

Measured mean values of contact angle on Scots pine and Norway spruce samples

Wood samples	Contact angle with diiodomethane (± SD), °	Contact angle with ethylene glycol (± SD), °	Contact angle with water (± SD), °	Number of contact angle values in group, n
Norway spruce	22.22 ± 0.59	58.90 ± 0.86	70.10 ± 1.46	20
Scots pine	32.70 ± 2.43	55.73 ± 2.07	78.58 ± 1.14	20

Table 3

Calculated mean surface free energy characteristics of wood samples

Wood samples	Surface free energy, γ_S, mN m^{-1}	Coefficient of determination	Acid (electron-acceptor) component, γ_S^A, mN m^{-1}	Base (electron-donor) component, γ_S^B, mN m^{-1}
Norway spruce	47.07	0.67	0.00	15.78
Scots pine	35.75	0.85	0.00	9.66

donors, because electron-acceptor component approaches zero and electron-donor component dominates. The electron-donor component of pine reached 24.2 mN m^{-1} (Abed et al., 2012). We noticed the same trend for surface free energy components, only we got the lower surface free energy component value. It could be explained with the fact that in S.E. Abed et al. (2012) research the moisture content of wood and test liquidsis not specified.

Wood is acidic in bulk but basic in the surface (Gindl et al., 2001). During aging of the wood, hydrophobic extractives migrate to the surface and decrease the surface energy of wood (Wolkenhauer et al., 2009). To prove causation between acid-base components and wood aging, further study is needed.

Conclusions

Acid–base approach is a suitable method to calculate surface free energy and its characteristics of wood from the values of contact angle. Further theoretical and experimental studies to evaluate the liquid penetration rate in wood tracheids, wood roughness and aging factors and also moisture content are needed to develop and to obtain unequivocal contact angle values and, consequently, surface free energy. Indirect methods of liquid drop contact angle value estimation must be used because direct determination is not feasible on wood surfaces with open capillaries.

References

1. Abed S.E., Ibnsouda S.K., Latrache H. (2012) Comparative Study of Physic-Chemical Characterization and Microbial Adhesion of Oak Wood with Other Wood Species. In: Chuteira C.A., Grão A.B. (eds) *Oak: Ecology, Types and Management,* Nova Science Publishers Inc., New York, pp. 219-230.
2. Baldan A. (2012) Adhesion phenomena in bonded joints. *International Journal of Adhesion and Adhesives*, 38, pp. 95-116.
3. Chau T.T., Bruckard W.J., Koh P.T.L., Nguyen A.V. (2009) A review of factors that affect contact angle and implications for flotation practice. *International Journal of Adhesion and Adhesives*, 31, pp. 127-134.
4. Erbil H.Y. (1997) Surface Tension of Polymers. In: Birdi K.S. *CRC Handbook of Surface and Colloid Chemistry*, CRC Press, Boca Raton, pp. 265-312.
5. Fuentes C.A., Tran L.Q.N., Dupont-Gillain C., Vanderlinden W., de Feyter S., van Vuure A.W., Verpoest I. (2011) Wetting behaviour and surface properties of technical bamboo fibres. *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 380, pp. 89-99.
6. Gérardin P., Petrič M., Petrissans M., Lambert J., Ehrhrardt J.J. (2007) Evolution of wood surface free energy after heat treatment. *Polymer Degradation and Stability,* 92, pp. 653-657.
7. Gindl M., Sinn G., Gindl W., Reitener A., Tschegg S. (2001) A comparison of different methods to calculate thee surface free energy of wood using contact angle measurements. *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 181, pp. 279-287.
8. Mazolla L., Bemporad E., Carassiti F. (2012) An easy way to measure surface free energy by drop shape analysis. *Measurement,* 45, pp. 317-324.
9. Nowak E., Combes G., Hugh Stitt E., Pacek A.W. (2013) A comparison of contact angle measurement techniques applied to highly porous catalyst supports. *Powder Technology,* 233, pp. 52-64.
10. Rubina T., Stalidzāns E., Dimiņš F., Kūka P., Morozovs A. (2009) Raksturojošā kontaktleņķa vērtības un virsmas enerģijas noteikšana koksnei (Determination of the characteristic value of the contact angle and surface energy for wood). *Latvijas Lauksaimniecības universitātes raksti,* 22 (317), 100-112. lpp. (in Latvian).
11. Winfield P.H., Harris A.F., Hutchinson A.R. (2001) The use of flame ionisation technology to improve the wettability and adhesion properties of wood. *International Journal of Adhesion and Adhesives*, 21, pp. 107-114.
12. Wolkenhauer A., Avramidis G., Hauswald E., Militz H., Viöl W. (2009) Sanding vs. Plasma treatment of aged wood: A comparison with respect to surface energy. *International Journal of Adhesion and Adhesives*, 28, pp. 18-22.
13. Zhang Y., Wang S. (2006) Study of Surface Energy Characteristics of Poplar and Yellow Pine Strands. *Chinese Forestry Science and Technology*, 5, pp. 7-10.

LEACHING OF HEAVY METALS FROM SOILS STABILIZED WITH PORTLAND CEMENT AND MUNICIPAL SOLID WASTE INCINERATION BOTTOM ASH

Juris Burlakovs[1], **Dace Arina**[2], **Vita Rudovica**[1], **Maris Klavins**[1]
[1]University of Latvia
[2]Latvia University of Agriculture
juris@geo-it.lv; dace.arina@gmail.com

Abstract
Heavy metals are worldwide spread pollutants in soils of functioning as well as abandoned industrial territories, landfills, military areas with its historical contamination, and other sites contaminated by industrial activities. Development of soil and groundwater remediation technologies is a matter of great importance to diminish the hazardous impact of pollution to humans and environment. Sustainable solution can be found for remediation of industrial areas using the stabilization / solidification (S/S) technology, which refers to binding of waste contaminants to a more chemically stable form. Geotechnical properties of soil treated with Portland cement (PC) can be improved when municipal solid waste incineration (MSWI) ash is used as the combined additive. Ash is composed mainly of metals, so environmental impact must be evaluated if it is used as amendment in the cement industry. The use of MSWI ash in stabilization of contaminated soils would be useful for the sustainable environmental management in two ways: S/S contaminated soil gains better geotechnical stability and waste incineration industry gets rid of the ash with high metal content. The aim of research is to provide pilot batch experimental results for leaching of heavy metal compounds when S/S technology is used for contaminated soils using PC and MSWI bottom ash additives. Mineral soils were spiked with copper, PC and MSWI were added in known proportions and leaching tests applied. Main results show that PC addition allows to chemically stabilize soil; thus, heavy metals are not leached out from combined mass of spiked soil and MSWI bottom ash.
Key words: stabilization / solidification, remediation, batch leaching test, environmental management.

Introduction

Soil and groundwater are environmental compartments that are primarily influenced by industrial development with increasing amount of industrial wastes and inadequate dumping of them. Former dump sites of mixed waste can be composed of hazardous waste as well as all other types of waste. In the former Soviet Union, various kinds of municipal, residential and construction waste as well as hazardous substances and materials were often dumped in these dump sites. It causes a large number of contaminated sites that are disseminated in post industrialized countries (Prokop et al., 2000; Critto et al., 2006). Municipal solid waste (MSW) management is an increasing problem for both developed and emerging countries, particularly where the population density is high. After recovery of the recyclable materials, most part of MSW is currently landfilled that contributes to related problems due to lack of available land, environment protection issues, and health concerns (Bethanis et al., 2002). Incineration of MSW offers an advantage as the volume reduction of waste can reach up to 90%, but the incineration also produces by-products (bottom and fly ashes) in amount of about 33 wt.% (weight percent) of the incinerated waste (Qiao et al., 2008). Ashes must be processed before land filling or reused to avoid leaching of heavy metal ions and resulting consequent pollution (Sabbas et al., 2003; Reijnders, 2005). Since MSWI ash contains high amount of various heavy metals and salts, serious environmental problems will occur if the waste is not treated properly before final disposal. Some approaches for MSWI ash disposal have been proposed, mainly for recycling into construction materials (Schreurs et al., 2000; Nishigaki, 2000; Mangialardi, 2003).

Stabilization / solidification (S/S) technologies for soil remediation have been used for decades in order to get waste contaminants to a more chemically stable form, thereby resulting in a more environmentally acceptable waste form. Typically, the stabilization processes also involve some form of physical solidification as shown (Shi and Fernandez-Jimenez, 2006). Solidification encapsulates contaminants in a solid matrix while stabilization involves formation of chemical bonds to reduce contaminant mobility (Mulligan et al., 2001).

In order to improve the physical properties of the stabilized soil, bottom and fly ashes from different industries (such as incinerators) are used as additives in cement. Environmental impact is assessed by leaching tests that are based on extraction to define the possibility of the solidified mass to release contaminants into the environment (Kosson et al., 2002). The compressive strength characterizes how the solidified mass ensures its safe disposal (Gailius et al., 2010), such type of research is an object of geotechnical study and is described widely. Natural soils are often complex assemblages of soil fractions, components and possibly contaminants, and S/S treatment introduces new components which react through complex chemical interactions to produce

more stable forms with less mobile components. However, long-term effectiveness and chemical durability of S/S treated materials are still not well known (Bone et al., 2004). The resulting scenario is that stabilized material are undertaken without an understanding of the interactions and controlling factors (John et al., 2011).

The aim of this research is to study on leaching of metal ions and toxic compounds from contaminated soil stabilized with MSWI bottom ash and PC. As there are suggestions and environmental assessment data for proper use of S/S technology for remediation in Freeports of Riga and Liepaja (Liepaja Navy Port Environmental Research, 1996; Report on Heavy Metal Contamination…, 2010; Burlakovs and Vircavs, 2011), obtained data can be used to make some important conclusions in batch level about the environmental safety if the S/S remediation technology with cement and MSWI bottom ash would be applied. Compression testing results for geotechnical S/S applications using only PC for stabilization of contaminated soil in Riga Freeport are published before (Report on Heavy Metal Contamination…, 2010; Burlakovs and Klavins, 2012).

Materials and Methods

Research work was done in time period between July 2011 and January 2013. A mineral soil sample was taken during geotechnical field work from in the depth interval 4.3-4.6 m in Daugava floodland area in Rīnūži, Riga City. Air-dried soil samples were sieved through a 2-mm sieve. To determine the particle size, samples were treated with 0.1 *M* NaOH to break down aggregates. Sands were sieved and fractions finer than 0.05 mm were determined by pipette analysis (Reeuwijk, 1995). On the basis of the US Department of Agriculture soil texture classes, the fractions from 0.063 to 2.0 mm are classified as sand, those from 0.002 to 0.063 mm are classified as silt, and those finer than 0.002 mm are classified as clay (Manual IIIa, 2012). Homogenous sample with properties as 87.5 wt. % sand, 12.5 wt. % silt was distinguished. Soil pH was measured in 1 *M* KCl (1:2.5 mass-to-volume ratio) in triplicate. Cation exchange capacity for soil was determined 5.1 mEq $100g^{-1}$, so it is not significantly influencing the results for leaching experiment. Samples were spiked with copper sulphate (ReagentPlus, >98.0%) in known concentration of 300 mg kg^{-1}, divided in 6 homogenous parts and

Table 1

Content (mg kg^{-1}) of metals in bottom ash determined using X-ray fluorescence spectrometry method

Element	Numbers of sample					
	1	2	3	4	5	6
As	20.9	1.2	0.5	0.6	0.9	0.4
Ba	587	600	34.2	113	87.9	185
Br	9.1	1.3	4.1	10.3	5.9	2.4
Cd	1.6	1.2	1.1	1.6	1.5	0.7
Co	16.3	6.0	11.4	16.2	14.7	6.6
Cr	117	63.6	6.8	6.5	64.5	23.8
Cs	9.8	3.6	6.8	9.7	8.8	4.0
Cu	61.9	32.4	59.3	107	41.0	26.4
Mn	453	74.4	47.9	126	161	136
Mo	9.8	7.2	4.6	6.5	5.9	4.0
Ni	16.3	8.4	2.3	19.4	14.7	5.3
Pb	109	241	5.0	27.1	26.1	9.2
Rb	17.0	6.5	4.1	17.8	12.9	11.2
Sb	26.1	4.4	0.5	21.3	2.9	2.9
Sn	9.8	2.4	4.6	3.2	2.9	108
Sr	130	39.6	38.8	116	117	39.6
V	32.6	12.0	22.8	32.3	29.3	13.2
Zn	355	2904	73.0	120	252	110
Zr	29.3	8.4	6.8	80.8	44.0	13.2

mixed with MSWI bottom ash and PC. The municipal solid waste (MSW) samples were taken from mechanical waste pre-treatment centres in Latvia after mechanical shredding, screening and separation of metal (Arina and Orupe, 2012). The ash content was determined according to the standard LVS EN 15403:2011 (Solid recovered fuels - Determination of ash content, 2011) (equipment – furnace CHOJI). The 'CLR-7K' XRF fluorescence spectrometer was used for analyzing elements in the ash according to the LVS EN 15411:2012 (Solid recovered fuels – Methods, 2012) for the determination of the content of trace elements (As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Mn, Ni, Pb, Sb, Se, Tl, V and Zn) (Table 1).

MSW was incinerated at high temperature in order to get the residual comparable to real incineration process at the industrial facility. Major elements were found at high wt. % in the MSWI, such as Ca (13.7-21.3%), Al (1.0-8.0%), Cl (0.7-10.0%), Fe (0.5-2.2%), K (1.1-3.5%), Mg (3.0%), P (0.4-1.4%), S (0.7-3.3%), Si (3.0-15.0%), Ti (0.4-3.2%). The primary purpose of MSWI bottom ash is to improve physical stability of solidified mass and assist to the Portland cement (PC). PC clinker is manufactured by burning at high temperature a raw meal consisting mainly of limestone and clay (Gineys et al., 2010). When cement is mixed with the water a paste is produced that surrounds all the individual pieces of aggregate to make a plastic mixture. A chemical reaction called hydration takes place between water and cement and then concrete normally changes from the plastic to the solid state in about 2 hours and thereafter concrete continues to gain strength as it cures.

MSWI bottom ash with known elemental content (Table 1) and all the six samples were treated with ordinary PC (class 500) at the mixing ratio 50:35:15 (50 wt. % spiked soil with copper sulphate: 35 wt. % MSWI bottom ash: PC 15 wt. %). Three additional samples were made without the addition of MSWI bottom ash in order to help better interpret results. One was spiked with copper and cemented, one not spiked, but cemented, the last was used for the control as the blank – only soil without any additives was used for the leaching experiment.

Setting time of a cementitious mixture is referred to as the period when water is introduced into the mixture system to the onset of hardening. Final setting time is defined as the 5-mm cap ring leaves no noticeable mark when placed on the surface of the mortar mixture (Yin et al., 2006).

During the batch leaching test vessels were filled with distilled water in the liquid-to-solid-ratio 10:1. Under continuous agitation at the rate 100RPM the batch leaching test was done for samples with agitation time period of 24 hours and the pH H_2O level was measured for all samples before and after the period. After this time the liquid was let to set down for about 10 minutes. For the determination of inorganic compounds, the liquid was filtered over a 0.45μm filter. Afterwards, the content of leached metals was determined by ICP-MS (Perkin Elmer ELAN DRC-e) method. Leaching tests were performed for six samples with MSWI bottom ash and PC binder additive. Soil samples without MSWI were used for batch testing as 'control samples', but the blank sample was used for the control of whole experiment. For data mathematic analysis MS Excel was used.

Results and Discussion

Spiked and not spiked control samples with PC has similarities in terms of leaching behaviour comparably to bound with MSWI bottom ash and PC both. That means that addition of PC is enough strong to keep out the copper (Cu) from leaching without the assistance of ash. The blank has shown no significant amount of heavy metal leaching, pH level of eluate was 6.7.

Only those results which are over the detection limit of the ICP-MS instrument and are larger than leaching result from the blank sample are set given at Table 2. pH level for the eluate from the batch experiment was ranged from 10.0 to11.5.

Stabilized / solidified waste acceptance criteria can be used to evaluate the effectiveness of the treatment. This criterion is chosen because S/S technology is widely used for treatment and two main parameters are measured for determination of the effectiveness of remediation – UCS (not described in this research) and leachability limits. Regulatory leachability limits are most important in this case, in order to see the effectiveness of binding. Therefore, regulatory limits at a disposal site in the United Kingdom (Sollars and Perry, 1989) are given for the Cu, which is 5 mg L^{-1} or comparing to results in Table 2, would be 50 mg kg^{-1}, if the L/S ratio 10 is applied like in this batch case.

The obtained results have shown that stabilized soil with MSWI bottom ash and PC has diminished leaching level , and it is at the acceptable level. The results show that S/S remediation method has high efficiency in respect to heavy metal binding (Table 2). Regulatory limits of England and Wales (Environmental protection..., 2005) for non-hazardous monolithic waste for metals are not exceeded, limits are given in Table 2 in order to provide the general overview. In this study, these limits are taken for the evaluation, as parameters are more realistic for reducing of pollution spread out from contaminated brownfields to the environment. Elements that are not shown in Table 2 during this study were under the detection limit. The analysis of chromium as well as arsenic should be done using sequential extraction procedure described in (Tessier et al., 1979) and / or

Table 2

Leaching from stabilized Cu spiked (300 mg kg^{-1}) soil (50 wt.%) with PC (15 wt.%) and MSWI ash (35 wt.%)

	Numbers of samples						
Elements	1 (mg kg^{-1})	2 (mg kg^{-1})	3 (mg kg^{-1})	4 (mg kg^{-1})	5 (mg kg^{-1})	6 (mg kg^{-1})	UK limit, leaching mg kg^{-1}
As	0.07	0.05	0.09	0.03	0.04	0.10	2
Ba	0.7	1.3	0.07	0.2	0.16	0.8	100
Co	0.05	0.05	0.04	0.03	0.06	0.03	-
Cu	1.3	1.8	13	0.9	5.3	1.2	50
Mn	0.03	0.11	0.05	0.04	0.03	0.20	-
Ni	0.13	0.14	0.05	0.05	0.06	0.04	10
Pb	0.43	0.60	0.20	0.21	0.22	0.20	10
Rb	3.9	5.2	3.4	2.0	5.1	5.3	-
Sr	8.9	9.5	0.4	1.5	2.1	1.9	-
V	0.24	0.37	5.7	0.51	0.62	1.2	-
Zn	0.09	0.22	0.09	0.03	0.04	0.08	50

standard EN15192, which says that under environmental conditions chromium in compounds exists in the trivalent, Cr(III), or the hexavalent, Cr(VI) state. Cr(III) is an essential trace element for mammals, including humans, whereas it is presumed that Cr(VI) compounds are genotoxic and potentially carcinogenic in humans. Interconversion of trivalent and hexavalent chromium species can occur during sample preparation and analysis, but these processes are minimised to the possible extent by the sample preparation methods prescribed by standard of determination of Chromium(VI) in solid material by alkaline digestion and ion chromatography with spectrophotometric detection (Characterisation of waste…, 2006).

By comparing results of Tables 1 and 2, leaching can be analysed as it describes the absolute content of MSWI bottom ash, and it gives the overview of leaching from copper contaminated soil admixed with PC and MSWI bottom ash.

Soil sample originally does not contain significant amount of heavy metals nor the PC does; therefore, the leaching of heavy metal compounds can be calculated. Arsenic (As) leaching from stabilized samples is not highly dependant on the amount of it in parent mass of MSWI bottom ash, leaching is quite constant and is not exceeding 5 wt. % of allowed by legislation in the UK. The main interest in this study is the amount of copper (Cu) leached from the spiked mass stabilized with MSWI ash and PC. Results show that significant leaching is seen in eluate from samples No. 3 and 5, but they are not exceeding the safety threshold. Contamination of Cu salt is very well immobilized in the mass combined at the batch experiment and is not a subject of concern. Next element of interest from the point of view of environment is lead (Pb), the leaching is also relatively constant and not higher than 8.7 wt. % of allowed by the legislation in the UK. Heavy metals and other elements also are well included in stabilized mass – the leached wt. % in eluate is just 0.009 wt. % for Pb, same as zinc (Zn) that has negligible leaching (0.03 wt. % from total mass of ash) according to the experimental data. Nickel (Ni) has just 0.006 wt. %, barium (Ba) 0.002 wt. %, As 0.015 wt. %, cobalt (Co) 0.003 wt. %, Cu 0.012 wt. %, manganese (Mn) 0.0006 wt. %, vanadium (V) 0.06 wt. % of mass leached out from the total mass of stabilized spiked soil. Rubidium (Rb) and strontium (Sr) with similar chemical properties and good solubility has higher leaching, but these elements are not of a high concern as these are very common in the environment and are essential for biological systems.

Further evaluation of MSWI ash applications for stabilization of contaminated soils in industrial areas and brownfields must follow as many bonuses can be got from such type of remediation: 1) immobilization of contaminated soils; 2) increased compressive stability of S/S remediated soils; 3) MSWI bottom ash is successfully input in industrial structure (pavement, road, solid area for construction). Batch tests must be amended with column test studies, pilot research in pilot remediation areas, additional studies of main

elements of concern and risk analysis for changing environmental conditions and presence of hazardous ecotoxicological chemical interaction impact factors. Stabilization / solidification (S/S) technologies for soil remediation have been used for decades in order to get waste contaminants to a more chemically stable form, thereby resulting in a more environmentally acceptable waste form.

Stabilization of contaminated soils in industrial areas and brownfields has such benefits: 1) contaminated soils are immobilized; 2) compressive stability of S/S remediated soils improves; 3) MSWI bottom ash is successfully used in construction. Batch tests for environmental study must be approved by column test studies and pilot research in pilot remediation areas as well as ecotoxicological risk of applications must be considered.

Conclusions

Batch tests are only to evaluate general opportunities of S/S technology use in remediation, further research must be done in a pilot scale, environmental risks evaluated as well as monitoring of leaching done during real-time remediation process and after that. This study has shown that it is possible to stabilize / solidify contaminated soil using MSWI bottom ash and PC having enough good results in diminishing the leaching of heavy metals and other elements of concern.

Acknowledgements

This research was supported by the European Social Fund (ESF) agreements No. 2009/0138/1DP/1.1.2.1.2/09/IPIA/VIAA/004 and 2009/0180/1DP/1.1.2.1.2/09/IPIA/VIAA/017 for the doctoral research grant awards of first two sequential authors.

References

1. Arina D., Orupe A. (2012) Characteristics of Mechanically Sorted Municipal Wastes and Their Suitability for Production of Refuse Derived Fuel. *Environmental and Climate Technologies*, Issue 1, June 2012, pp. 18-23.
2. Bethanis S., Cheeseman C.R., Sollars C.J. (2002) Properties and microstructure of sintered incinerator bottom ash. *Ceramics International,* 28, pp. 881-886.
3. Bone B.D., Barnard L.H., Boardman L.H., Carey P.J., Hills C.D., Jones H.M., MacLeod C.L., Tyrer M. (2004) Review of scientific literature on the use of stabilisation / solidification for the treatment of contaminated soils, solid wastes and sludges. *Environmental Agency, Science Report* SC980003/SR2, Environmental Agency, UK, 343 p.
4. Burlakovs J., Klavins M. (2012) Stabilization and Solidification Technology Implementation in Latvia: First Studies. *International Journal of Environmental Pollution and Remediation,* 1 (1), pp. 1-6.
5. Burlakovs J., Vircavs M. (2011) Possible Applications of Soil Remediation Technologies in Latvia. *RTU Zinātniskie Raksti*, 13. sēr., Vides un klimata tehnoloģijas. 7 ., pp. 46-53.
6. Critto A., Cantarella L., Carlon C., Giove S., Petrzzelli G., Marcomini A. (2006) Decision Support-Oriented Selection of Remediation Technologies to Rehabilitate Contaminated Sites. *Integrated Environmental Assessment and Management*, 2 (3), pp. 273-285.
7. Environmental protection, England and Wales. The Landfill (England and Wales) (Amendment) Regulations. Statutory Instruments No. 1640. (2005) Available at: http://legislation.data.gov.uk/uksi/2005/1640/made/data.htm?wrap=true, 20 February 2013.
8. Gailius A., Vacenovska B., Drochytka R. (2010) Hazardous Wastes Recycling by Solidification / Stabilization Method. *Materials Science,* 16 (2), pp. 165-169.
9. Gineys N., Aouad G., Damidot D. (2010) Managing trace elements in Portland cement – Part I: Interactions between cement paste and heavy metals added during mixing as soluble salts. *Cement and Concrete Composites,* 32, pp. 563-570.
10. John U.E., Jefferson I., Boardman D.I., Ghataora G.S., Hills C.D. (2011) Leaching evaluation of cement stabilisation / solidification treated kaolin clay. *Engineering Geology,* 123, pp. 315-323.
11. Kosson D.S., van der Sloot H.A., Sanchez F., Garrabrants A.C. (2002) An integrated framework for evaluating leaching in waste management and utilization of secondary materials. *Environmental Engineering Science,* 19(3), pp. 159-204.
12. Liepājas ostas vides izpēte (Liepaja Navy Port Environmental Research) (1996) *ES PHARE programme and the Government of Latvia,* Riga, Baltec Associates Inc., 80 lpp. (in Latvian).
13. Mangialardi T. (2003) Disposal of MSWI fly ash through a combined washing-immobilisation process. *Journal of Hazardous Materials,* 98, pp. 225-240.

14. Manual IIIa: Sampling and Analysis of Soil (2006) FSCC (Forest Soil Co-Ordinating Centre). *ICP Forests, 2006: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests.* UNECE ICP Forests Programme Co-ordinating Centre, Hamburg. p. 26. With annexes; Available at: http://icp-forests.net/page/icp-forests-manual, 27 January 2013.
15. Mulligan C.N., Yong R.N., Gibbs B.F. (2001) Remediation Technologies for Metal-contaminated Soils and Groundwater: An Evaluation. *Engineering Geology,* 60, pp. 193-207.
16. Nishigaki M. (2000) Producing permeable blocks and pavement bricks from molten slag. *Waste Management,* 20, pp. 180-192.
17. Qiao X.C., Ng B.R., Tyrer M., Poon C.S., Cheeseman C.R. (2008) Production of lightweight concrete using incinerator bottom ash. *Construction and Building Materials,* 22 (4), pp. 473-480.
18. Prokop G., Schamann M., Edelgaard I. (2000) Management of contaminated sites in Western Europe. *Topic Report, No 13/1999*, European Environment Agency, Copenhagen, pp. 17-32.
19. Reijnders L. (2005) Disposal, uses and treatments of combustion ashes: a review. *Resources, Conservation and Recycling,* 43, pp. 313-336.
20. Atskaite par piesārņojuma ar smagajiem metāliem izpēti un tehniski – ekonomisko plānojumu rekultivācijai (Report on Heavy Metal Contamination Research and Technical Economic Planning for Remediation) (2010) Riga, Europroject Ltd., vol 1, 2 lpp. (in Latvian).
21. Reeuwijk van L.P. (1995) *Procedures for Soil Analysis*, Fifth edition. ISRIC Technical Paper 9. Wageningen, The Netherlands, 100 p.
22. Sabbas T., Polettini A., Pomi R., Astrup T., Hjelmar O., Mostbauer P., Cappai G., Magel G., Salhofer S., Speiser C., Heuss-Assbichler S., Klein R., Lechner P. (2003) Management of municipal solid waste incineration residues. *Waste Management,* 23 (1), pp. 61-88.
23. Schreurs J.P.G.M., Sloot van der H.A., Hendriks Ch. (2000) Verification of laboratory-field leaching behavior of coal fly ash and MSWI bottom ash as a road base material. *Waste Management,* 20, pp. 193-201.
24. Shi C., Fernandez-Jimenez A. (2006) Stabilization / Solidification of Hazardous and Radioactive Wastes with Alkali-activated Cements. *Journal of Hazardous Materials*, B137, pp. 1656-1663.
25. Sollars C.J., Perry R. (1989) Cement-based stabilization of wastes: practical and theoretical considerations. *Water and Environment Journal,* 3, pp. 125-132.
26. Standard LVS EN 15192:2006 Characterisation of waste and soil - Determination of Chromium(VI) in solid material by alkaline digestion and ion chromatography with spectrophotometric detection (2006) *Latvian Catalogue of Standards.* Available at: https://www.lvs.lv/stdPreview/LVS%20EN%2015192_2007_P.pdf, 1 March 2013.
27. Standard LVS EN 15403:2011 Solid recovered fuels - Determination of ash content (2011) *Latvian Catalogue of Standards.* Available at: https://www.lvs.lv/lv/services/catalogue/standardDetails.asp?std=30590, 27 February 2013.
28. Standard LVS EN 15411:2012 Solid recovered fuels – Methods. (2012) *Latvian Catalogue of Standards.* Available at: https://www.lvs.lv/en/services/catalogue/standardDetails.asp?std=21900, 25 February 2013.
29. Tessier A., Campbell P.G.C., Blosson M. (1979) Sequential extraction procedure for the speciation of particulate trace metals. *Analytical Chemistry*, 51 (7), pp. 844-851.
30. Yin C.Y., Mahmud H.B., Shaaban M.G. (2006) Stabilization/solidification of lead-contaminated soil using cement and rice husk ash. *Journal of Hazardous Materials* B137, pp. 1758-1764.

IN-SITU PHYTOREMEDIATION: A REVIEW OF NATURAL AND CHEMICALLY ASSISTED PHYTOEXTRACTION

Alfreda Kasiulienė, **Valdas Paulauskas**
Aleksandras Stulginskis University, Lithuania
alfreda.kasiuliene@gmail.com; valdas.paulauskas@lzuu.lt

Abstract
There are about 3,000-4,000 heavy metal contaminated sites across Lithuania. According to Lithuanian legal framework, the only way to manage this pollution is ex-situ cleaning which requires excavation, transporting, storage place and later monitoring. This indicates the urgent need of innovative technologies that would be not only cost-effective but also environmentally friendly and have a public acceptance. Such technologies are natural and chemically enhanced phytoextractions. Both technologies incorporate plants that can accumulate excessive amounts of heavy metals. During continuous phytoextraction plants accumulate heavy metals throughout all vegetation period and are harvested together with heavy metals when desired biomass is gained. At chemically assisted phytoextraction metal binding chelates are added to increase heavy metal uptake by plants. Since phytoextraction is considered as promising green technology, many efforts are laid to find the most suitable hyperaccumulator plants as well as ecologically safe chelating agents. This paper intends to overview latest researches done at phytoextraction field and look over this kind of remediation possibilities in Lithuania.
Key words: heavy metal, soil, phytoextraction, chelating agent, hyperaccumulator plants.

Introduction

At the beggining of the 2012 Lithuanian geological survey under The Ministry of Environment adduced its 'Annual report 2011'. Besides other important topics such as geological mapping, groundwater monitoring, etc., report also covered impact assessment of contaminated sites. This project was financed by European Union funds and it aimed to a preliminary inventory of potentially polluted sites in 39 districts of Lithuania. After generalizing gathered data, Lithuanian geological survey indicated that there might be about 3,000-4,000 sites across Lithuania dangerous to environment and human health. Such sites, contaminated with hydrocarbons, persistent pesticides and heavy metals (HM) should be of priority importance for the environmental sector where not only further detailed investigation is needed but also application of remediation technologies (Lithuanian geological survey, 2012).

From the economic point of view, restoration of contaminated lands always involves loss of material recourses and usually application of remediating technologies is avertable. However, under certain circumstances it cannot be avoided and becomes the only possibility to preserve precious elements of ecosystem or whole ecosystem (Lithuanian geological survey, 2012).

Best demonstrated available technologies (BDAT) for soil remedy usually cover immobilization, soil washing and phytoremediation. Nevertheless, field applications or super-funded projects are performed only in developed countries. In developing countries such projects are depreciated due to the lack of information about its advantages, awareness by the governments, and scarcity of funds (Wuana and Okieimen, 2011).

A new 'Plan on contaminated land management for 2013-2020' was approved by the Lithuanian Minister of Environment in August, 2012. This plan aims to evaluate scale of chemically contaminated lands, safely manage dangerous sites in order to diminish negative impact to the environment and human health and ensure good soil and groundwater quality status. It was also stated that there are two ways when dealing with polluted soil. The first one goes for ex-situ soil cleaning where soil has to be transported to cleaning sites. The second one goes for cleaning of deeper layers in-situ. However, the second method only fits for contamination with hydrocarbons (Order by the Minister of Environment of Lithuanian Republic, 2012). Altogether, this plan only reveals a demand of innovative remediation technologies and especially for heavy metal contamination as this practice of 'dig and dump' technology does not solve the situation (Pulford and Watson, 2002).

When considering proper technology for soil, polluted with heavy metals, phytoextraction can offer a numerous advantages over excavating, immobilization or soil washing. The basic idea that plants can accumulate unusually elevated metal levels is very old and cannot be traced to any particular source (Evangelou et al., 2007). However, first results from pilot scale projects appeared only in recent decades and new questions concerning phytoextraction emerged all along.

Materials and Methods

A phytoextraction technology for HM contaminated soil remedy was the main object of this review. There was an intention to determine the extent how widely and effectively this technology is used worldwide and to overlook the potential of phytoextraction in

Lithuania or similar latitudes. Having summarized material gathered from scientific literature analysis, it was possible not only to reveal background of this technology, but also give guidelines for assessing the efficacy of phytoextraction. Plants for possible usage for phytoextraction purposes in Lithuania were identified by comparing plant species specified in scientific literature to those that are native to Lithuania under certain climatic and pedogenic conditions.

Results and Discussions

Natural phytoextraction

Terms of phytoextraction and phytoremediation are often taken as synonyms. However, phytoremediation is a concept while phytoextraction is one of five clean-up technologies that incorporate plants (remaining four technologies are rhizofiltration, phytostabilization, phytovolatilization, phytodegradation) (Pulford and Watson, 2002). Phytoextraction is identifiable above all other phytoremediation techniques, and for this reason it gains increased attention from scientists.

Metal tolerant plants that have a capability to accumulate high levels of HM are seeded or transplanted into a spoiled soil and are cultivated using relevant agricultural procedures. Hyperaccumulator plants absorb compounds containing heavy metals through root system and transport them to above-ground green parts for accumulation. When desired biomass is reached, vegetation of plants is stopped by harvesting them as well as removing accumulated HM permanently (Prasad and Freitas, 2003).

Natural phytoextraction should be considered as a long term technology for heavy metal removal from vast contaminated territories. However, it can be applied only to sites that contain low to moderate levels of pollution as vegetation cannot persist in highly contaminated media. Such sites should have suitable landscape for agricultural machinery and other equipment also should be free of debris, fallen trees or boulders (Kumar et al., 1995).

Hyperaccumulator plant species have to meet several basic criteria: to be tolerant of increased levels of heavy metal and efficient at transporting HM from roots to shoots. It is also desired that such plants would yield high biomass in spite of harsh soil conditions (Wuana and Okieimen, 2011). However, among 45 (at least) plant families such ideal hyperaccumulator simply does not exist. Though, there are reported about 400 species that can accumulate one heavy metal or in very rare occasion's two heavy metals (Lasat, 2000) and contrary to desired skills, all those plants are slow growing and produce low biomass; thus, metal accumulation is limited as well (Comis, 1996).

On the one hand, plant based technologies are low-cost not only during the establishment phase but also from a future maintenance perspective. These costs of growing plants are significantly lower in comparison to costs of ex-situ technologies, like excavation, vitrification, soil washing, etc. Moreover, green technologies such as phytoextraction always have better public recognition as it is less disruptive to ecosystems, and therefore it is easier to carry out a project. On the other hand, there are some problems that can arise all along, i.e. wood with accumulated heavy metals can be used for fuel resulting in emissions of HM aerosols to the atmosphere, or contaminants can be released back to the environment together with old leaves, dead branches or stems, which are left on-site (Marques et al., 2009).

Chemically assisted phytoextraction

As it was mentioned above, natural hyperaccumulators grow slowly and yield lesser biomass due to the excess of HM. To overcome these shortfalls, chemically assisted phytoextraction was settled. The basic idea of enhanced phytoextraction is that the use of metal binding chelating agents may stimulate metal accumulation in plants. This is due to the fact that chelates can bind with single metal ion via several bonds, and newly formed chelate-metal complexes are soluble and thus more bioavailable (Garbisu and Alkorta, 2001). Different heavy metals have different bioavailability properties as Cd, Ni, Zn, As, Cu, Se are readily bioavailable; Co, Mn and Fe are moderately bioavailable, but Pb, Cr and U are hardly bioavailable HM (Miller, 1996).

pH is the main driver that affects plant uptake not only for heavy metals but also for all nutrients. Slight pH change can be performed by plants itself as H^+ ions are released from rhizosphere to the soil. However, reducing pH in an artificial way can lead to a better HM bioavailability. For this reason, most of the chelating agents are acids or compounds of an acidic origin (Alkorta et al., 2004). Probably the best known acidifying agent is ethylenediaminetetraacetic acid (EDTA). Although this versatile acid capable to form from 4 to 6 bonds with heavy metal can be applied to Cd, Cu, Ni, Zn phytoextraction (Vaičikauskaitė et al., 2011), considerably more research was carried out with lead. In general, Pb and chemically assisted phytoextraction with EDTA is the most investigated object in all phytoextraction research fields. According to the lab experiments, it is calculated that high biomass yielding Pb accumulators such as Indian mustard (*Brassica juncea*), sunflower (*Helianthus annuus*), and maize (*Zea maize*) can accumulate from 180 kg up to 530 kg lead per hectare in case EDTA is applied as a chelating agent. Nevertheless, the ethylenediaminetetraacetic acid received a lot of criticism in recent years as application of this compound causes several negative effects. EDTA is very persistent and not only does it take quite a lot time to decompose but also it is easily leachable and

has a strong adverse influence on soil microorganisms as well. Alas, such side effects are often averted (Evangelou et al., 2007; Wu et al., 2003).

Apart from EDTA, phytoextraction is proceeded with N-hydroxyethylenediaminetriacetic acid (HEDTA), diethylenetriaminopentaacetic acid (DTPA), trans-1,2-cyclohexanediaminetetraacetic acid (CDTA), ethylene glycol tetraacetic acid (EGTA), ethylenediaminedi (O-hydroxyphenylacetic) acid (HEIDA), ethylenediamine-N,N'-disuccinic acid (EDDS), nitriloacetic acid (NTA), N,N'-bis-(2-hydroxybenzyl) ethylenediamine-N,N'-dipropionic acid (HBED), citric acid, malic acid and other acidic chelating compounds (Alkorta et al., 2004).

Effectiveness of metal bioavailability has strong relationship between chelate affinities to heavy metal. Some artificial chelating agents have an expressed affinity to particular metal, i.e., EDTA to lead, EGTA to cadmium, citrate to uranium. Yet, many other chelates do not have such stipulations and this may lead to undesired reactions with other cations after application to the soil as elevation of bioavailability of one particular HM can inhibit the other ones.

In 1998, Salt with other scientists published a paper where a scheme of chelate enhanced phytoextraction was described and fifteen years later nothing changed. At first, contaminated territory must be evaluated in order to select the best fitting combination of hyperaccumulator plants and chelating agents. After that, soil is ploughed; plants are seeded or transplanted and looked after using relevant agriculture techniques during all vegetation. Heavy metal binding agents are inserted into the soil at the time when plants reach desired biomass and after a short period of an intense metal accumulation (several days or week(s)), harvesting of the above ground part is performed. Removed plants can be incinerated or composted. In some cases it is wise and economically beneficial to recover heavy metals from harvested biomass. Moreover, this HM recovery is becoming a new technology of phytomining.

Chelating compounds are inserted into the soil just before harvesting due to the fact that an excessive HM accumulation leads plants to strong stress and death subsequently. It is important to follow this intense metal accumulation phase as above ground parts of a dead plant can bring back accumulated HM into the soil (Alkorta et al., 2004; Evangelou et al., 2007). On the other hand, there are records, that chelating agents can be added to the soil through several times (two or three) so that plants get adaptation to it (Wenzel et al., 2003).

Assessing the efficacy of phytoextraction

In the EU Council Directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC) marginal values of heavy metal concentrations in arable land are presented. They are as follow: 3 mg kg^{-1} dry weight (DW) for Cd, 140 mg kg^{-1} DW for Cu, 75 mg kg^{-1} DW for Ni, 300 mg kg^{-1} DW for Pb and Zn, 1.5 mg kg^{-1} DW for Hg (Council Directive 86/278/EEC). Limiting concentrations become as target values when evaluating contaminated site and setting on field applications. (Grčman et al., 2001)

In theory, metal accumulation can be calculated by determining metal concentrations in plant tissues, multiplied by the drop in soil metal concentrations (Ghosh and Singh, 2005) although in reality it is a bit more complicated, as various biotic and abiotic factors are affecting phytoextraction, and sometimes it is difficult to express them in numbers. Yet, generalized efficacy of phytoextraction can be expressed in three ways (Zhuang et al., 2005; Zhang et al., 2010) which are described in Table 1.

When calculating these parameters a couple of assumptions should be kept in mind: (1) plants uptake heavy metals only from top soil (0-20 cm) where active root system occurs and no deeper pollution is at present; (2) repeated cropping will give the same results every year (Wuana and Okieimen, 2011).

Possible hyperaccumulator plants in Lithuania

Many authors give a number reaching 400 species from at least 45 plant families, that are capable of heavy metal accumulation (Lasat, 2000; Garbisu and Alkorta, 2001; Prasad and Freitas, 2003; Alkorta et al., 2004;

Table 1

Parameters for evaluating the efficacy of phytoextraction

Parameter	Notation	Expression	Unit
Bioaccumulation factor	f	metal concentration in plant shootmetal concentration in soil	-
Amount of extracted metal	M	metal concentration in plant tissue *biomass	g kg^{-1}
Phytoremediation time	t_p	metal concentration in soil needed to decrease*soil massmetal concentration in plant shoot*plant shoot biomass*number of croppings	years

Evangelou et al., 2007; Wuana and Okieimen, 2011). Families that dominate are: *Asteraceae, Brassicaceae, Caryophyllaceaea, Cyperaceae, Cunouniaceae, Fabaceae, Flacourctiaceae, Lamiaceae, Poaceae, Violaceae* and *Euphobiaceae*. *Brassicaceae* family has the largest number of HM accumulating plants – 87 and one of the most cultivated crops for phytoextraction is Indian mustard (*Brassica juncea)*. Hyperaccumulator tends to uptake heavy metals as long as they are bioavailable in the soil (Prasad and Freitas, 2003). Although the function of this process is yet not known, there is a hypothesis that metal hyperaccumulation works as a defence mechanism against plant pathogens and predators (Sagner et al., 1998). By definition, a hyperaccumulator has to uptake at least 100 mg g^{-1} DW of cadmium, arsenic and some other trace metals, 1,000 mg g^{-1} DW of cobalt, copper, chromium, nickel and lead and 10,000 mg g^{-1} DW of manganese (Wantanabe, 1997).

It is required that hyperaccumulating plants would grow quickly and produce high biomass yield. However, due to the presence of heavy metals nearly all hyperaccumulators are slow growing and yield small amount of biomass. For this reason, phytoextraction focuses on combination of traditional cultures gaining loads of green mass, like maize, tobacco (*Nicotiana tabacum*), Indian mustard, oat (*Avena sativa*), barley (*Hordeum vulgare*), poplar (*Populus tremula*) and chelating agents, like EDTA. Proper combination of hyperaccumulating plant and chelating agent is a key to a successful phytoextraction (Alkorta et al., 2004).

It was stated before, that Lithuania lacks innovative technologies for heavy metal removal from the soil. As phytoextraction could become an option, it is necessary to have basic knowledge about Lithuanian soil and climate. Although, there are about 400 plant species that can be characterized as hyperaccumulators, not all of them can be cultivated in Lithuania or other countries located in similar latitudes. Major influence for selection of agricultural species gives the physical composition of the soil. Sandy loams, sands and clays are dominant in Lithuania. Due to moist and cool climate in Lithuania, soils are characterized as leachable and for this reason natural and anthropogenic chemical compounds easily move downwards to groundwater. Unfortunately, Lithuanian soils barely act like filters that could protect lakes, rivers as well as artesian and shaft wells from transfer of various substances and because of this management of contaminated sites is essential. Due to a constant loss of carbonates, another concern of soil acidification arise which subsequently leads to chemical soil degradation. Today about a quarter of Lithuanian arable land has a pH of about 5.5. It indicates decreased productivity and demand for more investments. Moreover, acidic soils tend to be a good habitat for deep-rooted weeds which damage drainage systems and decrease an economic land value in general (Lithuanian Geological Survey, 2008).

From an agricultural land use perspective, nearly 60% goes for arable land and 36% for grasslands and pastures. In arable lands 37.32% is declared as winter cereal (wheat (*Triticum spp.*), triticale, barley, rape (*Brassica napus*), 34.85% as summer cereal (wheat, triticale, oats, rye (*Secale cereal*), barley, barley (malt), vetches (*Vicia orobus*) and various mixtures, rape) and 18.29% as industrial crops (maize, peas (*Pisum sativum*), buckwheat (*Fagopyrum esculentum*), beans (*Phaseolus vulgaris*), lupines (*Lupinus perennis*), flax (*Linum usitatisimum*), sugar beets (*Beta vulgaris*), potatoes (*Solanum tuberosum*) (Lithuanian agriculture: facts and numbers 2012, 2013).

When relating to plant species that are referred in scientific literature as possible hyperaccumulators and those plants that are commonly cultivated in Lithuania, it is clear that many traditional Lithuanian plants (crops, vegetables and grasses) can be grown for phytoextraction purposes. This gives an advantage as plants are readily adjusted to climatic conditions and phytoextraction project for contaminated land management may be facilitated as usual agricultural equipment can be used.

However, there are very scarce data about phytoextraction researches in Lithuania. Main species that were used for such studies are ryegrass (*Lolium sp.*), meadow grass (*Poa annua*) and meadow fescue (*Festuca pratensis*). Jankaite (Jankaitė, 2007) in her doctoral thesis analyzed Cu, Cr, Zn, Pb, Mn, Ni uptake by these three grasses at three different heavy metal concentrations. It was also desired to reveal at which vegetation stage HM are absorbed most. Another goal was to find the most effective mixture of these three plant species for HM extraction from contaminated soil. After pot-experiments were carried out, the conclusion was drawn that ryegrass, meadow grass and meadow fescue are suitable for extraction of HM that can be often found at roadsides: Cu, Pb, Zn, Mn and Cr. The best effect was obtained by ryegrass as it diminished the concentration of Cu from 20 mg kg^{-1} to 3.35 mg kg^{-1}, Pb from 5 mg kg^{-1} to 1.4 mg kg^{-1}, Mn from 12.4 mg kg^{-1} to 8.4 mg kg^{-1}, Zn from 11.5 mg kg^{-1} to 4.05 mg kg^{-1}, Ni from 3.0 mg kg^{-1} to 0.93 mg kg^{-1} and Cr from 2.3 mg kg^{-1} to 1.08 mg kg^{-1}. It was suggested that grass mixture should hold about 80% of ryegrass, 10% of meadow fescue and 10% of meadow grass. This mixture cleaned the soil, decreased concentrations of heavy metal as follow: Cu from 9.25 to 6.85 mg kg^{-1}, Pb from 10.15 mg kg^{-1} to 5.1 mg kg^{-1}, Mn from 502.5 mg kg^{-1} to 253.5 mg kg^{1}, Zn from 25 mg kg^{-1} to 10.6 mg kg^{-1}, Ni from 4.0 mg kg^{-1} to 1.05 mg kg^{-1}

and Cr from 14.5 mg kg^{-1} to 4.25 mg kg^{-1} respectively at average artificial pollution.

Some investigations were performed with red clover (*Trifolium pratense*). In Mikalajėnė and Jasulaitytė, 2011 it was specified that a certain breed of red clover 'Arimaičiai' was able to diminish Ni concentration in the soil from 50 mg kg^{-1} to 31 mg kg^{-1}, Cr from 60 mg kg^{-1} to 31 mg kg^{-1}, Zn from 150 mg kg^{-1} to 105 mg kg^{-1}, Pb from 70 mg kg^{-1} to 48 mg kg^{-1}, Cu from 45 mg kg^{-1} to 15 mg kg^{-1} in a 6 - month period. It is also concluded that red clovers tend to uptake heavy metals mostly in first months of growth.

As Lithuania has a strong database on agricultural plant cultivation, so it could be applied for phytoextraction as well. Table 2 gives a list of plants that were referred as possible for HM uptake from polluted soil by various researchers. The table also indicates heavy metals that were recorded at elevated concentrations in plant tissues. However, this table does not reveal whether these plans are natural hyperaccumulators or chelating agents were used, thus, it is also difficult to compare the efficiency of phytoextraction.

Perspectives for phytoextraction

Phytoextraction is considered as perspective and cost effective technology designated to clean soil contaminated with heavy metals (Robinson et al., 2003). Although this technology has several advantages regarding chemical and physical remedy, it also has several scarcities as well. In order to overcome these disadvantages, gene engineering is evoked. It aims to create such hyperaccumulator plants that could easily fulfil desired criteria: 1) quickly growing; 2) high biomass yielding; 3) heavy metal tolerant. This can be achieved by transplanting genes that are responsible for metal tolerance and accumulation into quickly growing plants. On the other hand, gene engineering and genetically modified organisms still have a very sturdy negative response from the society (Baker and Whiting, 2002).

Another possible prospect is to combine phytoextraction technology with forestry or bioenergy production (Robinson et al., 2003). Suitable crops for this purpose such as poplar or willow trees could be incinerated or used for bio-fuel production. As it is known, heavy metals in the remaining ash are tightly bound and thus do not pose an environmental risk.

Table 2

Plants for phytoextraction available in Lithuania

Plant		Metals	References
Common English name	Latin name		
Alpine pennygrass	*Thlaspi sp.*	Cd, Zn, Ni	Lombi et al., 2001
Amaranth	*Amaranthus sp.*	Cd, Zn, Fe	Prasad and Freitas, 2003
Barley	*Hordeum vulgare*	Zn	Evangelou et al., 2007
Birch	*Betula sp.*	Zn	Pulford and Watson, 2002
Bread wheat	*Triticum aestivum*	Pb	Shen et al., 2002
Carnation, pink	*Dianthus sp.*	Cd, Zn, Pb	Evangelou et al., 2007
Common bean	*Phaseolus vulgaris*	Cu, Pb, Zn	Evangelou et al., 2007
Green pea	*Pisum sativum*	Pb	Evangelou et al., 2007
Indian mustard	*Brassica juncea*	Pb, Zn	Alkorta et al., 2004
Lettuce	*Lactuca sativa*	Cd, Cu, Zn	Kulli et al., 1999
Maize	*Zea mays*	Pb	Alkorta et al., 2004
Meadow fescue	*Festuca pratensis*	Cu, Cr, Zn, Pb, Ni	Jankaitė, 2007
Meadow grass	*Poa annua*	Cu, Cr, Zn, Pb, Ni	Jankaitė, 2007
Morning glories	*Ipomoea sp.*	Pb	Kamhapati et al., 2003
Oat	*Avena sativa*	Zn	Ebbs and Kochian, 1998
Poplar	*Populus tremula*	Cr, Cu, Zn	Pulford and Watson, 2002
Radish	*Raphanus sativus*	Cu, Fe, Mn	Walker et al., 2003
Rape	*Brassica napus*	Cu, Pb, Zn	Alkorta et al., 2004
Red clover	*Trifolium pratense*	Ni, Cr, Zn, Pb	Mikalajūnė and Jasulaitytė, 2011
Ryegrass	*Lolium sp.*	Cu, Cr, Zn, Pb, Ni	Jankaitė, 2007
Sunflower	*Helianthus annuus*	Pb	Alkorta et al., 2004
Turnip rape	*Brassica rapa*	Pb, Zn, Cd	Shen et al., 2002
Willow	*Salix sp.*	Cd, Zn, Cu	Pulford and Watson, 2002

Such HM containing ashes are often used for road building base and according to US EPA (2005) no leaching ever occurred.

Conclusions

1. Phytoextraction could be treated as a green cost-effective technology. It cannot replace traditional technologies for soil remedy but is applicable to large areas where heavy metal contamination is low to moderate level.
2. Natural phytoextraction is based on natural hyperaccumulator plants which accumulate heavy metals during the whole vegetation period, whereas chemically assisted phytoextraction incorporates acidifying as well as metal-chelating agents in order to increase HM uptake by plants prior harvesting.
3. Efficacy of phytoextraction can be expressed via 3 different parameters: bioaccumulation factor, amount of extracted metal and phytoremediation duration. However, in reality these parameters are affected by many biotic and abiotic factors, and it is difficult to evaluate them.
4. The only possible way to manage heavy metal contaminated soil in Lithuania is ex-situ cleaning (mainly 'dig-and-dump') and phytoremediation as well as other best available demonstrated technologies according to US EPA have no legal framework yet.
5. Mainly grass species were investigated for phytoextraction purposes in Lithuania. One of the most promising plants is ryegrass, capable to decrease concentrations of Cu from 20 mg kg^{-1} to 3.35 mg kg^{-1}, Pb from 5 mg kg^{-1} to 1.4 mg kg^{-1}, Mn from 12.4 mg kg^{-1} to 8.4 mg kg^{-1}, Zn from 11.5 mg kg^{-1} to 4.05 mg kg^{-1}, Ni from 3.0 mg kg^{-1} to 0.93 mg kg^{-1} and Cr from 2.3 mg kg^{-1} to 1.08 mg kg^{-1}.
6. Traditional species of cereal and vegetables grown under Lithuanian climatic and pedogenic conditions can be used for natural and especially for chemically assisted phytoextraction purposes, later on biomass can be incinerated or used for bio-fuel production.

References

1. Alkorta I., Hernandez-Allica J., Becerril J.M., Amezaga I., Albizu I., Onaindia M., Garbisu C. (2004) Chelate-enhanced phytoremediation of soils polluted with heavy metals. *Reviews in Environmental Sciences and Biotechnology*, 3, pp. 55-70.
2. Baker A.M.J., Whiting S.N. (2002) In search of the Holy Grail – a further step in understanding metal hyperaccumulation *New Phytologist*, 155, pp. 1-7.
3. Comis D. (1996) Green remediation: using plants to clean the soil. *Journal of Soil and Water Conservation*, 51, pp. 184-187.
4. Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31986L0278:EN:NOT, 11 March 2013.
5. Ebbs S.D., Koschian L. (1998) Phytoextraction of zinc by oat (*Avena sativa*), barley (*Hordeum vulgare*) and Indian mustard (*Brassica juncea*). *Environmental Science and Technology*, 32, pp. 802-806.
6. Evangelou M.W.H., Ebel M., Schaeffer A. (2007) Chelate assisted phytoextraction of heavy metals from soil. Effect, mechanism, toxicity, and fate of chelating agents. *Chemosphere*, 68, pp. 989-1003.
7. Garbisu C., Alkorta I. (2001) Phytoextraction: A cost-effective plant-based technology for the removal of metals from the environment. *Bioresource Technology*, 77, pp. 229-236.
8. Ghosh M., Singh P. (2005) A review on phytoremediation of heavy metal and utilization of its byproducts. *Applied Ecology and Environmental Research*, 3, pp. 1-18.
9. Grčman H., Velikonja-Bota Š., Vodnik D., Kos B., Leštan D. (2001) EDTA enhanced heavy metal phytoextraction: metal accumulation, leaching and toxicity. *Plant Soil*, 235, pp. 105-114.
10. Jankaitė A. (2007) Sunkiųjų metalų pakelėse tyrimai ir įtakos aplinkai įvertinimas (Research on heavy metals on the roadside and evaluation of their influence on the environment). *Doctoral Thesis*, pp. 158. (in Lithuanian).
11. Kambhampati M.S., Begonia M.F., Bufford Y. (2003) Phytoremediation of a lead-contaminated soil using morning glory (*Ipomoea lacunosa* L.): effects of a synthetic chelate. *Bulletin of Environmental Contamination and Toxicology*, 71, pp. 379-386.
12. Kulli B., Balmer M., Krebs R., Lothenbach B., Geiger G., Schulin R. (1999) The influence of nitrilotriacetate on heavy metal uptake of lettuce and ryegrass. *Journal of Environment Quality*, 28, pp. 1699-1705.
13. Kumar P.B.A.N., Dushenkov V., Motto H., Raskin I. (1995) Phytoextraction: the use of plants to remove heavy metals from soils. *Environmental Science and Technology*, 29, pp. 1239-1238.

14. Lasat M.M. (2000) Phytoextraction of metal from contaminated soil: a review of plant/soil/metal incineration and assessment of pertinent agronomic issues. *Journal of Hazardous Substances Research*, 2, pp. 1-25.
15. Lithuanian agriculture: facts and numbers 2012 (2013) Agriculture Information and Rural Business Centre. Available at: http://www.vic.lt/?mid=75, 14 March 2013.
16. Lithuanian geological survey (2008) Dirvožemis – gyvoji žemės oda (Soil – living Earth skin). 12 p. (in Lithuanian).
17. Lithuanian geological survey (2012) Annual report 2011. 130 p. Available at: http://www.lgt.lt/images/Metines%20ataskaitos/VIDINIAI.pdf, 10 September 2013. (Both in Lithuanian and English).
18. Lombi E., Zhao F.J., Dunham S.J., McGrath S.P. (2001) Phytoremediation of heavy-metal contaminated soils: natural hyperaccumulation *versus* chemically enhanced phytoextraction. *Journal of Environment Quality,* 30, pp. 1919-1926.
19. Marques A.P.G.C., Rangel A.O.S.S., Castro P.M.L. (2009) Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. *Critical Reviews in Environment Science and Technology*, 8, pp. 622-654.
20. Mikalajūnė A., Jasulaitytė G. (2011) Cleaning of soil contaminated with heavy metals using red clovers. *Proceedings of Environmental Engineering 2011: The 8th International Conference on Environmental Engineering, Vilnius, Lithuania,* pp. 221-227.
21. Miller R.R. (1996) Phytoremediations. Ground-water remediation technologies analysis center (GWRTAC)-Technology overview report TO-96-03, GWRTAC-O-Series, 26 p.
22. Order by the Minister of Environment of Lithuanian Republic (2012) Įsakymas dėl Užterštų teritorijų tvarkymo 2013-2020 plano patvirtinimo (Plan approval on contaminated land management for 2013-2020). Came in force since 4th of October, 2012, 8 p. (in Lithuanian).
23. Prasad M.N.V., Freitas H.M. (2003) Metal hyperaccumulation in plants – biodiversity prospecting for phytoremediation technology. *Electronic Journal of Biotechnology*, 6, pp. 285-305.
24. Pulford I.D., Watson C. (2002) Phytoremediation of heavy metal-contaminated land by trees – a review. *Environment International*, 29, pp. 529-540.
25. Robinson B., Fernandez J.E., Majedon P., Myranon T., Murillo J.M., Green S., Clothier B. (2003) Phytoextraction: an assessment of biogeochemical and economic viability. *Plant and Soil*, 249, pp. 117-125.
26. Sagner S., Kneer R., Wanner G., Cosson J.P., Deus-Neumann B., Zenk M.H. (1998) Hyperaccumulation, complexation and distribution of nickel in *Sebertia acuminate*. *Phytochemistry*, 47, pp. 339-347.
27. Salt D.E., Smith R.D., Raskin I. (1998) Phytoremediation. *Annual Reviews of Plant Physiology and Plant Molecular Biology*, 49, pp. 643-668.
28. Shen Z.G., Li X.D., Wang C.C., Chen H., Chua H. (2002) Lead phytoextraction from contaminated soil with high-biomass plant species. *Journal of Environment Quality*, 31, pp. 1893-1900.
29. US EPA (2005) Using coal ash in highway construction: a guide to benefits and impacts. Info national service center for environmental publications, Cincinnati. OH, 20 p.
30. Vaičikauskaitė A., Paulauskas V., Kumpienė J. (2011) Immobilisation of Trace Elements Using Alkaline Industrial By-Products. *Proceedings of Rural Development 2011: The 5th International Scientific Conference on Rural Development, Akademija, Lithuania,* pp. 462-469.
31. Walker D.J., Clemente R., Roig A., Bernal M.P. (2003) the effects of soil amendments on heavy metal bioavailability in two contaminated Mediterranean soils. *Environmental Pollution*, 122, pp. 303-312.
32. Wantanabe M.E. (1997) Phytoremediation on the brink of commercialization. *Environmental Science and Technology*, 31, pp. 182-186.
33. Wenzel W.W., Unterbrunner R., Sommer P., Sacco P. (2003) Chelate-assisted phytoextraction using canola (*Brassica napus* L.) in outdoors pot and lysimeter experiments. Plant soil, 249, pp. 83-96.
34. Wu L.H., Luo Y.M., Xing X.R., Christie P. (2003) EDTA-enhanced phytoremediation of heavy metal contaminated soil with Indian mustard and associated potential leaching risk. *Agriculture, Ecosystems and Environment*, 100, pp. 307-318.
35. Wuana R.A., Okieimen F.E. (2011) Heavy metals in contaminated soils: a review of sources, chemistry and best available strategies for remediation. *ISRN Ecology*, 20 p.
36. Zhang X., Xia H., Li Z., Zhuang P., Gao B. (2010) Potential of four forage grasses in remediation of Cd and Zn contaminated soils. *Bioresource Technology*, 101, pp. 2063-2066.
37. Zhuang P., Ye Z.H., Lan C.Y., Xie Z.W., Shu W.S. (2005) Chemically assisted phytoextraction of heavy metal contaminated soils using three plant species. *Plant and Soil*, 276, pp. 153-162.

THE DESIGN GUIDELINES FOR THERAPEUTIC SENSORY GARDENS

Linda Balode
Latvia University of Agriculture
linda.balode2010@inbox.lv

Abstract
The research topic is sensory, healing, rehabilitation and horticultural gardens, and the related discourses. The first part of the paper describes the historic development of the rehabilitation and health gardens in Latvia. Then he research paper takes a look at the main aspects which dominate in the rehabilitation and sensory visual and functional garden sites in the world. The quest to create contemporary landscape sites for health reasons is still one of the main subjects to explore and find definitions for. The methodology used in this paper is descriptive, from the perspective of historical relaxation gardens and health sites. The aim of this research is to define the main development lines of health sites in Latvia, trying to answer such questions as: How we can start developing sensory gardens and what is needed for their development in the future? To achieve the goal, it is necessary to absorb the world experience and exchange best practices, find innovative solutions, and adapt advanced rehabilitation center area landscapes to individual needs. When creating the healing gardens, the aesthetic and functional criteria have to be applied. Depending on the availability of the natural environment, health and satisfaction will be enhanced.
Key words: Horticultural therapy, Sensory gardens, Healing gardens, Rehabilitation, Sanatorium.

Introduction

The world experience shows that architecture is closely linked with other fields of science, such as, biology, mathematics, philosophy, aesthetics, psychology, physics and others. Professional and well-landscaped outdoor sites or well-designed indoor interiors can be both functionally effective and also strengthen and improve health processes – it is a new architectural trend, called 'Design and health' (Dilani, 2001). The study and analysis of how the environment affects the human and vice versa, including also the relationships between individuals and different groups, is called the environmental psychology. Both positive and negative lessons - learned from environmental psychology - are useful not only to the landscape architects, but also to designers, architects and urban planners. In the landscape architecture the design and positive health processes are intertwined in the healing or health gardens (Cooper and Barnes, 1999). There is an increased interest in human and environmental studies all over the world, and the studies reveal many interesting facts proving that a person's interaction with environment improves his or her mental and physical health. Most gardens give aesthetic pleasure, but sensory and therapeutic gardens are created to functionally reveal all five of the human senses: vision, touch, smell, taste and hearing (Fig. 1.).

The sensory gardens are developed near the kindergartens, hospitals, schools, as well as the care-homes and other medical facilities. The surrounding environment affects not only the way of thinking, but also the person's intellectual development. Already in 1810 in his book 'Theory of Colours' J.V. Goethe published the research on how optics affects human psyche. Unlike the physicist Newton, he emphasized the role of emotions and experience in how we perceive the colours (Goethe, 1810). The healing power of nature, the sun and fresh air have already been used in the previous centuries in planning and landscaping the

Source: graph created by the author (2013)

Figure 1. Examples of the five human senses.

gardens near the medieval monasteries, infirmaries, 19th century Pavilion type hospitals, 20th century shelters and sanatoriums. The plants, light, water and other nature elements can cause in a person many different feelings.

In most of the medical institutions of Latvia, the green area is obsolescent and non-functional. Latvian landscaped sites need new and innovative ideas. One of the solutions is the development of Latvian therapeutic gardens. And thus the research subject is: Therapeutic and rehabilitation gardens. The present article discusses the landscape rehabilitation areas and their functional significance in Latvia and abroad. The aim of the present research is to analyze and summarize the available historical papers, scientific research literature, publications, documents, and electronic resources on the Latvian health resort gardens, as well as the global experience of the medical treatment's impact on people. On the basis of the worldwide therapeutic gardens that are used in scientific research, the author surveyed and analyzed the newly formed Latvian therapy gardens and identified the most important features of rehabilitation and sensory gardens. The study provides a scientific research article on rehabilitation gardens in the world. It summarizes the historical and presently available documents on the Latvian current rehabilitation gardens. The author also looked into some further opportunities to create the rehabilitation gardens in the landscape sites of Latvia.

Materials and Methods

The research paper is based on international scientific studies on therapeutic gardens, as well as on the analysis of Latvian therapeutic gardens. The literature on the Latvian health resort parks, healing gardens and sensory trails has been summarized and analysed. The study has been conducted on the healing effect of the international therapeutic gardens on humans. To complete the research tasks, the articles on the history of health resorts of Latvia, scientific research literature, publications, documents and electronic media have been analysed. Using the gathered scientific information and analytical matrix, the sensory garden guidelines for Latvia have been developed. The research is based on the current development tendencies of the rehabilitation gardens, but also taking into account the historical relaxation sites. The study analyzes the rehabilitation garden literature of the period from 1800 to 2013. The study deals with two historical health resort rehabilitation gardens of this country that have already been closed, as well as four newly created gardens, that currently are the only existing ones in Latvia.

Results and Discussion

International trends in developing rehabilitation and sensory gardens

In creating health gardens and parks it is important to take into account the fact that the outdoor site needs to be a place where one can also have an aesthetic pleasure and emotional feelings. The design of outdoor site needs to be thought out, so the visitor has a strong desire to explore the garden till its last trail and plant. As every work of art, also the health garden's value is its 'open ending' for further exploration of reality. People tend to grasp a thing from all of its sides – similarly, how a person relives the nature in its body. The same way, in a rehabilitation garden it cannot be said where nature ends and a person begins (Merleau – Ponty, 1967).

The rehabilitation garden's space is traditionally divided into geometrical squares with trails and a fountain in the central part of the garden. The selection of rehabilitation garden's plants includes many plants that are daily used as herbal teas, spices, food or flowers. In the mid-20th century in western countries the healing rehabilitation gardens slowly disappeared from the medical institutions. It can be explained with the rapid development of medical and other technologies. The gardens located near the medical institutions were made smaller, to give space to the car parks in their territory. Balconies and terraces were replaced with modernized ventilation equipment. Due to the rapid industrial development the medical institutions lost the beautiful sceneries that could be seen out of their window. The urban landscape was booming and the nature, its healing power was left forgotten. After the Second World War the hospitals were designed as multi-story buildings, not as Pavilion-type buildings. More emphasis was put on the comfort of hospital's staff, not patients (Gerlach –Spriggs et al., 1998). In the 21st century the medical institution gardens were made based on technologically advanced equipment, ignoring the emotional needs of patients, their families and staff to mentally recover in an outdoor site (Cooper and Barnes, 1999).

In the recent years there has been an increasing tendency to develop the sensory or therapeutic gardens near the medical facilities. Discussions with the patients reveal their longings for the nature's beauty, countryside's peacefulness – bird songs, smell of soil and flowers. Many of them are locked in the medical facilities or their homes without a chance to enjoy the things that for healthy people are self-evident. It is also important for people with various disabilities as they get to explore the world through touch, hearing, taste and smell. Only in silence when enjoying the

God's given richness and mightiness of the nature, and feeling the seasonal changes, a person can relax from the urban environment, find peace and spiritual balance. The aesthetical and sensory enjoyment of the rehabilitation and therapeutic gardens helps these people to return to social life. These kinds of projects are already known to other countries. The most common types of therapeutic gardens are: Alzheimer's, healing, rehabilitation, cancer patients' and meditation gardens etc. The rehabilitation gardens are specially designed to intensify the particular senses that patients need. Many of these gardens have separated zones – for different age groups, treatment specifics or sensory stimulus. Those separated zones have different design techniques, flowers, aromatic herbs, trees and bushes. In the ancient Rome it was popular to plant different medical plants near the soldier medical facilities. Every plant had its own function and therapeutic effect. The fennel (*Foeniculum vulgare* L.) was used as a sedative, the garlic (*Allium sativum* L.*)* improved the functions of the heart, the willows were used as an antiseptic, but the sage (*Salvia officinalis* L.) who was less therapeutic had a religious meaning. In the Roman military hospitals the key role to recovery was given to the courtyard, fresh air and physical activity (Umbani, 2011). The sensory gardens should have benches, lighting and for physically disabled people – heightened plant beds. The recommended height for the heightened plant beds is 0.75 m, with a place for the legs – 0.5 m. The plant beds should be accessible from all sides. The heightened plant beds, vertical plant walls, pots and containers will also help people in wheelchairs to participate in the gardening – to sow, to weed and take care of plants. For blind or visually impaired people it's important to have the information on objects in Braille. The sensory gardens have trails with different types of pavement. The recommended width for trails is for 1 person – 1.40 m, and for two people – 1.90 m. If it's not possible to have the recommended width, then after every 100-200 metres there should be a square of 1.80×2.0 m. The pavement should be non-slip, safe and with a normal slope. For the safety reasons there should be handrails with size of 0.70 and 0.90 m. The New Zealand transport strategy (NZTS) has defined the provisions for improving the standards and design of the pedestrian sites. The strategy includes world's best practices in planning, designing and maintaining the pedestrian infrastructure networks. The trail infrastructure strategies have been developed also in Australia, the United States and in many other countries (Land Transport NZ, 2009).

Besides the high quality trails the other four most important elements in the garden are – the shed (especially for Alzheimer's patients), separating walls, relief and water. The water plays a key role in the healing gardens. In the summer it keeps the air nicely cool and moist, creating sounds and senses. A fountain can be in the garden as a landmark. It is recommended to have a separating wall or fences in the healing garden or park. The walls secure the patients' physical and mental safety, reducing also the risk of getting lost in the garden (Beckwith and Gilster, 1997). In Persia the walls in the gardens were used to keep the fragrances of roses (*Rosa* L.), jasmine (*Jasminum* L.) and fruit trees (Hobhouse, 2003). In the sensory gardens you need to be careful with plants that have strong fragrances, as well as flowers that have a lot of pollen or flying seeds. To evade the hay fever or asthma, it is recommended to choose plants that are pollinated by birds or insects and aren't self-pollinating plants. The blind people can touch everything in the garden, and with the help of Braille to learn about the sites or the plants. The garden offers to smell and hear freely – it's a possibility to relax. Many international research papers have analysed the positive effects of these gardens. The United States have many good examples of rehabilitation gardens that are overseen by the American Society of Landscape Architects (ASLA). Since 1999 there is also an online database of therapeutic landscapes (Therapeutic Landscapes Network, 2013). American studies have proven that gardens improve the relations between nurses and patients (Lappe, 1987). Similar studies in Japan show that even in a relatively short time period (two months) the patients' self-esteem and cognitive functions increase (Endo, 2003; Nomura and Hashimoto, 2006).

Rehabilitation and sensory gardens in Latvia

The sensory gardens that are located near the rehabilitation facilities are called the healing or therapeutic gardens. The landscaped environment of the therapeutic gardens is specially designed for people with physical or mental disabilities, for small children to develop their feelings and senses, and for elderly, hospital patients, as well as for the visitors and staff. The goal of the rehabilitation and healing gardens is to improve person's health and well-being, to advance the recovery with the help of interaction with the nature. In the fast-paced and exhausting day-to-day life, it is important to find time for the relaxation and recuperation. Relaxation and treatment in a site rich with natural healing resources shortens the time necessary for medical rehabilitation and recuperation of the human body. The research and written evidence dating back to the 15th century show that sulphur springs in Baldone health resort had many healing qualities that gathered patients from all over the country. Baldone sulphur spring health resort was located relatively high above the sea level, where the

air is dry and rich with ozone. The area had many hillocks that heart disease patients could use for the exercises. Since 1992 Baldone resort is closed and the use of mineral waters has stopped (Kūrorts, 2010). The Kemeri resort has also been closed since 1994. The Kemeri resort was opened in 1838. In 1801, in St. Petersburg for the first time a chemical test was made for the Kemeri sanatorium sulphur springs. Soon after that the test results of Latvian-born chemist, pharmaceutist and nature scientist David Hieronim Grindels were published. The health resort offered mainly the hydrogen sulphide and mud baths, but also the regimen and silence helped the patients to recover faster. In the territories of Latvian health resorts there also were landscaped parks for walking and relaxation that helped to recover faster (Sarma, 2008).

The Bruknas manor is located in Davini parish, Bauska region, by the shores of Iecava river. Since 2001 the historical building is a home for 'Mount blessing community' and the cultural centre 'Bruknas manor'. 'Mount blessing community' is a mental and physical rehabilitation site for people suffering from addictions. In 2006 the community introduced a drama therapy method that relaxes the body and mind from the tension. Using different exercises and creative tasks, drawing and writing, it is possible to analyse the persons' feelings and determine what is depressing them. The community is based on the drug addiction community 'Senacolo' model – this community is located in Medjugorje, Bosnia and Herzogovina, and its spiritual patronage is Mother Teresa from Calcutta. The main problem for the addicts is not the drugs, alcohol, gambling and other addictions, but rather the lack of will to live. In 2007 the 'Mount blessing community' in a project tender received the financing and in manor's park developed a Renaissance-style garden. The garden's symmetrical squares are made from decorative vegetable and herbal plants. The crops are changed every year, thus symbolizing the changeability of the world. The idea of this kind of layout for the garden came from the Italian monastery gardens from 15th and 16th century. In the 6.7 ha manor territory is located not only the landscaped park with Renaissance-style geometrical garden, but also ponds, 6.9 ha of pastures, fruit and berry garden. The nature, seasonal changes, liturgical rhythm of time, prayers, work in the garden, maintaining and renovating the Bruknas manor help people to purify and return back to normal life. Through spiritual guidance and work therapy people can find again the meaning in life and get rid of various addictions (Ušča, 2008).

Rehabilitation gardens help to bring back the joy of life not only for the people suffering from various addictions, but also to severely and terminally ill patients. Liepaja Society of the Blind unites more than 480 visually impaired and blind people, as well as the people with different kind of disabilities from Liepaja and 11 Kurzeme regions. The organization focuses on the rehabilitation, employment, education, accessibility and other isues related to the persons with disabilities and their social inclusion. In 2011, in Ziemupe, Pavilosta region the construction works began to develop the "Garden of Soul Relieve". In the farm 'Laivenieki' and its 6 ha territory, from which 1.3 ha is forest. It is planned to develop a site where people with special needs can relieve their soul, relax, meet and communicate with other people in a peaceful and harmonious countryside environment. The 'Garden of Soul Relieve' will be developed based on patients' senses (vision, hearing, smell, taste, touch, proprioceptive senses). The specially developed landscape design and innovative ideas based on patients' previous experiences and memories will help to fasten the recovery. It is planned to create a pond with sandy waterfront and a sauna, with places for swimming and fishing. A few kilometres from the farm there is the Baltic sea, giving an additional value. The garden will be a unique environment for people whom their disabilities have deprived of the possibility to enjoy the nature's beauty (Dvēseles Veldzes Dārzs, 2012).

On May 27, 2012 the sensory trail 'Juši' was opened in Ligatne national park, Sigulda. In the planning of this trail participated both experienced landscape artists and children, and youngsters from Sigulda region Creativity Centre in which a young researchers team called 'Juši' has been created. Experts from the Nature Conservation Agency and Gauja National Park Foundation, as well as Sigulda region Creativity Centre worked on the development of the sensory trail. The project was supported by the culture, environment and tourism agencies. The main idea of 'Juši' project is to encourage children's interest and give them a possibility to explore this world through their feelings. The goal is to give the children and youngsters a chance to spend their free time innovatively and creatively, and acquire knowledge that later might be useful in the study process. In the modern technological world all that children and adults need is accessible by computer or mobile phone. Our cognition process ends there. But a person has also his senses that allow him to see, explore, understand and feel the world. To maintain those senses they need to be trained. At the beginning of the trail, behind the Sigulda New Castle pond, you can see the 'Juši' trail map created by the artist Iveta Īle. Through the entire route there is guidance near the sensory objects and what kind of senses can be experienced near them. In the near future it is planned to develop the trail further

and introduce many new ideas and designs (Zālīte, 2012).

In May 2013, in Valmiera the development works will begin in the territory of Gauja steep coasts, where the Olympic centre plans to create the 'Gauja Steep Coast Sensory Park'. Valmiera Olympic centre has the management rights over 349 314 m² territory until December 31, 2017 – it includes 159 314 m² of 'Steep coasts' and 190 000 m² of 'Recreation park'. Two trails are planned to develop in the park with the total length of 3.3 km. The park will be for people of all ages, starting from small children up to seniors. The 'Gauja Steep Coast Sensory Park' will offer a possibility to experience nature with all of the five senses: hearing, vision, touch, smell and taste. In the 'Senses trail' it will be possible to feel with bare feet different kind of natural material coverings (pine (*Pinus sylvestris* L.) cones, needles, moss (*Bryophyta* L.), pebble stones, sand, chestnuts (*Castanea* L.) etc.). It is planned to have in the park constructions that help to train the balance, as well as the 'Educational trail', in which the visitors will be able to explore the local flora and fauna. In cooperation with ornithologist Andris Klepers there will be developed an observation site for the martlets (*Apodiformes* L.) – birds of the swallow (*Hirundo rustica* L.) family. The sensory park will also have the 'Nature school' – it will be a green classroom both for nature teachers and students to learn in an open air. The park is located next to the Sport Rehabilitation centre, where people can do sports, swim in the pool, relax in the sauna and enjoy the healthy herbal teas (Gaujas Stāvo krastu Sajūtu parks, 2013). Latvia has many natural countryside landscapes, forgotten traditional farms, manor parks, social care homes, kindergartens and Soviet period green territories near the schools that are outdated, non-functional, but may serve as a foundation for the development of new sensory and rehabilitation gardens (Fig. 2.)

Psychological support is formed not only in the social attitudes, but also in the environment in which the person lives. The visit to this garden develops not only feelings and senses of small children and teenagers, but also enables residents of any age with various disabilities to spend their free time interactively. The old school neighborhoods have become mentally and physically outdated landscape. Old manor parks are the cultural heritage of this country and an important tourist sites, but without innovative ideas they are stagnating. To continue the development of this kind of projects in Latvia, it is necessary to do a more detailed research on the planning, designing and maintaining of the rehabilitation and sensory gardens.

Conclusions

In the world and also in Latvia there is a growing interest in the studies of people and environment that show how the relations between these two factors improve the human health. The selection of the location plays an important role when creating the rehabilitation garden. How can we start developing sensory gardens and what is needed for their creation in the future? To achieve the goal, it is necessary to absorb the global experience and exchange the best practices, to find innovative solutions, and adapt the advanced rehabilitation center area landscapes to individual needs. The garden will be more effective and beneficial if it is located near the sea, a river, or a healing source. Furthermore, the proximity of the forest and fresh air is an integral part of rehabilitation garden ingredients. Latvia has natural landscapes,

Source: graph created by the author (2013)

Figure 2. Health gardens development opportunities for Latvia.

many healing springs and mud deposits, countless well-preserved traditional Latvian farms, historical manors and parks that could be used for the development of sustainable rehabilitation and therapeutic gardens. While doing the research on sensory gardens we have to take into account this important factor – the climate of Latvia. Most of the existing gardens are located in the countries with warm climate. We have to search for appropriate plants, trails, square structures and other elements that can be used in the local climate. In the Baltic Sea region a good example can be found in Alnarp, Sweden, where in the territory of the Swedish University of Agriculture Sciences there has been developed a rehabilitation garden with different garden areas to treat people in distress. Before building rehabilitation or sensory gardens in Latvia, it is important to define the target audience. After finding the appropriate location we have to identify the needs of potential visitors. Whether they are small children, hospital patients or seniors from care homes – every group has its landscape vision and viewing angle. For Latvia to have the development of rehabilitation gardens we must have an overseeing organization that would gather and coordinate the newest tendencies and search for the funding.

References

1. Beckwith M.E., Gilster S.D. (1997) The paradise garden: A model garden design for those with Alzheimer's disease, Activities, Adaptation and Aging, New York: Haworth,Vol. 2, 22, (1-2), pp. 3-16.
2. Cooper M.C., Barnes M. (1999) Healing gardens: Therapeutic benefits and design recommendations. *John Wiley and Sons*, New York, pp. 27-86.
3. Dilani A. (2001) Design and health – The therapeutic benefits of design. Stockholm: AB Svensk Byggtjänst, pp. 31-38.
4. Dvēseles Veldzes Dārzs (Soul Refreshment Garden) (2012) Projekts. Liepājas neredzīgo biedrība (Liepaja Association for the Blind). Available at: http://www.redzigaismu.lv/lat/jaunakie-projekti/projekts-dveseles-veldzes-darzs/, 18 March 2013. (in Latvian).
5. Endo H. (2003) Change of dementia care management after implementation of long-term care insurance. Clinical neurology, *Rinsho Shinkeigaku*, Japan, 43 (11), pp. 788-790.
6. Gaujas Stāvo krastu Sajūtu parks (Gauja steep coast senses park) (2013) Valmieras District Council. Available at: http://www.valmiera.lv/zina/par-valmieru/veidos-gaujas-stavo-krastu-sajutu-parku-valmiera, 7 March 2013. (in Latvian).
7. Gerlach - Spriggs, Kaufman R., Warner Jr. (1998) Restorative Gardens: The Healing Landscape. New Haven, *Yale University Press*, CT and London, 5 p.
8. Goethe J.W. (1810) Zur Farbenlehre (Theory of Colours). In: J. Naydler (ed.), *Geothe on Science: Anthology of Goethe's scientific Writings* (1996), *Floris Books*, Edinburg, 116 S. (in German).
9. Hobhouse P. (2004) Gardens of Persia. Carlsbad, *Kales Press*, California, 192 p.
10. Kūrorts (Resort) (2010) Baldone District Council. Available at: http://www.baldone.lv/Lapas/N_Kurorts.htm, 10 April 2013. (in Latvian).
11. Land Transport NZ (2009) Pedestrian planning and design guide. *NZ Transport Agency WOKA KOTAH*, 188 p.
12. Lappe J.M. (1987) Reminiscing: The Life Review Therapy. *Journal of Gerontological Nursing*, 13 (4), pp. 12-16.
13. Merleau - Ponty M. (1967) Signes, *Gallimard*, Paris, 234 p.
14. Nomura N., Hashimoto T. (2006) *Group reminiscence therapy for Japanese elderly community. Shinrigaku Kenkyu*, Japan, 77, pp. 32-39.
15. Sarma I. (2009) Ķemeru kūrorta vēsture (Ķemeru resort history). *Jūrmalas Kūrorta Ziņas (Jurmala Resort Messages).* Pavasaris – vasara, 4. lpp. (in Latvian).
16. Therapeutic Landscapes Network (2013) Available at: http://www.healinglandscapes.org/about/history.html, 20 March 2013.
17. Umbani L.U. (2011) Preventive therapy in Complementary Medicine. Xlibris Corporation, USA, pp. 453-455.
18. Ušča A. (2008) Bruknas muiža piedzīvo straujas pārmaiņas (Bruknas Manor is experiencing rapid change). Available at: http://www.pilis.lv/c_zinas/zinja.php?id=2997, 3 April 2013. (in Latvian).
19. Zālīte R. (2012) Siguldas novada Jaunrades centrs 'Juši' (Sigulda Regional Innovation Centre 'Jusi'). Available at: http://old.vidzeme.com/i.php?v=lat&jid=2016, 2 May 2013. (in Latvian).

THE LATVIAN LANDSCAPE AS SEEN FROM THE ROAD

Kristīne Vugule
Latvia University of Agriculture
Kristine.Vugule@llu.lv

Abstract
Roads play an important role in our daily surroundings and provide access to landscape. Views from the road create the first impression about the country. It is important to pay attention to the landscapes along the roads used by tourists. The purpose of this study was to obtain general overview of the current state, identify existing and disappearing features of the road landscape in Latvia. Research on road landscape perception and design is well developed in the USA and some countries in Europe. The assessment of the current state and proposals for the road landscape development in Latvia are fields which are little discussed and need more attention. The research was carried out in several sections of the main roads and some sections of regional and local roads in July and August, 2011 and August, 2012. Photography method was used. Analysis of the results shows that the main reasons of aesthetic quality loss in road landscapes is lack of planning and management, indicating the necessity to find ways for rural landscape quality enhancement.
Key words: road, landscape quality.

Introduction

Nowadays roads play an important role. Intensity of the main road use in Latvia increases by 4% per year (Latvijas ilgtspējīgas..., 2010). Besides serving as transport corridors, roads bring tourists from other countries. Many of the landscapes are seen from the road; thus, views from the road generate the impression about the whole country. With the development of tourism industry, the number of tourists visiting Latvia increases every year (Tūrisms - galvenie..., 2013). The Latvian Tourism Marketing Strategy (Latvian Tourism..., 2010) foresees the development of trans-border cooperation to sell all three Baltic States as a joint travel destination. It is important to pay attention to the landscapes along the roads used by tourists in Latvia in order to achieve the goals regarding the integrated tourism, culture, health and nature infrastructure services set in the Sustainable Development Strategy of Latvia 2030 (Latvijas Republikas..., 2010).

The research on the road landscape perception (Appleyard et al., 1964; Steinitz, 1990; Garré et al., 2009; Denstadli and Jacobsen, 2011), assessment methods (Brown, 2003; Matijošaitienė, 2010; Ramírez et al., 2011), classification (Grazuleviciute-Vileniske and Matijosaitiene, 2010) and design has been well developed in the United States of America and some countries in Europe. National road authorities offer landscape design and treatment guides for the road landscapes (Beautiful Roads..., 2002; A Guide..., 2005). The planning strategies for the road landscapes have been developed in some countries. For example, Denmark has the structural concept for the motorway environment. It explicates the generic policy on panoramas and motorway zones in the National Spatial Planning Act to protect the Dutch motorway panoramas (Piek et al., 2011).

There are regulations (Ceļu projektēšanas..., 2000) and methodology for the new road design and the old road reconstruction, the law on road use, management and development (Likums par..., 1992) in Latvia, but they do not influence and deal with the road landscape on a larger scale. The assessment of the current state and proposals for the road landscape development in Latvia are fields, which need more attention.

According to their importance, roads in Latvia are classified into state roads, municipality roads, business company roads and farmstead roads. State roads are divided into main, regional and local roads. State roads and road partition zones are the property of the Republic of Latvia and are managed by the state holding company 'Latvian State Roads'. Municipality roads are owned and managed by the municipalities, enterprises, whereas private roads are managed by their owners (Likums par..., 1992). Territories along the roads are owned by individuals, enterprises, municipalities and each of them plans the development and management of their properties in different ways. A variety of interests, uncoordinated planning and management result in the loss of landscape's aesthetic quality.

There are few regulations regarding the road side management in the Latvian law on protection belts. Some municipalities have identified scenic roads in their development plans (Rīgas rajona..., 2008). Neither legislation nor regulations can create beauty or attractive roads; however, it can help to improve the necessary conditions and potentials for incorporating aesthetic aspects into road design indirectly. The overall strategy of the landscape development along the roads in Latvia is missing.

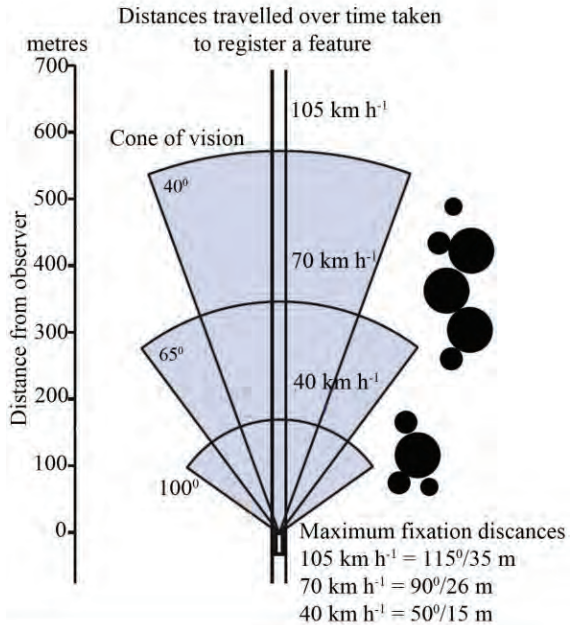
The aim of the research was to look at the current state of landscapes seen from the road, identify existing and disappearing features of road side

landscape, define problems and gather materials for further research on this topic.

Theoretical background of the road landscape definition and road landscape perception

In this study, road landscape is seen as a view from the road with all the surroundings. Visual perception zone from the road can be of different width. It depends on relief, the placement of forests and their distance from the road. Taking into account the vision possibilities of humans, the road landscape was considered to be 1 km to each side from the central axes of the road. Road side consists of foreground, formed by objects up to 25 – 30 m from the road side, middle ground, which is 130 – 150 m from the road side and background (Melluma and Leinerte 1992). The relationship between the mobile road user, the driver and the passenger within the vehicle and the roadside landscape is more complex than relationship between a person who views the landscape from a stationary position. Certain features of the landscape can only be viewed at a particular speed (Figure 1).

The speed at which the driver travels determines how far ahead, in what duration, and at what angle it is possible to focus on and appreciate the landscape. Roadside landscape elements are perceived gradually, on a move, in different angles. This is an important point for the road landscape evaluation.



Source: after Bell (1997)

Figure 1. Distance travelled over time taken to register a feature.

Materials and Methods

Filed survey took place in July and August, 2011 and August, 2012. It was carried out on sections of the main road E-77 Meitene – Jelgava – Riga, sections of E-77 road Rīga – Cēsis, E-22 Rīga – Rēzekne, A-6 Rīga – Daugavpils, E-22 Jelgava – Ventspils (Figure 2) and on some sections of regional and local roads.

Main roads were chosen as they are used by tourists travelling through Latvia and visiting the Baltic States. Considering former research on road landscape assessment in other countries (Denstadli and Jacobsen, 2011; Ramírez et al., 2011), a photography method was chosen. Most of field study photos were taken from the passenger's seat at the average driving speed of 90 km per hour in a driving direction to the right side of the road. Pictures were taken during the day time on both driving directions. Canon EOS 60D camera was used. Viewpoints were not mapped, while pictures were taken on the move. The aim of the field survey was to get general overview of the present state and select shorter sections for future research and monitoring. Photos from the road E-77 section from Meitene to Jelgava were taken using a 1.5 m high tripod, which is similar to the passenger eye height. Viewpoints from this section were marked on an aero photo map.

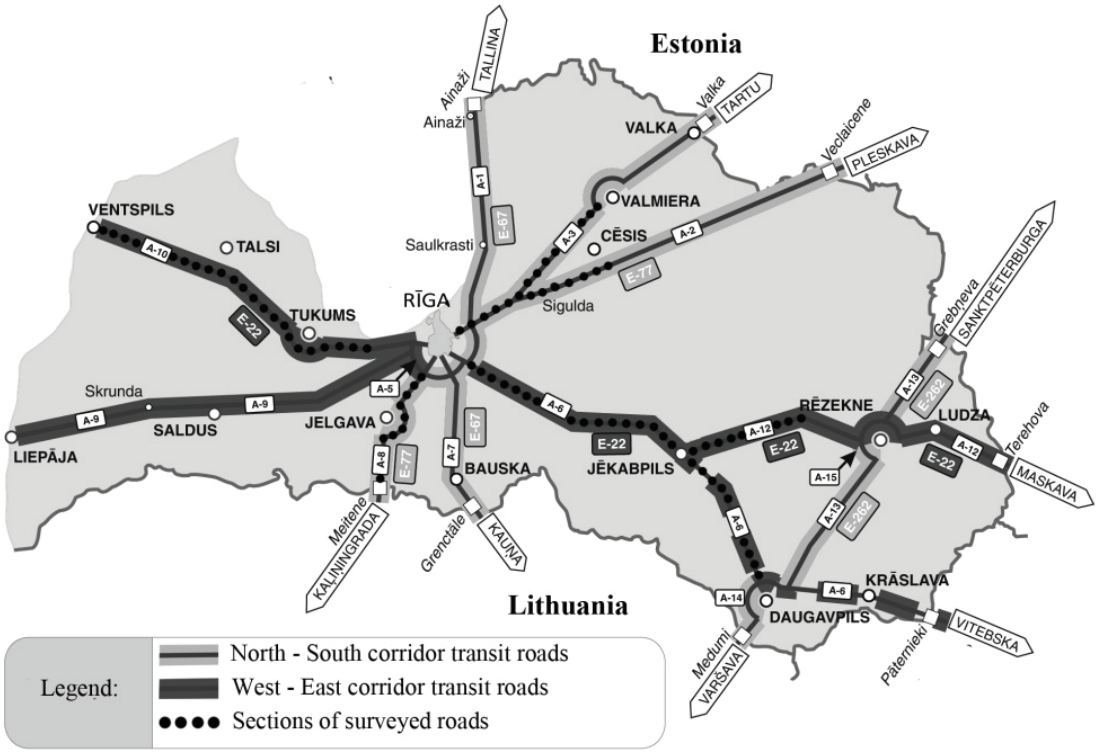
Landscape elements were analysed according to the distance from the road and were grouped into point and line elements according to their size and form. Road landscapes were analysed according to their types of use: agriculture landscapes, forest landscapes and mosaic landscapes, where forests change with open agriculture fields, pastures or meadows.

Results and Discussion

Landscape elements in foreground

The following point elements were observed: old trees, stork nests on electricity poles, road signs, road utility houses and other buildings. The most significant differences between these elements are on those sections of the roads were road reconstruction work has taken place recently. In these sections road utilities are in better condition, old Soviet time bus stops have been changed to more modern, but minimal facilities. Most of the houses close to the road are in poor condition or abandoned. This was noticed on all roads. It would be necessary to carry out the survey of residents to find out the reasons for this situation.

The following line elements along the roads were observed: ditches, protection plantings, safety walls and sound protection fences, electricity lines, tree avenues. Grass along the road sides is cut several times per summer, but ditches often are overgrown



Source: by author on the map of the Traffic Ministry (Valsts autoceļu..., 2001)

Figure 2. Sections of the road landscape field study.

Source: by author (2012)

Figure 3. Unmanaged road protection plantings along the road E-77 Meitene – Jelgava.

with bushes and block the view to the landscape behind. This raises the question about the ownership, owners interests, capacity and wish to manage the property. Most of the problematic situations were noticed on the border between the state property and private owners.

Protection plantings are in different conditions, mostly unmanaged for a long time (Figure 3).

Monotonous protection plantings continue for several kilometres in some road sections. (Figure 4 and 5). Visibility is one of the main landscape quality values. Unmanaged protection plantings and ditches with overgrowing vegetation damage the aesthetic quality of the landscape.

Different style and quality fences and safety walls dividing private houses from the road appear close to the road.

The use of noise barriers and other structures should also be sensitively treated and integrated to avoid simplifying and narrowing down the field of view of the road user. Visual field treatments should not be homogeneous and appear disconnected from the existing landscape. Large extensive areas of the roadside landscape should not be perceptually monotonous, and screening treatments should not create unnatural looking, simplified and repetitive vegetation patterns (National Roads..., 2005).

Tree avenues and rows of different age oaks (*Quercus robur* L.), lime trees (*Tilia cordata* Mill.) and sometimes other tree species are present in the

Source: by author (2012)

Figure 4. Continuous protection plantings along the road E-77 Meitene – Jelgava.

Source: by author (2012)

Figure 5. The hidden view to the agricultural landscape behind the protection plantings along the road E-77 Meitene – Jelgava.

Source: by author (2012)

Figure 6. Tree avenue on the road A3 Riga – Valmiera.

roadside landscape (Figure 6). Sixty tree avenues are protected by law (Noteikumi par..., 2005a), the rest are endangered in the case of road reconstruction. Road planning and managing authorities consider tree avenues as dangerous and tend to remove them. It is argued by some landscape architects and planners. This landscape feature was once widespread across Europe and draws on a long and rich heritage. It offers numerous benefits for the landscape and the environment, and also for safety and economic terms (Pradines, 2009).

The research on the value of Latvian rural landscape shows the importance of such elements as detached farmsteads, old oak trees (*Quercus robur* L.), stork (*Ciconia ciconia)* nests, avenues or rows of oak and lime trees (*Tilia cordata* Mill.) in traditional Latvian countryside landscape (Bell et al., 2007). The retention and incorporation of locally distinctive features promote regional identity including orientation, or a sense of place, for the road user within the road corridor.

Landscape elements in the middle ground and background

The following elements were observed in the middle ground: solitary trees, farmsteads, new villages, remnants of Soviet time farms, advertising billboards .

Solitary trees in the fields from the former farmsteads are typical to the Latvian countryside and can be visually lost in cases of field overgrowing with bushes. Houses further from the road are in better condition than the ones in foreground. House owners often do not pay any attention to the view of their property from the road. Farming equipment, unnecessary household things are stored away from the owner's eyes but in the sight of road users.

New villages close to cities appear in the landscape. It is seen that new houses are built. They bring in new elements and variety in the landscape, but the lack of planning and design which does not harmonize with their surroundings often cause negative visual impact. Recent research on this topic shows that new family house villages bring visual, aesthetical, structural and functional changes into the landscape and there is a need for tools of landscape ecology and sustainable landscape planning for designing the interior landscape compositional space of the new private house territories (Zigmunde, 2010).

Half demolished, individual farms or buildings of the collective farm (kolkhoz) period as the evidence of our history still exist in the countryside. These buildings need a new function or have to be removed.

Advertising billboards appear close to cities, villages or separate objects connected with tourism. Distance of placement is at least 30 m from the road (Noteikumi par..., 2005b). Advertisements in so low density as observed in the study do not lower the landscape quality.

Tendencies in agriculture landscapes seen from the road

Photography method allows noticing general tendencies and processes in the landscape, spot separate features. Most remarkable and positive trend is returning of herds to landscape. Driving along the countryside, one can notice cows (*Bos primigenius Taurus)*, horses (*Equus caballus)*, sheep (*Ovis aries)* and goats (*Capra aegagrus hircus)*. Cattle are the best open landscape managers. The area of pastures

and meadows has increased from 605,7 thousand hectares in the year 2000 to 651,2 thousand hectares in the year 2011 (Pļavas un..., 2013). Due to changes in land management techniques hay racks change to hay rolls (Figure 7). Such elements as milk can stands disappear. New crops like rape and cornfields appear.

Typical Latvian countryside landscape is associated with cultivated fields, country estates without hedges or fences (contrary to those in other parts of Europe) (Bell et al., 2007). Keeping open view to agriculture landscape is essential in road landscape design, as well as creating and maintaining views towards the attractive components of the landscape and managing the edges along the road.

Tendencies in forest landscape seen from the road

Clear cuttings with free standing ecological trees are the most noticeable features in the forest road landscape. Contrasts between the forests, open areas and few lonely trees are so high, that it has negative visual impact. There are only a few clear cuttings along the road E-77 Riga – Sigulda where the landscape design principles have been applied. There is available some information on forest landscape design (Bell and Nikodemus 2000), but it is not

Source: by author (2012)

Figure 7. Hay rolls. Road E-22 Riga – Tukums.

Source: by author (2012)

Figure 8. Overgrowing of agriculture land, the road A-3 Valmiera – Riga.

used in practice very much. Forest covers 50.9% of the country's territory according to the State Forest Service data. Forest landscapes are often seen from the road and there is large potential to enhance them by the application of landscape design principles.

Tendencies in mosaic landscape

Field study shows that agriculture land overgrows with bushes and trees, while forest areas expand (Figure 8). This corresponds to the research about patterns of afforestation on abandoned agriculture land in Latvia (Ruskule et al., 2012).

Abandonment of agriculture land and subsequent natural afforestation have been common features of the contemporary Latvian rural landscape, particularly in the period since 1990. This process affects the structure, ecology and visual qualities of the landscape.

According to the research of Z. Peneze, Latvian people are not indifferent to the processes taking place in the countryside landscape. The countryside in general is associated with nature, forests, agriculture fields and fresh air. When asked about the characteristic features of the Latvian countryside in the 21st century, respondents paid most attention to overgrowing of agriculture land, forest cutting, left farmsteads and poor quality roads. Overgrowing is evaluated as a negative trend (Penēze, 2009). It is a problem which needs attention in future. Latvia has ratified the European Landscape Convention, which emphasizes the importance of landscape in the formation of local cultures. Landscape is the basic component of the European natural and cultural heritage, contributing to human well-being and consolidation of the European identity (Likums par..., 2007). It is necessary to find the ways for rural landscape quality enhancement.

Conclusions

Results of the research show that landscape reflects priorities and life style of today`s society and economic status of the state. Functional solutions and economic issues are the basis for today`s landscape development. Following problems were detected -open landscapes and views from the road are formed chaotically; objects with historical and cultural value start to disappear from the zone of visibility, thus decreasing the visual quality of landscape and losing identity of the place. A negative trend is the disappearance of long distance views as a result of field overgrowing and afforestation. New landscape elements bring variety to the landscape in territories were new houses have been built, but it does not lead to higher aesthetic quality in all cases.

Landscape development is influenced by the state policy in agriculture, forestry and rural development. Disharmonised policies in these fields lead to chaotic landscape development.

It is necessary to raise importance of this question and think about the landscape development conception at all levels – local municipality, region, state as well as establish specific instruments to regulate the activities of land owners in future. It is necessary to find the best way to talk to land owners, show the importance of problems and propose possible solutions. Besides the state road development and management plan, there is a need for road landscape preservation and development policy.

References

1. Appleyard D., Lynch K., Myer J.R. (1964) *The View from the Road*, MIT Press, Cambridge, MA, 64 p.
2. Bell S. (1997) *Design for Outdoor Recreation*, Spon Press, London, UK, 261p.
3. Bells S., Nikodemus O. (2000) *Rokasgrāmata meža ainavas plānošanai un dizainam* (Handbook for Design and Planning of Forest Landscape). Valsts meža dienests, LTS International Ltd., Rīga, 75 lpp. (in Latvian).
4. Bell S., Penēze Z., Nikodemus O., Montarzino A., Grīne I. (2007) The value of Latvian rural landscape. In: *European Landscapes and Lifestyles: The Mediterranian and beyond.* Edicoed Universitarias, Lusofonas, Lisbon, pp. 347-362.
5. Brown G. (2003) A method for assessing highway qualities to integrate values in highway planning. *Journal of Transport Geography*, 11(4), pp. 271-283.
6. *Beautiful Roads - A Handbook of Road Architecture* (2002) Danish Road Directorate, Copenhagen, Denmark, 63 p.
7. Denstadli J.M., Jacobsen S.Kr.J. (2011) The long and winding roads: Perceived quality of scenic tourism routes. *Tourism Management*, 32(4), pp. 780-789.
8. Garré S., Meeus S., Gulinck H. (2009) The dual role of roads in the visual landscape: A case-study in the area around Mechelen (Belgium). *Landscape and Urban Planning*, 92(2), pp. 125-135.
9. Grazuleviciute-Vileniske I., Matijosaitiene I. (2010) Cultural Heritage of Roads and Road Landscapes: Classification and Insights on Valuation. *Landscape Research*, 35(4), pp. 391-413.
10. Latvijas ilgtspējīgas attīstības stratēģija līdz 2030. gadam (Sustainable development strategy for Latvia ill the year 2030) (2010) Latvijas Republikas Saeima. Available at: http://www.latvija2030.lv/upload/latvija2030_saeima.pdf, 3 March 2013. (in Latvian).

11. Tūrisms - Galvenie rādītāji (Tourism – Main indices) (2013) Latvijas Republikas Centrālā statistikas pārvalde. Available at: http://www.csb.gov.lv/statistikas-temas/turisms-galvenie-raditaji-30322.html, 3 March 2013. (in Latvian).
12. Pļavas un ganības (Meadows and pastures) (2013) Latvijas Republikas Centrālā statistikas pārvalde. Available at: http://data.csb.gov.lv/Dialog/Saveshow.asp, 3 March 2013. (in Latvian).
13. Ceļu projektēšanas noteikumi (Road design regulations) (2000) Latvijas standartu katalogs. Availabe at: https://www.lvs.lv/lv/services/catalogue/standardListByICS.asp?ics=426, 9 March 2013. (in Latvian).
14. Latvian Tourism marketing Strategy 2010 – 2015 (2010) Latvian Tourism Development Agency. Available at: http://www.tava.gov.lv/sites/tava.gov.lv/files/dokumenti/strategiskie-dokumenti/Latvian-tourism-marketing-strategy-2010-2015.pdf, 9 March 2013.
15. Likums par autoceļiem (1992) (Law about roads). LR likums. Available at: http://www.likumi.lv/doc.php?id=65363, 3 March 2013. (in Latvian).
16. Likums par Eiropas ainavu konvenciju (2007) (Law about European Landscape Convention). LR likums. Available at: http://www.likumi.lv/doc.php?id=156001, 3 March 2013. (in Latvian).
17. Matijošaitienė I. (2010) Identification of Hedonomic Road Landscape in Lithuania. *Environmental Research, Engineering and Managemenet, 4*(4), pp. 72-78.
18. Melluma A., Leinerte M. (1992) *Ainava un cilvēks* (Landscape and Human). Avots, Rīga, 176. lpp. (in Latvian).
19. A Guide to Landscape Treatments for National Road Schemes in Ireland (2005) National Roads Authority Available at: http://www.nra.ie/Publications/DownloadableDocumentation/Environment/file,3481,en.pdf, 9 March 2013.
20. Noteikumi par aizsargājamām alejām (2005a) (Regulations about protected tree avenues). MK noteikumi Nr. 888. Available at: http://www.likumi.lv/doc.php?id=123129, 3 March 2013. (in Latvian).
21. Noteikumi par reklāmas objektu vai informācijas objektu izvietošanu gar ceļiem, kā arī kārtību, kādā saskaņojama reklāmas objektu vai informācijas objektu izvietošanai (2005b) (Regulation about the placement of billboard advertisements and information along the roads and order for advertisment coordination or information object placement). MK noteikumi Nr. 402. Available at: http://www.likumi.lv/doc.php?id=110209, 9 March 2013. (in Latvian).
22. Penēze Z. (2009) *Latvijas lauku ainavas izmaiņas 20. un 21. gadsimtā: cēloņi, procesi un tendences* (Changes in Latvian rural landscape in 20th and 21st century: reasons, processes and tendencies). Promocijas darba kopsavilkums, Latvijas Universitāte, Rīga, 255 lpp. (in Latvian).
23. Piek M., Sorel N., Middelkoop M. (2011) Preserving panoramic views along motorways through policy. In: Nijhuis S., Lammeren R., Hoeven F. Research in Urbanism Series, IOS Press BV, Amsterdam, Netherlands, pp. 261-277.
24. Pradines C. (2009) Road infrastructures: Tree avenues in the landscape. Available at: http://www.historicroads.org/documents/CEP-CDPATEP-2009-15-TreeAvenues_en.pdf, 9 March 2013.
25. Ramírez Á., Ayuga-Téllez E., Gallego E., Fuentes J.M., García A.I. (2011) A simplified model to assess landscape quality from rural roads in Spain. *Agriculture, Ecosystems and Environment*, 142(3-4), pp. 205-212.
26. Ruskule A., Nikodemus O., Kasparinska Z., Kasparinskis R., Brūmelis G. (2012) Patterns of afforestation on abandoned agriculture land in Latvia. *Agroforestry Systems*, 85-2, pp. 215-231.
27. Valsts autoceļu tīkla saglabāšanas un attīstības programma 2000-2015 (State road maintenance and development program 2000-2015) (2001) Satiksmes ministrija. Available at: http://lvceli.lv/files/Publicejama%20projektu%20dokumentacija/Valsts%20autocelu%20tikla%20saglabasanas%20un%20attistibas%20programma_2000_2015%20gads_2.pdf , 9 March 2013. (in Latvian).
28. Rīgas rajona Siguldas novada teritorijas plānojums 2008-2020 (Territorial plan of Sigulda parish Riga region 2008-2020) (2008) Siguldas novada dome Available at: http://www.rpr.gov.lv/uploads/filedir/Ter_plaanojumi/Novadi%20un%20pagasti/Sigulda/TIAN.pdf, 9 March 2013. (in Latvian).
29. Steinitz C. (1990) Toward a sustainable landscape with high visual preference and high ecological integrity: the loop road in Acadia National Park, U.S.A. *Landscape and Urban Planning*, 19(3), pp. 213-250.
30. Zigmunde D. (2010) *Latvijas urbānās un lauku ainavas ekoloģiskā un estētiskā mijiedarbe* (The Aesthetic and Ecological Interaction of the Latvian Rural Urban and Inference). Promocijas darba kopsavilkums, Latvijas Lauksaimniecības Universitāte, Jelgava, 83 lpp. (in Latvian).

THE EFFECT OF TIMBER PROPERTIES ON THE BEHAVIOUR OF BENDING ELEMENTS UNDER LOADING

Aivars Brokāns
Latvia University of Agriculture
brokans.aivars@inbox.lv

Abstract
Timber structure is a very complex system with its own specific character that causes a lot of difficulties for designers to predict its precise behaviour under loading. Timber construction behaviour under load is affected by many factors that in most cases influence timber constructions in a negative manner. Part of these influencing factors are properties of material, the other are components of the environment where the timber construction is located.
This paper presents the results of experimental research where seventeen softwood *(Pinus Sylvestris)* timber beams of rectangular cross section were tested in four point bending under long-term load in uncontrolled microclimate conditions (unheated building, all year round weather in the region of Latvia). Values of mechanical properties (modulus of elasticity), physical properties (density, amount of latewood, number of annual rings in 1 cm of wood) were measured at the start of the test; while monitoring of moisture content of wood, relative humidity and air temperature were performed simultaneously for the whole period of test.
It has been observed that the main factors that significantly influence timber beam behaviour during period under load in natural climatic conditions are modulus of elasticity (MoE), density of wood and number of annual rings per 1 cm of wood. Amount of latewood showed an insignificant impact on timber beam behaviour under load.
Key words: Timber, beams, behaviour, MoE, density.

Introduction

Molecular structure of wood is a very complex system with uneven distribution of molecules. J. Bodig and B.A. Jayne (1982) found that wood has very manifold physical and mechanical properties because of its anisotropy and fibrous structure which needs to be taken into consideration when using wood in construction.

Strength and stiffness of timber structures depend on many factors. The biggest impact on the strength properties of timber is provided by MoE, density of wood, number of annual rings per 1 cm of wood, as well as moisture content, amount of latewood and other factors.

The modulus of elasticity is one of the most important elastic constants of the material and parameter of its quality (Dinwoodie, 2000). Research of F. Divos and T. Tanaka demonstrated that the most important strength predictor parameter is MOE. S.Y. Zhang (1997) proved that modulus of elasticity is poorly and least linearly related to the wood density.

Fibers are the principal element that is responsible for the strength of wood (Panshin and Zeeuw, 1980). The presence of defects such as checks, cross grain, pitch pockets, shakes, and wrap causes a considerable reduction in the mechanical properties of the timber (Dinwoodie, 2000).

Density and microfibril angle (indicators of strength and stiffness) are the most important determinants of wood quality. Wood density indicates the amount of actual wood substance present in a unit volume of wood (Cave and Walker, 1994). A.J. Panshin and C. de Zeeuw (1980), D.J. Cown (1992), J.M. Dinwoodie (2000) reported that density is a general indicator of cell size and is a good predictor of strength, stiffness and other properties. Basic density is closely related to structural timber strength (Harvald and Olesen, 1987). Wood density is affected by the cell wall thickness, the cell diameter, the earlywood to latewood ratio and the chemical content of the wood (Cave and Walker, 1994).

Timber consists of earlywood and latewood where latewood forms cells with thicker walls, which means that increasing amount of latewood will increase the density and strength of the timber (Illston and Domone, 2004).

Since the behaviour of timber beams under load is influenced by many factors, the aim of this research is to give a comprehensive view about some mechanical and physical influencing factors of timber beams in a natural environment under load.

Materials and Methods

The test was started in December 2011 in Jelgava, Latvia, and was carried out in a newly constructed house which is not currently inhabited. This house was not heated in the winter period; therefore, the climatic conditions were not controlled in any way that allowed checking the timber beam behaviour under load in variable climatic conditions of ambient humidity and temperature.

The experimental test represents a loading of seventeen (free of knots) pinewood (*Pinus sylvestris* L.) beams in four-point bending. The bending test setup and static model are given in Figure 1. The timber beam cross section nominal dimensions (height and width) were 60 mm and 30 mm respectively.

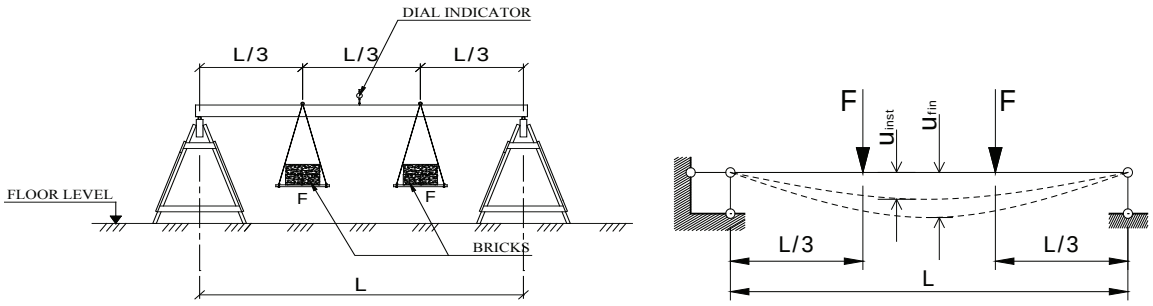


Figure 1. Long-term bending test setup and static model.

Concentrated forces were represented by clay and silicate bricks which were suspended on timber beams. The deflection measurements were made with dial indicators. Measuring precision of indicators – 0.01 mm. Measuring diapason of indicators – 50 mm. The dial indicators were placed in the middle of the span on the compressed side of the beam. The environmental climatic condition parameters were recorded once during the day. Temperature (T, °C) in the room and outdoors was fixed with mercury-in-glass (Hg) type thermometers.

Determining Modulus of Elasticity

Theoretical MoE in four-point bending was calculated after registering instantaneous elastic deflection (u_{inst}) immediately (1 minute) after loading. Theoretical MoE of rectangular cross-section elements, which are loaded in bending with two symmetrical concentrated forces, was calculated using equation (1):

$$MoE = \frac{F \cdot a}{4 \cdot b \cdot h^3 \cdot u_{inst}} (3 \cdot L^2 - 4 \cdot a^2), \quad (1)$$

where: F – sum of two concentrated forces, kN;
a – distance from support to concentrated force, cm;
L – timber beam span, cm;
b – width of cross section, cm;
h – height of cross section, cm;
u_{inst} – instantaneous deflection, cm.

Measuring wood density

The density of timber beams (ρ) was determined following the methodology of the standard LVS EN 408:2003 and LVS EN 384:2004 before the start of the test. The density of timber beams (ρ) was determined by oven-dry method using samples with a full cross section dimensions (60 mm x 30 mm x 30 mm) free from knots and resin pockets from the both ends of timber beams. Samples were oven-dried at 103 °C ± 2 °C until constant mass was achieved. Constant mass is attained when the results of two successive weighings, carried out at an interval of 6 hours, do not differ by more than 0.1% of the mass of the test piece. Dimensions of the test pieces were measured before oven-drying and after drying with slide gauge with an accuracy of 0.1 mm.

Determining amount of latewood and number of annual rings in 1 cm of timber

Two specimens with dimensions of 20 x 20 x 20 mm were cut out from a cross section of every timber beam. On the plane of the cross section in the radial direction, boundaries of whole annual rings were marked with a section of 20 mm. Number of annual rings in that section were counted (N). Dimensions (l) between end marks of whole annual rings were measured with an accuracy of 0.5 mm. Width of latewood (b_l) in every annual ring was measured with accuracy of 0.1 mm. Number of annual rings (n) per 1 cm of timber cross section were calculated using equation (2):

$$n = \frac{N}{l} \quad (2)$$

where: N – number of whole annual rings;
l – dimension between end marks of whole annual rings, cm.

Amount of latewood (m) percentage was calculated with accuracy of 1% using equation (3):

$$m = \frac{\sum b_l}{l} \quad (3)$$

where: Σb_l – sum of latewood in one specimen between end marks of whole annual rings, cm;

The correlation was provided between the main timber beam long-term loading behaviour affecting factors – MoE, amount of latewood, annual rings in 1 cm of wood, density, timber beam span to height ratio (L h^{-1}), moisture content of wood and other variables.

A regression analysis was made between the most important timber beam behaviour under load affecting factors; and coefficient of determination R^2 was calculated, too.

Table 1

Summary of timber beam properties

Timber beam marking	Span L, cm	Distance between supports a, cm	Force F, kN	Density of wood ρ, k gm^{-3}	MoE $E_{app.inst}$, kN cm^{-2}	Amount of latewood m, %	Number of annual rings in 1 cm	Inst. defl. u_{inst}, cm	MC w, %	L h^{-1}	MoE ρ^{-1}
KS-4.10	150	50	0.31	533	948.69	48	5.90	0.80	31	26.00	1.78
KS-4.9	150	50	0.31	457	514.42	57	3.40	1.30	26	25.40	1.13
KS-4.8	150	50	0.31	485	610.26	41	4.80	1.20	32	25.67	1.26
KS-4.7	150	50	0.31	572	1509.26	50	6.00	0.50	32	25.86	2.64
KS-3.10	132	44	0.40	526	1025.69	28	4.50	0.60	32	22.50	1.95
KS-3.9	132	44	0.40	577	916.65	52	7.40	0.70	29	22.54	1.59
KS-3.8	132	44	0.40	484	506.73	45	3.50	1.20	19	22.59	1.05
KS-3.7	132	44	0.40	499	781.77	50	5.10	0.90	20	22.69	1.57
KS-3.5	132	44	0.40	437	797.15	42	2.70	0.79	20	22.58	1.82
KS-3.3	132	44	0.40	450	898.89	44	4.30	0.77	29	22.80	2.00
KS-3.2	132	44	0.40	607	1294.89	44	7.20	0.48	32	22.59	2.13
KS-3.1	132	44	0.40	534	1324.58	45	8.00	0.48	33	22.59	2.48
KS-2.5	120	40	0.20	478	647.18	49	4.50	0.35	19	20.47	1.35
KS-2.4	120	40	0.20	545	1255.03	49	6.00	0.18	19	20.67	2.30
KS-2.3	120	40	0.20	518	962.54	46	8.30	0.24	19	20.92	1.86
KS-2.2	120	40	0.20	455	591.56	48	3.30	0.38	19	20.47	1.30
KS-2.1	120	40	0.20	609	1170.93	36	6.40	0.19	19	20.71	1.92

Results and Discussion

Results of mechanical and physical properties of timber beams at the start of the test are summarized in Table 1. Results of all timber beams show that specimens that are used in test have various mechanical and physical properties.

Modulus of elasticity varied in the range from 506.73 kN cm^{-2} to 1509.26 kN cm^{-2} with a mean value of 926.84 kN cm^{-2} with a coefficient of variation (COV) of 33%. The value of COV of 33% for MOE is high even for the wood where good COV is in within 10 to 15%.

Density of timber beams varied in the range from 437 kg m^{-3} to 609 kg m^{-3} with a mean value of 516 kg m^{-3} and with a COV of 10%.

One of the most important timber physical factors from the results of experimental research is the number of annual rings per 1 cm, which presented values from 2.7 to 8.3 with a mean value of 5.4 with a COV of 32%. The higher the number of annual rings per 1 cm, the better the quality of structural element – timber beams having higher strength and stiffness as well as behaviour under load is much better. This fact is testified by the good positive coefficient of correlation (0.76 and 0.68) between the number of annual rings, density of wood and MoE (see Table 2).

The ratio of modulus of elasticity to density (MoE ρ^{-1}) helps to counteract the effects of the large variety of wood. Ratio MoE ρ^{-1} varied in the range from 1.05 to 2.64. This ratio is a good predictor of strength and stiffness of timber beams. Correlation analysis between MoE ρ^{-1}, density of wood and the number of annual rings per 1 cm of wood showed an average positive relationship (0.55 and 0.57) that approximately allow to predict the strength properties of timber beams used in this test.

Moisture content (MC) of timber beams at the start of the test varied in range from 19% to 33% with a mean value of 25% with a COV of 24%. Relative deformation of timber beams are directly connected with MC of wood and temperature of the environment. The increase in strength and stiffness when moisture content of wood is relatively stable, can be explicitly seen in Figure 5. Increase of relative deformation in time at lower MC is much smaller (from the 61st day of the test till the end of the test) than it was at the start of the test (from 1st to the 61st day of test) when an active drying period of timber beams

Table 2

Correlation between main timber beam properties affecting factors

	Density of wood	MoE	Amount of latewood	Number of annual rings in 1 cm	Inst. defl.	MC	L h^{-1}	L u^{-1}	MoE ρ^{-1}
Density of wood	1								
MoE	0.76	1							
Amount of latewood	-0.17	-0.19	1						
Number of annual rings in 1 cm	0.76	0.68	0.02	1					
Inst. defl.	-0.49	-0.62	0.19	-0.53	1				
MC	0.29	0.41	-0.18	0.29	0.22	1			
L h^{-1}	-0.08	-0.01	0.18	-0.16	0.70	0.65	1		
L u^{-1}	0.49	0.51	-0.12	0.47	-0.85	-0.41	-0.62	1	
MoE ρ^{-1}	0.55	0.96	-0.20	0.57	-0.59	0.39	-0.01	0.44	1

was observed together with a fast decrease of air temperature.

Amount of latewood in all specimens showed values from 28% to 50% with a mean value of 46% with a COV of 14%. Amount of latewood presented very low relationship with other examined factors. T. Kubo and S. Jyodo (1996) stated that amount of latewood in the growth ring largely determines the density of the wood, which in turn affects its strength and stiffness, however, the results of this test do not approve this relationship (see Table 2). Coefficient of correlation r presented low relationships between amount of latewood and all other inspected factors.

Correlation between main affecting factors was provided and the results of analysis are summarized in Table 2.

The relationship between instantaneous deflection and all other factors was variable. Test results showed a good correlation with span to height ratio L h^{-1} (0.70); an average correlation with density (-0.49), MoE (-0.62), the number of annual rings (-0.53), MoE ρ^{-1} (-0.59); low correlation with amount of latewood (0.19) and MC (0.22). From these results we can conclude that instantaneous deflection of timber beams mostly depends on span to height ratio and only after that deflection are influenced by mechanical and physical factors.

Linear regression analysis between main mechanical factor MoE and physical properties of timber beams, and coefficient of determination R^2 are illustrated in Figure 2.

Regression analysis between MoE and other influencing factors showed that only two factors (density of wood and number of annual rings per 1 cm of wood) have a reckonable influence on MoE in terms of this test. Coefficient of determination R^2 recorded values of 0.51 and 0.49 that is an average tight relationship. The relationship between MoE, MC and amount of latewood showed low values of coefficient of determination R^2 – 0.158 and 0.0154 respectively, so those two factors have no reckonable influence on MoE in terms of this test.

To give general overview about behaviour of all timber beams under load during the period of test, the average curve of relative deformation versus time is given in Figure 3. It has to be taken into account that on the 61st day of the test (peak of the relative deformation curve) half of attached load was removed to simulate real climatic conditions of nature with doubled amount of permanent load for the winter period. This operation was made because of the requirements of the creep test under natural environment.

The conception of that how deformation of timber beams under load is influenced by MC of wood and temperature of the environment is illustrated in Figure 4. Deformation of timber beams increases together with drying of wood and fluctuations of temperature till the 61st day of the test when half of the attached load was removed, and persistent increase of temperature and period of stable MC were recorded. Simultaneously with constant period of MC, increment of relative deformation was low. We can conclude that the behaviour of timber beams under load is significantly affected by variations of MC and temperature. I have not studied influence of stress level on behaviour of timber beams in this test, but fast increment of deformation in time span when higher load was attached prove that the stress level has a significant influence on timber beam behaviour under load.

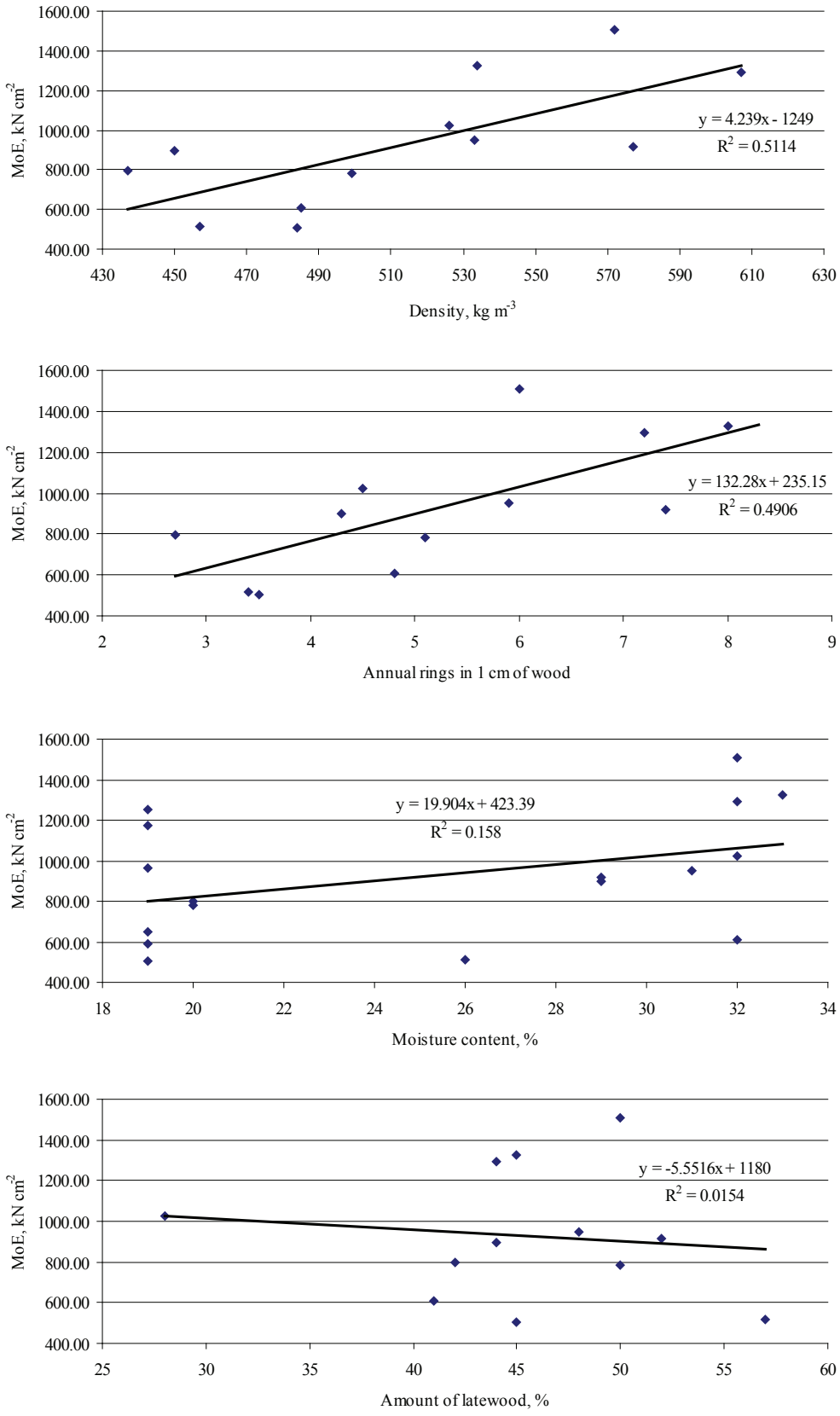


Figure 2. Relationships between MoE and main timber beam physical properties.

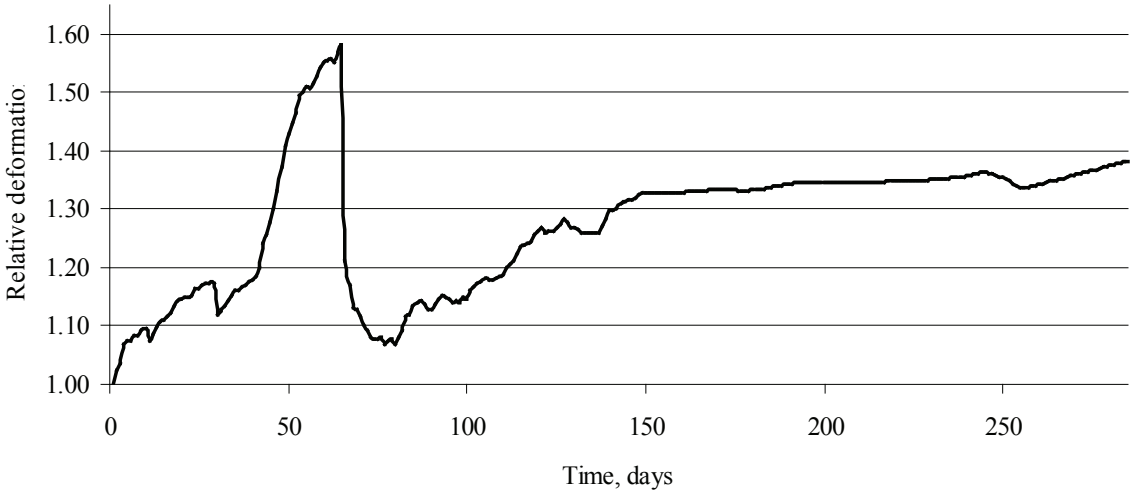


Figure 3. Average curve of relative deformation versus time.

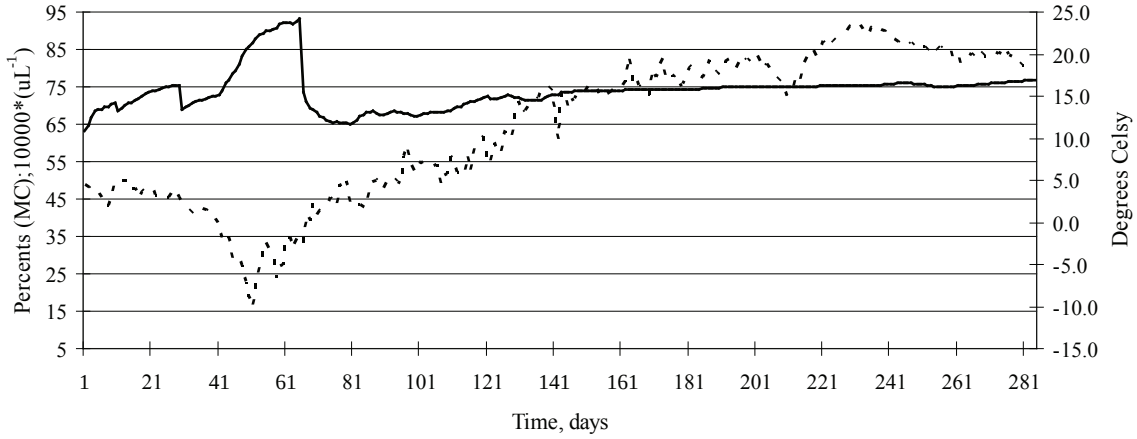


Figure 4. Average relative deformation, moisture content and temperature versus time.

Conclusions

1. This research gives a general insight into the behaviour of bending elements under load in natural environmental conditions and main behaviour influencing factors. Part of these influencing factors are mechanical and physical properties of material (MoE, density, amount of latewood, number of annual rings per 1 cm of wood and MC), others are a component of the environment (temperature) where bending elements are located.
2. The most important mechanical and physical influencing factors of bending elements are MoE, density of wood and number of annual rings in 1 cm of wood. The higher is the value of every of those three factors, the better is the behaviour of timber beams under load.
3. Instantaneous deflection of timber beams for the most part is negatively influenced by increasing span to height ratio (L h^{-1}) and afterwards by material properties – MoE, density of wood and number of annual rings in 1 cm of wood. Amount of latewood and MC in terms of this test have a low impact on the instantaneous deflection of timber beams.
4. Fluctuations of MC of wood and temperature of the environment have a reckonable negative influence on the behaviour of bending elements. In the period of variable environment temperature and drying of wood, increment of deformation was much bigger than it was in the span of time of stable temperature and much lower level of MC of wood.

References

1. Bodig J., Jayne B.A. (1982) *Mechanics of wood and wood composites*. Van Nostrand Reinhold, New York, 712 p.
2. Divos F., Tanaka T. (2005) Relation between static and dynamic modulus of elasticity of wood. *Acta Silvatica et Lignaria Hungarica*, Vol. 1, pp. 105-110.
3. Dinwoodie J.M. (2000) *Timber - its nature and behaviour.* E&FN Spon, London, 257 p.
4. Zhang S.Y. (1997) Wood Specific gravity-mechanical property relationship at species level. *Wood Science and Technology* 31(3), pp. 181-191.
5. Panshin A.J., Zeeuw C. (1980) *Textbook of wood technology.* 4th edition. McGraw-Hill, NewYork, 722 p.
6. Cave I.D., Walker J.C.F (1994) Stiffness of in fast grown plantation softwoods: the influence of microfibril angle. *Forest Products Journal* 44(5), pp. 43-48.
7. Cown D.J. (1992) Corewood (Juvenile Wood) in *Pinusradiata* – should we be concerned? *New Zealand Journal of Forestry Science*, 22(1), pp. 87-95.
8. Harvald C., Olesen P.O. (1987) The variation of the basic density within the juvenile wood of Sitka spruce (*Picea sitchensis*). *Scandinavian Journal of Forest Research* 2, pp. 525-537.
9. Illston J.M., Domone P.L.J. (2004) *Construction materials. Their nature and behaviour.* 3rd edition. Spon Press, London, 557 p.
10. Kubo T., Jyodo S. (1996) Characteristics of the annual ring structure related to wood density variation in sugi (*Cryptomeria japonica*). *Mokuzai Gakkaishi* 42, pp. 1156-1162.
11. Latvijas standarts LVS EN 384:2004 Konstrukciju kokmateriāli - Mehānisko īpašību raksturlielumu un blīvuma noteikšana *(Structural timber – Determination of characteristic values of mechanical properties and density)*, (2004) Standartizācijas birojs (LVS), Riga, Latvia, 15 lpp. (in Latvian).
12. Latvijas standarts LVS EN 408:2003 Koka konstrukcijas - Konstrukciju kokmateriāli un līmētie koka izstrādājumi - Dažu fizikālo un mehānisko īpašību noteikšana *(Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties)* (2003) Standartizācijas birojs (LVS), Riga, Latvia, 30 lpp. (in Latvian).

WIND-WAVE RELATIONSHIP: A CASE OF THE LITHUANIAN COAST OF THE BALTIC SEA

Egidijus Kasiulis, **Petras Punys**
Aleksandras Stulginskis University, Lithuania
egidijus.kasiulis@gmail.com

Abstract
In this paper regression analysis was adopted to assess the wind-wave relationship between wind speeds and wave heights on the Lithuanian coast of the Baltic Sea. In the coastal observations register missing data of visual wave observations occur because of the fog, ice, evaporation or other meteorological phenomenon. There is also inconsistency in instrumental measurements of wave heights in the Lithuanian coast due to technical issues. First step to fill the gaps in the wave height data is to find a strong relationship between wind speeds and wave heights. In this study correlation coefficients for Nida and Klaipėda coastal hydrometeorological stations data both taking and not taking into consideration wind blowing directions were calculated. Every data set used in this study was treated separately and it was revealed that applying nonlinear regression the most common model for wind-wave relationship analysis on Lithuanian coast is DR-Hill model, while applying multivariable regression it is Full Cubic model. Relationship between wind speeds and wave heights always can be improved by removing swell waves from correlation.
Key words: regression analysis, wind speeds, wave heights, Lithuanian coast, Baltic Sea.

Introduction

Waves originate during the process of wind blowing over the surface of water body. Wind transfers part of its energy into the water resulting in a natural phenomenon known as wind waves. Therefore, the relationship between wind speed and wave height may seem obvious. However, there is no linear relationship between these parameters in the oceans. Buoys, that are located in the oceans, are recording data not only of waves that are caused by the local wind, but also of waves that are born in storms in distant areas. The wind and wave relationship is not linear because the measured wind speeds are generated locally, but the wave heights include waves generated form almost anywhere.

Manual wave forecasting diagram was developed by Groen and Dorrestein (1976). This diagram can be used to predict wave heights and periods when wind speed (m s^{-1}), his duration in hours and fetch (km) are known. But this easy to use diagram becomes difficult to apply at unsteady winds. Same can be said about any wave growth functions at the same conditions (Alomar et al., 2010). Limited fetch, unsteady winds and swell become reasons why predictions of significant wave heights as well as applications of wind wave generation and development functions are complicated not only in the ocean areas (Andreas and Wang, 2007; Hwang et al., 2011).

On the other side, there is an example of Lake Michigan, that is enclosed body of water and swell waves do not occur on such a large scale in these conditions, as they do in the open oceans. Thus, relationship via correlation between wind speed and wave height here can be found (Liu et al., 1984). It is already known, that wave fields in the Baltic Sea are similar to those on large lakes (Lepparanta and Myrberg, 2009). For the statistical assessment of wave climate and extreme events it is necessary to use data from complete time series with constant intervals in time domain. Wave data are often incomplete due to various reasons and wind-wave correlations can be the method to fill the gaps in the wave height time series (Dreier et al., 2011).

Instrumentally measured data on the Lithuanian coast of the Baltic Sea is available from 2011. Nevertheless due to technical issues collected data is irregular. This is one of the reasons why wave heights in parallel are measured visually. Still, missing data of visual wave observations occur because of the fog, ice, evaporation or other meteorological phenomenon. Hence, finding a strong relationship between wind speeds and wave heights can be the first step for developing a methodology to fill the gaps in wave height data.

The objective of this article is to assess the relationship between wind speeds and wave heights on the Lithuanian coast of the Baltic Sea by evaluating wind-wave correlations both taking and not taking into consideration wind blowing directions. Main task to achieve this objective is to find best linear, nonlinear and multivariable regression model fit for selected data sets.

Materials and Methods

Observation data from Klaipėda and Nida coastal hydrometeorological stations was used for this study. Daily average wave heights and wind speeds were calculated using 1993-2008 coastal observations register. Depending on a season visual observations of wave heights are performed and noted into this

Table 1

Selected coefficients for wind blowing directions

N	NNE	NE	ENE	E	ESE	SE	SSE
0	-0.25	-0.5	-0.75	-1	-0.75	-0.5	-0.25
S	SSW	SW	WSW	W	WNW	NW	NNW
0	0.25	0.5	0.75	1	0.75	0.5	0.25

register one, two or three times during the daylight. Parallelly wind speeds are noted in the same register, yet wind speeds are measured instrumentally.

Only observations of wind waves were used to calculate daily average wave heights. Swell waves were eliminated according to Manual for hydrometeorological stations and posts (Государственный..., 1984) used in the Lithuanian coast. In this manual wind-induced waves are described as rough sea in the direct effect of the same wind at the moment of observation. Wind blowing and wave propagation directions in deep water must coincide, or differ by no more than 45°. In shallow nearshore areas this difference can be greater, due to refraction (Государственный..., 1984). Observers of Environmental Protection Agency's Department of Marine Research in Lithuania use this wind wave detection method to the present day. Furthermore, types of waves are always noted in the coastal observations register. In this register noted mixed type of waves (wind waves together with swell) were also eliminated from daily average wave heights calculation.

The assessment of wind-wave relationship is divided into two parts. In the first part linear and nonlinear regression analysis for wind waves at the same data sets is performed without taking into consideration wind blowing directions. In the second part multivariable regression analysis is performed (taking into consideration wind blowing directions). For each part of the assessment different sets of data were selected according to Kasiulis (2011).

Wind blowing directions are introduced by changing daily prevailing wind directions into selected coefficients. Coefficients were selected taking into account prevailing wind directions together with their fetches on the Lithuanian coast of the Baltic Sea.

Study was carried out using Curve Expert Professional software. All values of regression analysis results and gained parameters values are presented with 95% confidence interval. All equations to each data set are the best model fits based on standard error. Every data set is treated separately, because comparing the results gained by all types of regression is difficult. Use of correlation coefficients in nonlinear regression is questionable, while comparing via coefficient of determination is impossible, because best fitted models functions may have different number of independent variables. Only linear and nonlinear regression results are possible to compare via standard error.

In this study small correlation is from 0.2, medium correlation is from 0.5 and strong correlation from 0.7. This paper is a continuation of the study that was published in Kasiulis (2011).

Results and Discussion

In Kasiulis (2011) a simple linear regression was adopted to evaluate relationship between wind speeds and wave heights on the Lithuanian coast. First, annual correlations, using daily average wind speeds and wave heights from 1993-2008 Klaipėda and Nida coastal hydrometeorological stations data, were calculated (Table 2). After that, all 16 years daily average wind speed and wave height data of the same period from Nida coastal hydrometeorological station was put into one graph obtaining correlation coefficient of 0.72 (Fig. 1). All these results from

Table 2

Annual correlation coefficients between wind speeds and wave heights (Kasiulis, 2011)

	1993	1994	1995	1996	1997	1998	1999	2000
Klaipėda	0.85	0.74	0.74	0.46	0.80	0.62	0.64	0.78
Nida	0.61	0.68	0.65	0.38	0.82	0.66	0.72	0.83

	2001	2002	2003	2004	2005	2006	2007	2008
Klaipėda	0.55	0.73	0.65	0.58	0.69	0.49	0.77	0.76
Nida	0.53	0.76	0.81	0.70	0.84	0.62	0.84	0.79

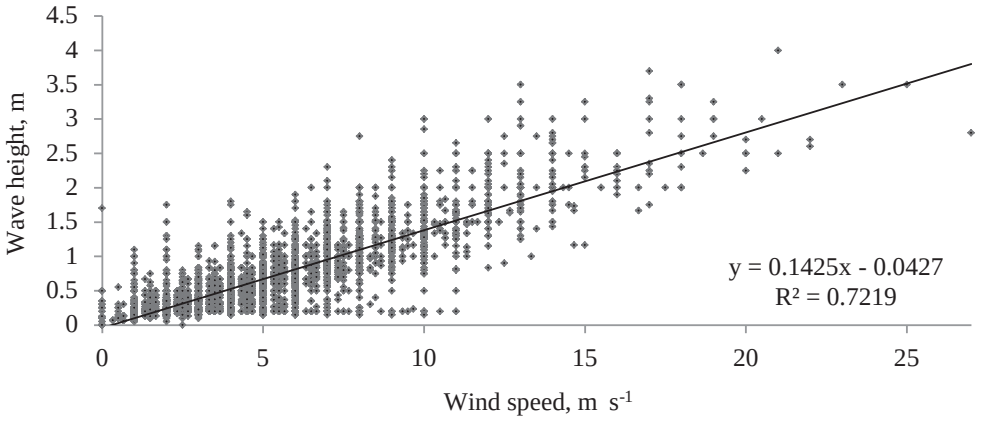


Figure 1. Correlation between Nida coastal hydrometeorological station daily average winds speeds and wave heights data (1993-2008) (Kasiulis, 2011).

Table 3

Results of simple linear regression analysis eliminating swell waves

Coastal hydrometeorological station	Year	Linear equation $y = a+bx$		Annual correlation coefficient	Standard error	Coefficient of determination
		a	*b*			
Klaipėda	1996	-0.10	0.14	0.81	0.23	0.66
Nida	1996	0.05	0.11	0.78	0.20	0.62
Klaipėda	2006	-0.16	0.18	0.82	0.26	0.67

Kasiulis (2011) were obtained by not taking into consideration wind blowing directions and including swell waves into correlation.

According to Table 2 and Fig. 1 there are not only 12 cases of medium, but even 3 cases (Klaipėda and Nida 1996; Klaipėda 2006) of small correlation between wind speeds and wave heights. Thus, from this set of data it is clear that it is misleading to state that there is always linear relationship between wind speeds and wave heights in the Lithuanian coast. First step of this study is to repeat simple linear regression analyses to the same data sets from which swell waves are eliminated. All data sets with small correlation are selected for this part of study. Results are presented in Table 3.

Elimination of swell waves changes correlation between wind speeds and wave heights from small to strong. Still this linear equation cannot be used to fill the gaps in wave height data, because not only the standard errors indicate that dispersion around the regression line is relatively large, but also coefficients of determination indicate that regression line does not fit the data well. This can be improved by applying nonlinear equations (use of higher than 5th degree polynomial regressions is avoided). An example of linear and nonlinear regression model fit is shown in Fig. 2.

By applying 5th degree polynomial regression (equation $y = a + bx + cx^2 + dx^3 + ex^4 + fx^5$, parameters a = 0.13, b = 0.12, c = -0.03, d = 0.003, e = 0.0004, f = -0.00003) to the Klaipėda coastal hydrometeorological data (the year 1996) these values were obtained: correlation coefficient of 0.91, standard error of 0.16 and coefficient of determination of 0.83. In parallel gained values using nonlinear regression that were obtained for other data sets are presented in Table 4. Results of standard errors of nonlinear regression analysis indicate that nonlinear regression line gives more accurate prediction of wave heights (Fig. 2). Basically, this line is reliable for filling the gaps in wave height data on Klaipėda coast, however, its use is questionable on Nida coast.

Next part of this study is an assessment of the relationship between wave heights and wind speeds on the Lithuanian coast by taking into consideration wind blowing directions. For this part data sets with medium - 0.62 (Klaipėda 1998 and Nida 2006) and strong - 0.76 (Klaipėda 2008 and Nida 2002) correlation were selected (Table 2). Firstly, nonlinear regression analysis for these four data sets was performed. The obtained results are presented in Table 4.

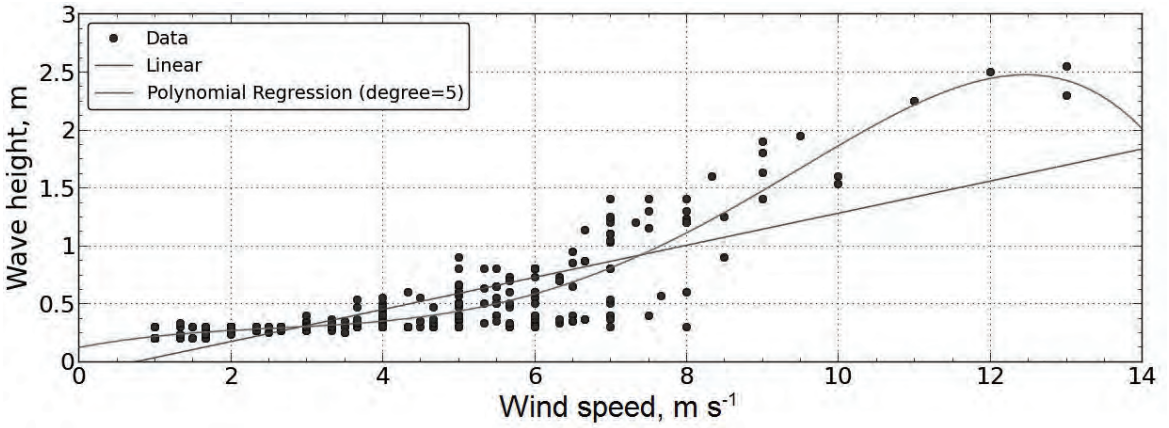


Figure 2. Linear and nonlinear regression model fit for Klaipėda coastal hydrometeorological observation data (the year 1996).

Table 4

Results of nonlinear regression analysis

Nonlinear regression model			Annual correlation coefficient	Standard error	Coefficient of determination
name	equation	parameters			
Nida 1996					
Gaussian	$y = ae^{\frac{-(x-b)^2}{2c^2}}$	a = 2.2 b = 19.1 c = 8.4	0.79	0.20	0.63
Klaipėda 2006					
DR-Hill	$y = \alpha + \frac{\theta \cdot x^{\eta}}{\kappa^{\eta} + x^{\eta}}$	α = 0.28 θ = 2.2 η = 4.5 κ = 7.7	0.87	0.23	0.75
Klaipėda 1998					
Polynomial (5th degree)	$y = a + bx + cx^2 + dx^3 + ex^4 + fx^5$	a = -0.20 b = 0.71 c = -0.34 d = 0.07 e = -0.005 f = 0.0001	0.92	0.22	0.85
Nida 2006					
Polynomial (3rd degree)	$y = a + bx + cx^2 + dx^3$	a = 0.31 b = -0.10 c = 0.04 d = -0.002	0.91	0.27	0.82
Klaipėda 2008					
DR-Hill	$y = \alpha + \frac{\theta \cdot x^{\eta}}{\kappa^{\eta} + x^{\eta}}$	α = 0.28 θ = 2.2 η = 4.5 κ = 7.7	0.92	0.22	0.84
Nida 2002					
DR-Hill	$y = \alpha + \frac{\theta \cdot x^{\eta}}{\kappa^{\eta} + x^{\eta}}$	α = 0.22 θ = 2.4 η = 2.8 κ = 9.3	0.85	0.32	0.72

Table 5

Full Cubic regression equation with parameters

Data set	$y = a + bx_1 + cx_2 + dx_1^2 + ex_2^2 + fx_1^3 + gx_2^3 + hx_1x_2 + ix_1^2x_2 + jx_1x_2^2$									
	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*
Nida 2006	-0.18	10.2	0.22	-3.2	0.80	0.44	0.38	-2.6	1.1	-0.83
Klaipėda 2008	-1.1	16.7	0.26	-11.2	-0.07	2.6	0.71	-4.5	2.5	-0.17
Nida 2002	-1.1	14.3	-2.2	-7.7	1.0	1.6	0.64	2.4	0.26	-1.9

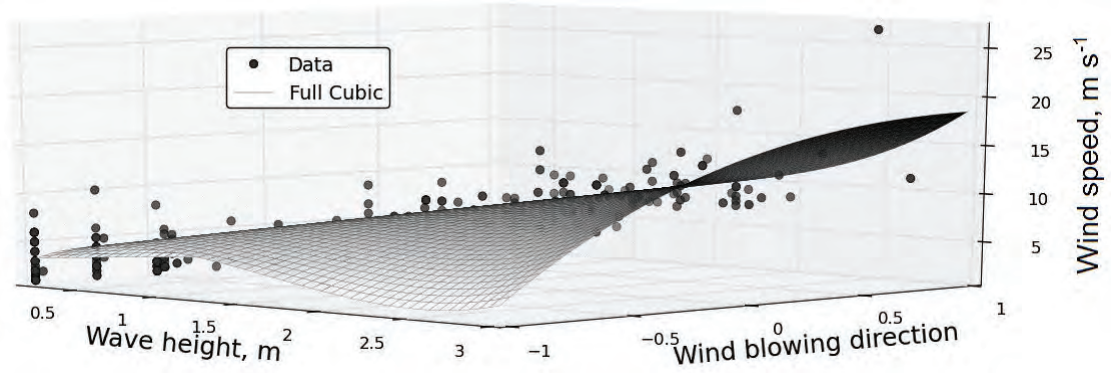


Figure 3. Multivariable regression model fit for Nida coastal hydrometeorological observation data (the year 2002).

Next step is to perform multivariable (3D) regression analysis by adding into consideration wind blowing directions. Applying multivariable regression change equation and values of standard error, so comparing it is not expedient. Therefore nonlinear and multivariable regression analysis results are non-comparable. Here presented results of multivariable (3D) regression are best fits for each data set via standard error.

Multivariable Rational regression (equation $y = (a + bx_1 + cx_2) / (1 + dx_1 + ex_2)$, parameters a = -1.9, b = 20.1, c = 1.9, d = 1.3, e = 0.83) was applied for 1998 Klaipėda data set. Obtained correlation coefficient and coefficient of determination are: 0.92 and 0.84. For the rest three data sets Full Cubic regression was applied. Full Cubic equation with parameters for each data set is presented in Table 5.

Using multivariable regression gained correlation coefficients and coefficients of determination are: for Nida 2006 - 0.90 and 0.81; for Klaipėda 2008 - 0.92 and 0.85; for Nida 2002 - 0.86 and 0.75. The example of multivariable regression model fit results is presented in Fig. 3.

Conclusions

1. A small linear wind-wave relationship can be transformed into strong by eliminating swell waves from correlation. The best improvement was gained using Nida 1996 data set (from 0.38 to 0.78).
2. Applying nonlinear regression revealed that the most common model for wind-wave relationship analysis on the Lithuanian coast is DR-Hill model (3 cases of best fit). Still, the lowest standard error was gained applying 5th degree polynomial regression model (Klaipėda 1996; 0.16).
3. Applying multivariable regression for wind-wave relationship analysis by taking into account wind blowing directions revealed that the most common model is Full Cubic model (3 cases of best fit). The best combination of correlation coefficient and coefficient of determination was gained using Klaipėda 2008 data set (0.92 and 0.85).

Acknowledgements

The authors would like to acknowledge EPA Department of Marine Research in Lithuania for providing Klaipėda and Nida coastal hydrometeorological station data.

References

1. Alomar M., Bolanos-Sanchez R., Sanchez-Arcilla A., Sairouni A. (2010) Wave growth under variable wind conditions. In: Smith J.Mc., Lynett P. (eds) Coastal Engineering 2010. *Proceedings of the 32nd International conference*, Shanghai, China, pp. 1-11.
2. Andreas E.L., Wang S. (2007) Predicting significant wave height off the northeast coast of the United States. *Ocean Engineering*, 34, pp. 1328-1335.
3. Dreier N., Schlamkow C., Frohle P. (2011) Assessment of future wave climate on basis of wind-wave-correlations and climate change scenarios. *Journal of Coastal Research*, 64, pp. 210-214.
4. Groen P., Dorrestein R. (1978) *Zeegolven. KNMI Opstellen op Oceanografisch en Maritiem Meteorologisch Gebied. No. 11* (Sea waves. RNMI Drawing up on oceanographic and marine meteorological field. No. 11). Koninklijk Nederlands Meteorologisch Instituut, 'S-Gravenhage, Nederland, 124 S. (in Dutch).
5. Hwang P.A., Garcia-Nava H., Ocampro-Torres F.J. (2011) Observations of wind wave development in mixed seas and unsteady wind forcing. *Journal of Physical Oceanography*, 41, pp. 2343-2362.
6. Kasiulis E. (2011) Statistical analysis of the Baltic Sea wave height data for evaluating energy potential. *Proceedings of CYSENI 2011: The 8th Annual International Conference of Young Scientists on Energy Issues*, Kaunas, Lithuania, pp. 397-406.
7. Lepparanta M., Myrberg K. (2009) *Physical Oceanography of the Baltic Sea*, Springer, Chichester, UK, 378 p.
8. Liu P.C., Schwab D.J., Bennett J.R. (1984) Comparison of a two-dimensional wave prediction model with synoptic measurements in Lake Michigan. *Journal of Physical Oceanography*, 14, pp. 1514-1518.
9. Государственный комитет СССР по гидрометеорологии и контролю природной среды (1984) Наставление гидрометеорологическим станциям и постам. Выпуск 9. Гидрометеорологические наблюдение на морских станциях и постах. Часть 1. Гидрологические наблюдение на береговых станциях и постах (Manual for hydrometeorological stations and posts. Issue 9. Hydrometeorological observations in marine stations and posts. Part 1. Hydrological observations in coastal stations and posts). Гидрометеоиздат, Ленинград, 311 с. (in Russian).

THE IMPACT OF INTERPOLATION METHOD PARAMETERS ON THE ACCURACY OF PREDICTED VALUES

Gitana Vyčienė, **Vilda Grybauskienė**
Aleksandras Stulginskis University, Lithuania
gitana.vyciene@asu.lt

Abstract
Kriging is a method of interpolation, which predicts unknown values from data observed at known locations. This method uses a variogram to express spatial variation, and it minimizes the error of predicted values which are estimated by spatial distribution. The objective of the current work was to investigate how the accuracy of predicted runoff average depth values ranges by applying ordinary Kriging interpolation method when parameters of the method are altered. The simulation was tested by the following method parameters on: fitted semivariogram model, lag size, neighboring points, the number of sectors of the circle.
The best results of the spatial distribution of runoff average depth were received applying the ordinary Kriging method when the exponential variogram is used, the lag size being 27 km while 6 contiguous points and the orbicular scheme divided into sectors in 45° angle are taken. Applying the Ordinary Kriging method having selected all parameters with probability p = 0.95 the model described about 74% of all investigated values.
Key words: Geostatistical modeling, Kriging interpolation method, runoff average depth.

Introduction

With the changing economic situation, natural researches are becoming more and more expensive. In addition, it is impossible to select enough data to make accurate hydrologic calculations because of the decreasing network of water gauging stations. Most often measuring is made according to certain schemes that are spread in points. It can be the net of either hydrologic or meteorological stations. Spatial interpolation might be used in order to assess the values between measuring points without measuring them (Burrough and McDonnell, 1998). Interpolation is applied to find horizontal position, and when it is necessary to calculate the values of a chosen point in which any gauging was never performed.

The principles of geostatistics and interpolation by Kriging are described in a large number of literature resources in the world (e.g. Cressie, 2004; Arnaud et al., 2002; Bacchi and Kattogoda, 1995; Franke, 1982). In Lithuania, the spatial interpoliation has been mainly applied to modelled relief (Kumetienė and Zakarevičius, 2006a; Kumetienė, 2006b; Kumetienė, 2006c), meteorological data (Šarauskienė and Rimavičiūtė, 2000), soil pollution data (Marcinkonis and Karmaza, 2007). Also, Lithuanian scientists employ the method of spatial interpolation in order to identify tendencies of noise distribution and investigate the distribution of forestry parameters. However, spatial modelling in hydrology is still a new field in Lithuania.

When conducting the research, ordinary Kriging method was employed, which is based on statistical analysis of random measures. Ordinary Kriging method calculates values by constant, yet unknown average. Kriging method forms semivariograms so that variability could be determined, i.e. the graph, which shows the change in semivariance, the distance between points with defined values increasing. Kriging algorithms use various mathematical functions for the spatial modeling of the variability of z values between known points (Johnston et al., 2001; Dumbrauskas et al., 2006; Jordan and Mellese, 2003). The parameters of these functions are then optimised for the best fit of the experimental semivariogram. The interpolated surface is then constructed using statistical conditions of unbiasedness and minimum variance.

When pursuing the analysis of the spatial distribution of the selected characteristics, it is extremely important to properly select parameters of the method because they determine the accuracy of values and display of spatial distribution for the selected characteristics. The following four basic parameters are analysed in the article: selecting the semivariogram model, interpolation step, number of neighbouring points and the scheme of searching for neighbouring points. The first significant step when starting interpolation of the characteristics researched is to select the theoretical curve, which, could conform to mathematical description of the analysed data. ArGIS geostatistics tool base allows selecting even 11 models, namely Gaussian, Exponential function, orbicular, etc. Having selected the appropriate variogram model, the next stage is to choose the step of interpolation. The selection of the step size has a significant impact on empiric semivariogram, e.g. if a step is large, autocorrelation of small size can be concealed. If a step is too small, numerous empty groups can occur whereas sizes in groups will be too small to obtain significant information about groups. When interpolating unknown values, it is equally important to choose the sufficient number of neighboring points and the range of their search. You can assume that as the locations get farther from the prediction location, the measured values will

have less spatial autocorrelation with the prediction location. As these points will have little or no effect on the predicted value, they can be eliminated from the calculation of that particular prediction point by defining a search neighborhood. The specified shape of the neighborhood restricts how far and where to look for the measured values that will be used in the prediction. It is also possible that distant locations may have a detrimental influence on the predicted value if they are located in an area that has different characteristics than those of the prediction location. The third reason to use search neighborhoods is for computational speed (Laffan, 2002; Krivoruchko and Gribov, 2002; Araghinejad and Burn, 2005).

The objective of the current work was to investigate how the accuracy of predicted runoff average depth values ranges by applying ordinary Kriging interpolation method when parameters of the method are altered.

Materials and Methods

Runoff average depth was selected for the research. In addition, the combination of 74 points was used. The selected 74 water gauging stations (WGS) almost totally cover the area of Lithuania. The data of runoff average depth, introduced in the book "Lithuanian rivers. Hydrography and Runoff" were used for the analysis (Gailiušis et al., 2001). Before starting the procedure of interpolation, centroids of all river basins, moreover, values of the analysed characteristics accumulated by WGS were transferred to these centroids. Therefore, when conducting the subsequent analysis, these points of centroids were used.

The research was conducted using ArGIS software, which contains the model of Geostatic analysis.

On the basis of geostatic analysis, one can determine dependence of the predicted values on parameters of interpolation method.

When conducting the research, the following interpolation method parameters were tested:

- Semivariogram model;
- Interpolation step;
- Number of neighboring points;
- Scheme of search for neighboring points.

When pursuing the interpolation process, first of all initial validation of the obtained data set was carried out. Cross validation was employed in order to identify the accuracy of the interpolation method selected. The parameters of the method listed are selected during the interpolation process. The basic principle of the technique involves removing points one at a time and checking the estimate given at the point that is removed with the actual value. The greater number of points involved in a prediction, the more accurate a prediction will be. The cross validation produces parameters that are useful in assessing the error involved in the prediction. During the procedure each value is modelled and compared with the factual one. The obtained difference between real and modelled value was used to identify statistical parameters (Kumar, 2006; Jordan, 2003).

The impact of selected method parameters on the accuracy of the results was estimated when calculating: mean error (*ME*), root mean square error (*RMSE*), root mean squared standardized errors (*RMSSE*), standard deviation (*SD*). Ideally, the mean should be close to zero, which would indicate an unbiased prediction. The mean is, therefore, the mean error associated with the interpolation surface created. The value of the root mean squared error (*RMSE*) depends on the set of data investigated. However, the lower the value, the closer modelled values to the investigated ones are. If the root mean square standardized value is lower than one, the predicted values are overestimated, whereas a value higher than one indicates underestimation (Jones, 1997; Knight et al., 2005; Laffan, 2002). Although more statistical parameters are used during cross-validation procedure, the volume of the article limited the choice to three basic parameters.

Satisfaction of selected model parameters and investigated data were checked by the determination coefficient R^2 and F statistics. The closer is the coefficient of determination to one, the better suited are model parameters for investigated data. Determination coefficient multiplied by 100 obtained percentage index show proportion of the measured values which evaluate the model with selected parameters. If $F > F_{\alpha}(k_1,k_2)$, so with the probability $p = 1-\alpha$, we can argue that the model with selected parameters satisfy the investigated data (Čekanavičius and Murauskas, 2002).

Results and Discussion

While starting geostatistical analysis of runoff average depth, the most appropriate interpolation methods were selected according to the reticence whereas values of the characteristic investigated were predicted. The impact of the selected modelling parameters on the accuracy of modelled values was tested when comparing them with those proposed by the programme.

During geostatic interpolation of the selected data initially variogram was composed of the obtained data set. It allowed us to decide on autocorrelation of the obtained data. Five most frequently appearing models were validated.

The relevance of the selected theoretical curve to describe the characteristics researched was estimated on the basis of root mean squared standardized errors as well as a graph nugget, partial sill, and the range. As it has been mentioned, the programme

Table 1

Semivariogram model parameters during the analysis of runoff average depth

Semivariogram model	Nugget	Partial sill, m	Range, m	RMSSE, mm	t-statistic	F-statistic	α	R^2
Spherical	95.56	251.47	149466	0.87	0.15	1.87	0.05	0.66
Exponential	52.14	385.31	268192	0.95	0.10	1.90		0.68
Gaussian	104.75	143.80	54892	0.85	0.17	1.80		0.63
Circular	68.86	177.50	58786	0.88	0.13	1.88		0.67
Hole Effect	107.86	129.73	87130	0.84	0.18	1.82		0.62

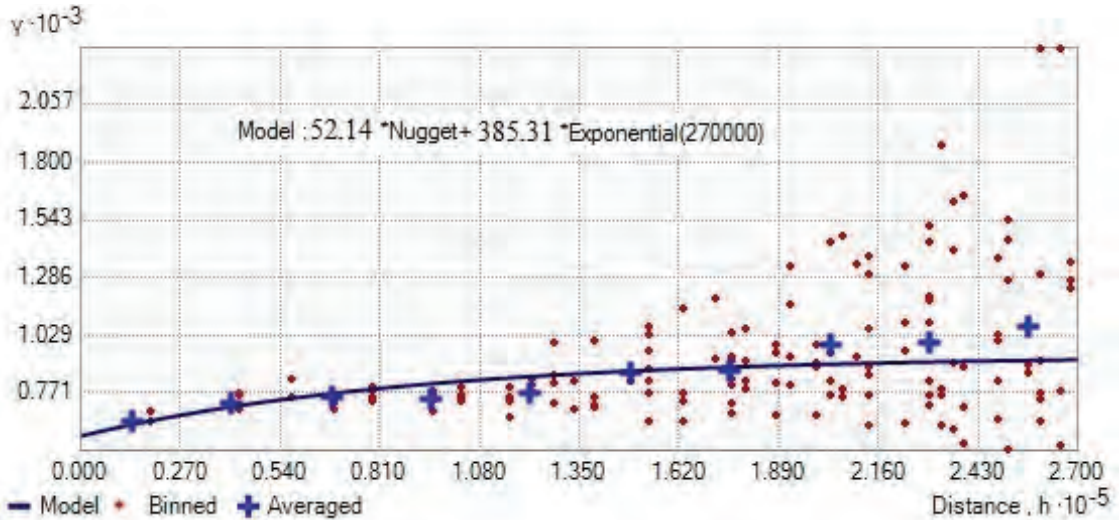


Figure 1. Fitted variogram model for runoff average depth data.

suggests applying an orbicular model of variogram on the basis of reticence. On the other hand, if we estimated the results (see table 1) according to root mean squared standardized errors, it must be as close to one as possible. In addition, the best results were obtained by applying exponential model. If we based our estimations on values of the graph nugget, this measurement is ascribed to non-accuracy, i.e. when measurement of the same characteristics at the same point provides different results. The lowest value of variogram graph nugget (namely, 52.14) was obtained to describe data by using exponential curve as well (see Fig.1). Due to the limited length of the article, all the obtained semivariogram model pictures of the observed characteristic are not included in this paper.

Since we get $F > F_{\alpha}(k_1, k_2)$, so selected exponential variogram model with probability p = 0.95 described about 68% of all investigated data values, and another 32% of the values the selected model does not describe.

Subsequently, the impact of interpolation step size on the accuracy of modelled values was validated. Initially 33 km interpolation step was selected during cross-validation procedure and, therefore, further options of changing the step size were compared to modelling average values of runoff average depth of this size. When selecting the initial interpolation step, the variogram model and its functioning, having changed the size of interpolation step, were constantly observed. Table 2 presents information about the changes of statistical parameters investigated according to the step size.

The longest distance from any point in Lithuania until functioning WGS is about 24 km whereas in the case studied, when the data of 74 WGS were analysed, this distance increases up to 29.4 km.

Smaller interpolation step (lag) was intended for use. However, when the step is shorter than 10 km, the number of points investigated decreased significantly and in such a case we did not succeed in identifying the relationship between neighboring points of the investigated characteristics (h_{vid}) with regard to the distance, i.e. it was not possible to identify the autocorrelation of these sizes.

Having selected the step of 10 km, we found that 72% of errors ranged from + 13.43 up to - 13.43 mm, while 92% of them occurred within the range of + 21.70 – 21.70 mm whereas the remaining errors exceeded this range. The highest error was found in the Svyla river near Guntauninkai WGS. The modelled value was 27.56 mm higher than the value

Table 2

The analysis of value accuracy predicted according to the step size

Lag size, km	*SD*, mm	*RMSE*, mm	*RMSSE*, mm	Weights neighbors	*t*-statistic	*F* statistic	*α*	R^2
10	13.43	10.85	0.88	20	0.29	1.71	0.05	0.60
15	13.05	10.73	0.88	20	0.20	1.81		0.63
20	13.11	10.81	0.95	20	0.24	1.79		0.61
27	12.91	10.74	0.95	20	0.09	1.89		0.69
33	12.98	10.86	0.95	20	0.12	1.83		0.64

investigated. The efficiency of the selected step size can be assessed according to the calculated root mean square standardized error (0.88 mm), which must be as close to one as possible, and , thus, this option is not appropriate because it manifests how exactly the characteristic values studied are predicted.

When applying 15 km interpolation step, the root mean square standardized error (0.88 mm) remainedthe same as it was when applying 10 km step. The errors in this case range within lower margins and 72% of errors fall into the interval ranging from + 13.05 mm to 13.05 mm. If we based our estimation on the root mean square standardized error, then it could be stated that the same results were obtained (0.95 mm) by applying the 20 km, 27 km, and 33 km step. Moreover, afterwards increasing the step, the accuracy of modelled values decreases.

If comparing the proposed impact of the model step size on the accuracy of modelled values, it could be noticed that having decreased the step up to 20 km, the average number of range points remains the same, i.e. 20. Only the size of root mean square errors decreases in 0.05 mm. However, if we based our estimation on standard deviation, the best result was obtained while applying 27 km (when applying this step, all investigated points can be estimated) because when interpolating values, they are least digressed from the mean, i.e. 78.59 ± 12.91 mm.

When applying 27 km lag size, with probability p = 0.95 described about 69% of all investigated values, and another 31% of the values does not describe. When increasing the step (lag size), the accuracy starts decreasing again (R^2 = 0.64 and SD = 12.98 mm).

The number of neighboring points was another parameter that was studied. The set of data analysed consists of 74 points. In such a case accuracy of interpolation was estimated by neighboring points 6, 9, 12, 15. When starting interpolation, the programme based on reticence selects 5 neighboring points while searching for the value predicted. The accuracy of modelled values was evaluated by statistical parameters, which are presented in table 3.

The obtained results demonstrate that the lowest square value of the error (10.73 mm) was received by using 6 neighboring points for interpolation because, when increasing their number, values of root mean square errors and standard deviation increase as well. The highest root mean square standardized error value (0.96 mm) was received having compared modelled and investigated values, also using 6 neighboring points. While estimating the value of standard deviation, this option is best as well as the value of standard deviation obtained was the lowest and modelled values around the average are spread in 78.59 ± 12.87 mm. Having applied the search number

Table 3

The analysis of modelled value accuracy with regard to number of neighboring points

Point number	*SD*, mm	*RMSE*, mm	*ME*, mm	*RMSSE*, mm	Weights neighbors	*t*-statistic	*F* statistic	α	R^2
5	12.91	10.81	0.21	0.95	20	0.15	1.83	0.05	0.67
6	12.87	10.73	0.20	0.96	24	0.10	1.89		0.70
9	12.89	10.80	0.21	0.95	36	0.12	1.84		0.67
12	12.89	10.84	0.22	0.95	48	0.12	1.84		0.66
15	12.90	10.83	0.23	0.94	39	0.14	1.82		0.62

of 6 neighboring points, with probability 95% we can describe about 70% of all investigated values. As we can see from the results, by increasing the point number, the model accuracy describing values does not increase.

The last parameter, the impact of which on the modelled values for accuracy was validated, was selecting the scheme for neighboring point search. Here the law, claiming that points, which are closer next to each other are more similar than those located at a further distance and, therefore, increasing the distance between points and the value investigated, they will be less related to the modelled values, can be applied. Search schemes of neighboring points are affected by the data, which is used for interpolation and modelling the surface of spatial distribution.

Search scheme of the circle for neighboring points is usually employed when the impact on all directions is equal. However, if any dominating impact on modelled values is observed, then the most frequently used search scheme of neighboring points is divided into sectors. Three potential options of neighboring point search scheme divided into serctors, the pictograms of which are provided in table 4.

When searching for the value modelled, it is identified in the centre of the circle and neighboring points are searched for it. All neighboring points, when calculating the value of searched point, bring in different percentage, i.e. the closest points have the weight of more than 10 %, whereas further points will have the weight of correspondingly 5 to 1%.

When applying the circular scheme for search of neighboring points, the worst results were obtained (see table 4). In this case the lowest root mean square standardized error (0.947 mm) and the highest value of root mean square errors (10.89 mm) as well as the average of errors (0.91 mm) were obtained. These results show that the parameter selected will inaccurately predict values.

The results were compared with the option, which, according to reticence, is proposed by the programme itself as the most favourable one. The programme suggests selecting circular scheme for modelling, which is divided into 4 sectors in 45° angle. In this case root mean square standardized error obtained is at the closest distance to one (0.952 mm) and the lowest root mean square errors is 10.81 mm although root mean square errors of the same size were obtained by also applying the forth search scheme of neighboring points. Nevertheless, applying the forth scheme, the standard deviation is 12.94 mm and the mean of errors is 0.31 mm higher than employing the third scheme.

As we can see from results, changing parameters of interpolation method, the accuracy of predicted runoff average depth values did not change significantly. Though, it should be emphasized that interpolating other hydrological characteristics, the results may vary. It is also very important not just rely on statistical parameters but also follow spatial distribution map of analyzed characteristic (to prevent a lot of closed areas).

Having estimated all modelling parameters, one can claim that it is most advisable to investigate spatial dispersion of runoff average depth by applying exponential model of semivariogram, interpolation step of 27 km, and 6 neighboring points as well as circular search scheme divided into 4 sectors in 45° angle. So the map of runoff average depth spatial distribution while interpolating by ordinary Kriging method with selected parameters is illustrated in picture 2. Analyzing the spatial distribution map of runoff average depth the predicted values in 22 centroids (WGS) was higher than investigated, but the received error does not exceed 5%. The highest

Table 4

Analysis of modelled value accuracy with regard to the search scheme for neighbouring points

Schemes of search for neighbouring points	*SD*, mm	*RMSE*, mm	*ME*, mm	*RMSSE*, mm	*t-statistic*	*F statistic*	*α*	R^2
Circle 	14.22	10.89	0.91	0.947	0.25	1.74	0.05	0.60
Circle 	12.93	10.83	0.27	0.949	0.14	1.83		0.65
Circle 	12.87	10.81	0.20	0.952	0.10	1.82		0.74
Circle 	12.94	10.81	0.31	0.951	0.13	1.83		0.65

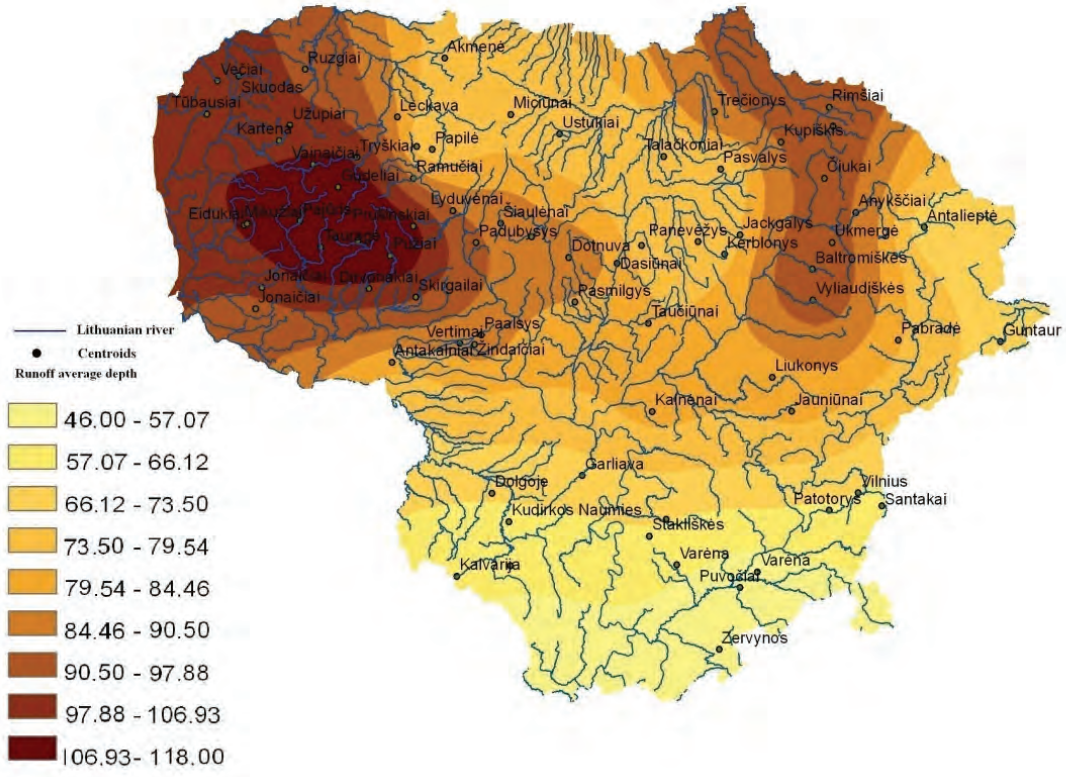


Figure 2. Spatial distribution map of runoff average depth.

error 39 mm was in Bernatoniu centroid (WGS) and the most errors are between 39-(-26) mm. Having selected all the parameters, the interpolation model with probability p = 0.95 described about 74% of all investigated values.

Conclusions

The article provides only general understanding about the selection of interpolation method parameters, analyzing their impact on accuracy of selected hydrological characteristic interpolation. It is crucially important to appropriately select the following interpolation parameters while modeling surface of spatial distribution from runoff average depth. It is also very important not just rely on statistical parameters but also follow spatial distribution map of analyzed characteristic.

The accuracy of predicted runoff average depth values with probability p = 0.95 dependent on the applied variogram model, lag size, neighboring points and search scheme of neighboring points. The investigated values and the predicted values of the interpolation accuracy is within 60-74%. In the present case, changing parameters of interpolation method the accuracy of predicted runoff average depth values did not change significantly.

The best results of the spatial distribution of runoff average depth were received by applying the ordinary Kriging method when the exponential variogram is used as well as 6 contiguous points and the orbicular scheme divided into sectors in 45° angle are taken. Analyzing the spatial distribution map of runoff average depth the predicted values in 22 centroids (WGS) was higher than investigated, but received error does not exceed 5%. Applying the Ordinary Kriging method having selected all parameters with probability p = 0.95, the model described about 74% of all investigated values.

Acknowledgements

The research was supported by Research Council of Lithuania Project „Hydrokinetic resources of the rivers and damless technology for power generation" No. MIP-097/2012.

References

1. Araghinejad S., Burn D.H. (2005) Probabilistic forecasting of hydrological events using geostatistical analysis. *Hydrological Sciences Journal*, 50, pp. 837-856.
2. Arnaud P., Bouvier C., Cisneros L., Dominguez R. (2002) Influence of rainall spatial variability on flood prediction. *Journal of Hydrology*, 260(1-4), pp. 216-230.

3. Bacchi B., Kattogoda N.T. (1995) Indentification and calibration of spatial correlation patterns of rainfall. *Journal of Hydrology*, 165 (1-4), pp. 311-348.
4. Burrough P.A., Mcdonnell R.A. (1998) *Principles of Geographical Information Systems*. Oxford University Press, New York, p. 333.
5. Cressie N. (2004) *Statistics for Spatial Data*. JohnWiley & Sons, New York, p. 504.
6. Čekanavičius V., Murauskas G. (2002) *Statistika ir jos taikymai* (Statistics and its applications). Vilnius:TEV. Vol II., p. 272. (in Lithuanian).
7. Dumbrauskas A., Mozgeris G., Šikšnys A. (2006) Nemuno vagos dugno skaitmeninio paviršiaus modelio sudarymo ypatumai (Pecularities of digital terrain model generation for the Nemunas river bed). In: *Vandens inžinerija: šiuolaikiniai tyrimo metodai ir technologijos*, Lithuanian University of Agriculture, pp. 17-19. (in Lithuanian).
8. Franke R. (1982) Smooth Interpolation Of Scattered Data By Local Thin Plate Splains. *Comp. & Maths*. With Apls, 8(4), pp. 237-281.
9. Gailiušis B., Jablonskis J., Kovalionkovienė M. (2001) *Lietuvos upės*. *Hhidrografija ir nuotėkis* (Lithuanian rivers. Hydrography and runoff). Kaunas, Lietuvos energetikos institutas, p. 794. (in Lithuanian).
10. Johnston K., Ver Hoef J.M., Krivoruchko K., Lucas N. (2001) *Using ArcGIS Geostatistical Analyst*. Redlands CA, ESRI Press, p. 300.
11. Jordan J.D., Mellese A.M. (2003) Spatially distributed watershed mapping and modeling. *Journal of Spatial Hydrology*, 2, pp. 2-29.
12. Jones C.B. (1997) Surface modeling, spatial interpolation. *Geographical Information Systems, Computer Cartography*, 12, pp. 197-213.
13. Kumetienė A., Zakarevičius A. (2006a) Skaitmeninių reljefo modelių tikslumo sąsajų su modeliavimo parametrais ir reljefo morfometrinėmis savybėmis regresinė analizė (Digital terrain model accuracy interfaces with the simulation parameters and morphometric terrain characteristics regression analysis). *Geodezija ir kartografija*, XXXIIt, 3, pp. 71-76. (in Lithuanian).
14. Kumetienė A. (2006b) Skaitmeninio reljefo modelio sudarymas skirtingais geostatistiniais reljefo modeliavimo metodais (Digital terrain modeling by different geostatistical relief modeling methods). *Geografija*, t. 42, 1, pp. 28-32. (in Lithuanian).
15. Kumetienė A., Sužiedelytė-Visockienė J. (2006c) Skaimeninio reljefo modelio patikslinimas mozaikos funkcija (Corrections of digital terrain model accuracy by mosaic function). *Geografija*, t. 42, 2, pp. 35-40. (in Lithuanian).
16. Kumar V. (2006) Kriging of groundwater levels – a case study. *Journal of Spatial Hydrology*, 1, pp. 81-94.
17. Knight Y., Jenkins G., Morris K. (2005) Comparing rainfall interpolation techniques for small subtropical urban catchments. In: Modelling and Simulation, pp. 1674-1680.
18. Krivoruchko K., Gribov A. (2004) Geostatistical interpoliation and simulation with non-euclidean distances. Available at: http://downloads2.esri.com/campus/uploads/library/pdfs/30588.pdf, 12 March 2013.
19. Laffan S.W. (2002) Using process models to improve spatial analysis. *International Journal of Geographic Information Science*, 16(3), pp. 245-257.
20. Marcinkonis S., Karmaza B. (2007) Fosforo akumulcijos duomenų vizualizcija potencialios taršos židiniuose (Visualisation of phosphorus accumulation data in potential pollution sources). *Žemdirbystė*, 1, pp. 64-73. (in Lithuanian).
21. Šarauskienė D., Rimavičiūtė E. (2000) Drūkščių ežero terminio režimo analizę taikant GIS duomenų bazę (Analysis of Lake Druksciai Thermal Regime Database Using GIS). *Geografijos metraštis, 33*, pp. 417-423. (in Lithuanian).

ADVANTAGES OF THE PNEUMATIC PULSE METHOD FOR DEHYDRATION OF THE SEWAGE SLUDGE

Igors Gusarevs
Latvia University of Agriculture
orvi@inbox.lv

Abstract
Utilization of the sewage sludge is pressing and crucial environmental and economic challenge. High moisture content of the sludge is one of the main difficulties during the process of the sewage sludge utilization. Experimental drying module has been designed and manufactered to identify and verify effectiveness of the main parameters of the thermal drying of the sewage sludge with application of the pneumatic pulse method. The pulser is supposed to be part of the technological scheme in order to speed up the process of drying and saving energy. The pulser supplies hot air into the drying chamber with time intervals by pulse. In the drying chamber the airflow dislodges water molecules from the material by means of pulses and then they are taken away from the drying chamber. For the convenience of the comparison and evaluation of the executed experiment the following general characteristics were selected: drying rate – i – kg min^{-1}; power consumption – q – kWh kg^{-1}. The greatest effect in application of the pneumatic pulse method for dehydration of the sewage sludge was achieved at the angle of incidence equal to nearly 90° of the airflow on the dried sample and higher temperature. The experiment showed that application of the pneumatic pulse method for dehydration of the sewage sludge allows to reduce power consumption and speed up the process of drying. The process of drying can be executed at lower temperatures.
Key words: sewage sludge, pneumatic pulse method, dehydration of the sewage sludge.

Introduction

Utilization of the sewage sludge (SS) is pressing, and it is crucial environmental and economic challenge.

Over the last years more than 50% of the SS produced in Latvia every year remain on the temporary storage grounds near the treatment facilities or in other places (Gemste and Vucāns, 2010). It means that year by year a growing amount of the SS impedes proper work of the treatment facilities and causes aggravation of the environmental situation.

High moisture content of the sludge is one of the main difficulties during the process of the SS utilization. Mechanical methods of removing moisture from the SS allow to reduce its percentage up to 800 g kg^{-1}. However, in the condition of shrinkage of required land plots for the sludge sites application of the mechanical methods of the SS dehydration require increased power consumption. Thermal drying of the SS is not applied in Latvia.

Thermal drying of the SS is executed mainly upon completion of the mechanical dehydration. After the thermal dehydration the SS is clean, free from worms and pathogens bulk material with 100-500 g kg^{-1} moisture content (Gusarevs, 2012). Upon completion of the thermal drying, the SS can be considered as treated according to the conditions of the Cabinet Council № 362 of May 2, 2006 (Noteikumi par notekūdeņu dūņu…, 2006). After the completed dehydration the overall amount and volume of the SS decreases several times, and all this significantly reduces cost of its further utilization. Dehydrated and decontaminated SS may be considered a valuable product and used as either a fertilizer or fuel.

The task of the modern technology on treatment of the SS is to meet the contemporary challenge and transform SS into the environmentally safe product as well as apply the SS valuable components with the significant reduction of the sludge amount as a result of dehydration. Selection of the method applied shall be determined by local conditions and taking into account physical and chemical properties of the sewage sludge, sanitary and epidemiological requirements, and technical and economic calculations (Gusarevs, 2012).

Application of the pulse technology of the dehydration for the utilization of the SS may allow to speed up the process of drying, reduce power consumption and capital investment executing the process of dehydration at lower temperatures and in less hazardous explosive conditions.

Taking into account the novelty of the method, comprehensive studies are required to determine fundamental parameters and factors during the process of design, production and operation of the pulse equipment applied for the dehydration of the SS.

Materials and Methods

It is a well-known fact that thermal drying with application of the pneumatic pulse method significantly speeds up the process of drying bulk materials (Engeļbrehts et al., 2003). Mechanically dehydrated SS is a large-capacity homogenous mass. An experimental drying module has been designed

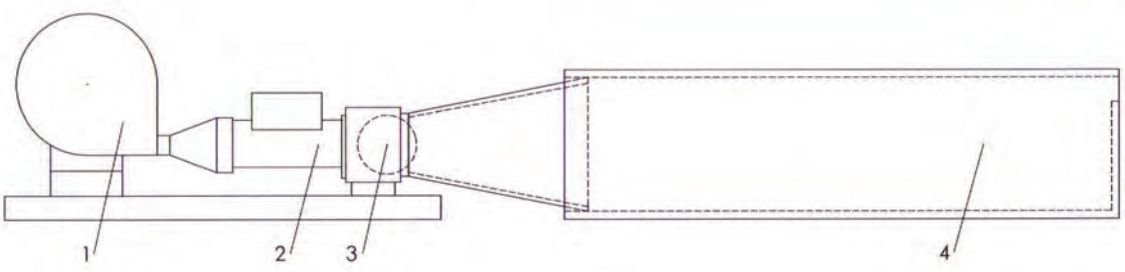


Figure 1. Scheme of the experimental drying module.
1 – a blower; 2 – an electric heat generator; 3 – a pulser; 4 – a drying chamber.

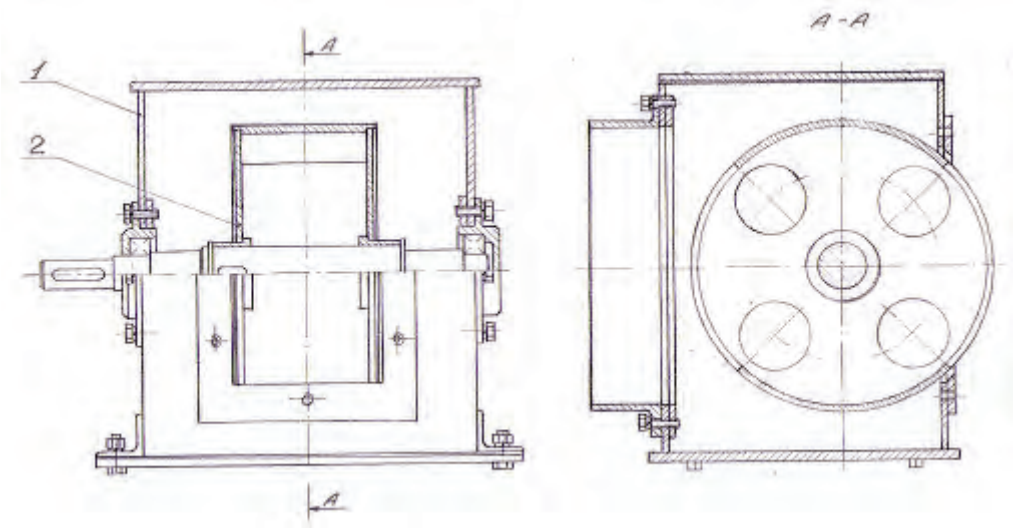


Figure 2. Pulser.
1 – a body; 2- a hollow cylinder.

and manufactured to identify and verify effectiveness of the main parameters of the thermal drying of the SS with application of the pneumatic pulse method. A diagram of the experimental drying module is shown in the Figure 1.

First, the blower delivers the airflow into the heat generator. While passing through the heat generator heated air enters into the pulser. Then, the pulser supplies hot air into the drying chamber with time intervals by pulse. In the drying chamber the airflow dislodges water molecules from the material by means of pulses and they are then taken away from the drying chamber.

The pulser is supposed to be a part of the technological scheme in order to speed up the process of drying and saving energy. The pulser is a hollow cylinder rotating in the close body. The cylinder is divided on the perimeter into four equal sectors. Two opposite sectors are open, and airflow freely comes through them. By rotating pulser sectors open and close, the outgoing air duct in the body from time to time, thereby producing regular breaks in the airflow delivery – pulses (Figure 2). One rotation of the pulser axis produces two pulses.

Parameters of the main parts of the experimental drying module were selected upon determination of the dried sample weight required for the experiment as well as executed preliminary calculations.

Blower.

Type – AAVA 400/P T2.

Power – N = 0.55 kW.

Amount of airflow – Q = 200 $m^3 h^{-1}$.

Pressure – P = 2650 Pa.

Diameter of the outlet of the air channel – d = 54 mm.

Electric heat generator.

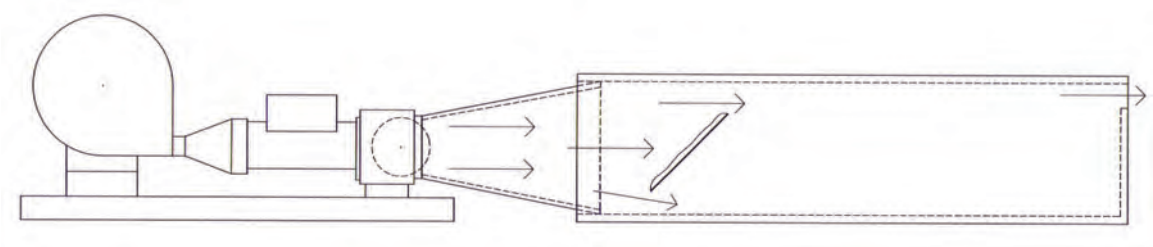
Power, max. – N = 2.4 kW.

Amount of airflow – Q = 140 $m^3 h^{-1}$.

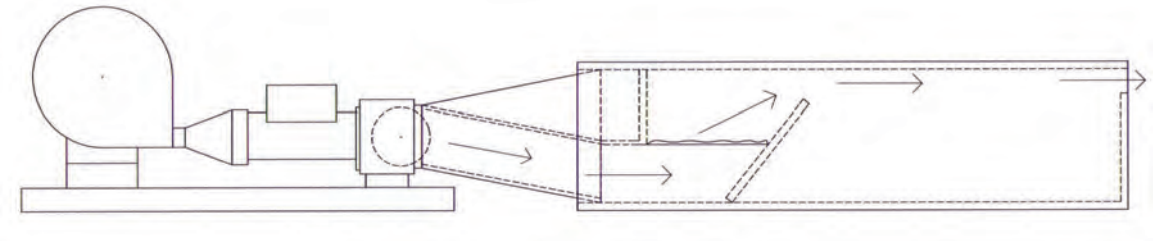
Temperature regimes – T_1 = 50 °C, T_2 = 100 °C.

Diameter of the air channel – D = 160 mm.

The blower is connected to the heat generator by means of the cone with an angle of 10°. Operating temperature mode was determined as T_1 = 50 °C. Drive of the pulser is executed by means of the geared



a) Airflow on the material.



b) Airflow from the bottom.

Figure 3. Rectangular drying chamber.

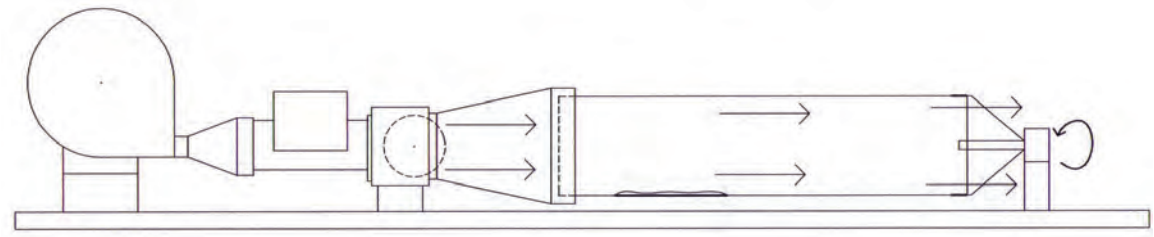
motor HU 40S 72K4, 122 rotations per minute. The pulser provides 4 pulses per second.

In the experiment the following has been tested:

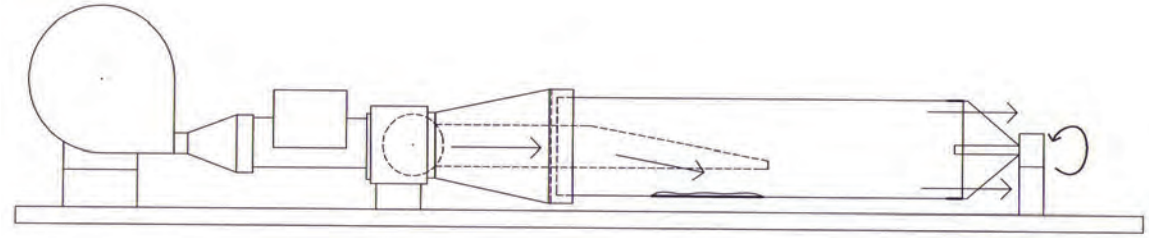
- impact of the pulse airflow on the drying process of the SS;
- impact of the temperature modes on the drying process of the SS using pneumatic pulse method;
- impact of the angle of incidence of the airflow on the material in the process of SS drying using pneumatic pulse method.

Since the above-mentioned parameters are closely linked, their characteristics were recorded simultaneously during the experiment. Research was carried out in a fixed rectangular drying chamber and in a rotating cylindrical drying chamber.

Structure and dimensions of the rectangular drying chamber (Figure 3) were determined based on the characteristics of the airflow and taking into account access to the dried sample. Angle of incidence of the airflow on the dried sample was defined in 30° and 45°. Subsequently, upon making structural changes,



a) Airflow in parallel to the material.



b) Airflow on the material.

Figure 4. Rotating cylindrical drying chamber.

a supply of the airflow to the drying chamber was delivered from the bottom.

A rotating cylindrical drying chamber (Figure 4) was applied in view of the fact that the drying chamber taken as a prototype of the industrial equipment for drying and burning SS has the same cylindrical shape. Dimensions of the rotating cylindrical drying chamber were determined based on the airflow characteristics.

Table 1

Basic index

No	Parameter of the drying chamber	Sample position in the chamber.	Temperature of the airflow, t °C	Drying rate (i), kg min^{-1}	Energy consumption (q), kWh kg^{-1}	Note
1.	Rectangular shape. Without pulser.	30° to the airflow.	18	0.00125	10.929	
2.	Rectangular shape. With pulser.	30° to the airflow.	18	0.00105	13.932	
3.	Rectangular shape. Without pulser.	45° to the airflow.	19	0.00130	11.000	
4.	Rectangular shape. With pulser.	45° to the airflow.	19	0.00159	9.430	
5.	Rectangular shape. Without pulser.	45° to the airflow.	50	0.00140	38.000	Indoor + 19 °C
6.	Rectangular shape. With pulser.	45° to the airflow.	50	0.00220	24.650	Indoor + 19 °C
7.	Rectangular shape. Without pulser.	Airflow from the bottom	50	0.00212	24.290	Indoor + 24 °C
8.	Rectangular shape. With pulser.	Airflow from the bottom.	50	0.00225	20.000	Indoor + 24 °C
9.	Rectangular shape. Without pulser.	Airflow from the bottom.	50	0.00200	24.793	Indoor + 20 °C
10.	Rectangular shape. With pulser.	Airflow from the bottom.	50	0.00173	26.974	Indoor + 20 °C
11.	Rotating cylinder. Without pulser.	Expanded in a cylinder.	50	0.00527	9.159	Indoor + 20 °C
12.	Rotating cylinder. With pulser.	Expanded in a cylinder.	50	0.00540	9.850	Indoor + 20 °C
13.	Rotating cylinder. Without pulser.	Expanded in a cylinder.	50	0.00542	9.840	Indoor + 16 °C
14.	Rotating cylinder. With pulser.	Expanded in a cylinder.	50	0.00565	9.428	Indoor + 16 °C
15.	Rotating cylinder. Without pulser.	Airflow is directed to the sample.	50	0.00487	10.950	Indoor + 7 °C
16.	Rotating cylinder. With pulser.	Airflow is directed to the sample.	50	0.00648	8.226	Indoor + 7 °C

The airflow was delivered in parallel with the dried sample in the cylinder or alternatively was directed towards the dried sample.

For the convenience of the comparison and evaluation of the executed experiment the following general characteristics were selected:

- drying rate – i – kg min^{-1};
- power consumption – q – kWh kg^{-1}.

Results and Discussion

Main characteristics obtained in the process of the executed experiments are produced in Table 1.

The experiment has shown the following:

- when the angle of incidence of the airflow on the dried sample was 30°, the pneumatic pulse method showed no advantages;
- when the angle of incidence of the airflow on the dried sample was 45°, the drying rate of the pneumatic pulse method increased, and power consumption reduced in relation to the non-pulse delivery of the airflow;
- when temperature of the airflow increased up to 50 °C, the drying rate of the pneumatic pulse method increased, and power consumption reduced in relation to the non-pulse delivery of the airflow;
- when the airflow was supplied from the bottom in this experiment, the pneumatic pulse method showed no advantages;
- when the airflow was delivered to the rotating cylindrical drying chamber parallelly to the dried sample, the pneumatic pulse method showed no significant advantages;
- when the airflow was directed towards the dried sample in the rotating cylindrical drying chamber, the drying rate of the pneumatic pulse method increased, and power consumption reduced in relation to the non-pulse delivery of the airflow.

The greatest effect in application of the pneumatic pulse method for dehydration of the SS was achieved at the angle of incidence equal to nearly 90° of the airflow on the dried sample and higher temperature.

Conclusions

The experiment has confirmed the following:

- the pulse airflow does speed up the process of the SS drying;
- when the pneumatic pulse method is applied, the drying rate of the SS tends to speed up at the higher temperature of the airflow;
- an angle of incidence of the airflow equal to nearly 90° is the most effective when the pneumatic pulse method is applied for dehydration of the SS.

The experiment showed that application of the pneumatic pulse method for dehydration of the SS allows to reduce power consumption and speed up the process of drying. The process of drying can be executed at lower temperatures. Taking into account results of the experiment and interest on the part of the process equipment, manufacturers (company VOMM) mutual development of the technologies and equipment is intended at the next stage of the research.

References

1. Gemste I., Vucāns A. (2010) *Notekūdeņu dūņas* (Sewage sludge). Otrais papildinātais izdevums. Latvijas Lauksaimniecības universitāte, Jelgava, 174 lpp. (in Latvian).
2. Engeļbrehts A., Dobrodušins M., Gerdt O., Pētersons R. (2003) Paņēmiens birstošu materiālu žāvēšanai pseidoverdošā slānī, hidrotriecienu viļņu ģeneratora žāvētava tā realizēšanai (The method of loose material drying in fludised bed, fluid shock wave generator and the dryer for the method realisation). Available at: http://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&II=0&ND=..., 21 March 2012. (in Latvian).
3. Gusarevs I. (2012) Pneumatic pulse method in the technology of dehydration and utilization of the sewage sludge. In: A*nnual 18th International Scientific Conference Proceedings „Research for Rural Development 2012" Volume No. 2*, Latvia University of Agriculture, Jelgava, pp. 180-183.
4. Gusarevs I. (2012) Dzeramā ūdens nosēdumu un notekūdeņu dūņu žāvēšanas paņēmiens un iekārta, karstā gaisa plūsmu padodot impulsveidīgi (Pulse method for drying of drinkable water sediments and sewage sludge by hot airflow feeder). Available at: http://www.patbib.gov.lv..., 12 March 2013. (in Latvian).
5. Noteikumi par notekūdeņu dūņu un to komposta izmantošanu, monitoringu un kontroli (Terms of sewage sludge and compost utilization, monitoring and control) (2006) LR Ministru kabineta noteikumi Nr. 362. Available at: http://www.likumi.lv/doc.php?id=134653, 21 March 2012. (in Latvian).

THE CHANGE OF WATER QUALITY IN THE SINKHOLES IN LITHUANIAN KARST ZONE

Aurelija Rudzianskaite
Aleksandras Stulginskis University, Lithuania
Aurelija Rudzianskaite@asu.lt

Abstract
The paper overviews the research material related to occurrence of sinkholes and change of their water quality in the conditions of increasingly natural environment and minimal anthropogenic impact. Sinkholes create favourable conditions for interaction of surface and groundwater. Identification of possible sources of sinkholes pollution is very important in solution of groundwater safety problems. Water quality investigations are carried out in 4 sinkholes, which are of different age and have differently overgrown slopes. Sinkhole water quality may worsen due to accumulation of organic materials (increasing peat content) or natural changes of environment (abrasion of slopes, overgrowth, etc.), while anthropogenic impact is minimal. Water quality in peat-filled sinkholes and young sinkholes with mineral slopes is different. Water of peat-filled sinkholes has bigger amounts of $N\text{-}NO_3$, P_{Total}, SO_4 and BOD_7 than water in young sinkholes. The highest $N\text{-}NO_3$ and SO_4 concentration is observed in the sinkhole that is overgrown with trees and shrubs.
Key words: karst zone, sinkhole, water quality, natural environmental.

Introduction

The karst phenomena occurs in different countries. Central America constitutes a significant international carbonate karst landscape with an area totalling about 23% of its total land (Kueny and Day, 2002). Slovenian karst areas extend over 43% of the country, where karst groundwater contributes up to 50% of the total drinking water supply (Kovačič and Ravbar, 2005). Over 80% of Serbian populiation and industry use groundwater for water supply. The main aquifer systems are formed in alliuvial deposits and highly karstified carbonate rocks (Stevanovič et al., 2007). The karst groundwater use in the North and South China (Lu, 2007).

The subsurface of all three Baltic Republics of Estonia, Latvia and Lithuania with a total area of 175,000 km^2, is composed of karst sediments of various age and type. The Ordovician, Silurian, Devonian, Carboniferous and Permian limestones, dolomites, gypsum, gypsiferous dolomites etc., are outcroping or covered with a thin Quaternary strata (Paukštys, 1996).

Karst in the North Lithuania is matured not only at the land surface but also in the subsurface. Surface karst forms are represented by sinkholes, karst shafts, land subsidences, lakes, dolines. Subsurface forms are the enlarged dissolution voids, cavities and caves. More than 8500 sinkholes, different in size and shape, are counted in the region of active gypsum karst covering the area of 400 km^2 (Paukštys, 1996; Narbutas et al., 2001).

Under normal conditions the concentration of Ca, SO_4, Mg, HCO_3 ions in the Lithuanian surface waters rarely exceed the maximum concentration limits adopted in Lithuania. However, in the karst landscape these concentrations are often higher due to dissolution of gypsum and dolomite (Satkūnas et al., 2006).

The rate of chemical denudation of soluble rocks is one of the main factors determining the intensity of karst process. Gypsum rocks are most soluble in North Lithuanian karst region. Due to rapid water circulation between surface and underground water, gypsum rocks dissolve and are carried out to the Lielupe River. Gypsum denudation is mainly predetermined by water balance which depends on meteorological conditions, especially precipitation and evaporation. The highest intensity of gypsum denudation is during the spring flood, the lowest in the dry period. In comparison with 2009, it increased from 156 to 167 m^3 km^{-2}. This denudation intensity value is by 9% lower than the average value for 1994-2010 yet even by 44% exceeds the value for 1963-1979 (Taminskas, 1999; Taminskas and Mikulėnas, 2010; Taminskas et al., 2011).

The unique ecological structure with a variety of biological processes is formed by specific conditions in water bodies. Karst lake bottom sediment is the ecological zone, where specific econiches are formed by organisms decomposing organic substances till the final products – CO_2 and H_2S (Paškauskas et al., 1998).

Some new (for Lithuania) species of zooplankton were found in karst region water basins - Keratella valga Ehrenberg, K. valga heterospina Klausener, K. testudo Ehrenberg, Notholca labis Gosse, Notomata aurita Muller, Bosmina kessleri Uljanin. According to amount and species of planktonic algae in the lakes, sinkholes and Tatula river are an eutrophicated water body (Kasperovičienė et al., 1998).

In an ecologically susceptible karst zone, a regular formation of sinkholes is a hazard for the safety of people and buildings and creates favorable

conditions for the migration of contaminants into the groundwater. Polluted drinking groundwater is dangerous for people‘s health. The salt-saturated water becomes more aggressive and intensifies karst process of the rocks lying below.

The main human activities influencing karst development are groundwater extraction and agriculture (Paukštys, 1996). The foreign researches (Dell Rose et al., 2004) maintain that karst formation may be either natural or caused by man’s activities.

The naturalness of environment not always ensures the proper water quality. Water quality can decline due to unused arable land, which is not taken care of, the meadow overgrown with scrub and trees or fallow and other natural changes in the environment.

Soil chemical properties were compared to evaluate the advantages and negative effects of various treatments of soil renaturalization. After a 10-year period of different land use, soils didn’t differ cardinally in organic matter content and their mineralization parameters (C%, total N% and C/N ratio). Soil properties were closer to those of arable than forest soils. Unfertilized soils of sward cenoses drastically declined in available P and K (Marcinkonis, 2007). The trees and the shrubs in the channels at the beginning of vegetation had an impact on water quality (nitrate nitrogen concentration decreases) (Lamsodis, 2001). The microorganism increased in the surface of virgin soil. However, nutrients leached more intensively, especially nitrogen (Žėkaitė et al., 2007).

In the Lithuanian karst region, where the hydraulic link between the surface and groundwater is very good, even small sources of pollution (pollutants from precipitation and surface runoff, remains of decomposition of organic materials) may entail substantial changes of ground water quality (Taminskas, 2002).

The 67 indicator species (55.5% of all zooplankton taxon) which show organic matter in the water body of karst zone were determined (Kasperovičienė et al., 1998). Three expressed layers of organic matter synthesis in the water column were determined. They are: epilimnion – phytoplankton primary production; the upper layer of hypolimnion – anoxic photosynthesis by bacteria and anaerobic hypolimnion in 4 m deep – dark CO_2 assimiliation by various chemosynthetic bacteria (Paškauskas et al., 1998).

In order to protect groundwater quality in karst region, it is necessary to otbtain comprehensive information about the natural processes in this region.

The aim of the paper is to ascertain the peculiarities of change water quality of sinkholes in the natural environment conditions with minimal anthropogenic impact.

The changes of water quality were analyzed according to sinkholes age and its slopes overgrowth.

Materials and Methods

Geological and hydrological setting of the Lithuanian karst region

The karst processes highly active in North Lithuania (mainly in Biržai and Pasvalys administrative districts) are related to Upper Devonian gypsum and dolomites that occur beneath the Quaternary cover. The cover of karstified rocks consists mainly of Quaternary deposits (loam and sandy loam, sand, gravely sand, gravel clay, silt); in some places karstified rocks are overlain by the Pamūšis Formalion (dolomitic marl, clay and other) and the Įstras Formation (dolomite) of Upper Devonian (Марцинкявичюс и Буцявичюте, 1986; Narbutas et al., 2001; Dėnas and Račkauskas, 2005).

The thickness of the cover of karstified rocks in the karst area varies from parts of the first meter up to 70m and has a common tendency to increase southwards and especially westwards (Марцинкявичюс и Буцявичюте, 1986; Račkauskas, 2004). Sinkholes are located in the areas with the cover thickness less than 25 meters. In the areas where the cover thickness is up to 5 m new sinkholes are forming intensively.

According to age, the sinkholes were divided in new (emerged in the last 20 years), young (emerged 20-100 years ago), old (emerged 100-1000 years ago) and very old (more than 1000 years ago) sinkholes. 5273 young and new sinkholes were distinguished (Minkevičius, 2011).

The North Lithuania karst region is located in the eastern part of the Baltic artesian basin. The active water change zone is up to 270 m thick and includes aquifers in the Quaternary and in the Įstras –Tatula, Kupiskis-Suosa, Sventoji-Upninkai formations of the Upper Devonian. This series of aquifers is underlain by the 60-100 m thick regional aquitard of the Narva Formation. The main source for recharge of the Įstras –Tatula and Kupiskis-Suosa aquifers is shallow groundwater and surface water. Variations in level and chemical composition of groundwater are determined by the rate of infiltration of precipitation. Ground collapse usually affects the Quaternary cover and permits ready recharge of surface water into the Upper Devonian aquifers. Areas with such intensive water circulation in open gypsum systems are referred to as the intensive karst zone (Juodkazis, 1992; Paukštys, 1996; Satkūnas et al., 2006). Water of the aeration zone mostly infiltrates through vertical fissures until it reaches either horizontal channels or impermeable soil layer. A large amount of rainwater is collected in the bottom of the sinkholes, which are open holes or filled with permeable deposits (Narbutas et al., 2001).

Most of the sinkholes of the karst region are dry. They collect and temporarily retain atmospheric or groundwater only during spring floods. The newly occurring sinkhole in the course of time becomes shallow as a result of sedimentation processes and transforms into small bogs. As a result of a very good hydraulic link between the surface and ground water, part of sediments is eliminated with the ground runoff (Taminskas, 1999).

Location of studied sinkholes

The studies of water quality in sinkholes were carried out in the active karst zone in 2008-2012 (Fig. 1).

The sinkhole 1 was old age and peat – filled, covered with marsh vegetation, it was usually dry in the summer. The sinkhole area is 0.105 ha. Sinkhole was surrounded by meadows, at 25 m distance from the stream G-1.

The sinkhole 2 (few merged sinkholes) was old and peat – filled, overgrown with trees and shrubs, it is dry in the summer. The trees and shrubs covered area was 0.572 ha.

The sinkhole 3 was a new one. Water regularly filled it about 2 m from the ground surface. Slopes were mineral ground, mostly overgrown with grass vegetation, but fast growing shrubs, abrasion going on the slopes. The sinkhole area is 0.021 ha. The sinkhole was surrounded by meadows.

The sinkhole 4 was young, water filled about 0.5 m above the ground surface, the coast was covered with wetland vegetation. The sinkhole area is 0.057 ha. In this environment, there were many dry and old sinkholes covered with grasses.

To evaluate groundwater quality, two wells were installed in sinkholes 1 and 2, while were absent surface water in sinkhole. During the study period, surface water samples were collected from the sinkholes 3 and 4.

Analysis of water and slopes soil samples was carried out at the Chemical Analysis Laboratory of Water Management Institute of ASU. Chemical analysis included the following methods: nitrate-nitrogen ($N\text{-}NO_3$) – photocolorimetric with analyser "FIA star 5012 system"; total phosphorus (P_{Total}) – spectrometric method, after mineralization with potassium persulphate; sulfate (SO_4) (in the water and in the soil samples) – gravimetric, pH (in water samples) and pH_{KCl} (in soil samples) – potentiometric

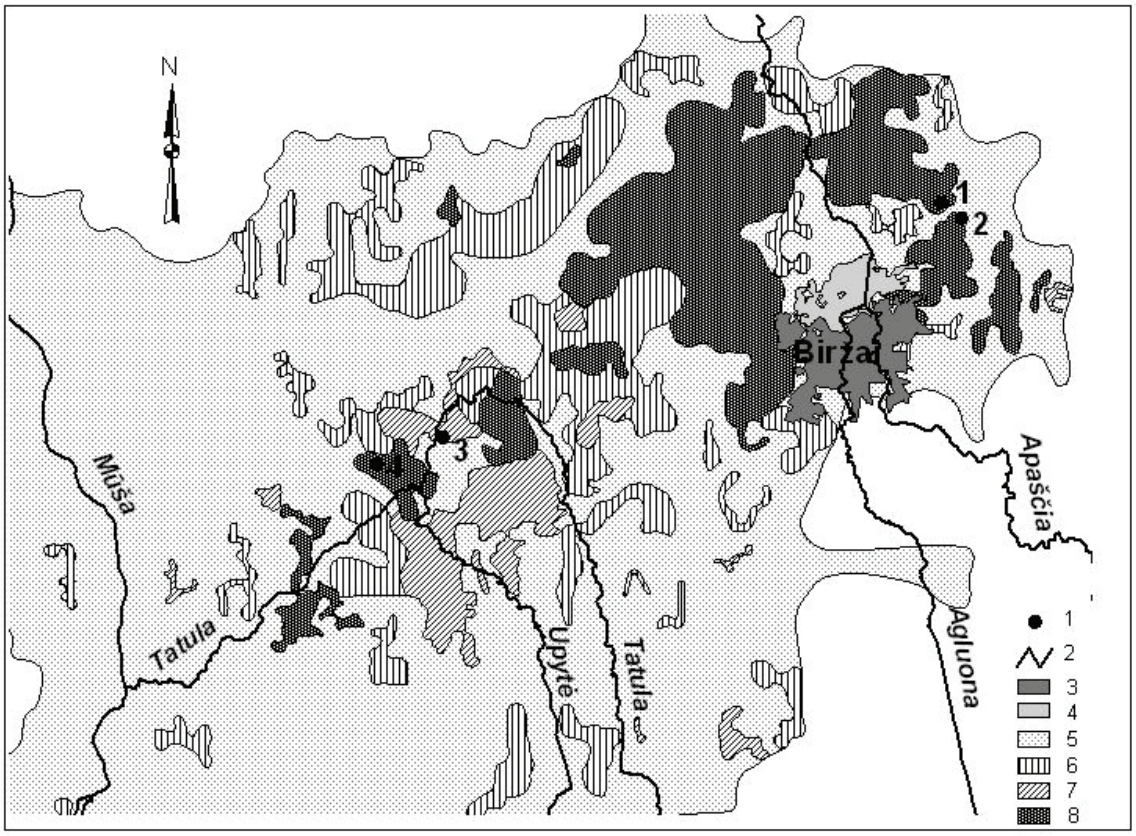


Figure 1. Scheme of study site: 1 – studied sinkholes; 2 – river; 3 – Town Biržai; 4 – Lake Širvena. According to the number of sinkholes, the karst terrain is divided into groups: 5 – <20 sinkholes km^{-2}; 6 – 20-50 sinkholes km^{-2}; 7 – 50-80 sinkholes km^{-2}; 8 – >80 sinkholes km^{-2}.

Table 1

Soil chemical properties in slope of sinkhole

Sinkhole	pH_{KCl}		SO_4, mg kg^{-1}	
	Depth of soil samples, cm			
	20	60	20	60
1	7.03	7.13	99.3	86.0
2	5.23	5.18	184.1	216.2
3	7.30	7.73	73.5	95.7

with glass elektrode; biochemical oxygen demand (BOD_7) – the amount of oxygen, which is used in seven day period for biochemical oxidation of organic particles under aerobic conditions.

In the scheme of study site the active karst terrain was marked according to the Lithuanian Geological Survey map.

Acidity – alkalinity index pH was from (5.18) to neutral reaction (7.73) in slope soil of investigated sinkholes (Table 1). The lowest value of pH_{KCl} was found in the slope soil of sinkhole 2 within peat filled and overgrown with trees and shrubs. The highest value of pH_{KCl} (neutral reaction) was in the soil of sinkhole 3. The highest amount of sulphates in slope soil was found in the sinkhole 2 overgrown with trees and shrubs.

The sinkhole 4 was filled with water and soil samples not taken.

In the paper research material was used by different researchers, and the investigation was carried out in Water Research Institute of ASU.

Statistical evaluation of the research data is based on standard deviation and correlation analysis.

Results and Discussion

pH in water of investigated sinkholes was neutral (6.5-7.3) or slightly alkaline (7.7-8.3) (Table2). Slightly alkaline water was most cases (87% of all samples) in the sinkhole 3 and sinkhole 4 (83% of all samples) but the lowest in the sinkhole 2 (14% of all samples) and sinkhole 1 (23% of all samples). The lower pH was in water from sinkholes (1 and 2) covered with peat.

In the karst lakes the largest part of the water balance income is composed by precipitation fall on the surface of the lake (Taminskas, 1997).

The snow in karst region contained organic nitrogen concentration from 0.3 to 0.78 mg N L^{-1}, inorganic nitrogen – 0.46 to 0.77 mgN L^{-1}, organic phosphorus – from 0.019 to 0.059 mg P L^{-1}, inorganic phosphorus concentration - 0.006 to 0.012 mg P L^{-1}. The precipitation on the total contained phosphorus 0.021-0.301 mg L^{-1}, average nitrate 1.9 mg L^{-1} and sulphate - 15.3 mg L^{-1} (Chomčenko et al., 2000; Rudzianskaitė and Šukys, 2008).

In the study period nitrate nitrogen (NO_3-N) concentrations ranged from 0 to 0.97 mg L^{-1} in sinkholes 1, 3 and 4 (Table 2). In most cases NO_3-N concentration in water of sinkhole was similar to this concentration in precipitation. The higher concentrations (up to 0.97 mg L^{-1}) were in the sinkhole 1 covered with marsh vegetation and particularly high (up to 32.2 mg L^{-1}) concentration in the sinkhole covered with trees and shrubs and 41%

Table 2

Fluctuation of pH, nitrate nitrogen (N-NO_3) and total phosphorus (P_{Total}) concentration in sinkhole water

Sinkhole	pH				N-NO_3				P_{Total}			
					mg L^{-1}							
	Mean	Min	Max	St.dev	Mean	Min	Max	St.dev	Mean	Min	Max	St.dev
1	7.1	6.5	7.8	0.44	0.10	0	0.97	0.25	0.42	0.042	1.32	0.40
2	7.2	6.8	8.3	0.33	11.39	0	32.2	11.01	0.35	0.036-	1.03	0.31
3	7.8	7.3	8.3	0.28	0.02	0	0.189	0.04	0.05	0.017	0.132	0.03
4	7.7	6.8	8.1	0.29	0.01	0	0.059	0.02	0.05	0.013	0.118	0.03

of the measurements exceeded 10 mg L^{-1}. The higher NO_3-N concentration in this sinkhole was at the time when water was hold above the ground surface.

In all sinkholes higher nitrate nitrogen concentrations (0.01-21.78 mg L^{-1}) were in the cold period than in the vegetation period (0.009-5.8 mg L^{-1}). During the summer time, when the photosynthesis intensifies in surface waters, the nitrate concentration reduces due to the fact that it is assimilates by aquatic organisms (Diliūnas and Kaminskas, 2003). Particularly high concentrations of NO_3-N (average cold period 21.78 mg L^{-1}) were found in the sinkhole 2 covered with trees and shrubs. At this time, the water was usually upper to the ground. One of the reasons for determining the amount of nitrate nitrogen can be mineralization of tree leaves and shrubs and compound access with leaf. Depositions of nitrogen (oxidized and reduced) were increased under canopy because of wash – off dry deposition from foliage and foliar leaching. But the load of nitrogen under canopy during the vegetation period was smaller because of canopy uptake. The load of nitrogen under the canopy was reduced 2-3 times, the accumulation of nitrogen dominated (Juknys et al., 2002).

The higher total phosphorus (P_{Total}) concentrations (0.036 to 1.32 mg L^{-1}) were found in the sinkhole filled with peat than in the younger sinkhole (0.017 to 0.132 mg L^{-1}) in the vegetation period.

SO_4 concentration (up to 1175 mg L^{-1}) and Ca (up to 540 mg L^{-1}) dominated in the lake water, when the lake bottom connected with gypsum layers (Taminskas, 1997). Sulphur leaching with precipitation increased during the warm season, and after 1-2 months its leaching increased in the stream water (Baužienė, 2005). It can be assumed that investigated sinkholes are mainly fed with rain water and water quality determines nutrient amount in the soil. The higher SO_4 concentrations were in sinkholes 1 and 2 (average up 88.5 mg L^{-1}, standard deviation ± 50.7) covered with peat than younger sinkholes 3 and 4 (average up 16.4 mg L^{-1}, standard deviation ± 9.4) (Fig. 2). The more humus and total nitrogen are in soil, the

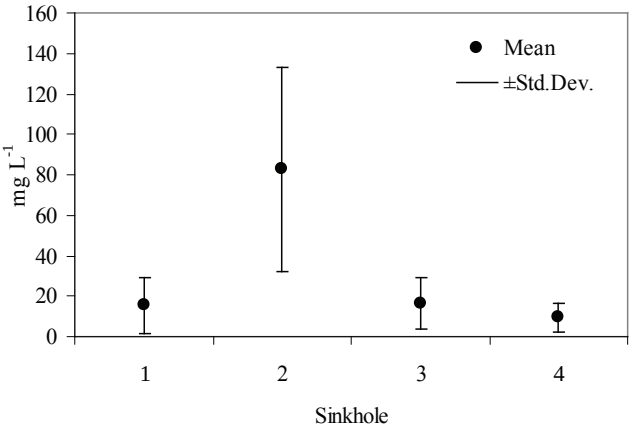


Figure 2. Concentration of sulphate in the water of sinkholes.

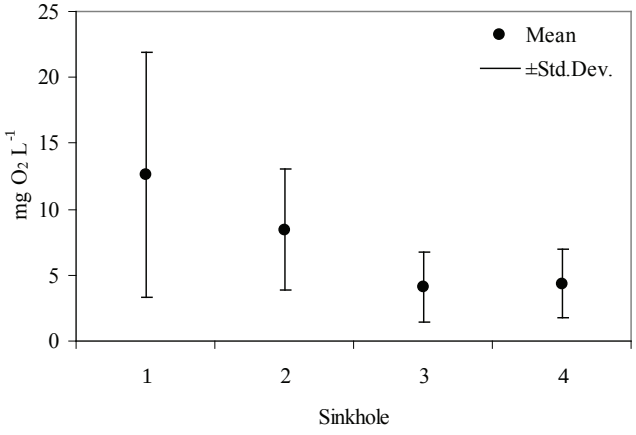


Figure 3. Concentration of organic matter (according to BOD_7) in the water of sinkholes.

more sulphur is there. Sulphur compounds oxidized to sulphates in the aerobical condition. Sulphur is reduced to hydrogen sulphide in anaerobic condition. The low (0.01-0.8%) sulphur is in the mineral soil and more (1%) - in the peat soil (Adomaitis, 1998).

The highest concentrations of sulphate (7.0 to 172.0 mg L^{-1}) in the sinkhole 2 covered with trees and shrubs may be related to the tree conopy uptake and the sulfate amount (up to 216.2 mg kg^{-1}) concentration in peat soil. Literature sources (Juknys et al., 2002) state that the load of different substances with throughfall is rather different from that in open areas. Total load of sulphur to forest ecosystems is more intensive than it is in open areas because of more intensive dry deposition.

Higher SO_4 concentration was in sinkholes 1 and 2 in the cold period, but in sinkholes 3 and 4 - in the vegetation period.

The organic matter fluctuation was present in investigation sinkholes related to sedimentation. Higher concentration (1.91-32.0 mg O_2 L^{-1}) of organic matter according to BOD_7 was in the water of sinkhole filled with peat than in younger sinkholes (1.4 -14.2 mg O_2 L^{-1}) (Fig. 3).

The highest rate of sedimentation is characteristic to genetically young karst lakes. This is determined by an intensive slope abrasion. Inorganic material dominates in the sediments of such lakes – up to 79% of the total amount of sediments. In an older lake with more stable shores, the slope abrasion slows down whereas the content of organic material increases. A particularly great part of sediments is composed of products of trees growing on the shores of lakes which directly get into the karst lakes. The tree products represent the main source of organic material and nutrients getting into the karst lakes (Taminskas, 1999). The water in the peat soil has more organic matter (Никаноров, 1989).

Literature sources (Kaiser et al., 2001) state that change in composition of dissolved organic matter during a year influences the migration of these materials. In summer and autumn, soluble organic matter forms under the influence of decay processes (as a result of strong oxidation), in winter and spring they are leached out like sediments of recently destroyed biomass. In the latter period, organic matter is characterized by increased mobility, strong biodegradation and weak interaction with metals.

More organic material was found in the open sinkholes 1, 3 and 4 in the vegetation period. In warm and sunny period concentration of organic matter is higher than that in cold and not sunny time due to intensive photosynthesis in surface water bodies (Diliūnas and Kaminskas, 2003).

In the sinkholes densely covered with trees, where the surface layer of water is in the shade, there is hardly any direct sunlight; therefore, the surface temperature is lower. This kind of isolation affects microorganisms (Žvikas et al., 2002). The precipitation averages to 10% less on the wooded sinkholes than on sinkholes that are not covered with trees. During the vegetation period, especially when there is low-intensity rainfall, the growth reduces runoff on the slope. When the vegetation period finishes, the organic matter is washed into the sinkhole (Taminskas, 2002).

Precipitation amount fluctuation explains only 42-59% (coefficient of determination r^2 = 0.42-0.59, Student's test t_{actual}=3.61-5.36>$t_{0.05}$=1.725) of variation of the organic matter concentration in the studied open sinkholes (3 and 4), because other variables are not considered.

Conclusions

1. Sinkholes create favourable conditions for interaction of surface and groundwater. Identification of possible sources of sinkholes pollution is very important in solution of groundwater safety problems.
2. Sinkhole water quality may worsen due to accumulation of organic materials (increasing peat content) or natural changes of environment (abrasion of slopes, overgrowth), while anthropogenic impact is minimal.
3. In most cases, $N\text{-}NO_3$ (0-0.97 mg L^{-1}) and P_{Total} (0.017-0.042 mg L^{-1}) concentrations in water of sinkholes were similar to this concentration in precipitation (respectively 0.429 mg L^{-1} and 0.021-0.301 mg L^{-1}).
4. Water quality in peat-filled sinkholes and in young sinkholes with mineral slopes is different. Water of peat-filled sinkholes has higher amounts of $N\text{-}NO_3$ (0-32.2 mg L^{-1}), $P_{Total.}$ (0.36-1.32 mg L^{-1}), SO_4 (2.7-172.0 mg L^{-1}) and BOD_7 (1.91-76.0 mg O_2 L^{-1}) than water in young sinkholes.
5. The highest $N\text{-}NO_3$ (up 32.2 mg L^{-1}) and SO_4 (up 172 mg L^{-1}) concentration was observed in the sinkhole that is overgrown with trees and shrubs.

References

1. Adomaitis T.R. (1998) Siera (Sulphur). in J. Mažvila (eds). Lietuvos dirvožemių agrocheminės savybės ir jų kaita. Petro ofsetas, Kaunas, pp. 123-129. (in Lithuanian).
2. Baužienė I. (2005) Sieros srautas Aukštaitijos kompleksinio monitoringo stoties geosistemoje (Flux of sulphur in the geosystem of Aukštaitija complex monitorin station). Geografijos metraštis, 38 (1), pp. 72-79. (in Lithuanian).

3. Chomčenko R., Juodkazis V., Rudzianskaitė A., Taminskas J. (2000) Maisto medžiagų dinamika Šiaurės Lietuvos karsto rajono geosistemoje (Dynamics of nutrients in the geosystem of the karst region in North Lithuania). Vandens ūkio inžinerija, 11 (33), pp. 57-71. (in Lithuanian).
4. Delle Rose M., Federico A., Parise M. (2004) Sinkhole genesis and evolution in Apulia, and their interrelations with the anthropogenic enviroment. Natural Hazards and Earth System Sciences, 4, pp. 747-755.
5. Dėnas Ž., Račkauskas V. (2005) Šiaurės Lietuvos karstinio rajono karstėjančių uolienų dangos storio ir petrografinės sudėties žemėlapis M 1:50 000: GIS sluoksnių sudarymas ir analizė (Compilation and analysis of GIS layers of the map of cover thickness and petrographical composition of karstified rocks (North Lithuanian karst area). scale 1:50 000). Geologija, pp. 48-58. (in Lithuanian).
6. Diliūnas J., Kaminskas M. (2003) Paviršinio vandens sudėties kaita infiltracijos į gruntinį vandeningąjį sluoksnį procese (Change of surface water composition during infiltration to shallow aquifer). Litosfera, 7, pp. 109-117. (in Lithuanian).
7. Juknys R., Žaltauskaitė J., Stakėnas V. (2002) Aplinką rūgštinančių junginių iškritų tyrimai (Investigation of acidifying compounds deposition). Aplinkos tyrimai, inžinerija ir vadyba, 3(21), pp. 31-37. (in Lithuanian).
8. Juodkazis V. (1992) Lietuvos karstas: hidrogeologija ir požeminio vandens apsauga (Lithuanian karst: hydrogeology and groundwater protection). Geologija, 13, 195 p. (in Lithuanian).
9. Kasperovičienė J., Mažeikaitė S., Vitėnaitė T. (1998) Kai kurie planktoninių hidrobiontų biologinės įvairovės aspektai Šiaurės Lietuvos karstiniame regione (Some aspects of planktonic hydrobionts diversity in the karst region of North Lithuania). Geografijos metraštis, 31, pp. 71-83. (in Lithuanian).
10. Kaiser K., Guggenberger G., Haumaier L., Zech W. (2001) Seasonal variations in chemical composition of dissolved organic matter in organic forest floor layer leachates of old-growth Scots pine (Pinus sylvestris L.) and European beech (Fagus sylvatica L.) stands in northeaster Bavaria, Germany. Biogeochemistry, 55 (2), pp. 133-143.
11. Kovačič G., Ravbar N. (2005) A review of the potential and actual sources of pollution to groundwater in selected karst area in Slovenia. Natural Hazards and Earth System Science, 5, pp. 225-233.
12. Kueny J.A., Day M.J. (2002) Designation of protected karstlands in Central America: a regional assessment. Journal of Cave and Karst Studies, 64(3), pp. 165-174.
13. Lamsodis R. (2001) Apie prielaidas melioracijos griovių gamtinėms funkcijoms plėtoti (On preconditions for the development of natural functions of drainage chnnels). Vandens ūkio inžinerija, 16 (38), pp. 61-67. (in Lithuanian).
14. Lu Y. (2007) Karst water resources and geo-ecology in typical regions of China. Environmental Geology, 51, pp. 695-699.
15. Marcinkonis S. (2007) Ariamų žemių renatūralizacija: poveikis dirvožemio agrocheminiams rodikliams (Renaturalization of arable land: effect on agrochemical parameters of soil quality). Žemės ūkio mokslai, 14 (2), pp. 18-22. (in Lithuanian).
16. Minkevičius V. (2011) Šiaurės Lietuvos karstinio rajono teritorijos pastovumo karsto atžvilgiu žemėlapis. (Stability map of the territory of North Lithuanian karst region). Lietuvos geologijos tarnybos 2010 metų veiklos rezultatai. Vilnius, pp. 60-61. (in Lithuanian).
17. Mikulėnas V. (2005) Nauji suaktyvėjusio karstinio proceso Biržų rajone geologiniai tyrimai (New Geological Investigations of Active Karst Processes in Biržai District). Geologijos akiračiai, 2, pp. 33-41. (in Lithuanian).
18. Narbutas V., Linčius A., Marcinkevičius V. (2001)Devono uolienų karstas ir aplinkosaugos problemos Šiaurės Lietuvoje (Karst of the Devonian rocks and the problems of environment protection in North Lithuania), Agora, Vilnius, 191 p. (in Lithuanian).
19. Paškauskas R., Antanynienė A., Budrienė S., Krevš A., Kučinskienė A., Šlapkauskaitė G., Šulijienė R. (1998) Biologinių procesų įvairovė ir specifiškumas karstiniame Kirkilų ežere (The diversity and peculiarity of biological processes in the karst Kirkilai lake). Geografijos metraštis, 31, pp. 62-69. (in Lithuanian).
20. Paukštys B. (1996) Hydrogeology and groundwater protection problems in karst region of Lithuania. Geology Society of Lithuania, Vilnius, 72 p.
21. Račkauskas V. (2004) Šiaurės Lietuvos karstinio rajono karstėjančių uolienų dangos storio ir litologinės sudėties žemėlapis 1:50 000 masteliu (The map of thickness and lithological composition of the cover of karstified rocks (North Lithuanian karst area). Lietuvos geologijos tarnybos 2003 metų veiklos rezultatai, Vilnius, pp. 25-26. (in Lithuanian).

22. Rudzianskaite A., Sukys P. (2008) Effects of groundwater level fluctuation on its chemical composition in karst soils of Lithuania. Environmental geology, 56 (2), pp. 289-297.
23. Satkūnas J., Taminskas J., Dilys K. (2006) Geoindicators of changing landscapes – an example of karst development in North Lithuania. Geological Quarterly, 50 (4), pp. 457-464.
24. Stevanovič Z., Jemcov I., Milanovič S. (2007) Management of karst aquifers in Serbia for water supply. Environmental Geology, 51, pp. 743-748.
25. Taminskas J. (1997) Vandenskyrinio karsto hidrologiniai ypatumai (Peculiarity of karst watershed hydrology). Geografijos metraštis, 30, pp. 100-107. (in Lithuanian).
26. Taminskas J. (1999) Smegduobių susidarymas ir raida (Generation and development of karst pits). Geografijos metraštis, 32, pp. 194-203. (in Lithuanian).
27. Taminskas J., Marcinkevičius V. (2002) Karst geoindicators of environmental change: The case of Lithuania. Environmental Geology, 42, pp. 757-766.
28. Taminskas J. (2002) Smegduobių apsaugos optimizavimas (Optimization of sinkholes protection). Geografijos metraštis, 35, pp. 87-94. (in Lithuanian).
29. Taminskas J., Mikulėnas V. (2010) Šiaurės Lietuvos karstinio rajono kraštovaizdžio monitoringas (The monitoring of North Lithuanian karst region). Lietuvos geologijos tarnybos 2009 metų veiklos rezultatai. Vilnius, pp. 34-35. (in Lithuanian).
30. Taminskas J., Mikulėnas V., Dagys B. (2011) Gipso cheminės denudacijos ir karstinių reiškinių tyrimai Investigation of gypsum chemical denudation and karst phenomena). Lietuvos geologijos tarnybos 2010 metų veiklos rezultatai. Vilnius, pp. 67-70. (in Lithuanian).
30. Žėkaitė V., Baniūnienė A., Aleinikovienė J., Armolaitis K. (2007) Unikalūs bandymai Perlojoje (Unique experiment in Perloja). Mano ūkis, Nr.1, pp. 40-42. (in Lithuanian).
31. Žvikas A., Paškauskas R., Kučinskienė A. (2002) Statinis karstinių ežerų hidromikrobiontų struktūros ir funkcijų įvertinimas (Static evaluation of the structure and functioning of hydromicrobes in karst lakes). Ekologija, 1, pp. 40-47. (in Lithuanian).
32. Марцинкявичюс В.И., Буцявичюте С.В. (1986) Геологические и гидрогеологические условия развития сульфатного карста в северной Литве (Geological and hydrological conditions for the development of sulphate karst in Notrh Lithuania). Geologija, 7, с. 104-121. (in Russian).
33. Никаноров А.М. (1989) Гидрохимия (Hydrochemistry). Гидрометеоиздат, Ленинград, 351 с. (in Russian).

IMPACT OF THE FIELDS, FERTILIZED WITH MANURE FROM BIG LIVESTOCK COMPANIES ON DRAINAGE WATER QUALITY

Stefanija Misevičiene
Aleksandras Stulginskis University, Lithuania
Stefanija.Miseviciene@asu.lt

Abstract
The paper presents data on the water quality in drainage from manure-fertilized areas in a large livestock company (629 conditional livestock) from 2008 to 2012. The scheme of investigation consists of two field variants: manure-fertilized and non-fertilized. Researches are carried out in drained areas, where the drainage water is drained away through outlets. The nitrogen rate 170 kg ha^{-1} is used annually to fertilize fields in spring. The aim of the research was to ascertain the impact of large livestock company fields fertilized annually with manure on the water quality in drainage.
For the purpose of chemical investigations, water samples from drainage were taken once per month. Water analyses were carried out by the accredited Chemical Analytical Laboratory of the Water Management Engineering Institute of Aleksandras Stulginskis University according to specified methods.
Investigation results have demonstrated that fields fertilized annually with manure raised the contents of N_{min} and P_2O_5 in the soil by 1.5 and 2.2 times respectively in comparison to the non-fertilized ones. The increase in these contents was conditioned by the higher air temperature and the lower rainfall. The seasonality of N_{total} concentrations in drainage water was discovered: higher concentrations were identified in autumn and winter, lower concentrations – in spring and summer. Due to low dissolubility in the soil, low P_{total} concentrations were identified in drainage water. The highest concentrations were identified with the start of drainage operation.
Key words: drainage water, soil, concentration, manure.

Introduction

Due to new manure handling technologies, litter-free manure and liquid manure are prevailing in the intensive production livestock farms. The content of nutrients in such types of manure is considerably lower than in litter manure. Obviously, the fertilization with manure raises the contents of humus and nutrients in the soil, however, under conditions of plenty fertilization, the wash up of nutrients through drainage into streamlets is more intensive. It was determined by means of researches that 30–35% of nitrogen and 10–15% of phosphorus passing into surface water bodies are from agricultural sources (Staniszewska and Shung, 2002).

As stated by scientists, it is very complicated to identify the correlation between water quality fluctuations in streamlets subjected to diverse factors in their basins (Vagstad et al., 2001); therefore, various opinions exist. It was ascertained that the wash up of nitrogen is highly influenced by natural factors, soil composition, density of raised livestock, content of meadow, farming activities in the drained area, season, and mostly by local factors (Kyllmar et al., 2006; Rudzianskaitė and Šukys, 2001; Morkūnas et al., 2005). It was determined that the diffused water pollution is directly related to the used quantities of fertilizers, grown plants, and the overall culture of farming (Meissner et al., 1998). It was ascertained by Finnish scientists that the water quality of small streamlets depends more on seasonal meteorology than on changes in land production structure or technology (Vuorenmaa et al., 2002). Similar results are also announced by other scientists stating that seasonal meteorology has a considerably higher impact on the wash up of nitrogen than the diverse land exploitation practice (Stalnacke et al., 2002). Continually grown plants of one species induce also the higher migration of nitrogen in the soil (Bakhsh et al., 2001). However, the periodical fertilization with manure considerably improves properties of the soil with a light granulometric composition (Tripolskaja and Šidlauskas, 2010).

Large quantities of manure accumulate in large livestock companies, where many animals mass in one place. The spread of manure in fertilized fields affects the surface water as a diffused pollution. There are some cases, when due to high transport costs companies are used to spread manure in the same fertilized areas not far from farms every year. The danger is that fields may become over-fertilized and many nutrients may be washed up into the environment. The pollution of drainage water is most possible when the rain falls after fertilization with manure (Geohring et al., 2001; Smith et al., 2001).

The aim of this research was to ascertain the impact of large livestock company fields fertilized annually with manure on the water quality in drainage. To reach the goal, there were several tasks set: observe the migration of contaminants in fertilized fields' area; collect and analyse long-term information on the state of natural elements of the environment and its changes in local scale; gather information on the quality of

drainage water in fertilized fields of large livestock companies; assess its status and changes, depending on fertilization rate and meteorological conditions.

Materials and Methods

Investigations of the drainage water quality were carried out in a livestock company field fertilized with manure in 2008–2012. Drained areas, where the drainage water is drained through outlets, Dr.1 and Dr.2 (Fig. 1.), were selected for investigations.

Figure 1. Scheme of study object:
Dr.1, Dr.2 – drainage outlets,
D1, D2 – soil sampling places.

The soil of the research subject is sandy loam. In the layer 0-40 cm of the fertilized area, the humus content in the soil fluctuated from low (1.2%) to high (4.9%). The content of mineral nitrogen fluctuated from 14.2 to 289 kg ha^{-1} what corresponded to the nitrogen content I (very low) and V (very high) respectively. The content of mobile phosphorus was from 36 mg kg^{-1} to 615 mg kg^{-1}, i.e. the content of phosphorus fluctuated from the very low value to the very high onr. The content of humus in non-fertilized soil fluctuated from the very low value (1%) to moderate value (3%). The content of mineral nitrogen fluctuated from 10.9 to 130 kg ha^{-1}, what corresponded to the nitrogen content I (very low) and V (very high). The observed content of mobile phosphorus in such soil was from 10 to 325 mg kg^{-1}, i.e. it fluctuated from the very low value to the very high one (Mažvila, 1998).

For the purpose of chemical investigations, water samples from drainage were taken once per month. Water analyses were carried out by the accredited Chemical Analytical Laboratory of the Water Management Engineering Institute of Aleksandras Stulginskis University according to methods specified in the literature (Unified…, 1994).

N_{total} was determined by applying the spectrometric method, by mineralizing with potassium persulphate, P_{total} – by applying the spectrometric method, after mineralization with potassium persulphate.

Soil samples for agrochemical investigations were taken monthly from the depth of 0 - 60 cm at every 20 cm. To identify the content of nitrogen in the soil, the following research methods were applied: ammonium nitrogen ($N\text{-}NH_4^+$) – colorimetric with Nessler's reagent in KCl extract; nitrate nitrogen ($N\text{-}NO_3^-$) – potentiometric with selective electrode. Analyses of $N - NH_4^+$ and $N - NO_3^-$ were carried out by means of analyser "FIA Star 5012". To identify phosphorus oxide (P_2O_5), a photo-colorimetric method A-L was applied.

To fertilize the research fields, litter-free manure of cattle was used, and the fertilization took place in spring. The composition of manure was identified from one extract prepared by burning with concentrated sulphuric acid (H_2SO_4) and selenium (Se) catalyst. Nitrogen was identified by Kjeldal method, phosphorus – by molybdic method. According to the fertilizing value of manure, the following contents of total nitrogen passed into manure-fertilized fields each year: 2008 – 169 kg ha^{-1}, 2009 - 168 kg ha^{-1}; 2010 - 169 kg ha^{-1}, 2011 – 169 kg ha^{-1}, 2012 – 170 kg ha^{-1}. P_{total} passed into fertilized fields as follows: 2008 - 23 kg ha^{-1}, 2009 - 27 kg ha^{-1}; 2010 - 28 kg ha^{-1}, 2011 – 34 kg ha^{-1}, 2012 – 36 kg ha^{-1}. Maize for cattle forage was grown in experimental fields.

Table 1

Meteorological conditions of the study periods

Indices	Year				
	2008	2009	2010	2011	2012
Precipitation, mm	574	736	722	574	723
% of the climate standard	97	125	122	97	123
Average air temperature, °C	+8.5	+7.2	+6.2	+7.9	+6.7
Deviation from the climate standard, °C	+2.4	+1	0	+1.7	+0.4

To determine the rainfall and air temperature, data from Dotnuva Meteorology Station were used (Table 1).

It is evident from the presented data that two years were dry (2008 and 2011), when the rainfall rate was

97% of the climate standard. 2009, 2010 and 2012 were wet years, and the rainfall rate was 125, 122 and 123% respectively of the climate standard. The average air temperature exceeding the standard temperature was observed four years: 2008, 2009, 2011 and 2012, +2.4, +1, +1.7 and +0.4 °C respectively. In 2010, the air temperature corresponded to the climate standard.

Results and Discussion

Research results have demonstrated that the higher content of mineral nitrogen was observed in the field fertilized with manure. The noticeably higher content of mineral nitrogen in the soil was identified in 2008 (401 kg ha^{-1}) and 2011 (558 kg ha^{-1}) (Fig. 2).

The accumulation of mineral nitrogen in the soil was influenced by the favourable meteorology (r = 0.38, $t_{theor95\%}$=2.0<$t_{act.}$=2.84). It was ascertained by means of partial correlation analysis that the lower rainfall (r = -0.22) and the higher air temperature (r = 0.37) conditioned the higher nitrogen concentrations in the soil fertilized with manure. The similar impact of the meteorology was observed on the concentration of nitrogen content in the non-fertilized soil (r = 0.35, $t_{theor95\%}$=2.0<$t_{act.}$=2.59). In this variant also, the lower rainfall (r = -0.27) and the higher air temperature (r = 0.33) have raised the content of nitrogen in the soil.

During the research period, the highest concentrations of N_{total} were observed in the field

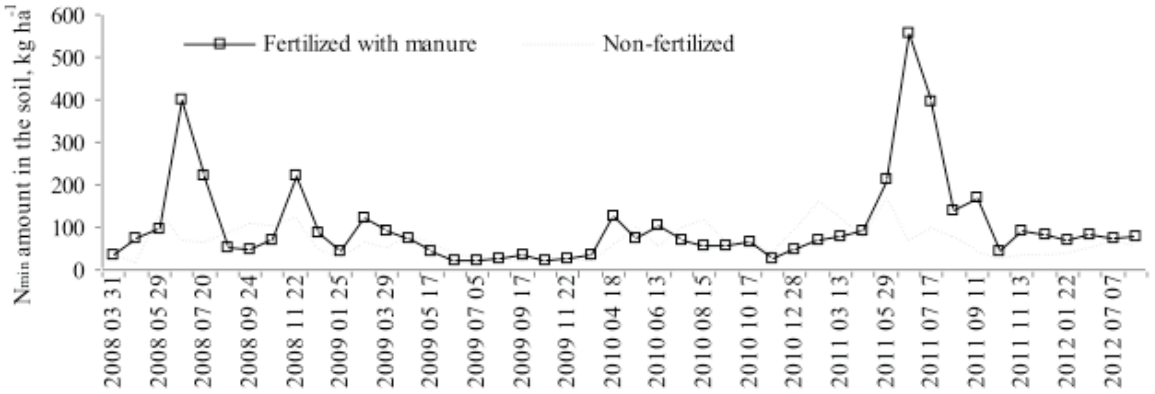


Figure 2. N_{min} fluctuation in the soil in 0-60 cm deep.

Table 2

N_{total} concentration fluctuation in drainage water in seasons, mg L^{-1}

Year	Season				Average per year	Standard deviation	Variation coeficient, %
	spring	summer	autumn	winter			
Fertilized							
2008	20.9	-	23.5	20.5	21.4	1.4	7
2009	14.2	17.7	10.1	8.4	13.3	5	38
2010	7.6	6.6	7.8	5.8	6.9	1	15
2011	6.5	6.7	6.0	11.9	6.7	1.4	34
2012	11.6	14.9	8.6	11.5	11.7	2.6	22
Non-fertilized							
2008	10.6	-	11.2	12.5	11.1	4.8	43
2009	12.2	13.9	6.5	5.5	10.5	4.0	38
2010	4.6	4.9	4.8	5.4	4.9	1.7	34
2011	3.5	-	-	3.9	3.6	0.3	9
2012	3.6	3.2	3.9	3.8	3.6	0.3	8

fertilized with manure in 2008. The average annual concentration of N_{total} was 21.4 mg L^{-1}. In the non-fertilized field, the highest concentration was also observed in 2008, i.e. 11.1 mg L^{-1} (Table 2).

It is specified in the literature that agricultural plants cultivated exert influence on the wash up of some other nutrients from the soil (Kinderis, 1991). The least quantities of nitrates are washed up from perennial grass areas (1.4-3.7 kg ha^{-1}), but the highest quantities – from bean and maize areas (6.8-11.5 kg ha^{-1}). The factor that maize was grown in both research versions could have conditioned higher concentrations of research chemical elements.

Researches point out that concentrations of mineral nitrogen in drainage water highly depend on the crop rotation, crop harvest and fertilization with nitrogen. The highest concentrations of mineral nitrogen in drainage water (13.1 – 13.9 mg L^{-1}) were observed in cultivation of cereal and cultivated crop. The least concentration of mineral nitrogen was obtained in grass rotation (9.6 mg L^{-1}), and by applying the rotations of cereal and cultivated crop. Concentrations increased by 19 and 26% (Aksomaitiene et al., 2007; Aksomaitienė et al., 2003) respectively.

It was ascertained by means of correlation analysis that concentrations of N_{total} in drainage water were raised by the content of mineral nitrogen in the soil during autumn and winter, and vice versa; during spring and summer, concentrations have decreased, since the best part of mineral nitrogen was used to grow the green-mass of cultivated plants (Table 3).

The values of correlation rates demonstrate that the correlation in fertilized area is moderate; in non-fertilized area, it is weak in winter and spring but strong in summer and autumn. In the fertilized area, during the spring and summer seasons, the reverse correlation was identified between the research parameters: the more mineral nitrogen is accumulated in the soil, the less concentration of N_{total} is observed in drainage water, whereas it was obtained during the autumn and winter seasons that great accumulations of mineral nitrogen in the soil raise the concentration of N_{total} in drainage water. It could be explained by that in spring and summer, mineral nitrogen is used by plants, but in autumn and winter, when the harvest has been stored up, the content of mineral nitrogen is washed up from the soil into drainage.

In the non-fertilized experimental field, during each season, inversely proportional correlations were identified between the content of mineral nitrogen in the soil and concentrations of N_{total} in drainage water. It could be explained by that the whole content of mineral nitrogen accumulated in the soil was used by plants; therefore, low concentrations of N_{total} in drainage water were identified.

Table 3

The relationship between N_{min} amount in the soil and N_{total} concentration in drainage water

Indices	Season			
	Fertilized			
	spring	summer	autumn	winter
Relationship	y = - 0.0678x+17.866	y = - 0.0188x+13.562	y = 0.0405x+6.6561	y = 0.1205x+2.6063
R^2	0.32	0.27	0.28	0.42
r	0.56	0.52	0.53	0.65
n	11	10	9	8
$t_{theor.95\%}$	2.26	2.31	2.36	2,45
t_{act}	2.04	1.72	1.65	2.09
Non-fertilized				
Relationship	y = - 0.0761x+12.767	y = - 0.1197x+16.018	y = 0.0555x+3.488	y = - 0.0201x+8.383
R^2	0.18	0,56	0.57	0.08
r	0.42	0.75	0.75	0.28
n	10	7	5	7
$t_{theor.95\%}$	2.31	2.57	3.18	2.57
t_{act}	1.31	2.53	1.98	0.65

Note. Relationship reliable, when $t_{act} > t_{theor95\%.}$

Table 4

The differences in P_2O_5 concentrations in the fertilized and non-fertilized soil mg kg^{-1}

Indices	Season							
	spring		summer		autumn		winter	
	fertilizer	non-fertilizer	fertilizer	non-fertilizer	fertilizer	non-fertilizer	fertilizer	non-fertilizer
Average	307.8	139.6	251.4	117.6	237.6	121.6	300.0	119.0
$F_{theor95\ \%}$	2.8		2.7		2.7		3.8	
F_{act}	4.3		8.1		10.9		6.9	
$t_{theor95\ \%}$	2.12		1.75		2.14		2.56	
t_{act}	5.1		3.1		3.86		4.89	

Note. Relationship reliable, when $F_{act} > F_{theor95\ \%}$ and $t_{act} > t_{theor95\%}$.

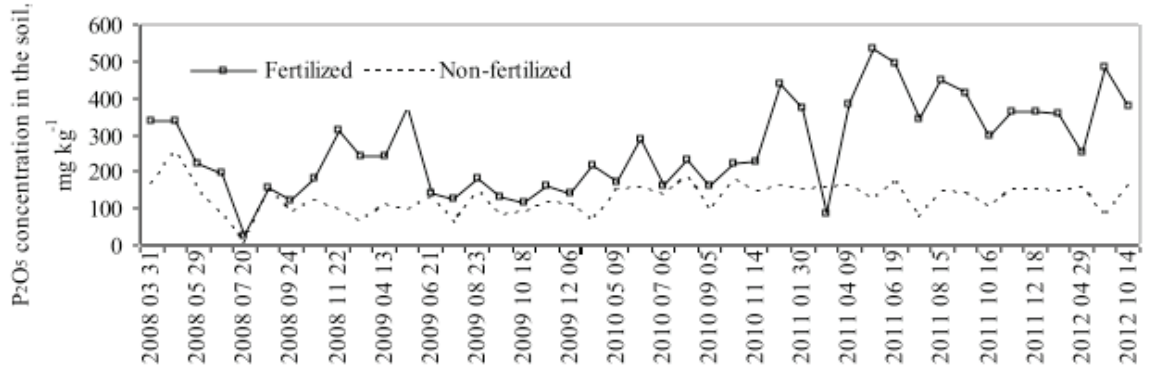


Figure 3. Mobile phosphorus fluctuation in the soil in 0-60 cm deep.

In ordrer to ascertain, whether concentrations of mobile phosphorus were different in two variants of soil, the analysis was carried out. The analysis has demonstrated that differences between versions were significant (Table 4).

By taking into consideration the average values of mobile phosphorus concentrations, it is evident that the fertilized area was fairly phosphorous during all research seasons (the content of phosphorus in the soil fluctuated from 237.6 to 307.8 mg kg^{-1}). The soil in the non-fertilized area was moderately phosphorous (the content of phosphorus in the soil fluctuated from 117.6 to 139.6 mg kg^{-1}).

The figure 3 evidences the impact of fertilization on accumulation of phosphorus in the soil. The contents of mobile phosphorus in the fertilized area were higher than in the non-fertilized area in the research period. The greatest difference was observed in winter - 60% and spring - 55%. In summer, the content of mobile phosphorus in the field fertilized with manure was higher by 53%, and in autumn - by 49%.

Phosphorus is very stable and low-soluble in the soil. Phosphorus changes into soluble form in the soil, when primary minerals containing phosphorus decay; plant remains become mineral, when soil is fertilized with organic and mineral fertilizers (Томпсон and Трoy, 1982). With decomposition of organic substances, plants assimilate phosphorus only after dissolution of organic compounds. Thus, plants assimilate best and easiest phosphorus existing in the soil solution or absorbed in the particle surface of the solid soil part. Due to the fact that phosphorus is low-soluble in the soil, its content in the soil accumulates. Its higher contents accumulate in places, where fields are fertilized; however, its content decreases marginally also in the non-fertilized area. Since, during mineralization, soluble phosphorus is used by plants, the very low content of this element is washed up into drainage water.

The values of correlation rates demonstrate that, in fertilized area and non-fertilized area, correlations of the P_2O_5 content in the soil and concentrations of P_{total} in drainage water are weak in spring and winter, moderate in summer, and strong in autumn. In both variants, the reverse correlation between the research parameters was identified during all seasons: the higher P_2O_5 concentrations in the soil, the less concentration

Table 5

The relationship between amount of P_2O_5 in the soil and P_{total} concentration in drainage water

Indices	Season			
	Fertilized			
	spring	summer	autumn	winter
Relationship	y = - 0.0007x+0.392	y = - 0.0001x+0.1181	y =- 0.0006x+0.2506	y = -0.0006x+0.4123
R^2	0.24	0.34	0.63	0.05
r	0.49	0.58	0.79	0.22
n	11	10	9	8
$t_{theor95\%}$	2.26	2.31	2.36	2,45
t_{act}	1.69	2.02	4.56	0.55
Non-fertilized				
Relationship	y = - 0.00002x+0.0226	y = - 0.0001x+0.0029	y = -0.0003x+0.0475	y = - 0.0007x+0.125
R^2	0.009	0,45	0.80	0.17
r	0.09	0.67	0.89	0.41
n	10	7	4	7
$t_{theor95\%}$	2.31	2.57	3.18	2.57
t_{act}	0.26	2.02	2.81	1.19

Note. Relationship reliable, when $t_{act} > t_{theor95\%.}$

of P_{total} in drainage water. It could be explained by that phosphorus is low-soluble; therefore, its soluble part is used by plants in spring and summer, and in autumn, when fields are left uncovered by plants, its greater quantities are washed up into drainage water. It was demonstrated by a strong and statistically reliable correlation between the content of mobile phosphorus in the soil and concentrations of P_{total} in drainage water in the fertilized variant during the autumn season (Table 5).

It is stated by foreign authors that concentrations of phosphorus and its compounds in drainage water are determined by hydrological conditions (Salazar et al., 2011). The greatest wash up of phosphorus

Table 6

P_{total} average concentrations fluctuation in drainage water in seasons mg L^{-1}

Years	Season				Average per year	Standard deviation	Variation coeficient, %
	spring	summer	autumn	winter			
Fertilized							
2008	0.02	-	0.02	0.17	0.06	0.08	133
2009	0.29	0.08	0.18	0.39	0.23	0.23	100
2010	0.33	0.12	0.12	0.20	0.19	0.13	68
2011	0.06	0.06	0.03	0.12	0.06	0.03	50
2012	0.03	0.03	0.03	0.06	0.04	0.01	25
Non-fertilized							
2008	0.01	-	-	0.02	0.01	0.004	40
2009	0.02	0.01	0.02	0.08	0.04	0.05	125
2010	0.01	0.01	0.01	0.003	0.01	0.006	60
2011	0.03	-	-	0.01	0.02	0.02	100
2012	0.01	0.03	0.01	0.03	0.02	0.01	50

takes place in the initial phase of drainage run-off formation in spring and autumn, later, concentrations decrease and the correlation with drainage run-off becomes weaker (Wesström and Messing, 2007). In order to reduce the pollution of drainage water by phosphorus compounds, fields should not be fertilized when infiltration conditions in the soil are the best. In Lithuania, due to changeable weather conditions, the drainage run-off usually forms in December; therefore, higher average concentrations of P_{total} were observed during the winter season than in spring, summer and autumn: in the fertilized area by 1.3, 2.7, 2.4 times respectively, in the non-fertilized area by 1.5, 1.5 and 3 times respectively (Table 6).

In order to ascertain whether concentrations of P_{total} were different in drainage water drained away from the fertilized field and the non-fertilized field, the data analysis was carried out by applying the Data Analysis Program. It was ascertained that concentrations of P_{total} in both versions differed significantly: in spring ($F_{calc.}$ = 148.9>$F_{theor.95\%}$ = 2.97 $t_{calc.}$=3.04>$t_{theor.95\%}$ = 2.23), in summer ($F_{calc.}$ = 17.2>$F_{theor.95\%}$ = 4.1; $t_{calc.}$=5.86>$t_{theor.95\%}$ = 2.23), and in autumn ($F_{calc.}$ = 63.1>$F_{theor.95\%}$ = 8.8; $t_{calc.}$=2.34>$t_{theor.95\%}$ = 2.26). In winter, no differences between concentrations in the fertilized field and the non-fertilized field were identified ($F_{calc.}$ = 16.8>$F_{theor.95\%}$ = 4.2; $t_{calc.}$=1.86<$t_{theor.95\%}$ = 2.3).

Conclusions

1. Large livestock company fields fertilized annually with manure have raised the contents of N_{min} and P_2O_5 in the soil, and concentrations in the soil fertilized with manure were higher by 1.5 and 2.2 times respectively in comparison to the non-fertilized soil.
2. The higher content of $N_{min.}$ both in manure-fertilized soil and non-fertilized soil was conditioned by the lower rainfall and the higher air temperature.
3. The correlation analysis has demonstrated that concentrations of N_{total} in drainage water increased due to the content of $N_{min.}$ in the soil in autumn and winter, and inverse - decreased in spring and summer, as the best part of $N_{min.}$ was used to grow the green-mass of cultivated plants.
4. Due to fertilization, the content of mobile phosphorus in soil increases: the area fertilized with manure became fairly phosphorous, and the non-fertilized area was moderately phosphorous.
5. Due to low dissolubility, low concentrations of P_{total} in drainage water were identified. The highest concentrations were identified with the start of drainage operation.
6. It was ascertained by means of correlation analysis that concentrations of P_{total} of both versions in spring, summer and autumn differed significantly. In winter, no differences between concentrations in fertilized and non-fertilized fields were identified.

References

1. Aksomaitienė R., Gužys S., Petrokienė Z., Kutra S. (2007) Mineral nitrogen and phosphate cycles in different agroecosystems. *Journal of sustainable agriculture*, 29, 4, pp. 39-60.
2. Aksomaitienė R., Gužys S., Petrokienė Z. (2003) Mineralinio azoto apykaitos agroekosistemoje ryšys su jos produktyvumu ir jį nulemiančiais veiksniais (The dependence of mineral metabolism on agroecosystem productivity and related factors). *Vandens ūkio inžinerija*, 23(43)-24(44), pp. 69-78. (in Lithuanian).
3. Bakhsh A., Kanwar R.S., Karlen D.L., Cambardella C.A., Balley T.B., Moorman T.B., Colvin T.S. (2001) N management and crop rotation effects on yield and residual soil nitrate levels. *Soil science,* 166 (8), pp. 530-538.
4. Geohring L.D., McHugh O.V., Walter M.T., Steenhuis T.S., Akhtar M.S., Walter M.F. (2001) Phosphorus transport into subsurface drains by macropores after manure aplications:implications for best manure management practices. *Soil science*, 166 (12), pp. 896-909.
5. Kinderis Z. (1991) Ar drenažo vanduo labai teršia? (Does drainage water pollute a lot?). *Žemėtvarka ir melioracija.* pp. 96. (in Lithuanian).
6. Kyllmar K., Carlsson C., Gustafson A., Ulen B., Johnsson H. (2006) Nutrient discharge from small agricultural catchments inSweden. Characterisation and trends. *Agric. Ecosyst. & Envir*., 115, pp. 15-26.
7. Kutra G., Gaigalis K. (2007) Požeminio ir drenažo vandens užterštumas azoto junginiais tvartų teritorijose (Analysis of investigations on underwater and drainage water pollution with nitogen compounds on farms implementing EU nitrate dirctive). *Vandens ūkio inžinerija,* 32 (52), pp. 80-87. (in Lithuanian).
8. Mažvila J. (1998) Lietuvos dirvožemių agrocheminės savybės ir jų kaita (Lithuanian soil agrochemical characteristics and their change). Kaunas, 196 p. (in Lithuanian).
9. Meissner R., Seeges I., Rupp H. (1998) Lysimetr studies in East Germany concerning the influence of set aside of intensively farmed land on the seepage water quality. *Agricultural ecosystems & Environment,* 67, pp. 61-173.

10. Paviršinių vandens telkinių būklės nustatymo metodika patvirtinta Lietuvos Respublikos aplinkos ministro 2010 m. kovo 4 d. įsakymu Nr. Dl-178. (Surface water pools' state evaluation methodology). (2010) Order of the Minister of Environment of the Republic of Lithuania No. D1 – 178 of March 2010. *Valstybės Žinios*, No. 29, 1363 p. (in Lithuanian).
11. Morkunas V., Rudzianskaite A., Sukys P. (2005) Influence of agriculture on soil water quality in in karst regiono f Lithuania. *Irrigation and Drainage,* 54, pp. 53-361.
12. Salazar O., Wesstrom I., Joel A. (2011) Identification of hydrological factors controlling phosphorus concentration in drainage water in sandy soils. *J. Soil Sci. Plant Nutr.,* 11 (2), pp. 1-46.
13. Smith K.A., Jackson D.R., Pepper T.J. (2001) Nutrient losses by surface run-off following the application of organic manures to arable land. 1. Nitrogen., *Environmental Pollution*, 112, pp. 1-51.
14. Stalnacke P., Bechmann M. (2002) Trends in nutrient runoff from agriculture basins in Norway. Agricultural effects on ground and surface waters: research at the edge of science and society, Iss. 273, pp. 67-271.
15. Staniszewska M., Shung E. (2002) Status of organic agriculture in the countries of the Baltic Sea Region. *Landbauforschhung Volkenrode*, 52 (2), pp. 5-79.
16. Tripolskaja L., Šidlauskas G. (2010) Tarpinių pasėlių žaliajai trąšai ir šiaudų įtaka atmosferos kritulių filtracijai ir azoto išplovimui (The influence of catch crop for green manure and straw on the infiltration of atmospheric precipitation and nitrogen leaching). *Žemdirbystė-Agriculture*, vol. 97, No.1, pp. 3-92. (in Lithuanian).
17. Rudzianskaitė A., Šukys P. (2000) Karsto rajono dirvožemių drenažo vandens mineralizacija ir jos poveikis upelių vandens kokybei (Drainage water mineralization of karst region soils and its impact on stresam water quality). *Vandens ūkio inžinerija*, 11 (33), pp. 81-90. (in Lithuanian).
18. Unifikuoti nuotekų ir paviršinio vandens kokybės tyrimų metodai. D.1 (1994) (Unified Study Methods of Wastewater and Surface Water Quality. D.1). Aplinkos apsaugos ministerija, Vilnius, 223 p. (in Lithuanian).
19. Vagstad N., Stalnacke P., Andersen H.E. (2001) Nutrient losses from agriculture in the Nordic and Baltic countries – Measurements in small agricultural catchments and national agro-environmental statistics. Nordic Council of Ministers, *TemaNord*, 591, pp. 5-48.
20. Vuorenmaa S., Rekolainen S., Lepisto A., Kenttamies K., Kauppila P. (2002) Losses of Nitrogen and Phosphorus fro Agricultural and Forest Areas in Finland during the 1980s and 1990s. *Environ. Monit. Assess*., 76, pp. 213-248.
21. Wesstrom I., Messing I. (2007) Effects of controlled drainage on N and P losses and N dynamics in a loamy sand with spring crops. *Agric. Water Manage*., 87, pp. 229-240.
22. Томсон Л.М.П., Троу Ф.Р. (1982) Почвы и их плодородие (Soils and their productivity). – Москва: Колос, Перевод с английского Э.И. Шконде. 382 с. (in Russian).

GRISHANIN FACTOR AS CRITERION FOR RIVER STABILITY ESTIMATION

Saulius Vaikasas, Raimundas Baublys
Aleksandras Stulginskis University, Lithuania
s.vaikasas@delfi.lt; raimundas.baublys@asu.lt

Abstract
The article presents the natural and regulated stream bed stability and self-regulation issues. River beds equilibrium patterns are defined by Lane principle, observed in natural beds, while this balance is disturbed in regulated ones which has been confirmed by research. Natural and regulated rivers stability was evaluated by beds hydrodynamic stability criteria. It showed that the investigated natural rivers bed is stable enough. Under accumulated silt particle sizes in natural river beds, the formation regularities of meanders were determined. The investigated river meanders patterns confirmed the formation of natural river meanders characterizing patterns. It was found that regulated Lithuanian streams through self-beds meandering are useful not only for the natural diversity formation, but also increase meandering bed sediments conveyance capacity and stability from 3 to 3.5 times. Adapting to these naturally occurring processes and using the extensive channel maintenance techniques, it is possible to force the disruption of regulated streams hydrodynamic equilibrium self-recovery and biodiversity. The aim of research - according to the selected river bed hydrodynamic stability criteria to perform comparative analysis of stability of regulated and natural streams.
Key words: hydrodynamics of streams, channel stability, self-regulation.

Introduction

The theory of naturally formed rivers in the natural environment and stream flows of self-regulation and their interaction with the river furrows suggests that while designing their beds, all of them conform for the minimum energy (entropy) law (Leopold et al., 1991). This means that the flows of these rivers and their beds interaction through a historically long period of time evolve towards a dynamic equilibrium in such a way that the current conditions of flow potential energy comparable loss of water and sediment transport would be the lowest (Stream..., 1998). Therefore, for any reasons, natural flow can also change its bed or adapt to new conditions, depending on the change of the water and sediment flow (River.., 1998; Newsletter..., 1998). This show to both, the river bottom sediments form adaptation, as well as the bed forms and meanders changes or periodically flooded valley areas of vegetation cover change (Schuman, 1997). The river-bed stability, development and adaptation to changes in flow and sediment transport conditions patterns were examined in the last century (Lane, 1955; Schuman, 1977).

By artificially controlling rivers, we inevitably encounter with river bed stability and bed processes dynamic irregularities. The recovery degree of damage varies depending on the intensity of the process of the bed. Therefore, research of bed processes intensity is important for two reasons: to maintain a constant current of rivers and streams by cost efficient means and partially or fully restore, i.e. naturalize rivers. Thus, it becomes important to investigate, analyze and evaluate such beds deformation conditions and reasons, to evaluate their riverbed processes as well as intensity. We had to choose the river hydrodynamic stability criteria and based on them to perform the comparative analysis of regulated and natural beds consistency. The main results of this work are described in this article.

The aim of research - according to the selected river bed hydrodynamic stability criteria to perform comparative analysis of stability of regulated and natural streams.

To reach this aim the following tasks are:

- to describe bed processes of both natural and regulated streams in a dynamic balance by Lane equilibrium equation;
- to evaluate bed stability by using K.V.Grishanin criterion M and Altunin criterion M_A;
- to estimate dependence of stability criterion M and the ratio B h^{-1} in researched rivers;
- to assess the dependence of river bed width and length of the meanders for the small rivers.

Materials and Methods

Selection of streams bed stability criteria

The balance of each natural river between sediments discharge (Q_s) and bottom sediment particle mean diameter (D_{50}) is directly proportional to the average stream discharge (Q_w) and the longitudinal gradient of the river bed (S) (Lane, 1955; Schuman, 1977):

$$Q_s \times D_{50} \approx Q_w \times S \quad (1)$$

So, at least one of the changes of these river important variables inevitably causes change in all the remaining variables. The law is identified in the natural beds, but it is noticed that this balance increasingly

dominates in regulated streams as well, which are recently unsupervised, and they involve natural beds processes of recovery (Vaikasas and Ždankus, 2005).

Sediment discharge Q_s is calculated by Leyer-Peter and Muller equation (Karamisheva et al., 2006):

$$Q_s = 8(s-1)^{0.5} D_{50}^{1.5} g^{0.5} \left[\left(\frac{n}{n'} \right)^{1.5} \theta - \theta_{cr} \right]^{1.5} \quad (2)$$

Here: Q_s – sediment discharge, $m^2 s^{-1}$;
D_{50} – mean sediment particle size, mm;
s – specific gravity (ratio between the density of sediment and fluid density);
g – acceleration due to gravity, $m s^{-2}$;
n – the Manning roughness coefficient;
n' – the Manning-Strickler grain roughness coefficient;
θ – the Shield's dimensionless shear stress parameter;
θ_{cr} – the Shield's critical dimensionless shear stress parameter.

According to the above-mentioned Lane (1955) law, natural rivers, as unique natural systems, are able to modify and adapt their beds form, sediments and the longitudinal slope (as opposed to artificially adjusted and enhanced bed). Rivers do it over a sufficiently long period of time while changing both, a bed form as well as its position in the plan, regulating the bottom surface roughness and sediment leaching and deposition (River.., 1998). Self-regulation processes of natural streams take a long time in stable climate conditions. That lets to evolve river into a stable constant width and depth of the beds in which the local flow accelerations change the slowdown, while the average velocities and longitudinal slope remains almost constant. An almost constant and comparative river flow of energy loss at the same time stabilizes and remains constant. K.V. Grishanin, famous hydraulics professor, observed and applied this natural beds feature (Grishanin, 1969; 1971; 1972; 1979; 1990; 1992). The professor analyzed the well-established, slow-changing natural currents and found an open alluvial bed stability criteria, linking it to form the bed of the formative flow stream energy:

$$M = \frac{d(gb)^{1/4}}{Q^{1/2}} = \left[\frac{d}{b} \frac{1}{Fr^2} \right]^{1/4} \quad (3)$$

Here: M - the Grishanin dimensionless rivers bed stability coefficient;
d – average bed depth in river cross section, m;
b – river bed width in river cross section, m;
Q – bank full discharge, $m^3 s^{-1}$;
g – acceleration due to gravity, $m s^{-2}$;
Fr – dimensionless Froude number, characterizing river flow kinetic and potential energy ratio in measured cross section. Froude number is defined as:

$$Fr = \frac{v}{(gd)^{1/2}} \quad (4)$$

Here: v - the mean velocity in river cross section, $m s^{-1}$;

The above mentioned equations (2) and (3) show the form of a steady bed dependence of the river flow on relative energy, depending on the riverbed bank full discharge. The increasing energy and Froude number decreases bed stability, and erosion processes are expected. According to K.V.Grishanin, in plain rivers it is likely when M < 0.90. The bed becomes stable when $M > 0.92$, while for $M > 1.1$ is likely silting and sedimentation processes. The criteria have been tested for different soil conditions by other researchers, and all of them confirmed the reliability (Grinvald et al., 1988; Nikonora et al., 2009; Vaikasas and Ždankus, 2005). Their studies have shown that this stability criterion value varies depending on the river bottom soil, the banks overgrowth and bed meanders length. For example, the assessment of the major Lithuanian rivers, the Nemunas, the Neris, the Sventoji and the Minija the value of $M = 0.915$, so the river state is close to the steady (Vaikasas and Ždankus, 2005). Submountain riverbeds formatted from large rocks are stable and at lower values of M (Grinvalds et al., 1988), and the overgrown banks of the river also increase banks stability (Nikonora et al., 2009; Dabrovski et al., 1997; Rimkus et al., 1993). Thus, these studies confirm that the riverbed sediment size and banks overgrowth affect bed processes. To evaluate river sediment transport, erosion and sedimentation conditions were used as another bed stability criteria M_A (Altunin, 1979):

$$M_A = \frac{a_y^4 d^{4/3}}{D^{1/6}_{50} (b/d)^4} \quad (5)$$

Here: $a_y = f(v/v_0)$ - criteria of river bed stability;
v – the mean velocity in river cross section, $m s^{-1}$;
v_0 - the limitary unwashed velocity in river cross section, $m s^{-1}$;
D_{50} – mean sediment particle size, mm.

Both, the stability criteria M and M_A are used for assessing the stability of the river bed, which describes a stable bed form by comparative flow kinetic energy

and the average particle size of the bottom layer. In other words, the self-regulation of the river uses first silt and bed, if necessary, by changing its shape. However, it is more characteristic for mountain and sub mountain rivers with a high kinetic energy and longitudinal slope. Meanwhile, the plain rivers' flow supports forced choice of easy flowing place, while the longitudinal slope S is adjusted by changing the length of the bed meanders help.

In the term of river bed processes natural and regulated streams have special similarities and differences. One of the most important differences is the meandering of natural stream in horizontal and vertical planes. As shown by Danish scientists, the measurements meander length L depends on width of the stream b (River..., 1998; Rehabilitating..., 1995). It is usually found that $L = (10 \div 14)\ b$. Many researchers argue that the flow of water flowing energy is given up to form its smooth flow path and shape. In natural stream beds, not altered by human activities, the above-mentioned dynamic balance usually stabilizes over a long period of time meaning that depending on the flow discharge and slope, the bed form corresponding to amount of transported sediment occurs, so the river adjusts its kinetic and potential energy ratio and friction losses with the help of river meanders.

The object of investigation

River self-naturalization processes in the hilly landscape are sufficiently intense due to the higher slope and kinetic energy of flow. However, the rivers of self-recovery are slow in plain areas. Since Lithuania's landscape is flat, it is relevant to analyze plain rivers and river bed processes in them in order to determine how well self-recovery processes are in regulated rivers in plain area.

The rivers of the Jiesia basin with slopes characterizing plain rivers were chosen for this reason. The river Jiesia is one of the small tributaries of the river Nemunas. The length of the Jiesia river is 62 km. The Jiesia river basin area is 473.7 km^2. 63% of the basin surface is covered with heavy mechanical composition of soils with poor filtration properties. The basin woodland is 20%. There are only two lakes (both located in one of the tributaries – the Šventupis basin). The Jiesia river basin rivers network consists of 358.7 km of river beds. During land reclamation period 259.5 km or 72.4% of the Jiesia basin streams were regulated, while 99.2 km or 27.6% of natural streams were left (Jablonskis et al., 2001) unchanged.

The natural and regulated Jiesia river basin sections of streams were chosen as objects of investigation. Selected sections are divided into groups according to the slope (S <0.1% and S> 0.1%) and the dominant soil (sand, sandy loam, loam, clay, peat). The longitudinal slope of sections was measured using the normal technical leveling method measuring the height difference between the start and end points of the section. The predominant soil is determined by geological surveys drill. The flow discharge was measured by the ultrasonic flow meter at the characteristic profiles of the section. The flow discharge rate was greater than 0.5 m^3 s^{-1} in the object of research.

Three streams were chosen for the research, in each of which 50 m long sections, natural and regulated, were singled out. Each section is divided into 5 sections every 10 m. Three test samples of the stream substrate have been taken in each cross-section using geological probe. Sample intake places are evenly distributed in the bottom width of the tested section (on the left bank, right bank and in the middle of river bed). Granulometric composition of samples is determined by sieving and particle hydraulic coarseness extraction methods. According to composed granulometric curves of every sample average particle sizes of representing samples were determined. Water sample was taken in every section for investigating the amount of suspended particles in the flow. Also, stream width and depth measurements were performed at characteristic points of each section profiles. According to these measurements, the average flow depth, bed wet perimeters and cross section areas were calculated in each profile.

Results and Discussion

According to the available measurement data (flow discharge, slope, sediment discharges and average particle size) bed processes can be described in a dynamic balance of both natural as well as regulated streams. The Lane equilibrium equation (1) was used to evaluate and describe the processes taking place in the rivers beds.

The Lane equation parameters were collected during field measurements or estimated for further calculations. Flow discharge and slope of sections are presented in Table 1.

Table 1

Flow discharge and slope of sections

River name	Discharge, Q_w m^3 s^{-1}	Slope, S
Kumė (regulated)	0.42	0.0100
Kumė (natural)	0.43	0.0012
Maisys (natural)	0.55	0.0012

After the sediment flow calculations by formula (2), it was defined that in the regulated Kume section sediment discharge is up to 1.266 m^2 s^{-1} m, while in natural Kume and Maisys sections measurements of sediment discharge Qs values are 0.013 and 0.002 m^2 s^{-1} m, respectively. This clearly shows that

sediment discharge in the natural sections is much smaller than the regulated one where bed stability is less according to erosion potential.

Average particle size D_{50} was determined by the results of sample grading. It was showed that average particle size (D_{50}) in natural streams is higher than the regulated one. Accordingly, the average particle size 0.600 mm dominates in the natural stream of Maisys and – 0.160 mm in natural stream Kume. Meanwhile, the average particle size 0.037 mm yielded in the regulated Kume river section.

According to the research data and the calculated results, river beds dynamic equilibrium was evaluated. The Lane law equation (1) was used to estimate the dynamic equilibrium on both sides given in Table 2.

Table 2

Comparison of the investigated parameters according to Lane's law

River name	Q_w*S	Q_s*D_{50}
Kumė (regulated)	0.0042	0.0473
Kumė (natural)	0.0005	0.0021
Maisys (natural)	0.0007	0.0012

According to the survey results, it was found out that processes in the natural stream Maisys the best satisfy the requirements for the Lane equilibrium equation (the ratio of the equation sides $Q_{w*}S/Q_s * D_{50}$=1.73), a natural Kume section - 4.15, while the Kume river regulated section – 11.26. This shows that the equilibrium of natural bed processes is more settled in natural streams of Maisys and Kume, while bed processes in regulated Kume river section show that intensive erosion processes (characteristic to regulated sections) are still going on. The results also indicate that Lane's law is well suited to evaluate bed stability, which may indicate the intensity of the natural hydrological balance recovery processes taking place in regulated rivers.

In order to assess stability of steady and slowly flowing natural watercourses, bed stability criteria, known as K.V. Grishanin criterion *M* (equation (2)) were also calculated. The results of calculation are presented in Table 3.

Table 3

Stability criteria M of investigated sections

River name	M
Kumė (regulated)	0.68
Kumė (natural)	0.81
Maisys (natural)	0.87

The average of criteria *M* is 0.84 (range 0.81-0.87) in natural rivers and 0.68 in regulated ones. That shows that difference of criteria M between natural and regulated rivers is 0.16. The results show that the stability criteria *M* of natural watercourses compared to regulated sections are significantly closer to 1. Differences between criteria *M* and 1 are 0.16 (16%) on the average in natural researched rivers and 0.32 (32%) in the regulated ones. It shows that difference between criteria *M* and 1 are twice higher in regulated rivers than in natural ones. As noted above, the K.V. Grishanin stability criteria reach ($M > 0.92$) for plain landscape rivers. However, criterion M value is less than 0.90 for the researched rivers sections. This indicates that bed stability has not yet been sufficient in natural Maisys and Kume rivers (respectively, M=0.87<0.92 and M= 0.81<0.92). Meanwhile, this stability criterion is only M = 0.68, i.e. 0.68 << 0.92 for the regulated Kume river section. This shows that the regulated section is very unstable, and it is still under intensive bed regeneration process. In that case the river bed will be able to stabilize naturally just over a sufficiently long period of time.

The criteria M_A (Altunin, 1979) characterize the bed stability by river bed sediment transport, erosion and sedimentation conditions which are calculated by the formula (4).

Table 4

Stability criteria M_A of investigated sections

River name	M_A
Kumė (regulated)	0.65
Kumė (natural)	0.84
Maisys (natural)	0.87

As mentioned above, these criteria allow to evaluate the stability and bottom sediment of river-bed. It depends on flow velocities, bed shallowness consistency and stability conditions.

This criterion also showed that stability criteria M_A for the natural Maisys and Kume rivers are 0.8724 and 0.8356 respectively, i.e. close to 1. Meanwhile, stability criterion M_A is 0.6514 in regulated Kume section. A comparison of stability criteria M_A and *M* shows that the criterion values coincide in natural Masys and regulated Kume sections, and only a 3.7% difference in the natural Kume section, which does not exceed the tolerance limits.

The calculated stability criterion *M* values were compared with previous studies, in which larger Lithuanian rivers have been studied (Vaikasas and Ždankus, 2005). In order to be compared, criteria *M* values in these research work flow width and depth ratio B h^{-1} were used. The dependence of stability criterion *M* and the ratio B h^{-1} is presented in Figure 1.

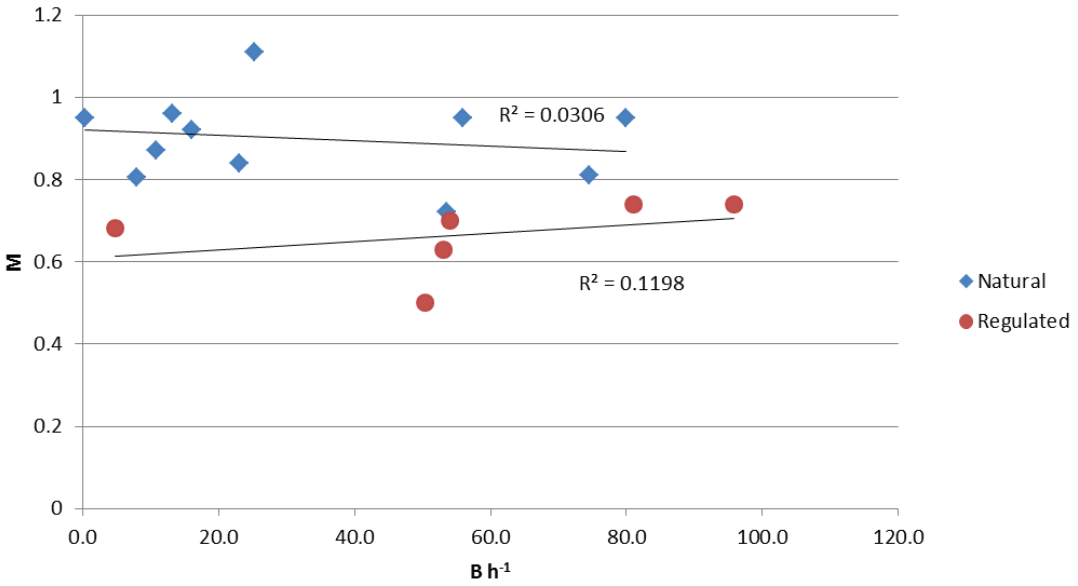


Figure 1. The dependence of stability criterion *M* and the ratio B h^{-1} in natural and regulated Lithuania rivers.

As it can be seen in the graph (Figure 1), the stability parameter *M* values vary from 0.80 to 1.1 ranges in Lithuania natural rivers. Small natural rivers, including Maisys and Kume, also are in the same range, because parameter ratio B h^{-1} is equal to 10.86 and 7.88, respectively. Meanwhile, stability parameter *M* values distribute from 0.50 to 0.74 ranges in regulated rivers. The ratio B h^{-1} is only 4.72 for regulated river Kume section, while the stability parameter value drops to 0.65. It means that the stability parameter M sufficiently characterizes the level of river stability in natural and regulated rivers.

As we can see, the coefficient of determination R^2 is 0.03 and 0.12 for natural and regulated rivers respectively. The values of determination coefficient show that relationship between parameters *M* and B h^{-1} is rather weak. However, this article is to show that the coefficient of *M* values of natural and regulated watercourses are obviously different - natural beds *M* parameter values are greater than 0.72, regulated - smaller than 0.74. From this we can conclude that natural and regulated rivers stability obviously differ.

The river bend length increasing could be means of the kinetic energy regulatory for analyses of river stability and recovery processes. Larger diameter river bed sediment layer is formed due to higher velocities at hydrodynamics axis of the river bed. Silt particles average values of sampling showed where and what size particles are located. Under the current medium-sized silt particles layout plans river bed meanders formation patterns have been determined.

According to the location of silt in the plans, it can be determined how and to what size curves for experimental river bed are formed. It can be stated that bends are formed in natural Maisys and Kume river sections, while meanders formation patterns are not detected in regulated Kume river.

Analyzing the exploratory bed meanders lengths, it is available to use addiction found by Danish scientists: $L = (10 \div 14)b$. It was found that the constant river bend length is $L = 20\text{-}25$ *m.* in the natural Kume river section and Maisys river bend is formed with a length of $L = 60$ *m.* According to the above mentioned dependence for length of the meanders $L=(10 \div 14)b$, it can be assumed that for the smaller rivers, which furrow width small enough, the relative riverbed meanders effect is greater than for the larger rivers due to the closer coast effect. The evaluation of investigational natural river sections can also be stated that curves in selected sections are characteristic for natural furrows. This is confirmed by results of accumulated silt and coarse location in the investigated sections.

Conclusions

1. Dynamic equilibrium Lane's law describing dynamic processes in natural and regulated watercourses. This law confirms that dynamic equilibrium (equation aspect ratio, respectively - 1.73 and 4.15) is well-established in the Maisys and Kume rivers natural sections. Dynamic equilibrium ratio value is 11.25 in the regulated Kume river section. That indicates that regulated sections are still under intensive erosive processes.
2. The river bed stability criterion *M* indicates that the stability of the researched sections is not sufficient (respectively $0.87 < 0.92$ and $0.81 < 0.92$) yet. This

stability criterion is only 0.68, i.e. 0.68 << 0.92 in the regulated Kume river section. This shows that the regulated section is very unstable and it is still under intensive bed recovery process.

3. The assessment of river bed stability under the criterion M_A provides that the natural beds in Maisys and Kume, criterion value to 0.8724 and 0.8356, and the regulated Kume section - 0.6514. Comparing stability criteria M_A and M values showed that these two criteria properly assess river's bed stability.
4. Accumulated silt particle size and their distribution confirm the formation of bed patterns. It was found that the relative small river bed meanders effect is greater than in the larger rivers.

References

1. Altunin V.S. (1979) Мелиоративные каналы в земляных руслах (Reclamation channels in watercourses). Moscow, 255 c. (in Russian).
2. Grinvald D.I., Nikonora V.I. (1988) River turbulence. Hydrometeoizdat, Leningrad, 152 p.
3. Grishanin K.V. (1969) Dynamics of channel flow. Hydrometeoizdat. Leningrad, 427 p.
4. Grishanin K.V. (1971) Stability of river channels. Meteorology and Hydrology. Leningrad, 10, pp. 69-75.
5. Grishanin K.V. (1972) Stability of river channels and kinematic waves. State Hydrological Institute. Leningrad, 190, pp. 37-47.
6. Grishanin K.V. (1979) Dynamics of channel flows. Hydrometeoizdat. Leningrad, 326 p.
7. Grishanin K.V. (1990) Foundations of dynamics of channel flows. Hydrometeoizdat. Leningrad, 154 p.
8. Grishanin K.V. (1992) Hydraulic resistance in natural streams. Hydrometeoizdat. St. Petersburg, 181 p.
9. Jablonskis J., Gailiušis Br., Kovalenkovienė M. (2001) Lietuvos upės. Hidrografija ir nuotėkis. (Lithuanian rivers. Hydrology and discharge). Kaunas: LEI, 792 p. (in Lithuanian).
10. Karamisheva R.D., Lyness J.F., Myers W.R.C., Cassels J.B.C., O'Sullivan J. (2006) Sediment transport formulae for compound channel flows. Proceedings of the Insttution for Civil Engineers. Water Management 159, pp. 183-193.
11. Lane E.W. (1955) The importance of fluvial morphology in hydraulic engineering. Proceedings of the American Society of Civil Engineering 81, 745 p., pp. 1-17.
12. Leopold L.B., Rosgen D.L. (1991) Movement of bed material class in gravel streams. Proceedings of the V Federal Interagency Sedimentation Conference. Las Vegas, Nevada. pp. 183-188.
13. Newsletter ECRR (European Centre for River Restoration) /NERI. (1998) December. 8 p.
14. Nikonora N.F., Nikonora V.I. (2009) Self-regulated effects in open-channel flows: Application to vegetated channels. Proceedings of 33rd IAHR Congress. [CD Rom], Vancouver, Kanada. pp. 6653-6660.
15. Rehabilitating Danish Streams. (1995) Ministry of Environment and Energy, Denmark, Miljo – Th, 11, 28 p.
16. Rimkus A., Vaikasas S. (1993) Natūralizuojamų sureguliuotų upelių hidraulinės problemos. (Hidraulic problems of naturalized regulated streams). Melioracija: Mokslo darbai / LMI. pp. 63-72. (in Lithuanian).
17. River Restoration News 1998 (1998) Newsletter of the River Restoration Centre. Denmark, Silsoe Campus, Nowember, 1, 8 p.
18. Schuman S.A. (1977) The fluvial system. John Willey and Sons, New York. 338 p.
19. Stream Corridor Restoration. Principles, practices and processes. (1998) Available at: http:/www:usda:gov/stresam restoration newtofc.httm, 11 March 2013.
20. Vaikasas S., Ždankus N. (2005) Analysis of Lithuanian river channels bed stability (Referring to Grishanin Number). Water Management Engineering, 2(5), pp. 107-112.

THE CYCLES OF PHOSPHORUS IN CROP ROTATIONS DIFFERING IN FERTILIZATION

Saulius Gužys
Aleksandras Stulginskis University, Lithuania
saulius.guzys@asu.lt

Abstract
The investigations were carried out during the period 2006-2011 in the land of the Water resources management institute of ASU, in the village of Lipliūnai on Endocalcari Endohypogleyic Cambisol (CMg-n-w-can). The base of investigations is 3 drainage systems, which contain cereals differing in fertilization and grass crop rotations. The aim of investigations is to determine the crop rotations differing in fertilization and these relations with cycles of phosphorus in agroecosystem.
Higher productive was perennial grass crop rotation. In the conditions of cereal crop rotations this productive was 3-46% lesser.
The highest concentration of $P\text{-}PO_4^{3-}$ in drainage water was received in the conditions of higher fertilization cereals crop rotation while highest concentration of total P was in the conditions of grass crop rotation. The concentration of $P\text{-}PO_4^{3-}$ in drainage water essentially depends on amount of mobile P_2O_5 in soil, fertilization, productivity of field crops, drainage runoff as well as cumulative balance of P.
The highest leaching of $P\text{-}PO_4^{3-}$ and total P by drainage was received under the conditions of higher fertilization cereals crop rotation. The leaching of $P\text{-}PO_4^{3-}$ essentially depends on fertilization, drainage runoff as well as cumulative and yearly balance of P. The application of all crop rotations was distinguished by positive P balance.
Key words: phosphorus, yield, concentration, leaching, balance.

Introduction

In total in the earth crust there is 0.12% of phosphorus. The main source of phosphorus is orthophosphates. In soil they become mobile at weathering of primary minerals – compounds with Ca, Fe and Al of various solubility are formed.
According to assimilation of plants and mobility, mineral phosphates can be divided into 3 groups:

1. Phosphates in a solution of soil.
2. Phosphates on the surface of particles of a hard part of soil. Under certain conditions – when there is diffusion, they can pass into a solution. It is mobile phosphorus, with which plants are provided for a long time.
3. The phosphates assimilated with difficulty are a part of primary and secondary minerals. They pass into a liquid phase; however, they are slowly released during weathering (Adomaitis et al., 1998).

There is more phosphorus in soil than in deep subsoil. It is less phosphorus deep in soil. A large quantity of soil in the upper layers is accounted for by the fact that plant roots lift it from the upper layers.

Phosphorus is one of the basic elements necessary for all living beings. Lithuanian soils have very little of mobile phosphorus. If additionally not fertilized, phosphorus resources in soil could only yield cereal crop of 2.0 t ha^{-1}. And the least level of phosphorus content in soil compensated by weathering process is 20-50 mg kg^{-1} P_2O_5 (Mattson, 1998; Loes et al., 2001).

The analysis of leading countries in agricultural use of phosphorus has revealed 2 main problems:

1. Phosphorus accumulation in soil because of fertilization to the level exceeding the value for agricultural plants.
2. Migration of phosphorus from the system "soil – plant" and its accumulation in superficial reservoirs (Some phosphorus..., 1998; Delgado and Scalenghe, 2008).

Phosphorus exchange in the agro-ecosystems of the majority of countries is similar. Specialized farms, using mineral and organic fertilizers, destroy natural cycles of phosphorus, phosphorus penetration exceeds its extraction from fields with vegetative production; therefore, this element is accumulated in soil (Sharpley et al., 1998; Sharpley et al., 2001; Mattson, 1998; Heckrath et al., 1997). For the last 65 years in Great Britain excess of phosphorus has reached 1000 kg ha^{-1} both in herbages, and in the regions of arable agriculture (Withers et al., 2001).

Although some authors (Some phosphorus..., 1998; Bunemann et al., 2005) assert that phosphorus added with fertilizers is very immobile and for 24 hours remains in the upper layer of soil (0-25 cm), many other researchers indicate that in the regions of increased phosphorus content its leaching with superficial water and with drainage grows, and eutrophication of reservoirs is encouraged (Sharpley et al., 1998; Sims, 1998; Geohring et al., 2001; Hooda et al., 1999; Lundenkvam, 1997). The research carried out in Canada has shown that the risk of accumulation of P on a surface of soil is higher in the clay soils moderately supplied with phosphorus. In Sweden, it was determined that leaching-out of P with drainage

did not exceed 2 kg ha^{-1}, if the amount of mobile P_2O_5 was less than 150 mg kg^{-1}. Any gain of phosphorus in soil proportionally increased its concentration in drainage water. The research of various agricultural systems carried out in Lithuania has shown that intensification of agriculture insignificantly enlarges the washed out quantity of phosphorus, and basically depends on the structure of soil, the content of phosphorus and humus (Bučienė, 2003). However, judging by the results of many researches done over a long period of time, it was determined that when applying the amounts of mineral fertilizers larger than require plants, phosphorus content in soil depending on its acidity also increases in depth of 40-60 cm (Končius et al., 2004). After 12 years of systematic fertilization with straw manure mixed up with mineral fertilizers ($N_{45\ 150}$ P_{50} K_{150}), a substantial growth of organic phosphates up to depth of 55 cm has been found (Tripolskaja, 2004).

There are quite a few researches estimating migration of phosphorus compounds with application of various land management. In Norway, it was determined that the highest losses of P take place during autumnal tilling. During cultivation of winter plants P losses decrease. Leaching of P also grows when larger than rational quantity of fertilizers is used (Lundenkvam, 1998).

The aim of our research is to evaluate the migration of phosphorus applying different fertilization.

Materials and Methods

The research was carried out in the period from 2006 to-2011 in the Middle-Lithuanian lowland, on the ground of Faculty of Water and Land Management land of the Water Resources Engineering institute at Aleksandras Stulginskis University, in the village of Lipliūnai. The basis of research – 3 drainage systems (12-16 ha), in each of them a separate rotation of field plants was used with different quantities of fertilizers (Table 1).

The plants were fertilized only with mineral fertilizers. The testing field was industrial; therefore, the quantity of fertilizers used for each crop rotation was limited by financial possibilities of the farm. The following kinds of plants were grown: sugar beet (*Beta vulgaris* L. var. saccharifera) 'Belmonte', spring barley (*Hordeum vulgare* L.) 'Ūla', a winter wheat (*Triticum aestivum* Host.) 'Portal', permanent grasses (red clover (*Trifolium pratense* L.) 'Liepsna' + timothy grass (*Phleum pratense* L.) 'Gintaras II'), spring wheat (*Triticum aestivum*) 'Nandu', winter rape (*Brassica napus* L.) 'Valesca'.

Soil - Endocalcari Endohypogleyic Cambisol (CMg-n-w-can), light loam on a sandy loam. Before testing the soil had a neutral reaction (ph_{KCl} 7.1-7.2), phosphorous and very phosphorous (158-232 mg kg^{-1} of P_2O_5), with low and average mobile potassium value (62-114 mg kg^{-1} K_2O). The content of humus and overall content of nitrogen changed from 1.6 to 4.4 and from 0.07 to 0.3%. For determining the agrochemical characteristic of soil the samples were taken in the autumn after harvesting, by drilling to the depth of 60 cm every 20 cm adhering to genetic horizons. In each variant combined samples were taken from 15-20 holes.

Water drainage was measured by volumetric method every 3 days. Its samples during running off were taken every 10 days. Concentration of P-PO_4^{3-}

Table 1

Rotations of field plants and fertilizing them with phosphorus (kg ha^{-1} of active substance)

Years	Crop rotation		
	Cereals, lesser fertilization	Cereals, higher fertilization	Perennial grasses
2006	Spring barley P26	Spring barley P42	Sugar beet P52
2007	Winter rape P39	Sugar beet P74	Spring wheat P26
2008	Winter wheat P26	Spring wheat P46	Perenial grasses P0
2009	Spring wheat P33	Spring barley P63	Perenial grasses P0
2010	Spring barley P32	Winter wheat P52	Perenial grasses P0
2011	Winter wheat P48	Winter wheat P68	Spring wheat P48
Total fertilization of crop rotations			
	P204	P345	P126

in water was determined by colorimetric method. Soil analyses were carried out by the following methods: humus – by Tyurin method, mobile P_2O_5 and K_2O – by AL-method, overall N – by Kjeldahl method. The area of registration sites of cereals and grasses is 30 m^2, of accumulating sites - 45 m^2. The crop of plants was determined during 6-8 repetitions. The crop of the total energy was calculated on the basis of the literature (Jankauskas et al., 2000). In vegetative production the quantity of P is defined from 1 extract burned with concentrated H_2SO_4, hydrogen and a Se-based catalyst. The data were processed by the methods of mathematical statistics. The methods of disperse and correlation-regressive analysis were applied. Errors for each variant were calculated separately (Dyke, 1994).

The symbols and abbreviations used in the paper: r – correlation coefficient; $x_{ekstr.}$- a function extremum; LSD_{05} – a limit of reliability difference (95%), * reliable 95%, ** – for probability of 99%, V% - variation factor, Rv – variation amplitude, Sx – standard error.

Results and Discussion

The data of soil research have shown (Table 2) that the soil of all fields of crop rotation was neutral and alkalescent.

Table 2

Agrochemical properties of soil on the testing field

Crop	pH_{KCl}	mg kg^{-1}	%	
rotation		P_2O_5	K_2O	N total
Cereals, lesser fertilization	7.07	215	92	0.29
Cereals, higher fertilization	7.33	144	124	0.23
Perennial grasses	7.28	129	76	0.09

In the beginning of research the highest content of phosphorus was in fields with lesser and higher rotation of cereals, accordingly 215-144 mg kg^{-1}. The highest content of potassium was on the field of rotation of cereals with larger fertilization. An abundance of humus and overall content of nitrogen in soil (4.32 and 0.29%) was showed by the rotation of cereals with lesser fertilization. The research of plants crop on the field with various crop rotations (Table 3) have shown that in most cases the highest fertility was in the rotations of cereals with lesser fertilization and of grasses.

For 6 years of research the rotation of cereals with larger fertilization accumulated 974, and that of grasses – 1009 GJ ha^{-1} crops of total energy. This is 77% and 84% more compared to the least productive crop rotation with smaller fertilization.

Average study of phosphorus compounds concentration in drainage water (Table 4) has shown a little difference in $P\text{-}PO_4^{3-}$ using various crop rotations. If rotation with higher fertilization of cereals is used, it has a small increase (33%) and reaches 0.008 mg L^{-1}.

The correlation-regressive analysis of research data has revealed (Table 5) that concentration of $P\text{-}PO_4^{3-}$ in drainage water was formed by many environmental factors. When the content of phosphorus in soil increases, concentration of phosphates in drainage water is changed in direct ratio, and when fertilization and fertility of field plants change, the concentration of this compound in drainage water is changed parabolically. Larger fertilization than 34 kg ha^{-1} of active substance P enlarges this concentration and by increasing fertility of field plants above 200 GJ ha^{-1} – reduces it. When drainage runoff increases, the concentration of $P\text{-}PO_4^{3-}$ in it decreases in inverse ratio. The least concentration of $P\text{-}PO_4^{3-}$ in drainage water takes place at small positive balance of phosphorus (+8 kg ha^{-1}). More superfluous balance enlarges this concentration. The data on total leaching of phosphorus compounds have shown (Table 6) that both phosphates, and overall phosphorus mostly

Table 3

Average crop of the total energy of field plants GJ ha^{-1} (main and sideline products)

Crop rotation	2006	2007	2008	2009	2010	2011	**Sum±Sx**
Cereals, lesser fertilization	62	79	126	93	80	109	**549±50.7**
Cereals, higher fertilization	62	310	145	103	160	194	**974±74.3**
Perennial grasses	253	103	258	234	67	94	**1009±82.1**
LSD_{05}							**200.0**

Table 4

Influence of various crop rotations on the average annual concentration of phosphorus in drainage water

Crop rotations	mg L^{-1}	
	$P\text{-}PO_4^{3-}$	Total P
Cereals, lesser fertilization	0.006±0.0003	0.016±0.0008
Cereals, higher fertilization	0.008±0.0004	0.019±0.0011
Perennial grasses	0.006±0.0002	0.021±0.0009
LSD_{05}	0.003	0.007

are leached using rotation of cereals with higher fertilization. In comparison with rotation of grasses, there was leached out 59% of phosphates, and 23% more of overall phosphorus. Leaching of phosphorus compounds using rotation of cereals with lesser fertilization and that of grasses differed slightly. The performed correlation-regressive analysis of dependence of phosphates phosphorus leaching with drainage from environmental factors has shown (Fig. 1) that it mostly depended on applying phosphoric fertilizers, drainage effluent, annual and cumulated balance of phosphorus in the agro-ecosystem. Unlike the concentration of $P\text{-}PO_4^{3-}$ in drainage water the content of soil phosphorus and productivity of the agro-ecosystem did not have influence on leaching of phosphorus with drainage. Thus, leaching of $P\text{-}PO_4^{3-}$ with drainage under the influence of applying phosphoric fertilizers changes parabolically, and the lowest value is achieved at fertilization of 42 kg ha^{-1} (active substance). At further growth of fertilization, leaching of phosphates increases. Under the influence of annual drainage runoff and annual balance of P, leaching of phosphates with drainage is changed in direct ratio, and grows at increase of these indices. Under the influence cumulated balance of phosphorus, the phosphatic leaching is changed parabolically and the least is received at a small balance of P in the agro-ecosystem (+8 kg ha^{-1}). The most superfluous balance of P increases the leaching of $P\text{-}PO_4^{3-}$ with drainage.

The data of phosphatic balance study have shown that when crop rotation of grasses was used, almost in

Table 5

Dependence of $P\text{-}PO_4^{3-}$ concentration in drainage water (y) from environment factors ($x_{1\text{-}5}$)

Index	Regression equation	Coefficient	Extremum
Amount of mobile phosphorus in soil	$y=0.956+0.0267x_{1;}$	r=0.40*	-
Phosphorus fertilization kg ha^{-1} a.m.	$y=7.53-0.17x_2+0.0025x_2^2$	h=0.40*	34
Yield GJ ha^{-1}	$y=2.32+0.038x_3-0.000095x_3^2$	h=0.32	200
Annual drainage runoff mm	$y=7.04-0.0283x_4$	r=0.31	-
Cumulative P balance kg ha^{-1}	$y=5.23-0.025x_5+0.00017x_5^2$	h=0.58**	8

Table 6

Influence of various crop rotations on total leaching of phosphorus with drainage

Crop rotations	kg ha^{-1}	
	$P\text{-}PO_4^{3-}$	Total P
Cereals, lesser fertilization	0.015	0.057
Cereals, higher fertilization	0.027	0.070
Perennial grasses	0.017	0.057
LSD_{05}	0.008	0.01

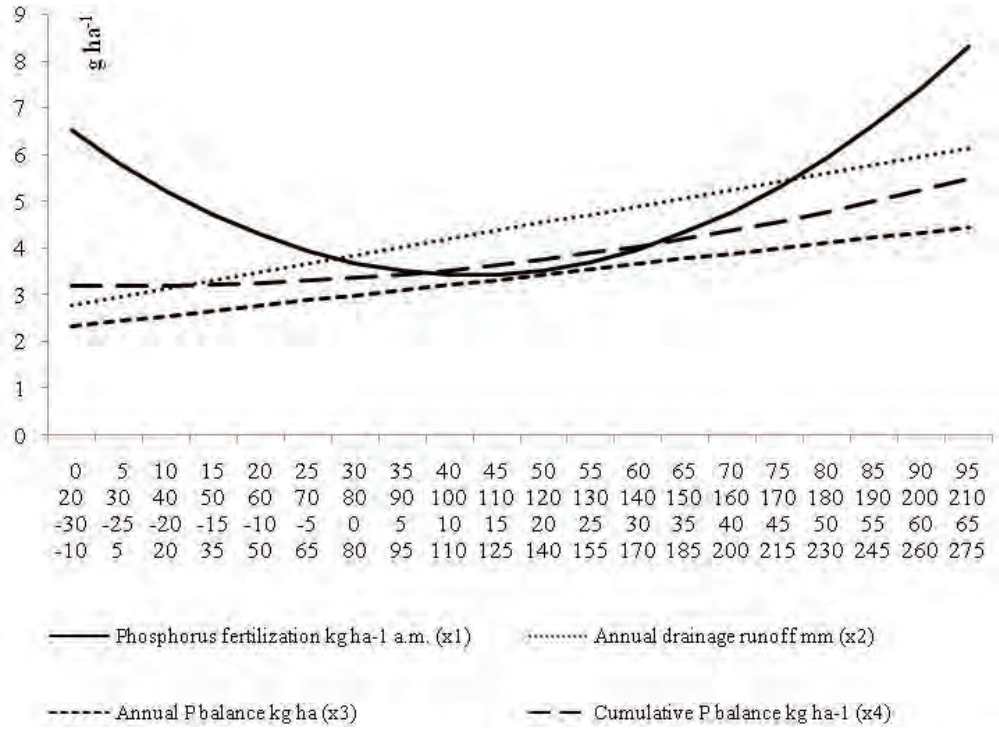


Figure 1. Dependence of P-PO_4^{3-} leaching with drainage (y) g ha^{-1} from environment factors (X_{1-4}).

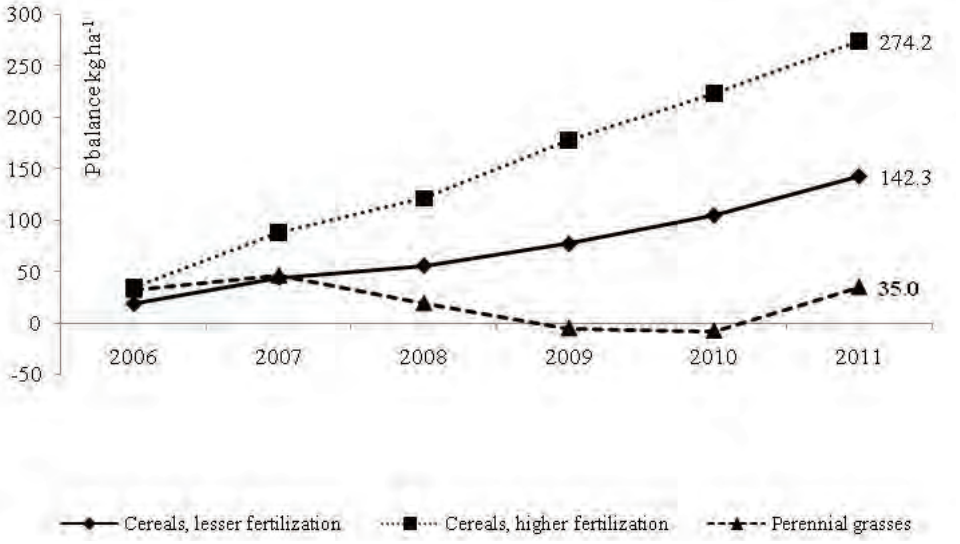


Figure 2. Influence of various crop rotations on cumulative balance of phosphorus.

all cases it was slightly positive and after 6 years of research was +35.0 kg ha^{-1} (Fig. 2). It was much more superfluous in the conditions of crop rotation with lesser fertilization. The largest balance of phosphorus was in crop rotation with larger fertilization – after 6 years of research its excess reached 274.2 kg ha^{-1}.

Conclusions

The study of various crop rotations in a deeper red soil with light loam (RDg4-K2) having more glei, carried out in 2006-2011 at Aleksandras Stulginskis University (ASU), allows making the following main conclusions and generalizations:

1. The largest total fertility of field plants was in the least fertilized crop rotation of perennial grasses (1009 GJ ha^{-1}). Crop-producing power of sowing rotations with larger and smaller fertilizations of cereals was 3 and 46 % less accordingly.
2. The largest concentration of phosphatic phosphorus in drainage water was received using crop

rotation with larger fertilization, and the largest concentration of overall P – using crop rotation of grasses, 0.008 and 0.021 mg L^{-1}. When using crop rotation with smaller fertilization and almost no fertilized crop rotation of cereals concentration of P-PO_4^{3-} in drainage water decreases for 25% to 0.006 mg L^{-1}.

3. Concentration of phosphatic phosphorus in drainage water mainly depended on the phosphorus content in soil, application of P fertilizers, fertility of field plants, drainage effluent and cumulated balance of P. The largesr leaching of phosphates and overall phosphorus with drainage was received using the most fertilized rotation of cereals applying larger fertilization (0.027 and 0.07 kg ha^{-1}). Leaching of phosphatic phosphorus through drainage basically depended on fertilization by P, drainage effluent, annual and cumulated balance of P.
4. Application of all crop rotations showed positive cumulated balance of P. After 6 years, a grass crop rotation demonstrated small positive balance of P (35.0 kg ha^{-1}), but the most abundant cumulated excess was in the crop rotation with larger quantities of fertilizers (274.2 kg ha^{-1}).

References

1. Bučienė A. (2003) *Žemdirbystės sistemų ekologiniai ryšiai*. (Ecological dependence on cropping systems). Klaipėda, 2003, 176 p. (in Lithuanian).
2. Bunemann E.K., Heenan D.P., Marshner P., Mcneili A.M. (2006) Long – term effects of crop rotation, stubble management and tillage on soil phosphorus dynamics. *Soil Research,* Vol. 44(6), pp. 611-618.
3. Delgado A., Scalenghe R. (2008) Aspects of phosphorus transfer from soils in Europe. *Journal of Plant Nutrition and Soil Science*, vol 171, Iss 4, pp. 552-575.
4. Dyke G.V. (1994) *Comparative experiments with field crops*. 2nd edition. London, 224 p.
5. Geohring L.G., Mchugh O.V., Walter M.T., Steenhuis T.S., Akhtar M.S., Walter M.F. (2001) Phosphorus transport into subsurface drains by macropores after manure application. *Soil science*, vol. 166, iss.12, pp. 896-909.
6. Heckrath G., Brookes P.C., Poulton P.R., Goulding K.W.T. (1997) Phosphorus looses in drainage water from an arable silty clay loam soil. Phosphorus loss from soil to water. Waalingford: CAB international, pp. 367-368.
7. Hooda P.S., Moynagh M., Svoboda I. F., Edwards A.C., Anderson H.A., Sym G. (1999) Phosphorus loss in drain flow from intensively managed grassland soils. *Journal of Environmental Quality*, vol. 28, pp. 1235-1242.
8. Jankauskas B., Jankauskienė G., Šveda S.A. (2000) Derliaus energetinio įvertinimo skaičiavimo metodų palyginimas.(The comparison of methods of yield energetical evaluation). *Žemdirbystė*, t. 72, pp. 239-250. (in Lithuanian).
9. Končius D., Bernotas S. (2004) Kalkinimo ir tręšimo įtaka vasarinių rapsų derlingumui bei fosforo, kalio ir kalcio kiekiui dirvožemyje. (The influence of liming and fertilization on yield of spring rape and amount of phosphorus, potassium as well as calcium in soil.) *Žemdirbystė*, t.85, pp. 56-67. (in Lithuanian).
10. Loes A.K., Oggard A. (2001) Long term change in extractable soil phosphorus (P) in organic dairy farming systems. *Plant and soil*, No. 237, pp. 321-332.
11. Lundenkvan H. (1998) P – losses from three soil type at different cultivation systems. Seminar *Phosphorus balance and utilization* Agr*iculture Towards sustainability*, vol. 137, No. 7, pp.177-185.
12. Mattson L.P. (1998) Swedish long term soil fertility experiments. Seminar *Phosphorus balance and utilization*. Agr*iculture Towards sustainability*, vol. 137, No. 7, pp. 177-185.
13. Sharpley A., Gburek W. (1998) Agricultural phosphorus and water quality: sources, transport and management. *Agricultural and food science in Finland*, vol. 7, pp. 297-314.
14. Sharpley A.N., Mcdowell R.W., Kleinman P.J.A. (2001) Phosphorus loss from land to water: integrating agricultural and environmental management. *Plant and Soil*, vol. 237, iss. 8, pp. 287-307.
15. Sims J.T. (1998) Agricultural phosphorus and water quality. Commun. *Soil science and plant Anal*., No. 11-14, p. 1394.
16. Some phosphorus research work by the Royal Swedish Academy of agriculture and forestry. (2001) Phosphorus balance and utilization Agriculture. *Plant and Soil*, iss. 2, pp. 287-302.
17. Tripolskaja L. (2004) Ilgalaikio trąšų naudojimo įtaka dirvožemio savybėms lizimetriniuose įrenginiuose. (The influence of long term usage fertilizers on soil properties in lysimeters). Žemdirbystė, t. 85, pp. 17-27. (in Lithuanian).
18. Withers P.J.A., Edwards A.C., Foy R.H. (2001) Phosphorus cycling in the UK agriculture and implications for phosphorus loss from soil. *Soil use and Management*, vol. 17, p. 139.

THE IMPACT OF LAND DRAINAGE ON NEVEZIS RIVER FLOW

Laima Taparauskiene, **Antanas Maziliauskas**, **Otilija Miseckaitė**
Aleksandras Stulginskis University, Lithuania
Laima.Taparauskiene@asu.lt; Antanas.Maziliauskas@asu.lt; Otilija. Miseckaite@asu.lt

Abstract
Most of the regulated rivers are situated in the middle part of Lithuania. Approximately 90% of all agricultural lands are drained in the basin of Nevezis River, which is one of the most sensitive basins in Lithuania due to the lack of water and potential anthropogenic pollution. The goal of the research is to assess the impact of drainage on Nevezis river flow. Following the data series of 62 years, it was determined that water balance of Nevezis basin is characterized by negative water balance during May-September due to higher evapotranspiration than average precipitation amount of the same period. It was stated that the average annual flow coefficient of the whole 10th hydrologic region of Lithuania was 0.3 till reclamation. It decreased to 0.28 during the period of intensive reclamation; however, the average annual flow was 0.35 from the year 1980, i.e., it increased in comparison with the period till reclamation. The average flow coefficient of warm period was 0.10 till reclamation, and remained the same during the period of 1956-1980, while the data of 1981-1995 show that the average flow coefficient increased – 0.11. After assessing the meteorological conditions and soil water balance of the basin of Nevezis River it might be stated that the primary reason of water lack in the basin is climatic conditions. Drainage systems can hardly have a significant impact on wateriness of Nevezis River.
Key words: flow, water balance, land reclamation.

Introduction

Land drainage is one of the most active anthropogenic activities. The drainage changes the physical properties of soil, hydrographical network of the territory; therefore, the conditions of hydrological regime also changes (Lukianas, 2006). Lasinskas (1975) stated that the investigations of many researchers enable to propose that the flow increases approximately by 10-15% immediately after the drainage was installed. However, this effect decreases over time, and finally the increase of flow has become steady at 3%. As drainage systems are installed, the structure of agricultural lands changes. Thus, its alterations change the hydrological regime of rivers (Oginski, 2007; Ren et al., 2002). Marcenas (1991) has stated that drainage and intensive farming reduces the flow during seasons and the whole year. Zelionkienė et al. (1997) found out that as the size of drained areas increases, the coefficients of river flow of river basins decrease in spring season (in March – May), while in summer – autumn season (in June – October), it is on the contrary. Pauliukevičius (2007) states that a strong factor, reducing the smallest flow modules of 30 days, is the drained areas (r = -0.81). Though Zucker and Brown (1998) state that drainage has no influence on the total flow, i.e., it is almost the same as in the fields with no drainage. Additionally, they found out that drainage reduced the surface runoff from 29 to 65%, as well as the maximum discharge from drained fields from 15 to 30%. Robinson and Rycroft (1999) highlights that drainage significantly reduces the maximum discharge in less permeable soil, and slightly increases it in more permeable soil. It is also argued that drainage increases the total runoff and at the same time – the runoff during dry periods. Furthermore, Moore and Larson (1980) state that the results of drainage research suggest the increase of annual runoff and increase of maximum discharge of rainfall flow; however, the increase of peaks occurs only in micro basins, and the aforementioned increase is quickly compensated in lower streams. According to Klocking and Haberlandt (2002), the land use impacts on extreme flood events are small, the land use changes affect mainly the water availability. Lately Lukianas and Ruminaite (2009) have analysed the data of spring floods and summer freshets of river flow and have determined that the area of drained lands has no impact on the change of characteristics of river flow. Additionally Ruminaite and Barvidiene (2011) determined that the increase of area of drained lands has no significant impact on the change in height of flow in Tatula River during spring and summer seasons. Nevertheless, in Lithuania, it is more often stated that the flow of Nevezis river decreases because of intensively drained area. Dumbrauskas and Larsson (1993, 1997) stated that more data are required to confirm the aforementioned effect. Although the flow of Nevezis River was decreasing significantly during the period of investigation, the authors failed to relate it with dynamics of drained areas.

The aim of paper is to assess the impact of drainage on Nevezis river flow.

Materials and Methods

Most of the regulated rivers are situated in the middle part of Lithuania. There are 422 rivers in the basin of Nevezis and 383 (or 91%) of them are regulated (the total of 252 rivers and 131 small streams) (Jablonskis et al., 2007). The length of Nevezis is 209 km, while the area of the basin is

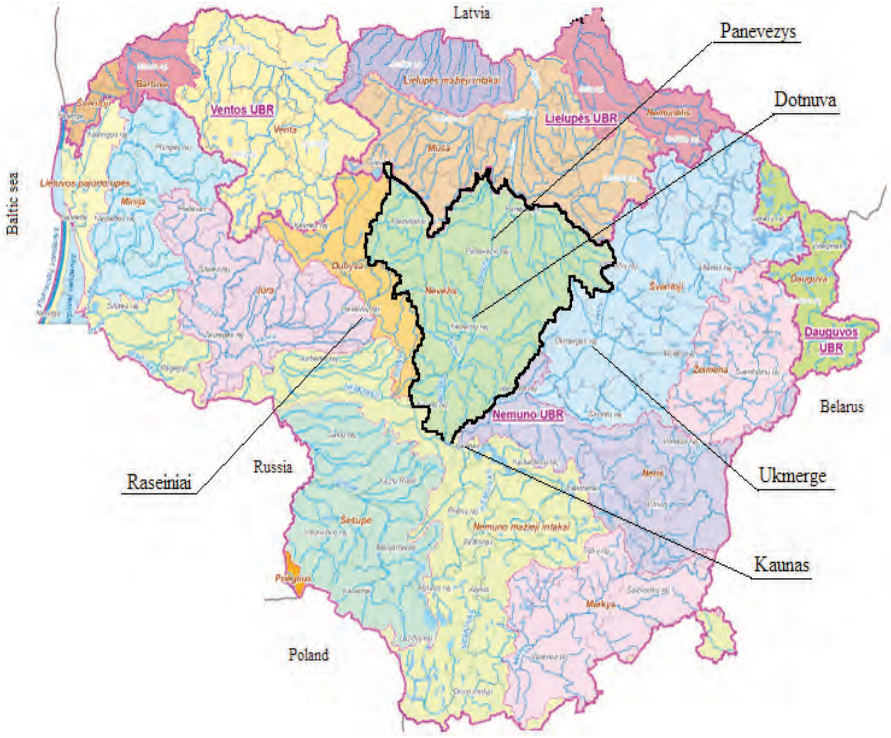


Figure 1. Nevezis basin (Aplinkos apsaugos..., 2008).

6 146 km^2, and the discharge at mouth is 30 m^3 s^{-1} (Fig. 1). While analyzing the change of Lithuanian river flow and its relationship with drainage intensity, first, it was sought to assess the income and expenses of water of river basins. The basin of Nevezis River is one of the most sensitive basins in Lithuania due to the lack of water during summer and potential anthropogenic pollution – was selected for water balance assessment. The basin of Nevezis belongs to the climatic sub-region of Central Lithuania, which is characterized by warm spring and summer, as well as the lowest amount of precipitation in the republic. The average annual air temperature is – 5.6-6.5 °C. 650–700 mm precipitation falls in the basin of Nevezis River each year, and 70% of it – during the warm season (Kilkus and Stonevičius, 2011).

The terrain of basin is uneven – the highest point is 184 m above the sea level, while the lowest – 20 m (at mouth), the average height of basin is 77 m, while the average surface slope of basin is 0.027 m km^{-2}. Approximately 90% of all agricultural lands are drained in the basin of Nevezis River.

The data analysis in the present paper is based on the water balance method. Hydrological and meteorological data of the period of 1945 – 2007 of Kaunas, Dotnuva, Panevezys, Ukmerge and Raseiniai meteorological stations were followed. The collected data were used as base, while analyzing the possible change of soil moisture in the basin of Nevezis River.

The balance of the whole basin was made, according to the simplified equation:

$$W_{n+1} = \Delta W_n - ET + H - N \quad (1)$$

here ΔW_{n+1} - productive soil moisture at the end of the period, mm;
ΔW_n – productive soil moisture at the beginning of the period, mm;
H – precipitation mm;
N – flow from the layer of soil, mm;
ET– evapotranspiration, mm. Determined, according to dependence under Lithuanian climatic conditions:

$$ET = 0.5\sum d + 105 \quad (2)$$

here Σd – average amount of daily air humidity deficit during vegetation period, mb.

The calculations were made during vegetation period (May – September). It was assumed that at the beginning of vegetation, as snow has melted, the soil moisture deficit is equal to zero, the soil moisture reserve is equal to accumulative soil volume. Dirse (2001) determined that the productive reserve of soil moisture in Lithuanian loamy soil is 100 mm. Flow to deeper soil layers was considered only in case, when the productive reserve of soil moisture

was equal or higher than 100 mm during the vegetation period.

To assess the impact of drainage on Nevezis river flow was used flow coefficient: the ratio of runoff high ($h_{0,}$ mm) and rainfall (H_0, mm) for the same period:

$$\alpha_0 = \frac{h_0}{H_0}. \quad (3)$$

The results obtained were subjected to the linear statistical analysis (LSD, program ANOVA). The impact of drainage effects were compared using the least significant difference test at the level of 95% (LSD_{05}, p-0.05) probability. Correlation relation is assessed, according to the value of correlation coefficient R.

Results and Discussion

Following the data series of 62 years, it was determined that the average precipitation amount during the vegetation period is lower than the evapotranspiration of the same period. The generalized patterns of precipitation and evapotranspiration are shown in Figure 2. According to research of Zhi et al. (2009), the land use change increased evapotranspiration by 8.0%, while the climate variability decreased it by 103.0%.

The results of calculations of the water balance for the vegetation season during May – September are presented in Figure 3. The calculated water balance shows that the analyzed period is characterized by negative water balance. This demonstrates that the total evapotranspiration in the basin of Nevezis is often higher than the amount of precipitation.

After calculating the water balance, according to the moving averages of five years, it was revealed that the vegetation periods, when water expenses exceed income, dominate. The trend curves are clearly rising in the main part, which forms the water balance – along Panevezys and Dotnuva, and still rising along Kaunas and Ukmerge. Correlation relation is moderate in Panevezys (R=0.51), Dotnuva (R=0.76) and Kaunas (R=0.4). Finally, the trend remains neutral and water balance is close to zero only in the western part of basin, along Raseiniai. In summary, it might be stated that a negative water balance is typical for northern and central zone of basin of Nevezis River, while the eastern and western part of basin is characterized by water balance, which is close to zero.

The areas of wet land in the region of basins of Nevezis River make 70-90% of total area. The analysis of change of too wet lands and drained areas within 1960-2007 years revealed that the drained areas made about 2% of total area of wet lands up to 1960 (1.7% of basin). What is more, 35% of total area of wet lands (28% of basin area) was drained till 1971, and 58% of area of the Nevezis River basin (Nevezis along Panevezys - 68%) on average or 70% of total area of all wet lands was drained till 2000. Recently, the size of area of drained lands has been decreasing. The area of more than 361.0 ha has been drained in the basin of Nevezis, 354,118 ha from which was drained by drainage, while 7,470 – by ditches. Following the data of 2007, the drained areas left for self-decay made 4,932 ha (0.8%), while those, drained by ditches, made 32 ha (0.01%). It is quite complex to make a more accurate assessment of change of Nevezis flow due to reclamation, since there is a lack of observation

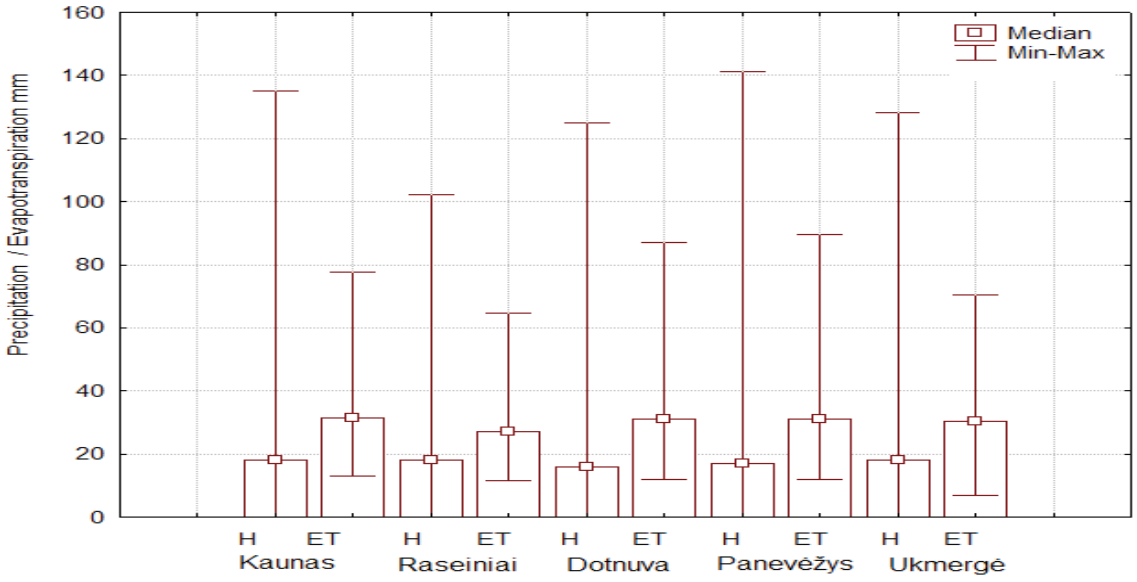


Figure 2. Precipitation (H) and evapotranspiration (ET) in the basin of Nevezis.

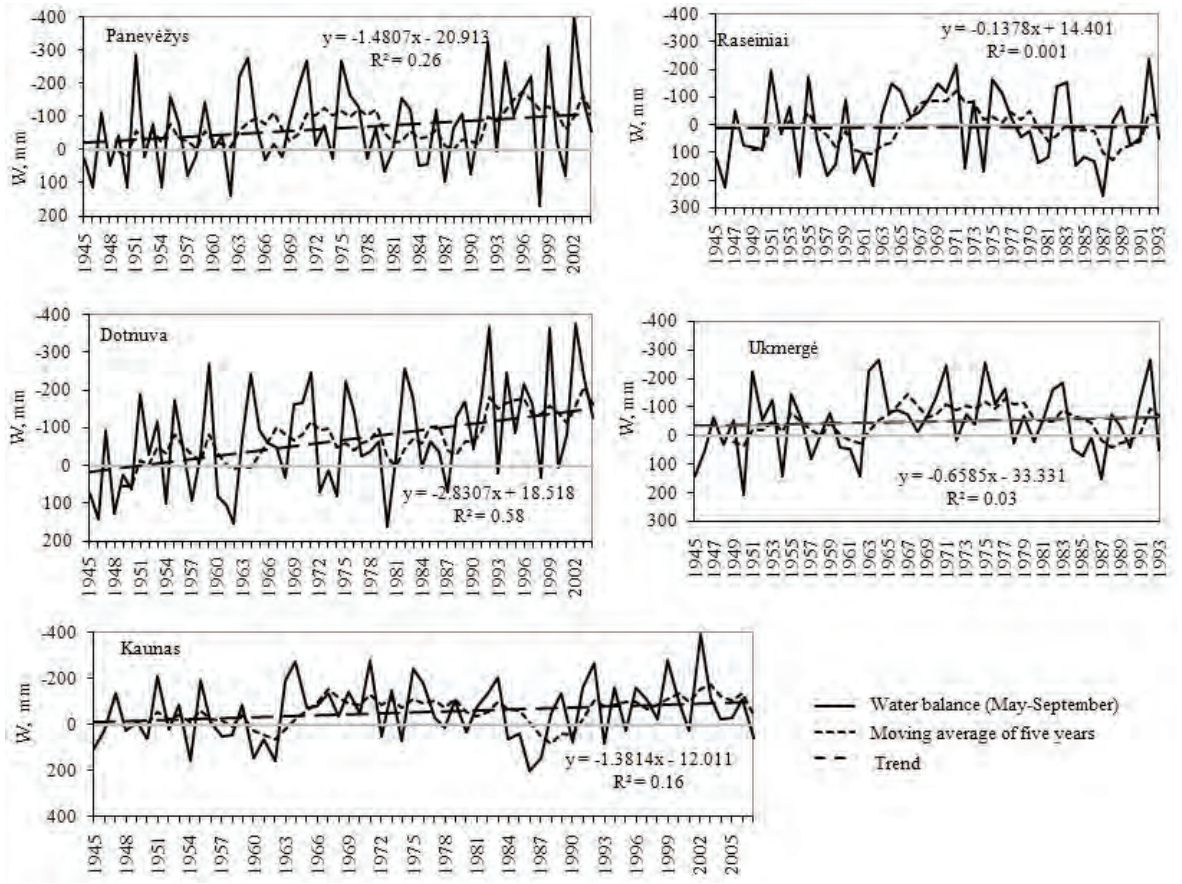


Figure 3. Water Balance tendencies in the Basin of Nevezis.

data from the start of reclamation. According to available coefficients of river flow of hydrologic region, it is known that during the period, when there were not more than 1-3% of drained areas in the basins of rivers, the annual flow coefficient in Dotnuvele (Dotnuva) was 0.29, and 0.10 during the period of June – October; while in Nevezis (Panevezys) the coefficient was 0.31 and 0.11, respectively.

During the period of 1956-1975 (the years of most intensive land drainage) the flow coefficient of Dotnuvele decreased – 0.25 (annual) and 0.05 (June – October), while the flow coefficient of Nevezis River increased – 0.35 (annual) and 0.15 (June – October). During the next 20 years the flow coefficient of Nevezis River increased to 0.36 and 0.18, respectively. Observations were no longer implemented in Dotnuvele. During the periods of 1956-1980 and 1981-1995 the annual flow coefficient also increased in other rivers of basin of Nemunas River – Juosta (Jackagalys) from 0.27 to 0.37, Nevezis (Dasiunai) from 0.28 to 0.36, Smilga (Pasmilgys) – from 0.27 to 0.30. The flow coefficient of warm period (June – October) also increased in Nevezis (along Panevezys and Dasiunai) from 0.15 to 0.18 and from 0.10 to 0.11. It remained the same in Juosta, and only the flow coefficient of Smilga decreased during June – October from 0.09 to 0.06.

In summary, it might be stated that the average annual runoff coefficient of the whole 10th hydrologic region of Lithuania, which includes a major part of basin of Nevezis, was 0.30 till reclamation. It decreased to 0.28 during the period of intensive reclamation. However, the average annual coefficient was 0.35 from 1980, i.e., it increased in comparison with the period till reclamation. The average coefficient of warm period was 0.10 till reclamation, and remained the same during the period of 1956-1980, while the data of 1981-1995 show that the average coefficient increased – 0.11.

After summarizing the data and comparing them with the growth of drained areas within the period of 1956 – 1996, it was determined that reclamation systems have no statistically significant impact on total (annual) river runoff (Table 1). Therefore, there is no reason to state that reclamation systems reduce the total river runoff. Following the statistical Fisher criterion, it was determined that data differ significantly, thus, other factors influence the size of river runoff. The aforementioned arguments are also confirmed by Lukianas et al. (2008), who examined

Table 1

Comparison of Averages of Drained Areas and Runoff in Lithuanian Rivers by Anova

Period	Drained Areas in River Basin %	Runoff mm	Correlation coefficient R	Fisher criterion F	Critical Fisher criterion value F_{kr}	Probability
till 1956	1.1	253.8	0.14	119.8	4.05	p>0.05
1956 - 1961	4.3	268.2	-0.15	422.3	3.98	p>0.05
1961 - 1966	10.4	232.8	-0.19	216.5	3.95	p>0.05
1966 - 1971	21.8	223.7	-0.18	324.5	3.96	p>0.05
1971 -1976	32.0	198.8	-0.28	198.0	3.94	p>0.05
1976 - 1981	37.9	269.5	-0.05	223.7	3.94	p>0.05
1981 -1986	46.4	281.7	-0.05	173.0	3.94	p>0.05
1986 - 1991	44.8	295.0	-0.07	272.9	3.94	p>0.05
1991 - 1996	46.6	258.1	-0.34	217.7	3.96	p>0.05

the characteristics of runoff of rivers of sub-basin of Lielupė, and the characteristics of change in runoff distribution throughout a year, as well as the patterns of runoff differences. The research, carried out by these scientists, revealed that drainage has no substantial impact on the changes of river runoff. After analyzing the size of river runoff during the period of June – October across Lithuania, it was determined that as reclamation works become more intensive, there is a relationship between river runoff during the warm period and the drained areas. However, it largely depends on the analyzed period and its duration, for example, the greatest impact was determined during the period of 1991 – 1996.

After assessing the meteorological conditions and soil water balance of the Nevezis River basin, according to above analysis, it might be stated that the primary reason of water lack in the basin of Nevėžis River is climatic conditions. Drainage systems can hardly have a significant impact on wateriness of Nevezis River. A similar opinion is shared by Lukianas and Ruminaite (2009), who determined that more intensive drainage shortens the duration of spring flood and discharges the same water quantity within a shorter period. However, the annual duration of drainage flow demonstrates a small contribution of drainage to the total flow of rivers. After determining the common trends, it also might be stated that the water balance in the Nevezis River basin will be more negative in the future, since, according to research of Staras (2002), the changes in structure of water balance of basins of Lithuanian rivers in the 21st century will be mostly determined by increase of precipitation amount (especially during the warm period), expected in scenarios of climate change, and predicted increase of air temperature. Therefore, precipitation will less accumulate in snow cover, while the evapotranspiration will increase.

Conclusions

1. The basin of rivers of Nevezis is characterized by negative water balance during the warm period, i.e., water income (precipitation) is lower than water expenses (evaporation). The common trends allow stating that the water balance in the basin of Nevezis River will be even more negative in the future.
2. While summarizing the observation data of the period from 1951-1995 of the whole hydrologic region, it might be stated that as the number of drained areas increased, the flow coefficients decreased during spring season (March – May), while the flow coefficients of summer – autumn (June – October) increased.
3. The average annual flow coefficient was 0.30 till reclamation, it decreased to 0.28 during intensive reclamation. However, the average annual flow coefficient was 0.35 from 1980, i.e., it increased in comparison with the period till reclamation. The average flow coefficient of warm period was 0.10 till reclamation, and remained the same during the period of 1956-1980, while the data of 1981-1995 show that the average flow coefficient increased – 0.11. The reclamation systems have no statistically significant impact on annual river runoff in the period of 1956 – 1996.

References

1. Aplinkos Apsaugos Agentūra (2008) Preliminarus Nemuno upių baseinų rajono valdymo planas (Preliminary Management Plan of Basins of Rivers of Nemunas). Available at: http://files.gamta.lt/aaa/pranesimai/Nemuno_UBR_Valdymo_planas_12_27.pdf, 15 November 2012.

2. Dirse A. (2001) Žemės ūkio augalų vegetacijos laikotarpių drėgmingumas (Moisture of Agricultural Plants during Vegetation Periods). *Žemės ūkio mokslai*, 3, pp. 51-56. (in Lithuanian).
3. Dumbrauskas A., Larsson R. (1993) Effects of changes in land use on runoff in the Nevezis basin, Lithuana. Report 3173, p. 26.
4. Dumbrauskas A., Larsson R. (1997) The Influence of Farming on Water Quality in the Nevezis Basin. *Aplinkos tyrimai, inžinerija ir vadyba*, 2(5), pp. 48-55.
5. Jablonskis J., Kovalenkovienė M., Tomkevičienė A. (2007) Lietuvos upų ir upelių vagų tinklas (Channel Network of the Lithuanian Rivers and Small Streams). *Annales Geographicae* 40 (1), pp. 46-56. (in Lithuanian).
6. Kilkus K., Stonevičius E. (2011) Lietuvos vandenų geografija (Lithuanian waters geography). 186 p. (in Lithuanian).
7. Klocking B., Haberlandt U. (2002) Impact of land use changes on water dynamics – a case study in temperate meso and macroscale river basins. Available at: http://www.sciencedirect.com/science/article/pii/S1474706502000463, 07 November 2012.
8. Lasinskas M. (1975) Ūkinės veiklos įtaka vandens balansui (The influence of economic activities on the water balance). *Trumpi pranešimai. XXI dėstytojų mokslinės konferencijos medžiaga*. Kaunas, pp. 203-204. (in Lithuanian).
9. Lukianas A. (2006) Melioracijos hidrotechninių statinių poveikio gamtinei aplinkai tyrimai ir vertinimas (Reclamation works of hydraulic impact on the natural environment, research and evaluation). *Vilnius: Technika*. 31 p. (in Lithuanian).
10. Lukianas A., Ruminaite R. (2009) Periodiškai šlapiu žemiu sausinimo drenažu įtaka upių nuotekiui (Impact of drainage on periodically wet land). Available at: http://www.tandfonline.com/doi/pdf/10.3846/1648-6897.2009.17.226-235, 10 December 2012. (in Lithuanian).
11. Marčėnas V. (1991) Sausinimo ir intensyvios žemdirbystės poveikis upių nuotėkiui (Impact of drainage and intensive agriculture on river flow). *Regional hydrometeorology*, 14, pp. 33-45. (in Lithuanian).
12. Moore I.D., Larson C.L. (1980) Hydrologic Impact of Draining Small Depressional Watersheds. *Journal of Irrigation Drainage*, 106, pp. 345-363.
13. Nustatyti žemių sausinimo ir tvenkinių poveikį upių baseinų vandens balanso elementų pokyčiams ir gamtinei aplinkai: baigto mokslo tiriamojo darbo ataskaita (To determine the impact of land drainage and ponds on changes in elements of water balance of river basins and on natural environment: report of completed research) (1997) LVŪI, temos vadovė V. Zelionkienė. Vilainiai, 127 p. (in Lithuanian).
14. Oginski B. (2007) Hydrological response to land use changes in Central European lowland forest catchments. Available at: http://www.tandfonline.com/doi/pdf/10.1080/16486897.2007.9636902, 22 November 2012.
15. Pauliukevičius H. (2007) Nuotėkį lemiančių veiksnių santykinių reikšmių ir regresijos lygčių taikymo galimybės (Relative significance of the flow formatting factors and possibilities to apply the regression equations). *Water management engineering*, 31(51), pp. 58-65. (in Lithuanian).
16. Ren L., Wang M., Li C., Wei. Z. (2002) Impacts of human activity on river runoff in the northern area. *Journal of Hydrology,* 261, pp. 204-217.
17. Ruminaite R., Barvidiene O. (2011) Impact of Land Drainage and Natural Factors on the Changes of the Hydrological Regime of the Tatula River. Available at: http://dspace.vgtu.lt/bitstream/1/1267/1/654-658_Ruminaite_other.pdf, 10 December 2012.
18. Robinson M., Rycroft D.W. (1999) Agricultural Drainage. *Agronomy Monograph number*, 38, pp. 767-800.
19. Staras A. (2002) Vandens balanso modelių pritaikymo galimybės upių nuotėkio analizei (Possibilities of Adaptation of water balance models to river flow analysis). *Geografija*, 38, (1), pp. 11-14. (in Lithuanian).
20. Zucker L.A., Brown L.C. (1998) Agricultural Drainage: Water Quality Impacts and Subsurface Drainage Studies in the Midwest. Available at: http://ohioline.osu.edu/b871/index.html, 03 November 2012.
21. Zhi L., Wen-zhao L., Xun-chang Z., Fen-li Z. (2009) Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. Available at: http://www.sciencedirect.com/science/article/pii/S002216940900479X#, 27 November 2012.

A STUDY ON POSSIBILITIES OF ELECTRONIC DOCUMENT CIRCULATION IN PUBLIC SECTOR FOR RURAL DEVELOPMENT

Toms Leikums
Latvia University of Agriculture
toms_leikums@programmer.net

Abstract
Electronic circulation of documents and electronic services have become the most significant IT development trend in the public sector. During the last few years public sector institutions in all Europe have significantly improved the quality of the provided services. With the evolving options offered by the internet and the digital signature getting more widely used, citizens expect a more up-to-date approach to communications from governmental institutions. Successful operation of electronic services would not be possible without a proper circulation of electronic documents on the national level. This article briefly inspects the history of the electronic service development and analyses the conditions of the development, deals with the experience of different countries with the implementation of e-services. Particular attention has been paid to Latvia, its current situation and historical analysis of e-services. A special part is dedicated to Agricultural Ministry of the Republic of Latvia which is most closely related to national rural development, projects of transition towards electronic document circulation and provision of electronic services.
Key words: e-services, public sector, electronic document management.

Introduction

Electronic services is just one component on the way towards the complete e-government, yet it is one the most important steps in order for the citizens to realize that the public sector is changing and following the latest technological possibilities, thus offering a wider and more qualitative range of services. The desire of the citizens to use electronic services has been emphasized also by the Greek specialists Vassiliadou and Dimosthenis Boutakidis: 'The digital economy is now firmly welded to the hull of the 'real' economy. Consumers do not simply have an Internet connection and a mobile phone – they use these to increase their personal efficiency, whether to keep up with friends, check the weather, pay their taxes or make a purchase. Moreover, because digital tools are so widely available, everyone in the ecosystem – businesses, governments, individuals – seek to operate through digital channels whenever possible' (Vassiladou et al., 2011).

Electronic services are closely related to other basic concepts of the e-government: electronic document management, one-stop agency principle, unified clients' database, reciprocal integration of informational system not only on the level of one institution, but the whole public sector. However, actually all the processing of electronic services is incorporated into workflows of electronic document circulation – service applications are received and registered, document management systems create workflows for their processing, and answers to the applicant are being prepared, registered and sent out.

A vast majority of the society think that electronic services only refer to general issues that concern all the population in a country, for instance, electronic declaration of place of residence, tax declarations, social insurance etc. However, gradually many different electronic services have been developed that refer to specific branches of national economy – education, medicine, agriculture, tourism and even culture or sports. This article deals with Latvian experience with digitalization of electronic services for rural sector. Ministry of Agriculture of the Republic of Latvia and its subordinate institutions are responsible for this process. The author of the article is involved into several projects closely related to development and implementation of electronic services offered by the Agricultural Ministry on daily basis, and is responsible for the environmental development and maintenance of the electronic document circulation in all the institutions of rural sector in the governmental institutions. This article also deals with the basic concepts of electronic services, conditions for their successful implementation, experience of Latvia and other countries, as well as practical examples, problem situations and their solutions based on the experience of the Agricultural Ministry of the Republic of Latvia. Additionally, special attention in this research has been paid to electronic document circulation which is both thematically and technologically most closely related to the digitalization of the services and their further operation.

The aim of this study is to verify the importance of electronic services and electronic document circulation in public sector for rural development.

Tasks of the study:

- To analyze the development of electronic services and conditions of transition to electronic document circulation;
- To exemplify the experience of implementing electronic services in Latvia and other countries;
- To conduct a case study on the project by Agricultural Ministry of the Republic of Latvia

about the implementation of electronic services and improvement of electronic document circulation.

Object of the study: electronic services and their impact on rural development.

Materials and Methods

In this study the following methods and materials have been used:

- Research of literature and internet sources – sources related to electronic services and their historical development have been inspected;
- Analysis of experience from different countries – implementation of electronic services in different countries in Europe (including Latvia) has been inspected and analysed;
- Evaluation – the essence of the electronic services has been inspected and conditions of their development have been set;
- Practical research – the experience of service electronization at the Agricultural Ministry of the Republic of Latvia has been examined, the author of the article has been involved in the digitalization project himself. Within the framework of this study all services in the ministry and its subordinate institutions have been analyzed; system analysis, service development and integration with basic activity and support process systems have been accomplished. Thus, 29 e-services have been created.

Results and Discussion

Electronic services and their history

The most popular electronic services emerged during the beginning of the most active development stage of the internet. Nowadays most popular movies and series database *IMDB* started to work in the year 1990. In 1995, both the online shop *amazon.com* and the online auction portal *eBay* were launched. Amongst other pioneers that gained worldwide fame we can name the free e-mail service *Hotmail*, *Babel Fish* translation service for the public web, internet payment system *PayPal* and peer-to-peer file exchange *Napster*. However, long before these services there were others that are familiar only to internet users of that time – *Compuserv* electronic mail, *CB Simulator* online chat, *FidoNet* bulletin board system and others. However, the majority of these titles are nowadays considered to be mere webpages and with the concept of e-services users understand something else – electronic services offered in the public sector.

Taking into account the fact that electronic services can be very different, they do not have a unified definition and it depends on the way the types of e-services are being regarded. Charles F. Hofacker, Ronald E. Goldsmith, Eileen Bridges and Esther Swilley define e-services as 'an act or performance that creates value and provides benefits for customers through a process that is stored as an algorithm and typically implemented by networked software' (Hofacker et al., 2007). As we can see, this definition emphasizes the technological side of e-services. Swedish specialists Eva Soderstrom and Jesper Holgersson place a more significant emphasis on the availability of the services: 'An e-service is an artefact for electronic delivery of services and is one major trend in recent technological developments. For example, it is used to boost e-government adoption, externally to citizens and businesses as well as internally for increased efficiency of work processes' (Soderstrom et al., 2011).

As this study deals with the electronic services offered in the public sector, the author of the article offers another definition: Electronic service is a state service that is publicly available on the internet and has been recorded into normative acts; it enables private and legal bodies to acquire the necessary information, material or non-material goods and increases the opportunities to take part in the work of governmental institutions, and also to align with other processes of social life.

Conditions of development of electronic services

Electronic services fall within the range of one of the basic rules of business – demand makes meeting supply. However, while analysing the public sector e-services, this statement is not as unequivocal. For years people, when communicating with governmental institutions, have got used to everything being processed in their presence and in paper format, often even not considering that these processes could be significantly facilitated in digital environment. This refers particularly to Eastern European countries, including Latvia. Public sector in these countries has been harshly criticized for their disproportionately large bureaucratic apparatus. In order to acquire a single document, people have to visit several governmental institutions, collect stamps on their documents and spend inadequate amount of time to accomplish this. This problem is particularly topical for people in the countryside who are forced to go to the capital where the majority of governmental institutions are located. Therefore it is very positive that during the last few years in the developing countries there are increasingly more options of e-services that people can use.

One of the most important conditions for the development of electronic services is the digital signature and its availability. When personally handing in a document, the applicant verifies its authenticity with his/her signature and presents a valid ID document. In the electronic environment it

is only possible if the service user has his own digital signature. As one can see, the destiny of e-services is directly dependent on the options of identification, and there is no point for governmental institutions to offer their services online if people are not able to use them. As the most positive example one can mention the neighbouring country of Latvia – Estonia, where since the beginning of 2000 the digital signature has been integrated into ID cards of citizens. This is also the reason for the rapid further development of e-services there. Latvia has fared much harder as the digital signature was only introduced in 2005 and actually started to work only by 2009. However, even until 2012 people were not eager to use it and always chose more traditional ways of communication. The usage of the digital signature was inconvenient, expensive and required good computer skills. In lieu thereof the number of available electronic services was rather insignificant – 4. Since the beginning of 2012, banks have overtaken the responsibility of ensuring the authenticity and people can verify the authenticity of submitted documents with the help of their bank cards and internet banking means. Therefore, people have started to use e-services much more actively and pursuant to that governmental institutions have also livened up, projecting and creating many new services that are available online.

The second most important condition of development of electronic services is whether services are available and user-friendly. First, people have to have information about the mere existence of the necessary service and the way to access it. There is no use of an electronic service if it is created and hidden on the third level menu on the home page of some ministry. Public sector institutions have to gradually change the traditional way of thinking and get adjusted to technology development trends. Currently every institution has a home page (which actually is a *home page* with static information and only minor interaction options), yet it is necessary that in near future it is completely changed or even a new site is developed that could be really called a portal with its main accent placed on electronic services. When analysing home pages of Latvian governmental institutions, the author of the article has found out that they are mainly orientated towards the placement of huge amount of information, and this information is mainly prepared in a way that makes it understandable and accessible only for people working in the public sector. These are legislative acts, meeting protocols, concepts, structures of institutions and lists of employees, annual plans and reports etc. It is very complicated for people looking for concise and comprehensive information not to get lost in websites of public institutions – they are mainly information storage places and are not customer-oriented. Thus, the development and implementation of electronic services into existing web pages is inconvenient and sometimes even cannot be accomplished as many of these webpages have been developed a long time ago and the technologies used do not support implementation of more complicated functionalities.

The third most important condition is whether the usage of a particular electronic service is convenient. On the way towards e-government and following the recommendations and demands of the leading institutions of the European Union, there is a number of activities that are being carried out only because there was a request from 'the top'. With e-services it means that they are being created for their mere existence, so that one can report that the overall process of digitalization is being carried out. However, particularly with e-services their user-friendly usage, interface and accessibility are of utmost importance – even more than for any other information system. Any person can be the potential customer of electronic services – of any age and any level of computer literacy. This condition is particularly important when developing electronic services for the rural sector, as people in the countryside and the ones working in the agricultural sector not always have good IT skills and even a relatively simple e-service can make them drop using it and instead choose to settle the matter personally. This problem is closely related to accessibility issues mentioned before. If a presumably existing e-service has to be searched on several home pages of different institutions, its accessibility can be automatically assessed as low.

Implementation of e-services – Latvian experience

First e-services in Latvia were introduced starting with the year 2006 – directly after the implementation of digital signature:

- Electronic declaration of place of residence (Office of Citizenship and Migration Affairs);
- Access to the national register of vehicles and drivers (Road Traffic Safety Directorate);
- Electronic declaration of taxpayers (State Revenue Service);
- Electronic reference for owners of real estate about persons registered in their estate (Office of Citizenship and Migration Affairs, State Land Service).

However, the usage of electronic services was prevented by the low distribution of digital signature. Statistics give evidence that practically the digital signature was used solely in governmental institutions (see Table 1); therefore, employees of these institutions were the only potential clients of the aforementioned services (Briedis et al., 2008).

Currently the number of e-services available in Latvia is already rather numerous in a large

Table 1

Issued digital signature smart cards

Smart cards	Until 06.2007.	Until 07.2007.	Until 08.2007.	Until 09.2007.	Until 10.2007.	Until 11.2007.	Until 01.2008.
Altogether created	4500	7490	8644	9050	9650	10780	12950
incl. public sector workers	3900	6820	7920	8300	8900	9990	12150

range of branches or groups of interest (place of residence, real estate, building industry, finances, EU financing, family, children, health, social services, education, business, culture, sports, arts, rural sector, employment, labour rights, labour protection, public debates, elections, awards, rights' protection, personal status, consumer rights, government purchases, transportation, tourism, migration, consular services, environmental protection) (Latvija.lv, 2013). Altogether there are 55 electronic services available for people in Latvia. As a positive factor we can emphasize the placement of all electronic services in one place – portal Latvija.lv. Thus, people have no difficulties in accessing them because the services are grouped not by their affiliation to some ministries or governmental institutions providing the services, but by topics. Hence the consumers do not have to know which governmental institution is responsible for a particular service and all the necessary actions can be accomplished in one place, not on different home pages of numerous institutions. However, in many cases it is inevitable to use already existing web sites. Latvija.lv was originally presented as a catalogue of links and only gradually it was supplemented with diverse integration modules and options to create a fully-fledged service within the framework of the portal. Thereby many governmental institutions have already developed and implemented electronic services into their home pages. Even now many services in portal Latvija.lv only contain the necessary information and, in order to access them, one has to go to the home page or external information system of the responsible institution (for instance, the e-service provided by the Rural Support Service for acquiring area payment from the state or the EU). However, such method is acceptable as the main thing for the customer is to be aware that all nationally available e-services are accessible together in one place. Overall we can see that the development of e-services is currently in full swing and in near future Latvian people will use them even more, thus significantly improving the attitude towards governmental institutions too. The inevitable development of electronic services has been emphasized by J. Briedis as well: 'It is exactly the e-services should become everyday life for all of us the same as it was with the e-banking within previous stages. The potential number of e-service customers would be all people in Latvia who have reached a particular age, etc. Also, elderly people who are not going to learn the new technologies themselves will be anyway able to deal with the state with the help of other family members or social workers, still staying home. This would be particularly important for people with special needs' (Briedis et al., 2008).

When inspecting the disadvantages, we can mention a very low popularity of the portal Latvija.lv – a very small number of people in Latvia know of its existence. When in need of a governmental service, most people still choose to use traditional methods – calling the institution (if it is known which institutions offer the service) or searching for information on its home page. The importance of marketing has been emphasized in a study carried out in Denmark: 'Denmark: Efficient e-Government for Smarter Public Service Delivery': 'Enhance the public awareness of already implemented e-government solutions through a massive promotion and marketing effort to motivate and increase the use of the e-government services already in place. To this end, a strong and effective channel-management strategy also needs to be put in place, and relentlessly pursued by the whole public sector.' (OECD, 2010) Darrel M. West inspects this issue much deeper and places the main emphasis on the enthusiasm of people: 'Public opinion about e-government is quite relevant to the diffusion of innovation. Technologies are not going to spread and be in a position to transform society and government unless the public is receptive to the new invention, generally positive about its usage, willing to employ it themselves, and not limited by subgroup in terms of who can use the technology. If citizens are divided about the technology or there are large numbers of people who are not able to take full advantage of it, the ability of the public sector to integrate technology and use it as a force for long-term change will be limited' (West, 2005).

Implementation of e-services – experience in other countries

Among the European countries one always sets Estonia as one of the most strikingly good examples. Even the UK, where during the last few years the emphasis has been placed on the desire to offer more

and more state services electronically, singles out the good example of Estonia and highlights the fact that one has much to learn from the neighbouring country of Latvia. Mike Bracken, Executive Director, UK Government Digital Service, Cabinet Office after his visit to Estonia says: 'We explored how dozens of Government services are delivered by small teams, focussed on user needs, and we saw how Estonia had devised an identity system that works for them. I left with a keen understanding of how all this underpins the culture and economic growth of the country. Since my return I have been reflecting on the core reasons for their success and I've boiled it down to a number of key areas where Estonia has definitely got it right. They started with an engineerled culture, have a particular approach to identity assurance, have humble attitudes and welcome a broad church of SME's. Pretty much the approach that we are taking in Government Digital Service' (Bracken, 2012). In the following part of the article Mike Bracken emphasizes the great Estonian success with the usage of identification (ID) cards and high internet availability in the whole territory of Estonia, as well as the fact that the development of e-services involves many small and medium-sized companies (SME). After the visit that took place in the end of 2012, the UK started a closer cooperation with Estonia in order to adopt its highly valued experience with the implementation of electronic services. In February 2013, an intergovernmental agreement was signed: 'The Memorandum of Understanding between the two countries will enable sharing of knowledge and capability in design, architecture and security of digital services, and see the formation of joint projects' (Glick, 2013). It is interesting that initially the agreement was signed between the UK and Estonia, yet it is foreseeable that in the near future other countries will be able to join the agreement too. It is possible that also Latvia will have an opportunity to improve the digital environment of public sector by taking part in an experience exchange programme with two countries considered to be highly technologically developed. UK Cabinet Office minister Francis Maude has repeatedly underlined that it is the UK that has lots to learn from Estonia: 'Estonia is one of the most connected countries in the world and a trailblazer in public sector ICT and cyber security. I was hugely impressed when I visited Estonia last year by how much of government there is online, with e-voting, e-health, e-schools and virtually all tax returns completed online in minutes' (Glick, 2013).

Among countries that have engaged in a serious implementation and popularization of electronic services we have to mention France, Germany, and Denmark where already in 2010 the development of electronic services was set as one of the main priorities of national development: 'Denmark is at the forefront of e-government development and implementation and holds leading positions in all international rankings. This is the result of the continuous commitment and strategic approach shown by the Danish government in using ICT to strengthen the performance of its public sector to provide high-quality public services to its citizens and businesses. In recognition of the instrumental value of e-government to boost the quality, efficiency and effectiveness of the public sector, and to foster co-ordination and co-operation across levels of government, thus increasing the citizens' trust in their government, Denmark believes that e-government is a 'must'' (OECD, 2010). Denmark singles out the technical availability of electronic services as to be most crucial: 'Ensuring broadband penetration and enhancing citizens' ability to access and use the services and information provided electronically are prerequisites to ensure that a society can take full advantage of the opportunities offered by e-government and facilitate an increased uptake' (OECD, 2010). We have to mention that Danish approach might get much more current and usable for Latvia as well because not everywhere in the regions there is an internet access of high quality and one often forgets that the first necessity is a computer and web access, not a ready-to-use e-service.

Electronization of services and implementation of one stop agency principles is taking place in other EU countries as well. As an example for one stop agency principle we can name ChechPOINT in the Czech Republic. Within the framework of this project 2320 contact points throughout the whole country were introduced – and there are all the same public services available as in governmental institutions. With the help of IT the Citizen Service Centres in Cyprus offer 64 services and free people from the need to visit various governmental institutions and ministries. Electronically one can access such services as document issue (birth certificates, residency permits), acceptance of submissions (request for a passport or various benefits). In Finland, there are Citizen services 'one stop shop' offering a wide range of governmental and municipal services in the whole country. Services include both submission of documents and applications, customer consultations for service choice and initialisation, as well as some help with getting to know e-services.

Services provided by the Agricultural Ministry of the Republic of Latvia

In order to promote the availability of e-services and thus facilitate the overall rural development, the Agricultural Ministry of the Republic of Latvia started a new project in 2009 – within its framework there would be created a unified portal for the rural sector that would embrace all the e-services related to

agricultural sector, as well as contain all the necessary information that is somehow not included in portal Latvija.lv.

In all the institutions at the Agricultural Ministry an actual communication in real time is the historically accustomed and most common means of communication. If the service is not a mere registration of data into IS and contains factual creation of documents or delivery of goods (for instance, ear tags provided by Agricultural Data Centre), the presence channel is most common means for service delivery because:

- customers mainly need a legal document which can be presented in other institutions and for third persons. However, there are cases when all the necessary information is available in registers and other governmental institutions can acquire this information from these registers and not from the issued document in paper format (for instance, registers of Food and Veterinary Service);
- the institution cannot identify the related payment procedure without a payment confirmation document;
- in order to receive the service outcome personal identification is necessary.

Customer service takes place in central and regional offices of particular institutions. In the Ministry of Agriculture and its affiliations service rendering and customer service was up to now organized according to normative acts and general guidelines on customer service in governmental institutions, found in the State Administration Structure Law.

When dealing with the document circulation and service rendition mechanism at the Agricultural Ministry and its affiliations, several problems in need of conceptual solutions were discovered:

- Normative acts determine the functions of the institution, not service rendition.
- There is no unified client identification and client management.
- Service rendition is organized differently.
- There is no unified client segmentation and channel strategy according to client segments.
- Inter-institutional cooperation is underdeveloped.
- No governmental institution is carrying responsibility for service development and customer service issue solutions on the sector level. Thus every institution organizes service rendition and customer service processes on its own. Every institution has developed its own inner procedures for service rendition which partially or fully establishes the processes of both information requests and acquisition of documents, as well as the process of information processing and the delivery of the end document.
- The clients of the Ministry of Agriculture and its affiliations often overlap, but the customer service is scaled and the means of identifying the client are different. When registering into a database of different institutions, the client has to submit identical data. The client is attached to one institution only; thus, the same client is not identifiable in other institutions. A client who needs to visit two or more institutions in person or, use non-presence channels, is forced to apply to several institutions in presence, or, using different non-presence channels, for instance, by emailing documents, calling each institution or visiting home pages of each institution. Thus, it is not only extra time wasted by the customer but also the financial means of the customer that are spent in order to communicate with different institutions using parallel channels. Moreover, using the presence channel as the main channel, the risk of inexpedient resource usage is caused.

In order to overcome the aforementioned problems, following principal tasks are proposed:

- Establish national norms on service rendition and customer service on the state level;
- Establish a unified, centralized portal for rural sector services;
- Create a unified customer database and provide an identical identification for all clients. Unified customer identification principles should ensure that:
  - A customer of one institution is automatically considered to be a client of all rural sector institutions and this client can be unambiguously identified during the first contact. Thus technically the client should be able to apply for any service provided by the Ministry of Agriculture in every institution (one stop agency principle).
  - The customer is identifiable in every institution of the Ministry of Agriculture and its affiliations, i.e., their information systems.
- Ensure unified customer segmentation and appropriate channel choice (channel strategy);
- Centralize service rendition non-presence channels;

As the main task we have to emphasize the development of a branch portal and its incorporated electronic services. The branch service portal should provide the following functions:

- Provide information about all institutions, their services and acquisition channels;

- Provide an option of applying for services, submit necessary documentation and choose the channel for the receipt of the service;
- Provide an option of receiving certifications and references in a self-service mode;
- Provide an option of receiving services in a self-service mode;
- Provide an option of paying for the service;
- Provide an option of following the history of applied services and their statuses;
- Provide an option of applying to a consultation with a branch specialist;
- Provide and option of submitting complaints and following their review statuses etc.

The self-service portal by the Ministry of Agriculture is being created as an environment of accepting electronic submissions and applications and receiving answers, where the applicant can perform all the necessary actions for submitting an application. In order to ensure this, the portal has to contain electronic service user interfaces, web services for performing particular functions in support systems, for example, ensuring payment processing, and for performing function in the base systems. All the developed e-services will be published in the portal. The plan foresees that the unified branch portal and the majority of e-services will become available in the second half of 2013. Mainly the technological development and testing is already done and the project is in its closing phase. One can assume that the new branch portal will significantly facilitate the communication between farmers and governmental institutions, speed up the acquisition of different notes and certifications, and also unburden some of the tasks of the employees of governmental institutions when the unified customer register will start working. All the electronic documents created from the e-services will go into central electronic document circulation system. Unified classification and indexation will make it easy and fast to assess information about all the department documents' location and access electronic documents being stored in one common document storage place. Due to the branch specifics it will never be possible to ensure that all the services provided by the governmental institutions in the rural sector are available electronically, yet the goal is to digitalize as much of available services as possible.

Conclusions

1. Development of electronic services and provision of electronic document circulation is one of the most important pre-conditions of further development of state administration and adequate communication between the governmental institutions and people.
2. By developing electronic services an effective, economic, open, inclusive and democratic state administration and information society are being promoted, including the electronization of governmental services, enhancing the accessibility and quality of publicly available information and e-services, promoting the quality of national registers and integration, reducing the administrative burden for the people, business people, governmental and municipal institutions, and promoting the opportunities of citizens to take part in state administration and other social life processes. With the help of the internet, people and enterprises can receive services faster, in more convenient way and with no temporal restrictions – disregarding working hours and locations of institutions.
3. Most of all electronic services are necessary for people living in regions as it is more complicated for them to get to the capital where the majority of public sector institutions are located. Hence, the development of electronic services directly promotes the overall rural development.
4. It is important that the created electronic service is really working. The initiative to create an electronic service has to come from the public sector with the main goal – to make the communication between people and governmental institutions easier. Neither the state, nor the people would gain anything from an electronic service that is complicated to use, expensive to maintain or is created only with a sole purpose that there should be such a service. The creation of an e-service cannot be the goal in itself – it has to serve a purpose and promote, and unburden the work of both people and state administration.
5. After implementing electronic services one has to perform their activity and functionality analysis on a regular basis in order to determine if the service is working as planned, if it has a sufficient number of users and if there are any changes needed.
6. For all the technological twists and turns, the main thing is that the e-services are working and getting popular, that people are responsive and eager to use them; therefore it is essential that on the state level there would be a well-weighed and customer-oriented marketing plan that would inform people about the existence of e-services and their customer-friendly usage.

Further research

Future research can include the following questions:

- Interface and user-friendliness of electronic services – how to make e-services comprehensible and convenient for everyone;

- Promotion of e-services – the best way how to inform people about the availability of electronic services and their user-friendliness;
- Financial gains of replacing services provided in person with e-services – the analysis of costs of current services and a comparison with the development, implementation and maintenance of e-services.

References

1. Bracken M. (2012) International: What we could learn from Estonia. Available at: http://www.holyrood.com/2012/09/what-we-could-learn-from-estonia, 01 March 2013.
2. Briedis J., Lauriņš P. (2008) E-pārvaldes attīstība Latvijā (Progress in Developing 'E-Government' in Latvia). Latvijas Universitātes raksti, 721.sēj., 201-216. lpp. (in Latvian).
3. Glick B. (2013) UK teams up with Estonia to develop digital public services. Available at: http://www.holyrood.com/2012/09/what-we-could-learn-from-estonia, 01 March 2013.
4. Hofacker C.F., Goldsmith R.E., Bridges E., Swilley E. (2007) E-Services: A Synthesis and Research Agenda. In: Evanschitzky H., Iyer G.R. (eds) E-Services. Opportunities and Threats. *Journal of Value Chain Management*, Vol.1, No1/2, Deutscher Universitats-Verlag, Wiesbaden, Germany, pp. 13-44.
5. Latvija.lv (2013) Available at: https://www.latvija.lv, 02 March 2013.
6. OECD (2010) Denmark: Efficient e-Government for Smarter Service Delivery, OECD Publishing. Available at: http://dx.doi.org/10.1787/9789264087118-en, 01 March 2013.
7. Soderstrom E., Holgersson J. (2011) Using Virtual Communities to Involve Users in E-Service Development: A Case Study. In: Klinger K. (ed) Business Organizations and Collaboration Web. Practices, Strategies and Patterns, Business Science Reference, Hershey, USA, pp. 61-75.
8. Vassiladou S., Boutakidis D. (2011) ICT Adoption in Farm Management, as a Mean of Implementing Agricultural Governance. In: Klinger K. (ed) *Agricultural and Environmental Informatics, Governance and Management*, Information Science Reference, Hershey, USA, pp. 172-181.
9. West D.M. (2005) *Digital Government. Technology and Public Sector Performance*, Princeton University Press, Oxfordshire, United Kingdom, 234 p.

REGIONAL INEQUALITIES OF THE AGRICULTURAL ECONOMY IN LATVIA (1935–1939)

Janis Paiders, Juris Paiders
University of Latvia
paidersjanis@inbox.lv; jpaiders@inbox.lv

Abstract
The aim of this research is to evaluate the spatial differences of the agricultural economy of Latvia during the First Republic by using spatial autocorrelation calculations. Morans's I coefficient of spatial autocorrelation is used to describe the spatial relations of the analyzed indicators.
The obtained results show that Moran's I for more than half of the obtained parameters is greater than 0.5, which indicates a rather high spatial autocorrelation. It was observed that variations of the spatial autocorrelation values can be explained by what affects these parameters. Spatial autocorrelation is significantly higher for those parameters whose value depends mainly on the variety of natural factors (land use, specific crop share). Moran's I value for those parameters whose values depend on the actions by the local government in rural parishes is considerably lower (for example, budget allocation, etc.)
A large portion of the examined parameters characterizing the level of parish economic development show the biggest differences when comparing Latgale with the rest of Latvia. In the case of such regional differences, Moran's I is usually within 0.5–0.7, indicating moderately close spatial autocorrelation. For many indicators regarding agriculture and land use many southern parishes within
Jelgavas and Bauskas county show a very considerable difference from the rest of Latvia showing much higher rate of agricultural production.
Key words: Latvia, Moran's I, spatial autocorrelation, rural parishes, regional inequality.

Introduction

A proper scientific answer has not been given to the question of how different economic systems contribute to the reduction of regional inequality in Latvia. We can look at three radically different periods in the history of the country: the First Republic (1918–1940), the Soviet period (1945–1990), and the period since the restoration of independence (from 1991).

By applying the same methodology of spatial inequality measurements to equal territorial units in all three periods, it is possible to compare how different goals of the state and the public, along with different economic and social stimuli, promote or reduce spatial inequality.

The objective of the present work is to evaluate the spatial differences of the agricultural economy of Latvia during the First Republic by using spatial autocorrelation calculations (Moran's spatial autocorrelation coefficient) – parameters characterizing agriculture, the economy and inequality. Moran's I spatial autocorrelation coefficient is quite frequently used in the analysis of factors affecting agriculture (Overmars et al., 2003; Ping et al., 2004; Saizen et al., 2010). The main tasks to reach the given objective of the research were:

- to gather sufficient data on a parish level for the analyzed timescale. In order to calculate the Moran's I spatial
- autocorrelation it was necessary to create a spatial matrix where all neighbor parishes are defined for every rural parish. Proper study of the available literature about the analyzed timeframe and the methods used in this research was also necessary for the successful interpretation of the results.

As the use of the spatial autocorrelation coefficient was substantiated only in 1950 (Moran, 1950), this type of analysis was not conducted during the First Republic. Therefore, the first and most labor-intense task in achieving the research objective was developing a spatial autocorrelation matrix in accordance with the administrative divisions of 1937.

In studies on economy during the First Republic period (1918–1940), the main focus is placed on the common economic trends (Skujenieks, 1927; Skujenieks, 1938; Labsvīrs, 2000; Azisilnieks, 1968; Rutikis, 1960; Strods, 1992; etc.). In analyzing agricultural economy, the maximum scale of regional differences is the county level (Bokalders, 1927; Bokalders, 1947; Žagars, 1975; Krastiņš, 2001). In the present work, the basic unit of spatial differences is the parish, significantly expanding the scope of research.

Materials and Methods

Data

The study area consists of 513 rural parishes of Latvia. Cities have not been included in the statistical analysis of this research mainly because most of the parameters regarding agriculture have not been compiled in the cities. As part of the analysis, 56 parameters have been selected that characterize the rural parishes of Latvia during the period from 1935 to 1939. All selected parameters encompass 513 rural parishes and pertain to their economy, agriculture,

land use, etc. Some parameters characterize farms by size (ha), legal status, etc. Other parameters characterize farms by land use (arable land, pasture land, meadows, forests) or arable land by crop type. Individual parameters characterize the economic condition of parishes by the budgetary revenues and expenditures of the parish's local government.

Population data are based on the census of 1935 (Salnītis, 1939), while most agricultural values were obtained from the agriculture census of 1935, 1937 and 1939 (Maldups, 1937; Maldups, 1940). Data on the budget indicators of parish local governments were obtained from the available statistical information in parish descriptions (Maldups, 1937). Some parameters were derived from other sources, e.g., from business census (Maldups, 1937).

Methods

Correlation and linear regression analysis has been used to determine the interrelations of the examined parameters. Moran's I (Moran, 1950) has been used to determine the spatial autocorrelation value of the parameters – it is similar to the correlation coefficient and is a dimensionless measure. The value of Moran's I can range from -1 to 1. If the value is close to 1, it is indicative of high spatial autocorrelation, which means that a high value of a parameter in one territory means a high value also in the neighboring areas. Conversely, if Moran's I is close to 0, it means that the spatial nature of the parameter's dispersion is random.

For the purposes of the work, Moran's I is calculated using the following formula:

$$I = \frac{N}{\sum_i \sum_j w_{ij}} * \frac{\sum_i \sum_j w_{ij}(X_i - \bar{X}) * (X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2}$$

where X_i – the value of variable X in area i,

$\bar{X}$ – the average value of variable (X_i)

w_{ij} – the spatial weights matrix. Value $w_{ij} = 0$ if territory i does not share a border with area j and $w_{ij}=1$ if area i has a shared border with area j

N – the number of areas examined

I – Moran's autocorrelation coefficient

To make it possible to calculate Moran's I for the examined parameters, it was necessary to create a spatial matrix in which the neighboring areas are defined for each of the 513 examined rural parishes. Neighboring areas were understood to mean parishes with a shared border. Using the same spatial matrix for all examined parameters allows comparing the Moran's I values between the various researched indicators.

In the interest of clarity, the calculated Moran's I as part of the work has been described in detail only for part (12) of the 56 parameters (Table 1.). The selection of the parameters to be analyzed in detail was based on variety, picking only one of multiple similar parameters. Along with Moran's I, the average value and value spread was also analyzed for these parameters, presenting the differences between the parishes with the highest and the lowest values, compared to the average value of the parameter.

During the research, preparation and analysis of cartographic material was also carried out, displaying indicators with high and low Moran's I. All calculations have been made by the author in Microsoft Excel, while the cartographic material was prepared in QGIS1.7.2.

Results and Discussion

The obtained results show that Moran's I for more than half of the obtained parameters is greater than 0.5, which indicates a rather high spatial autocorrelation. It was observed that variations of the spatial autocorrelation values can be explained by what affects these parameters. Spatial autocorrelation is significantly higher for those parameters whose value depends mainly on the variety of natural factors (land use, specific crop share). Moran's I value for those parameters whose values depend on the actions by the local government in rural parishes is considerably lower (for example, budget allocation, etc.).

The table (Table 1) presents 12 of the 56 examined parameters, indicating their Moran's I value, the average value, as well as the average value in the 10 parishes with the highest and the lowest value. In cases where Moran's I is very high (>0.7), geographic areas with higher or lower value of the relevant indicator are relatively small areas with 10–20 parishes (e.g., all parishes of one district, etc.) in which the values are very significantly different from the rest of the territory.

Out of all 56 parameters, the highest spatial autocorrelation was observed for the proportion of flax in the total area sown in 1937. On average, only 2.35% of the area sown was allocated to flax in a parish. The usage intensity of this crop shows great geographic dispersion; it is practically not cultivated at all in Kurzeme, Zemgale, as well as in some counties of Vidzeme, but plays an important role in Latgale region, as well as in parishes of Valmiera county. In some parishes of Jaunlatgale and Rēzekne county, flax constitutes more than 15% of the total area sown.

The reason for the high spatial autocorrelation of flax is connected with the fact that specific areas can be singled out with higher value of the parameter, where the value differs significantly from the rest of Latvia. There are also geographic areas with higher value of

Table 1

Differences in Moran's I value for analyzed parameters

Parameter	Moran's I	$\bar{X}$	$\bar{X}$ of 10 parishes with the highest value	$\bar{X}$ of 10 parishes with the lowest value
Flax, % of total arable land, 1937	0.86	2.35%	18.07%	0.00%
Winter wheat, % of total arable land, 1937	0.77	3.21%	13.38%	0.09%
Arable land, % of total farm land	0.75	47.12%	87.57%	18.98%
Pigs per farm	0.72	3.80	7.82	1.20
Proportion of youths aged 8–14, 1935	0.67	11.07%	18.45%	5.94%
Revenue, taxes in 1936/37 per capita (LVL)	0.65	12.64	21.67	5.62
Farms with area of 5–10 ha in 1939 (%)	0.65	11.00%	43.89%	1.56%
Population density in 1930	0.62	19.25	56.17	6.79
Average area (ha) per farm in 1937	0.59	22.62	36,81	7.64
Proportion of youths aged 8–14 attending schools, 1935	0.40	81.55%	94.91%	63.05%
Spending on education per capita in 1936/1937 (LVL)	0.19	1.89	3.63	0.68
Farms with area up to 1 ha in 1939 (%)	0.11	3.89%	27.69%	0.00%

Data: (Salnītis, 1939; Maldups, 1937; Maldups, 1940).

the indicator for most other crop types, however the contrast with the rest of Latvia is not as great, as the relevant crop is cultivated more widely. An example is the total area of winter wheat, which is the greatest in parishes of Jelgava and Bauska county.

Moran's I is high (greater than 0.7) also for the proportion of arable land within the total farm land area, as can be seen in the prepared map (Figure 1), as well as for the average number of pigs per farm. The

relative standard deviation of each parameter is relatively low (more than 4 times as low as for the proportion of flax), but maintains high spatial autocorrelation at such relatively low dispersion. The highest values of the arable land proportion, similarly as for winter wheat, are found in parishes of Jelgava and Bauska county, as evidenced by the high positive correlation of both parameters (R^2 = 55% in linear regression analysis). As regards the number of pigs in a farm, generally much lower values of the parameter are observed in parishes of Latgale, mainly due to the much lower area of farms in Latgale compared with farms in the rest of Latvia.

Relatively high spatial autocorrelation (Moran's I from 0.5 to 0.7) is observed for those parameters in which the greatest differences are noted between parishes of Latgale and the rest of Latvia, allowing to isolate Latgale as a geographic area with larger or smaller value of the parameter. For example, the proportion of youths aged 8–14 is generally much higher in counties of Latgale region – almost 40% higher in the rural parishes of Latgale than in the rest of Latvia. The same contrast is observed for the proportion of farms with area of 5–10 ha, as well as for population density, which is considerably higher in counties of Latgale region.

The situation is interesting in regard to the proportion of youths attending school, which shows a less-close Moran's I indicator (0.4) than the aforementioned parameters. The relative standard deviation of this parameter, compared with the other analyzed parameters (Table 1), is the lowest. This indicator in Latgale is generally lower than in the rest of Latvia, however, the overall lowest school attendance has been shown in individual rural parishes of Kurzeme and Vidzeme with very low population density.

Spatial autocorrelation has been determined as a factor with low significance for a very small part of the 56 analyzed parameters. For example, in regard to educational publications of the parish local governments in 1936/1937 and the proportion of farms with area up to 1 ha. The educational publications are the responsibility of each individual parish's local government, and under such conditions the indicator is significantly different between neighboring areas even with similar economic situation and other factors. The distribution of farms with area up to 1 ha, in turn, is mainly connected with the distribution of large and small villages.

The proportion of arable land (Figure 1) is an example of a parameter with high spatial autocorrelation (Moran's I = 0.75). Significant

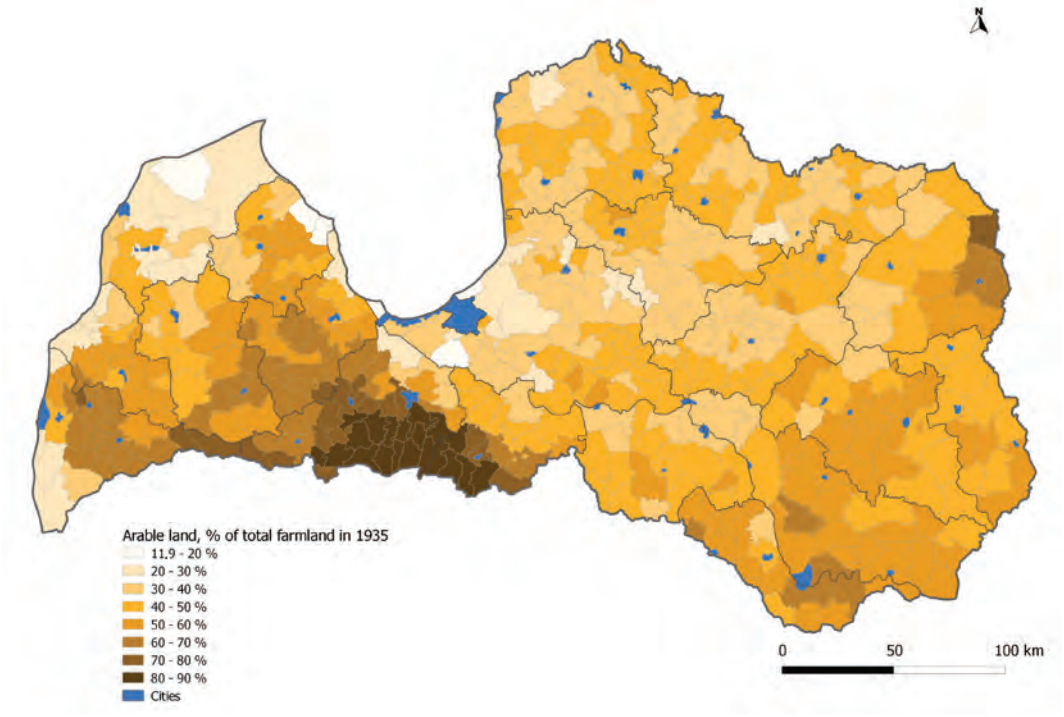


Figure 1. Arable land, % of total farmland in 1935.
Data: (Maldups, 1937).

clusterization of rural parishes with high proportion of arable land can be observed. Parishes with the highest proportion of arable land are concentrated in the southern part of Jelgava and Bauska county in the Zemgale region, along the Lithuanian border. Parishes with low intensity of arable land use also have common location trends, mainly concentrating in seaside parishes.

The reason for these differences is mainly connected with the fact that the intensity of arable land use depends on soil fertility, terrain and the suitability of various climatic factors. In parishes with fertile soil and other suitable natural conditions, the use of arable land is more intense than, for example, in seaside parishes, where soil is sandy and infertile, making them more suitable for cattle farming and leading to larger pasture land and meadow areas. For this parameter, large spatial autocorrelation is connected with the fact that the spatial distribution of the relevant natural factors is not tied to administrative borders.

The proportion of small farms with area up to 1 ha (Figure 2) serves as an example of an indicator with a low and insignificant spatial autocorrelation (Moran's I = 0.11). The size of such farms is much smaller than the area of land necessary to provide the household with food, which means that the owners are either hired workers in other (large) farms or their economic activity falls into industries other than agriculture.

In the spatial distribution of this parameter, it can be noticed that the clusterization of areas with similar values is very insignificant. The main factor determining the proportion of small farms in a parish is the distribution of large and small villages with large proportion of small farms. These populated areas have sufficiently greater role of non-agricultural sector that usually have a way smaller land parcels than people working in the agricultural sector.

Analysis of the economic condition of Latvian rural areas on the parish level allows conducting detailed mathematical analysis of the available statistics of the time. At that time, information available on the parish level was examined mainly when conducting cartographic analysis of the data, and cartographic material on the parish level was generally prepared only for individual parameters, as the process was labor-intensive.

By applying such methods of quantitative analysis as calculation of spatial autocorrelation or regression analysis, it is possible to obtain more-accurate information about the economic situation in Latvia during the period. Detailed mathematical analysis of historical data has not been sufficiently carried out in Latvia. Changes of indicators characterizing land use have been examined (Penēze, 2009), however analysis

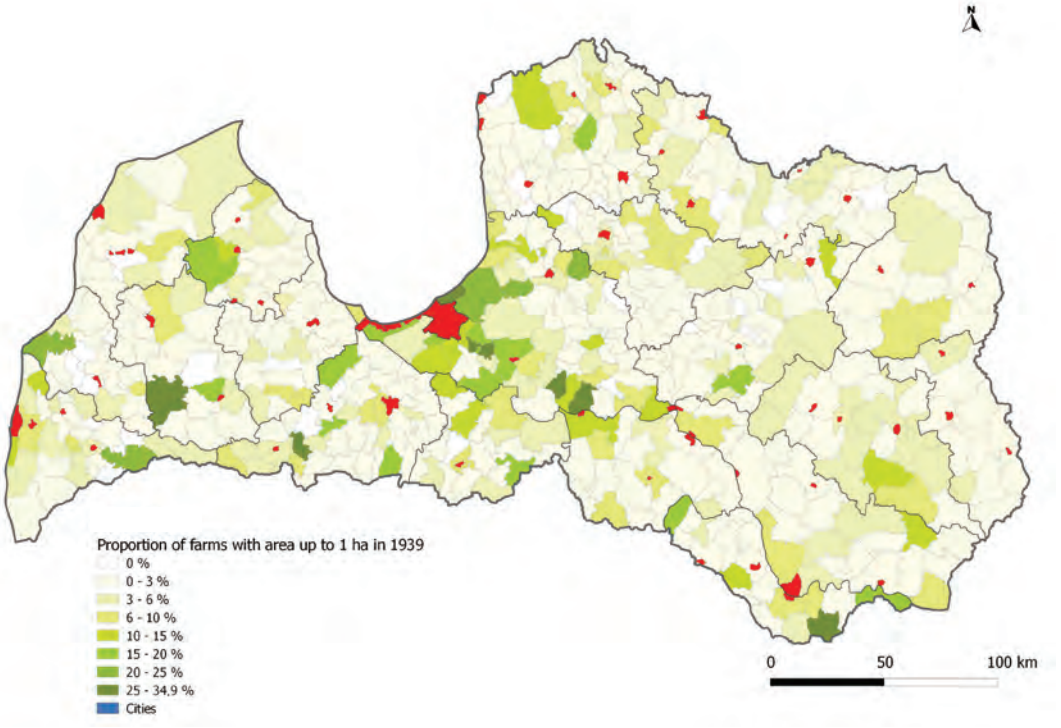


Figure 2. Proportion of farms with area up to 1 ha in 1939. Data: (Maldups, 1939).

of many indicators characterizing the economic condition has been conducted only on the county level (Bokalders, 1927; 1947; Žagars, 1975; etc.). Further research in this area will allow obtaining more-complete information about the regional dispersion of the Latvian economy in the 1930s, as well as to compare the regional differences of specific indicators characterizing the agricultural economy with the present-day situation.

Conclusions

Only since 2012 when the National Library of Latvia made their digitized materials available for the general public research using large scale statistical analysis about the First Republic became possible. Before that the creation of a large scale statistical database of the analyzed time period would be highly time consuming.

The obtained results evidence that spatial autocorrelation is highest for economic indicators affected mainly by natural factors (land use, distribution of sown areas); their Moran's I values are generally much higher.

Moran's I for the proportion of flax and winter wheat is 0.86 and 0.77, respectively, pointing to a very high spatial autocorrelation. It allows for quantitative identification of individual regions with very high values of the respective parameters.

A large portion of the examined parameters characterizing the level of parish economic development show the biggest differences when comparing Latgale with the rest of Latvia. In the case of such regional differences, Moran's I is usually within 0.5–0.7, indicating moderately close spatial autocorrelation.

References

1. Aizsilnieks A. (1968) Latvijas saimniecības vēsture 1914–1945. (Latvian economic history 1914–1945). Stokholma, Daugava, 983. lpp. (in Latvian).
2. Bokalders J. (1927) Lauksaimniecība (Agriculture). Rīga, A. Gulbja apgāds, 381-619. lpp. (in Latvian).
3. Bokalders J. (1947) Latvijas ekonomiskie-ģeogrāfiskie pamati (The economic-geographic foundations of Latvia). Stokholma, Zelta Ābele, 188. lpp. (in Latvian).
4. Krastiņš O. (2001) Latvijas saimniecības vēsturiskā pieredze 1918–1940. (Historical experience of the Latvian economy 1918–1940). Rīga, 223. lpp. (in Latvian).

5. Labsvīrs J. (2000) Latvijas Lauksaimniecības kolektivizācija 1944–1956. (Collectivization of Latvian agriculture 1944–1956). Rīga, Zinātne, 216. lpp. (in Latvian).
6. Maldups A. (1937) Apriņķu un pagastu apraksti (Descriptions of counties and parishes). Valsts Statistikas Pārvaldes izdevums, Rīga, 654. lpp. (in Latvian).
7. Maldups A. (1940) Lauksaimniecības skaitīšana Latvijā 1939.gadā (Agriculture census in Latvia in 1939). Valsts Statistikas Pārvaldes izdevums, Rīga, 128. lpp. (in Latvian).
8. Moran P.A.P. (1950) Notes on Continuous Stochastic Phenomena. *Biometrika* 37, pp. 17-23.
9. Overmars K.P., Koning G.H.J., Veldkamp A. (2003) Spatial autocorrelation in multi-scale land use models. Ecological Modelling. Vol 164, (2-3), pp. 257-270.
10. Ping J.L. (2004) Exploring spatial dependence of cotton yield using global and local autocorrelation statistics. Field Crops Research, Vol 89, (2-3), pp. 219-236.
11. Penēze Z. (2009) Latvijas lauku ainavas izmaiņas 20. un 21. gadsimtā: cēloņi, procesi un tendences (Changes of the Latvian rural landscape in the 20th and 21st century: causes, processes and trends). Doctoral thesis. Rīga, Latvijas Universitāte, 255. lpp. (in Latvian).
12. Rutkis J. (1960) Latvijas ģeogrāfija ar fiziskās, augu un dzīvnieku, politiskās, iedzīvotāju, saimniecības, satiksmes un reģionālas ģeogrāfijas nodaļām (Latvian geography with chapters on physical, plant and animal, political, population, economic, transport and regional geography). Stokholma, Apgāds Zemgale, 794. lpp. (in Latvian).
13. Saizen I., Maekawa A., Yamamura N. (2010) Spatial analysis of time-series changes in livestock distribution by detection of local spatial associations in Mongolia. Applied Geography. Vol 30, (4), pp. 639-649.
14. Salnītis V. (1939) Ceturtā tautas skaitīšana Latvijā 1935. gadā (The fourth census in Latvia in 1935). Valsts Statistikas Pārvaldes izdevums, Rīga, 672. lpp. (in Latvian).
15. Skujenieks M. (1938) Latvijas statistikas atlass XX (Latvian statistical atlas). XX. Rīga, Valsts statistiskā pārvalde, 66. lpp. (in Latvian).
16. Skujenieks M. (1927) Latvija. Zeme un iedzīvotāji (Latvia. Land and inhabitants). Rīga, A. Gulbja apgāds, 752 lpp. (in Latvian).
17. Strods H. (1992) Latvijas lauksamniecības vesture (Agricultural history of Latvia). Rīga, Zvaigzne, 287. lpp. (in Latvian).
18. Žagars Ē. (1975) Sociālistiskie pārveidojumi Latvija 1940–1941. (Socialistic transformations in Latvia 1940–1941). Rīga, Zinātne, 975, 252. lpp. (in Latvian).

POLYCENTRICITY MEASURES AND REGIONAL DISPARITIES

Juris Hāzners[1;2], Helma Jirgena[3]
[1]Latvia University of Agriculture
[2]Latvian State Institute of Agrarian Economics
[3]Institute of Economics by Latvian Academy of Sciences
juris@lvaei.lv

Abstract
The concept of polycentric development at multinational, national and regional level is broadly used in academic research of regional development and spatial planning. It is also reflected in the normative agenda by the European Union. However, polycentricity has been considered a fuzzy concept, and it still lacks commonly accepted definition or measurement methods. Albeit a plethora of researchers and policy makers favors polycentric development as a tool for reduction of regional disparities, these statements are not based on empirical foundations. The research objectives are twofold and consecutive. The first objective is to define the morphological measures of polycentricity and apply these measures at country level. The second objective is to empirically test the following hypotheses: regional disparities in countries with polycentric urban system are less pronounced than in countries with monocentric urban system; income distribution in countries with polycentric urban system is more equal than in countries with monocentric urban system. The hypotheses stated by the objective of the study can be rejected: regional disparities in countries with polycentric urban system are not less pronounced than in countries with monocentric urban system; income distribution in countries with polycentric urban system is not more equal than in countries with monocentric urban system. The research results clearly suggest the polycentric development cannot be considered a tool for diminishing regional disparities and providing more cohesion between regions.
Key words: regional development, polycentricity measures, regional disparities, non-parametric tests.

Introduction

According to the European Union Treaty, the concept of territorial cohesion assumes fair access for citizens and economic operators to Services of General Economic Interest (SGEI), irrespective of the territory to which they belong. SGEI include important issues such as transport networks, energy and communications. Generally, cohesion means balanced distribution of human activities in territorial terms. The European Spatial Development Perspective (ESDP) was adopted by EU ministers responsible for spatial planning in 1999. One of the guidelines of ESDP is the promotion of polycentrism in the European Union. The concept of polycentrism is applied at community level, individual country level and regional level within the individual country. At community level, polycentrism means the establishing of alternative development centers to the existing ones, where the wealth and population are concentrated in a relatively small geographic areas. At national level, polycentrism means the development of interdependent networks of towns as alternatives to the large cities. At regional level, polycentrism means the integration of the rural areas with small and medium-sized towns. The promotion of territorial cohesion has to be based upon the improving the factors of competitiveness. The factors of competitiveness are constituted by the territorial imbalances besides the major imbalances in the EU, such as distribution of population and wealth and the geographical handicaps affecting certain areas. The imbalances identified are between centre and periphery at a larger, EU scale; gaps between towns in the centre and those in the periphery at a smaller, individual country scale; relationship between towns and the countryside with the growing suburbanisation of the countryside or even complete isolation of the most scarcely populated areas. Geographically handicapped areas include islands, peripheral mountain areas and the most remote regions with problems of market access and integration into their economic surroundings. Expanded capacity of research and innovation in the least-favored regions, improved accessibility via road, rail and air transport, improved telecommunications via broad-band networks are the main factors of competitiveness which could correct the identified imbalances. ESDP concludes that more polycentric regional shape provides more equal income distribution in the region. The idea of polycentricity as an important policy goal was supported in the "Territorial Agenda of the European Union" agreed in 2007. A guiding document for EU new cohesion policies prepared by Barca (2009) "An Agenda for a Reformed Cohesion Policy" stressed the role of networked polycentric regions in order to promote balanced territorial development and to overcome the disadvantages arising from big urban agglomerations. Research studies favoring polycentric development view network of evenly spread cities and towns as regional strength. Moreover, retained explicit centre - periphery division is considered a threat to a region. In many European countries, polycentric development is seen as a tool for diminishing regional disparities presumably created by monocentric urban system. Monocentric or polycentric urban systems

often are associated with divergence or convergence between the regions. The extent of regional disparities is considered lower in polycentric systems. Bacic and Sisinacki (2007) simply state that monocentric development of Croatia (the city of Zagreb) has produced more negative effects than positive ones without providing any empirical foundation of this or specifying these effects. Moreover, it is a priori assumed that Croatia is monocentric. Haite (2012) analyzes the performance of Latvian socio-economic indicators, such as GINI index, general unemployment level, GDP and poverty risk. Her study concludes that Baltic States in general, and Latvia in particular, are explicitly monocentric countries. A necessity of internal model of polycentric development in Latvia is stressed. Metropolitan planning in Copenhagen and Stockholm areas, on the contrary, is based upon the expectations of annual population increase in these capital cities over one per cent between now and 2030. Office of Regional Planning, Stockholm County Council (2010) in Stockholm's regional plan assumes the metropolitan core alone cannot handle the anticipated growth, and focus is on seven or eight suburbs with relatively dense mix of jobs and housing. Municipal Plan, The City of Copenhagen (2011), on the other hand, focuses attention on increasing density and job growth in the city center area. Thus, the regional planning in these countries does not view faster metropolitan growth as a threat.

The concept of polycentricity can be analyzed either from morphological or functional perspective. The morphological approach is structural and it focuses on the coexistence of more than one urban center, usually ranked by their population. The functional approach is based upon the interaction measures which usually include the movement of people, goods and information. The present study deals with the morphological aspects of polycentricity.

The objective of the study is to empirically test the following hypotheses: regional disparities in countries with polycentric urban system are less pronounced than in countries with monocentric urban system; income distribution in countries with polycentric urban system is more equal than in countries with monocentric urban system.

Materials and Methods

Data on city sizes and their locations within the regions in 188 countries were retrieved from Thomas Brinkhoff's online database which contains latest available information provided by governmental statistical institutions in every country. Using a larger number of countries to calculate the morphological measures would provide for a more unbiased scales in comparison with only 27 European countries used by Meijers and Sandberg (2006). Information on regional GDP per capita and regional unemployment was retrieved from OECD Statistical extracts database. Out of the 188 countries, data on GDP per capita in regions were available on 50 countries. Data on regional unemployment were available on 43 countries. The income disparities within a country are represented by GINI index. It is defined as follows (Gini, 1912):

$$\sum_{i=1}^{n}\sum_{j=1}^{n}|y_i - y_j| \quad (1)$$

where n - sample size, y_i - income of the i-th individual in the sample, - arithmetic mean income of the sample. The Gini coefficient takes on values between 0 and 1 with zero interpreted as no inequality and one as total inequality. Data on GINI index were retrieved from The World Bank data collection. Data on GINI index were available on 158 countries.

For every country, data on the latest year available were retrieved for socio-economic variables.

The methods used by Meijers and Sandberg (2008) are applied with some adjustments. Regional disparities in a country can be evaluated by the coefficient of variance of socio-economic variables, such as GDP per capita and the level of unemployment. Coefficient of variance CV is calculated by the following formula:

$$CV(x) = \frac{\sigma(x)}{\mu(x)} \quad (2)$$

where x - array of data, σ(x) - standard deviation of x, and μ(x) - mean of x.

In every country, urban system is characterized by a spatial distribution of cities and relative sizes of cities with the largest population. Rank-size distribution or Zipf's Law characterizes the regularity in the distribution of city sizes. In an individual country, ten largest cities are ranked according to their population. Both logarithms of the ranks and city sizes are calculated. The values of the logarithms of city sizes are regressed on logarithms of city ranks in regression equation:

$$y_i = \alpha x_i + \beta \quad (3)$$

where y_i - decimal logarithm of i-th largest city in a country, x_i - decimal logarithm of the rank of i-th largest city in a country, α - regression slope, β - regression intercept. If plotted on a diagram, regression line shows the "centricity" of the urban system. In monocentric countries line is steeper. In polycentric countries line is flatter. A single measure of rank-size distribution is the regression slope. Spatial distribution of cities over the country territory is measured by the spread of ranked largest cities across the regions in the country, where number of cities equals to the number of regions. A single measure of spatial distribution is

the number of regions with at least one largest city divided to total number of regions. To compute the polycentricity score, a standardized scale has to be introduced depending on z-scores of both measures. Z-scores for i-th country are calculated by the following formula:

$$Z=\frac{x_i-\mu}{\sigma} \quad (4)$$

where x_i - calculated measure for i-th country, μ- mean of calculated measure for all countries, σ - standard deviation of calculated measure for all countries. A value of 100 is attributed to a z-score of 0. A value of 20 is attributed to standard deviation from mean. Standardized values of both measures are computed for every country. A single polycentricity score for the country i is calculated as an average of these two standardized values.

Results and Discussion

The regression slopes for rank-size distribution of cities and measures of spatial distribution of cities across the regions were calculated for 188 countries. The values of calculated regression slopes varied from -1.99 in Congo (the most pronounced dominance of the major city) to 0.49 in Malaysia (the least differences in the population of ten largest cities) (Figure 1).

The scores for spatial distribution varied from 0.29 in Argentina (concentration of the largest cities in a few regions in the country) to 1.00 in Iraq (at least one of the largest cities is located in every region). Distribution of cities in EU countries (excepting Malta) according to their in rank-size and spatial spread is shown in Figure 2. Countries with both marked dominance of major cities and uneven spatial distribution of cities are plotted at the lower left quarter of the diagram. Only Greece can be considered monocentric by both measures. Countries with marked dominance of major cities and more even spread of cities over the regions are plotted at the lower right quarter of the diagram. These countries include Baltic states, Hungary, Bulgaria, Slovenia, Czech Republic, Finland, Denmark, Austria and Ireland. Countries with less pronounced dominance of major cities and uneven spread of cities are plotted at the upper left quarter of the diagram. These countries include Portugal and Luxembourg. Countries that are polycentric by both measures are plotted at the upper right quarter of the diagram. These countries include Slovakia, Romania, Poland and Belgium. Germany, Cyprus, UK, Spain, the Netherlands, Sweden, Italy and France can be considered neither monocentric or polycentric by both measures.

Countries with both marked dominance of major cities and uneven spatial distribution of cities are plotted at the lower left quarter of the diagram. Only Greece can be considered monocentric by both measures. Countries with marked dominance of major cities and more even spread of cities over the regions are plotted at the lower right quarter of the diagram. These countries include Baltic states, Hungary, Bulgaria, Slovenia, Czech Republic, Finland, Denmark, Austria and Ireland. Countries with less pronounced dominance of major cities and uneven spread of cities are plotted at the upper left quarter of the diagram. These countries include Portugal and Luxembourg. Countries that are polycentric by both measures are plotted at the upper right quarter of the

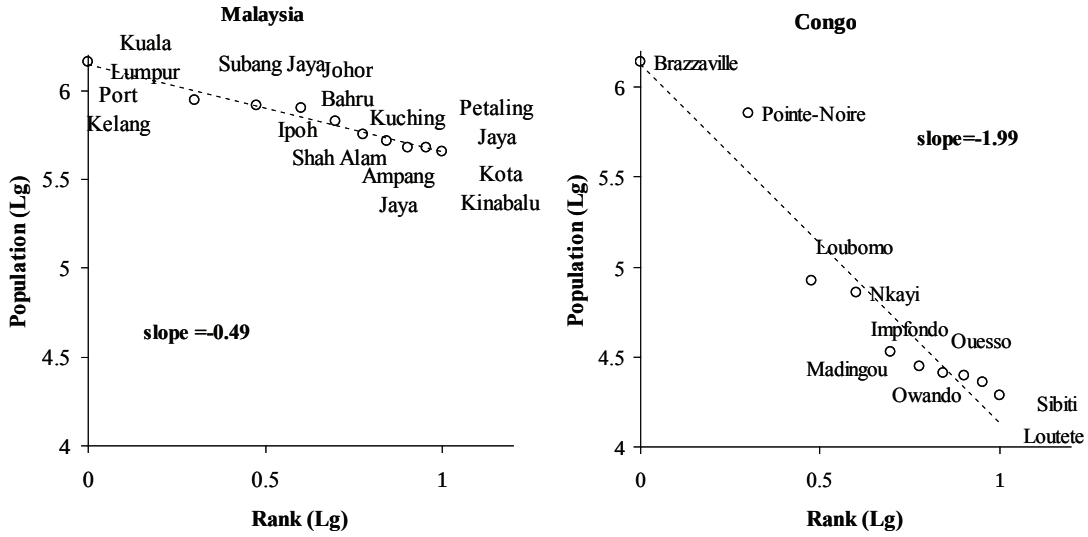


Figure 1. Rank-size distribution of the largest cities in Malaysia and Congo.
Source: research findings, Brinkhoff (2012).

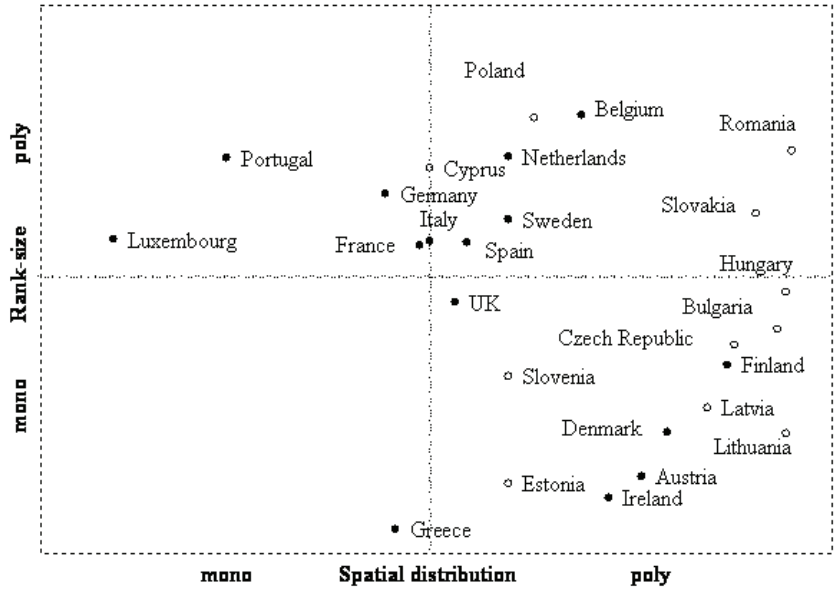


Figure 2. Rank-size distribution of the largest cities in Malaysia and Congo.
Source: research findings.

Table 1

Polycentrity scores and socio-economic variables of EU-27 countries

Country	Spatial distribution score	Rank-size score	Polycentricity score	GINI index	CV of regional GDP	CV of regional unemployment
Austria	110.7	79.9	95.3	29.1	0.20	0.42
Belgium	104.6	126.0	115.3	33.0	0.37	0.56
Bulgaria	124.5	98.6	111.5	45.3	0.42	0.60
Cyprus	89.4	119.1	104.3	29.0	n.a.	n.a.
Czech Republic	120.2	96.7	108.4	18.8	0.38	0.40
Denmark	113.4	85.5	99.4	21.8	0.25	0.37
Estonia	97.4	79.0	88.2	36.0	0.48	0.52
Finland	119.4	94.0	106.7	26.9	0.18	0.43
France	88.3	109.3	98.8	29.1	0.36	0.43
Germany	84.9	115.9	100.4	28.3	0.23	0.44
Greece	85.9	73.1	79.5	34.3	0.24	0.42
Hungary	125.4	103.4	114.4	31.2	0.44	0.40
Ireland	107.4	77.1	92.2	34.3	0.36	0.17
Italy	89.4	109.9	99.6	36.0	0.25	0.58
Latvia	117.4	88.6	103.0	35.7	0.52	0.18
Lithuania	125.4	85.3	105.3	37.6	0.38	0.30
Luxembourg	57.4	110.0	83.7	22.9	n.a.	n.a.
Netherlands	97.4	120.7	109.1	25.3	0.16	0.23
Poland	99.9	125.6	112.7	34.2	0.24	0.14
Portugal	68.8	120.5	94.7	34.4	0.28	0.28
Romania	125.9	121.3	123.6	31.2	0.40	0.49
Slovakia	122.4	113.4	117.9	20.6	0.55	0.51
Slovenia	97.4	92.7	95.0	31.2	0.24	0.36
Spain	93.2	109.8	101.5	34.7	0.20	0.41
Sweden	97.4	112.6	105.0	25.0	0.12	0.15
UK	92.0	102.1	97.0	27.9	0.48	0.33

Source: research findings, OECD (2012), The World Bank (2012).

diagram. These countries include Slovakia, Romania, Poland and Belgium. Germany, Cyprus, UK, Spain, the Netherlands, Sweden, Italy and France can be considered neither monocentric nor polycentric by both measures.

The values of polycentricity score ranged from 76.1 in Congo (the most monocentric country) to 123.6 in Romania (the most polycentric country). The median value of array of 188 countries is 99.7. Thus, of Baltic States only Estonia can be considered "explicitly" monocentric with polycentrity score of 88.2. Latvia and Lithuania scores 103.0 and 105.3, respectively. The dominance of Zagreb in Croatian city rank-size distribution is outweighed by rather even spatial distribution of cities, and Croatia can be considered polycentric with score of 106.5. The values of both measures for EU countries along with the values of respective socio-economic variables are shown in Table 1.

To test the null hypothesis H0: there is no significant relationship between the polycentricity score and selected socio economic variables, Spearman rank correlation coefficients Rho between polycentricity scores and corresponding values of coefficients of variance of regional GDP per capita, coefficients of variance of regional unemployment and GINI indexes were calculated. Computed values are provided in Table 2.

The test results show that negative correlation between polycentricity score and GINI index in 158 countries is too low to be meaningful. Positive correlation between polycentricity score and coefficient of variance of regional unemployment level in 43 countries is too low to be meaningful. Positive correlation between polycentricity score and coefficient of variance of regional GDP per capita in 50 countries is low. None of the three computed Rho values exceed critical value. Null hypothesis cannot be rejected in each of three cases.

To further support the obtained results, the following null hypothesis H0: there are no significant differences in three variables between the countries with lower and higher polycentricity scores, was tested by Mann-Whitney U-test. For GINI index, data set of 158 countries was divided into two groups by median of polycentricity scores. For coefficients of variance of regional GDP per capita, data set of 50 countries was divided into two groups by median of polycentricity scores. For coefficients of variance of regional unemployment, data set of 43 countries was divided into two groups by median of polycentricity scores. Computed values for Mann-Whitney U-test are provided in Table 3. As the computed z-value does not exceed the critical value for the 5% confidence interval for all three variables, null hypothesis cannot be rejected.

The null hypothesis H0: there are no significant differences in socio-economic variables between countries divided into quartiles by polycentricity scores, was tested by Kruskal-Wallis test. For GINI

Table 2

Spearman Rank Correlation between polycentricity scores and socio-economic variables

	GINI index	CV of regional GDP per capita	CV of regional unemployment
Sample size	n=158	n=50	n=43
Spearman' s Rho	-0.096	0.230	0.064
2-sided p-value	0.230	0.108	0.682
Rho critical value	0.156	0.279	0.301

Source: research findings.

Table 3

Mann-Whitney U-test results between polycentricity scores and socio-economic variables

	GINI index	CV of regional GDP per capita	CV of regional unemployment
Sample size of the lower score	n1=79	n1=25	n1=21
Sample size of the higher score	n2=79	n2=25	n2=22
2-sided p-value	0.466	0.058	0.682
Z computed value	0.73	1.89	0.24
Z critical value	1.96	1.96	1.96

Source: research findings.

Table 4

Kruskal-Wallis test results between polycentricity scores and socio-economic variables

	GINI index	CV of regional GDP per capita	CV of regional unemployment
Sample size of the 1st quartile	n1=40	n1=13	n1=11
Sample size of the 2nd quartile	n2=39	n2=12	n2=10
Sample size of the 3rd quartile	n3=39	n3=12	n3=11
Sample size of the 4th quartile	n4=40	n4=13	n4=11
P-value	0.61	0.03	0.35
Chi-squared computed value	1.81	9.00	3.30
Chi-squared critical value	7.82	7.82	7.82

Source: research findings.

index, data set of 158 countries was divided into four quartiles of polycentricity scores. For coefficients of variance of regional GDP per capita, data set of 50 countries was divided into four quartiles of polycentricity scores. For coefficients of variance of regional unemployment, data set of 43 countries was divided into four quartiles of polycentricity scores. Computed values for Kruskal-Wallis test are provided in Table 4. As the computed z-value does not exceed the critical value for the 5% confidence interval for GINI index and variance of regional unemployment, null hypothesis for these variables cannot be rejected. For variances of regional GDP per capita, computed chi-squared value exceed the critical value for the 5% confidence interval and null hypothesis cannot be rejected. The alternative hypothesis H1: there exists marginal differences in variances of regional GDP between countries divided into quartiles by polycentricity scores, can be accepted.

Research results are in line with the findings of Meijers and Sandberg (2006) for the EU countries and Veneri and Burgalassi (2012) for Italian regions.

Conclusions

1. The research results have not supported the existence of statistically significant differences in three socio-economic variables between countries with higher and lower polycentricity levels. Thus, higher polycentricity cannot be associated with less regional disparities.
2. Higher polycentricity score can rather be associated with more marked regional disparities in GDP per capita.
3. The hypotheses stated by the objective of the study can be rejected: regional disparities in countries with polycentric urban system are not less pronounced than in countries with monocentric urban system; income distribution in countries with polycentric urban system is not more equal than in countries with monocentric urban system.
4. The research results clearly suggest the polycentric development cannot be considered as a tool for diminishing regional disparities and providing more cohesion between regions.

References

1. Bacic K., Sisinacki J. (2007) Embracing Polycentricity within the Croatian Regional Development Policy. In: *Proceedings from the International Conference "New concepts and approaches for Urban and Regional Policy and Planning?"* Leuven, Belgium, pp. 123-132.
2. Barca F. (2009) An agenda for a reformed cohesion policy. A placebased approach to meeting European Union challenges and expectations, Independent Report prepared at the request of Danuta Hubner, Commissioner for Regional Policy. Available at: http://www.europarl.europa.eu/meetdocs/2009_2014/documents/regi/dv/barca_report_/barca_report_en.pdf, 15 October 2012.
3. Brinkhoff T. (2012) City Population database. Available at: http://www.citypopulation.de, 14 October 2012.
4. Commission of the European Communities (1999) European Spatial Development Perspective: Towards Balanced and Sustainable Development of the Territory of the EU. Agreed at the Informal Council of Ministers responsible for Spatial Planning in Potsdam, May 1999. Luxembourg: Office for Official Publications of the European Communities. Available at: http://ec.europa.eu/regional_policy/sources/docoffic/official/reports/pdf/sum_en.pdf, 15 October 2012.

5. European Union (2007) Territorial Agenda of the European Union: towards a more competitive and sustainable Europe of diverse regions. Common Policy paper. Agreed on the occasion of the Informal Ministerial Meeting on Urban Development and Territorial Cohesion in Leipzig on 24th and 25th May 2007. Available at: http://www.eu-territorial-agenda.eu/Reference%20Documents/Territorial-Agenda-of-the-European-Union-Agreed-on-25-May-2007.pdf, 15 October 2012.
6. Gini L. (1912) *Variabilità e mutabilità (Variability and Mutability).* C. Cuppini, Bologna. Reprinted in Memorie di metodologica statistica (Ed. Pizetti E, Salvemini T). Rome: Libreria Eredi Virgilio Veschi (1955) (in Italy).
7. Haite I. (2012) Polycentric development assessment using the hierarchy method. *International journal of economics and finance studies*, Vol 4, No 2, pp. 127-136.
8. Meijers E., Sandberg K. (2006) Polycentric development to combat regional disparities? The relation between polycentricity and regional disparities in European countries. In: *Proceedings from the 46th Congress of the European Regional Science Association.* University of Thessaly, Volos, Greece, pp. 225-244.
9. OECD (2012) Statistical extracts database. Available at: http://stats.oecd.org/Index.aspx?DatasetCode=CRSNEW, 20 December 2012.
10. Office of Regional Planning, Stockholm County Council (2010) Guide to the Regional development plan for the Stockholm region - RUFS 2010. Available at: http://www.tmr.sll.se/Global/Dokument/publ/2010/RUFS_2010_short_version.pdfhttp://www.tmr.sll.se/Global/Dokument/publ/2010/RUFS_2010_short_version.pdf, 11 November 2012.
11. The City of Copenhagen (2011) Municipal Plan 2011, Available at: www.kk.dk/kp11, 12 November 2012.
12. The World Bank (2012) Economic and Social Council database. Available at: http://data.worldbank.org/indicator/SI.POV.GINI, 20 December 2012.
13. Veneri P., Burgalassi D. (2012) Questioning polycentric development and its effects. Issues of Definition and measurement for the Italian NUTS 2 Regions. *European Planning Studies* 20 (6), pp. 1017-1037.

GEOGRAPHICAL TRENDS IN EXPORT MARKET OF LATVIAN FISHERIES PRODUCTION

Antons Berjoza, **Juris Paiders**
University of Latvia
antons.berjoza@inbox.lv; jpaiders@inbox.lv

Abstract
Since joining the European Union Latvian fish industry has undergone a serious process of change and reform. Not all of them were welcomed by people working in the industry or those related to it. Consequently, the reform backed by the European institutions and legislature changed the dynamics and consistency of Latvian fish industry. As of 2004 many Latvian fishing vessels were scraped and even greater number of smaller fishing boats followed the same fate. Fishing and processing of the catch for Latvian shore regions is not only one of common and basic occupations, but also provides a large spectre of other services, as fishing in general is a complex industry providing a lot of jobs for seashore residents, primarily in primary, and secondary sectors of economy, and in smaller extent in tertiary, more precisely in distribution, trade and food services.
This paper focuses on a research conducted on the expansion of Latvian fish industry product export market from a spatial, geographic perspective and analyzes the volumes and directions of outflow of goods to the recipient countries worldwide in period from 2000 to 2011. The analysis was done using correlation of yearly cargo flows and the spatial relations of major export directions, by historic and modern economic tendencies of the industry.
Results give a picture of modern trends in export market geography and its changes during the first decade of the new century that is the ongoing transformation of East-oriented processed goods market into diverse one, which in future will largely depend on Western countries.
Key words: fishing industry, geographical diversification, export directions.

Introduction

Latvian fishing industry as a primary source for populace income has existed on the shores of the Baltic Sea and the Gulf of Riga for centuries and the dramatic change due to standardization and strict administration of fishing activities in waters surrounding the European Union (further the EU). Introduction of quota system on fishing in the Baltic Sea and other European waters led to a decrease in competitiveness of Latvian fishermen and, respectively, of products manufactured by the local processing plants. Comparatively, countries with longer connections with the European community, such as Norway, received more favourable quotas and fishing allowances, than the EU newest members. As a result, countries which were dominating the fishing market so far, kept their privileged position and those who just joined were strangled by the strict and tight regulations, to which they now had to adapt. In the process of adaptation, the dominating countries had a chance to enter new country markets and using the lapse of activity from the local entrepreneurs grab a considerable share, with cheaper prices and greater mass of products (Peter, 2008).

The process of change for Latvian fishery sector was quite similar to the one undergoing in other newest EU countries, such as Lithuania, Estonia, Poland, etc. Fishing vessels being scraped for compensation money, some left in docks for the same purpose, and some are being sold somewhere else, particularly to other EU member states. While primary sector of the fish industry was reducing its size and was restricted in terms of active fishing and supply of raw fish market, Latvian participants of secondary sector, namely enterprises that actually process and sell fishing products were left with little option as to reduce their production or to find new suppliers of raw fish, it was partially solved with cooperation inside three Baltic states. In years from 2004 to 2011, the total volume and sum of trade in fresh, live or raw fish among these three states rose dramatically, as the indicator of cooperation between the chain cells of the same industry in these three closely related countries (Berjoza, 2012).

The aim of the research was to explore and analyze the geographical trends of Latvian fisheries production export markets, by completing the following tasks:

- Review the related literature and historical insight in sector's development and productivity;
- Analyze and evaluate the statistical data on export of fishery goods;
- Define the trends, examine their origin, and evaluate the prospective scenario for future development based on current tendencies.

The research, on the one hand, was obstructed by the lack of recent research in the relevant field, and on the other hand by excessive amount of literature on research on fisheries and fish industry by scientists of other specializations, with different viewpoints and purposes (Fadejeva and Meļihovs, 2009; Motova, 2008; Eičaitē and Motova, 2008; Igloi, 2007; Brodin, 2001). Nevertheless, all that could be overcome by moulding of economic, ecological, judicial and

historical sciences in one complex research based on spatial relations of statistical data. In process of acquisition and reorganisation of export data, all of the mentioned fields were used at some point to explain or address shifting pattern of change in the market tendencies.

Before the research was carried out, the literature on the topic was studied and compared in terms of subject matter and methodology for its potential use in the planned data analysis or collection. Specifically, the author has tried to overview literature in the Baltic Sea Region (further BSR) and in the biggest fishing countries around the world, where 'biggest' corresponded to a traditional and emerging importance in the country's economy, life and culture.

For BSR almost all countries were included in the overlook, specifically Latvia's neighbouring countries Lithuania and Estonia, big regional giants like Sweden and Finland. As for the Western Part of Europe, specific attention was paid to Norway, as it is the top fishing country, with long cultural and economic attachment to fishing and sea in general. Outside of Europe big fishing countries like Japan, India, China, etc. were overlooked in an attempt to find the best way of understanding concerns in their fishing industries and potential development patterns.

Compared to the goals of this research, other studies conducted on fisheries and fishing industry in general mostly included those, that concerned fishing areas environments (Pulkkinen et al., 2009; Stal et al., 2008; etc.), fish stocks and economic impact of policies on actual fishing sectors and industries' sub-divisions (Grubliene, 2010; Waldo et al., 2010; Gaasland, 2007; Haken and Tveteras, 2007; Shivarov et al., 2005; etc.) or its change in regard to the latest changes in the overall situation in the region of interest or regions of most abundant fishing areas (Bruckmeier and Larson, 2008; Stokke, 2009; etc.).

Of all papers and publications studied, only the following coincide with the topic of the conducted research: Setala et. al. (2008), who studied the fish market in the Northern Baltic Sea area, though stressing spatial integration of market, basically its allocation and spatial connections, with little regard to general flow of products; Elvestad (2009), who explored the relations between policies and interests of entrepreneurs, as well as its impact on free market relations between the actors of fish market in Norway; and Guo (2008), who analysed the trade of fishery products between China and US, which is quite similar to what was done in featured research, but in respect to trade between two countries. As it was mentioned above, the research discussed in this paper, focuses on tracking and comprehending geographical trend in export market change and dynamic of Latvian fisheries production, while relevant papers and researches feature some or number of elements used in it, or cover particular topics discussed or mentioned, like the sea contamination, fishing quotas, trade agreements and governmental policies.

Materials and Methods

The primary source of data for this research was the Latvian National Statistics Bureau, which hosts large databases on all foreign trade positions, from which statistical data sets were acquired. The given data from 2000 to 2011 was separated using standard international Combined Product Nomenclature with 4 and 8 digits, and the analyzed groups are shown in Table 1.

Separation given in Table 1 describes the general groups analyzed, but 8 digits Combined Nomenclature gives a more precise differentiation into sub-groups, by fish or vertebrates species, sub-species, preparation type and package, when referred to 1600 group of products.

Table 1

Fish products separated in groups by 4 digits Combined Nomenclature

4 digit nomenclature codes	Explanation
0300	Fish, shell fish, molluscs and other aquatic invertebrates
----0301	----Live fish
----0302	----Fresh or chilled fish
----0303	----Frozen fish
----0304	----Fresh, chilled or frozen fish fillets
----0305	----Dried, salted, smoked fish, the pickles, etc.
----0306	----Shell fish, crustaceans and its pickles, fillets, etc.
----0307	----Molluscs other than crustaceans and fish
1600	Meat, fish, shell fish, mollusc and other aquatic invertebrate products
----1604	----Prepared or preserved fish, caviar and caviar substitutes prepared from fish eggs

Considering the information gathered from the database, that features yearly reports on all available countries, it was important to separate countries with no relation to the mentioned trading groups, and further to make a data division by regions, countries and seasons.

Further analysis composed of data sorted by country was used, separated in groups by total export values, accumulated in 12 years, creating 5 classes, from sporadic export destinations, with total of less than 10 thousand Lats (further Ls), to major trading partners, with over 1 million Ls. The separation was essential as the yearly export of fish industry products is considerably smaller than those of agricultural or forestry sectors, or even of other industries and as the processed data has shown, varies around 100 thousand Ls, rarely exceeding 500 thousand. Additional analysis using sliding-mean and correlation matrix was used to find the possibilities of segmentation and clusterization of export markets.

On the third stage of analysis the processed data were observed using visualisation to find spatial grouping and potential clusterization of export at particular moments in time. Given results were also analyzed using comprehensive approach, e.g. the reason for particular flows was searched in more in-depth relationships, like brand names, personal and corporative connections. This included comparison within product groups and between them to indicate possible dynamics, which could be relevant to changes in national or the EU fishing policies and heterogeneous development inside industry.

Results and Discussion

The conducted research showed that there are particular relations in export market, that can be attributed both to spatial and economic parameters. Figure 1 shows that there are differences among exported products groups and those differences strongly rely on economic conditions and situation within industry. It is noticeable, that export volume grew dramatically after Latvia joined the EU, but the growth was limited and in 2007 it experienced a decline due to its failure to take a solid position in Western European and overseas markets. In 2008 the volumes rose dramatically as the beginning of economic crisis, pushed entrepreneurs to fill the market with their goods to earn as much as possible. That can be seen in the following year as a declining trend in Total Volumes; for the time of economic recovery (from 2009) export volumes show a steady growth, which is a positive sign for the industry.

Despite this positive tendency, another underlying process is more worrying. As can be seen above and also from the research of Berjoza (2012), Fadejeva and Meļihovs (2009), for almost all its history Latvia has been exporting processed fish, like smoked, salted, pickles and others, but as of 2009 the dominating group is un-processed fish, basically raw fish in different conditions or primarily processed (fillets). That indicates that processing plants in Latvia are not coping with the preposition, or are using cheaper fish from abroad, increasing the imports. In the years following the implementation, and due to the EU legislation and policies on fishing in Latvia, processed fish export has been showing an unstable tendency,

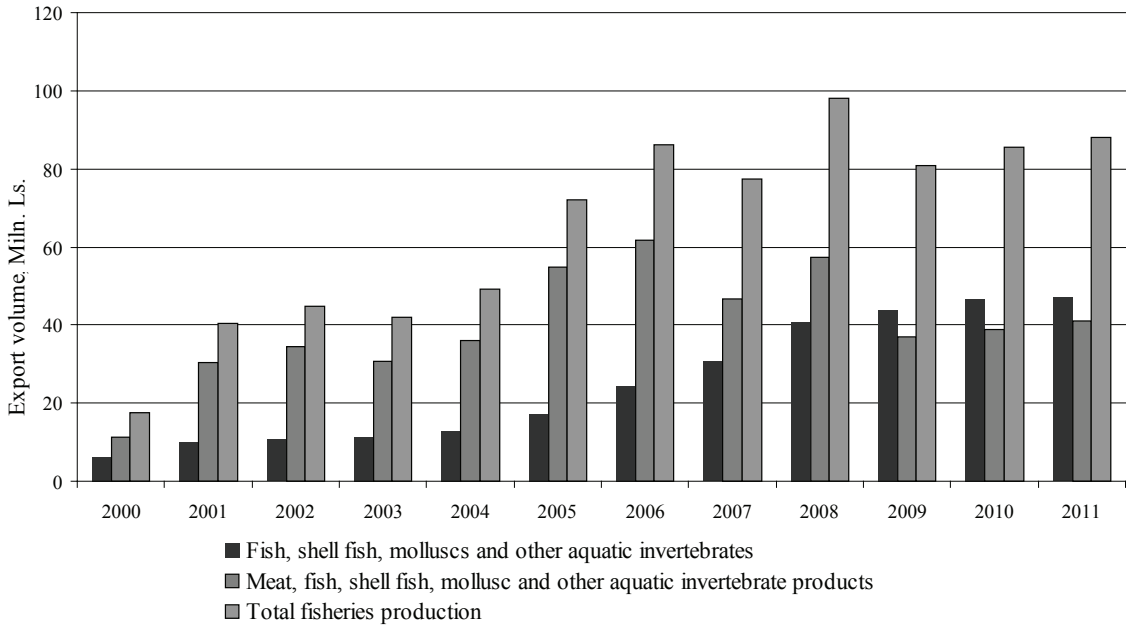


Figure 1. Total volumes of Latvian fish industry exports by year.

and only lately it does show a stable steady growth. As deeper research proved, it happened due to the open market, as many companies tried to push their goods to the 'West', where they encountered more competition compared to the 'East'.

Analyzing export group differentiation by regions it was clear, that increase in raw fish was primarily connected to a push to the 'West', as the shares of western markets grew in the destination of majority of Latvian unprocessed fish products. As for processed products, the share of eastern market was always great, it dwindled just after 2004, but rose again amidst economic crisis, which greatly reduced the share of major western markets, such as the USA, the Czech Republic (see Figures 2 and 3). It is also significant to note that before 2004, Latvian fisheries export was more diverse geographically, Latvian fish products, especially unprocessed segment of it, was highly demanded in Sweden, Japan, Thailand, Cambodia and other countries outside Europe, but after 2004 majority of unprocessed products diverted to the EU countries.

In case of processed products, the dominating market was and is Russia, since the 19th century Latvia was a supplier of canned, slated and smoked fish for Russian market, during Soviet era this trend expanded to both the USSR and Eastern Block. Even after the independence, Latvian companies and plants continued to supply all former republics, even those, which seemed far and quite closed as Turkmenistan and Belarus (Berjoza, 2012). Processed products are exported in much greater amounts to other European countries, e.g. outside the EU, and Middle Asian and Transcaucasian regions; trend for export to North America and further abroad diminished due to heavy global economic conditions. After 2004 there was a sharp increase in export to Estonia and a propitious decline in export to Russia. It is explained by particular circumstances of inter-border trade between Estonia and Russia, mainly in address to gaps in trading policies, which made re-export through Estonia quite advantageous. Luckily these gaps were closed, and now direct export to Russia is growing again, as well as to other countries, like Lithuania, Belarus, etc.

More detailed observation of export tendencies show more information on trends of export market and its geographical feature. It was observed that fish products are more frequently exported to Eastern and Central European markets, while other products tend to reach farther locations, such as Asia and Mediterranean. For the Eastern Europe best products of choice are various canned fish products particularly made from sprat (*Sprattus sprattus)*, herring (*Clupea harengus harengus* and *Clupea harengus membras*) and mackerel (*Scomber scombrus*). In western destination, more sophisticated and rare species are being exported, like tunas, salmons, etc. Unfortunately, many issues still persist, like cod fishing and quotas, as the demand for highly evaluated cod products always was a question for BSR fishing nations, it was noted by Eero et al. (2007), and again complemented by this research, that cod fisheries in the Baltic Sea are diminishing, and the possibilities for its development lay in comprehensive and long term sustainable approach to fishing and preserving its natural habitats, which as of late were severally damaged by anthropogenic pollution and activity.

Observing the general market tendencies, it can be noted that the EU free trade zone and trading agreements have played a tremendous role in changing Latvian fisheries production export market. As it is observed in Figure 4, the export is highly dependent

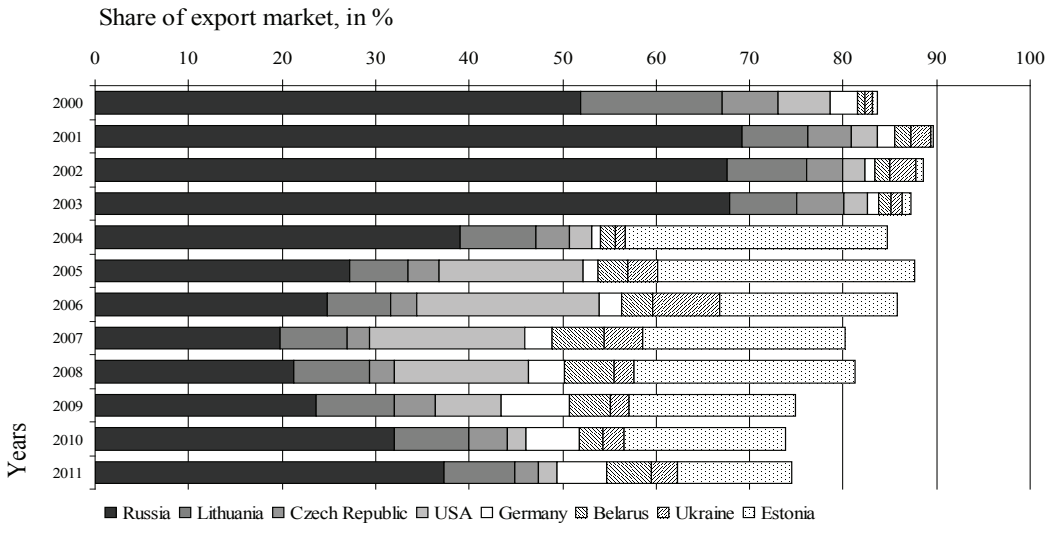


Figure 2. Share of export market by country in % for observed period.

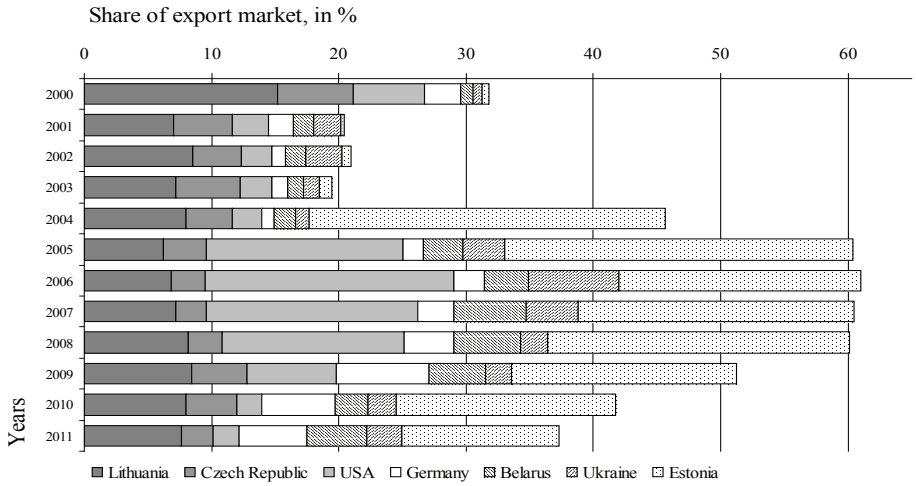


Figure 3. Share of export market by country in % for observed period (without Russia).

on product type, e.g. group (Those listed in Table 1 are arranged in a sequence, where greater number means longer preservation time).

Products that can be preserved for a longer time are sold further and in more various places, and those with a small period of storage are exported to closer areas. For instance, living fish is exported to Estonia and Lithuania, rarely to Sweden, Poland or Germany, while frozen fish is sold almost anywhere. The figure demonstrates that those countries available by sea can purchase fish almost directly from boats, while others prefer to get primarily or secondarily processed fish or processed products. Secure economic ties are also a part of a force that affect export markets: Latvian strong economic relationship with other Baltic States, Poland and Germany increase a provability

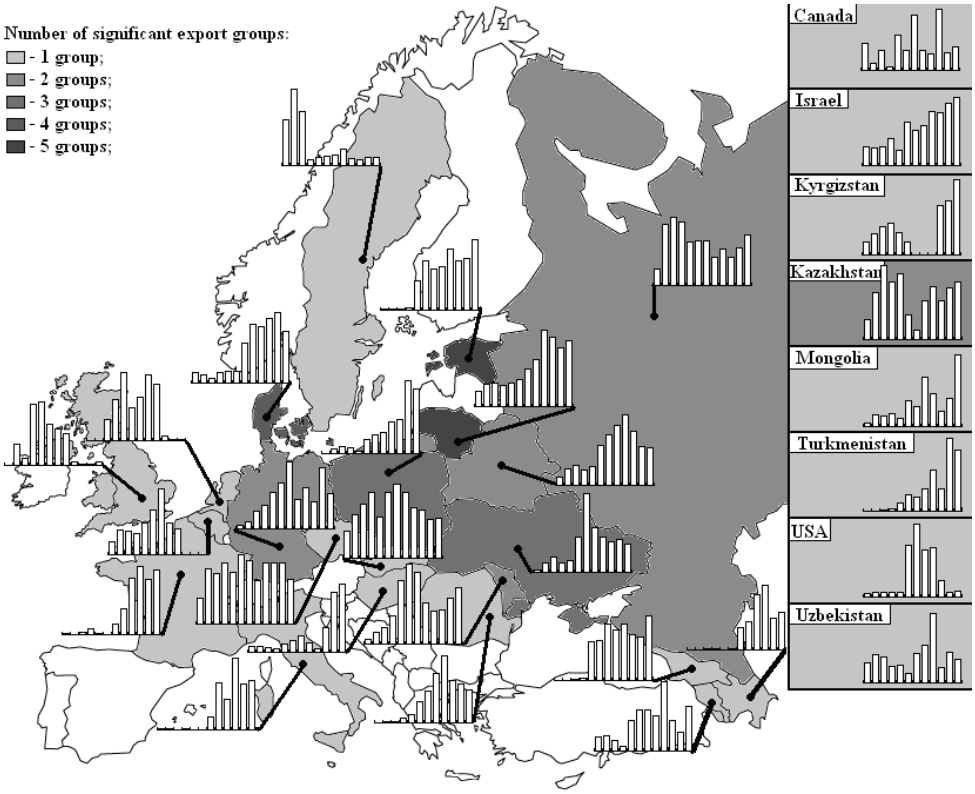


Figure 4. Major export market by exported number of product groups and total export volume dynamic.

of product export to those markets, similarly export volumes indicate, that after the integration into the EU Latvian export rose dramatically, while the share of other European countries decreased, the prices grew, which again increased the overall export volume. Following the economic crisis, export volumes to many countries outside the EU dwindled, it also cut down exports to many other locations (not shown in Figure 4), where Latvian products used to head. But post-crisis development indicates that local entrepreneurs are solidifying their positions in the neighbouring markets, especially in the eastern ones, which dominate in processed product exports, and are conducting a push with unprocessed products into the EU markets, such as French, Czech, Slovakian, Polish ones (see Figure 4).

Conclusions

1. The analysis of geographical trends showed that Latvian fishery products are not being exported as widely as they used to prior to the EU integration, but share volumes of it grew, because of increasing prices and effectiveness not only of fishing, but also processing plants. Results also indicate that despite the new EU trade agreements a lot of export still goes outside the EU - to post-soviet republics, and even further to Northern America and Mediterranean.
2. Prior to joining the EU Latvian fisheries production was sold all over the world and the main portion of its processed goods went to Russia, as all companies enjoyed decades old and upheld prestige provided by years of positive and proven connections and demand. But with new markets opening in front of many entrepreneurs, exports to the 'East' dwindled due to an attempt to conquer the 'West', unfortunately the economic crisis hit those attempts hard.
3. In post-crisis years there was a considerable solidification of trading markets, where goods were sold to smaller group of countries, but for the maximum income. This in many aspects helped companies and plants to survive the shortcomings of economic recess, and now there are indicators that the trade flows are recovering and restructuring. Recess pushed many to reconsider their export policies and it is expected that in a few years Latvian fisheries products might be encountered in European markets, as downslide of trade during crisis, was due to a particular unfamiliarity of customers with goods proposed, and the second push will be more successful. In terms of exported goods, within the past decade the consistence changed dramatically - prior to the EU about 65 % of all export volume was on part of processed fish products, while 17% were fish fillets, but after 2004 the processed good's share rose to over 75%, as other types of goods saw a decline. Now, on the other hand, the processed gods make up less than 50% of export volume, while fresh fish is 20% and above, chilled and frozen fish and fish fillets make around 12% each. That indicates a fall in the overall industrial output, as it is more advantageous for local fisherman to sell their catch abroad and not to the local plants.

References

1. Ayer N.W., Tyedmers P.H. (2009) Assessing alternative aquaculture Technologies: life cycle assessment of salmonid culture systems in Canada. *Journal of Cleaner Production*, 17(3), pp. 362-373.
2. Barton J.R., Floysand A. (2010) The Political ecology of Chilean salmon aquaculture, 1982-2010: A trajectory from economic development to global sustainability. *Global Environmental Change*, 20(4), pp. 739-752.
3. Barton J.R., Murray W.E. (2009) Grounding Geographies of Economic Globalisation: Globalised Spaces in Chile's Non-Traditional Export Sector, 1980-2005. *Tijdschrift voor economische en sociale geografie*, 100(1), pp. 81-100.
4. Berjoza A. (2012) Latvijas zivsaimniecības produkcijas eksporta tirgu ģeogrāfijas tendences. (Geographical trends in export market of Latvian fisheries production). In: Krišjane Z., Laiviņš M., et al. (eds.) *Ģeogrāfija mainīgajā pasaulē. IV Latvijas ģeogrāfijas kongress (Geography in the changing world. IV Geographical Congress of Latvia)*. University of Latvia, Riga, Latvia, 9-10. lpp. (in Latvian).
5. Blazer V.S. (2011) Fisheries Currents: Understanding Fish Mortalities in the Potomac Drainage. *Fisheries*, 26(1), p. 40.
6. Borquez R., Aliro-Hernandez A., Adrian (2009) Status of and trends in the use of small pelagic fish species for reduction fisheries and for human consumption in Chile. *FAO Fisheries and Aquaculture Technical Paper*, 518, pp. 289-324.
7. Brodin A. (2001) Russian Port-Projects in the Baltic Sea: A brief Analysis of Russian Ports and Projected Ports in the Baltic Sea Fringe. *International Journal of Maritime Economics*, 3(4), pp. 387-401.
8. Bruckmeier K., Larsen C.H. (2008) Swedish coastal fisheries–From conflict mitigation to participatory management. *Marine Policy*, 32(2), pp. 201-211.

9. Cantillon S. (2009) Behind the Fish Market Facade. *The IMP Journal*, 3(1), pp. 50-74.
10. Carroll C., Vucetich J.A., Nelson M.P., Rohlf D.J., Phillips M.K. (2010) Geography and Recovery under U.S. Endangered Species Act. *Conservation Biology*, 24(2), pp. 395-403.
11. Chen S., Li L., Yang X., Cen J.W., Wu Y., Diao S. (2007) Present situation of tilapia industry and measures of improving export competition power. *South China Fisheries Science*, 1, pp. 75-80.
12. De Silva S., Francis D.S., Tacon A.G.J. (2011) Fish oil in aquaculture: in retrospect. In: Turchini, G. M. Et al. (eds.) *Fish oil replacement and alternative lipid sources in aquaculture feeds,* CRC Press, Boca Roton, Flo, pp. 1-20.
13. Delgado C.L., Wada N., Rosegrant M.W., Meijer S., Ahmed M. (2003) Fish to 2020: supply and demand in changing global markets. *The World Fish Center*, pp. 105-136.
14. Donnelly K.A.-M., Karlsen K.M. (2010) Lessons from Two Case Studies of Implementing Traceability in the Dried Salted Fish Industry. *Journal of Aquatic food Product Technology,* 19(1), pp. 38-47.
15. Doring R., Egelkraut T.M. (2008) Investing in natural capital as management strategy in fisheries: The case of the Baltic Sea cod fishery. *Ecological Economics,* 64(3), pp. 634-642.
16. Echeverria R., Gopinath M. (2008) Export Behaviour in the Chilean Agribusiness and Food Processing Industry. *Chilean Journal of Agricultural research*, 68(4), pp. 368-379.
17. Eero M., MacKenzie B.R., Karlsdottir H.M., Gaumiga R. (2007) Development of international fisheries for the eastern Baltic cod (*Gadus morhua*) from the late 1880s until 1938. *Fisheries Research. History of marine animal populations and their exploitation in northern Europe,* 87(2/3), pp. 155-166.
18. Eičaitē O., Motova A. (2008) Tendencies for production and foreign trade of fishery products in Lithuania. *Market Research: Agricultural and Food Products,* 39(1), pp. 104-109.
19. Fadejeva L., Meļihovs A. (2009) *Latvijas Tautsaimniecības nozaru kopējās faktoru produktivitātes un faktoru izmantošanas novērtējums* (Latvian economic sectors in total factor productivity and the use of assessment factors). Available at: http://80.233.167.45/public_files/images/img_lb/izdevumi/latvian/citas/pet_2009-3_fadejeva-melihovs.pdf, 21 April 2011. (in Latvian).
20. Gaasland I. (2007) Agriculture versus fish – Norway in WTO. *Food Policy*, 34(4), pp. 393-397.
21. Grubliene V. (2010) Lithuanian Cluster of Sea Economics – Instrument of Sustainable Regional Development. *Business, Management and Education*, 8(1), pp. 66-78.
22. Guo M. (2008) Features and the comparative analysis of the Sino-US aquatic products trade. *Journal of Shanghai Fisheries University*, 2, pp. 232-237.
23. Haken E., Tveteras R. (2007) Potential Rent and Overcapacity in the Swedish Baltic Sea Trawl Fishery. Available at: https://gupea.ub.gu.se/bitstream/2077/19625/1/gupea_2077_19625_1.pdf, 16 April 2012.
24. Igloi G. (2007) Supporting rural development from structural funds in new EU member states. *Studies in Agricultural Economics*, 107, pp. 47-60.
25. Makino M. (2011) Japanese Fisheries Today. Fisheries Management in Japan. *Fish & Fisheries Series*, 34, pp. 41-62.
26. Motova A. (2008) Management of Lithuanian open Baltic fishing fleet in accordance with the multiannual cod resource management plan. *Management theory and studies for rural business and infrastructure development*, 14(3), pp. 78-68.
27. Pulkkinen K., Suomalainen L.-R., Read A.F., Ebert D., Rintamaki P., Valtonen E.T. (2009) Intensive fish farming and the evolution of pathogen virulence: the case of *columnaris* disease in Finland. *Biological Science*. 277(1681), pp. 593-600.
28. Setala J., Laitinen J., Virtanen J., Saarni K., Nielsen M., Honkanen A. (2008) Spatial integration of freshwater fish markets in the Northern Baltic Sea area. *Fisheries Research*, 92(2/3), pp. 196-206.
29. Shivarov A., Kulmala S., Lindroos M. (2005) Fisheries Management Costs: The Case of Baltic Salmon Fishery. Available at: http://www.helsinki.fi/taloustiede/Abs/DP10.pdf, 12 April 2012.
30. Stokke O.S. (2009) Trade measures and the combat of IUU fishing: Institutional interplay and effective governance in the Northeast Atlantic. *Marine Policy*, 33(2), pp. 339-349.
31. Vetemaa M., Eero M., Hannesson R. (2002) The Estonian fisheries: from Soviet system to ITQs and quota auctions. *Marine Policy*, 26(2), pp. 95-102.
32. Vetemaa M., Eschbaum R., Albert A., Saks L., Verliin A., Jūrgens K., Keslers M., Hubel K., Hannesson R., Saat T. (2010) Changes in fish stocks in an Estonian estuary: overfishing by cormorants? *ICES Journal of Marine Science*, 67(9), pp. 1972-1979.
33. Waldo S., Paulrud A., Jonnson A. (2010) A note on the economics of Swedish Baltic sea fisheries. *Marine Policy*, 34(3), pp. 716-719.

FOOD WASTAGE PROBLEMS IN A PERSPECTIVE OF EATING HABITS: A REVIEW PAPER

Tatjana Tokareva
Latvia University of Agriculture
tatjana.tokareva@inbox.lv

Abstract
Even though thousands of people suffer from hunger each day, there are people that simply throw away their food, imposing serious environmental, social and economic consequences. Food waste concept, however, is not as strictly defined as it varies from research to research. The classification itself can be specific to certain regions and cultures, and it can even be affected by the eating habits of the researchers. This review paper aims to unify the theoretical knowledge of food wasting with examples from actual research, evaluating data from the perspective of eating habits and finding motives for such an action, such as family and friends' influence, incomes, lifestyle, religion, mass media etc. Previously done studies show that people are less concerned about reducing food wastage when it comes to environmental and social problems, but are the most motivated if they see a real opportunity to save money.
Key words: nutrition, environment, economic impact, attitude, packaging, consumption style.

Introduction

Even though thousands of people in the world suffer from hunger every day, there also exists the other extremity: people who just throw their food away. According to information provided by the Food and Agriculture Organization of the United Nations (FAO), all around the world about one-third of food that was meant to be consumed by humans gets lost or wasted. The amount of produced, but lost/wasted food is about 1.3 billion tons each year. At the same time, the information provided by FAO shows that 925 million people are starving every day. Food wasting is also money wasting, and it generally negatively affects the environment in which we live (Gustavsson et al., 2011).

It is a long process to get food from the production stage to the actual consumption stage. That is why some food amounts are decreased at all stages: during agricultural production, harvest/slaughtering, postharvest handling and storage, processing and packaging, distribution and also during consumption. The food amount that gets decreased during food production and handling stages is called 'lost' food. Food that already reached the consumer, but was not fully consumed, is called 'wasted' food (Gustavsson et al., 2011).

Nowadays, the food wasting problem is being discussed more and more, but there is not much research conducted and a decrease or increase in food wastage can be affected by very different factors. The aim of this review paper is to identify these factors and offer a view on this problem from an eating habits' perspective.

Hypothesis: The food wasting problem is closely connected to eating habits.

Materials and Methods

The aim of this review paper was to summarize the research conducted previously, identify variables that must be considered in this review paper, identify gaps in knowledge and provide the evaluation of the problem. Primary sources are scientific papers, monographs, fundamental documents that are closely related to the subject, which could be found in the scientific databases and as free sources on the Internet. Papers were selected by the search terms and also by the provided references in the studies that were found.

Results and Discussion

Wasted food is defined as food that is discarded and not fully consumed (Princeton University Dictionary, 2006); it is closely related to attitudes and behaviours. Food gets 'lost' if it is affected by structural causes such as weak infrastructure, technological obsolescence, lack of refrigeration, etc. (Gustavsson et al., 2011). If the food loss problem in poor countries could be solved by investing money in infrastructure, processing and storage technologies and facilities, that is mostly by investments, then in rich countries to solve a food wasting problem, it is necessary to change people's attitude towards food, their habits and even laws.

Food can also be wasted in stages prior to direct consumption, for example: when farmers do not harvest all the crops, when vegetables and fruits are thrown away because of their shape, when big supermarkets have too much food on display, so people are given a false idea of a vast choice, etc. Because of that, lots of food gets wasted easily, especially if supermarkets do not have their own kitchens and cannot make all kinds of cultivated products from those products that have lost their selling-appeal (Schneider, 2008)

The food waste concept, however, is not so strictly defined and it varies from research to research. Moreover, classification itself can be specific to a particular region or culture, and can be affected by the eating habits of the researchers. Thus, the classification not only includes the stage of food that gets discarded,

but also it can include the interpretation of what is considered avoidable and non-avoidable food waste. While, for example, J. Langley et al. (2010) consider all preparation by-products and residues of food preparation inedible and therefore non-avoidable, researches that cooperate with Waste and Resources Action Programme use an additional subcategory of 'possibly avoidable food'. Possibly avoidable food is considered edible and defined as 'food and drink that some people eat and others do not (e. g. bread crusts), or that can be eaten when food is prepared in one way but not in another (e. g. potato skins)' (Household Food …, 2009). As for avoidable food, studies generally agree that wholly unused and partly consumed food would be avoidable, but the classification of the post-preparations and consumption residues differ.

No matter what the classification is, the Millennium Development Goals report that was conducted in 2012 by the order of United Nations shows that nowadays most people see food as only a finished product, neither visualizing the whole **production cycle** nor the resources that are needed to be used. That is why in human minds the link between food and its impact on the environment and the economic situation is not so obvious. Not fully consuming the food that has been produced is not only unethical, but also socially irresponsible. That increases inequality between wealth and poverty, between developed and developing countries, between over-nutrition and hunger (The Millennium Development…, 2012). Ethical and social aspects create a real cost to the whole society.

Often, when people say that they do not waste their food, they really believe in what they say, because the food that is meant to be thrown away does not stay stored in the house for too long, and that is why people do not really see the actual amount of food they waste because considering the amount of food that gets consumed, the wasted part of it seems insignificant (Jones, 2004)

Each year the **price** of food products gradually increases, and it is believed that to reduce the food prices, the food production increase must be managed (How to Feed…, 2009). It is not borne in mind that lots of food products are already simply discarded and that the possible food production increment can only increase wasted food amounts.

In order to promote the idea of **using food sustainably**, Members of the European Parliament called for 2014 to be designated as the European Year against Food Waste. In the year 2012, the European Commission set a target to reduce food waste by 50% (Parliament calls…, 2012). But in order to achieve this goal, it is important to determine how much food is discarded and unused right now, it is possible to determine food waste amounts only if the current situation regardless of food waste in Europe is researched.

According to EUROSTAT data in 2006 in Europe, 89 million tons of food got wasted at a household level, per capita 179 kg (Preparatory study…, 2010). But in the research 'Global Food Losses and Food Waste', which was carried out from August 2010 to January 2011 by the Swedish Institute for Food and Biotechnology (SIK) on request from the Food and Agriculture Organization of the United Nations (FAO), data already shows that, in Europe, the overall per capita loss/waste has increased, and now it is 280-300kg/year (Gustavsson et al., 2011). According to EUROSTAT data, 42% of produced food is wasted at the household level, 14% - catering facilities, 39% - food producers and traders - 5% (Preparatory study…, 2010).

To be able to tackle this complex problem, it is important to know the extent of it as well as **people's motivations**, so that we could understand why some people throw away their food so easily. It is important to view food wasting in the aspect of eating habits, because according to Judith Rodriguez, the person who all her life has researched topics closely connected to nutrition and consumer sciences, and also has defended her dissertation on the topic 'Dietary Compliance Patterns of Elderly Puerto Ricans: Implications for Biomedicine', **eating habits** determine not only the food we eat, but refer to why and how people eat, what food they eat, and with whom they eat it, as well as the ways people obtain, store, use, and discard food (Rodriguez, 2011). Individual, social, cultural, religious, economic, environmental, and political factors influence people's eating habits. Thus, in this definition it is clearly stated that eating habits are the ones that affect food wasting.

Food wasting is connected not only to how/under what conditions we discard our food, but also **why we buy** certain food. In Latvia, for instance, customers often choose to buy imported products (Foreign trade of Latvia …, 2012), thus not supporting local producers. Consequenly, if this food is not consumed completely because these imported products are tasteless, low-grade goods, not only consumers, but also local manufacturers suffer.

Also, what is considered the **edible part of a product** may differ from people to people, like fish heads: in some cultures it is considered a privilege to eat this part of a fish, but in other cultures fish heads just get easily discarded. Similar situation occurs regarding meat people choose to consume. The French often eat horse meat, but the British consider eating this meat unethical. Also, the pickiness when it comes to vegetables and fruits about their shapes, colours, etc. is strongly connected to food wasting (Murcott, 1982)

Not only the ways people obtain food are important when it comes to the food wasting problem, but also how people tend to **store** their food is closely connected to how long food will stay fresh and good enough for eating (Gustavsson et al., 2011).

Even though food wasting problems are nowadays being discussed more and more by all kinds of political and public organizations, the problem is still not viewed from all aspects and viewpoints. Like sociologists see food wasting as more of an individual habit that is closely connected to acquired behavior (Bourdieu, 1984), but economics researchers view food wasting more from the cost perspective and its effect on the environment (Venkat, 2011). Unfortunately, it is not possible to reduce the money that gets wasted when people throw away food they have previously bought, or to reduce the money that is needed for recycling, if eating habits and the factors that help them to form are not discussed.

Table 1 describes how people's habits form in different levels, from micro to macro. At all levels different factors play a strong role in the habit - forming process. Like on a micro or the so called personal level, individual mentality, expectations, family, and close friends can affect one's habits of food wasting. For example, it can be considered a right action to cook more than a person can eat and then discard the leftovers, or a person might be too picky when it comes to food, and it can be encouraged by family/friends, so the food that is not too good for one mouthful can easily get discarded. (Gronow, 1997; Randall, 1999)

At meso level one's **incomes** can affect their way of shopping and food wasting, suggesting that the more people buy food the more they waste it. According to K.D. Hall et al. (2009), because of the increased food availability and marketing, and the increased supply of cheap, readily available food, Americans are not able to match their food intake. That also causes the oversupplying of food and an increase in food waste, which then has profound environmental consequences.

At meso level, **lifestyle** also affects the way how a person obtains, stores, uses, and discards food (Beardsworth and Keil, 1997). Like people, who call themselves 'Freegans' are the ones that choose to reclaim and eat food that has been already discarded. Also, at this level it is important to talk about the place of residence, because it does not only affect what food people can buy and the range of products available, but also how good the **recycling system** in that region is (Arsova, 2010), and that can also be closely connected to **local traditions (**Rodriguez, 2011).

At macro level people's choices affect such factors as, e.g. **religion** that can dictate what kind of food and food parts are suitable for meals, and in this way indirectly influence food wasting (Hubbard, 2007). **Media** has a great deal of influence on the masses; such things as asking for leftovers after a meal at a restaurant is a wasteful eating habit that can both be manipulated by the media and big corporations, some of which are often the sponsors of certain 'information' (Randall, 1999)

No matter how important the food wasting problem is, there is not that much global research conducted on this matter and even less research trying to study a situation in a definite country, searching for the causes of the problem, and offering solutions to this issue. Australia's government should be mentioned as the one that has financed such research. According to the research based on an online survey of 1,603 main grocery buyers across Australia, the extent of food waste is related to both household income and the number of household occupants, meaning that the amount of food wasted increases with household income and decreases with larger household sizes. Households with four or more occupants waste the least food per person, while people living by themselves waste the most. Single-person households waste more than other households on a per person basis; however, there is a category of household that wastes even more: households in which two unrelated people live together (Baker et al., 2009). This research, like

Table 1

Eating habits forming levels and factors that affect them

	Micro level *Symbolic Interaction Theory*	**Meso level** *Developmentalism Theory*	**Macro level** *Social conflict Theory*
Factors that influence such a behaviour	Mentality Family Friends	Culture Style of living Place of residence Incomes Traditions	Religion Mass media Country's economic situation

Source: made by the author based on works of Bourdieu (1984), Gronow (1997), Randall (1999), Ballantine and Roberts (2009).

other research that was conducted all over the world, shows that vegetables and fruits are wasted the most, but people also waste a lot of food in restaurants, not even often noticing how much food they leave on their plates after they have finished eating. They have paid for it, so they have wasted not only food, but also their own money. In restaurants people often leave their plates not completely clean, not because of the bad taste of the food, but mainly because of the portion sizes that are too large, and in some places it is not common to ask for leftovers (Your Scraps…, 2013). Meat and fish is the 3rd group of products that gets wasted. This kind of waste is closely connected to the region's culture. Thus, what people choose to eat more often, meat or fish, is wasted more than the other (Ventour, 2008) one.

The research 'A life cycle approach to the management of household food waste – A Swedish full-scale case study' similar to lots of other researches has shown that the biggest part of wasted food form vegetable food waste that also produces lots of methane during decomposition (Bernstad and Cour Jansen, 2011). An enormous increase of food waste generation affects local authorities that need to manage, treat and dispose the waste that forms. So in a way, if people themselves would do the sorting of the food waste, composting and conducting **anaerobic processes** would become easier, and thus it would help the local environment (Arsova, 2010). In order to achieve this, it is important to set 'right' moral values/ eating habits and also motivate people to do extra work and sort food that is meant for discarding.

As regards environmental concerns, they motivate people less than the opportunity to save **money**. Twice as many respondents of the Australian research replied that financial considerations would be the main reason to avoid wasting food compared to those who cited the environmental benefits. In addition to the direct financial benefits to households, reducing food waste has the capacity to deliver significant environmental benefits at no cost to the government. Food retailers represent a major barrier to implementing effective food waste policies, since their profits are contingent on the amount of food sold rather than the amount of food consumed. To overcome this, better public understanding of the problems associated with food waste needs to be treated as a priority at all levels. Without considerable policy change in this area, household waste is likely to grow as incomes rise and the number of occupants in each household shrinks (Baker et al., 2009).

Though people mostly do not deliberately waste their food, most of the respondents of the Australian research admitted that they think about how they can waste less, therefore, save more money. Like householders, who believe that buying food that will be eaten is the best way to reduce food waste, report that they usually take a list when they go shopping. However, many of these respondents also agreed that they often buy things on the spur of the moment. Householders who believe that reducing food waste is best achieved by **planning** meals around the food they already have were also likely to think about how they might incorporate leftovers into a meal. However, many of these respondents said that they often plan meals based on what they want to eat rather than around the food that they have already purchased (Baker et al., 2009). These results also correlate with results of research conducted in Romania in 2012 (268 Romanian consumers participated in the survey) and show that the intention not to waste food does not have a significant effect on reported food waste.

Rather, planning and **shopping routines** explain most of the variance in food waste, with the latter having the largest influence. Planning routines have a negative effect on food waste, while shopping routines are positively associated with food waste. Moral attitudes and lack of concern exert a significant positive and negative impact on the intention not to waste food, respectively. In terms of relative importance, moral attitudes are the most important in explaining individuals' intentions (Stefan et al., 2012).

Overall, the pattern 'perceived behavioural control – shopping routines' has the greatest relative importance in explaining reported food waste (Stefan et al., 2012). In most cases people waste food that is still good for consumption because of the misleading labelling and unsuitable packaging. The packaging is important, because it helps to store food for a longer time, and also makes food more likeable for the costumers. However, food can also get easily spoiled if the wrong kind of package is used or the quality of the packaging is low. Dried food, for example, can be safely packaged in recycled cardboard containers because there is no medium for the transfer of potential contamination to the product (Nerlita, 2011). Such materials could be used to increase the supply of packaging materials and reduce food losses.

Sometimes **packaging** is not the problem: buying food that is not suitable for consumption can occur because retailers offer food too close to its expiry date, thus increasing the potential for wastage. That is why the European Parliament came up with the idea of dual-date labelling that could be introduced to show until when food may be sold (sell-by date) and until when it should be consumed (use-by date) (Parliament calls…, 2012).

It is also important to explain the difference between 'best before' and the safety-related 'use by' dates to customers. Date marks give a guide to how long food can be kept before it begins to deteriorate or may become unsafe to eat and that would help to

reduce food wasting. Foods that must be eaten before a certain time for health or safety reasons should be marked with a use by date. Foods should not be eaten after the use by date and cannot legally be sold after this date because it may pose a health or safety risk. Most foods have a best before date, and it is still possible to eat this food for a while after the best before date as they should be safe, only they may have lost some quality (Ventour, 2008).

A lot of food gets wasted, because people do not really **plan** what they are going to eat. That is why food is being bought and then never used, or so many products are being bought, that it is not possible to eat them completely, before the possible period of use for these products expires. In lots of cases, people prefer to buy food that can be stored for a long time as this kind of food is much cheaper. Also, because of the great amount of food that is bought, people are not always able to use the products in time before expiration (Gunders, 2012).

Conclusions

1. Even though the food waste problem is being discussed on very different political levels, there is no systematic review of scientific debates about food waste – that is why politicians in lots of countries do not have scientifically based research materials, which would help them to make informed decisions and take action to reduce food wastage.
2. Food waste is a complex problem, because the food waste concept is not so strictly defined, and it varies from research to research. Also, the classification itself can be specific to certain regions, cultures and eating habits, but eating habits can be influenced by individual, social, cultural, religious, economic, environmental, and political factors. That is why it is important to view food wasting problem from perspectives of different disciplines.
3. Each year the prices of food products gradually increase, and it is believed that to decrease food prices, the food production increase must be managed, but it is not borne in mind that lots of food products are already simply discarded, and that the possible food production increment can only increase wasted food amounts and have an even stronger negative influence on environment. Unfortunately environmental concerns motivate people less, when it comes to decreasing food wastage, than the opportunity to save money.

References

1. Arsova L. (2010) *Anaerobic digestion of food waste: Current status, problems and an alternative product*, Columbia University, New York City, USA, 77 p.
2. Baker D., Fear J., Denniss R. (2009) What a waste. An analysis of household expenditure on food. *Policy Brief,* 6, pp. 25.
3. Ballantine J., Roberts K. (2009) *Our social world: Introduction to Sociology*. 2nd edition, Pine forge press, California, USA, 680 p.
4. Barthes R. (1979) Toward a Psychosociology of Contemporary Food Consumption. Available at: http://annhetzelgunkel.com/uj/food/image/Psychosociology%20of%20Contempo%20Food%20Consumption%20-%20Barthes.pdf, 12 February 2013.
5. Beardsworth A., Keil T. (1997) *Sociology on the menu: an invitation to the study of food and society*. Routledge. London, UK, 277 p.
6. Bernstad A., Cour Jansen J. (2011) A life cycle approach to the management of household food waste – A Swedish full-scale case study. *Waste Management*, 31, pp. 1879-1896.
7. Bourdieu P. (1984) *Distinction: a Social Critique of the Judgement of Taste*, Harvard University Press, UK, 613 p.
8. Bourdieu P. (1984) *Distinction: a social critique of the judgement of taste*, Harvard University Press, Massachusetts, USA, 613 p.
9. Food waste: Princeton University Dictionary. (2006) Available at: http://dictionary.reference.com/browse/food+waste, 19 September 2012.
10. Foreign trade of Latvia in April (2012) Latvijas Statistika. Available at: http://www.csb.gov.lv/en/notikumi/foreign-trade-latvia-april-2012-33391.html, 12 February 2013.
11. Gronow J. (1997) *The Sociology of Taste*. Routledge, UK, 199 p.
12. Gunders D. (2012) *Wasted: How America Is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill*, NRDC: Natural Resources Defense Council, New York City, USA, 26 p.
13. Gustavsson J., Cederberg C., Otterdijk R., Alexandre Meybeck A. (2011) *Global food losses and food waste*. Study conducted for the International Congress. FAO: Food and Agriculture Organization of the United Nations, Rome, Italy, 38 p.

14. Hall K.D., Guo J., Dore M., Chow C.C. (2009) The Progressive Increase of Food Waste in America and Its Environmental Impact. Available at: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0007940, 20 February 2013.
15. *Household Food and Drink Waste in the UK* (2009) Waste and Resources Action Programme, WRAP, Banbury, UK, 95 p.
16. How to Feed the World in 2050 (2009) FAO: Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf, 14 February 2013.
17. Hubbard R. (2007) *Food, Culture and Identity,* University of Missouri, Columbia, USA, 14 p.
18. Jones T. (2004) Using Contemporary Archaeology and Applied Anthropology to Understand Food Loss in the American Food System. Available at: http://www.ce.cmu.edu/~gdrg/readings/2006/12/19/Jones_UsingContemporaryArchaeologyAndAppliedAnthropologyToUnderstandFoodLossInAmericanFoodSystem.pdf, 20 February 2013.
19. Langley J., Yoxall A., Heppell G., Rodriguez E.M., Bradbury S., Lewis R., Luxmoore J., Hodzic A., Rowson J. (2010) Food for thought? – A UK pilot study testing a methodology for compositional domestic food waste analysis. *Waste Management and Research,* 28, pp. 220-227.
20. Murcott A. (1982) Symposium on food habits and culture in the UK. Available at: http://journals.cambridge.org/download.php?file=%2FPNS%2FPNS41_02%2FS0029665182000342a.pdf&code=d0e1cfbb695697c279829c68c457666d, 09 February 2013.
21. Nerlita M. (2011) Appropriate food packaging solutions for developing countries. Study conducted for the International Congress. Germany. Available at: http://www.fao.org/docrep/015/mb061e/mb061e00.pdf, 12 February 2013.
22. Parliament calls for urgent measures to halve food wastage in the EU (2012) European Union Parliament Plenary Session 19-01-2012 Avalaible at: http://www.europarl.europa.eu/news/en/pressroom/content/20120118IPR35648/html/Parliament-calls-for-urgent-measures-to-halve-food-wastage-in-the-EU, 15 February 2013.
23. Preparatory study on food waste across EU 27. (2010) Technical Report - 2010 – 054. European Commission (DG ENV) Executive Summar. Bio Intelligence Service, Available at: http://ec.europa.eu/environment/eussd/pdf/bio_foodwaste_report.pdf, 21 February 2013.
24. Randall S. (1999) Television Representations of Food: a case study of Rick Stein's 'Taste of the Sea' *International Journal of Tourism and Hospitality Research: The Surrey Quarterly*, 1, pp. 41-55.
25. Rodriguez J. (2011) Eating Habits. Available at: http://www.faqs.org/nutrition/Diab-Em/Eating-Habits.html, 18 February 2013.
26. Schneider F. (2008) Wasting food – An insistent behavior. Available at: http://www.ifr.ac.uk/waste/Reports/Wasting%20Food%20-%20An%20Insistent.pdf, 05 February 2013.
27. Stefan V., Herpen E., Tudoran A.A., Lähteenmäki L. (2012) Avoiding food waste by Romanian consumers: The importance of planning and shopping routines*. Food Quality and Preference*, 2013-28, pp. 375-381.
28. *The Millennium Development Goals report* (2012) United Nations, UN, New York, USA, 72 p.
29. Venkat K. (2011) The Climate Change and Economic Impacts of Food Waste in the United States. *Journal on Food System Dynamics*, 4, pp. 431-446.
30. Ventour L. (2008) *The food we waste,* Waste and Resources Action Programme, WRAP, London, UK, 237 p.
31. Your Scraps Add Up: Reducing food waste can save money and resources. (2013) Natural Resources Defense Council, NRDC. Available at: http://www.nrdc.org/living/eatingwell/files/foodwaste_2pgr.pdf, 07 March 2013.

CAREER-RELATED POSSIBLE SELVES OF RURAL ADOLESCENTS

Janis Pavulens
Latvia University of Agriculture
pavulens@inbox.lv

Abstract

The first independent career related decisions are made during the ninth grade of the elementary school when the further educational institution is selected. The concept of possible selves can be used in career education to help students increase self-awareness, explore and generate options, and formulate plans to achieve future goals. The aim of the article is to examine rural adolescents' ability to generate career-related possible selves and plausible strategies to attain these possible selves. On the basis of the Possible Selves Theory, the open-ended measure was developed by the author. The pilot research was carried out in Latvia in January 2013. Forty six nine-graders from two rural elementary schools and two rural secondary schools participated in the research. Next year and adult possible selves generated by rural adolescents include such domains as education, employment, leisure activities, physical and personal development, as well as interpersonal relationships and lifestyle. The most important ones are domains of education and employment. Statistically significant differences of the results among the gender subgroups are not found in the research, statistically significant differences exist between the possible selves and their attaining strategies generated by rural secondary school students and rural elementary school students.
Key words: expected possible selves, feared possible selves, adolescence, career, career management.

Introduction

Employment and business in knowledge society is featured by relatively often changes in an individual's career and by a possibility to receive life-long career guidance, by a simplified access to career guidance support services by all people, and by promotion of career management skills throughout a life time (Sultana, 2012). During a certain individual's development stage, promotion of career management skills is a task to be carried out by the school which is an institution of formal education. According to the liberally rational educational paradigm, education is a tool to ensure community development and its sustainability, as well as a guarantee of competitiveness and welfare for society as a whole and for each individual separately. Support for labour market liberalization is one of the fundamental tasks of education; therefore, much attention is being paid to vocational and career education (Katane, 2007). According to the ecological approach (which is a post-modern constructionist approach in its core), the main task of education is to promote development of the skills which help to live in a changeable environment, to further responsible and independent individuals who are able to assess situations and make proper decisions, study independently and improve themselves, their development (Briede and Pēks, 2011).

Current understanding of career education (Karjeras izglītība ..., 2009) has limitations and does not sufficiently provide an active, constructive student's cooperation in improvement of his/her career management skills.

In the author's opinion the Possible Selves Theory is one of the possible theoretical concepts based on which it would be possible to develop a career education model according to the principles of constructivism, where active student's cooperation is included in developing his/her career management competences.

Possible selves (PS) are the future-oriented hypothetical images of oneself one would like to attain or of oneself one would like to avoid, which are generated within individual's life context (Markus and Nurius, 1986; Oyserman et al., 2002). It is believed that in rural community adolescents develop in restricted, poorer environment which does not offer possibility to try and master several role models related to education and employment; therefore, construction and maintenance of future selves in those domains are more complex and harder for rural adolescents (Shepard, 2003).

Unfortunately, there is no research carried out in any population group in cultural environment of Latvia. To find out the most characteristic peculiarities how the rural nine-graders generate PS, a pilot research described in this article was carried out in two rural elementary schools and two rural secondary schools in January 2013.

The aim of the article is to examine rural adolescents' ability to generate career-related possible selves and plausible strategies to attain these possible selves.

Materials and Methods

The research of career-related PS of rural adolescents is based on the principles of liberally rational educational paradigm. The theoretical part of the research consists of the study and theoretical analysis of the scientific and methodological literature

on career development, career management and concept of possible selves. The empirical part deals with the answers to the following questions: 1. What are the most important domains in which rural adolescents generate next year and adult possible selves (PS)? 2. What is the proportion of rural adolescents' career-related PS among other PS? 3. What is the balance of rural adolescents' PS within various domains? 4. What strategies do rural adolescents consider as the most important ones to attain their expected PS and avoid their feared PS? 5. Are there any statistically significant differences in generating PS between different genders and among adolescents studying in different types of educational institutions?

To carry out the empirical part of the research, a questionnaire was designed based on the Possible Selves Questionnaire developed by D. Oyserman (Oyserman et al., 2004; Oyserman, 2004), the open-ended measure, which is 'more preferable if possible selves of participants must be found out' (Oyserman and Fryberg, 2006; Lee and Oyserman, 2009).

The empiric part of the research was carried out in 4 rural general education schools: in 2 secondary schools and 2 elementary schools. Fifty five nine-graders were asked to participate in the research. Nine questionnaires (16% of the total number of questionnaires) were excluded from the further processing, as no possible selves were specified written there. Research sample consists of 46 nine-graders, 20 girls (43% of respondents) and 26 boys (57% of respondents). The respondents are between ages 14 and 17 (Mean (M) = 15.39, Standard Deviation (SD) = 0.71). 8 girls and 9 boys are rural elementary school students (37% of respondents), 12 girls and 17 boys are rural secondary school students (63% of respondents). Distribution differences of gender subgroups within the school types are not statistically significant ($\chi^2 = 0.14$; $p = 0.71$).

Adolescents were asked to generate 4 expectations and 4 concerns for the coming year, and describe any strategies they had for working toward their expected and away from their feared or to-be-avoided next year PS, as well as to generate 4 expectations and 4 concerns for the year 2018, and describe any strategies they had for working toward their expected and away from their feared or to-be-avoided adult (year 2018th) PS. To clarify adolescents' PS, respondents were encouraged to think about the next year, imagine what they will be like, and what they will be doing next year, as well as to think about ways they would not like to be next year, about things they are concerned about or want to avoid being like and write their expectations or concerns. To establish existing strategies used by adolescents, they were asked to write what they have been doing this year to attain their goals and what they did this year to reduce the chances that this would describe them next year for each expected goal and each concern. Similar procedures for expectations and concerns, as well as strategies for the year 2018 were provided.

Responses were content-coded, expected and feared PS were categorized into one of nine domains: education (including all activities related to learning and training, their processes and results, including studies to obtain professional education (art, music and sports schools) and independent improvement of skills, as well as status and roles related to studies), employment (all activities, status and roles related to paid employment, self-employment, and business), physical/health related (general body descriptive responses, as well as health description), interpersonal relationships (family, friends, relationships, and social interactions), leisure activities (all activities not included into the education and employment categories, social duties), lifestyle/material (material possessions and living situation, including moving and independency/dependency) (for expected and feared selves) or non-normative/risky behaviour and external harm/victimization (for feared selves only). Any strategies for attaining expected PS or avoiding from feared PS were categorized into one of six domains: learning (purposeful development of one's own knowledge, skills, and abilities, competences within the framework of formal, non-formal and informal education), compliance with the rules, leisure activities, interpersonal relationships, self-management, search for support and information.

The coding system was based on findings obtained by B. Shepard, A. Marshall, D. Oyserman, H. Markus, P. Unemori, H. Omoregie, M. Knox, J. Funk, R. Elliott, and E.G. Bush (Oyserman and Markus, 1990a, 1990b; Shepard and Marshall, 1999; Knox et al., 2000; Shepard, 2003; Oyserman, 2004; Unemori et al., 2004). Data coding was carried out by an independent career counsellor not involved in and not informed about the research.

MS Excel and SPSS 16.0 have been used to process the research data. To find out proportion of career-related PS in each PS group, relative frequencies of each expected and feared PS category were calculated in each PS group, e.g., as for the next year expected PS, the number of possible selves in a given category was divided by the total number of the next year expected PS generated by a participant (Shepard, 2003). The analogous procedures were followed for calculating relative frequencies for the next year feared PS, adult expected PS and adult feared PS. Likewise calculation of relative frequencies of the strategies was carried out in each PS group. The descriptive statistics indicators (Mean, Standard Deviation) were calculated. The non-parametric criterion – Kolmogorov-Smirnov Z was calculated testing for normality of the distribution,

the non-parametric criteria – Mann-Whitney U and Chi-squares were calculated analysing differences of distribution among the subgroups.

Results and Discussion

While carrying out the study and theoretical analysis of the scientific and methodological literature on career development and career management, it was found out that a term 'career' in the XXI century is defined as 'the sequence and variety of paid and unpaid work roles a person undertakes throughout a lifetime' (Career Education ..., 2009), 'the evolving sequence of person's work experiences over time' (Arthur et al., 1989), 'the sequence of employment-related positions, roles, activities and experiences encountered by a person' (Arnold and Silvester, 2005). It is believed that 'career embraces life roles in the community and home, leisure activities, learning and work, and that everyone has a career' (Career Education ..., 2009).

Career development is a lifelong process 'of managing learning, work, and transitions in order to move toward a personally determined and evolving preferred future' (Hiebert, 2006), 'of skills acquisition and building through a continuum of learning, development and mastery'. Career development enables people to be in charge of their own career (Jarvis, 2003). Researchers point out that career development may be both intentional and also unintentional. Intentional career development is 'about actively creating the life one wants to live, while unintentional career development occurs anyway, because none of individuals can avoid learning, experiencing, living, working and changing' (Haché et al., 2006).

The main condition of purposeful, intentional career development is developed career management competencies, 'the understandings, skills and attitudes that people use to develop and manage their career, to understand themselves better, make informed decisions about learning and work options, act on their decisions and participate effectively at work and in society' (Career Education ..., 2009).

Career management is described as a process by which individuals develop, implement, and monitor career goals and strategies; career management is an individual - not an organizational - activity. It is a process in which 'an individual creates an accurate picture of his or her talents, interests, values and preferred lifestyle, as well as alternative occupations, jobs and organizations and develops realistic career goals based on this information; develops and implements strategies designed to achieve goals, as well as obtains feedback on the effectiveness of the strategy and the relevance of the goals' (Greenhaus et al., 2009).

During changeable circumstances people initiate changes in their lives or adjust themselves to rapid environmental changes by setting and designing goals and directions of changes according to their 'conceptions of self in future' (Cornford, 1995); career development requires not only regular reflection on the self and the environment and receptivity to feedback, but also the imagination of possible selves, ensuring career (and life as a whole) designing motivation (Savickas et al., 2009).

Possible selves (PS) are the future-oriented component of self-concept, 'the hypothetical images of the self one would like to attain or of the self one would like to avoid' (Oyserman et al., 2002) 'constructed by individual, derived from representations of the self in the past, they include representations of the self in the future' (Markus and Nurius, 1986). Individuals construct PS by synthesizing what they know about their traits and abilities and what they know about the skills needed to become various future selves (Oyserman et al., 2002). Possible selves 'can function as a set of goals that motivate future behaviour and provide means of understanding current experiences' (Shepard, 2004). PS include images, values, emotions and goals, as well as 'strategies to attain these possible selves' (Plimmer, 2012).

The construction of possible selves entails the recruitment of imaginative capacity and self-reflection of the individual to create a set of hoped-for, expected, and feared future selves. A hoped-for self is defined as an aspired self that one desires to become which may or may not be realistic. An expected self is a self that one believes one can realistically become. If a possible self is viewed as reachable, specific action strategies become attached to that self. A feared self is a possible self that one does not want to become, yet fears becoming. The feared self acts as a motivator so that concrete actions (strategies) are taken to avoid that future possible self (Shepard and Marshall, 1999).

PS have maximum motivating efficiency if they are balanced with contrary PS in the same domain. Unbalanced hoped-for and feared PS reduce potentially positive influence of feared PS to the individual's behaviour expressed in his/her efforts to avoid feared conditions. In this case the individual has a view about the situation which he/she does not want to experience; however, he/she does not have a view about the preferable direction. Existence of several hoped-for or expected PS without feared PS, in its turn, generates threats of superficial approach regarding their implementation; adequately feared PS ensure persistence desired for PS implementation (Oyserman and Markus, 1990a).

Career development evolves according to changes in individual's identity and self-conception, i.e., according to development (creating, testing, discarding

and revising) of new provisional selves (Ibarra, 1999). Provisional selves are generated based on observations of careers and lifestyles of other people, and they are tested to find out their compliance with individual values, competences, demands and style. Individuals identify prototypes of what constitutes desirable performance and harmonize further on their identity with those prototypes, creating the personalized range of possible roles and selves (Plimmer and Schmidt, 2007).

Formation of such provisional selves takes place especially actively during adolescence. An adolescent is any person between ages 10 and 19; adolescence is a period of life during which independence and dependence exist at the same time. The main peculiarities of the period of adolescence are as follows: preparation for life in future, setting of personal goals and selection of educational and employment direction. Active cooperation while transition to the adult life, awareness of and preparation for possible future are expected from adolescents in post-modern society. Orientation towards the future, including a view of possible future, insight on one's own life in it, goals, plans and assessment of possible (anticipated) results are considered as an important development task during adolescence (Laihiala-Kankainen et al., 2010).

According to findings by J. Piaget, at the stage of a certain operation child's thinking is still restricted by the given information, however, during the stage of formal operations (starting from the age of 11-12 years) adolescent's thinking may go beyond previously given information (Gudjons, 2007), adolescents may start grasping abstract and possible issues, recognizing themselves as a 'contemplative, self-determining, relational and continuous being', which is able not only to remember the past and be aware of the presence, but also 'to imagine their future, their possible selves' (Shepard, 2003), a focus on the future is intrinsic to the social role of adolescence (Oyserman et al., 2004). Adolescents' ability to think hypothetically enables them to visualise possible future, to connect present events with possibilities in future (Oyserman et al., 2002). This is a stage when 'individuals attempt to understand themselves and find their place in the job market, as well as through classes, work experience, and hobbies try to identify their interests and capabilities and figure out how they fit in with various occupations' (Šverko, 2006).

An adolescent generates his/her prospective life course within a certain social environment, therefore, success of generating depends on both adolescent's freedom of choice and creativity in making his/her prospective life course and also on support provided by those around them (Laihiala-Kankainen et al., 2010). Adolescents are ready and they wish to receive feedback from their peers, the media, parents, and other adults, as they actively look for confirmation in responses to their behaviour and actions from those around them during social interaction regarding vital capacity of their prospective life course. They compare their behaviour with role models available in society (Oyserman et al., 2004).

Social environment provides a context in which adolescents receive feedback on the self qualities considered as valuable, significant, and necessary. It is believed that comparing to the city environment, development of adolescents in rural communities takes place in restricted, poorer context, which does not offer several role models related to education and employment for trying and mastering, therefore, construction and maintenance of future selves in those domains are more complex and harder for rural adolescents (Shepard, 2003).

Previous researches (e.g., Shepard, 2003) confirm that during the period of adolescence while generating PS the most important are educational, occupational, and familial domains. During the times of educational transition young people are more likely to be thinking about the educational and occupational challenges.

It was found out in the empirical part of the research that the total PS number generated by each adolescent was within the range of 1 to 16 (maximum possible number of PS) ($M = 12$, $SD = 3.98$), frequency distribution did not significantly differ from the normal distribution (Kolmogorov-Smirnov $Z = 1.33$; $p = 0.06$). Ten adolescents (22% of respondents) made 16 PS, the maximum possible number of PS. Distribution differences of the generated PS were not statistically significant among the gender subgroups (Mann-Whitney $U = 236.0$; $p = 0.59$), distribution differences among the elementary school students and secondary school students also were not statistically significant (Mann-Whitney $U = 209.5$; $p = 0.40$).

Distribution of the generated PS number within PS groups (next year expected selves, next year feared selves, adult expected selves, adult feared selves) statistically significantly differed from the normal distribution (all calculated Kolmogorov-Smirnov $Z > 1.49$; $p < 0.02$). When comparing distribution by means of the Mann-Whitney criterion, it was found that distribution differences of the generated PS number among the genders in the PS groups (all calculated Mann-Whitney $U > 210.0$, all calculated $p > 0.22$) and among the school subgroups (all calculated Mann-Whitney $U > 195.5$, all calculated $p > 0.21$) were not statistically significant.

When comparing distribution of the number of generated next year expected selves and next year feared selves ($\chi^2 = 3.45$; $p = 0.48$), as well as of the

number of adult expected PS and adult feared PS ($\chi^2 = 1.31$; $p = 0.86$), it was found out that distribution differences were not statistically significant.

The most frequently mentioned PS domains were education and employment. Within the next year expected PS group the most frequently mentioned categories were education, interpersonal and leisure activities, within the next year feared PS group the most frequently mentioned categories were education and non-normative (risky) behaviour. Within the adult expected PS group the most frequently mentioned categories were employment and education, and within the adult feared PS group employment and non-normative (risky) behaviour prevailed (Table 1).

A possible balanced PS number was stated for each respondent and a balanced PS proportion was calculated within the next year PS and adult PS groups. Proportion distribution complied with the normal distribution, next year PS Kolmogorov-Smirnov $Z = 1.09$, $p = 0.19$, adult PS Kolmogorov-Smirnov $Z = 1.00$, $p = 0.27$. Balanced PS proportion was 38% in the next year PS group, it was 43% in the adult PS group, proportion differences among the gender and the school type subgroups were not statistically significant (all calculated Mann-Whitney $U > 134.5$, all calculated $p > 0.09$).

At least one balanced PS pair was generated in the next year PS group by 65% of respondents (in the adult PS group by 70% of respondents). Distribution differences of the balanced PS among the gender and the school type subgroups were not statistically significant. Statistically significant differences ($\chi^2 = 10.30$; $p = 0.01$) were found when comparing next year PS generated by the secondary school students and those generated by the elementary school students. 24% of elementary school students and 41% of secondary school students had not generated any balanced next year PS pairs, 76% of elementary school students and 31% of secondary school students had generated one balanced next year PS pair, 8 (28%) secondary school students generated two balanced next year PS pairs.

The nine tenth (89%) of balanced next year PS were generated within the education domain, 3% were related to employment, 3% were related to personality traits, and 5% were related to interpersonal relationships; in the adult PS group, in its turn, 30% were related to education, 50% were related to employment, 12% were related to interpersonal relationships, and 8% were related to lifestyle.

Distribution of the number of strategies necessary to achieve PS within the selection did not statistically significantly differ from the normal distribution (Kolmogorov-Smirnov $Z = 0.68$; $p = 0.74$), each adolescent had generated from 1 to 16 strategies ($M = 7.28$, $SD = 3.62$). Proportion of the generated strategies in each PS group varied, proper strategies in the next year expected PS group were generated for 89% of PS, in the next year feared PS group - for 66% of PS, in the adult expected PS group - for 52% of PS, in the adult feared PS group - for 43% of PS.

Differences in the number of strategies generated in each PS group were not statistically significant among the subgroups of respondents' gender (all calculated Mann-Whitney $U > 171.5$; all calculated $p > 0.20$).

It was found out that there were statistically significant differences among the school subgroups in terms of the number of generated strategies both in the adult feared PS group (Mann-Whitney $U = 126.0$; $p = 0.03$) and in the total number of strategies (Mann-Whitney $U = 150.0$; $p = 0.03$). Elementary school

Table 1

Relative Frequencies of Possible selves

Category	PS groups			
	Next year		Adult	
	expected possible selves	feared possible selves	expected possible selves	feared possible selves
Education	0.56	0.33	0.29	0.12
Employment	0.07	0.08	0.42	0.30
Interpersonal Relationships	0.12	0.09	0.10	0.12
Physical/Health-Related	0.02	0.10	0.05	0.06
Leisure Activities	0.18	0.00	0.04	0.01
Personality Traits	0.03	0.10	0.02	0.05
Lifestyle/ Material	0.02	0.09	0.08	0.15
Non-normative/ Risky Behaviour	-	0.11	-	0.16
External Harm / Victimization	-	0.10	-	0.03

Table 2

Relative Frequencies of Strategies in PS groups

Category	PS groups			
	Next year		Adult	
	expected possible selves	feared possible selves	expected possible selves	feared possible selves
Learning	0.60	0.41	0.73	0.40
Compliance with the rules	0.02	0.16	0.02	0.15
Leisure activities	0.20	0.00	0.03	0.02
Interpersonal relationships	0.09	0.11	0.06	0.05
Self-management	0.05	0.27	0.11	0.24
Search for support and information	0.05	0.05	0.05	0.13

students generated strategies only for 27% of PS in the adult feared PS group (students of the secondary schools – for 54% of PS). Comparing the number of all generated strategies, it was found out that secondary school students had generated strategies for 69% of PS, but elementary school students – for 54% of PS.

The most frequently mentioned strategies were learning and self-management. The most frequently mentioned strategies in the next year expected PS group were learning and involving in leisure activities, the most frequently mentioned strategies in the next year feared PS group were learning, compliance with the rules and self-management. The most frequently mentioned strategies in the adult expected PS group were learning and self-management. Strategies dominating in the adult feared PS group were as follows: learning, self-management, compliance with rules, and searching for support and information (Table 2).

Assessing correlation between the generated strategies and PS, it was found out that according to respondents, the most important strategy in the education PS domain was learning (a strategy of this category was mentioned in 86% of responses to achieve the expected PS, or to avoid feared PS regarding education). Less important were the following strategies: compliance with the rules (5%), self-management (5%), and search for support and information (4%). Learning was the most important strategy also in employment domain (67%), while less important were such categories as self-management (13%) and searching for support and information (15%).

Career-related adult expected PS included a desire to have a good job, also including satisfaction with the chosen profession, proper choice of profession (20% of respondents, 16% of the total number of all adult expected PS). Thirty five adult expected PS of the rural nine-graders included a job in a particular profession. The profession mentioned most often was a motor mechanic (it was mentioned 5 times, i.e., almost 20% of male respondents had referred to such a possibility in their adult expected PS), adult expected PS of the girls included jobs in such professions as hospitality specialists (it was mentioned 4 times, it was also approximately 20% of the total number of female respondents) and cooks (it was mentioned 3 times, 15% of the total number of female respondents). A soldier was mentioned three times in the questionnaires, a forester, a worker and a police officer, as well as entrepreneurship were mentioned twice. Such professions as a driver, a frontier guard, an architect, a programmer, an electrician, a mechanic, a manager of a farm, and a supervising engineer (for boys), as well as a shop-assistant, lawyer, and a hairdresser (for girls) were mentioned once in the questionnaires.

Adult feared PS included wrong profession choice, having undesired job due to force majeure (3 responses), janitor's job (2 responses), as well as a status of an unemployed person (23 responses, 50% of respondents, 67% of adult PS).

Conclusions

1. Rural adolescents' next year and adult (after five years) PS include such domains as education, employment, leisure activities, physical and personal development, as well as interpersonal relationships and lifestyle. The highest balanced proportion of PS is found in the domain of education and employment. Proportion of career-related PS depends on how distant future PS are generated for; expectations and concerns related to education prevail in PS of the nearest future; employment is important for adult PS; high importance of education remains.
2. Rural adolescents view learning as the most important strategy both for achieving expected

PS and for avoiding feared PS; leisure activities relatively often are used to achieve next year PS. Self-management and compliance with the rules are considered as important strategies that help avoiding feared PS.

3. Statistically significant differences are not found among the subgroups of respondents' gender regarding PS and strategies for their achieving/avoidance. Statistically significant differences were expressed twice less in the number of generated strategies among rural elementary school students the and strategies generated by the nine-graders of rural elementary schools, and those generated by rural secondary school students regarding avoidance of adult feared PS.

References

1. Arnold J., Silvester J. (2005) Work psychology: understanding human behaviour in the workplace. Pearson Education, Harlow, England, 718 p.
2. Arthur M.B., Hall D.T., Lawrence B.S. (1989) Handbook of Career Theory. Cambridge University Press, Cambridge, USA, 572 p.
3. Briede B., Pēks L. (2011) Ekoloģiskā pieeja izglītībā (Ecologic Approach to Education). Latvijas Lauksaimniecības universitāte, Izglītības un mājsaimniecības institūts, Jelgava, 160 lpp. (in Latvian).
4. Career Education and Guidance in New Zealand Schools (2009) Ministry of Education, Wellington, New Zealand. Available at: http://nzcurriculum.tki.org.nz/Curriculum-resources/Career-education, 7 February 2013.
5. Cornford I. (1995) Career counseling, possible selves and changing occupational skill requirements. *Australian Journal of Career Development*, Vol. 4, pp. 40-42.
6. Greenhaus J.H., Callanan G.A., Godshalk V.M. (2009) Career Management, Fourth Edition, SAGE Publications, Thousand Oaks, California, USA, 512 p.
7. Gudjons H. (2007) Pedagoģijas pamatatziņas (Basic Points of Pedagogy). Zvaigzne ABC, Rīga, 394 lpp. (in Latvian).
8. Haché L., Redekopp D.E., Jarvis P.S. (2006) Blueprint for Life/Work Designs. Available at: http://206.191.51.163/blueprint/documents/BPFULLEDITION.doc, 15 February 2013.
9. Hiebert B. (2006) Career Counselling Competencies. In: Greenhaus J.H., Callanan G.A. (eds). Encyclopedia of Career Development, SAGE Publications, Thousand Oaks, California, USA, pp. 92-94.
10. Ibarra H. (1999) Provisional Selves: Experimenting with Image and Identity in Professional Adaptation, Administrative Science Quarterly, Vol. 44, pp. 764-791.
11. Jarvis P.S. (2003) Career Management Paradigm Shift. Available at: http://www.lifework.ca/lifework/Media/lifework%20PDF/Prosperity2003.pdf, 15 February 2013.
12. Karjeras izglītība skolā (Career Education at School) (2009) Valsts izglītības attīstības aģentūra, Rīga, 212 lpp. (in Latvian).
13. Katane I. (2007) Paradigmas Latvijas izglītības vidē mūsdienās (Contemporary Paradigms in Educational Environment of Latvia). Latvijas Lauksaimniecības universitāte, Jelgava, 117 lpp. (in Latvian).
14. Knox M., Funk J., Elliott R., Bush E.G. (2000) Gender Differences in Adolescents' Possible Selves. Youth Society, Vol. 31, pp. 287-309.
15. Laihiala-Kankainen S., Kala-Arvisto U., Kraav I., Raschetina S. (2010) Ninth graders' values, goals and views about learning and school. A comparative analysis in three countries: Finland, Russia, Estonia, Finnish Educational Research Association, Jyväskylä, Finlandia, 215 p.
16. Lee S.J., Oyserman D. (2009) Possible Selves Theory. In: Anderman E., Anderman L. (eds). Psychology of Classroom Learning: An Encyclopedia, Macmillan Reference, Michigan, Detroit, USA, 412 p.
17. Markus H., Nurius P. (1986) Possible Selves. American Psychologist, Vol. 41, pp. 954-969.
18. Mirvis P.H., Hall D.T. (1994) Psychological Success and the Boundaryless Career. *Journal of Organizational Behaviour*, Vol. 15, pp. 365-380.
19. Oyserman D. (2004) Possible selves citations, measure, and coding instructions. Available at: http://www.sitemaker.umich.edu/culture.self/files/possible_selves_measure.doc, 15 February 2013.
20. Oyserman D., Bybee D., Terry K., Hart-Johnson T. (2004) Possible selves as roadmaps. *Journal of Research in Personality*, Vol. 38, pp. 130-149.
21. Oyserman D., Fryberg S. (2006) The possible selves of diverse adolescents: Content and function across gender, race and national origin. In: Dunkel C., Kerpelman J. (eds). Possible Selves: Theory, Research, and Application, Nova, Huntington, New York, USA, pp. 17-39.
22. Oyserman D., Markus H.R. (1990a) Possible Selves and Delinquency. *Journal of Personality and Social Psychology*, Vol. 59, pp. 112-125.

23. Oyserman D., Markus H.R. (1990b) Possible Selves in Balance: Implications for Delinquency. *Journal of Social Issues*, Vol. 46, pp. 141-157.
24. Oyserman D., Terry K., Bybee D. (2002) A possible selves intervention to enhance school involvement. *Journal of Adolescence*, Vol. 25, pp. 313-326.
25. Plimmer G. (2012) Adult Career Counseling Using Possible Selves-A Quasi-Experimental Field Study in Naturalistic Settings. *Journal of Career Assessment*, Vol. 20, pp. 53-70.
26. Plimmer G., Schmidt A. (2007) Possible Selves and Career Transition: It's Who You Want to Be, Not What You Want to Do. New Directions For Adult And Continuing Education, No. 114, Summer 2007 Wiley Periodicals, Inc., pp. 61-74.
27. Savickas M.L., Nota L., Rossier J., Dauwalder J-P., Duarte M.E., Guichard J., Soresi S., van Esbroeck R., van Vianen A.E.M. (2009) Life designing: A paradigm for career construction in the 21st century. *Journal of Vocational Behavior*, Vol. 75, pp. 239-250.
28. Shepard B. (2003) Creating Selves in a Rural Community. In: Roth W.-M. (ed) Connections'03. Proceedings of the University of Victoria Faculty of Education Research Conference. University of Victoria, Victoria, BC, pp. 111-120.
29. Shepard B. (2004) In Search of Self: A Qualitative Study of the Life-Career Development of Rural Young Women. *Canadian Journal of Counselling* / Revue canadienne de counseling, Vol. 38, pp. 75-90.
30. Shepard B., Marshall A. (1999) Possible Selves Mapping: Life-Career Exploration With Young Adolescents. Canadian Journal of Counselling / Revue canadienne de counseling, Vol. 33, pp. 37-54.
31. Sultana R. (2012) Learning career management skills in Europe: a critical review. *Journal of Education and Work*, Vol. 25, pp. 225-248.
32. Šverko B. (2006) Super's Career Development Theory. In: Greenhaus J.H., Callanan G.A. (eds) Encyclopedia of Career Development. SAGE Publications, Thousand Oaks, California, USA, pp. 789-792.
33. Unemori P., Omoregie H., Markus H.R. (2004) Self-Portraits: Possible Selves in European-American, Chilean, Japanese and Japanese-American Cultural Contexts. Self and Identity, Vol. 3, pp. 321-338.

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