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FOREWORD

It was a great honour for Latvia University of Life Sciences and Technologies to welcome you all to the conference that is so important in general and for me personally. If I could say it this way - the child was born 25 years ago and I was very close to this event in May, 1995. During its childhood the conference changed names each year. In 2000 among the participants of conference named 'Science – Latvia – Europe', first time were quests from other countries.
But from 2001 it became traditional 'RESEARCH FOR RURAL DEVELOPMENT'. The history of the conference states that there are 2141 presentations in total and 1456 publications at the proceedings.

In the celebration of the Annual 25th International Scientific Conference 'Research for Rural Development 2019' held at the Latvia University of Life Sciences and Technologies, in Jelgava, from 15 to 17 May, participants with different backgrounds from 12 countries did 156 presentations, enjoyed welcome dinner with Latvian folk songs and dances as well as tasted a special cake. During a social programme of the conference, the participants visited a malt production plant, Rundāle palace and had farewell lunch.

In the retrospect, four months later, we consider the Conference a great success in terms of interdisciplinary studies and networking opportunities. The sessions of the conference were structured so as to give all participants the opportunity to contribute to the primary purpose of the conference, which is discussion of important current issues facing rural development.
Thank you for your participation! We are sure that you have learned from the presentations and discussions during the conference and you can use the outcomes in the future.

The interdisciplinary proceedings of the Annual 25th International Scientific Conference 'Research for Rural Development 2019' (two volumes since 2010) are intended for academics, students and professionals. The subjects covered by those issues are as follows: crop production, animal breeding, agricultural engineering, agrarian and regional economics, food sciences, veterinary medicine, forestry, wood processing, water management, environmental engineering, information and communication technologies. The papers are grouped according to the sessions in which they have been presented.

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

Ausma Markevica
Chairperson
Annual 25th International Scientific Conference
'Research for Rural Development 2019'

CONTENTS

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USE OF THE LIDAR COMBINED FOREST INVENTORY IN THE ESTIMATION OF SAMPLE TREES HEIGHT

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Abstract
Precision of the forest inventory planning is still one of the most important problems in the forestry nowadays. The aim of this research was to estimate the sample tree height results of the combined forest inventory (LiDAR CFI) and LiDAR (Light Identification Detection and Ranging) height data by calculating an average value from sample tree neighboring pixel values in the ripening Scotch pine forest stands, comparing the results with the measurements of the height in the area. For the update of LiDAR calculated data and LiDAR CFI height results, the increment algorithms of the Latvian State Forest Research Institute 'Silava' were used, comparing the results with the sample plot measurements. Both results showed a close correlation – in the case of LiDAR CFI with R^2=0.82, LiDAR data with R^2=0.93, demonstrating a standard deviation: 2.40 and 2.75, accordingly and standard error: 0.11 and 0.13, accordingly. The results indicate that both technologies can be used in the forest management, offering reliable information about the forest inventory. Positive values were reached by minimizing the human error factor, which is problematic for the field inventory.
Key words: LiDAR, forest management, increment algorithms, tree height.

Introduction

One of the main tasks of the remote sensing is to develop accurate inventory and planning in the forest management. Technology allows analyzing the forest stands thoroughly, minimizing the human error factor (Dubrovskis *et al.*, 2017). The previous researches were connected with the identification of the tree species and growing stock volume comparison, using both LiDAR technology, harvester production data and forest inventory sample tables. The best result demonstrated the connection between harvester product data and LiDAR data (Seleznovs *et al.*, 2018). The study focused on the estimation and analysis of one of the most important forest inventory factors – the tree height. To complete the task, three data sources were chosen: LiDAR, based on the group of pixels with the calculated from neighboring pixels an average value for the sample tree height; LiDAR CFI, based on a combination of orthophoto and near infrared (NIR) data, and terrestrial measured heights of the sample trees. The results of this study can be attractive for the forest management companies, where the Scotch pine (*Pinus sylvestris)* is the dominating tree species. Previous studies have showed that the identification of forest inventory factors demonstrates better results in one-storey forest stands, and first of all in monocultures (Kulla, Sačkov, &Juriš, 2016). According to the inventory data, even-aged forest stands dominate in Latvia, and the last decades demonstrate the growth of the areas with the uneven-aged tree stands (www.geo.lu.lv). The use of LiDAR in these tree stands also demonstrates a good possibility for tree height identification; as the problems are common in the identification of the trees from the understorey (Brovkina, Zemek, & Fabiánek, 2015). The problems with the identification of tree height could also be caused by brushwood and relief specifics, where the laser beams cannot identify the tree stem beginning. This study will prove the tree height in the forest stands without brushwood and understorey. The aim of this research is an estimation of the sample tree height results taken from the combined forest inventory (LiDAR CFI) and LiDAR (Light Identification Detection and Ranging) height data by calculating an average value from the sample tree's neighboring pixel values and comparing the results with the measured heights.

Materials and Methods

Study area

The study was completed in Riga municipality-owned forest, to the east from the capital city of Latvia, in the Jugla district of Gauja forest department (Figure 1). For the study, the ripening Scotch pine tree stands in the fifth age class (81-100 years) were chosen. Scotch pine monocultures dominated the whole study area. For the study we created 30 sample plots with a radius of 12.62 m and an area of 500 m^2. In the sample plots, all trees with the height of more than 12m were measured. In total, the height of 455 trees growing in the sample plots were measured. The sample plot centers were marked using the 'QGIS' software. In the terrestrial research, the field computer 'Algiz 8X' was used. For the height measurements, the instrument Vertex Laser Geo was used. The middle of the sample plot was marked with the Vertex tripod, measuring the distance to the trees and their azimuth. Following formulas were used for the calculation of tree coordinates:

$$\Delta X = \text{distance} \times \cos \alpha \quad (1)$$

$$\Delta Y = \text{distance} \times \sin \alpha \quad (2)$$

$$X = X_0 + \Delta X \quad (3)$$

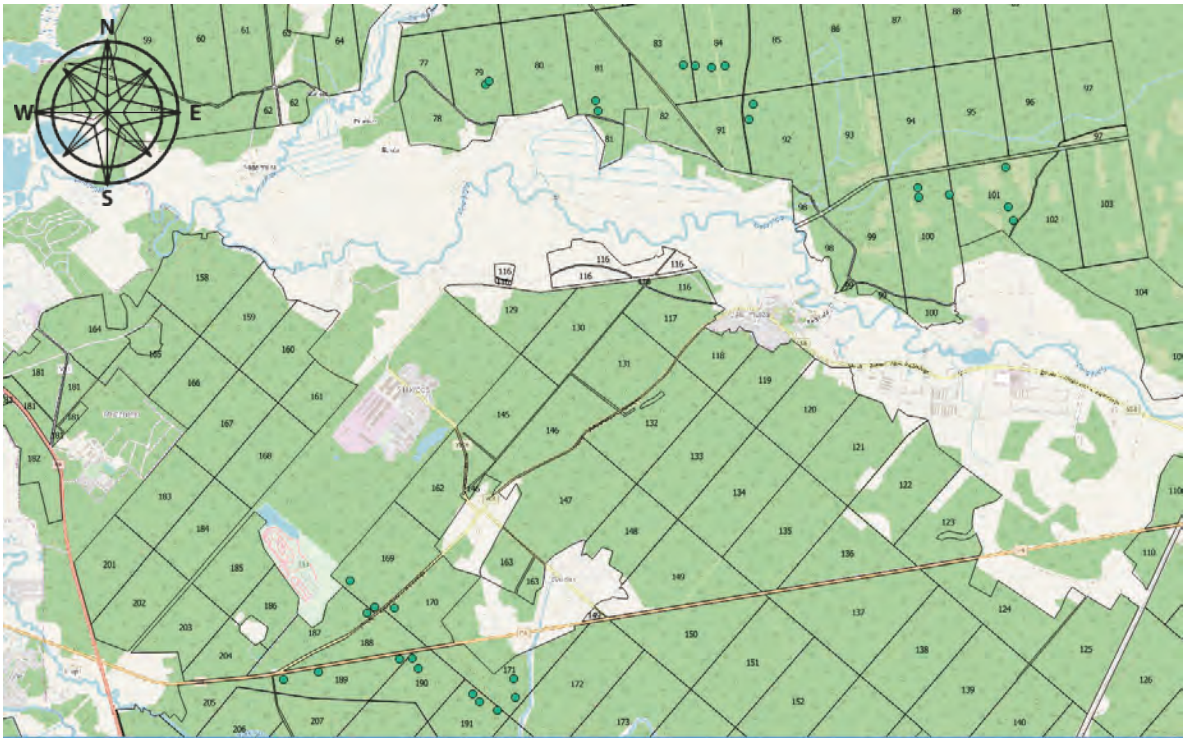

Figure 1. Allocation of study sample plots.

LiDAR data processing

$$Y = Y_0 + \Delta Y \quad (4)$$

where X_0 and Y_o are the coordinates of sample plot center. The angle value was converted from degrees to radians using Microsoft Excel program.

The basis of the LiDAR data for this study were scanned in the years 2013-2014 by the Latvian Geospatial Information Agency (LGIA) in Gauja forest department areas. Data was summarized as a group of pixels, representing the height value of the trees in a forest stand. To develop the precision of the LiDAR data value, it was decided to take the nearest pixels from the tree location, counting an average value of a concrete tree height. The second way in this study for counting of the tree heights was the use of the LiDAR CFI method, which is based on LiDAR data, orthophoto and near infrared (NIR) images. According to this method, the height of a tree is a local maximum calculated from the height values. For this aim the tree centers with the concrete parameters were chosen, based on LiDAR and NIR data (Table 1).

After the calculation of these parameters, the results were saved in the '.las' format. After the noise removal, LiDAR data processing followed. For this aim, in this study we used the Gauss matrix. Obtained from the matrix, the highest points of trees and distance to the terrain were registered as a tree height. For better results, interpretation identified the LiDAR points, which belong to a concrete tree. For

Table 1

Primary processing of LiDAR and NIR data

Group of data	Name of parameter	Description
NIR	Position of sample tree center	×
	h, e, i	Texture indicators, defined in accepted radius around a tree center
	nir	Value of NIR channel
LiDAR	Position of sample tree center	×
	h	Sample tree height
	Slope	Slope coefficient of crown top
	z_avg, z_sigma	Center indicators of foliage mass
	evp, vp, vpa	Dimension of tree crowns
	ntc, ntr, vpa	Neighboring tree interaction indicators
	histogram	Tree point vertical bar chart

the creation of a tree model, the points within a radius of 6 m from the crown top were used. NIR data helped to identify the sample trees. The result of NIR data quality depends on the quality of aero photo and size of pixels. During the tree identification process there are following phases: preparing and processing of the photo, and summarizing of the results. The photos have strict geographical binding and are cut into smaller photos. Sizes of the photo were based on the power of number 2. Fourier transform helped to develop the distinct model of the tree stand. Consequently, the information contained the LiDAR and photo data as well as sample tree location. This method was created in a cooperation between the Latvia University of Life Sciences and Technologies and the company 'Metrum'.

Increment algorithms

Created in the Latvian State Forest Research Institute 'Silava' by researching thenational forest inventory monitoring, the algorithms are suitable for five tree species of Latvia, including the Scotch pine (Donis, 2014). Algorithms are based on the calculated variable coefficients for each tree species, the tree age and the previously measured height:

$$H_2 = 1.3 + \frac{A_2^{b_1}}{b_2 + 100 \times b_3 X_0 + X_0 A_2^{b_1}} \quad (5)$$

$$X_0 = \frac{\frac{A_1^{b_1}}{H_1 - 1.3} - b_2}{100 \times b_3 + A_1^{b_1}} \quad (6)$$

where: A_1 – breast height age at the first measurement (ages); A_2 – breast height age at the second measurement (ages); H_1 – tree height at the period beginning (m); H_2 – tree height at the period end (m); b_1, b_2, b_3 – empirical coefficients (for the Scotch pine: b_1=1.113; b_2=-44.224; b_3=21.107). H_1 taken from LiDAR and LiDAR CFI data.

This formula was used in the update of the LiDAR and LiDAR CFI data, and the result compared with the measured height. The result of breast height age needed the correction in dependence on a forest stands' site index.

Data processing

During the research, the LiDAR and measured data were processed. For processing, the regression analysis was chosen, which was completed in the program R, analyzing the tree height and using one factor analysis. The results are presented in the graphics, showing information about coefficient of determination. Data analysis was completed with a confidence level of 95%.

Results and Discussion

Comparing the calculated LiDAR and LiDAR CFI data, the results of different tree height demonstrated different correlation. Previous methods compared different data sources of growing stock volume, analyzing the PRD production data, the field data and the LiDAR CFI technology. For the first time, a separate analysis of a tree height in this research was completed in Riga forests. During the research, the results from 30 specially located sample plots were compared, containing the information about the measured tree heights, and the calculated heights from LiDAR CFI data and LiDAR data sources, using increment algorithms. Figure 2 demonstrates the results of comparison of the measured heights to LiDAR CFI data calculated heights using an increment algorithm.

The results show that the determination coefficient is high – R^2=0.82 ($p<0.01$). The reason for thegood result is the minimization of human error. However, the risk of the human factor can be during the estimation of the trees because of the orthophoto

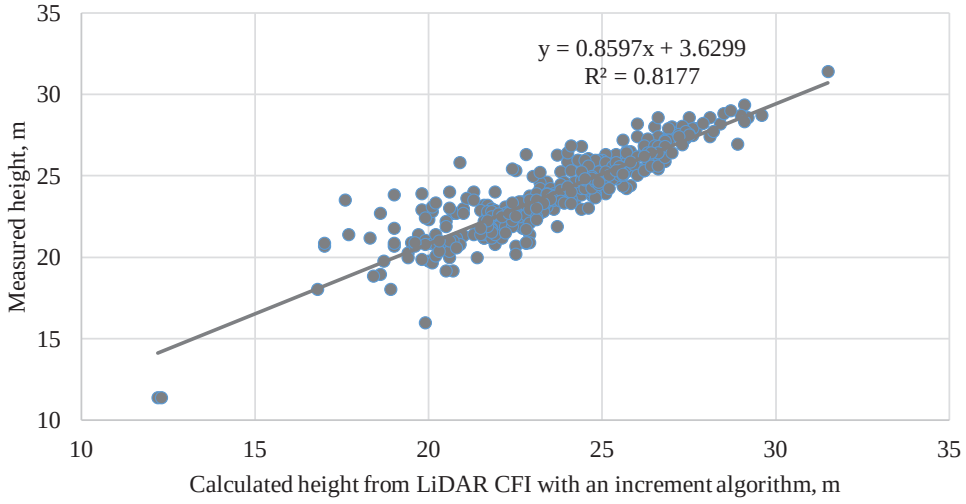

Figure 2. Comparison of measured tree height to calculated height from LiDAR CFI.

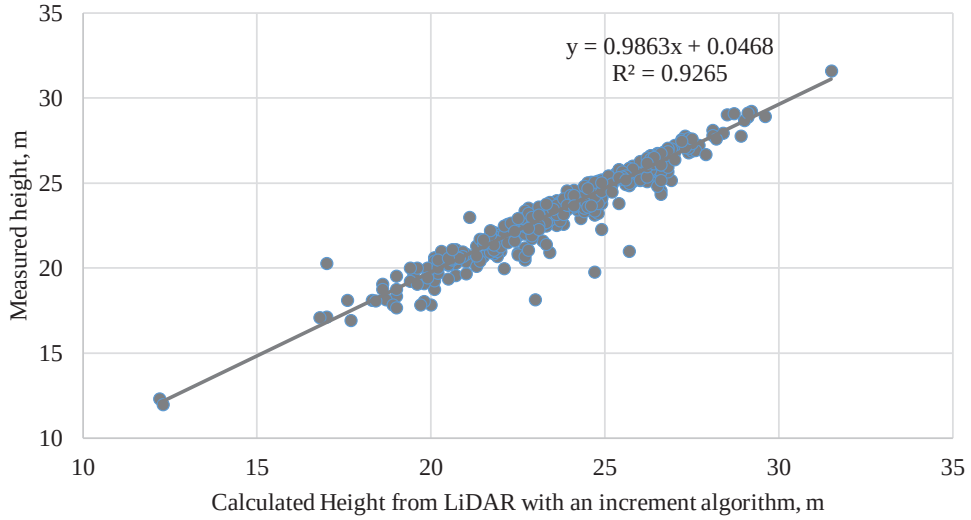

Figure 3. Comparison of measured tree height to calculated height from LiDAR data.

quality and the GPS coordinates errors. This method accepts a tree height as a local maximum, although it can belong to the neighboring trees. Better results were obtained by the comparison of measured height data and calculated height from LiDAR data, given in Figure 3.

The strong correlation can be explained by the minimizing of the human factor in the analysis of the LiDAR data. In this method not only the height value from a coordinate is used, but also the neighboring height values, calculating the mean result as a tree height. By comparing different values, the result is better than in the case of an analysis of the aerial photo and local maximums. One of the most important problems is the accuracy of GPS coordinates, because during the data analysis some of the points were located in the empty areas, where there are no identified growing trees. These points were located nearby to the identified tree groups. Although not straight growing trees were specially marked during data analysis, the identification of the height using CFI method was considerably more difficult than during the height calculation from LiDAR data. This is one of the causes why the LiDAR CFI method is supposed to have a higher risk of the human error. The other reasons are the quality of aerial images, inaccuracy of the coordinates and the amount of analyzed values, because only one value is taken for a height from local maximum instead of analyzing neighboring values.

For this particular study were chosen forests, where in the next 15 years a final felling is planned, that is why reliable information about the forest inventory data is topical for the forest owner. For updating one of the most important inventory data – tree height – the increment algorithms were used, which originally came from the national forest inventory monitoring sample plots and for the first time were used in the forest management, highlighting the bright perspectives for the use of these algorithms in the forest management planning. In the case of our study, in plots there were one-storey stands without any brushwood. Even-aged and one-storey forest stands are most suitable for the remote sensing, because of a good terrain and possibility of scrupulous stem analysis (Hancock *et al.*, 2012). In Latvia, the results of LiDAR CFI and LiDAR data processing could definitely be integrated into the forest management forecasting system, providing the probable information about the tree height. In practice it means that 82% of LiDAR CFI data changes are described by the model and in the case of the LiDAR data processing – even 93% described by the model. An attractive place of data integration could be the forests nearby Riga, because of their simple structure and high amount of Scotch pine monoculture. The use of the remote sensing and LiDAR technology as well is not disturbed by high amount of tree species, understorey and, as a result, the quality of images allows to analyze the forest virtually, saving the human and time resources (Wulder *et al.*, 2012). In contrast to field inventory, LiDAR technology demonstrates better calculation possibilities of the main forest inventory data, such as growing stock volume and breast height diameter by the thorough analysis of every tree stem, and reducing the mistakes from the yield tables (Mielczarek, Bałazy, & Zawiła-Niedźwiecki, 2015).

Despite the good results of the technology, one of the most topical questions for the forest inventory remains the analysis of uneven-aged forest stands with a few storeys. The tree identification in these stands is considerably worse than in even-aged monocultures and mixed one-storey forest stands. One of the solutions could be the development of laser scanning technology and another one could be continuation

of the research in remote sensing area, putting the main emphasis on diameter at breast height, basal area, forest site indexes and tree interrelations in the uneven-aged forest stands. In case of successful research, the forecasting model could help the forest owner in the decision making aspects concerning the forest management planning.

Conclusions

1. Comparison of LiDAR CFI calculated height with the measured height demonstrated a strong correlation (R^2=0.82).
2. Calculated height from LiDAR data demonstrated a better correlation (R^2=0.93).
3. The increment algorithms could be used for height forecasting in the forest management planning, because of the good study results.
4. The use of LiDAR technology in forest management reduces the risk of the subjective factor in the forest inventory, bringing the excellent planning possibilities for the forest owner.

Acknowledgements

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STRUCTURAL DIVERSITY OF DEAD WOOD IN SMALL-SCALED PROTECTED FOREST PARCELS IN LATVIA

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Abstract
Dead wood is a significant component in forested ecosystems. In Fennoscandia and Baltic countries, set-aside forest areas, also called woodland key habitats (WKHs), have been created for nature conservation purposes in the production forest landscape. We performed a comparative study on dead wood substrate availability in different WKH types in Latvia. We measured standing trunks and downed logs to estimate biological quantities and qualities for coarse woody debris substrate. In this study, we found out that dead wood availability ranges, on average, from 38.2 to 149.5 m^3 ha^{-1}. This study showed that moderate quantity and quality of dead wood has been found in different types, but the fine quality coarse woody debris was scarcely presented. In general, WKHs provide moderate and high level of qualities and quantities of structural features in the production forest landscape.
Key words: disturbance dynamics, tree mortality, woodland key habitats, coarse woody debris, diversity of the dead wood.

Introduction

Achieving an optimal amount of coarse woody debris is essential for species depending on this substrate in forested ecosystems. The lack of dead wood substrate is particularly common in production forests. To fulfill the forest certification requirements and to reach the nature conservation targets outside the protected areas, a network of small-scale conservation areas at the forest stand level were established in the Baltic and Fennoscandian production forests. These small scale set-asides, also called woodland key habitats, have their average size from 0.7 ha in Southern Finland, 2.5 ha in Latvia to 4.6 ha in Sweden (Timonen *et al*., 2011), have been intact from management and function as hotspots for biodiversity purposes since 1990s (Anon, 2005). To select the forest parcels with a high value for biodiversity qualities, the vast stand-level survey was made in the production forest landscape, which included the criteria for stand structural features (e.g., mature or over-mature stand age, dead wood qualities), presence of indicator species, rare and threatened species, cultural heritage value and others. Most of the conservation targets in these small forest parcels are related to dynamic ecosystem processes, e.g., natural disturbances and succession, and biodiversity qualities, for example, presence of dead wood and large dimension trees, as well as, rare and threatened species (e.g. fungi, lichens, bryophytes, saproxylic species and vascular plants). Multiple studies on many organism groups have tested whether such a small-scale conservation approach is cost-efficient and provides expected outcomes. For instance, in an investigation into boreal forest ecosystems, Gustafsson (2000) and Perhans (2007) detected the occurrence of rare and threated bryophytes, lichens and vascular plants. However, the study on the edge influence on epiphytic lichens in boreo-nemoral swamp forests reports that the occurrence of rare species is higher at the distance of 40 – 50 m compared to 10 – 20 m and 20 – 30 m from the habitat's edge (Liepa & Straupe, 2015). Other studies have stated that small forest parcels are lacking habitat qualities due to their small size, isolation, influence of the edge effect, and lack of the core area due to their small size (e.g., Aune *et al*., 2005; Timonen *et al*., 2011; Liepa, 2017). Furthermore, these small forest parcels are characterized as 'edge habitats' where diverse dead wood substrate is available, because sites are more affected by changes in abiotic condition and, therefore, desiccation, wind, wildfire or other agents may cause the death of living trees.

In recent years, the awareness of the importance of dead wood in forest ecosystems has been widely discussed. It is known that dead wood provides important resources for a wide range of organisms, which directly and indirectly depend on this substrate. Besides this, dead wood also contributes to carbon sequestration (Ķeņiņa *et al*., 2018), nutrient cycles, enhancement of natural regeneration, as well as essentially provides substrate for many rare and endangered species. In particular, in Latvia 94 rare and threatened species both indirectly – 25 and directly – 69 are dependent on dead wood substrate (Cabinet of Ministers, No. 396). In boreal forest landscape, the occurrence of approximately 7000 species is linked to the above-mentioned characteristics (Stokland *et al*., 2012).

In general, dead wood is characterized as a dynamic substrate that can develop over time. Some studies have recorded the importance of dead wood continuity, because in each decay stage different taxa have been detected. Overall, the diversity of dead wood is characterized by tree species, diameter, length, decay stage and spatial distribution. The current dead

wood availability amount and critical values of dead wood substrate have been assessed in recent studies. For instance, in Sweden's production forest landscape the average amount of coarse woody debris is 6.1 m^3 per ha, in Finland – 5.4 m^3 per ha (Fridamn & Walheim, 2000), but the critical values for species in this biome vary from 15 – 20 m^3 per ha. Furthermore, in temperate forest ecosystems the values of thresholds range from 20 to 30 m^3 per ha (Muller & Butler, 2010). These values may be higher than general volume of dead wood found in the production forest landscape. Therefore, such small-scale protected forest parcels might favorably function as 'lifeboats' for species demanding dead wood substrate in the production forest landscape. In this study, we investigated the availability of dead wood substrate in different forest types. To evaluate whether protected small-scaled forest parcels provide high biodiversity qualities and continuity of dead wood substrate, we have described decay stage distribution, different sizes and currently available volume.

Materials and Methods

Forests of Latvia are located in boreo-nemoral biome (Sjörs, 1963), which combines the elements from both boreal and nemoral forests. This study was conducted in 45 forest stands in southern Latvia (Figure 1), which represent Zemgale geobotanical region.

These plots fall into Zemgale plain, are dominated by agriculture and have fertile, naturally well-drained soils. In contrast to Latvia in general, where the forest proportion is 52% (Mežu statistiskā inventrizācija, 2014), forested areas occupy approximately 20% of region's area, mostly in small patches. Historical analysis shows that forests have been much more common in this area a few centuries ago, mostly broad-leaved forests (Angelstam *et al.*, 2005; Galeniece, 1959). The most common tree species include Scots pine *Pinus sylvestris* L., silver birch *Betula pendula* Roth. and downy birch *Betula pubescens* Ehrh., Norway spruce *Picea abies* (L.) H. Karst., black alder *Alnus glutinosa* (L.) Gaertn., grey alder *Alnus incana* (L.) Moench., common aspen *Populus tremula* L., and broad-leaved species at their northern limit of the distribution. The climate ranges from transitional maritime to continental toward the eastern part of the country. The average temperature in February is -3.6 °C and 16.9 °C in July. Average yearly precipitation is approximately 709 mm.

In Zemgale, forests are managed predominantly for timber production and only small forest parcels are excluded from silvicultural practices. Study plots are located in state-owned forests and all stands have the status of protected habitats since 1990s as woodland key habitats (WKH, sensu Timonen *et al.*, 2010) – voluntarily set-aside forest stands. The complete inventory of natural values and biodiversity qualities is currently being carried out in Latvia and many of these woodland key habitats are properly transformed as European Union protected habitats (Evans, 2006). The manuals for criteria are mainly based on the presence of indicator species, rare and threatened species, and diversity of stand structural features. Study sites represented black alder WKHs with age ≥81 years, which are designated as an EU protected habitat type: Fennoscandian deciduous swamp forests (further – swamp forests), boreal Scots pine stands with age ≥120 years (further – coniferous forests), and nemoral broad-leaved stands dominated by common ash (*Fraxinus excelsior* L.) and Penducalate oak (*Quercus robur*) with age ≥120 years (further – broad-leaved forests). All studied stands were semi–natural, located in close proximity to each other and had been managed in a similar manner. The evident influence of silvicultural practices of forests within existing WKHs likely consisted of thinning and forest drainage; few of them are located nearby forest roads.

Data collection. A string of permanent sample plots was established in each study site from the stand edge

Figure 1. The location of study sites.

into forest interior (from S or SW side) to describe the gradient. The size of sample plots was 20×50 m. Plots represented forest edges with S or S–W exposition.

Stand structural features. Inside sample plots coarse woody debris (CWD) was measured by diving it into categories: standing dead trees and downed dead logs, and their items (diameter ≥10 cm and minimum length ≥1m). Tree species for those were determined whenever it was possible. Downed dead wood and their items were recorded at intersection with sample plot. In addition, downed dead wood items, such as branches anddowned shrubs were included as well as all remaining CWD under water, specifically, in swamp forests. The decay stage classification was from one to five following Stokland (2001). The volumes of CWD were computed using the volume formulas presented by Liepa (1996).

Results and Discussion

The highest average volume of dead wood quantities found in this study was 149.5 m^3 ha^{-1} in broad-leaved forest parcels. A high amount of dead wood was also found in swamp forest sites – 48 m^3 ha^{-1} (Figure 2). Standing dead wood made up 72% in swamp forest parcels, followed by 38% in coniferous stands and only 12% in broad-leaved forests. Following from the main cause of mortality, clear differences were found in broad-leaved forest stands, which are currently affected by ash dieback, particularly, in southern part of Latvia (Broka *et al*., 2017; Matisone *et al*., 2018). Historically, this region was dominated by Penduculate oak, common ash and small-leaved lime (*Tilia cordata* Mill.), however, only 4% of forests are associated with nemoral broad-leaved habitats (Fescenko, 2014). In contrast, natural gap dynamic processes are characterized by swamp forests, because large quantities of dead wood are standing snags and stems (Figure 2).

Multiple studies have revised quantities of dead wood in old-growth forest stands and in boreal and temperate European forest landscapes, where the average volume of dead wood is ranging from 8 to 141 m^3 ha^{-1} (Moning & Müller, 2008; Stokland *et al*., 2012). However, the equilibrium between the occurrence of standing dead wood and fallen logs is commonly suggested. According to the above mentioned, the proportion of standing and downed dead wood (49.5% and 50.5%, respectively) in the studied coniferous forest stands is fairly similar.

To classify the quantities of dead wood, also diameter distribution classes are commonly investigated. The diameter distribution of standing snags and stems showed a pattern where the highest proportion consists of small diameter classes in all studied sites (Figure 3). The highest proportion of medium-diameter classes (from 20.0 – 29.9 cm at the DBH) was recorded in coniferous forest parcels – on average 49.2%. The large dimension classes represent 20.3% in coniferous stands, followed by broad-leaved stands – 14.3% and swamp forests – 8.2%.

In general, few studies have reported the proportion of standing trees in different trunk diameter classes (Nilsson *et al*., 2003; Siitonen *et al*., 2000). Generally, the competitive exclusion is the main driver, which induces the mortality of small dimension trees.

It is known that many forest-dwelling species are related to the large-dimension dead wood substrate and, therefore, nature conservation is aiming at these quantities.

However, taking whole coarse woody debris substrate into account, the earlier decay stages 1 and 2 were most abundant in terms of occurrence, volume and

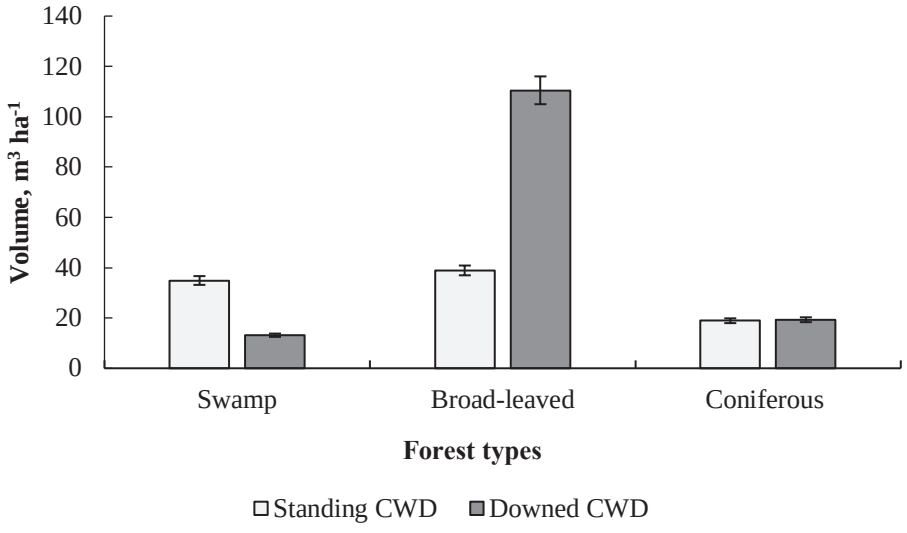

Figure 2. The average volume of standing and downed coarse woody debris in different habitat types: swamp, broad-leaved and coniferous. Error bars represent standard errors.

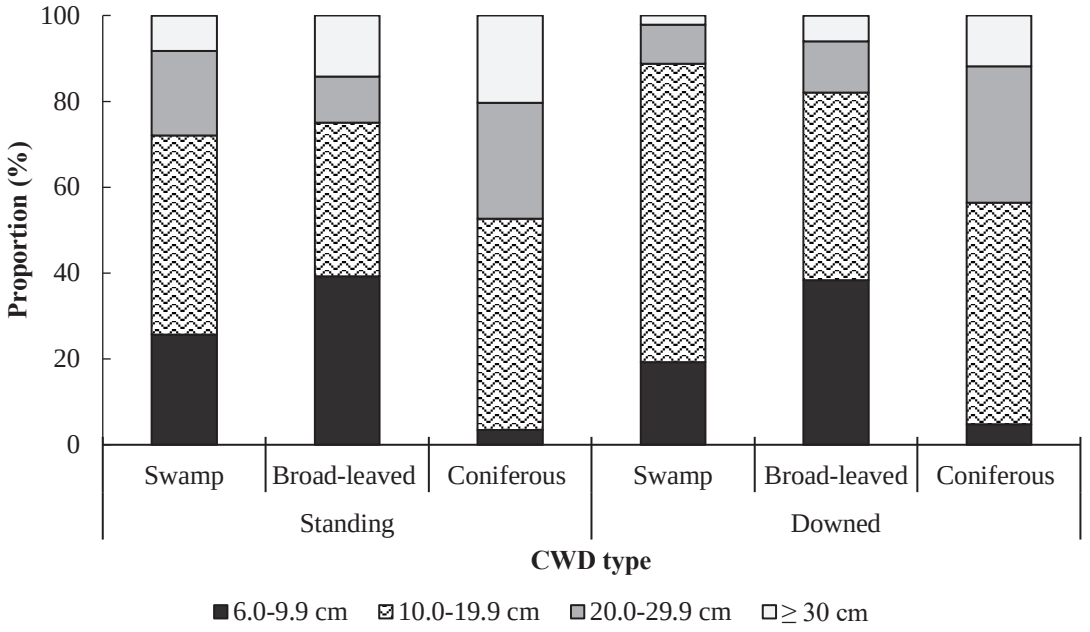

Figure 3. The proportion of coarse woody debris by diameter distribution in different habitat types: swamp, deciduous and coniferous habitats.

density (Figure 4). Decay stage 1 (recently dead trees with remaining bark and solid structure) comprised 87% in swamp forests, followed by broad-leaved and coniferous forests (54% and 42%, respectively). Only a small proportion of moderate decay stages are present in the studied areas, for instance, in broad-leaved forests – 9.4% and in coniferous – 15.3%, but in the swamp forests they were not found.

It is important to understand the decay dynamics of dead wood substrate to predict the substrate continuity in longer term. According to the studies, the decomposition of Norway spruce and Scots pine may take some decades, or even longer under constant climatic environments (Stokland, 2001). By contrast, it takes between 10 to 20 years for deciduous trees to reach the most decomposed decay class. The presence of many taxa from epixylic species, vertebrates, invertebrates, reptiles and amphibians to mammals strongly correlates with substrate decomposition rate. However, the decay stage, dimensions, spatial distribution, and biotic interaction, which can differ among diversity of woody plant species, biomes, and

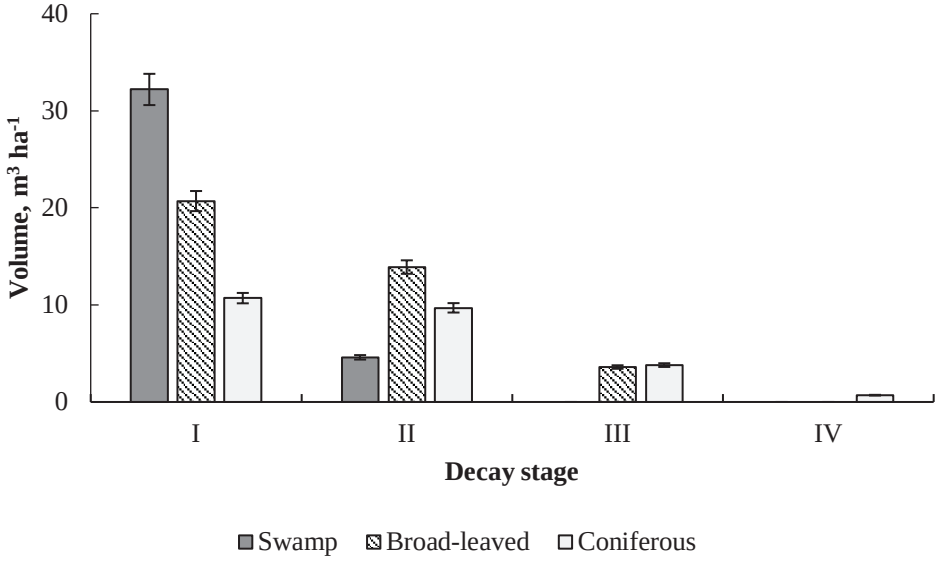

Figure 4. The volume of coarse woody debris by different decay stages in various habitat types: swamp, broad-leaved and coniferous habitats. Error bars represent standard errors.

landscapes, eventually characterize the dynamics of quality change and dead wood continuity in the forest ecosystems. In order to investigate long-term dynamics on dead wood quantities, common simulation models were used in the previous studies.

Conclusions

This study showed that moderate quantity and quality of dead wood has been found in different types of protected habitats in the production forest landscape. Results from this study also support the hypothesis that dead wood substrate occurs in fairly large quantities. In general, the total amount of dead wood, including snags, stems and logs are consistently available in small forest parcels for providing biodiversity qualities. The largest amount of substrate availability was particularly detected at the early decay stages. This might be correlated with human-induced disturbances in the adjacent forest matrix. However, the lack of available substrate and dynamic environmental conditions may have negatively affected the species with strong habitat requirements for stable microclimatic conditions. In addition, deeper investigation is needed to understand the spatial distribution patterns and to determine strict numbers for thresholds and compared dead wood quantities with managed stands in different age classes.

Acknowledgements

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DEVELOPMENT OF YOUNG STANDS AFTER DIFFERENT INTENSITY REGENERATION FELLINGS

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Abstract
The share of the renewable resources used continues to grow due to environmental, economic and political reasons. Consequently, intensification of forest management is ongoing and expected to continue in the future. Logging residues, such as treetops, branches and stumps, are a significant renewable energy source. Since the logging residues are noticeably richer in nutrients than conventionally harvested stems, there is a concern related to the negative impact of intensified harvesting on the ecosystems, productivity of the sites and sustainability of forestry in general. To evaluate the impact, this study has compared different intensity harvesting effect on the next rotation young stand productivity in eight sites in Latvia. In a nutrient-rich site, the productivity of Norway spruce was higher in the whole-tree harvest (WTH) subplot comparing to stem-only harvesting (SOH) subplot three years after the planting. Productivity of Scots pine in oligotrophic conditions was observed to be higher in SOH subplot comparing to WTH subplot two and three years after planting. Furthermore, in a site on a mineral soil relatively richer in nutrients no significant differences were observed. Comparing WTH to whole tree harvest + stump biomass (SB) extraction subplots, the productivity of Norway spruce was higher in WTH four to five years after the planting; in a mixed stand of Norway spruce and black alder no productivity differences of spruce were detected, but productivity of black alder was higher in WTH+SB subplot five years after the planting; in black alder stands a significantly higher productivity was observed in WTH subplot four and five years after the planting.
Key words: whole-tree harvesting; stump harvesting; stand productivity; Scots pine; Norway spruce; black alder.

Introduction

Consumption of renewable energy is growing globally due to both economic reasons and political influence. The European Union in its directive 2009/28/EC has set targets for renewable energy share in total energy consumption that member states have to reach in a specified timeframe. Renewable energy share in Latvia has to reach 40% by 2020 from 37.2% in 2016 (Eurostat, n.d.). Since forestry products are one of the main renewable energy sources in Latvia, intensification of forest management is present and expected in the future. Besides the most valuable forestry product – timber, logging residues such as treetops, branches, bark and roots are a significant renewable energy source (Castro *et al*., 2017).

As stems are not as rich in nutrients as foliage and twigs, stem-only harvesting (SOH) is considered to have little impact on the local ecosystem and site productivity in the future. Intensified forestry activities like whole-tree harvesting (WTH) as well as logging residue extraction from SOH sites rise concerns of sustainable site productivity (Wall, 2012). WTH may exhaust soil nutrient pools, especially on nutrient poor sites (Merino *et al.*, 2005; Tritton *et al.*, 1987), and also lower the nutrient availability in soil nutrient pools (Thiffault *et al*., 2011). On fertile soils, where there are risks of nutrient leaching and acidification of nearby waterbodies, logging residue extraction from felling sites may provide environmental benefits (Swedish National Board of Forestry, 2002). Stump biomass (SB) extraction may cause long lasting disturbance to the soil surface as well as carbon losses (Kaarakka *et al*., 2018), although it may lower the site preparation expenses for planting.

A review article (Wall, 2012) compiled results from 45 field experiments regarding tree productivity after WTH. Majority of them have reported a response of five years after planting, but the results are rather ambiguous. To further investigate the effects of different intensity regeneration fellings in local conditions, eight study sites were established in four different locally typical forest types. The aim of the study was to evaluate the effect of WTH and WTH+SB on young stand productivity.

Materials and Methods

Sites were named with letter combinations corresponding to different forest site types in Latvia.

Three of the study sites (sites DM1, KP, LN) are located in experimental forests of Kalsnava forest district (Figure 1; Table 1) where the development of young stands is measured in WTH and SOH subplots in different forest types: *Hylocomiosa* (mesotrophic conditions); *Oxalidosa tuf. mel.* (eutrophic conditions); *Myrtillosa* (oligotrophic conditions). In these study objects the regeneration felling was performed with a harvester in early spring 2013; logging residues and timber were extracted by a forwarder. Forestry operations were performed while the soil was frozen, and no significant soil damage was observed. In practice, approximately 70% of branches and treetops were removed from the WTH subplots. At SOH subplots slash was evenly scattered. On *Hylocomiosa* and *Myrtillosa* sites soil was prepared by disk trenching

in autumn 2014 and Scots pine (*Pinus sylvestris L.*) container seedlings were planted in spring 2015. On *Oxalidosa tuf. mel.* site Norway spruce (*Picea abies L.* (Karst.)) bareroot plants were planted in spring 2015 without soil preparation.

The rest of the study sites (sites DM2, DM3, DM4, VR1, VR2) are located in state forests in Northern Kurzeme Forestry (sites DM3, VR1), Zemgale Forestry (site VR2), Mid-Daugava Forestry (site DM2) and Western Vidzeme Forestry (site 6) in *Hylocomiosa* and *Oxalidosa* type forests. At each site, two subplots were established: WTH subplot; WTH + stump biomass (WTH+SB) extraction subplot. Regeneration felling in these study sites was performed in winter 2012. Between the subplots a buffer zone consisting of 10 m of WTH zone and 10 m of WTH+SB zone was established. Stump and root biomass harvesting was performed using two types of stump extraction scoops: a stump extraction scoop MCR-500 prototype, constructed in Latvia, mounted on a New Holland E215B excavator; a CBI stump extraction scoop, mounted on a tracked excavator Komatsu PC210LC. Three to six months after the harvesting in 2013, the harvested stump

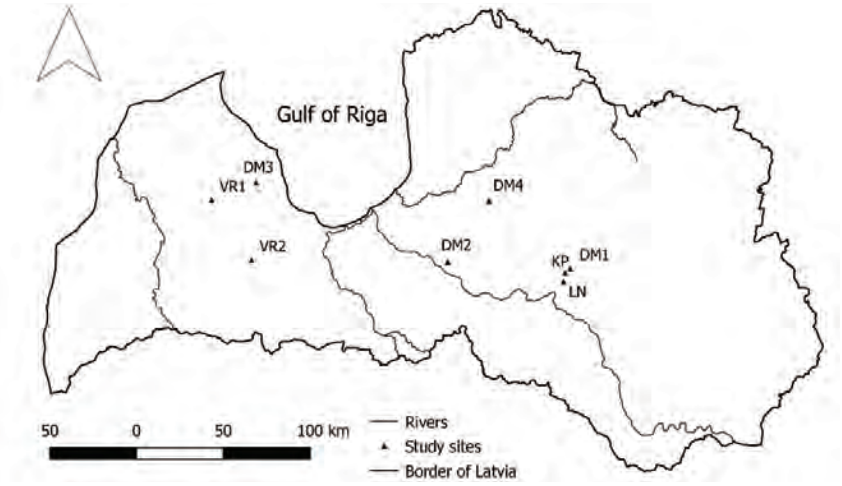

Figure 1. Location of the study sites.

Table 1

Description of the study sites

Site*	Site type*	Dominant tree species	Type of management**	Year of harvest	Year of planting	Coordinates (N;E)	Total felling area, ha	Planted density, n·ha^{-1}
DM1	*Hylocomiosa*	*Pinus sylvestris L.*	SOH; WTH	2013	2015	56° 44’ 10.44”; 25° 54’ 27.58”	1.8	~3,000
KP	*Oxalidosa turf. mel.*	*Picea abies L.* (Karst.)	SOH; WTH	2013	2015	56° 42’ 54.53”; 25° 51’ 33.39”	1	~2,000
LN	*Myrtillosa*	*Pinus sylvestris L.*	SOH; WTH	2013	2015	56° 40’ 10.71”; 25° 50’ 29.76”	0.7	~3,000
DM2	*Hylocomiosa*	*Picea abies L.* (Karst.); *Alnus glutinosa L.* (Gaertn.)	WTH; WTH+SB	2012	2013	56° 46’ 57.47”; 24° 45’ 16.63”	3.0	~2,100
DM3	*Hylocomiosa*	*Picea abies L.* (Karst.)	WTH; WTH+SB	2012	2013	57° 11’ 25.62”; 22° 56’ 0.64”	3.4	~2,100
DM4	*Hylocomiosa*	*Picea abies L.* (Karst.)	WTH; WTH+SB	2012	2013	57° 5’ 41.57”; 25° 9’ 11.30”	1.7	~2,100
VR1	*Oxalidosa*	*Alnus glutinosa L.* (Gaertn.)	WTH; WTH+SB	2012	2013	57° 5’ 46.48”; 22° 30’ 44.52”	2.0	~2,100
VR2	*Oxalidosa*	*Picea abies L.* (Karst.)	WTH; WTH+SB	2012	2013	56° 47’ 25.11”; 22° 54’ 7.69”	3.1	~2,100

* Site names correspond to the forest site types

** SOH – stem-only harvest; WTH – whole-tree harvest; WTH+SB – whole-tree harvest and stump biomass extraction

and root biomass was forwarded to the roadside for storage. Soil was prepared using an active disc plough and Norway spruce container seedlings, black alder (*Alnus glutinosa L.* (Gaertn.)) and Norway spruce bare root saplings with an improved root system were planted. In sites DM3, DM4, VR2, the forest regeneration was performed with Norway spruce, in site DM2 with Norway spruce and black alder, and in site VR1 – with black alder.

To evaluate the differences of young stand development after different intensity regeneration fellings, the tree measurements were performed in May 2016, April 2017 and May 2018 in the sites DM1, KP and LN. In June 2017 and May 2018 measurements of the young stands were performed in the sites DM2, DM3, DM4, VR1 and VR2. In sites DM1, KP and LN, the measurements were carried out in four round sampling plots (R=5.64 m; S=100 m^2) per subplot. In sites DM2, DM3, DM4, VR1 and VR2, the measurements were done in six circular sampling plots (R=5.64 m; S=100 m^2) per subplot. Young trees were counted in 10 cm height classes while evaluating if the tree was healthy, damaged or dead.

Data analysis and visualization was conducted with R (R Developement Core Team & R Core Team, 2018) using analysis of variance (ANOVA) with post-hoc LSD (Least Significant Difference) test. Different letters in results indicate statistically significant differences ($p<0.05$).

Results and Discussion

The mean height of planted Scots pines in 2018 in the sites DM1 and LN had reached the height class of 81 – 90 cm, while the planted Norway spruces in site KP had reached the height class of 101 – 110 (Figure 2). The mean height of the planted trees in all three sites, in both subplots, were statistically different from the previous year. Analysis of variance with post-hoc test did not show significant differences between the subplots during the first two study years, except in site LN in 2017. In site LN in the last two study years the mean height of the planted Scots pine was significantly higher in the SOH subplot. At the same time, in site KP the mean height of the planted Norway spruce was higher in the WTH subplot.

A study in Sweden (Egnell, 2016) on the effect of logging residue biomass removal from the clearcuts revealed an opposite relationship between the WTH and Norway spruce, as well as Scots pine growth. In addition, another study in Sweden (Egnell & Valinger, 2003) and a study in Finland (Wall & Hytönen, 2011) observed a negative impact on Norway spruce young stand height after WTH. No significant differences between WTH and SOH were also observed in the studies in Finland and Sweden (Saarsalmi *et al.*, 2010; Sikström, 2004). In contrast to our results, in the site LN, regarding Scots pine stand height, a positive WTH effect was observed in a study in Sweden (Egnell & Leijon, 1999) five years after planting, but no treatment effects were detected after seven years and onwards. In site DM1 during the study years no significant difference between the subplots in Scots pine stands was observed. Our results indicate the importance of plant nutrients provided by decomposing logging residue biomass to young stands in oligotrophic growth conditions.

Over time the density of planted trees has decreased due to natural competition and mortality, as well as damages caused by ungulates (Figure 2; Table 2). In the third year of the study in sites KP and LN the density of the planted trees had decreased. The density of Norway spruce stands was higher in the WTH

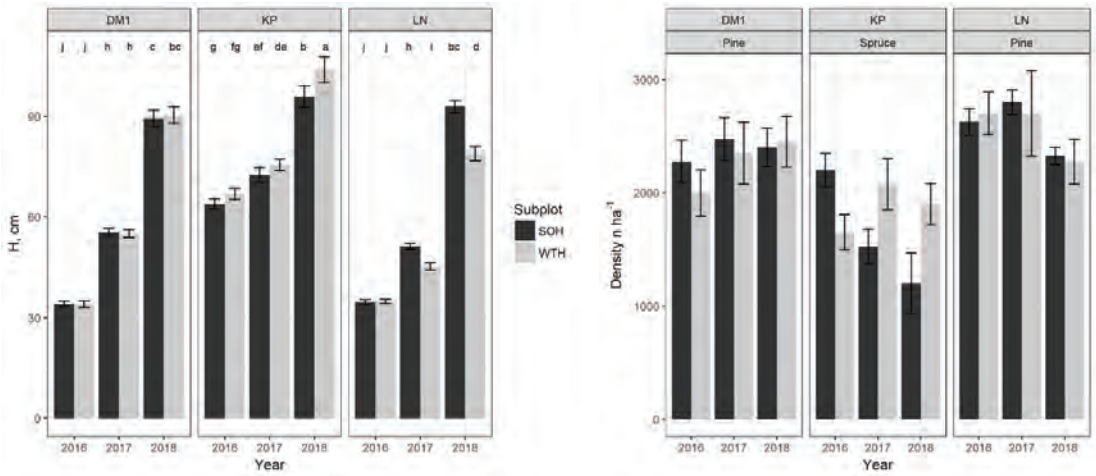

Figure 2. Comparison of mean stand height and density between the subplots of WTH vs SOH sites (DM1, KP and LN – site names as described in Table 1; SOH – stem-only harvest, WTH –whole-tree harvest; error bars present standard errors; different letters note statistically significant differences by ANOVA and LSD post-hoc test ($p<0.05$)).

Table 2

Stand densities in SOH and WTH subplots

Year	Site*	Healthy, n·ha^{-1}		Damaged, n·ha^{-1}		Alive, n·ha^{-1}		Dead, n·ha^{-1}		Natural*** pine, n·ha^{-1}		Natural spruce, n·ha^{-1}	
		SOH**	WTH**	SOH	WTH	SOH	WTH	SOH	WTH	SOH	WTH	SOH	WTH
2016	DM1	2,125	1,425	300	50	2,425	1,475	50	525	9,425	4,175	0	0
	KP	725	925	1,375	575	2,100	1,500	100	200	0	0	225	25
	LN	2,250	2,500	300	150	2,550	2,650	75	50	10,400	5,175	0	0
2017	DM1	2,150	2,225	325	100	2,475	2,325	0	0	7,575	7,025	10,025	9,775
	KP	850	250	575	1,775	1,425	2,025	100	50	0	0	250	125
	LN	2,725	2,550	75	150	2,800	2,700	0	0	11,850	3,725	225	300
2018	DM1	600	625	1,800	1,825	2,400	2,450	0	0	625	1,175	6,850	8,100
	KP	775	950	425	950	1,200	1,900	0	0	25	0	200	0
	LN	1,725	1,675	600	600	2,325	2,275	0	0	225	225	25	625

* Site names as described in Table 1
** SOH – stem- only harvest, WTH –whole tree harvest
*** Naturally regenerated

subplot of site KP. No significant differences in young Scots pine stands were observed regarding density.

A significant damage by ungulates to planted Norway spruces was observed in site KP in 2016 with consequences still noticeable in 2017 (Table 2). In year 2018 significantly less damaged trees were observed. In sites DM1 and LN, a significant damage to Scots pines by ungulates during winter was observed in 2018. Most damages were caused to upper branches because of the deep snow cover. The treetops were left intact because of successful treatment with *Cervacol*.

Naturally ingrown trees were more represented in SOH subplots during the initial year of the measurements. In year 2018 such relationships were no longer noticeable. In addition, the density of naturally regenerated trees in all three sites has decreased during the three study years.

According to literature data, the productivity of Norway spruce in WTH+SB sites may be affected negatively (Egnell, 2016; Persson, 2016). In our study, the mean height of planted Norway spruce was significantly higher in WTH subplots in sites DM3, DM4, and VR2 (Figure 3). In site DM2, where Norway spruce was planted in mixture with black alder, no significant differences were observed in the mean height of Norway spruce, but significantly higher mean height of black alder was observed in the WTH+SB subplot. In site VR1 significantly higher mean height of black alder was observed in WTH subplot.

During the timeframe of the study density of the planted trees in site DM2, DM3, DM4, VR1 and VR2 did not change significantly.

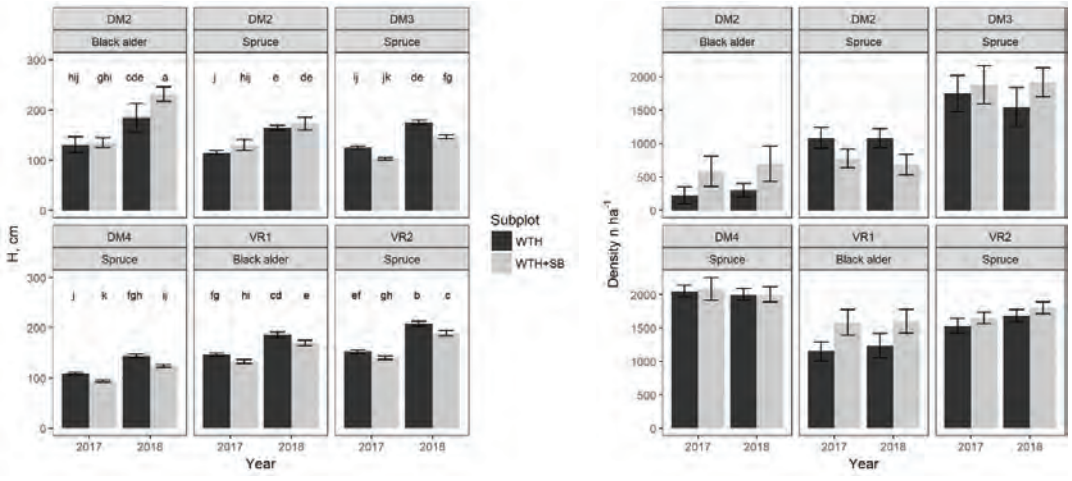

Figure 3. Comparison of mean stand height and density between the subplots of WTH vs WTH+SB sites (DM2, DM3, VR1 and VR2 – site names as described in Table 1; WTH – whole tree harvest, WTH+SB – whole three harvest and stump biomass extraction; error bars present standard errors; different letters note statistically significant differences by ANOVA and LSD post-hoc test ($p<0.05$)).

Table 3

Stand densities in WTH and WTH+SB subplots

Year	Site*	Tree species	Healthy, n·ha^{-1}		Damaged, n·ha^{-1}		Alive, n·ha^{-1}		Natural*** pine, n·ha^{-1}		Natural spruce, n·ha^{-1}	
			WTH**	WTH+SB**	WTH	WTH+SB	WTH	WTH+SB	WTH	WTH+SB	WTH	WTH+SB
2017	DM2	Spruce	1,083	650	0	0	1,233	1,233	200	183	0	100
	DM2	Black alder	150	583	0	0						
	DM3	Spruce	1,733	1,850	17	33	1,750	1,883	1,417	433	50	167
	DM4	Spruce	2,033	2,017	17	67	2,050	2,083	167	50	83	0
	VR1	Black alder	1,150	1,567	0	17	1,150	1,584	167	133	350	50
	VR2	Spruce	1,533	1,650	0	0	1,533	1,650	0	0	0	50
2018	DM2	Spruce	1,083	683	0	0	1,183	1,266	367	550	17	50
	DM2	Black alder	100	583	0	0						
	DM3	Spruce	1,550	1,917	0	0	1,550	1,917	2,167	1,117	183	133
	DM4	Spruce	1,950	2,000	50	0	2,000	2,000	317	167	117	0
	VR1	Black alder	1,233	1,600	0	0	1,233	1,600	433	1,150	783	283
	VR2	Spruce	1,683	1,800	0	0	1,683	1,800	17	33	17	350

*Site names as described in Table 1

**WTH –whole tree harvest, WTH+SB – whole three harvest and stump biomass extraction

***Naturally regenerated

In site DM2, DM3, DM4, VR1 and VR2 significantly less damaged trees were observed comparing to sites DM1, KP and LN (Table 2; Table 3). In addition, no mortality was detected. A research about natural regeneration after SB harvesting was conducted in southern Finland (Saksa, 2013), where more natural Scots pine seedlings and less natural Norway spruce seedlings were observed in SB harvesting sites. In sites DM2, DM4, VR2 no significant differences in the density of naturally ingrown Scots pine and Norway spruce trees was observed between subplots. Furthermore, density of naturally ingrown trees in these study sites was low. In site DM3 where Norway spruce was planted in combination with black alder natural Norway spruce density was low and no significant differences between subplots were observed, but naturally regenerated Scots pine density was significantly higher, especially in the WTH subplot contrary to the results of the mentioned Finnish study. In site VR1 in young stand of black alder naturally ingrown tree density was low, but in 2018 significant differences were observed: natural Norway spruce density was higher in the WTH subplot; natural Scots pine density was higher in the WTH+SB subplot similarly as observed in the Finnish study.

Conclusions

SOH vs. WTH

1. The effect of WTH tree height was not detected during three initial years after planting in site DM1; during first two years after planting in site KP; during first year after planting in site LN.
2. In site KP (site rich in nutrients) three years after planting statistically significant differences were detected – the height of Norway spruce was higher in the WTH subplot.
3. In site LN (oligotrophic growth conditions) two and three years after planting statistically significant differences were observed – the height of Scots pine was higher in the SOH subplot.

WTH vs. WTH+SB

4. In Norway spruce stands (site DM3, DM4 and VR2) tree height was significantly higher in WTH subplots – in the fourth and fifth year after planting in site DM4 and VR2, in the fifth year after planting in site DM3.
5. In mixed stands of Norway spruce and black alder (site DM2) no significant differences were observed regarding the height of Norway spruce; while the height of the black alder was significantly higher during the fifth year after planting in the WTH+SB subplot.

6. In black alder stands (site VR1) the height of trees in the WTH subplot both during the fourth and fifth year after planting was significantly greater than in the WTH+SB subplot.

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RESTORATION OF SPRUCE AND PINE IN NORTH-WEST RUSSIA

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Abstract
The analysis of regeneration processes on post-agrogenic lands allows establishing patterns and features of succession processes in phytocenosis, to identify the most appropriate measures to promote natural regeneration and to establish the possibility and feasibility of the production of forestry crops on lands left out of agricultural use. A study of forest regeneration processes in areas of fallow land for agricultural purposes adjacent to the floodplain of the Oredezh river in Gatchina district of Leningrad region. On the prepared study plots (0.25 ha) in different elements of the slope relief, the natural regeneration of pine and spruce and living ground cover was also taken into account. The soils on the objects of the study are agricultural soils of different thickness, from 30 to 45 cm. In two areas the soil is turfy, well-cultivated, concealed podzolic, ferrous illuvial soil on sands. On plots No. 3 – 5, the soil is turfy, well-cultivated, concealed podzolic, ferrous illuvial, clayey, on a red loam. The purpose of the study was to identify the nature of forest regeneration processes in areas of fallow land for agricultural purposes. It has been established that the composition of the emerging undergrowth depends on a number of factors: the type of soil, the taxation characteristics of the adjacent forest, the forest vegetation subzone, and the living ground cover. In these soil conditions on the deposits, young mixed undergrowth with a predominance of spruce and pine after a meadow stage of ruderal vegetation is formed.
Key words: regeneration of spruce and pine, postagrogenic lands, sandy and loamy soils.

Introduction

Pine (*Pinus sylvestris* L.) and spruce (*Picea abies* Kr.) belong to the main forest-forming species of the boreal zone. The analysis of regeneration processes on post-agrogenic lands allows establishing patterns and features of succession processes in phytocenosis, to identify the most appropriate measures to promote natural regeneration and to establish the possibility and feasibility of the forest crops production on lands left out of agricultural use. As of 2007, the total area of agricultural land used in Russia was estimated at 220 million ha. From 1961 to 2003, 58.3 million ha of land were withdrawn from economic circulation. From 1990 to 2007, the reduction of land used for arable land amounted to more than 10.8 million ha (Romanenko, 2008). A comparison of these values leads to the conclusion that during this period there was an increase in the deposit area by more than 20 million hectares. At present, about 56 million ha of agricultural land in Russia have been removed from circulation. In a number of regions of the North-West of Russia, about 40 – 60% of arable land is abandoned, and young softwoods grow there. Meanwhile, the lands excluded from the agricultural production have a high biological potential, as evidenced by the formation of highly productive undergrowth thereon (Kalinina *et al.*, 2009; Lyury, Goryachkin, & Karavaeva, 2010; Belousov, 2015; Golubeva, 2015; Danilov *et al.*, 2016).

The data of different authors on the composition of undergrowth on the post-agrogenic lands vary greatly. On the southern border of the common pine area, pine stands of different thickness are formed on abandoned arable land

For the conditions of the Upper Volga region, it has been established that in the initial stages of settlement 10 – 12 of tree-shrub species are involved in the deposits, of which only alder and birch belong to the predominant species in the formation of young growth. The formation of spruce forests without a change in the species composition in the territory of the European North may occur, including, on lands that used to be in agricultural use. Pine, alder, birch and willow take an active part in the regeneration of forest vegetation in fallow lands of the middle subzone of the taiga. Based on the analysis of literature data, the majority of naturally formed tree stands on former agricultural lands are distinguished by high productivity (Ia – I classes of bonitet).

The average bonitet of spruce plantations growing on farmlands is higher by 0.4 than that of spruce forests growing on indigenous lands. Lands left out of agricultural use have a leveled arable horizon, unlike forestlands, where the humus horizon is mosaic-related with the relief and parcel structure of vegetation, as well as the distribution of groups of trees. The acidity of these soils is also lower than the one of the forest soils, which makes mineral nutrients more accessible for tree species. The rate of overgrowing of plots depends on the area of abandoned fields. Plots up to 10 ha are overgrown in a few years after the withdrawal of land from agricultural use. On the plots of 100 ha or more, the process can be extended over decades. It is possible to speed up the process by implementing silvicultural activities aimed at promoting forest regeneration (Romanenko, 2008). Long-term use of land for arable land, although it leads to a profound transformation of ecosystems, does not preclude the

possibility of their regeneration after the removal of anthropogenic load to a climax or subclimax state over the foreseeable period. Post-agrogenic successions on the deposits go towards the formation of zonal types of ecosystems according to classical succession schemes, which can be transformed by the initial states of the deposits during their withdrawal and their subsequent anthropogenic use (Kalinina *et al.*, 2009; Romanenko, 2008). Post-agrogenic lands of the taiga zone of the North-West of the Russian Federation are at different stages of succession, which is manifested in the ecological and floristic features and the connection of certain plant species with the severity of microrelief. The lack of information and the disconnectedness of data on the course of the forest formation process on the former agricultural lands does not allow the formation of a scientifically based system of measures for the rational management of forestry in these areas. The solution of this problem requires a rational approach to the choice of the method of carrying out reforestation measures, ensuring the formation of high-yield forest stands of the required quality. This can be achieved through natural reforestation, with the use of effective measures to promote natural regeneration, as well as the creation of artificial tree plantations of various shapes and species. Based on the above, the purpose of the work carried out was the study of forest regeneration processes in areas of fallow lands.

Materials and Methods

The objects of study were areas of former arable land located in the most drained northern part of the Oredezhskoye plateau on Devonsky sandstones (N 59°20´677´´ E 30°10´536´´; N 59°20´603´´ E 30°10´439´´; N 59°20´747´´ E 30°05´952´´ N 59°20´739´´ E 30°05´899´´). Study areas of 0.25 hectares were laid in different elements of the slope relief of these areas and records were taken of the natural renewal of pine and spruce and of the living ground cover. Soil formation in this area takes place on a fairly young Quaternary relief, which was formed under the influence of several glacial processes, the result of which was a rather complex lithological pattern. At rather small areas thick deposits of sand moraine and loamy moraines are found, two-term deposits represented by sandy moraines, underlaid with loamy moraines and three-term deposits of sandy loam on moraine moraines, underlaid by Devonian sands, soil formation is also significantly affected by the difference in the depth underlain by loamy moraines. A strong microrelief has a strong effect. Soil cuts were made to determine the particle size distribution and thickness of the soil horizons. In all studied areas, the soil is agricultural ground (A_{arable}) of different thickness from 30 to 45 cm. Due to the light grain size distribution and considerable cultivation, the podzolic horizon A_2, and often the transition horizon A_2B in the profile, is not distinguished. Prescription deposits in the studied areas are of 25-35 years. The soil in plots No. 1 – 2 is turfy well-cultivated concealed podzolic ferrous illuval soils on sands. In plots No. 3 – 5, turfy is a well-cultivated concealed podzolic, ferrous illuval, clayey on a red-colored loam.

When considering the process of natural regeneration, the following indicators were defined, which allow assessing the success of forest regeneration: the number of undergrowth per unit area; reliability of undergrowth; the height structure of the undergrowth and the uniform distribution of the undergrowth by area (frequency).

Accounting of the undergrowth under the canopy of tree stands was carried out using two methods: continuous recounting and selective statistical method.

To take into account the number of undergrowth using circular sampling, circular platforms of 10 m^2 or R=1.78 m were laid (Gryazkin, 1997).

Circular platforms were laid at the same distance from each other in a free move using at least 3 moves. The circular platforms were laid using a 178 cm long pole. The center of the next circular platforms was installed using the same pole, by moving it forward for two lengths.

In accordance with the generally accepted classifications (Rules for Reforestation, 2007), the undergrowth was divided:

1) by height – into 3 categories of coarseness: small – up to 0.5 m, medium – 0.51-1.5 m and large – more than 1.5 m;

2) by density – into three categories: rare – up to 2 thousand, average density – 2-8 thousand, dense – more than 8 thousand plants per 1 ha;

3) by distribution in area – into three categories depending on occurrence (occurrence of undergrowth is the ratio of the number of discount areas with plants to the total number of discount areas established in the study plot or the cutting area, expressed as a percentage): uniform – occurrence over 65%; uneven – occurrence of 40 – 65%; group (at least 10 pieces of small or 5 pieces of medium and large copies of viable and close undergrowth).

The resulting material was processed using the methods of mathematical statistics according to the following formulas:

1) The number of undergrowth per hectare, pcs ha^{-1} (M_{ha}):

$$M_{ha} = \frac{\sum N \cdot 10000}{n \cdot S}, \quad (1)$$

where ΣN is the total number of undergrowth on all discount areas, taking into account conversion factors, n is the number of discount areas, S is the area of one-discount areas (10 m^2).

Table 1

Scope of survey

Study plot	The number of measured stems of the undergrowth		The number of discount areas for accounting LGC
	To determine diameter	To determine height	
ППП1	984	1091	250
ППП2	1045	1050	250
ППП3	467	906	83
ППП4	355	709	50
ППП5	183	351	61

The total number of undergrowth, taking into account the recalculation of small and medium-sized undergrowth into large, specimens:

$$\Sigma N = 0.5\Sigma N_{м} + 0.8\Sigma N_{ср} + \Sigma N_{кр},$$

where $N_{м}$ – the number of small undergrowth, specimens; $N_{ср}$ – the number of average undergrowth, specimens; $N_{кр}$ – the number of large undergrowth, specimens.

Occurrence rate τ, %

$$\tau = \frac{n_1}{n} \cdot 100, \quad (2)$$

where n_1 – is the number of discount areas where the undergrowth occurred.

2) The homogeneity coefficient – HC. This indicator shows the placement of undergrowth by area. If HC<1, the distribution of undergrowth is random, if HC≈1 the distribution is uniform, if HC>1 this is the group distribution.

$$HC = \frac{\sigma^2}{M_{sq}}. \quad (3)$$

Results and Discussion

The proximity of the semination source (at a distance of 40-50 m – wall of ripe mixed coniferous stand) allowed the pine tree and spruce to regenerate successfully at plot No. 1 (Table 4.2). On the study plot

Table 2

Characteristics of the natural regeneration undergrowth on the objects of study

Study plot	Undergrowth composition	Characteristics of the undergrowth of the predominant breed					
		Average			Number in terms of large, specimens ha^{-1}	Occurrence, τ, %	Homogeneity coefficient (HC)
		Age A_{mid}, years	Height H_{mid}, cm	Accretion in height Z_{mid}, cm year			
ПП 1	6.4P 2.6S 0.6A 0.3Al 0.1B +WT	6.5	191.9	29.5	2.684	80.0	9.0
ПП 2	7.2P 2.8S +B+A	5.4	107.4	19.9	3.020	75.1	3.3
ПП 3	5.2S 2.6WT 2.0B 0.1Al 0.1O +A	3.9	40.6	10.4	3.171	91.6	2.3
ПП 4	5.0S 1.6B 3.2WT 0.2O +P	10.1	69.3	6.9	4.642	84.0	9.1
ПП 5	5.1S 0.1P 0.8B 2.8WT 1.2A	3.0	197.0	65.6	2.557	72.1	3.0

Tree species: pine – P, spruce – S, aspen – A, willow – WT, birch – B, alder – Al, oak – O.

No. 1, the pine is prevailing species; the next in number is spruce. Birch, gray alder and aspen are represented to a much lesser extent. Single specimens represent tree willow. The average age of a pine tree was 7 years; the average height was 192 cm. The density of pine undergrowth was 2.684 specimens ha^{-1}. Spruce undergrowth has an average age of 5 years, an average height of 74 cm and a density of 1.105 specimens ha^{-1} In the second plot, the regeneration of pine and spruce was also recorded (Table 2). On the trial plot No. 2, the dominant species is pine; spruce is represented to a lesser extent. Single birch and aspen are found. The average age of a pine tree was 5 years; the average height was 107 cm. The density of pine undergrowth was 3020 specimens ha^{-1}. Spruce undergrowth had an average age of 7 years, an average height of 90 cm and a density of 1.160 specimens ha^{-1}. On the study plot No. 3, the predominant species is spruce. Birch and willow are represented slightly less. Aspen, alder and oak are represented in a small amount. On the study plot No. 4, the predominant species is spruce. Also, the willow tree is represented in a large number. Birch took a middle position in numbers on this trial plot. Single specimens represent pine and oak (Table). On the study plot No. 5, the predominant species is spruce. A slightly smaller number represents willow. Birch and aspen are represented almost equally, and the pine tree was encountered on the study plot least of all. Thus, on each study plot, undergrowth had an average density (from 2.557 specimens ha^{-1} to 4.642 specimens ha^{-1}). The largest number of undergrowth in the study plot No. 4 (4.642 specimens ha^{-1} probably was due to the weak development of the living ground cover (53.3%). The smallest amount of undergrowth was found on the study plot No. 5 (2.557 specimens ha^{-1}). This amount of undergrowth is due to the large projective cover of the living ground cover (103.2%), which makes it difficult to develop undergrowth.

In all study plots the pine undergrowth is viable, insignificant amount of unviable undergrowth was observed in the study plots No. 1, 2, 5. Single dry undergrowth was observed on the study plot No. 2. On study plots No. 3 and No. 4, all undergrowth is viable. In general, the distribution of spruce undergrowth by categories of condition showed that the conditions for the development of viable undergrowth are optimal at this stage, which is associated with rare undergrowth and fertile growing conditions.

Pine undergrowth is generally viable. Dry undergrowth was not found on any of the study plots. On the study plot No. 1, all undergrowth was considered viable. The insignificant amount of unviable undergrowth was observed on the study area No. 2 (2%). On study plots No. 4 and No. 5 unviable undergrowth was 20%. This suggests favorable conditions for the emergence and development of pine undergrowth (Table 4).

When analyzing the height structure of the undergrowth, it is necessary to note its diversity and heterogeneity in the study plots. Summarizing the data, we can say that the share of large and medium-sized undergrowth at all sites was definitely more

Table 3

Distribution of the spruce undergrowth by category status

Study plot	Species	Category of spruce undergrowth, %			
		Viable	Non-viable	Dry	Total Without dry
ППП 1	Spruce	99.7	0.3	0	100
ППП 2		98.3	1.7	0.01	100
ППП 3		100	0	0	100
ППП 4		100	0	0	100
ППП 5		95.5	4.5	0	100

Table 4

Distribution of the pine undergrowth by category status

Study plot	Species	Category of pine undergrowth, %			
		Viable	Non-viable	Dry	Total Without dry
ППП 1	Pine	100	0	0	100
ППП 2		97	2	0	100
ППП 3		-	-	-	-
ППП 4		80	20	0	100
ППП 5		80	20	0	100

Table 5

Height structure of the natural regeneration undergrowth

Species	Study plot	Height structure of the undergrowth, %		
		small	medium	large
Spruce	ПП 1	16	82	2
	ПП 2	12	84	4
	ПП 3	80	18	2
	ПП 4	51	41	8
	ПП 5	12	31	57
Pine	ПП 1	13	39	48
	ПП 2	15	66	19
	ПП 4	0	40	60
	ПП 5	20	0	80

than the one of small undergrowth. In general, it can be said that the undergrowth was mostly medium, and the average undergrowth prevailed in the study plots No. 1 and No. 2. On study plots No. 3 and No. 4 small undergrowth prevailed, and in No. 5 – large. Such a high-rise structure suggests optimal conditions for the development of spruce undergrowth. Such undergrowth is able to withstand under the influence of adverse factors, such as high and low temperatures, and strong wind. Such undergrowth is competitive

Table 6

Dependence of the projective cover on the living ground cover and natural regeneration undergrowth of tree species

Number	Projective cover, %				Total projective cover, %	Number of tree species, specimens ha^{-1}
	grass		shrubs	mosses		
	cereals, sedge	herbs				
ПП 1	9.6	75.0	0.04	3.86	88.5	Pine 2684 Spruce 1105 Birch 58 Aspen 121 Willow 8 Alder 100 *Total: 4076*
ПП 2	24.22	57.18	0	1.9	83.3	Pine 3020 Spruce 1160 Birch 16 Aspen 4 *Total: 4200*
ПП 3	0.4	40.3	0	30.4	71.1	Spruce 3142 Birch 2212 Aspen 48 Willow 2807 Alder 133 Oak 84 *Total: 8426*
ПП 4	1.71	30.8	0	20.8	53.31	Pine 92 Spruce 4642 Birch 2360 Oak 260 Willow 4460 *Total: 11814*
ПП 5	36.3	50.66	0	6.0	92.96	Pine 74 Spruce 2557 Birch 475 Aspen 656 Willow 1623 *Total: 5385*

against other species and living ground cover for water and light. At the same time, the undergrowth of spruce is protected from the strong sunlight.

In the height structure of pine undergrowth, on the whole, large undergrowth prevails; there is not much undergrowth. Large undergrowth prevails on the study plots No. 1, 4, 5. On the study plot No. 2, the average height of undergrowth prevails. This height structure is formed based on the need for undergrowth of a pine tree to get enough light and water. Large undergrowth successfully survives in a competitive environment and is resistant to adverse climatic factors.

According to the number of undergrowth, spruce is characterized as average. Placement on the area is uniform. The value of the homogeneity coefficient indicates the group placement of the undergrowth (HC>1). This is due to the biological and environmental properties of spruce. In biogroups, coenotic connections between its components are preserved. Due to these connections, parcel isolation of spruce in groups is preserved. The resumption of hardwood in such biogroups is difficult, respectively; the chances spruce introductions into the main layer of the formed stand are many times higher. For single undergrowth spruce, with the exception of large specimens with a high growth rate, such chances are usually small. According to the number and density of undergrowth, pine is characterized as rare with group placement by area. The magnitude of the homogeneity coefficient is less than one (HC<1), which also indicates the random nature of the placement of undergrowth in the area. On these sample plots, the living ground cover prevents the emergence of pine undergrowth. Soil conditions are also affected, which are probably more suitable for the development of spruce undergrowth.

The data given below (Table 6) show that a number of regularities are revealed between the number of regrowth of tree species and the total projective cover of the living ground cover. There is a close connection between the number of undergrowth and the total projective cover of the living ground cover. This is especially pronounced on the experimental object No. 4, where with a smaller total projective cover, the number of undergrowth is greater, and at the same time, there is no cereal and sedge plants. A great influence on the natural regeneration of tree species has a share of forbs, grass and sedge in the total projective cover. Between the undergrowth and the grass layer there is a competition for the light, the elements of mineral nutrition. Soil ramping also occurs. The increase in the share of cereal and sedge in the total projective cover entails a decrease in the number of undergrowth.

Conclusions

The composition of coniferous stands of spruce and pine depends on a number of factors:

1. The most important factors are soil type, characteristics of the adjacent forest and forest vegetation subzone.
2. At the surveyed plots, there is currently a successful renewal of economically valuable species – pine and spruce.
3. Density of coniferous undergrowth, its age and average height in these areas exceed the recommendations of the transfer to a wooded area of plantings of artificial or natural origin on the lands of the forest fund.
4. Soil has a significant impact on the development of undergrowth, largely determining the predominance of a particular tree species.
5. On sandy soils with underlying sand, the pine undergrowth prevails. Under loamy soils with underlaying loams, the undergrowth of spruce predominates. The presence of sod prevents the development of undergrowth. The cultivated soils are favorable for the undergrowth development.
6. In these soil conditions, on the deposits, a young mixed undergrowth is formed with a predominance of spruce and pine after a meadow stage of ruderal vegetation, depending on the underlying soil horizon under the former arable horizon.

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MACROSTRUCTURE AND DENSITY OF PINE AND SPRUCE WOOD ON FALLOW LANDS ON NORTH-WEST OF RUSSIA

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Abstract
Growing spruce and pine wood on land being out of active agricultural use is important for many European regions. The study of the qualitative characteristics of coniferous wood makes it possible to predict target indicators of the obtained raw materials. The influence of xylem structural elements on the density of spruce pine wood on the post-agrogenic lands of the boreal zone of Russia was studied. The objects of the research were spruce-pine stands growing on old arable land in the Gatchina district of the Leningrad region. Depending on the share of the species, various anatomical indicators of the macro-structure of wood influence the formation of the spruce and pine wood density. For the spruce part of the forest stand, the width of the annual increase makes a greater contribution to the formation of indicators of wood density. For the pine part of the forest stand, the density of the wood correlates with the proportion of late xylem. With a different proportion of the species, the influence of macro-structural elements on the density of wood changes. Conducted analysis of variance showed a significant effect of the forest stand composition on the anatomical macro-structure of spruce and pinewood.
Key words: pine, spruce, density of wood, anatomical macro-structure.

Introduction

The reduction of agricultural land in the last decade of the late XX century and the first decade of the XXI century is global. The problem of abandonment is manifested in the small and large agricultural sectors of Europe, the countries of South and North America, Australia, and countries of Asia, and it has been growing since the 1950s. More than fifty percent of the land is abandoned for reasons resembling the Russian ones: environmental, socio-economic, ideological, infrastructural, related to the transition of extensive agriculture to intensive one (Allen *et al*., 2005; Chenghua & Heping, 1992; Lyury, Goryachkin, & Karavaeva, 2010; Von Braun & Mirzabaev, 2016; Ramankutty & Foley, 1992).

Over the period of 1961-1987, according to the FAO, the area of agricultural land in Western Europe decreased by 11.4% of the world agricultural land and amounted to 25.1 million ha. Therefore, the problem of using land left out of agricultural use is relevant for European countries. In Russia, the main deposits body (45% of their total area) is located in the southern taiga subzone, where they represent about 20% of the territory (Romanenko, 2008).

The experience of growing coniferous tree plantations on post-agrogenic lands shows that such forest stands in terms of their reserve and productivity are superior to those planted on forestlands in many regions of Europe (Ruskule *et al.*, 2012; Zeidler, Vlastimil, &Schenfelder, 2018).The results of the research suggest that on former arable lands in North-West Russia, the joint cultivation of pine and spruce should be considered as a biologically justified silvicultural activity. On post-agrogenic lands trees show accelerated growth, which can lead to a decrease in the quality of wood. Earlier studies on this issue in various European countries show that, depending on the region of studies, the formation of spruce and pine wood density at the anatomical level can be influenced by various factors (Daugaviete *et al*., 2015; Bartoš, Souc˘ek, & Kacblek, 2010; Tomczak & Jelonek, 2013). Various authors have established trends in the density (physical and mechanical properties) of pine and spruce wood relative to growing conditions (Zeltiņš *et al*., 2018). Studies have shown that the radial growth of pine and spruce on the deposits is much higher than on forestlands (Golubeva, 2015; Lohov, 2011). A relatively rapid increase leads to an increase in the width of the annual ring and, consequently, to a change in the density of the wood. The basic density of pinewood on the fallow lands of the Arkhangelsk region is 10% lower than the average values for the study region. The increased density of spruce wood growing on old arable land is associated with a high percentage of late wood, which is more than average for the species. However, in contrast to the density of pine wood grown on fallow lands and having values below the average ones for the middle taiga subzone, spruce wood reaches a density of 60 years old and is close to the standard value. As for spruce and pine plantations of artificial and natural origin growing on the post-agrogenic lands in the Leningrad and Pskov regions, there is a high density of wood, however, the formation of wood density was influenced by various xylem structural elements (Danilov *et al*., 2016; Janusz & Danilov, 2018). The qualitative and quantitative indicators of pine and spruce wood growing on post-agrogenic lands in the conditions of the North-West of Russia are not lower than the average indicators for the region. The data on the basic density of

Table 1

The basic density of pine (*Pinus sylvestris)* and spruce (*Picea abies)* wood in the post-agrogenic lands of North-West Russia

Area	Species	Age, years	Base wood density, kg m^{-3}	Wood share, %	
				Early	Late
Leningrad region*	Spruce, forest crops	110	383	60	40
	Pine, forest crops	110	420	55	45
	Spruce, plantation crops	40	402	70	30
	Pine, plantation crops	40	422	65	35
	Spruce, natural plantations	120	460	55	45
	Pine, natural plantations	120	480	60	40
Pskov region*	Spruce, plantation crops	40	380	65	35
	Pine, plantation crops	40	360	60	40
Vologodskaya Oblast**	Pine, forest crops	55	360	73	27
	Pine, natural plantations	55	360	75	25
Arkhangelsk region***	Pine, natural plantations	65	400	55	45
	Spruce, natural plantations	60	388	67	33

According to * Danilov, 2016;** Lokhov, 2011; *** Golubeva, 2015.

wood in plantations on post-agrogenic lands in the Northwestern region given below show that in most cases the density of wood in pine and spruce is higher than the average indicators for the study region, which are: for spruce 370 – 380 kg per m^3, and for pine 400 – 410 kg per m^3. It should be noted that, depending on age and origin, the proportion of late and early wood in pine and spruce correlate differently in the annual growth and, therefore, affects the density of wood of these species.

Therefore, the task of our study was to reveal the influence of the xylem structural elements of pine and spruce on the density of their wood, as well as, to assess the contribution of the zone of early and late wood, and the width of the annual increment to the formation of the density of pine and spruce wood growing on post-agrogenic lands.

Materials and Methods

We have investigated four sites in the former arable lands with a stand of mixed trees of spruce and pine up to 80-85 years of age. The subjects of the research are located in the south-west of the Leningrad Region in the Gatchina District (Table 1). The soil represents a degraded agrozem covered with a humus horizon layer with presence of podsol 10 – 12 cm in thickness formed during formation of forest community. The underlying bed is a double-layer one, consisting of a red-colored moraine loam covered with a sandy loam horizon. The growing conditions of the region under investigation correspond to the I-Ia growth class.

To determine the parameters of the macrostructure and the physical properties of pine and spruce wood, cores were used that were obtained using an age drill at a height of 1.3 m from the root crown of 15 – 20 medium trees of the forest stand.. The age of the coniferous and deciduous species was determined by selected cores at the level of the root of the neck with the calculation of annual rings. Determination of wood basic density was performed according to recommendations of O.I. Poluboyarinova (1976) using the method of maximum moisture content of samples (Table 2). To study the elements of wood macrostructure in samples in the form of cores, the method of processing samples with a high resolution scanner was used, which, according to modern research, gives results with a measurement accuracy interval of ± 0.01 mm. The prepared wood sample, ground smooth and glued to the holder, was placed on a high resolution scanner, and the sample surface was scanned with an accuracy of 1200 dpi in full color mode (16.7 million colors). The digitized scanned image was adjusted subsequently in terms of brightness and contrast indicators to better distinguish early and late core wood. To measure the indicators of the wood macrostructure in the obtained image, the application ‘Geo-information system Panorama 10’ was used. The image was converted to a geographic information system with a resolution similar to the scanning resolution (conventionally, 1 m on an electronic map was taken as 1 mm). GIS tools were used to draw a line along the longitudinal axis of the core. For each annual increment, the boundaries of the zone of the late and early zones of wood were established and points were set on the line at the appropriate places. Thus, as indicators characterizing the macrostructure of wood, we measured the average width of the annual layers and the content of the late and early xylem in the annual layer during the life

Table 1

Taxation characteristics of pine and spruce stands on postagrogenic lands

Research object #1							
Species	Composition, %	A, years	D_{av},cm	H_{av},m	G,m^2	N ha^{-1}	M, m^3
Spruce	87	80	32.5	30.2	31.5	380	431
Pine	11	85	35.7	27.9	4.9	50	55
Aspen	0.5	50	17.4	21.7	0.2	7	2
Birch	1.5	60	19.4	22	1	33	9
Total:			32.6	30	37.5	470	497
Research object #2							
Spruce	55	80	27.1	28.2	23.3	405	309
Pine	38	85	35.2	27.8	18.9	197	215
Aspen	5	50	29.3	25.7	2.3	34	27
Birch	2	60	18.0	21.6	1.4	54	14
Total:			30.1	28.0	45.9	690	565

Table 2

Basic density of spruce and pine wood at the research objects (kg m^{-3})

Diameter class, cm	12	16	20	24	28	32	36	40	44	48
Research object #1										
Spruce	412	397	406	360	356	382	389	436	366	412
	448	446	383	356	385	373	360	418	341	448
Pine	-	-	376	384	413	419	392	387	376	379
	-	-	-	-	373	393	374	381	367	387
Research object #2										
Spruce	406	462	445	383	408	437	427	-	-	-
	564	407	435	390	449	459	-	-	-	-
Pine	-	-	-	396	348	404	367	377	374	323
	-	-	-	360	381	370	351	380	396	377

of the tree. These indicators were determined for all wood samples taken from model trees in the study plots. Later, the Microsoft Excel spreadsheet processor was used to systematize the obtained quantitative and qualitative data on the macrostructure of pine and spruce wood.

The collected field materials were processed by variation statistics methods; the processing of the obtained qualitative and quantitative data was carried out using the following software: Statistica 10, STATGRAPHICS Centurion XVI, and Microsoft Excel. Correlation and ANOVA analysis of the obtained data were used.

Results and Discussion

Depending on the fraction representation (%) classes of trunk diameter (cm) spruce and pine stands observed at different ratio share the late and early wood growth ring of wood (Figures 1-2). In the forest stand at the experimental object (1) with a predominance of spruce, there is a tendency to decrease in the proportion of late wood in the annual rings. In the stand with less spruce participation, this trend is not observed. For pine stands, there is a slight decrease in the share of late wood in annual rings towards large classes of trunk diameter at experimental sites.

The obtained data on the proportion of late and early wood in spruce and pine trees in thickness values at the study plots show different quantitative ratios in these stands. With a larger share of spruce in the composition of plantations in the macrostructure of annual growth, a greater percentage of early wood is observed than in the forest stand with lower participation thereof. The same trend is observed for the pine part of the stand. Apparently, an increase in the proportion of the species in the composition of the forest stands affects the increase in the growth of early wood. It should be noted that there is a large variability in the ratio of the proportion of late and early wood along the tree thickness values in the spruce element of plantations.

Conducted correlation analysis of data on the correlation of macro-structural elements and the density of spruce and pinewood showed a different correlation ratio between these indicators in plantations

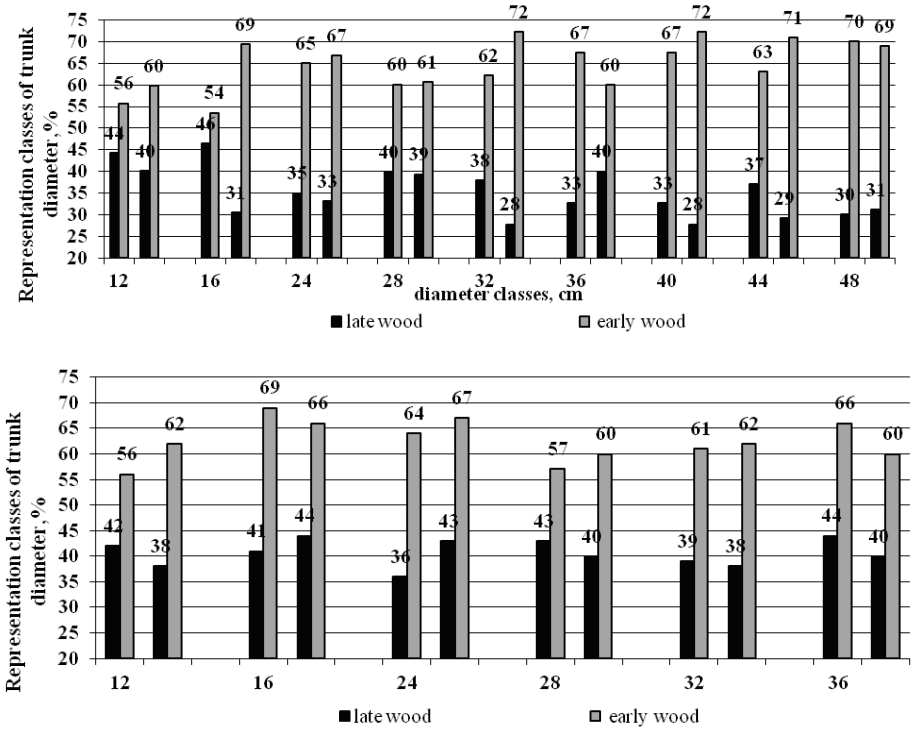

Figure 1. Spruce sample plot #1 & plot #2.

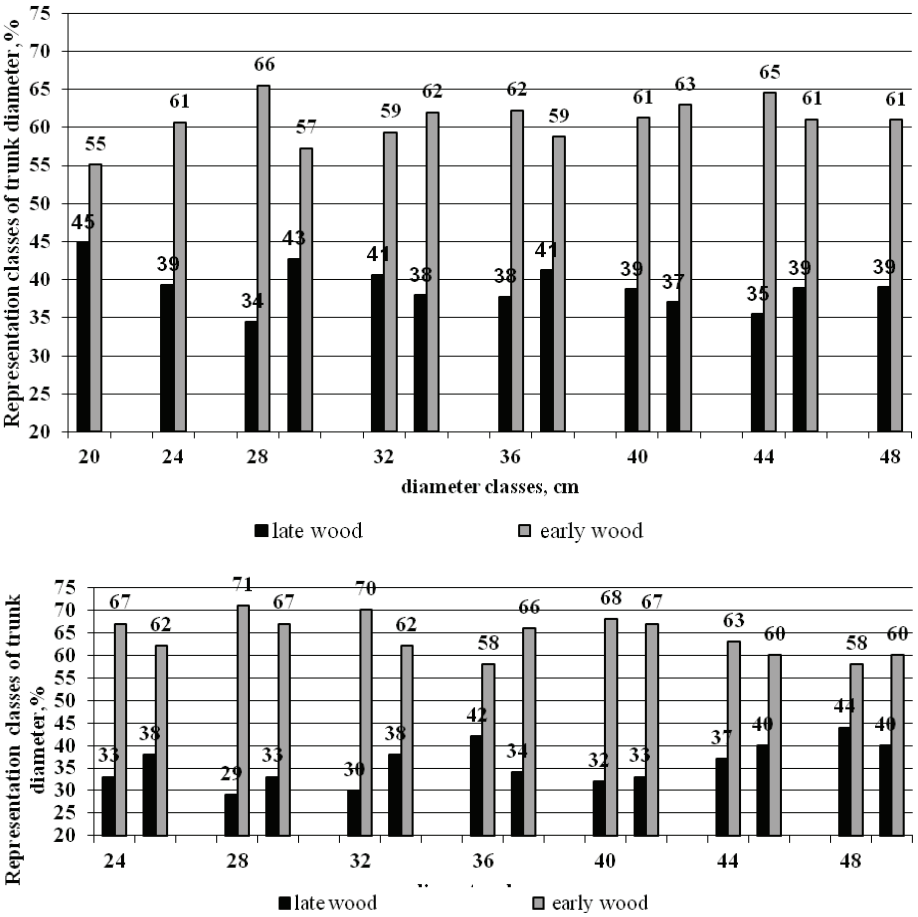

Figure 2. Pine sample plot #1 & plot #2.

Table 3

Rank analysis of correlation of macrostructure and density of spruce-tree and pine-tree wood in the mixed forests (by Spearman's criterion)

Pair of Variables	80%- spruce-tree in the composition			58%- spruce-tree in the composition		
	Valid N	Spear-man R	p-value	Valid N	Spear-man R	p-value
late wood zone & basic wood density	40	0.410	<0.05	26	0.513	<0.05
early wood zone & basic wood density		-0.251	<0.05		-0.201	<0.05
annual ring width & basic wood density		0.762	<0.05		0.654	<0.05
18%- pine-tree in the composition				38%- pine-tree in the composition		
late wood zone & basic wood density	28	0.772	<0.05	28	0.842	<0.05
early wood zone & basic wood density		-0.183	<0.05		-0.234	<0.05
annual ring width & basic wood density		0.524	<0.05		0.451	<0.05

Conducted analysis of variance of the data showed a significant difference in the xylem structural elements depending on the share of the species in the plantation (Table 4).

Table 4

Dispersion analysis of the significance of differences in the indicators of the spruce and pine wood macrostructure on experimental objects

Variables	Av.sq. deviation	Sum.sq. deviation	St.tr. deviation	Av.sq. deviation	F_{estim}	F_{table}	Value p
Pine 18% and 38%							
Late wood	0.00031	280.914	3407	0.08245	10,4	5.2	<0.05
Early wood	1.08542	2644.476	3407	0.77619	17.7	5.2	<0.05
Annual ring width	1.04910	4243.677	3407	1.24558	17.1	5.2	<0.05
Spruce 80% and 58%							
Late wood	10.4830	214.326	5506	0.03893	269.3	5.1	<0.05
Early wood	101.3796	4157.009	5506	0.75500	134.3	5.1	<0.05
Annual ring width	177.0627	5570.784	5506	1.01177	175.1	5.1	<0.05

with different shares of these species (Table 3). On the experimental object with a predominance of spruce, a closer correlation was found between the density of wood and the width of the annual increment (R_s=0.710). For the correlation between the density of spruce wood and the zones of late and early xylem, a moderate (R_s=0.410) and weak correlation (R_s=-0.251) was revealed. For the pine part of the forest stand, a bigger correlation was found between the density of wood and the zone of late xylem (R_s=0.772) than with the width of the annual increment (R_s=0.524). The density of pinewood correlates weakly with the zone of early xylem (R_s=-0.183). In a tree stand with a larger share of pine participation, the correlation between structural elements and wood density is slightly different. For the spruce part of the forest stand, the correlation between the density of wood and the width of the annual growth is lower (R_s=0.654), and with the proportion of late wood it is higher (R_s=0.513) than in the forest stand with its larger participation. For the pine part of the forest stand, the density of wood correlates more strongly with the proportion of late xylem (R_s=0.842) and less with the width of the annual increment (R_s=0.451). The correlation between the density of wood and the zone of early xylem is higher (R_s=-0.234) than in the forest stand with a lower participation of pine.

Conclusions

Based on the study, the following conclusions can be made:

1. On post-agrogenic lands, the density of spruce wood has a large correlation with the proportion of late xylem.

2. In the pine part of the forest stand, the density of wood correlates more closely with the proportion of late xylem.
3. With an increase or decrease in the composition of the forest stand of spruce and pine, there is a change in the content of the proportion of early and late wood in the annual growth.
4. With the change in the share of the species in the composition of the stand, the correlation ratio between the density of wood and the xylem structural elements changes.
5. The composition of the stand has a significant effect on changes in the spruce and pine wood macrostructure on the post-agrogenic lands.

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HABITAT MANAGEMENT FOR CAPERCAILLIE *TETRAO UROGALLUS* L. LEKS: THE SURVEY OF VEGETATION CHANGES

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Abstract
The capercaillie *Tetrao urogallus* L. is a typical bird species inhabiting structurally diverse coniferous forests. To increase the habitat quality of capercaillie leks, experimentally the habitat restoration in degraded ecosystems has been practiced. The main habitat restoration events are related to the reversion of hydrological regime and understorey layer management. The aim of this study was to find out how the management of lek sites – mowing of *Ledum palustre* L. and ground vegetation – promotes the regeneration of the vegetation typical of the capercaillie leks. Three sample plot blocks of 10x30 m have been established, which have been divided into 3 variants of 10x10 m. The first is a control plot, in the second plot an entire ground vegetation mowing was performed, while in the third plot – the ground vegetation mowing in a 3 m wide strip was carried out. The vegetation was determined using the Braun-Blanquet recording form before the management – in August 2015, and after the management – in August 2017. The condition of the habitat of capercaillie is inadequate before management, since *Ledum palustre* prevails in the ground vegetation. Both types of ground vegetation management have had a significant impact on the projective cover of *Ledum palustre*. After mowing the entire area, it has decreased by half, but after mowing in a strip, it has decreased by 30%. The ground vegetation mowing in a strip enhances positively the regeneration of dwarf shrubs and herbaceous vegetation.
Key words: *Tetrao urogallus* L., *Ledum palustre* L., habitat management, mowing of ground vegetation.

Introduction

The capercaillie *Tetrao urogallus* L. is the world's largest ground-nesting grouse species inhabiting the boreal forest landscape, with a specific preference for raised bog, old and bog-type forest patches. It is a typical bird species inhabiting structurally diverse coniferous forests, and it has a complex social structure of the population (Kalniņš, 1958; Hofmanis & Strazds, 2004). Therefore, capercaillie has been prioritized as umbrella species for indicating biodiversity qualities in the forest ecosystems (Pēterhofs, 2018). The capercaillie may show the changes in habitat use due to seasonality. However, during the winter time and early spring season birds utilize old-growth pine-dominated forest stands, and in the summer – dwarf shrubs, especially, bilberry areas (*Vaccinium myrtillus* L.) and insect-rich spruce forests (Spidsø & Stuen, 1988; Storch, 1993). In addition, breeding females prefer bog woodlands where cottongrass (*Eriophorum spp.*) is available. Furthermore, broods have been showed to positively associate with closed canopy in swamp forests with high invertebrate richness.

The capercaillie is red-listed species in many European countries. It is known that in the last decades many local populations of capercaillie have declined throughout the western and central European countries (Saniga, 2003), while recently the decrease in populations has also been recorded in Belarus (Zizas *et al*., 2012), Fennoscandia (Lindén, 2002) and Baltic countries (Lõhmus *et al*., 2017). Despite this, the present core area of the populations is in the western part of Russia and Fennoscandia. The underlying causes of population decline and, in some regions even extinctions, are still unclear, but most of the studies highlight the negative impact of human-induced changes in the forest landscape (especially, forest habitat fragmentation, isolation, loss of connectivity), the impact of climate change and rising temperature, and higher predation pressure. Also, the spatial requirements for capercaillie leks may consist of large areas, where males are using an area of at least 300 ha (Rolstad & Wegge, 1989). In Latvia, the conservation of capercaillie is aimed at the preservation of the forest stand level approach where 'lek-center' with an entire area, including buffers, is protected, also called micro-reserves. Furthermore, in Latvia, the area from strictly to voluntary protected lek sites is estimated as approximately 45.159 ha (Lõhmus *et al*., 2017).

Over the last decade, the forest and semi-open wetland drainage has been widely practiced in the northern temperate and boreal forests to increase the timber yields and reach sites for timber resources (Vasander *et al*., 2003). The recent calculation shows that in Latvia approximately 40% of peatland forests around the leks are classified as drained forest types, whereas the proportion of clear-cuts around leks are insignificant (Lõhmus *et al*., 2017). To increase the habitat quality of capercaillie leks, experimentally the habitat restoration in degraded ecosystems has been practiced. The main habitat restoration events are related to the reversion of hydrological regime (e.g. blocking ditches to raise water table) and understorey, and canopy layer management (e.g., mowing, burning or tree layer removal) (Hancock *et al*., 2011; Vasander *et al*., 2003).

The aim of this study was to find out how the management of lek sites – mowing of *Ledum palustre* L. and ground vegetation – promotes the regeneration of the vegetation typical of the capercaillie leks. In order to achieve the aim, the following tasks have been set: to characterize the vegetation of peatland pine forest stand in the lek of capercaillie before management, as well as to characterize and compare the ground vegetation of these stands after different types of management. Therefore, we hypothesize that the management of the capercaillie lek sites – mowing of the ground vegetation, especially, *Ledum palustre* – contributes to the regeneration of the ground vegetation typical of the pine peatlands.

Materials and Methods

The study was conducted in Latvia, which belongs to the boreo-nemoral vegetation zone. The mean air temperature in February is -3.6 °C and 16.9 °C in July. The climate is characterized from transitional maritime to continental toward the eastern part of the country. The average yearly precipitation is approximately 700 mm. The dominating tree species include Scots pine *Pinus sylvestris* L., silver birch *Betula pendula* Roth. and downy birch *Betula pubescens* Ehrh., Norway spruce *Picea abies* (L.) H. Karst., black alder *Alnus glutinosa* (L.) Gaertn., grey alder *Alnus incana* (L.) Moench., common aspen *Populus tremula* L., and broad-leaved species, whereas forest covers approximately 52% of the territory.

The studied capercaillie lek site is located in Plāņi rural municipality of Strenči county (Figure 1). The microreserve of the lek was established in 2003, with a total area of 167.7 ha having a buffer zone of 34.7 ha, characterized by different age classes of stands (70-180 years) dominated by Scots pine with an admixture of downy birch and Norway spruce. The number of breeding males for an area is from three to four.

Forest land drainage has been carried out in the area, so it is crossed by several ditches that have overgrown over time, but they have fulfilled their function, and the forest stands have become more productive whereas Norway spruce has often been detected. The drainage has also made changes in the ground vegetation, and currently *Ledum palustre* can be found over a wide territory, which in some places reaches the height of more than 1 m.

Three sample plot blocks have been established in the object or three repetitions of 10x30 m which have been divided into 3 subplots or variants of 10x10 m. In each variant, different ground vegetation management was performed during the vegetation period of 2015. The first is a control plot (control) where ground vegetation management or mowing was not carried out. In the second plot (management variant 1), an entire ground vegetation mowing was performed, while in the third plot (management variant 2) – ground vegetation mowing in a 3 m wide strip – in the center of the sample plot was carried out. Five 1x1 m square sample plots are located on the diagonal of the sample plot at certain distances – 1.4 m; 4.2 m; 7.0 m; 9.8 m and 12.6 m. The vegetation was determined in the sample plots using the Braun-Blanquet recording form (Muller-Dombois & Ellenberg, 1974) before the management – in August 2015 and after the management – in August 2017. The block scheme of sample plots is shown in Figure 2.

For each species, the mean projective cover has been determined using the data from 1x1 m sample plots. For plant species, a coefficient of occurrence was calculated according to Raunkier, which describes how frequently a given species is represented in all the investigated plots in total. The occurrence of plant species is equated to the parameter of consistency, determined by attributing it to the occurrence coefficient: I – <21, II – 21 – 40, III – 41 – 60, IV – 61 – 80, V – 81 – 100% (Muller-Dombois & Ellenberg, 1974).

For the comparison of the changes in species in different management variants, the Jacquard similarity

Figure 1. The location of the studied area.

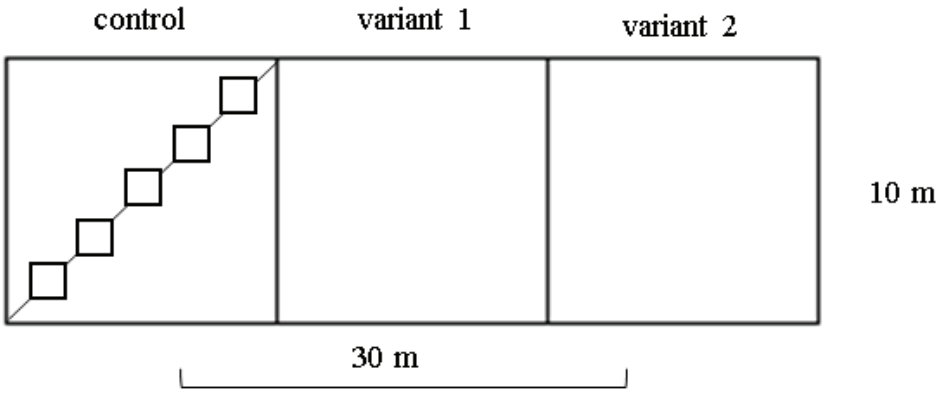

Figure 2. The block scheme of sample plots.

coefficient (J) was tested, which characterizes the number of species shared by two categories and the number of species unique to each category (commonly, these counts are marked as A, B and C) (Krebs, 1989).

$$J = \frac{A}{A+B+C}$$

T-test was used to analyze the data before and after the management (Arhipova & Bāliņa, 2006). Comparison of the mean projective cover of species depending on the management variant was carried out. A risk level of 5% ($P<0.05$) was used to define statistical significance. Data calculation was performed in MS Excel.

Results and Disscussion

Prior to the habitat management in 2015, the registration of ground vegetation species and their projective cover assessment were carried out in leks (Figure 3). In both layers – dwarf shrubs and herbaceous layer, as well as in the moss and lichen vegetation layer, nine species were identified: *Andromeda polifolia* L., *Calluna vulgaris* (L.) Hull, *Empetrum nigrum* L., *Eriophorum vaginatum* L., *Ledum palustre* L., *Oxycoccus palustris* Pers., *Vaccinium myrtillus* L., *Vaccinium uliginosum* L., *Vaccinium vitis-idaea* L. and *Aulacomnium palustre* (Hedw.) Schwagr., *Sphagnum magellanicum* Brid., *Dicranum polysetum* Sw. Ex anon. *Sphagnum capillifolium* (Ehrh.) Hedw., *Sphagnum palustre* L., *Pleurozium schreberi* (Brid.) Mitt., *Hylocomium splendens* (Hedw.) Shcrimp., *Cladina stygia* (Fr.) Ruoss, *Cladina arbuscula* (Wallr.) Rabenh. The most common species prior to the management are *Ledum palustre*, *Eriophorum vaginatum*, *Pleurozium schreberi* and *Sphagnum capillifolium*, which are the characteristic species of bog woodlands dominated by Scots pine (Ikauniece, 2017).

Before habitat management, the highest species cover was found for *Ledum palustre* (36.9 ± 1.8%)

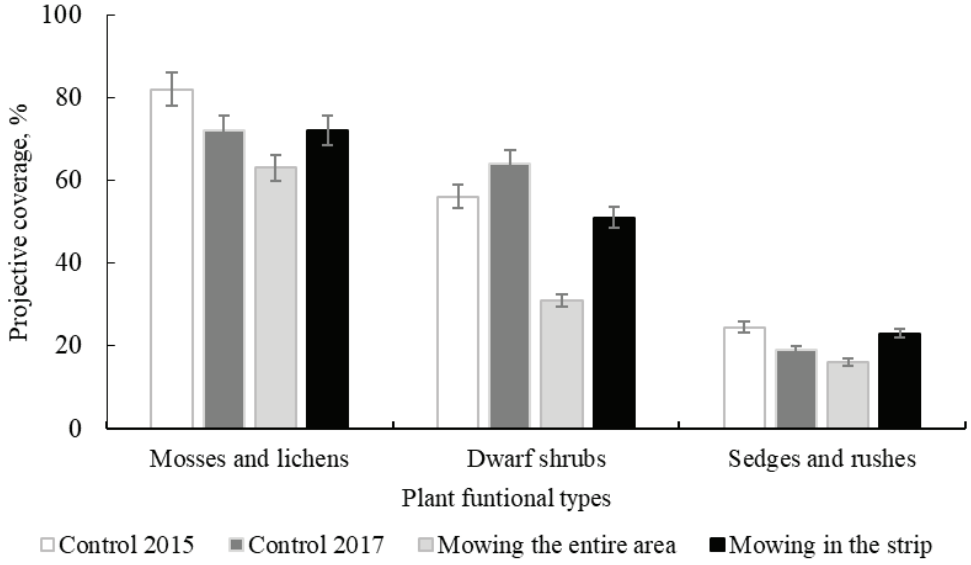

Figure 3. Plant functional type composition of the ground layer by management category. Mean projective coverage for each type, error bars indicate SE.

and *Eriophorum vaginatum* (24.5 ± 1.2%). The largest projective cover of mosses and lichens are *Pleurozium schreberi* (30.1 ± 1.5%), *Sphagnum capillifolium* (28.2 ± 1.4%) and *Sphagnum magellanicum* (13.9 ± 0.7%). For the other species in both vegetation layers the mean projective cover does not exceed 4%.

After the habitat management, data were collected in 2017. In total 10 species were recorded in the dwarf shrub and herbaceous layer, while 11 species were registered for mosses and lichens: apart from the species registered before, the presence of *Drosera rotundifolia* L., *Cladonia fimbriata* (L.) Fr. and *Polytrichum juniperum* Hedw. was found there. The highest occurrence of the following species was recorded in ground layer: *Ledum palustre, Eriophorum vaginatum* and *Oxycoccus palustris*, as well as *Pleurozium schreberi* and *Sphagnum capillifolium*.

After the management, in dwarf shrub and herbaceous layer the occurrence of *Ledum palustre* has decreased but with regard to other species, it has increased. In the layer of mosses and lichens, overall, for the species the occurrence has increased, but two species have been established only after the performed management practice. *Cladonia fimbriata* has been observed in shady areas, but *Polytrichum juniprum* – in open and semi-open patches. In literature it has been mentioned as a pioneer species, established after a natural disturbance (Strazdiņa *et al*., 2011).

In the controls, a significant projective cover is occupied by *Ledum palustre* (40.7 ± 2.0%) (Figure 4) and *Eriophorum vaginatum* (19 ± 1.0%). In the layer of mosses and lichens, *Pleurozium schreberi* (28 ± 1.4%) and also *Sphagnum capillifolium* (27.1 ± 1.4%) constitute the large proportion of coverage.

In the sample plots where mowing of the entire area was performed, *Ledum palustre* and *Eriophorum vaginatum* occupy the largest mean projective cover, however *Ledum palustre* cover has reduced significantly by half (19.1 ± 1.0%) (Figure 4), but coverage of *Eriophorum vaginatum* was decreased insignificantly (on average by 16 ± 0.8 %). This can be explained by the morphology of *Eriophorum vaginatum*, since it grows in clusters and regenerates in the clustering node, which is not affected during mowing. For several sphagnum and mosses, such as *Sphagnum capillifolium*, 20 ± 1.0%, forms the largest projection cover in the moss and lichen layer followed by *Pleurozium schreberi* (19 ± 1.0%), *Dicranum polysetum* (9.7 ± 0.5%) and *Sphagnum magellanicum* (8.9 ± 0.4%), but the absence of lichens was observed after habitat management.

In the sample plots where mowing was carried out in a strip, all above mentioned species are present in the ground vegetation layers. The largest projective covers, as before, are those of *Ledum palustre* and *Eriophorum vaginatum*. *Ledum palustre* projective cover (Figure 4) has decreased significantly ($p<0.05$) by 30%, while *Eriophorum vaginatum* has the highest cover here (21.2 ± 1.1%) – 10% higher than in the control sample plot and moderately higher than after mowing the entire area (Figure 4).

The results show that the management significantly affects the development of *Ledum palustre* after both mowing the entire ground vegetation and also after

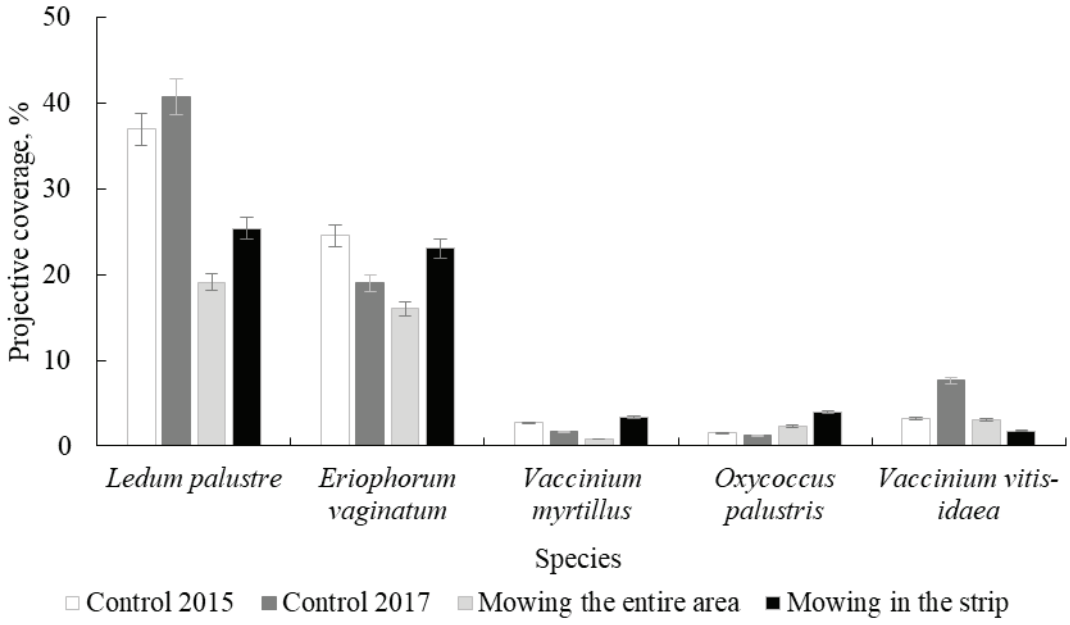

Figure 4. The projective coverage of *Ledum palustre, Eriophorum vaginatum, Vaccinium myrtillus, Oxycoccus palustris* and *Vaccinium vitis-idaea*. Mean projective coverage for each species by management category, error bars indicate SE.

mowing in a strip ($p<0.05$). There is also a significant difference in the development of *Oxycoccus palustris* after the entire ground vegetation mowing ($p<0.05$). The projective cover of *Oxycoccus palustris*, which is an important nutrient base species for capercaillie, increases significantly both after the entire area mowing and after mowing in a strip, but it decreases in the control sample plot, where *Ledum palustre* is a competitor with plant species and is one of the disturbing factors during the capercaillie breeding period, since it reaches the height of 71 ± 3.5 cm, which exceeds the height of ground vegetation suitable for capercaillie – 40 cm (Strazds *et al*., 2010). Coverage for *Oxycoccus palustris* rises only a few centimeters above the ground, so it has not been affected by mowing and it has been able to continue to grow and develop. The highest coverage of *Oxycoccus palustris* has been recorded just after the ground vegetation mowing in a strip, where the species coverage raised (Figure 4).

For the comparison of the changes in species in different management variants, the Jacquard similarity coefficient was determined. The changes were found in the dwarf shrub and herbaceous layer, comparing the control sites and those sites where an entire area mowing was performed (J=0.65), while the smallest changes were observed when comparing the control sites with sites where the mowing of ground vegetation was performed in a strip (J=0.85). It has been found that the species coverage of the tree layer affects the projective cover of *Ledum palustre*: with the increase in the tree layer projective cover, the projective cover of *Ledum palustre* decreases, while with the decrease in the projective cover of the tree layer, the projective cover of *Ledum palustre* increases (Figure 4).

Conclusions

1. The ground coverage of the habitat of capercaillie in the investigated breeding period before management is unsuitable, since *Ledum palustre* prevails in the ground vegetation. Its height is higher than the height of the ground cover suitable for capercaillie.
2. The ground vegetation management has contributed to the regeneration of only one species characteristic of capercaillie leks – that of *Oxycoccus palustris*. Its occurrence after the management has increased from 80% to 82.2%, and the projective cover has also increased by 20% after mowing the entire area and by 60% after mowing in a strip form.
3. Both types of ground vegetation management – the entire area mowing and mowing in a strip – have had a significant impact on the projective cover of *Ledum palustre*. After mowing the entire area, it has decreased by half, but after mowing in a strip, it has decreased by 30%.
4. The ground vegetation mowing in a strip, compared to the entire area mowing, enhance positively the regeneration of dwarf shrubs and herbaceous vegetation.

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EVALUATION OF POTENTIAL IMPACT OF SOIL SCARIFICATION PATTERN ON TREES' DAMAGES IN FUTURE COMMERCIAL THINNING

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Abstract
The aim of the study is to analyse the empirical data collected in 2017, explaining the distribution of mechanically damaged trees left after the commercial thinning, in order to characterize the potential impact of the change of soil scarification working direction on the intensity of damage to the trees left in the felling during the following pre-commercial thinning. The study found that extraction or leaving logging residues in the felling area did not significantly affect the productivity of the soil scarification, but in areas where logging residues were extracted, the depth of the furrows increased significantly, implying a better quality of soil preparation in these areas. The study did not identify the correlation between strip-road patterns (combined or uncoupled ends) with damage intensity, but the research hypothesis was confirmed that the number and proportion of damaged trees is significantly increasing at the ends of the technological corridors. A bigger increase of proportion of damaged trees at the end of strip-roads was found in pine stands. When modelling the effect of soil preparation and logging design on the proportion of damaged trees, species specific parameters should be used – the proportion of damaged trees at the corridor ends in pine stands is 68%, in spruce stands – 45% compared to the rest of the stand. The rest of the stand can be characterized by production statistics or by the results of the study – the average proportion of damaged trees in spruce stands is 4.9% and in pine stands – 0.8% of the remaining trees.
Key words: soil scarification, thinning, productivity, damages.

Introduction

Thinning is aimed to increase the profitability of forestry, while at the same time not impairing the growth conditions in the stand, therefore the planning of thinning is crucial for the future development of the stand. Soil preparation method also influences the further development of the stand. Comparing site mounding and disc trenching, the results obtained in Norway spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*) stands show that samplings planted on mounds forming deeper root system but in trenched sites the root system is formed parallel to the furrow (Celma *et al.*, 2019). Another study concluded that planting on mounds ensured higher productivity of Norway spruce and had no negative effect on quality or efficiency on thinning (Dzerina *et al.*, 2016). The quality of thinning is greatly influenced by the technical characteristics of the logging machines, as well as the capabilities and skills of the operators. The balance between productivity and damages to the remaining trees needs to be found. It is also important to carry out forwarding in such a way as to make as little damage as possible to the stems and roots. The risk of damages during winter is smaller than in the rest of the time. In Finland, research has shown that the risk of trunk and root damages is decreasing when working shorter shifts, as well as by performing thinning only during daylight hours. The risk of root damage is reduced by putting residues to strip-roads (Uusitalo, 2010).

Damages to the remaining trees, which affect the inner bark or deeper stem layers, can lead to the formation of a dry area and promote the decomposition (Shigo & Shigo, 1974), or significantly increase the risk of root rot infection, especially if the damages are in the root neck area. There is a very high (100%) likelihood of being infected with a root rot if the damaged area at the root neck area is at least 200 cm². The risk of infection is proportional to the area of damage. Although larch, oak and pine are not susceptible to the root rot infection, trees of these species suffer from the growth disturbances due to mechanical damages. But pine and spruce are susceptible to root rot infection, so the risk of infection is high even at relatively small trunk damage. According to research conducted in Finland, a 100 cm² bark abrasion results in 40% risk of being infected with a root rot that spreads further down the trunk about 20 cm per year (Isomäki & Kallio, 1974). The risk of spreading infection is largely influenced by the season, place and species of trees. Similarly, studies show that if the stem size ranges from 5 to 10 cm and from 17 to 35 cm, the growth of decayed trees over the next 10 years decreases by 13% and 35%, respectively. If the damages are at the root neck area, the impact on tree growth is more significant (Isomäki & Kallio, 1974). 70% of the roots are in the humus layer at 3 – 10 cm depth, therefore root damages during harvesting are unavoidable. Root lesions larger than 20 mm and closer than 0.7 m to the stem may become the site of infection of the root rot. Damages of the long marginal roots cause lasting effects on the growth, reducing it by up to 50%, but the possibility of the root rot infection entering the root lesions is twice as large as that of the trunk (Isomäki & Kallio, 1974). Earlier studies have shown

that trees growing on the edges of strip-roads have less growth than the remaining trees in the forest stand, which is likely associated with damage to the root system caused by logging techniques (Bredberg & Wästerlund, 1983; Eliasson & Wästerlund, 2007; Wästerlund, 1989). The growth is actually affected by the cumulative effect of lesions, which combine root damage and soil compaction on strip-roads (Prindulis, Kaleja, & Lazdins, 2016), but there will be a lack of research to demonstrate the impact of each type of damage.

In earlier experiments in Latvia, comparing the effect of strip-road density in delayed pre-commercial thinning, it was found that the average number of trees damaged in deciduous and coniferous stands is 7% of the total number of trees left. Coniferous stands had a relatively higher (2.7 times) proportion of root damage than deciduous stands. Thinning in coniferous stands in the trials was carried out in late autumn, which can be one of the main reasons for the relatively high proportion of damaged trees. In general, the rate of damaged trees in coniferous stands were by 21% less than in deciduous stands, which can be explained by the relatively high number of trees left (by 34% on average), respectively, the study shows a correlation between the total number of trees left and the number of trees damaged; in conifers, the correlation between the total number of trees left and the share of damaged trees has not been found. The largest proportion (25%) of damaged trees was found in conifers with 10 m between strip-roads, and the smallest – with 15 m between strip-roads. No correlation was found between damage to the trees left and the pattern of strip-roads. In conifers, a higher proportion of root damage was found in the stands where the width of the strip-roads is comparatively small (Kalēja *et al*., 2014; Petaja, Muižnieks, & Kalēja, 2017). The aim of the study is to analyse the empirical data collected in 2017, explaining the distribution of mechanically damaged trees left after the commercial thinning, in order to characterize the potential impact of the change of soil scarification working direction on the intensity of damage to the trees left in the felling during the following pre-commercial thinning.

Materials and Methods

The goal of time studies of soil tillage is to characterize the impact of logging residues on the productivity and time spent on maneuvers at the end of the furrows. Soil scarification time studies were done in 28 ha area, including 21 ha of *Myrtillosa, Hylocomiosa* and *Myrtilloso-sphagnosa* forest types on loamy soils and 7 ha in *Aegipodiosa* forest type on clay soils. Harvesting residues are laid on strip-roads in 17.6 ha and extracted in 10.4 ha area. Time studies are done during the daylight without interrupting the work process. The time while engine is switched on is recorded. The rest of the time is interrupted in time recording. At the start and end of the working day, the notes record the time when the job was started and completed. The working cycle is split by a single path, respectively; a new cycle begins at a turning point.

Mechanical damages of residual trees are counted in 77 ha of coniferous stands, where the prevalence of the dominant species (spruce or pine) is at least 70%. The average age of the stands is 37 years. At least 300 m long compartments with regular shape with low edge clearance (the smallest enclosure of the rectangle is at least 70% filled). In 2016, all stands were harvested in commercial thinning. The total length of the surveyed strip-roads is 31.2 km.

Location and type of damage of the remaining trees is recorded from the beginning of the strip-road in perpendicular to the longitudinal axis of the strip-road, as well as damage to the type of trunk or root. The counted damaged trees are marked with colour to avoid double counting. Each damaged tree is characterized by the number of the stand and strip-road, as well as the distance of the damaged tree from the beginning of the strip-road. Mechanical damage to undergrowth trees is not accounted. The starting point of each strip-road is always chosen at the side of the landing point.

Results and Discussion

A total driven distance during the soil scarification trials is 116 km. The average speed during the soil scarification is 2.93 ± 0.02 km h^{-1}. Outside the manoeuvring belts, the rate increases statistically significantly – up to 2.97 ± 0.01 km h^{-1}. The study did not detect significant differences in speed, depending on whether the harvesting residues are removed or left in a stand. The average mileage per 1 ha is 4.9 km (for more complex configurations – up to 8.5 km ha^{-1}, i.e. twice more than the average). The average depth of the furrow is 19 cm (15-21 cm). When logging residues were extracted, on average, 43 min of productive time were spent per 1 ha, if the harvesting residues are left in strip-roads – 37 min, excluding driving in and out of the stand. The difference is not statistically significant due to variation of the data. Comparing working time consumption for soil preparation in *Myrtillosa* and *Aegipodiosa* stand types, no significant differences have been found, although the consumption of productive working time for soil scarification in areas where logging residues are not extracted is slightly smaller than in areas where harvesting residues have been removed, respectively, 38 min ha^{-1} and 44 min ha^{-1}.

Most of the working time (79%) in the trials was used for the operation 'soil preparation', 12% of working time was spent on manoeuvring at the end of the furrows. The average manoeuvring time at the

end of each path is 20 seconds. In areas where logging residues have been removed, the manoeuvring at the end of each path averaged in 21 seconds, but in areas where logging residues left in strip-roads – 20 sec. The difference is not statistically significant when comparing different forest stand types and forest stands where the residues are extracted or left in strip-roads. The average distance between the paths is 4.8 ± 0.2 m. The average depth of the furrows is 18.6 ± 0.3 m (from 15.4 ± 0.4 m to 20.9 ± 1.4 m). The distance between the paths in the areas where the residues are left in strip-roads or extracted does not differ significantly. The average depth of the furrows in areas, where the residues are left in strip-roads, is 17.5 ± 0.4 cm, and in the areas where the residues are extracted – 19.7 ± 0.4 cm. The difference is statistically significant; the extraction of the residues improves the quality of soil preparation without significantly impairing productivity. The monitoring of forest regeneration has to be continued to find if there is a positive correlation between the depth of furrows and forest regeneration results in the long term.

The average number of damaged trees is 2.34%, including 2.22% outside the manoeuvring belts and 3.15% in the manoeuvring belts. The increase in the proportion of the damages in the manoeuvring belts (15 m from the edge of the felling area) is 41.9%. The increase in the share of the damages in different stands varies, in 6 out of 20 stands the damages at the ends of the strip-roads are not increasing. There were no stands where the number of damaged trees reduces at the ends of the strip-roads. Comparing the proportion of damaged trees in stands where the strip-roads are connected at the end or not connected no significant difference has been found. In spruce stands the increase in the damages at the ends of the strip-roads is not statistically significant; however the total proportion of damaged trees in stands where the strip-roads are connected is bigger.

The increase in the proportion of damaged trees is significant in pine stands. At the same time, no increase in the proportion of root damage has been found in pine stands. Weighted values have been prepared for the calculation model, taking into account the length of the strip-roads. In the pine stands included in the study, the weighted average proportion of mechanically damaged trees is 0.8%, in spruce stands – 4.9%. The increase of proportion of damaged trees in the manoeuvring belts compared to the rest of the stand is 68% in pine stands and 45% in spruce stands. The number and proportion of damaged trees in the 100-meter-long segment of strip-road in pine stands do not differ significantly, regardless of the length of the strip-road, although there is a tendency for the

Table 1

Activity data for calculation of length of strip-roads and soil scarification paths

Parameter	Symbol	Unit	Notes / default values
Soil scarification			
Distance between paths	d	m	4.8
Mineralized area	MJ	M^2 m^{-1}	1
Width of compartment	aD	m	100
Length of compartment	ab	m	500
Angle of furrows against axis	α	degrees	0-90°
Length of turning line	s_{apgr}	m	28
Driving speed	v	km h^{-1}	3
Thinning			
Distance between strip-roads	d	m	20
Width of strip-roads	p	m	4
Number of remaining trees in stand	N_s	No. ha^{-1}	800
Dominant species	-	-	Spruce or pine can be selected
Diameter of average tree	$D_{1.3}$	cm	18
Height of average tree	H	m	16
Share of damaged trees outside manoeuvring belts	BK_1	-	4%
Share of damaged trees inside manoeuvring belts	BK_2	-	31%
Angle of corridors against stand axle	α_1	degrees	$\alpha_1=\alpha+45^o$
Width of turning belt of forwarder	d_3	m	15

number and proportion of damaged trees decrease with an increase of the length of strip-roads. A similar trend has also been found in spruce stands.

The study involves felling sites extracted by various contractors, which probably had a significant impact on the results of the study, increasing the uncertainty of the calculated relationships. In order to characterize the impact of operator experience on these indicators, it is useful to carry out random sampling in subsequent studies, using automated data storage devices for recording of rut depth and stand composition. The results of such a study can be used to improve the training programs for operators and company managers.

Moderate correlation between density (basal area and number of trees) of a stand and the damaged

Table 2

Equations for calculation of productivity of soil scarification

Parameter	Symbol	Unit	Notes / default values
Turning distance	$S_{nog.}$	ha	$S_{nog.} = \frac{aD * ab}{10000}$
	S_{ABCD}	ha	$S_{ABCD} = \frac{ab * (aD + Aa)}{10000}$
Angle against axis of a stand 1°-90°			
Distance between paths	d^2	m	$d_2 = \frac{d}{\sin\left(\text{radians}\left(\text{if}(\alpha>90^o;180^o - \alpha;\alpha)\right)\right)}$
Length of straight path	AB	m	$AB = \frac{ab}{\sin(\text{radians}(\alpha))}$
β angle	β	degrees	$\beta=360^o - 90^o - \alpha$
Cathetus of rectangle triangle	Aa	m	$Aa = \tan(\text{radians}(\beta)) * ab$
Number of paths	N_{AB}	No.	$N_{AB} = \text{roundup}\left(\frac{Aa + aD}{d_2}\right)$
Total length of straight paths in parallelogram	s_1	m	$s_1 = AB * A_{AB}$
Total length of straight paths in compartment	s_2	m	$s_2 = \frac{S_{nog.}}{S_{ABCD}} * s_1$
Theoretical driving distance in compartment	s_3	m	$s_3 = \left((N_{AB} - 1) * S_{apgr.}\right) + s_2$
Driving distance	s_4	m ha^{-1}	$s_4 = \frac{s_3}{S_{nog.}}$
Time consumption	t	h ha^{-1}	$t = \frac{\frac{s_4}{1000}}{v}$
Mineralized area	t_1	ha ha^{-1}	$t_1 = \frac{s_4 * MJ}{10000}$
Angle against axis of a stand 0°			
Number of straight paths	N_{ab}	No.	$N_{ab} = \text{roundup}\left(\frac{ab}{d}\right)$
Length of straight paths in compartment	$\frac{s_1}{s_2}$	m	$\frac{s_1}{s_2} = N_{ab} * aD$
Theoretical driving distance in compartment	s_3	m	$s_3 = (N_{ab} - 1) * S_{apgr.} + \frac{s_1}{s_2}$
Driving distance	s_4	m ha^{-1}	$s_4 = \frac{s_3}{S_{apgr.}}$
Time consumption	t	h ha^{-1}	$t = \frac{\frac{s_4}{1000}}{v}$
Mineralized area	t_1	ha ha^{-1}	$t_1 = \frac{s_4 * MJ}{10000}$

trees was found in both pine and spruce stands after thinning. The correlation is characterized by a linear regression equation. No correlation has been found between the number of damaged trees and the residual basal area. This is in line with the advice of scientists to leave fewer trees during early thinning to produce larger-sized trunks in regenerative felling, thus reducing the number of damaged trees in thinning, too. In the calculation model, the relationship between the number of trees and the proportion of damaged trees is not taken into account, as the elaboration of a sufficiently accurate equation requires about 3 times larger number of the test objects. The results of the study are summarized in a model, which allows calculating the influence of the direction of soil preparation or tree columns on the productivity of soil preparation and damage of the leaves left in the regular shape stands. Table 1 lists the activity data necessary for the calculations.

The calculation of time consumption for scarification of 1 ha is summarized in Table 2. Depending on the angle of the soil preparation direction, relative to the base of the compartment, the calculation is divided into 2 scenarios – 1-90° and 0°. In the calculation, the selection of the scenario takes place automatically, depending on the parameters entered in the activity data table. Equations for calculation of share of trees damaged during thinning and length of strip-roads as well as other parameters are provided in Tables 3 and 4.

Table 3

Equations for calculation of share of trees damaged during thinning and length of strip-roads

Parameter	Symbol	Unit	Notes / values
Angle of corridors against axle of compartment	α	degrees	$\alpha=\alpha_{\text{soil scarification}}+45^{o}$
Width of manoeuvring belt	$S_{nog.}$	ha	$S_{\text{nog.}}=\frac{aD}{ab}$
	S_{ABCD}	ha	$S_{\text{ABCD}}=\frac{ab*(aD+Aa)}{10000}$
Angle of corridors against axle of compartment is 1°-90°			
Distance between corridors at the bottom of compartment	d_2	m	$d_2=\frac{d}{\sin\left(\text{radians}\left(\text{if}(\alpha>90^{o};180^{o}-\alpha;\alpha)\right)\right)}$
Length of straight path in strip-road	AB	m	$d_2=\frac{d}{\sin\left(\text{radians}\left(\text{if}(\alpha>90^{o};180^{o}-\alpha;\alpha)\right)\right)}$
β angle	β	degrees	$\beta=390^{o}-90^{o}-\text{if}(\alpha>90^{o};180^{o}-\alpha;\alpha)$
Cathetus of rectangle triangle	Aa	m	$\text{Aa}=\tan\left(\text{radians}(\beta)\right)*\text{ab}$
Number of straight paths	N_{AB}	No.	$N_{\text{AB}}=\text{roundup}\left(\frac{\text{Aa}+\text{aD}}{d_2}\right)$
Length of straight paths in the smallest triangle	s_1	m	$s_1=\text{AB}*N_{\text{AB}}$
Length of straight paths in the compartment	s_2	m	$s_2=\frac{S_{\text{nog.}}}{S_{\text{ABCD}}}*s_1$
Length of strip-road	s_4	m ha^{-1}	$s_4=\frac{s_2}{S_{\text{nog.}}}$
Length of manoeuvring path	d_4	m	$d_4=\frac{d_3}{\sin\left(\text{radians}\left(\left(\text{if}(\alpha>90^{o};180^{o}-\alpha;\alpha)\right)\right)\right)}$
Length of manoeuvring paths in compartment	$d_{4\,nog.}$	m	$d_{4\text{nog.}}=d_4*N_{\text{AB}}*2$
Length of manoeuvring paths per area unit	$d_{4\,ha}$	m	$d_{4\text{ha}}=\frac{d_{4\text{nog.}}}{S_{\text{nog.}}}$
Area of manoeuvring paths	$s_{apgr.}$	m²	$s_{\text{apgr.}}=\frac{d_2}{d_3}$
Number of manoeuvring paths in compartment	$n_{apgr.\,nog.}$	No.	$n_{\text{apgr.nog.}}=N_{\text{AB}}*2$

Parameter	Symbol	Unit	Notes / values
Area of manoeuvring paths in compartment	$S_{apgr.}$	ha	$S_{apgr.} = \frac{n_{apgr.nog.} * s_{apgr.}}{10000}$
Area of manoeuvring paths per area unit	$S_{apgr.\ ha}$	ha ha^{-1}	$S_{apgr.ha} = \frac{S_{apgr.}}{S_{nog.}}$
Area of strip-roads	$K_{nog.}$	ha	$K_{nog.} = \frac{s_2 * p}{10000}$
Share of area of strip-roads	$K_{nog.\ \%}$	-	$K_{nog.} = \frac{k_{nog.}}{S_{nog.}}$
Angle of corridors against axle of compartment is 0°			
Number of straight paths	N_{ab}	No.	$N_{ab} = \text{roundup}\left(\frac{ab}{d}\right)$
Length of straight paths per compartment	$\frac{s_1}{s_2}$	m	$\frac{s_1}{s_2} = N_{ab} * aD$
Distance driven	s_4	m ha^{-1}	$s_4 = \frac{\frac{s_1}{s_2}}{S_{nog.}}$
Length of manoeuvring path	d_4	m	$d_4 = d_3$
Length of manoeuvring paths in compartment	$d_{4\ nog.}$	m	$d_{4nog.} = d_4 * N_{ab} * 2$
Length of manoeuvring paths per area unit	$d_{4\ ha}$	m	$d_{4ha} = \frac{d_{4nog.}}{S_{nog.}}$
Area of manoeuvring paths	$s_{apgr.}$	m²	$s_{apgr.} = d_4 * d$
Number of manoeuvring paths in compartment	$n_{apgr.\ nog.}$	No.	$n_{apgr.nog.} = N_{ab} * 2$
Area of manoeuvring paths in compartment	$S_{apgr.}$	ha	$S_{apgr.} = \frac{n_{apgr.nog.} * s_{apgr.}}{10000}$
Area of manoeuvring paths per area unit	$S_{apgr.\ ha}$	ha ha^{-1}	$s_{apgr.ha} = \frac{S_{apgr.}}{S_{nog.}}$
Area of strip-roads	$K_{nog.}$	ha	$K_{nog.} = \frac{\frac{s_1}{s_2} * p}{10000}$
Share of area of strip-roads	$K_{nog.\ \%}$	-	$K_{nog.} = \frac{K_{nog.}}{S_{nog.}}$
Calculation of share of damaged trees			
Height coefficient	VH	-	Regulations of Cabinet of Ministers No 228, 07.03.2003
Basal area	G	m² ha^{-1}	$G = \frac{D_{1,3}^2 * \pi}{10000} * N_s$
Growing stock	M	m^3 ha^{-1}	$M = VH * G$
Average tree	$M_{vid.}$	m^3	$M_{vid.} = \frac{M}{N_s}$
Basal area of damaged trees	G_B	m² ha^{-1}	$G_B = G_{Bamj} + G_{Bmj}$
Growing stock of damaged trees	M_b	m^3 ha^{-1}	$M_B = M_{Bamj} + M_{Bmj}$
Number of damaged trees	N_B	No. ha^{-1}	$N_B = N_{Bamj} + N_{Bmj}$
Share of damaged trees	$N_{B\ \%}$		$N_{B\%} = \frac{N_B}{N_S}$

Table 4

Calculation of damaged trees in thinning

Parameter	Symbol	Unit	Manoeuvring belts	Outside manoeuvring belts
Basal area	G_{mj}	$m^2\ ha^{-1}$	$G_{\mathrm{mj}} = \frac{G * S_{\mathrm{apgr.}}}{S_{\mathrm{nog.}}}$	$G_{\mathrm{amj}} = G - G_{\mathrm{mj}}$
Growing stock	M_{mj}	$m^3\ ha^{-1}$	$M_{\mathrm{mj}} = \frac{M * S_{\mathrm{apgr.}}}{S_{\mathrm{nog.}}}$	$M_{\mathrm{amj}} = M - M_{\mathrm{mj}}$
Number of trees	N_{mj}	No. ha^{-1}	$N_{\mathrm{mj}} = \frac{N * S_{\mathrm{apgr.}}}{S_{\mathrm{nog.}}}$	$N_{\mathrm{amj}} = N - N_{\mathrm{mj}}$
Basal area of damaged trees	$G_{B\ mj}$	$m^2\ ha^{-1}$	$G_{\mathrm{Bmj}} = G_{\mathrm{mj}} * \mathrm{BK}_1 * (1 + \mathrm{BK}_2)$	$G_{\mathrm{Bamj}} = G_{\mathrm{amj}} * \mathrm{BK}_1$
Growing stock of damaged trees	$M_{B\ mj}$	$m^3\ ha^{-1}$	$M_{\mathrm{Bmj}} = M_{\mathrm{mj}} * \mathrm{BK}_1 * (1 + \mathrm{BK}_2)$	$M_{\mathrm{Bamj}} = M_{\mathrm{amj}} * \mathrm{BK}_1$
Number of damaged trees	$N_{B\ mj}$	No. ha^{-1}	$N_{\mathrm{Bmj}} = N_{\mathrm{mj}} * \mathrm{BK}_1 * (1 + \mathrm{BK}_2)$	$N_{\mathrm{Bamj}} = N_{\mathrm{amj}} * \mathrm{BK}_1$

The difference between the maximum and minimum predicted share of damaged trees is 0.42% (from 4.18% to 4.60%). The area occupied by the strip-roads (assuming a corridor width is 4 m) is 20 – 22%, depending on the slope of the strip-roads. The study proved that the variation of the share of damaged trees depending on the direction of the strip-road relative to the longitudinal axis of the compartment, is negligible, therefore the adaptation of the soil scarification pattern to optimize direction of strip-roads in later thinning, is not necessary and a design providing the lowest cost should be selected in soil scarification if no other requirements are set. The potential economic benefits because of a decrease in the proportion of damaged trees due to optimization of pattern of strip-roads do not outweigh the additional costs for soil scarification. In the example provided in this paper it is assumed that the quality of damaged trees is deteriorating and only the assortment of firewood can be produced from damaged trees and the remaining growing stock after the thinning is 164 $m^3\ ha^{-1}$, including 6.9 – 7.3 $m^3\ ha^{-1}$ of mechanically damaged trees, and the average tree is 0.21 m^3. AGM model is used in calculation of the stock changes (Šņepsts *et al.*, 2018), assuming that the 2nd thinning is done 20 years after the 1st thinning and 60 $m^3\ ha^{-1}$ including all damaged trees are extracted. Calculations of assortments were done according to the JSC 'Latvijas valsts meži' guidelines (AS 'Latvijas valsts meži', 2010). 48% of the volume will be saw logs and small logs, 41% paper pulp and 11% firewood. The difference in potential earnings in thinning is 8 EUR ha^{-1}, according to the prices of the round timber assortments available in the Central Statistical Bureau of 2018. Productivity of soil scarification in a regular configuration compartment, depending on the direction of soil scarification, varies by 7%, i.e. at an average soil preparation cost of 160 EUR ha^{-1}, the maximum theoretical cost deviation is 11.2 EUR ha^{-1}, i.e. more than the benefit due to reduction of the number of damaged trees.

Conclusions

1. The productivity of soil preparation in the study areas is not significantly affected by growing conditions and the presence of logging residues on strip-roads. The average time consumption per ha is 44 min, including 12% of time spent on manoeuvring at a perimeter of a stand.
2. The average distance between furrows does not differ, regardless of whether the logging residues are on strip-roads or extracted; in turn, the impact on the depth of the furrow is significant – extraction of the residues significantly increases the depth of the furrow improving the quality of the soil scarification.
3. The share of damaged trees at the ends of the strip-roads increases in the thinning significantly. The average increase in the proportion of damaged trees at the ends of the strip-roads compared to the rest of the strip-road increases by 45% in spruce stands and by 68% in pine stands.
4. The calculation model developed in the study proves that adapting the soil preparation design to the optimal placement of the strip-roads in thinning to be carried out 20-30 years after the soil preparation is not useful unless determined by nature protection or other conditions.

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TRANSFORMATION OF THE ORGANIC MATTER OF FOREST AND POST AGROGENIC SOILS OF THE BOREAL ZONE OF RUSSIA

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Abstract
The purpose of the study was to compare forest and postagrogenic soils by parameters such as carbon content in organic matter and total nitrogen to predict the fertility state of lands that are at the stage of restoration of woody vegetation. Areas with similar soil formation conditions were selected on the postagrogenic and forested lands having mature forest stands related with such types of forest: *Myrtillosum* forest, *Oxalidosum* and *Herbosa-Composita* forest, and also areas under the soil complexes of postagrogenic fallow lands. A number of physico-chemical indicators for the soil were assessed according to the methods generally accepted in soil science: the particle size distribution, the bulk density and the thickness of the pedogenic horizons were determined. An analysis of the carbon stocks in organic matter (C_{org}) and nitrogen (N_{total}) in the genetic horizons of the soils of myrtillosum, *Oxalidosum* and *Herbosa-Composita* forest types shows an increase in the content of organic matter and total nitrogen from *Myrtillosum* to *Herbosa-Composita* forest type. A comparative analysis of the physical and agrochemical state of postagrogenic and forest soils showed that, despite the previous anthropogenic impact, the agroland horizon retains a high content of organic matter and total nitrogen. The properties of postagrogenic soils in the studied areas are not deteriorated, and the transformation towards the natural forest soils of the region is not observed, despite the long period of fallowing.
Key words: organic matter, nitrogen, postagrogenic lands, *Myrtillosum, Oxalidosum* and *Herbosa-Composita* forest types.

Introduction

Soil organic carbon is one of the key elements of the global carbon cycle and can determine the properties of the soil, the content of available nutrient compounds for plants and the overall stability of the entire ecosystem. Soils deposit the most significant long-term volumes of organic carbon, for example, terrestrial ecosystems contain 4. 5 times more carbon from total land biomass and 3 times more than in the atmosphere (Zamolodchikov *et al*., 2005). The behavior of soil organic carbon is due to climate change and land cover or land use. In a soil ecosystem, organic soil carbon affects the physicochemical processes of the soil and serves as a source of nutrients for plants (Lurie *et al*., 2010). In recent years, predicting organic carbon stocks in soil has become a key issue due to the potential impact of carbon on climate change. Spatial prediction of organic carbon stocks in the soil has attracted considerable attention due to the large variation of organic matter at all levels.

The distribution of carbon and nitrogen in organic matter over the soil profile depends on many factors, the most important of which are: the mass and composition of incoming litter, its location (in the soil layers, in the litter layer, without contact with the soil), its decomposition intensity, acidity of decomposition products, and chemical properties of soil-forming rock. Recently, organic carbon content in undisturbed forest soils, as well as in soils derived from active agricultural circulation, is studied in many regions of Europe (Stolbovoi, 2002; Lopez de Gerenyu e*t al*., 2009; Tarnocai e*t al*., 2009; Golubeva, 2015; Baeva *et al*., 2017). The data from these studies suggest that restoration of tree species on postagrogenic lands will lead to a number of changes in the distribution of organic matter over the soil profile (Guzel, 1999; Melekhov, Antonov, & Lokhov, 2011; Golubeva, 2015; Ryzhova, Erohova, & Podvezennaja, 2014, Telesnina, 2015; Danilov *et al*., 2016). These changes associated with fundamentally different structures of functioning of postagrogenic ecosystems at the stages of meadows and forest biocenoses, are inevitable (Lopez de Gerenyu *et al*., 2009; Martens, Reedy, & Lewis, 2004; Poeplau *et al*., 2005; Zamolodchikov *et al*., 2005; Pan *et al*., 2011). Restoration of woody vegetation on postagrogenic lands will be accompanied by changes in the distribution of organic matter over the soil profile. These changes related to fundamentally different structures of functioning of meadow and woody biocenoses are inevitable. Meadow biocenoses have a short closed organic matter cycle, much of which is in the root fraction. In forest biocenoses, most of the synthesized substance goes to the growth of wood pulp of trunks and roots of trees, where organic matter would be located for many years and decades. In forest stands, most of the dead plant residues come at the soil surface in the form of leaf litter and woody debris, where they decompose, and their decomposition products are washed away with sediments and re-enter the soil. Forest detritus and woody debris decompose even much more slowly compared to the meadow one. Forest litter degradation takes place with the release of acidic decomposition products which, when released into the soil, affect the mineral part of the soil; that is manifested in the formation of a podzolic horizon in the soil profile.

In the meadow biocenoses, most of the intake of dead plant debris falls on the roots, and their decomposition takes place in the soil at the place of their formation. Meadow biocenoses differ from forest ones not only by a large mass of litter, but also by a high dispersion of plant residues in the top layer of soil, high nitrogen content, which contributes to their intensive decomposition and accelerated humification.

The changes will take place over a long period of time, amounting up to several decades. The first signs of changes will appear only after the tree crowns are closed, that is, with the beginning of formation of the forest phytocenosis. It is believed that the removal of arable land from crop rotation leads to an increase in the reserves of organic carbon in the soil due to the increasing amount of organic material introduced into it. But at the same time, it is necessary to take into account the level of agrotechnical measures carried out earlier for the studied soils. So, when the forest becomes overgrown with well-cultivated sod-podzolic soils, their humus state worsens (Litvinovich, Pavlova, & Chernov, 2002). On the other hand, there are studies that show the behavior of humus state indicators of postagrogenic soils in the course of natural forest regrowth using the example of soil time series derived from different crop rotation systems; they indicate an increase in the content of humus in the course of colonization of arable lands by vegetation and, on the contrary, some decrease in early stages of succession when a haying is overgrown (Telesnina, 2015). A comparative analysis of the carbon stocks behavior during postagrogenic succession in different regions of the European territory of Russia suggests that the same pattern is observed with the overgrowing of arable land with forest at different quantitative levels (Lurie *et al.*, 2010). At the first stages of succession, a decrease in soil carbon stocks is noted, with its subsequent increase at the following stages ranging from 30-80 to 150-170 years.

Estimates of carbon stock changes with a change in the nature of land use are of great interest: their greatest increase in soil up to 53% occurs with the natural regeneration of forest on former arable land. When forest plantations are created on arable land, carbon stocks increase by 18%, and they decrease on pastures by 10% (Guo & Gifford, 2002). In temperate climate conditions, the increase in carbon stocks in the soil makes 16 ± 7% during the first 20 years of forest formation in the former arable land (Poeplau, Don, Vesterdal, Leifeld, *et al.*, 2005). After 100 years, the carbon content increases by 83 ± 39% in the upper horizon with a capacity of 28 ± 13 cm, and taking into account litter – by 116 ± 54%. Many researchers recognize the leading role of organic matter in the formation of soil fertility (Fernandez-Martinez *et al*., 2014; Romanovskaya, 2006; Hooker, 2013). The main limiting factor in plant growth is often the content of available nitrogen in the soil. Its main part in the soil (up to 90%) is found in various specific humic substances, and only a small part of it is found in inhumified organic and mineral compounds.

Soil cultivation causes a diverse and profound effect on the biological, chemical, and physical properties of the soil, which leads to a change in the entire soil-forming process as a whole. Sod-podzolic soils lose their original features and acquire new ones. A powerful arable horizon is created there increasing the content of carbon, nitrogen and other elements of mineral nutrition. An increase in the carbon content is accompanied by a redistribution of the group composition of humic substances, an increase in the group of humic and a decrease in fulvic acids. Organic matter becomes less mobile, and more resistant to leaching and destruction. Along with a change in organic matter, an increase in the total nitrogen content is observed, but the amount of its hydrolysable fractions decreases (Fernandez-Martinez *et al*., 2014).

Boreal forests deposit carbon not only in woody biomass, but also in woody detritus, humus and in soil.

Forests growing on fertile soils with an adequate supply of nutrients can deposit about 30% of carbon for a long time; they absorb carbon during photosynthesis (Fernandez-Martinez *et al*., 2014). In contrast, forests growing on nutrient poor soils can deposit only 6% of carbon, since the rest of the volume is returned to the atmosphere.

Despite the availability of data on carbon stocks in the soils of various plant ecosystems, there is no complete picture of this issue. Therefore, the aim of the study was to compare forest and postagrogenic soils for such parameters as the carbon content of organic matter and total nitrogen, and to predict the fertility of land derived from active economic turnover.

Materials and Methods

Areas with similar soil formation conditions were selected on postagrogenic and forest lands within the limits of carbonate rocks in the south-west of the Leningrad Region in two administrative districts of Gatchina (30.2919086; 59.3695495999) and Volosovsky (59.370409; 29. 497581). We studied the content of organic matter and nitrogen in the profile of forest soils on 3 sites, under mature forest stands and on agricultural land derived from active agricultural use more than 35 years ago. For the study, spruce stands were selected as the most typical for the region of study. Indicators of forest stand on *Herbosa-Composita* forest types were at the age of 90 years, wood stock 400 m^3 ha^{-1}, average height 30 m, average diameter 36 cm. Indicators of forest stand on *Oxalidosum* forest types were at the age of 90 years, wood stock 350 m^3 ha^{-1}, average height 26 – 28 m,

average diameter 28 – 30 cm. Indicators of forest stand on *Myrtillosum* forest types were at the age of 90 years, wood stock 320 m^3 ha^{-1}, average height 26 m, average diameter 28 cm. Natural regeneration of woody and shrubby vegetation in the areas of fallow lands is represented by birch, aspen, alder, and willow shrub. The average height of hardwood is 2 to 4 meters. The distribution of woody vegetation is uneven. Wood stock in the studied areas is from 30 to 40 m^3 ha^{-1}. The research methodology is based on standard methods of soil science (Bankin *et al*., 2005). Soil pits and small trenches were laid in the most characteristic places of the surveyed area at each experimental site, excluding areas with non-typical microrelief elements and signs of soil disturbance. A number of soil physicochemical indicators were evaluated using generally accepted methods of soil science: the particle size distribution, the density of composition and the thickness of pedogenic horizons were determined. The density of composition of all horizons was estimated according to Kaczynski; carbon determination was carried out by dry ashing of total nitrogen according to Kjeldahl, pH of the salt extract – by the potentiometric method. Based on the data obtained, a comparative analysis was carried out.

Results and Discussion

The comparative analysis of the carbon stocks in organic matter (C_{org}) and nitrogen (N_{total}) in the genetic horizons of the soils of the *Myrtillosum, Oxalidosum and Herbosa-composita* forest types shows an increase in the content of organic matter and total nitrogen from the *Myrtillus* to *Herbosa-composita* forest and grass type (Tables 1-3). An integral indicator of soil fertility, which determines the productivity of the forest stand, is the C:N ratio in the humus horizon of the soil. In *Herbosa-composita* forest types, forest stands of productivity class I are mainly represented; in *Myrtillus* forest types, the productivity decreases to class II. At the same time, an increase in C:N ratio by organic matter in the humus horizons of the soil from 8 – 12 in *Herbosa-composita* types of forests to C:N about 17 – 18 in *Myrtillus* forest types and mountain *Oxalidosum* forest types is traced.

An analysis of the agrochemical indicators of highly productive forest stands shows that there is no clear correlation between the productivity of mature forest stands and acid-base indicators of the soil (Tables 1-3). Soil acidity in *Myrtillus* forest and *Oxalidosum* forest types increases down the soil profile. The lowest pH value was observed in the upper horizon, in the soil profile of a *Myrtillus* forest type, and it was equal to 3.7. In *Herbosa-composita* forest types, the pH is close to neutral values throughout the soil profile, since these soils are formed on a limestone moraine.

Low soil acidity in *Myrtillus* forest and oxalidosum forest types is associated with the impact of coniferous

Table 1

The carbon stock of organic matter (C) and total nitrogen (N) in the genetic horizons of forest soil *Myrtillus*, t ha^{-1}

Soil-forming rock Soil	Horizon Depth, cm		Volume weight, g cm^{-3}	$pH_{(KC1)}$	Soil organic matter			
					C_{org},%	C_{org} t ha^{-1}	C:N	N_{total}, t ha^{-1}
Moraine non-carbonate loam, Moderate and coarse humus podzolic	A_0	4.2	0.17	3.7	30	21.4	30.0	0.71
	A_1	0-10	0.63	3.6	3.05	19.22	18.2	1.06
	A_2	10-32	1.32	3.7	0.36	10.45	9.0	1.16
	A_2B	32-46	1.56	4.3	0.30	6.55	7.5	0.87

Table 2

The carbon stock of organic matter (C) and total nitrogen (N) in the genetic horizons of forest soil *Oxalis*, t ha^{-1}

Soil-forming rock Soil	Horizon Depth, cm		Volume weight, g cm^{-3}	$pH_{(KC1)}$	Soil organic matter			
					C_{org},%	C_{org} t ha^{-1}	C:N	N_{total}, t ha^{-1}
Moraine non-carbonate loam Moderate humus podzolic	A_0	0-5	0.14	3.8	28	12.2	23.0	0.53
	A_1	5-15	0.72	3.8	4.55	32.76	16.8	1.95
	A_2	15-27	1.44	4.1	0.60	10.37	12.0	0.86
	A_2B	27-49	1.51	4.4	0.48	15.95	9.6	1.66

Table 3

The carbon stock of organic matter (C) and total nitrogen (N) in the genetic horizons of forest soil *Herbosa-composita*, t ha^{-1}

Soil-forming rock Soil	Horizon Depth, cm		Volume weight, g cm^{-3}	$pH_{(KCl)}$	Soil organic matter			
					C_{org},%	C_{org} t ha^{-1}	C:N	N_{total}, t ha^{-1}
Carbonate loam, Leached soil	A_0	0-1	0.11	6.8	23	3.8	21.0	0.18
	A_1	1-10	0.9	6.8	3.8	34.2	12.0	2.85
		10-22	1.1	6.8	2.9	31.9	8.5	3.75
	A_2B	22-32	1.35	6.7	1.2	13.5	7.9	1.7
	B	32-60	1.55	6.8	0.86	37.3	7.5	5.0

litter on carbon-free soil-forming rocks, which favors actively the development of fungal flora involved in the decomposition of forest litter and mycotrophic feeding of tree species (Fedorchuk, Neshataev, & Kuznetsova, 2005). It is also worth noting the decrease in the content of organic carbon from the humus horizon to the podzolized ones: in the *Herbosa-composita* types of forest – by 2.8, in *Oxalidosum* – by 7.6, in *Myrtillus* forests – by 8.5 times. At the same time, there is a decrease with the depth of the C:N ratio profile:

– in sod-carbonate soil from 10 (in a layer of 0 – 20 cm) to 7.5 (in a layer of 32 – 60 cm);

– in sod-podzolic from 16. 8 (in a layer of 5 – 15 cm) to 9.6 in a layer of 27 – 49.

In the arable horizon of soils that are actively used in agricultural crop rotation in the area under study, the content of C_{org} ranges from 11.1 t ha^{-1} to 33. 3 t ha^{-1} (Boytsova & Regia, 2014).

As arable land overgrown with grass and shrub species of plants occurs, a certain increase of C_{org} content in upper horizon of postagrogenic soil is observed (Table 4). After removal of arable soil from agricultural use, weed vegetation begins to develop on them, which over time should be replaced by natural phytocenosis (Golubeva, 2015; Zamolodchikov *et al*., 2005; Lurie *et al.*, 2010; Telesnina, 2015). At the initial stages of overgrowing, the intake of a greater amount of fresh organic material in the form of plant and root litter increases as there is no alienation of biomass in the form of crop taken. All those contribute to the accumulation of carbon in the former arable horizon.

At present, the stage of overgrowth with trees and shrubs such as birches, aspens, and willows begins in the postagrogenic sites under study. Renewal is curtain in nature or occurs on micro depressions of the former fissures. The content of organic matter in the arable horizon of these areas of postagrogenic lands is at the level of mountain sorrel forest type, and the pH value on these soils does not have a wide variation in contrast to the forest soils of those forest types. The content of total nitrogen in these soils is high: from 5 to 7.4 t ha^{-1} at the level of the oak-grass type of forest.

Table 4

Characteristics of soil conditions of the surveyed land no longer used for agricultural purposes (prescription deposits of 30-35 years)

Site#.	Soil-forming rock Soil	Horizon, A arable, 50 cm	Volume weight, g cm^{-3}	$pH_{(KCl)}$	Soil organic matter			
					humus,%	C_{org}, t ha^{-1}	N_{total}, t ha^{-1}	C:N
1	Sod low-podzolic, gleied and loamy on red-brown sandy loam moraine	35.0	1.14	5.9	2.0	56.8	4.9	12.0
		15.0		5.9	1.0	11.3	2.5	5.0
2	Sod-podzolic sandy loam on the moraine deposits of Devonian rocks	30	1.27	5.3	2.7	54.0	5.1	10.6
		20		4.9	1.4	21.1	1.9	11.1
3	Sod-podzolic gleyic light loamy on moraine deposits of Devonian rocks	25	1.13	5.2	1.89	35.6	3.1	11.5
		25		5.2	1	18,8	1.6	11.8
4	Sod-podzolic, light loamy on moraine deposits of Devonian rocks	30	1.14	5.2	1.89	37.5	3.2	11.7
		20		5	1	14.5	1.4	10.4

The C:N ratio characterizing the enrichment of humus with nitrogen, for most agroland horizons of those soils is equal to 8 – 10, which corresponds to a high and moderate degree of availability of this element. A very high ratio (18 – 20) is characteristic of nitrogen-poor coarse-humus horizons of forest soils (Fedorchuk *et al*., 2005). By the content of C_{org} and N_{total} in the upper soil horizon, the following descending series is formed:

Herbosa-composita forest type > fallow land > *Oxalidosum* forest type > *Myrtillus* forest type > arable land.

Forest soils are characterized by a high level of variation of the C: N ratio along the profile. In the upper layer of postagrogenic soils, this ratio usually slightly varies and is 11 – 12, which confirms their high potential fertility.

No less important indicator reflecting soil fertility is the bulk density. 1.1 – 1.2 g cm^{-3} are suggested as the optimum values for loamy soils (Litvinovich, Pavlova, & Chernov, 2002; Golubeva, 2014). For arable horizons that are actively used in soil rotation, this figure ranges from 0. 8 to 1.1 g cm^{-3}. For forest soils, this indicator has a small value of 0.6 – 0.7 g cm^{-3} in the upper part of the profile (to a depth of 10 – 15 cm), and then begins to increase to 1.55 g cm^{-3} (at a depth of 30 – 40 cm). For fallow postagrogenic soils, the density of the arable layer varies from 1.11 to 1.4 g cm^{-3}, which indicates a tendency to compaction.

Conclusions

1. Summarizing the results for the comparative analysis of the physical and agrochemical state of postagrogenic and forest soils it can be noted that, despite the previous anthropogenic impact, the agroland horizons retain a high content of organic matter and total nitrogen.
2. The postagrogenic soil properties in the studied areas do not deteriorate and the transformation towards the natural forest soils of the region is not observed, despite the long period of fallowing (over 35 years). The tree vegetation on these lands is in the stage of formation and the stage of closure of the crowns has not come.
3. The total nitrogen content in the postagrogenic soils of the surveyed areas exceeds the indicators for the soils of the most productive forest types in the region under study. The carbon to nitrogen ratio in postagrogenic soils over the entire soil profile shows a higher fertility than in forest soils, where C:N is optimal only for the part of horizon A_1.
4. In forest soils, the largest supply of organic matter of carbon is concentrated in the litter; in the postagrogenic soils, it is concentrated in the upper layer of the former arable horizon. Unlike the forest soils, there is a slight increase in the compaction of the soil profile here.
5. With the overgrowth of developed low-carbon postagrogenic soils, its reserves will increase. The recovery time depends on the granulometric composition of the soil and on the difference in carbon reserves between the soils of the former arable land and the compared soils of the most productive forest types.

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MEDIUM-TERM IMPACT OF STUMP HARVESTING ON GENERAL SOIL PARAMETERS IN *HYLOCOMIOSA* SITE TYPE

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Abstract
Conifer tree stumps are a prospective source of bioenergy, but there are considerable uncertainties and risks associated with this forestry practice, and environmental consequences of stump harvesting are little studied in the Baltic countries. One of the major concerns is related to the risk of nutrient leaching that may cause pollution of watercourses and decline of tree growth in the next forest generation. The main aim of the present study was to estimate the effect of stump harvesting on general soil and soil solution parameters in three clear-cut areas located in *Hylocomiosa* site type (dominant tree species prior to clearfelling – *Picea abies* L. (Karst.)) over a period of 6 years after the stump removal. Two types of treatments were compared: whole-tree harvesting with only above-ground biomass removed (WTH) and whole-tree harvesting combined with the stump removal (WTH+SB). We found no acidification effect of soil and soil solution. Soil C and N stocks six years after harvesting were similar in the plots with and without stump removal, and demonstrated similar pattern of change in both studied treatments (WTH and WTH+SB). Nutrient content and patterns of change varied with the site and year, suggesting that the effects are rather site- than treatment-specific.
Key words: *Hylocomiosa*, stump harvesting, nutrients, soil, soil solution.

Introduction

Interest in forest bioenergy is growing rapidly on a global and regional scale, and stump harvesting is one of the alternatives to contribute to the transition from a fossil- to a bio-based economy (Berg, 2014). In addition to the production of woodfuel and creating additional revenue for the forest owners, stump extraction improves site preparation conditions and may potentially reduce infection with *Heterobasidion* (Walmsley & Godbold, 2010). Although in forest land in boreal and hemiboreal regions a significant amount of carbon is accumulated in the tree root biomass, only a few studies have been done in Latvia on this topic so far (Daugaviete *et al*., 2008; Bardulis *et al*., 2017; Liepiņš, Lazdiņš, & Liepiņš, 2018). There are, however, certain challenges associated with this forestry practice. These include both technical limitations related to large dimensions of stumps or insufficient area for the storage during field drying, as well as climatic and environmental considerations. Warm winters hamper the forwarding of stumps in wet sites, soil organic matter may be removed in the process, and several studies report negative impacts on forest soil carbon stores and greenhouse gas emissions. Increased soil erosion and compaction have been recorded after stump harvesting, as well as depletion of soil nutrient stocks and changes in nutrient cycling. The impacts on future productivity are uncertain, and there is a concern related to the loss of valuable habitat for fungi, mosses, bryophytes and insects. Moreover, uncharacteristic vegetation for forest may develop after the stump harvesting (Berg, 2014; Lazdinš & von Hofsten, 2009; Walmsley & Godbold, 2010). The previous findings on the effects of stump lifting are rather controversial; and the impact on environment and biodiversity seems to be largely site- and scale- dependent. It has been found that after stump harvesting nutrient leaching may increase (e.g., Palviainen *et al*., 2010, Walmsley and Godbold, 2010), but this is not necessarily true in all types of soils (Becker *et al*., 2016). While several studies conclude that stump harvest negatively affects species richness of understorey plants and reduces moss cover (e.g., Andersson, 2012; Kataja-aho, Fritze, & Haimi, 2011), Rudolphi & Strengbom (2016) report no significant long-term effect of this forestry practice on understorey and bryophytes. In Latvia, several studies have been conducted highlighting possible indirect long-term impact of stump harvest (Jansons *et al*., 2016; Čakšs *et al*., 2018). The aim of this study was to analyse the changes of general soil parameters six years after stump extraction in three mesotrophic sites in Latvia, comparing two types of treatments – whole-tree harvesting with only above-ground biomass removed and whole-tree harvesting with both above- and below-ground biomass removed.

Materials and Methods

Description of the study sites

Medium-term changes of general soil and soil solution parameters after biomass and stump harvest in hemiboreal conditions were evaluated in three research sites located in *Hylocomiosa* site type (dominant tree species before felling – *Picea abies* L. (Karst.)) in Latvia (Figure 1). Two sampling subplots were established at each research site: control subplot representing whole-tree harvesting, with slash removed (WTH); and treated subplot representing whole-tree harvesting, with both slash and stumps removed (WTH+SB). Between WTH and WTH+SB sampling subplots a buffer zone was established (10 m wide zone where stump and root biomass was removed

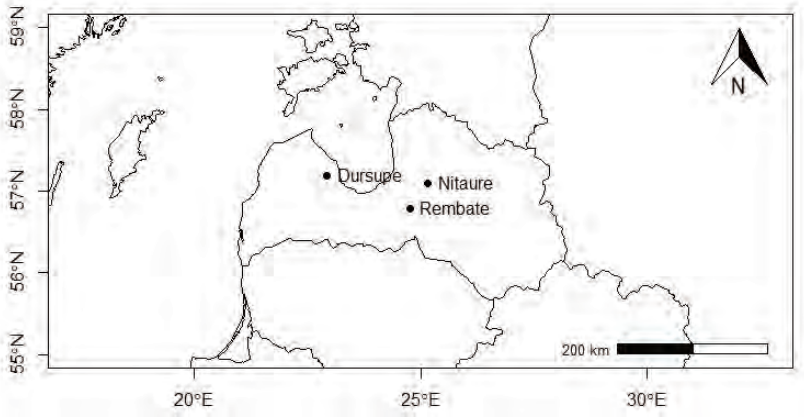

Figure 1. Location of the study sites.

Table 1

Description of the study sites at the moment of harvesting

Site	Location	Soil type (WRB)	Soil texture (FAO)	Average annual precipitation (2011-2018)	Mean annual air temperature (2011-2018)
Rembate	Mid-Daugava Forestry	*Folic Albic Podzols*	sand at 0–30 cm; sandy loam at 30–45 cm; sand at 45–80 cm depth	661.6 mm	7.5 °C
Dursupe	Northern Kurzeme Forestry	*Orsteinic Albic Folic Podzols*	sand	562.7 mm	7.3 °C
Nītaure	Western Vidzeme Forestry	*Folic Arenosols*	sand	753 mm	7.0 °C

and 10 m wide zone where stump and root biomass was left). Harvesting was performed in winter 2012 using two types of machinery: CBI stump extraction scoop mounted on a tracked excavator Komatsu PC210LC, and stump extraction scoop MCR-500 prototype constructed in Latvia mounted on a New Holland E215B excavator. In 2013 (3-6 months after harvesting), the harvested stump and root biomass was forwarded to the roadside for storage. After that soil preparation using active disc plough was performed and spruce container seedlings as well as black alder and spruce bare root saplings with improved root system were planted. Description of the study sites is summarized in Table 1.

Soil and soil solution sampling and analyses

In 2011 (one year before the stump harvesting) and in 2018 (six years after the stump harvesting) the soil was sampled in each sample plot at 0 – 10 cm, 10 – 20 cm, 20 – 40 cm and 40 – 80 cm depth in two sets: for bulk density and soil texture determination (with undisturbed soil sample probes - steel cylinder with a 100 cm³ volume); and for soil chemical analysis (with Dutch soil sampler probe). Soil samples were prepared and analyzed in the Forest environment laboratory of the Latvian State Forest Research Institute 'Silava' (LSFRI Silava) according to the standard methods approved by the ICP forest monitoring programme. Samples were prepared for analysis according to the LVS ISO 11464 (2005) standard. Fine earth fraction of soil (D < 2 mm) was used for soil chemical analysis and following parameters were determined: bulk density according to LVS ISO 11272:2017; total C content using elementary analysis according to LVS ISO 10694:2006; carbonate content using Eijkelkamp calcimeter according to LVS ISO 10693:2014, total nitrogen content using modified Kjeldahl method according to LVS ISO 11261:2002 L; soil pH in 0.01 M $CaCl_2$ solution according to LVS ISO 10390:2006; phosphorus and potassium content in soil was determined in concentrated HNO_3 extract according to LVS EN 14672:2006 and LVS ISO 9964-3:2000, respectively.

In all research sites, soil solution was sampled with suction tube lysimeters (Eijkelkamp), with soil solution sampler cups, made of porous ceramic (92% pure Al_2O_3), and a body of trace metal-free PVC installed vertically into the soil. Five pairs of suction tube lysimeters at 2 depths (30 and 60 cm) per sample plot (both in the control subplot and treated subplot) were installed in spring 2014. Soil solution was collected twice per month during the vegetation season in 2014 and 2015 and once per month in 2016, 2017 and 2018. The soil solution samples were analyzed in the Forest Environment Laboratory of LSFRI Silava. Nitrate nitrogen (NO_3^--N) concentration in water samples was

determined using FORMACSHT TOC/TN Analyzer (ND25 nitrogen detector), phosphate-phosphorus (PO_4^{3-}-P) was determined using an ammonium molybdate spectrometric method according to ISO 6878, potassium was determined using a flame emission spectrometric method according to ISO 9964-3:2000, pH was determined according to LVS ISO 10523:2012 and conductivity was determined according to LVS EN 27888:1993. Before chemical analysis, the water samples were filtered using borosilicate glass fiber filters without a binder.

Statistical analyses

Data processing and all statistical analyses were performed in *R* (R Core Team 2017). For all research sites, the data of soil and soil solution general parameters in treated plots (WTH+SB) were compared to the control plots of the sites (WTH). Statistical differences between the harvested and control plots were analyzed with the *Wilcoxon rank sum test* with continuity corrections.

Results and Discussion

Soil condition

Soil compaction, which is one of the possible consequences of stump lifting and may further negatively influence water infiltration and nutrient availability, generally was not observed in our study sites. Stump removal increased soil bulk density over pre-harvest measurements only at the 0-10 cm depth in Rembate, but in Dursupe and Nitaure, in the surface soil (0 – 10 cm), stump removal decreased the bulk density due to soil mixing that takes place during stump extraction (Table 2). According to previous studies, stump removal may increase soil bulk density, but in general, these effects appear to be short-term and are less severe as the impacts of repeated passes of forwarders during harvesting (Walmsley & Godbold, 2010). In British Columbia, Hope (2007) found that in the first year after harvesting, mineral soil bulk density was greater in all stump-removal treatments compared to the control, but 10 years after the treatment, bulk densities had decreased and no treatment effects were displayed.

Despite the lack of specific research of how stump harvesting influences soil acidification, some previous studies suggest that intensive stump removal should be avoided in sites sensitive to acidification and may intensify the acidification process also in other areas (Walmsley & Godbold, 2010). Our study did not reveal any soil acidification effects of stump harvesting after six years (Figure 2). Similar results were obtained by Hope (2007) who recorded no pH changes in either the forest floor or mineral soil horizon 10 years after the stump harvesting. Staaf & Olsson (1994) concluded that acidification effects in a Norway spruce (Picea abies (L) Karst) forest in southwest Sweden are the greatest over the short term, with soil solution pH returning to pre-treatment levels after 5 years. In contrast, Hyvönen *et al*. (2016) found slightly higher soil pH after the stump harvesting in Norway spruce stands in Central Finland.

Several studies have expressed concern that enhanced mineralization rates following the soil disturbance during stump harvesting may deplete the pool of nutrients in the soil and cause soil carbon losses (e.g., Reynolds, 2007; Staaf & Olsson, 1994). The effect of stump harvest on soil C and N pools is caused by the direct loss of C and N with harvested stump biomass, the altered soil organic matter decomposition rate due to soil disturbance and decreased litter production of the new stand (Jurevics *et al*., 2016). The results obtained in our study show similar trends both in all treated plots (WTH+SB) and in all control plots (WTH). The total organic C stock in soil (0 – 80 cm depth) in 2018 was lower, but the total N stock in soil (0-80 cm depth) was higher, if compared with respective values prior to harvesting in 2011. Thus, no significant effect of stump harvesting treatment on the total organic C or N stock in soil was detected, if compared to the whole-tree harvesting practice. Hyvönen *et al*. (2016) reported similar results describing

Table 2

Summary of impact of stump removal on soil bulk density (kg m³) in soil upper layers

Study site	Treatment	Soil layer		
		0 – 10 cm	10 – 20 cm	20 – 40 cm
Rembate	one year before treatment (WTH, 2011)	800.5	1354.5	1603.6
	six years after treatment (WTH+SB, 2018)	1224.3	1020.1	1443.1
	control (WTH, 2018)	847.9	1394.5	1298.5
Dursupe	one year before treatment (WTH, 2011)	1578.4	1676.0	1625.1
	six years after treatment (WTH+SB, 2018)	1352.6	1517.3	1511.0
	control (WTH, 2018)	1510.4	1473.7	1588.5
Nitaure	one year before treatment (WTH, 2011)	1567.0	1626.9	1665.5
	six years after treatment (WTH+SB, 2018)	1312.2	1540.4	1545.8
	control (WTH, 2018)	1572.3	1505.4	1563.0

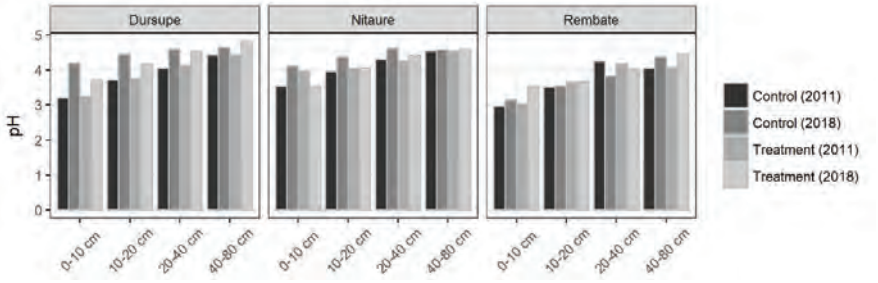

Figure 2. Impact of stump removal on soil pH_{CaCl2}.

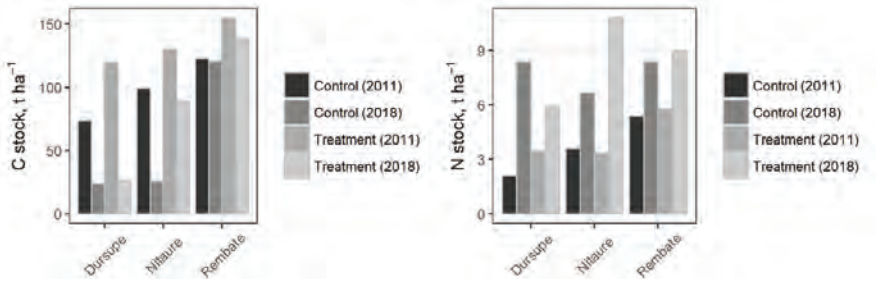

Figure 3. Impact of stump removal on carbon and nitrogen stock in soil (0 – 80 cm depth).

no significant treatment effect on the soil C and N pools after stump harvesting. Strömgren *et al*. (2012) also report small or absent effect of stump harvesting on CO_2 flux or soil decomposition processes during the first years after the stump harvesting compared to site preparation such as mounding. Karlsson & Tamminen (2013) found that C and N concentrations in the soil tended to be lower after stump harvesting, whereas the total C and N pools were not affected. Several studies suggest that the effect of stump removal on soil C and N pools is low, compared to the effect of slash removal (Egnell, 2016; Jurevics *et al*., 2016), as nutrient concentrations in slash are higher than in stumps and coarse roots (Iwald *et al*., 2013).

The buffering capacity of the soil is directly linked to the nutrient availability, and removal of base cations through harvesting therefore reduces the soil buffering capacity that may result in an increased acidification of soil and water. Second to N, P is the most important nutrient for the next forest generation. Results of our study do not reveal any decrease in P or base cation concentrations in the soil after stump harvesting; on the contrary, we observed a slight increase of P and K content in the soil (Figure 4), possibly related to the mineralization of fine slash and lower consumption of nutrients by the new forest generation, as the need for nutrients in conifers is relatively low during the first

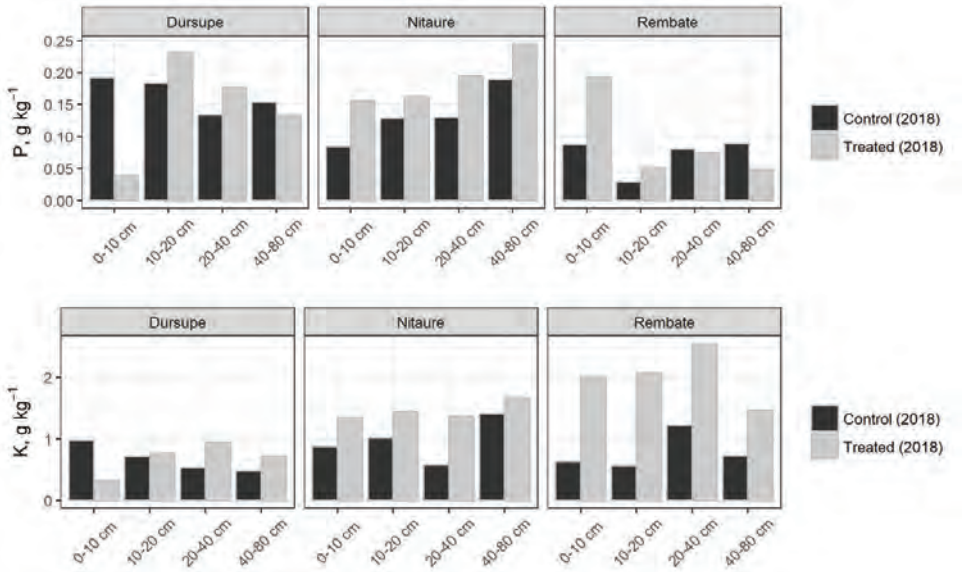

Figure 4. Impact of stump removal on phosphorus and potassium content in soil.

decades after stand establishment (Helmisaari *et al*., 2002). According to Hellsten *et al*. (2013), pine and spruce stumps have very low nutrient concentrations if compared, for example, with foliage or branches, as previously reported by Palviainen *et al*. (2004). The review performed by Ranius *et al*. (2018) highlights a more pronounced negative effect of stump harvesting on base cations than on phosphorus or nitrogen.

Soil solution

Some authors have recorded an increased nutrient, especially phosphorus (P), leaching following the stump harvesting (Palviainen *et al*., 2010; Walmsley & Godbold, 2010), which can be considered a serious environmental risk (Becker *et al*., 2016). In contrast to the expected acidification, we found no effect at all (Nitaure, Rembate) or detected even significantly ($p<0.05$) higher pH values in the treated plot (WTH+SB) compared to the control plot (WTH) in 2014-2016 in Dursupe (Figure 5).

Other parameters, however, showed a different pattern. Conductivity is directly related to the concentration of ions (dissolved salts) in the water.

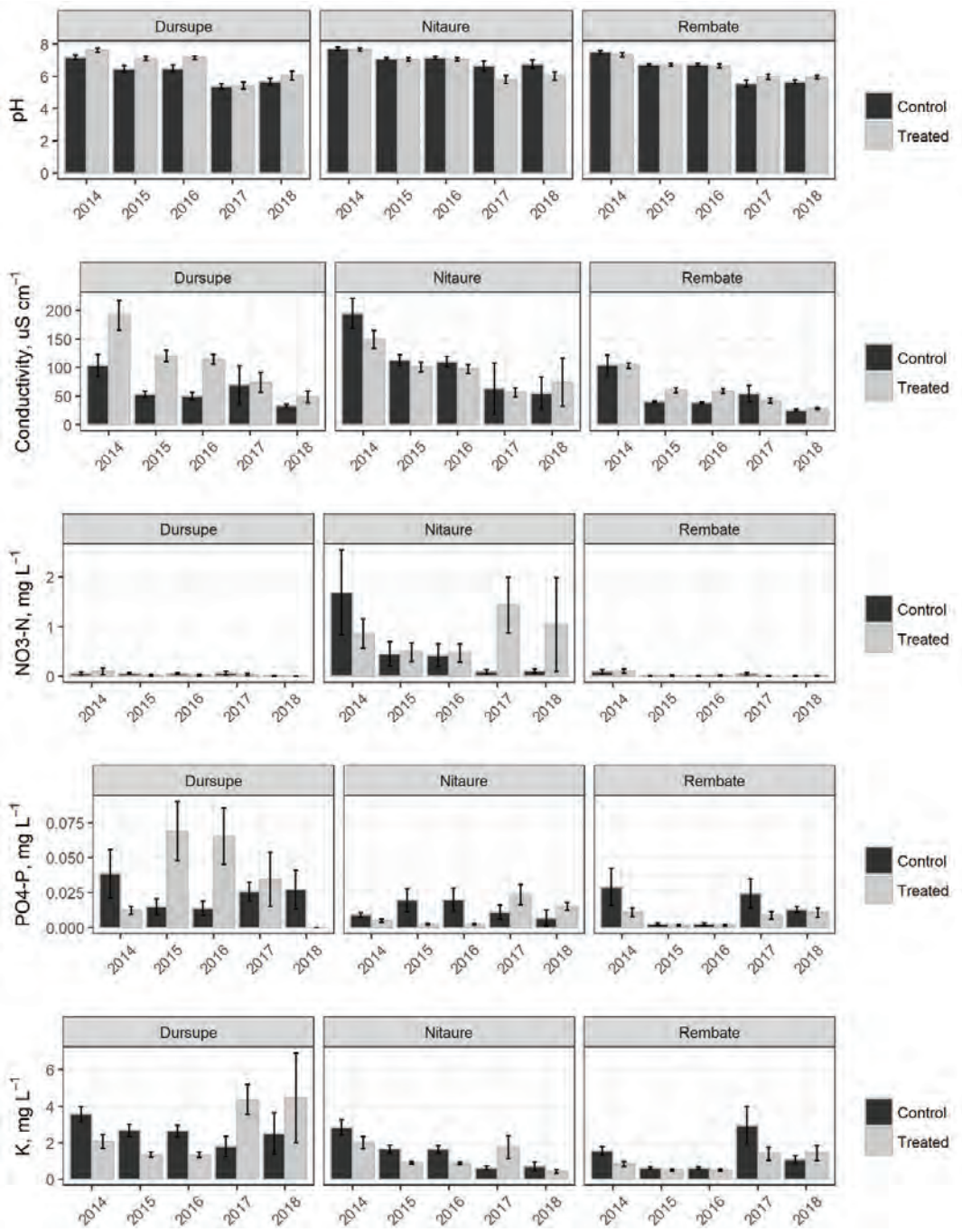

Figure 5. Impact of stump removal on general soil solution parameters and nutrient content.

Compared to the control plots (WTH), a significantly ($p<0.05$) higher soil solution conductivity in the treated plot (WTH+SB) was found in 2014-2016 in Dursupe and in 2015-2016 in Rembate, indicating a potentially increased leaching of salts in the treated plots. A similar effect was not observed in Nitaure. Nutrient content in soil solution for the different harvest treatments showed an irregular pattern. NO_3^--N concentration in soil solution significantly peaked only in the treated plot (WTH+SB) in Nitaure in 2017, while PO_4^{3-}-P concentration in soil solution significantly peaked only in the treated plot (WTH+SB) in Dursupe in 2015-2016. In contrast, K concentration in soil solution significantly peaked only in the control plot (WTH) in all study sites - in Dursupe in 2014-2016, in Nitaure in 2015-2016, but in Rembate in 2014. Other studies indicate that the forest site type, i.e. the soil, has a more pronounced effect on the annual nutrient leaching than soil disturbance caused by stump harvesting (Becker *et al*., 2016).

Conclusions

1. The results of the study of nutrient content in the soil in three mesotrophic sites, where stump harvesting was performed in 2012, revealed no acidification effect of soil and soil solution.
2. Soil C and N stocks six years after harvesting were similar in the plots with and without stump removal, and demonstrated a similar pattern of change in both studied treatments (WTH and WTH+SB).
3. Nutrient content and patterns of its change varied with the site and year, suggesting that the effects are rather site- than treatment-specific.

Acknowledgements

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FOREST MANAGEMENT CHALLENGES AND OPPORTUNITIES OF TWO-LAYERED BIRCH AND SPRUCE STANDS IN LATVIA

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Abstract
Forestry in Latvia in the 20th century was strongly focused on the establishment and management of pure Scots pine and Norway spruce stands trying to avoid any admixture of other tree species. Knowledge on the economic feasibility of the mixed stands' management is still rather poor in Latvia, while at the same time the establishment of mixed stands of Norway spruce and birch species has become an attractive management objective in Finland and Sweden. This paper used the data from the Latvian National Forest inventory to quantify the amount of birch stands with the second layer of spruce, as the first step to justify the development of recommendations for alternative management options in this type of stands. According to the results, there are 121 752 ha of birch stands with the second layer of Norway spruce, and most of those are located in *Hylocomiosa, Oxalidosa, Myrtillosa mel.* and *Myrtillosa turf.mel*. site types. The mean standing volume of birch stands with Norway spruce understorey was higher than in birch stands with no spruce understorey, and *Hylocomiosa, Oxalidosa, Myrtillosa mel.* were the most productive site types both in terms of total standing volume and that of the Norway spruce growing in the second layer. Analysed data also revealed that the management of birch stands already now differs strongly in state and private forests, in the latter being more focused on selective fellings. It is possible to develop and test alternative management methods of birch stands with the second layer of Norway spruce to maximise yield and reduce expenses of forest regeneration.
Key words: two-layered stands, growth, yield, *Picea abies*, *Betula sp.*

Introduction

Last three centuries of industrialization have raised living standards and developed economies but it has come at a significant cost to the Earth's natural systems – climate, water, air, biodiversity, forests and oceans are all under unprecedented, severe and increasing stress (Schwab, 2018). Under such circumstances, forest ecosystems face multiple challenges due to climate change, invasive species, urbanization, land use change and the interactions between these global change drivers (Pautasso, 2013). The International Union of Forest Research Organizations (IUFRO), leading global network for forest science cooperation in its strategy for 2015-2019 addresses the following five themes for the science collaboration – Forests for People; Forests and Climate Change; Forests and Forest-based Products for Greener Future; Biodiversity, Ecosystem Services and Biological Invasions; Forest, Soil and Water Interactions (IUFRO, 2015). Intensified forest management due to increasing demand for bioenergy and attempts to reduce the pressure on forests of higher environmental value is an important issue to consider, and in the light of this trend questions related to possibilities of increasing forest productivity and stability of forest stands are high on the agenda.

Mixed stands usually display greater stability against biological risks. They are reported to be less susceptible to wind throw (Lüpke & Spellmann, 1997), butt rot (Piri *et al.*, 1990) and other damage, therefore the establishment of mixed stands is considered as one of the most important adaptation and risk-reduction strategies (Reif *et al.*, 2010). They also provide more heterogeneity, thus securing a higher variety of ecological niches that may be utilized by different organisms, ensuring a positive effect on biodiversity (e.g., Jonsell *et al.*, 1998). Nutrient balance in mixed stands may be more favourable than in monocultures (Sverdrup & Stjernquist, 2002), and simulations performed by Shanin *et al.* (2013) indicate that mixed stands may be a viable option to increase forest carbon stock and mitigate climate change. One of them, suggested by simulations and observation in the field experiments, is that a positive mixing effect could result from utilization of different ecological niches (Pretzsch, 2009). Bāders *et al*. (2018) study reveals that a higher forest structural diversity with spruce admixture has a positive impact against insect damage both on stand and landscape levels.

Forestry in Latvia in the 20th century has largely focused on the establishment and management of pure Scots pine and Norway spruce stands striving to avoid any admixture of other tree species (Bušs, 1985). This kind of forest management was considered to be the most economically efficient because the economic value of birch was low at the time (Zālītis, 2006). Zviedris (1960) stated that transformation of two-layered birch stands with the second storey of Norway spruce into pure spruce stands is not possible by removing only a part of birches in the commercial thinning and Zālītis & Jansons (2014) support this opinion. At the same time, formation of highly productive pure Norway spruce stand by removing all the birches is not a customary practice in the current forest management.

Knowledge on the economic return from mixed stands is still very poor in Latvia, while at the same time the establishment of mixed stands of

Table 1

Representation coefficients for recalculation of results in the respective age classes

Age group	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120
Correction coefficient	1.05	1.00	1.00	1.07	0.98	0.98	0.98	0.98	0.95	1.01	0.90	0.80

Norway spruce and birch has become an attractive management objective in Finland and Sweden. As the future development of roundwood prices is uncertain, a two-species stand has a higher net present value when management decisions are based on predictions of market situation (Lohmander, 1992). Moreover, it may be possible to obtain significantly higher volume of wood in a mixed stand, but the results are very much site- and management regime-dependant. For example, results from the literature suggest that it is possible to reach a total yield of 800 m^3 in mixed spruce and birch stands within the same rotation period (Valkonen & Valsta, 2001). Tham (1988) reported a higher yield from a mixture of birch as shelter trees and spruce in the understorey than in a pure Norway spruce stand. At the same time, Frivold (1982) and Agestam (1985) indicated no higher production in mixed stands than in monocultures of Norway spruce. Very little is known about the economic and ecological effects of a management model where an overstorey of mature birch stand is removed and the second storey of Norway spruce retained for further development.

Considering all the above-mentioned, new approaches are needed to increase the sustainability of forest management on a national, regional and global scale, from the viewpoint of different ecosystem functions and services delivered by forests. However, before recommendations for any management changes may be developed, it is crucial to have information on the stands where the new management scenarios might potentially be applied. Therefore, the aim of the study was to quantify the area and productivity of birch stands with the second layer of Norway spruce that could potentially be converted to spruce stands after the removal of birch overstorey.

Materials and Methods

Data from the second cycle of the National Forest Inventory (2013-2017) were used to analyse the distribution of birch stands in Latvia. NFI is conducted since 2004; one cycle lasts five years and within each cycle a total of 16 157 circular sample plots is measured, recording information on the tree dimensions, damages, stand development as compared to the previous inventory, undergrowth and other parameters. All measurements are performed according to the methodology confirmed by the Latvian Ministry of Agriculture. As silver birch and downy birch are not recorded as separate species in the inventory and occasionally may occur in the same site types, in our analysis we did not separate them but referred to both *Betula pendula* and *Betula pubescens* species as 'birch'.

A sub-set of NFI plots was used for the analysis. The following criteria were applied for the sample plot selection: 1) only plots in the forest (land category code 10); 2) birch as dominant tree species in the overstorey; 3) the size of the sample plot (the sector in the forest) – at least 400 m^2. The total number of suitable sample plots for further analysis was 1807.

For a general analysis of birch forests, the stands were then divided into nine age classes with a step of 10 years (11-20; 21-30; 31-40; 41-50; 51-60; 61-70; 71-80, 81-90, 91+ years) excluding 225 sample plots with the stand age 1 to 10 years, as no second storey is usually formed within this age class. Further, sample plots with two-layered birch stands were selected for a more detailed analysis. For that, following criteria were applied: 1) in the age classes 11-20; 21-30; 31-40; 41-50 years the second layer of spruce had to be at least 10% of the total standing volume; 2) in the age class 51-60 years - second layer of spruce had to be at least 50 m^3 volume; 3) in the age class 61-70 years – the second layer of spruce had to be at least 60 m^3 volume; 4) in the age class 71-80 years – the second layer of spruce had to be at least 70 m^3 volume; 5) in the age classes 81-90 and 91+ years the second layer of spruce had to be at least 100 m^3 volume.

According to the NFI methodology, each m^2 of one 500 m^2 large sampling plot represents 0.8 ha. In our study, as we used a sub-set of plots with an area starting from 400 m^2, the results were corrected with the respective representation coefficients (Table 1) to maintain the same age structure as in NFI data totals.

Graphical analysis of the available data was carried out to identify and present the main characteristics of birch stands and birch stands with the second storey of Norway spruce. Data analysis was conducted in the MS Excel 2016.

Results and Discussion

The total area of stands with birch as the dominant tree species in our analysis comprised 770 570 ha, and the share of birch stands with Norway spruce in the second layer comprised 16% of this area (Table 2). The mean standing volume of the stands with spruce second layer was considerably higher in all studied age classes, and, depending on the age class, exceeded the standing

Table 2

Productivity and age structure of the birch stands in Latvia

	Birch stands			Birch stands with second layer spruce		
Age class, years	Area, ha	Standing vol., million m^3	Average standing vol., m^3 ha^{-1}	Area, ha	Standing vol., million m^3	Average standing vol., m^3 ha^{-1}
11-20	151 804	7.89	52	13 751	0.92	67
21-30	78 067	8.90	114	15 407	2.08	135
31-40	72 617	13.00	179	9 074	1.75	206
41-50	115 184	24.99	217	20 482	5.28	253
51-60	133 258	35.18	264	24 975	9.84	386
61-70	113 691	34.33	302	20 288	8.32	402
71-80	61 222	19.71	322	12 526	6.21	486
81-90	29 011	9.89	341	3 734	1.97	502
91-	15 716	5.20	356	1 515	0.77	505
Total	**770 570**	**159.09**		**121 752**	**37.14**	

volume of birch stands with no spruce second layer by 15 – 51%. The largest differences were observed in the age classes 71-80 years (51% exceedance), 81-90 years (47% exceedance) and 51-60 years (46% exceedance). The smallest differences were observed in 21-50 years old stands, where the mean standing volume of the stands with a spruce second storey was greater than that of the birch stands without Norway spruce by no more than 18%. In the age classes closest to the rotation age (51-60 and 61-70 years) the standing volume of the birch stands with spruce second layer exceeded that of the birch stands without spruce second layer by 46% and 33%, respectively.

Further analysis of the birch stands with second layer of Norway spruce was conducted in three age groups; the first group included stands aged 11-40 years, the second group – stands aged 41-70 years and the third group – stands aged 71+ years.

In general, there were 38 232 ha birch stands with the second layer of spruce at the age of **11-40 years** in Latvia. The total productivity in these stands was by 15-29% higher than average productivity of the birch stands without Norway spruce second storey. This age group is the one where it is possible to influence the species' composition and productivity the most. There is still opportunity to implement different forest management scenarios in these stands by the choice of method and intensity of the pre-commercial and commercial thinning.

The age group of **41-70 years** formed the largest proportion of the birch stands with second layer of spruce – 65 745 hectares with 23.44 million m^3

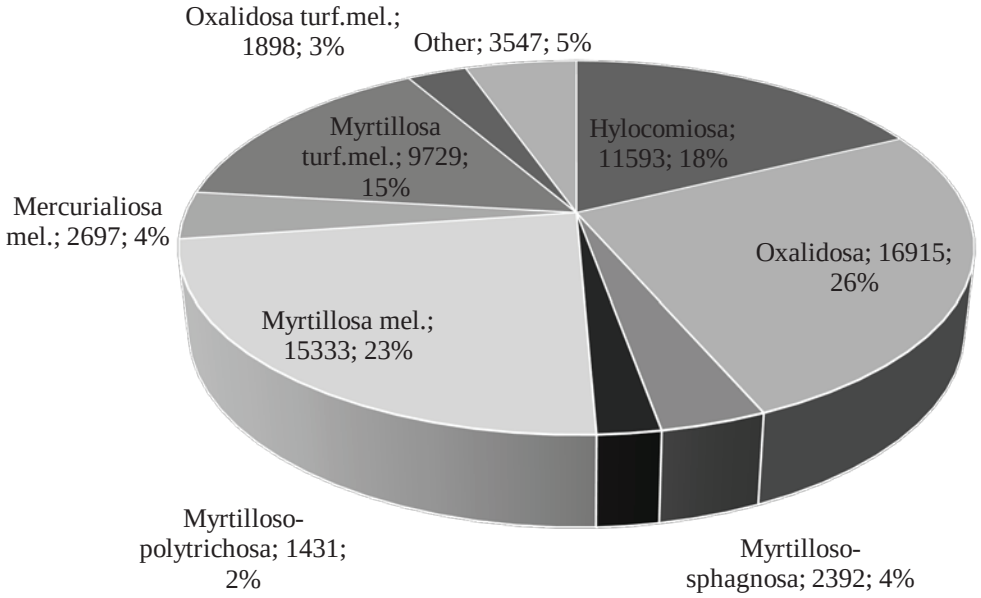

Figure 1. Distribution of 41-70 years old two-layered birch-spruce stands by forest type, area (ha) and share (%).

Table 3

Area and productivity of 71+ years old birch stands with second storey of Norway spruce by site type

Forest type name	Forest type abbreviation	Area, ha	Standing volume, million m^3	Average volume, $m^3\,ha^{-1}$	Average volume, spruce 2nd layer, $m^3\,ha^{-1}$
Hylocomiosa	Dm	4880	2.62	535	152
Oxalidosa	Vr	5250	2.73	519	112
Aegopodiosa	Gr	488	0.27	565	75
Myrtilloso-polytrichosa	Vrs	976	0.56	564	75
Dryopteriosa	Grs	488	0.20	409	105
Myrtillosa mel.	As	2843	1.63	570	159
Mercurialiosa mel.	Ap	966	0.31	317	102
Myrtillosa turf.mel.	Ks	976	0.37	374	120
Oxalidosa turf.mel.	Kp	909	0.26	287	87
		17 775	**8.95**	**492**	**126**

standing volume. The productivity in this age group was higher than for birch stands on average – by 17% in the class 41-50 years, by 46% in the class 51-60 years and by 33% in the class 61-70 years, thus marking these stands as attractive for alternative forest management methods that would include both short- and long-term management perspectives.

The largest share of all stands in this age group were located in the fertile *Oxalidosa* site type, but a considerable share of 41-70 years old birch stands with Norway spruce second layer was located also in the *Myrtillosa mel.* site type (mesotrophic sites on drained mineral soils), *Hylocomiosa* site type (mesotrophic sites on mineral soils) and *Myrtillosa turf.mel.* site type (mesotrophic sites on drained peat soils) (Figure 1). Thus, these site types stand out as the most productive and perspective for the planning and implementation of alternative management scenarios.

The total area of **71+ years** old birch stands with the second layer of Norway spruce comprised 17 775 ha. Similarly to 41-70 years old stands, also within this age group the largest part of birch stands with the second layer of Norway spruce was located in *Oxalidosa* (30%), *Hylocomiosa* (27%) and *Myrtillosa mel.* (16%) site types (Table 3). The average total stand productivity ($m^3\ ha^{-1}$) was above average in all three site types, and the standing volume of the second layer of Norway spruce exceeded the average value in *Hylocomiosa* and *Myrtillosa mel.* site types. Donis et al. (2018) reports that stands on peat soils had significantly more damaged stock in 2005 windstorm in Latvia than stands on mineral soils, therefore we have to be critical considering selective cutting method to remove the birch overstorey in *Myrtillosa turf.mel.* and *Oxalidosa turf.mel*. forest types.

Even though the largest share of the birch stands with a second layer of Norway spruce was located in the state forests, the percentage of this type of stands in the private forests was rather high as well – nearly one fifth of the total area of such stands (Figure 2). According to the statistically representative NFI data, the distribution of this type of stands in general was

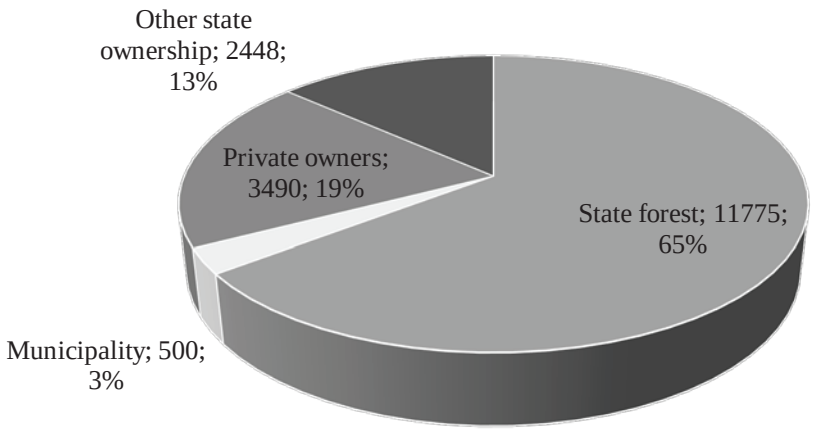

Figure 2. Distribution of 71+ years old two-layered birch-spruce stands by ownership type, area and share.

Table 4

Harvested volume and area in birch stands in state and private forests in 2016 and 2017 (Latvia State forest service data)

Harvested volume/felled area	Private		State	
	2016	2017	2016	2017
Volume clearfelling, million m^3	1.15	1.22	1.28	1.3
Area clearfelling, ha	5515	5731	4819	4607
Volume selective felling, million m^3	0.05	0.06	0.002	0.002
Area selective felling, ha	1299	1269	34	30

considerably higher than recorded in the State forest register. Similar results were obtained by Zālītis &Jansons (2014), who concluded that not only the total area of birch stands with the understorey of spruce was higher than expected but also the standing volume of the spruce understorey differed from that recorded in the State Forest register. While, according to the State forest register, the standing volume of Norway spruce growing in the second storey of birch stands was 42 m^3 ha^{-1}, actual measurements revealed that it is, in fact, considerably greater and equals 100 – 120 m^3 ha^{-1} on average. Results from literature suggest that mixed, two-layered birch-spruce stands may have high productivity, and reach even 800 m^3 ha^{-1} in one common rotation, as was demonstrated in the study by Valkonen and Valsta (2001).

In 2017, in the state forests selective fellings in birch stands were performed on an area of only 34 ha, and the total harvested volume was 2164 m^3, that is less than 0.01% from the total harvested volume of birch stands in general. Very similar situation was observed in 2016 when the area and harvested volume of selective fellings in birch stands in the state forests were nearly the same – 34 ha and 2167 m^3, respectively. At the same time in the private forests this kind of management was implemented on a much larger scale, and the harvested volume in the selective fellings performed in the birch stands was equal to 53 910 m^3, that is 4% from the total volume harvested in the final felling in the private forests. In 2017, the share of birch wood harvested in selective felling in the private forests had further increased (Table 4). Thus, it may be concluded that the management strategies in state and private forests dominated by birch differ already now.

This analysis of statistical data has made it obvious that there is a room for alternative approaches, as related to the management of birch stands. Zālītis et al. (2014) hypothesised that if the volume of the second storey of Norway spruce in a two-layered birch spruce stand is 100 m^3 ha^{-1} or greater, it is possible to establish a productive Norway spruce stand in the second generation after the removal of birch overstorey. There are approximately 60 permanent sample plots established and measured in all regions of Latvia where in 2010-2014 this type of management was implemented, leaving also a control plot. These sample plots will be re-measured in the coming years, to test the above-mentioned hypothesis.

Conclusions

1. Analysis of the Latvian National Forest Inventory data revealed that the area of birch stands with the second layer of Norway spruce equals 121 752 ha. Most of these stands are located in *Hylocomiosa*, *Oxalidosa*, *Myrtillosa mel.* and *Myrtillosa turf.mel.* site types. These stands are also the most productive in terms of standing volume and standing volume of the spruce second layer, therefore, they are potentially interesting for the implementation of alternative management scenarios.
2. The management strategies of birch stands in state and private forests differ already now. In 2016 and 2017 private forest owners applied selective felling method on 2568 ha of birch stands, while only 64 ha were felled with this method in the state forests in the same period.
3. Birch stands with the second layer of Norway spruce of age 41-70 years in *Hylocomiosa*, *Oxalidosa*, and *Myrtillosa mel.* forest types take up area of 43 841 ha and are considered as a main target group to apply selective cutting method to.

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POST-STORM REGENERATION OF NORWAY SPRUCE

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Abstract
Impact of abiotic (wind, summer drought) and secondary (bark beetle (*Scolytinae*)) or primary (cervids (*Cervidae*)) biotic factors affect the survival of Norway spruce (*Picea abies* (L.) Karst.) that is an economically important tree species. Norway spruce is mostly regenerated via planting – thus with significant investment. Therefore it is important to improve the resistance of Norway spruce stands as much as possible. Aim of the study was to characterize damages in Norway spruce stands by cyclonic wind storm and the regeneration of the stands, destroyed by the storm. Data from 4491 Norway spruce dominated stand, destroyed by the storm of 2005, from State Forest service database were obtained. Areas of post-storm sanitary clearcuts ranged from 0.1 to 7.6, mean 0.9 ± 0.02 ha. Most of the clearcuts were larger than 0.5 ha, demonstrating a relatively large size of gaps created by this natural disturbance. Changes of dominant trees species after the storm were statistically significantly affected by the forest type and type of regeneration. Overall, it happened in 55% of the former Norway spruce areas and was predominantly in cases, where natural regeneration was practiced. No indications of measures to increase stability of future stands against wind damages were found.
Key words: salvage logging, *Pice abies*, wind storm, forest management, windfirm stands.

Introduction

Climate change, linked to a higher productivity of Norway spruce (*Picea abies* (L.) Karst.), has been happening in a number of countries in the Baltic sea region (Pretzsch *et al.*, 2014); similarly also improved forest management has increased the growth. One of such measures is fertilization that has a long-lasting impact on the growth (diameter increment) of Norway spruce (Jansons *et al.*, 2016a). Further capacity of trees to increase the growth can be possible (Katrevics *et al.*, 2018; Katrevičs *et al.*, 2018) both due to the changes in silviculture as well as longer growing period (Krišāns *et al.*, 2016). Continuous rapid changes in climate might lead to limits of phenotypic plasticity of adaptation (Schmidt-Vogt, 1977). It may also cause changes in limiting factors, e.g. increasing influence of summer drought (Jansons *et al.*, 2015b; Matisons *et al.*, 2017), as well as increasingly suitable conditions for damaging agents, e.g. dendrophagous insects (Bāders *et al.*, 2018). Main climatic factors influencing growth of trees have been analyzed and compared between species (Jansons *et al.*, 2016b). Not only growth, but also wood quality and potentially decay can be affected by the sudden climatic changes, causing drought crack (Burneviča *et al.*, 2016; Zeltins *et al.*, 2016, 2018). Selection of fast-growing and robust provenances for particular sites (regions) is in the aims of forestry adaptation to climatic changes (Rieksts-Riekstins *et al.*, 2014; Matisons *et al.*, 2018). Long-term tree breeding has been developed for different commercially important tree species (Jansons, Gailis, & Donis, 2011), including *Picea abies*, and the potential for adaptation to climatic changes is considered in it (Jansons *et al.*, 2015a). Genotype x environment interaction evaluation is a crucial element in this approach (Jansons, 2008). Good regeneration of unmanaged Norway spruce stands also in larger gaps after the storm (without salvage logging) had been observed (Baders *et al.*, 2017), similar to that after clearcutting and planting. However, the advantage of planting is potential of further improvement (and ensured vitality, if rapid adaptation is of importance) due to application of progressive soil scarification methods and plants with high phenotypic and physiological (Haapanen *et al.*, 2015; Dzerina *et al.*, 2016; Celma *et al.*, 2018) characteristics. Overall, genetic gain of around 10% for stem volume growth by selecting a seed source can be achieved (Janson *et al.*, 2013), as well as increased the above-ground biomass (Lībiete-Zālīte & Jansons, 2011; Lībiete *et al.*, 2017).

Main causes of damages in European forests are fires, wind storms and bark beetles (*Scolytinae*). Their impact is expected to increase in future (Seidl *et al.*, 2014; Kitenberga *et al.*, 2018, 2019). It will influence the financial gain from forestry and tree species composition. Norway spruce can easily be affected by all of these factors. Fires mostly are human-caused, the climate change can only alter their size (Donis *et al.*, 2017). In contrast, the wind-storms are out of the anthropogenic control and have become increasingly more common, affecting large forest areas. Norway spruce is not stable due to superficial roots. Additionally, feeding damages by cervids (*Cervidae*) to the bark of the trees may be an important factor affecting spruces – both their growth and wind-resistance. Therefore, it is important to establish stands that are more stable than the current generation of trees.

The aim of the study was to characterize damages in Norway spruce stands by cyclonic wind storm and the regeneration of the stands, destroyed by the storm.

Materials and Methods

The study was carried out as an analysis of data on the most significant cyclone storm of recent decades, which took place on January 8-9, 2005.

Data regarding the regeneration of the damaged areas of storm in 2005, in which a salvage logging has been performed, have been obtained from a database of the State Forest Service, where information regarding the compartments prior to (2004) and after the storm (2018) can be found. Only forest compartments, where storm was noted as a primary cause of sanitary clearcut, have been selected and used for statistical analysis from the database, and a clearing after the storms of 2005 is checked when testing theaerophoto maps, provided that it is logically possible to connect them to the most recent database information on the same compartments. Overall, the analysis uses data from 4491 spruce stands, distributed evenly across Latvia. A binary logistical regression has been used to analyse the changes in the prevailing species (difference before and after regeneration): the variable is assigned a value of 0, where the dominant tree species have remained unchanged following the storm in the forest stand; and a value of 1 if the prevailing species has changed after the storm. It was further analysed how the prevailing species would change depending on the type and origin of the forest (planting or natural regeneration). Wind-damages were found in all forest types where Norway spruce dominated stands can be found in Latvia (Table 1).

Results and Discussion

Influence of the storm on Norway spruce stands is characterized by the size-distribution of sanitary clearcuts. The proportion of sanitary clearcuts with an area of not more than 0.3 ha represents 23% of the total number of sanitary clearcuts following the 2005 storm, those whose area does not exceed 0.5 ha – 41%, 1.0 ha – 71%, while the proportion of felling areas exceeding 1.0 ha is 28% of the total number of sanitary fellings after this storm. Absolute majority (76% both from number and total area) of all sanitary clearcuts are in Norway spruce stands on fertile mineral soil with normal moisture regime, even though in these areas, overall, only 49% are from Norway spruce stands (Latvian national forest inventory (NFI) data). Trees in such soils are expected to be more windfirm than in other. However, even though the storm happened in January, the ground was not frozen at the time – thus affecting the amount of damages. Also, in these conditions, trees have very good growth rates, potentially being higher than others – it would also affect (lower) their wind resistance. Such result indicates the necessity to pay special attention to the reduction of wind risks in stands very suitable for growth of Norway spruce, since the un-frozen soil during the winter will become more and more common due to global climate change. The result on the mean size of the area damaged to such an extent that sanitary clearcut (salvage logging)

Table 1

Post-storm regeneration of destroyed Norway spruce stands

Soil conditions	Forest types	Number of stands regenerated by						Proportion of spruce, %
		spruce (*Picea abies* (L.) Karst.)	birch (*Betula* spp.)	aspen (*Populus tremula* L.)	pine (*Pinus sylvestris* L.)	other species	all species	
Fertile dry mineral soil	*Hylocomiosa*	730	524	40	183	11	1488	49
	Oxalidosa	834	642	259	9	80	1824	46
	Aegopodiosa	23	45	15		5	88	26
Fertile wet mineral soil	*Myrtilloso-sphagnosa*	58	82	2	16	6	164	35
	Myrtilloso-polytrichosa	61	61	7		16	145	42
Fertile drained mineral soil	*Myrtillosa mel.*	132	102	7	25	4	270	49
	Mercurialosa mel.	79	67	22		11	179	44
Fertile drained peat soil	*Myrtillosa turf. mel.*	38	61	1	1	2	103	37
	Oxalidosa turf. mel.	35	82			14	131	27
Other	Other	24	46	2	18	9	99	24
Total	All	2014	1712	355	252	158	4491	45

Table 2

Parameter values of the model

Factor	χ^2 coefficient	Degrees of freedom	p-value
Forest type	434.96	16	< 0.001
Regeneration type	845.87	1	< 0.001

was necessary, was 0.9 ± 0.87 ha, minimum clearing area 0.1 ha, maximum clearing area 7.6 ha (Figure 1) Mean clearcut area is larger in stands on peat soils – they represent 5% of the total number of damaged stands and 8% of the total area. It is in accordance with earlier findings that more damages (as proportion on growing stock) can be found on peat soils (Donis *et al.*, 2018).

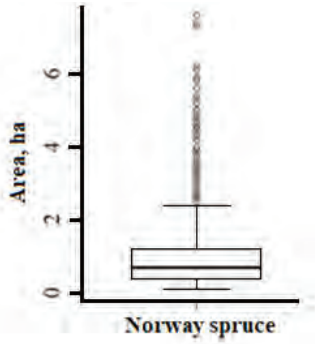

Figure 1. Distribution of size of sanitary clearcuts in Norway spruce stands after storm on January 8-9, 2005 (based on data from State Forest Service).

It demonstrates that the gap-dynamics, when only single trees or small groups of trees are falling, is not necessarily the only disturbance regime in Norway spruce forests. Combined with earlier findings on relatively successful post-storm regeneration of this species (Baders *et al.*, 2017), it leads to conclusion that close-to-nature silviculture for this tree species does not exclude a small size (as practiced in Latvia) clearcuts.

In a binary logistic analysis, it was found that the forest type, as well as regeneration type (planting or self-seeding) in sanitary clearcuts have a statistically significant impact ($p<0.01$) on the dominant species of trees 13 years after the storm (Table 2). However, in this case only 2 groups of forest types have been distinguished: on fertile soils and on poor soils (very seldom for Norway spruce stands, classified as 'other' in Table 1).

Natural regeneration in all forest type groups on fertile soils in most of the cases leads to dominance of species other than Norway spruce – mostly aspen and birch. From all naturally regenerated areas in such soil conditions only 19 – 21% are Norway spruce dominated (Figure 2). In general, this could increase the stability of future stands, since birch is more wind resistant (Donis *et al.*, 2018). However, it might negatively affect the productivity and thus the income for the forest owner (and economy as a whole). The highest share of natural regeneration (on average 50%) can be observed in forest types with peat soils: the sites, where the best productivity could

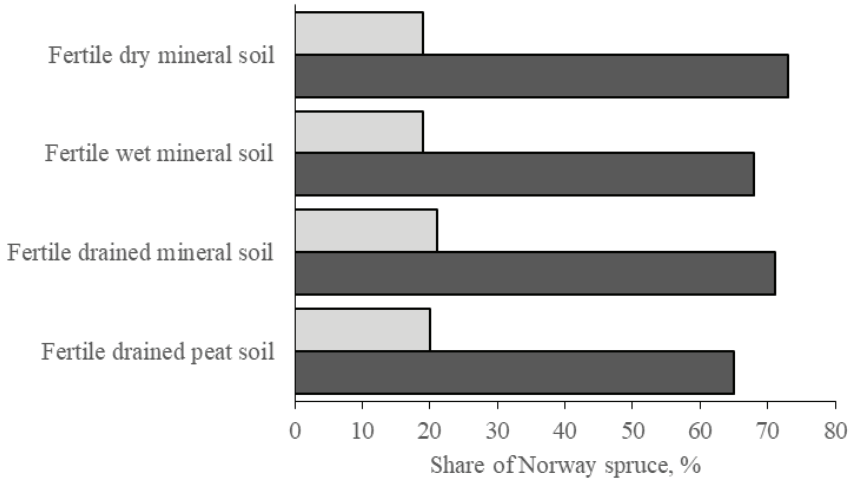

Figure 2. Share of Norway spruce in sites with fertile mineral or peat soils with differing moisture regime, depending on the regeneration method (based on data from State Forest Service): light grey – planting, dark grey – natural regeneration.

be achieved. Most of the Norway spruce young stands (78% on average) have formed after planting, and also most of planted areas (65 – 73%) are planted by Norway spruce. Thus – when the decision is made by the forest owner to invest in the forest regeneration, the less wind-resistant species is chosen. Such decision could be justified if the owners would also simultaneously apply measures to increase the wind-stability in stands, and/or apply it only on the very best soils, where other species grow notably slower than Norway spruce.

Conclusions

1. Wind-storm has created relatively large gaps in Norway spruce stands: 0.9 ± 0.02 ha; the openings in canopy cover due to storm impact, not exceeding 0.5 ha were 41% of the total number.
2. Majority (76% both from number and total area) of all sanitary clearcuts are in Norway spruce stands on fertile mineral soil; the proportion notably exceeded the share of these forest types in the total area of Norway spruce stands.
3. Changes of tree species after the storm happened in 55% of cases. Norway spruce had the highest share in the planted areas (78%), but lowest in naturally regenerated (19 – 21%) areas in forest types on fertile soils.

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IMPACT OF FOREST SOIL ENRICHMENT WITH NITROGEN FERTILIZER ON THROUGHFALL AND SOIL WATER CHEMICAL PROPERTIES

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Abstract
A demand for wood resources is increasing. In addition to drainage and appropriate regeneration and thinning, the forest soil fertilization may increase the future harvest rates. Therefore, the improved growth of forest stands raises in priority among the research topics related to forestry. The objective of the study is to evaluate the impact of nitrogen fertilizer on soil water and throughfall water chemical composition to elaborate recommendations for the forest fertilization. The trials were conducted in a birch stand and in three coniferous stands. Nitrogen containing mineral fertilizer (ammonium nitrate) was distributed in the study sites, while the control plots were left without any treatment. The water samples were collected a season before and a season after the soil treatment. The pH level, total nitrogen, potassium and phosphate were determined in throughfall and soil water samples. The chemical properties of throughfall water differed depending on the forest stand type. The concentration of nitrogen was higher in throughfall water samples collected from the birch stand. The mean concentration of total nitrogen was 1.6 ± 0.3 mg L^{-1} in the throughfall water samples from the birch stand compared to 1.03 ± 0.11 mg L^{-1} in the throughfall water samples from the coniferous stands. Although the forest soil was enriched with the nitrogen fertilizer, there was a significant increase in concentrations of potassium and phosphate in soil water samples from certain stands. It can be explained with changes in pH level that occurred after the forest soil treatment with ammonium nitrate. There was also a significant increase in total nitrogen concentrations in soil water samples at the depth of 30 cm from the treated plots of the coniferous stands – 15 ± 6 mg L^{-1}, compared to 1.5 ± 0.03 mg L^{-1} in the samples from the control plots. However, the concentrations decreased within two months and remained at a steady rate – slightly above the control level.
Key words: forest fertilization, ammonium nitrate, water chemistry.

Introduction

According to the studies, in particular, the agriculture and climate change related research, the ability to control the nitrogen cycle has been recognized as a substantial factor in the future of mankind. The usage of synthetic fertilizer has rapidly increased in the 20th century. Consequently, nitrate pollution and nitrous oxide as one of the greenhouse gas are considered to be the result of impacted nitrogen cycle (Stein & Klotz, 2016). However, it is commonly discussed that an increased growth of forest stand may facilitate climate change mitigation by removal of carbon dioxide in biomass (Houle & Moore, 2019). In addition, extra increment, induced by fertilizer, helps to meet the increasing demand for woody biomass. Initial fertilization, applied during the period of plantation, may increase the stem volume of Norway spruce (*Picea abies (L.) H.Karst.*) by 17% (Jansons *et al.*, 2016). Therefore, the forest soil enrichment with nitrogen containing fertilizer is an essential research topic related to the forestry and water chemistry.

Boreal coniferous forests are acknowledged as one of the most nitrogen limited ecosystems (Houle & Moore, 2019). In addition to the economic impact, forest fertilization is an effective measure to reduce greenhouse gas emissions. It is possible to achieve maximum additional radial increment in the 10th year after the application of ammonium nitrate. Theoretically it can be done in about 0.2% of state forests annually (Petaja *et al.*, 2018). Other research results show that, depending on the forest type under similar climatic regimes, simulated elevated rates of atmospheric nitrogen deposition (stands were treated with 50 or 150 kg N ha^{-1} yr^{-1}) may promote losses of nitric oxide from forest soil as a result of nitrification (Venterea *et al.*, 2003). It has been reported that since 1990s the rate of nitrogen atmospheric deposition in Europe has declined. Research findings report decrease in elevated nitrate concentrations in soil solution and mostly lower nitrogen deposition in the Eastern Europe (Schmitz *et al.*, 2019). However, if the soil treatment with nitrogen containing fertilizer is intended, the capacity of plant uptake must be considered. It is also important because nitrogen saturation may affect the tree health (Houle & Moore, 2019). In this context nitrates in soil solution indicate nitrogen availability in excess of biotic demand (Schmitz *et al.*, 2019).

Throughfall is a part of precipitation that filters through canopy and has an impact on soil water chemical quality. While falling through canopy, precipitation changes in terms of water quality and quantity. There is a difference in chemical composition of throughfall depending on dominant trees, namely, coniferous or deciduous trees (Tērauda, 2008). The chemical composition of throughfall may be impacted also by insect excreta (Reynolds & Hunter, 2004). Water pH level of throghfall from coniferous stand is

lower than the pH level of an open field precipitation (Tērauda, 2008). The amounts of nutrients that reach soil with throughfall usually are elevated, especially potassium (Pallardy & Kozlowski, 2008). Therefore, throughfall is also an important aspect to consider by estimating the impact on soil water properties. Nutrient, among them nitrogen and potassium, input in canopy occur through deposition – wet, dry and cloud deposition (Reynolds & Hunter, 2004).

To estimate the impact of fertilizer on forest soil solution and to distinguish any natural variations in chemical properties from the treatment impact, data should be compared from both control and fertilized plot (Stuanes, Kjønaas, & van Miegroet, 1995). In the experimental site of mature spruce, ammonium nitrate (35 kg N ha^{-1} yr^{-1}) was repeatedly applied to 500 m^2 plots and after 4 years of the treatment an increase in nitrate concentrations in soil solution was observed. Despite the ascertained nitrate leaching, 92% of inputs were preserved (Gundersen, 1998). Likewise, in the research related to the response of boreal ecosystem to eight years of ammonium nitrate addition, a high nitrogen retention capacity of two boreal coniferous stands was observed (Houle & Moore, 2019).

The aim of this study was to estimate the impact of the forest fertilization with ammonium nitrate on soil water and throughfall water chemical properties two years after the soil enrichment.

Materials and Methods

Study site

The research was conducted in four forest stands. Two of them are located in the central part and two – in the eastern part of Latvia. During 2016, the experimental plots were established in the forest sites managed by the Research forest station (Table 1).

Treatments

In period May – July, 2017 ammonium nitrate was spread in the experimental plots (Table 2). The fertilizer was applied manually in one pine stand (21-10-4) and mechanically in the rest of the stands.

Sampling and analyses

Each of the experimental sites has one control plot and one treatment plot – both located in the same forest stand. Lysimeters and throughfall collectors were installed according to IPC Forests guidelines (Convention on Long Range Transboundary Air Pollution, 2010). Each plot has three pairs of vacuum lysimeters and three throughfall water collectors. The vacuum lysimeters were installed at depths 30 cm and 60 cm to collect soil leachate. Rainwater was gathered with throughfall water collectors. Both soil water and throughfall samples were collected once per month. The period of field works was restricted by weather conditions, namely, average daily temperatures. First water samples were collected starting from May and field works lasted till September or October. The parameters determined in the water samples are: pH, N_{TOT} mg L^{-1}, K mg L^{-1} and PO_4^{3-} mg L^{-1}.

Statistical analysis

We used Mann-Whitney test p-values to determine the difference in chemical properties of water. The statistical tests were conducted at a 95% confidence level. The statistical tests were performed in IBM SPSS Statistics 22.

Results and Discussion

Figure 1 and Figure 2 illustrate changes in pH level of throughfall. PH level slightly elevates during the summer period and decreases in the autumn. The values vary from 5.8 to 7.3 mg L^{-1} in the control plots and from 5.3 to 7.6 mg L^{-1} in the treated plots.

Table 1

Description of experimental sites

Forest stand	Forest type	Age	Dominant tree type	Coordinates, X	Coordinates, Y
21-49-14	*Myrtilloso-sphagnosa*	15	Birch	56.709612	23.755750
11-18-5	*Hylocomiosa*	36	Spruce	56.736803	25.879994
11-210-5	*Myrtillosa*	67	Pine	56.681789	25.989758
21-10-4	*Hylocomiosa*	22	Pine	56.738765	23.719551

Table 2

Treatment in experimental sites

Forest stand	NH_4NO_3, t ha^{-1}	Area, ha	Month / year
21-49-14	0.44	0.18	05.2017
11-18-5	0.44	0.80	07.2017
11-210-5	0.44	1.50	07.2017
21-10-4	0.44	1.62	06.2017

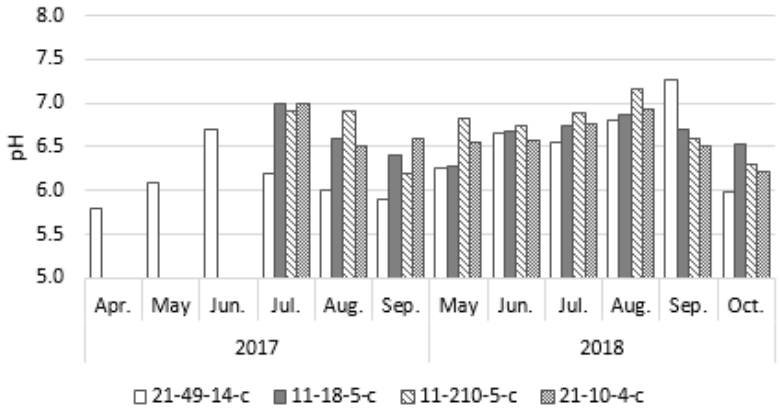

Figure 1. PH level in throughfall collected from control plots.

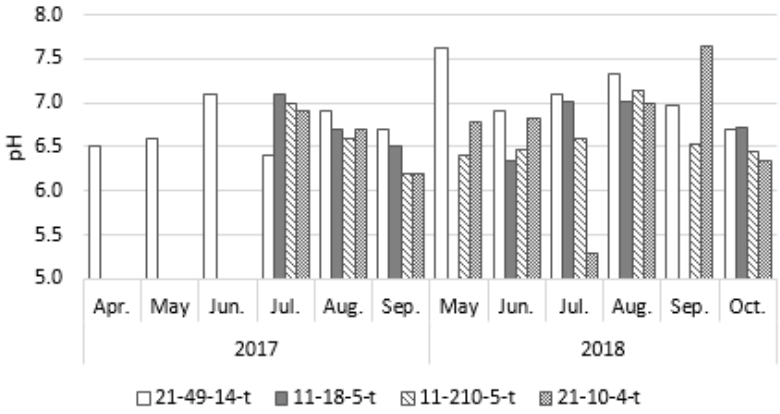

Figure 2. PH level in throughfall collected from treated plots.

The observed seasonal changes in pH level are related to the impact of the canopy on precipitation parameters. Namely, while flowing through the canopy, rainfall interacts with ions of leaves or needles. As a result, the average pH level of throughfall is higher than pH level of open field precipitation (Tērauda, 2008).

Figure 3 and Figure 4 illustrate changes in the total nitrogen concentrations of throughfall. Total nitrogen concentration values vary from 0.21 to 6.80 mg L^{-1} in the control plots and from 0.33 to 3.04 mg L^{-1} in the treated plots, but the mean values are 1.3 ± 0.2 mg L^{-1} in the control plots and 1.1 ± 0.1 mg L^{-1} in the treated plots.

After the forest soil enrichment with ammonium nitrate, there was no significant increase in the total nitrogen concentrations in water samples from fertilized plots. Elevated total nitrogen concentrations detected in May, June and July samples could be affected by pollen, needles or leaves that have accidentally fallen into the collectors. Birch is the dominant tree species of the forest stand 21-49-14. Since chemical properties of leaves differ from needles (Tērauda, 2008), the Figure 3 and Figure 4 elucidate the difference in total nitrogen concentrations between throughfall collected from the coniferous and the deciduous stands. Likewise, there were higher potassium and phosphate concentrations in the samples from the birch stand. The mean concentrations of potassium were 3.6 ± 0.6 mg L^{-1} in the samples from the birch stand and 2.1 ± 0.2 mg L^{-1} in the samples from the coniferous stands. Similarly, the mean concentrations of phosphate were 0.19 ± 0.04 mg L^{-1} and 0.10 ± 0.03 mg L^{-1} – from the birch and the coniferous stands, respectively.

Considering that nutrient status in soil may diversify depending on the forest type, soil water sample results of chemical analyses were divided into two groups. The first group consisted of data collected from the forest stands on dry mineral soil (11-18-5, 11-210-5 and 21-10-4) – *Hylocomiosa* and *Myrtillosa*, respectively. The second group was formed of data collected from the birch forest stand (21-49-14) on wet mineral soil – *Myrtilloso-sphagnosa*.

Figure 5, Figure 6, Figure 7 and Figure 8 illustrate the possible impact of ammonium nitrate fertilizer on soil water chemical properties. In the forest stands on dry mineral soil we observed an elevated pH level in the soil samples from the treated plots. It has also been reported on increased pH level in soil solution after the application of nitrogen containing mineral fertilizer (Aber *et al.*, 1989). We also observed a rapid increase in the total nitrogen concentrations in

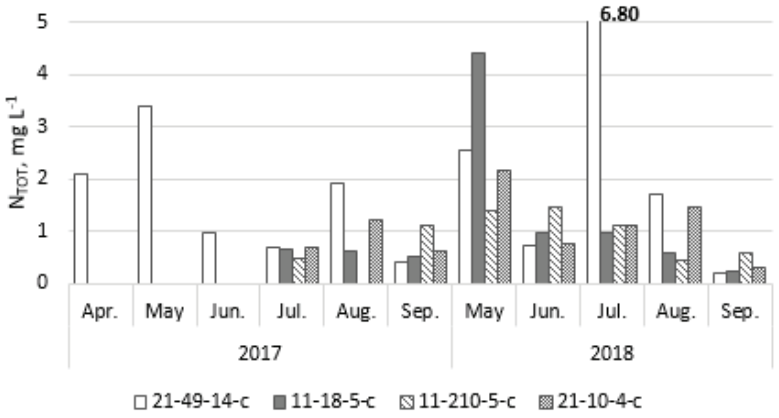

Figure 3. N_{TOT} mg L^{-1} concentrations in throughfall collected from control plots.

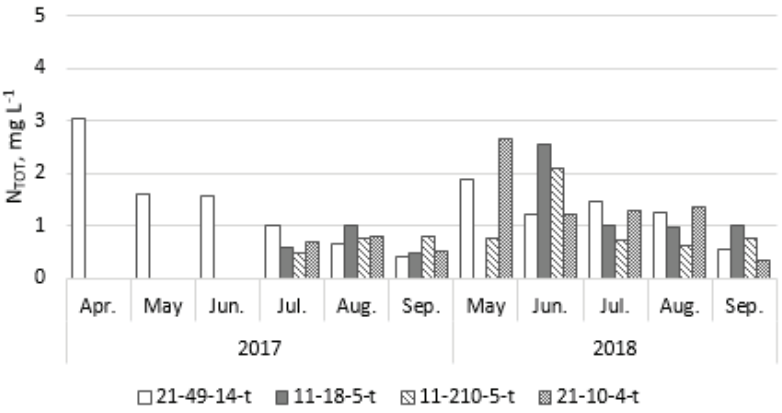

Figure 4. N_{TOT} mg L^{-1} concentrations in throughfall collected from treated plots.

soil water samples from the coniferous stands on dry mineral soil. The concentrations decreased within two months. There was also a slight increase in total nitrogen concentrations in the soil water samples from the birch stand on wet mineral soil; however, the concentrations were relatively low. In all data groups, larger data variation was observed in the soil water samples collected from 30 cm depth rather than from 60 cm depth (Stuanes, Kjønaas, & van Miegroet, 1995).

In both experimental groups, we observed a statistically significant increase in total nitrogen concentrations in soil water samples from the treated plots (Table 3). The mean concentrations were 1.5 ± 0.3 mg L^{-1} at the depth of 30 cm and 1.4 ± 0.3 mg L^{-1} at the depth of 60 cm in the soil water samples from the untreated control plots compared to 15 ± 6 mg L^{-1} at the depth of 30 cm and 5 ± 1 mg L^{-1} at the depth of 60 cm in the samples from the treated plots of the coniferous stands. The total nitrogen concentration increased more moderately in the soil water samples from the treated plot of the birch stand – 7.3 ± 0.9 mg L^{-1} at the depth of 30 cm and 5.4 ± 0.5 mg L^{-1} at the depth of 60 cm compared to concentrations in the

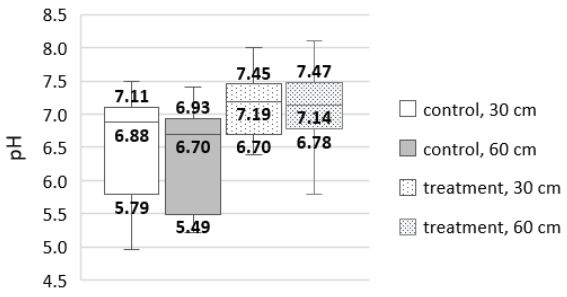

Figure 5. PH level in soil water collected from stands 11-18-5, 11-210-5, 21-10-4.

Figure 6. PH level in soil water collected from stand 21-49-14.

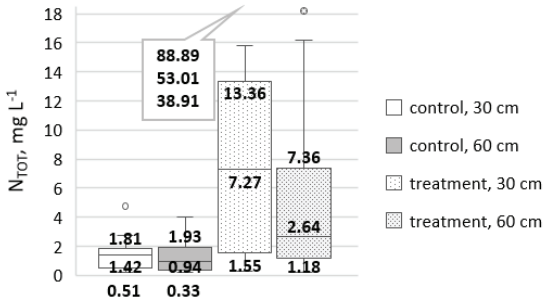

Figure 7. Nitrogen (N_{TOT} mg L^{-1}) concentration in soil water collected from stands 11-18-5, 11-210-5, 21-10-4.

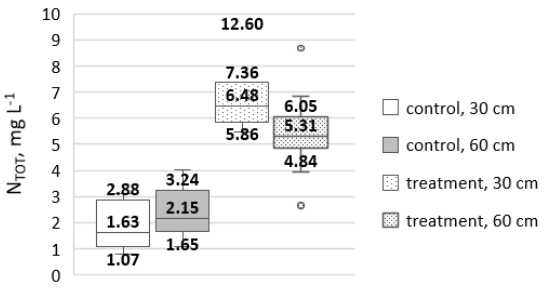

Figure 8. Nitrogen (N_{TOT} mg L^{-1}) concentration in soil water collected from stand 21-49-14.

Table 3

Mann-Whitney test p-values for soil water chemical parameters

Parameter	Forest stands 11-18-5, 21-10-4, 11-210-5		Forest stand 21-49-14	
	30 cm	60 cm	30 cm	60 cm
pH	0.017*	0.006*	0.682	0.503
K, mg L^{-1}	0.951	0.771	0.003*	0.736
N_{TOT}, mg L^{-1}	0.004*	0.023*	0.002*	0.001*
PO_4^{3-}, mg L^{-1}	0.004*	0.003*	0.206	0.860

* – a statistically significant difference

samples from the control plot – 1.8 ± 0.3 mg L^{-1} at the depth of 30 cm and 2.4 ± 0.3 mg L^{-1} at the depth of 60 cm. There was also a statistically significant increase in potassium concentrations in the soil water samples from the birch stand and a significant decrease in phosphate concentrations in the water samples from the coniferous stands. The mean concentrations of potassium at the depth of 30 cm were 0.26 ± 0.04 mg L^{-1} in the soil water samples from the control plot and 0.38 ± 0.06 mg L^{-1} in the samples collected from the treated plot of the birch stand. The concentrations of phosphate were 0.043 ± 0.006 mg L^{-1} at the depth of 30 cm and 0.06 ± 0.03 mg L^{-1} at the depth of 60 cm in the soil water samples from the untreated control plots compared to 0.019 ± 0.004 mg L^{-1} at the depth of 30 cm and 0.013 ± 0.003 mg L^{-1} at the depth of 60 cm in the samples from the treated plots of the coniferous stands.

Conclusions

1. Chemical parameters of throughfall do not indicate any impact of the nitrogen fertilizer. However, changes in throughfall chemical composition show the possible impact of pollen or needles that have fallen into collectors.
2. Two months after the ammonium nitrate spreading there was a short term increase in total nitrogen concentrations in the soil water samples collected in the treated plots. The concentrations diminished within two months, but stayed steady during the remaining monitoring period; however, relatively higher compared to the control plot.
3. In order to characterize more precisely the distributed fertilizer leaching, the chemical parameters of soil water samples should be statistically analyzed along with chemical properties of soil and needle samples.

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ANALYSIS OF LANDSCAPE PAINTINGS TO HIGHLIGHT THE IMPORTANCE OF FOREST ECOSYSTEM SERVICES IN LATVIA

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Abstract
Forests and woodlands provide a wide variety of ecosystem services that are usually classified within three categories: provisioning services, regulating (supporting) services and cultural services. While provisioning and regulating services are widely analysed, there is a lack of information about the cultural ecosystem services, particularly some sub-categories of these. In this study, we have focused on inspiration for creativity as a sub-category of cultural ecosystem services provided by forests and analysed the depiction of forest ecosystems in landscape paintings of Latvian artists. It may be concluded that forest ecosystems serve as an important source of inspiration for creativity and art, as may be seen in the landscape paintings of Latvian artists of the 20th century. Characteristic landscape features of birth and living places of the artists are reflected in their works. The performed analysis is the first of its kind in Latvia, and it may be further expanded, either by incorporating other aspects of creativity or adding economic dimension, for example, by surveying the art market.
Key words: Forest ecosystems, cultural ecosystem services, inspiration, creativity, landscape paintings.

Introduction

Forests and woodlands are multifunctional ecosystems and providers of multiple ecosystem services. The multifunctional and multiservice purpose of the world's forests is identified in the United Nations Forest Principles (1992), stating that 'forest resources and forest land shall be managed and used sustainably to fulfil social, economic, ecological, cultural and spiritual needs of present and future generations'. This definition is very similar to the one given in the Latvian Law on Forests (2000). The diverse services provided by forests include provisioning, regulating, cultural and supporting services (Shvidenko *et al.*, 2005; The Economics of Ecosystems and Biodiversity, 2010) or, in the Common International Classification of Ecosystem Services (CICES system), referred to as provisioning, regulation & maintenance and cultural services (Haines-Young & Potschin, 2018). Regardless of the classification system, cultural ecosystem services are recognized in all of them, and form an important and irreplaceable aspect of nature's contribution to people's welfare (Figure 1).

Cultural ecosystem services are recognized as an essential part of the contribution of nature to human welfare (Millenium Ecosystem Assessment, 2005), but at the same time there is very little information available concerning several categories of these services, including inspirational services. This fact is largely related to the difficulties that arise from attempts to describe and assign value to ecosystem services that provide no clear and direct material benefits. Even though it is clear that nature has a strong impact on culture and that natural and cultivated ecosystems inspire a wide spectrum of cultural expressions, scientific literature on this topic is scarce.

Millenium Ecosystem Assessment distinguishes five main types of inspirational services, namely, verbal art and writings that are inspired by nature, the performing arts, fine arts, design and fashion and the media in general. Nature is used as a source of inspiration in many literary works, it has influenced dance, song and theatre, a number of examples relate to the portrayal of different ecosystems in paintings, sculptures and works of craft, the beauty of the natural world has been largely reproduced in items of utilitarian use, and nature is widely used by various types of media to make programs and sell products (De Groot *et al.*, 2005).

In the Baltic and Nordic countries, forests are among the dominant terrestrial ecosystems, and they have largely influenced people's welfare by providing them with necessary resources, both directly and indirectly, through regulating the climate. At the same time, landscape has much more to offer than purely utilitarian values, and dominant ecosystems have doubtlessly shaped also the cultural identity of the inhabitants of the region. In Latvia, forests comprise more than a half of total land area (Ministry of Agriculture Republic of Latvia, 2019), and forest ecosystems have traditionally been of high importance in multiple ways. Apart from analysing traditional uses, significant landscape-scale studies have been conducted recently, pertaining to the ecological succession of forests and the importance of landscape diversity in reducing insect damage (e.g., Baders *et al*., 2017; Bāders *et al*., 2018a), but the information on the importance of dominant landscape types in the context of cultural ecosystem services remains scarce at best and non-existent at worst (depending on the sub-category of the investigated ecosystem service).

In this study, we have focused on a specific sub-category of ecosystem services, namely, inspiration for art. We have analysed how forest ecosystems have influenced the landscape paintings created in Latvia.

Figure 1. Ecosystem service groups as recognized by the main classification systems.

The aim of the study was twofold: 1) to identify the most important types of forest ecosystems for artistic inspiration, and 2) to establish whether the forest cover and landscape in the regions where the artists have worked have correlation with the emergence of landscape paintings with forest.

Materials and Methods

To evaluate the importance of different types of forest ecosystems and their elements as inspiration for art in Latvia, assessment of landscape paintings of Latvian artists was performed. We used two data sets: 1) The funds of the Artists' Union of Latvia (in total 512 paintings created during the 20th and 21st century); 2) Web-based available information from the artwork auction houses (in total 3131 paintings, auctioned since 2005, mainly from the 20th and 21st century, but a few paintings from the end of the 19th century as well). The websites of the auction houses contain photos of the paintings; therefore, it is possible to carry out visual assessment. Initially, 10 categories for the classification of all paintings were selected, namely: 1) no forest or forest elements; 2) pine (*Pinus sylvestris* L.) forest; 3) spruce (*Picea abies* (L).Karst.) forest; 4) birch (*Betula* spp.) forest; 5) mixed coniferous forest; 6) mixed deciduous forest; 7) mixed forest; 8) wetland forest; 9) forests with unidentified tree species; 10) forest fragments/elements in a different type of landscape. The number of the categories was further reduced, to ensure sufficient representation of forest landscapes in each group, and six categories were included in further analysis: 1) no forest or forest elements; 2) coniferous forest (pine, spruce and mixed conifer forests combined); 3) deciduous forest (birch and mixed conifer forest combined); 4) mixed forest; 5) forest with unidentified tree species; 6) forest fragments/elements in a different type of landscape. Wetland forest was excluded from further analysis due to very low representation. A basic statistical analysis was carried out to identify the most common forest landscapes in the paintings.

To evaluate, whether the forest cover in the country has had an impact on the willingness of the artists to picture this specific ecosystem, we correlated the available data on the forest cover (Kronītis, 1965; Bāders *et al*., 2018b) with the number of landscape paintings where different types of forests occur (mean values of decades). In this case, we omitted the paintings with only forest fragments but focused on those where forest was the dominant type of portrayed landscape. Complete set of data on both the forest cover in Latvia and number of respective paintings from the studied databases was available for the period from the 1900ties to 1990ties, therefore we used this specific timeframe.

To evaluate whether and how the creative work of the painters has been inspired by the dominant landscape of his birth and work place, we analysed the available information from the biographies of the painters that were included in our databases. The regions we used were following: 1) Rīga; 2) Rīga vicinity; 3) Latgale; 4) Zemgale; 5) Vidzeme; 6) Kurzeme; 7) unknown.

Results and Discussion

On average, pictures with forest landscapes or forest elements constituted 19% of the total number of all analysed paintings (the complete data set, covering the available records from the 20th and 21st century), the percentage being rather similar for both assessed

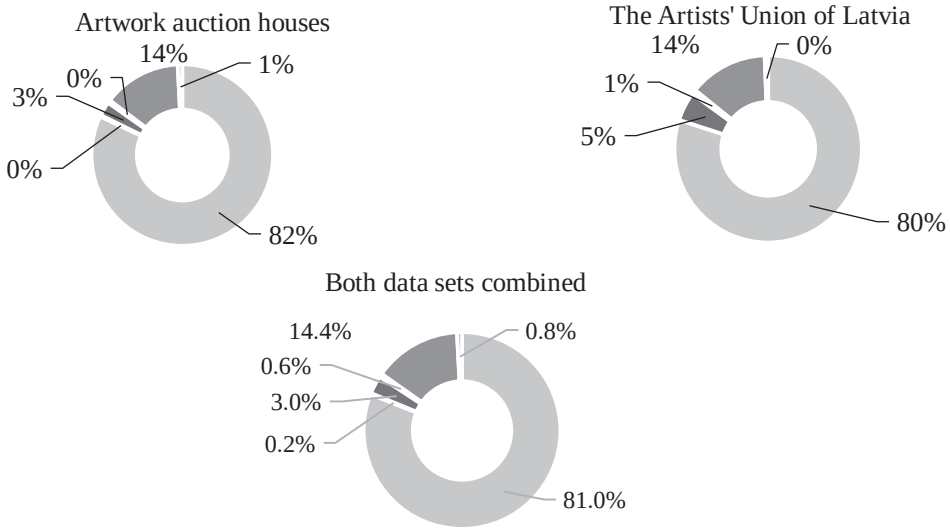


Figure 2. Occurrence of forest ecosystems and forest elements in the assessed paintings. Legend: – Paintings without forest of forest elements; – Paintings with coniferous forest; – Paintings with forests with unidentified tree species; – Paintings with deciduous forest; – Paintings with forest fragment/elements in different kind of landscape; – Paintings with mixed forest.

data sets (18% for the paintings from the auction houses and 20% for the paintings from the funds of the Artist's Union of Latvia). Also the percentage of paintings with forest fragments or forest elements was very similar for both datasets, on average constituting 76% of all paintings where forest landscape or elements were depicted at all. The next most common category was forest with unidentified tree species, followed by mixed forest, deciduous forest and coniferous forest (16%, 4%, 3% and 1% of all paintings with forest landscape or element, respectively) (Figure 2).

The representation of different forest types in the paintings reflect both the characteristics of the forest landscape of Latvia formed by relatively small stands (according to the official data of Latvian Forest Register, 2018, an average size of the forest compartment in Latvia is 1.26 ± 1.46 ha) with a patch-wise pattern of coniferous and deciduous forests, and also the aesthetic perception of the artists, preferring more colourful and irregular mixed or deciduous stands to relatively uniform and homogeneous conifer forests.

Forest fragments or forest elements are often used as a background or as an accent in paintings of other types of landscapes, to balance out the composition.

In Latvia, the forest cover has gradually increased throughout the 20th century, from 26% in 1920 to 44% in 1990. Ownership and land use structure changed

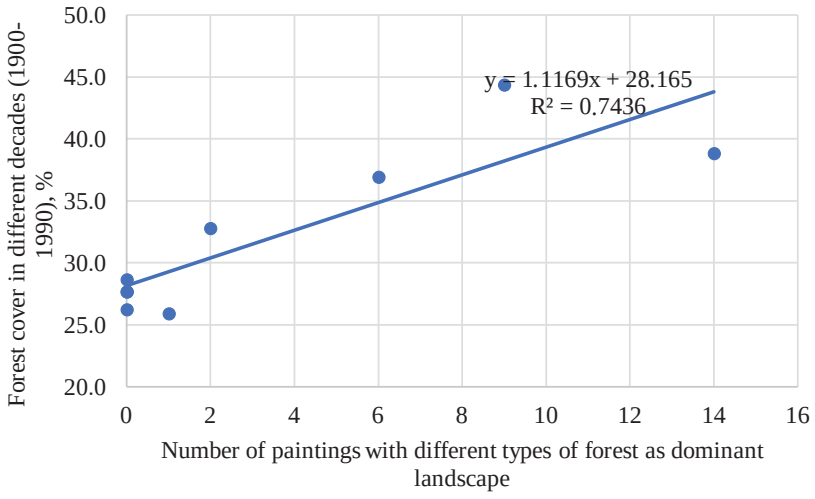


Figure 3. Correlation between forest cover and occurrence of forest depiction in the landscape paintings.

Table 1

Birthplaces of the analysed landscape painters (data set of the Artists' Union of Latvia; n=175)

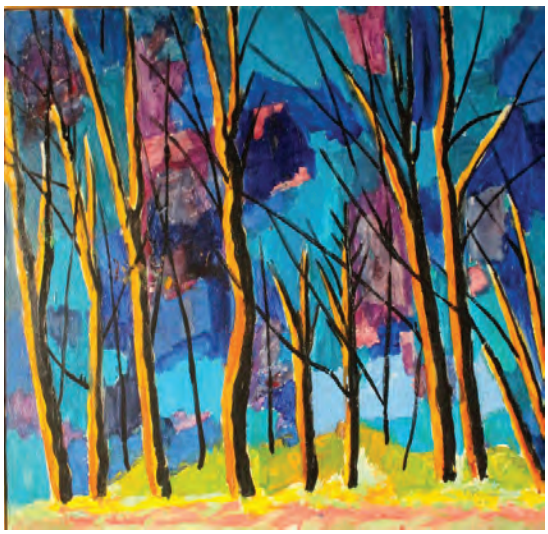
	Rīga	Rīga vicinity	Latgale	Zemgale	Vidzeme	Kurzeme	Unknown
Number of artists	51	14	12	18	36	22	22
Proportion, % from the total	29.1	8.0	6.9	10.3	20.6	12.6	12.6

after the WWI and proclamation of independence; forests mostly remained in state ownership but agricultural lands became private. During the 1930s, state policy promoted the afforestation of some agricultural areas, as farmers needed wood and timber and it was also thought that an increase of forest area would increase the export (Bells & Nikodemus, 2000). We found a positive correlation between the forest cover in Latvia and the number of paintings showing different types of forest; the correlation coefficient R=0.85 indicates close linear relationship, and the model is statistically significant, with p=0.007 (Figure 3). Caution is, however, needed in the interpretation of these results, as also other factors apart from the forest cover may have influenced this, for example, the increasing number of artists in general. In any case this may at least be considered as a significant trend, and obtained results indirectly confirm the importance of forest ecosystems as the source of inspiration for art.

More than one third of the analysed painters (65) were born in Rīga or Rīga vicinity. From other regions, Vidzeme was represented by the highest number of artists (Table 1). Part of them came from towns or cities, but in the rural areas, small towns are often located in a close proximity to forests, therefore, it may be assumed that the artists had a close connection

1. 20 years ago (1965). Ģederts Eliass, Zemgale

2. Sunny day in the forest (1962). Kārlis Miesnieks, Vidzeme



3. Autumn (1976). Rūdolfs Pinnis, Vidzeme

4. Autumn (1968). Jāzeps Pīgoznis, Latgale

Figure 4. Examples of landscape depiction in the paintings of Latvian artists of the 20th century.

to natural ecosystems. Even though, in the 20th century the places of residence of many artists have been varying, regardless of their places of birth due to complicated political situation, we may assume (also biographies of the artists confirm this) that many painters have spent most of their lives in their native regions. From the analysed data, it is not possible to conclude whether urban or rural environment has influenced their creative work. Regardless of the painters' places of birth – the capital or smaller towns – they have spent a lot of time in nature, painting in the plain air.

Below are given four examples of different rural landscapes painted by four Latvian artists; born in different regions of Latvia (Figure 4), and it is possible to distinguish some characteristic regional differences of landscape in their works of art.

Landscape No. 1 was painted by Ģederts Eliass (1887-1975), born in the rural district of Platone, Jelgava municipality, Zemgale region. Representative of realistic painting, he has worked in the scope of different genres. The presented example shows farmers working within a setting of a typical rural landscape of the Zemgale region. Zemgale is located in the southern part of Latvia, both now and historically it has the largest share of agricultural land and comparatively low forest cover.

The author of painting No. 2 is Kārlis Miesnieks (1887-1977). He was born in the rural district of Jaunpiebalga, Vidzeme region. Representative of the realistic painting, he has painted still lives, landscapes, genre paintings, portraits. The artist was born in Vidzeme, characterized with large forest areas. The painted landscape may be considered as rather typical for the region.

Landscape No. 3 is the work of Rūdolfs Pinnis (1902-1992). He was born in Madona, Vidzeme region. One of the best known and most popular Latvian artists, Rūdolfs Pinnis is the representative of fauvism style in Latvian painting. His works are full of dynamics and expression, saturated with colours. Many of his works show forest ecosystems, and even though it is hardly possible to distinguish the specific tree species or forest types due to the style he used, it may be assumed that the environment where the artist was born and lived had largely influenced his creativity.

The author of painting No. 4 is Jāzeps Pīgoznis (1934-2014). He was born in Silmala rural district, Latgale region. The artist was versatile in his creativity. Lakes, hills and small patches of forest are characteristic features of Latgale region, and these may be distinguished in the given example as well.

Certainly, the examples presented above are largely based on assumptions; the biographies of the artists are not always complete, often due to difficult political and economic situation in the 20th century. The personal style of each painter has influenced how nature was portrayed, and in many cases it was not possible to perform a more detailed analysis of the forest types. Still, these assumptions may certainly be considered as trends, and they provide an insight and an illustration of how the natural ecosystems supply cultural ecosystem services, namely, inspiration for the creativity. This study has confirmed, both directly and indirectly, that dominant ecosystems of a certain area, in this case – forests, are of high importance when shaping the cultural identity and, within it, creative expression of its residents (Figure 5). It has also indicated that works of art may be used to better understand and illustrate the importance of certain ecosystem types or their elements in sustaining and inspiring creativity. Through the paintings and other works of art, artists pass on their perception of the surrounding world and its values, thus enriching the cultural experience of others.

It has to be understood that culture is a complicated phenomenon that includes both tangible and intangible aspects, and the latter are very often lived or experienced rather than described or evaluated (Satterfield *et al.*, 2013). Still, attempts to quantify the intangible services are important, for these provide tools that allow including additional aspects in the planning of ecosystem management and are much needed to consider the multifunctional nature of the provided ecosystem services. A study on the inspirational value of ecosystems in popular music was performed by Coscieme (2015), and

Figure 5. Natural ecosystems as inspiration for creativity.

performing the analysis of the digital sector of the music industry, the author concluded that ecosystems have contributed $0.6 billion to the music industry in the time period of 10 years. Interestingly, one of the most important ecosystems in this regard was tropical forest ecosystem.

This kind of study, where the occurrence of a certain type of landscape has been analysed to attempt to quantify the significance of the given ecosystem in provision of cultural (inspirational) ecosystem services, is rare and, to the author's knowledge, the first of this kind in the Baltic region. It may be further expanded and detailed, both including additional aspects of creativity that are influenced by landscape and ecosystems and also by performing a more detailed analysis in the same direction, including analysis, for example, of the art market, thus striving to assign the studied ecosystem service monetary value.

Conclusions

1. The relatively high percentage of paintings with forest landscape or forest elements (almost one fifth from all the studied pictures) confirm the importance of forest ecosystems in the provision of cultural ecosystem services, namely, as inspiration for art in Latvia.
2. The most common representation of forest in the paintings is through forest elements or forest fragments in a different kind of landscape, so as to balance out the composition and accentuate the general theme. Forests with unidentified tree species and mixed forests come next in occurrence.
3. The number of paintings of forest ecosystems increase with increasing forest cover in Latvia during the 20th century. The relatively short distances and good accessibility enable also the artists from urban areas to go out in the plain air in the forest environment.
4. The characteristic landscape features of the birthplaces and working places of Latvian landscape painters are to some extent mirrored in their works and may have influenced their creativity.

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DEVELOPING A FRAMEWORK FOR CHARACTERIZING RECREATIONAL POTENTIAL OF FOREST AREAS USING WEIGHTED CRITERIA ANALYSIS

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Abstract
Forests offer a wide variety of ecosystem services, including cultural or recreational services. In that sense, state-owned forest lands hold the biggest responsibility to acknowledge and provide these services, where it is economically and ecologically viable. Suitability analysis has been extensively used to provide information on species conservation measures, and it is possible to apply similar techniques for potential supply of recreational services. A simple weighted overlay analysis was conducted to locate forest land areas most suitable for potential recreational activities. Several criteria were selected for the analysis, including forest stand parameters such as forest stand age, forest stand type and species, topographical diversity and remoteness. Basis for the weighting of the selected criteria were obtained from the social surveys, previous research work done in Latvia and the Baltics, and European scale scientific data on recreation preferences. The analysis showed that 20% of the total model area analyzed provide substantially high recreation potential. Furthermore, these preliminary data can be used for surveying and facilitating community involvement processes. Local tourism and nature leisure activities can be promoted by exploring possibilities of alternative forestry planning options, utilizing such multifunctional assessments of recreational supply.
Key words: forest recreation, spatial planning, suitability analysis, weighted overlay.

Introduction

Forest ecosystem services have been a hot topic in recent research, concerning both multitude of provided services and potential trade-offs between different ecosystem service groups. One such research area deals with forest recreational (cultural) services (Hermes *et al.*, 2018; Lankia *et al.*, 2015). As a non-tangible service, recreational potential and demand can be difficult to quantify in terms of spatial planning and managing resource harvests.

State forestlands in Latvia are managed on a 'three-pillar' basis – considering economic, social and ecological goals. There is extensive work done in the field of ecological habitat conservation and smart planning using landscape ecological approaches, although one could wish for clearer methodology and selection criteria related to the delineation of recreational areas (defined as 'Eco forests for recreational use'). Currently, approximately 3341 km^2 of state forest area is managed with this goal (LVM Geo, 2019). As a basis of multifunctional forestry, multiple services and resources should be valued and mapped, to provide a wider basis for decision making on different planning scales, and to avoid or diffuse possible conflicts (Pohjanmies *et al.*, 2017).

It is clear that not all forest landscapes can offer the same recreational quality, and there are several parameters or criteria that can influence the 'appeal' of certain forest area for recreation both from a planning standpoint and from a visitor's standpoint (Nielsen, Heyman, & Richnau, 2012; Ridding *et al.*, 2018). In Europe, research results on recreational and landscape preferences can be diverse based on regional and cultural differences (mixed, higher density forest stands in Central Europe or less dense coniferous forests in Scandinavia) (Ciesielski & Stereńczak, 2018). In Latvia, a country that is located in the boreo-nemoral forest zone, the main factor for determining site preference seems to be forest stand density and the presence of a strong understory (negative influence) (Donis, 2012). Criteria such as complexity, mistery or familiarity can also be drawn from photo stories, and results of such research in the Baltics also point towards a preference for coniferous, older stands to have higher recreational values (Hansson *et al.*, 2012). However, due to the fact that complex, emotional landscape preference features are hard to quantify, forest stand characteristics were the main parameters used to develop criteria for recreational provision for the purposes of this study.

The main goal of this research was to develop a method that delivers useful spatial information, ready to be applied for identifying and managing potential recreational sites. It is important to note that this research focuses on the supply aspect of the selected ecosystem service, not explicitly covering the demand. Recreational demand can be determined by using surveys, Delphi or public mapping methods. Landscape preferences in Latvia have been determined in earlier research works using large sample (n=~1000) surveys, which serve as an important basis for developing the recreational site criteria (Donis, unpublished). The subjectivity of recreational services makes it difficult to determine whether expert or public opinions are more crucial to determine recreation site quality and willingness to use this ecosystem service. This research can be continued fluidly by creating picture surveys or conducting on-site interviews, for confirmation and validation of supply- demand matches or mismatches.

Materials and Methods

The basic operational steps for the developed framework follow this scheme: collection of available geospatial or other data, evaluation of each data layer (criteria), reclassification of each criteria, overall weighting of each criteria and final output result (which can also be reclassified).

Using forest stand inventory data, the following criteria were chosen to represent the basic, preliminary features of recreational potential – forest stand age, forest stand density, forest stand type and dominating tree species. The motivation for the choice of these specific criteria was based on the previous research that has demonstrated that these features are among the most important when assessing the suitability of forest areas for recreation (mainly from the aesthetic point of view). These criteria were then used to identify unsuitable or unlikely areas for forest recreation activities and to locate areas with potentially high recreational values, based on preliminary analysis of literature, national survey and expert data, with the goal to find optimal recreational preference. Each site type was assigned a criterion value based on its most common expected characteristics (Table 2). The criteria were valued on a scale of 1 (low value) to 5 (high value) points, and further weighted using criteria weights (in this analysis the focus was on the forest stand parameters, rather than on the other criteria) (Table 1). It was assumed that every forest stand provides recreational opportunities to a certain level, but selective criteria like the occurrence of pine as a dominating species and older forest stands, for example, had higher point values. Literature sources varied slightly on several criteria, but information of broader preferences were analyzed in Latvian context, provided by the national survey data and previous research works. The three other criteria, based on abiotic and spatial distribution aspects, were used from other data sources. The proposed framework can be modified with additional criteria, based on the available data.

For the purpose of demonstrating the proposed method of estimating potential recreation values, two state forest areas (Nicas and Grobinas forest planning districts) were used as the study sites (the total area of 1695,4 km^2). The combined forest area

Table 1

Criteria used for the evaluation of recreational potential of forest areas

Criteria	Value scale (1 – lowest, 5 – highest)	Literature	Criteria weight
Forest stand age class* (of the dominant species; based on forest inventory results)	Young stands, middle-aged stands – 2 points Premature, mature stands – 5 points Overmature stands – 4 points	Hansson *et al.*, 2012; Donis, 2013	2
Forest stand type (defines stand composition and undergrowth) (Table 2)	Dry or drained, mineral soil based forest stands with less undergrowth – 5 points Wet, mineral or organic soil based forest stands – 3 points Drained forest types with a high productivity/dense undergrowth – 2 points	Donis, 2013; Donis, unpublished; Hansson *et al.*, 2012	2
Forest stand density	Stand density 1 to 3 – 3 points Stand density 3 to 7 – 5 points Stand density 7 to 9 – 4 points Stand density 10 and above – 1 point	Edwards *et al.*, 2012	2
Dominating tree species (can include mixed stands)	Pine – 5 points Other tree species – 3 points	Hansson *et al.*, 2012; Donis, 2013	2
Topographical diversity (calculated from DEM 20 m using Jenness, 2002)	No topographical diversity – 0 points Some topographical diversity – 2 points Noticeable topographical diversity – 3 points	Komossa *et al.*, 2018; Weyland & Laterra, 2014	1
Accessibility from local road networks	500 m – 5 points ~500 m to 2 km – 4 points 3 km and above – 2 points	Lībiete *et al.*, 2018	1
Proximity to current recreational areas (connectivity)	>1 km – 5 points 1 – 5 km – 4 points 6 – 10 km – 3 points 11 and above – 2 points	Authors' suggestion	1

* Age class interval for conifers and hardwoods is 20 years, for softwoods – 10 years, for especially fast-growing trees, e.g., grey alder or willow – 5 years. For conifers and hardwoods the division is the following: age classes I and II – young stand, age class III – middle-aged stand, age class IV – premature stand, age class V and VI – mature stand, age class VII+ – overmature stand. For softwoods division is the following: age classes I and II - young stand, age class III and IV – middle-aged stand, age class V – premature stand, age class VI and VII – mature stand, age class VIII+ – overmature stand.

Table 2

Values of individual site types for recreational provision

Forest growth/ biophysical conditions and criteria value points	Dry forests	Wet forests	Mire forests	Drained mineral based	Drained organic based
Forest type	*Cladinoso-callunosa* (5 points)	*Callunoso-sphagnosa* (5 points)	*Sphagnosa* (3 points)	*Callunosa mel.* (5 points)	*Calluna turf. Mel.* (3 points)
	Vacciniosa (5 points)	*Vaccinioso-sphagnosa* (5 points)	*Caricoso-phragmitosa* (2 points)	*Vacciniosa mel.* (5 points)	*Vacciniosa turf. mel.* (3 points)
	Myrtillosa (5 points)	*Myrtilloso-sphagnosa* (3 points)	*Dryopterioso-caricosa* (2 points)	*Myrtillosa mel.* (3 points)	*Myrtillosa turf. mel.* (3 points)
	Hylocomiosa (5 points)	*Myrtilloso-polytrichosa* (3 points)	*Filipendulosa* (2 points)	*Mercurialiosa mel.* (2 points)	*Oxalidosa turf. mel.* (2 points)
	Oxalidosa (2 points)	*Dryopteriosa* (2 points)			
	Aegopodiosa (2 points)				

of both districts potentially provides close-proximity, rural forest recreational services for regional capital Liepaja, as well as for several smaller towns and villages. Forest stand inventory data for the study area was combined with open source data provided by the LVM GEO platform and GIS Latvia 10.2 (GIS Latvija 10.2, 2019) open source database. In this analysis, only state forests were taken into account, excluding privately owned and strictly urban forests. State forests dominate in the study area. Digital elevation data from LGIA (10 m step) was used to determine topographical diversity as a criterion for recreational potential. Data on micro reserve habitat areas was used initially, but in the final spatial outputs these areas were omitted due to a very small coverage. All data was converted and used in raster format with the cell size of 100 m.

Using overlay criteria analysis (Weighted Sum tool) in ArcMap 10.x, the valued and reclassified data layers/criteria were weighted using the provided criteria weight value (see Table 1), summed together in a final data layer. The analysis values were further reclassified on a 1 – 5 scale. The final values of the recreational potential indicator are as follows – 1 being the lowest value for recreational potential and 5 being the highest. No data values (including mires and other land categories which are not a part of this analysis) and private forest areas were classified as 0 in this case.

Results and Discussion

As seen in the final output of the analysis (Figure 1), the spatial distribution of high or low recreational potential varies. Already existing recreational sites along the Bārta river and in the established nature parks or recreational infrastructure objects that are already in place coincide with some high recreational potential value areas as derived from the analysis, but since proximity of the existing recreation sites is one of the proposed criteria, these areas are not used for verification of the model results. Areas with lower recreational potential are identified north of Grobiņa and below Jēčupe river, which could be the result of specific forest stand types and management, as well as a lack of existing recreational infrastructure. From the planning standpoint, such results using the proposed framework could indicate that areas with high values may be further investigated and planning solutions may be implemented, if there are no existing recreational forest areas in the area, or if the model outputs match with public opinion or other sources of information for the planner (e.g., Latvia's State Forests or municipalities). Overall, 20% of the total valued forest area (excluding mires, clear-cuts and other areas) were determined to have very high recreational potential, while medium or average potential was assigned to 59% of the total valued area. Using the approach, reclassification of the model results can be done to identify the highest possible values and to avoid counting 'average' areas as high value ones. The methodological framework, as shown in the case example, is applied on a regional (municipal) planning scale, but it can be applied to various scales, by adjusting raster analysis cell sizes (both large scale country assessments and detailed, small scale watershed analysis could be conducted

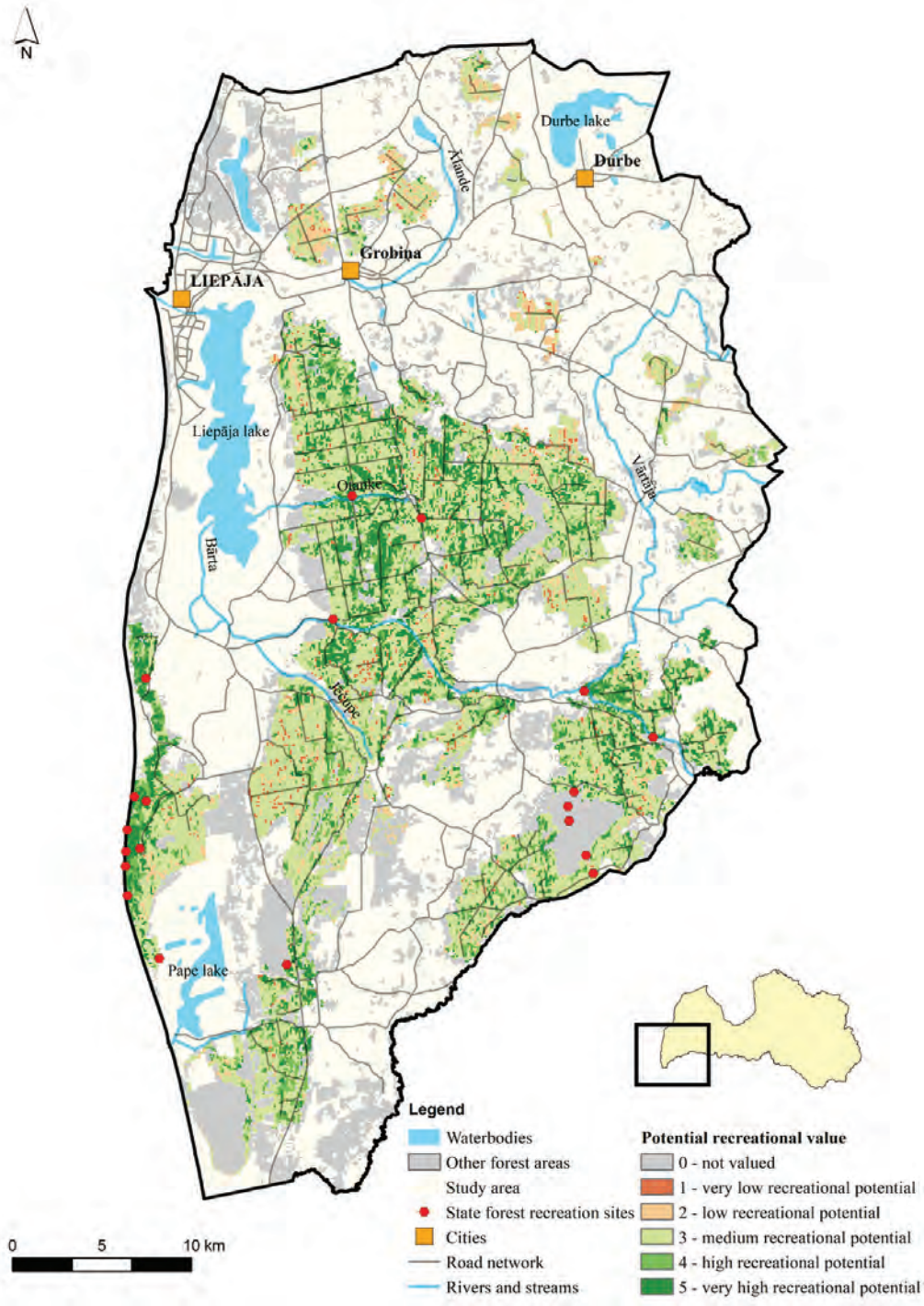

Figure 1. Demonstration of the results of the proposed method for assessing recreational potential in state forest areas.

using the framework). Available data for small-scale analysis might be constricted for criteria concerning topographical analysis (quality and resolution of available DEM), but forest inventory databases (which is the main aspect of this proposed framework) in Latvia have a reasonably detailed geospatial data resolution, which could be supplemented by remote sensing.

Multiple studies have been conducted on a European scale, and some include the weighted overlay aspects as used in this analysis (Komossa *et al.*, 2018). The scale of recreational potential research is often either on a small, urban scale or covering entire pan-European region. Multiple aspects and criteria used in this research involve synthesizing knowledge of different forest preferences from other regions of

Europe – both Central and Northern (Scandinavian), which creates more uncertainty for the results and practical applications. Although no survey methods were applied in this analysis, the results can be considered as a basic framework, which can be further detailed and adjusted for different types of recreational groups (for example, recreational foragers, mountain bikers, hikers or wildlife photographers). The criteria method is a viable solution from a GIS standpoint, as it gives flexible space to easily change criteria values and weights – analysis could be conducted to focus more on accessibility and topographical factors, for example, rather than on forest stand features as in this study. For example, extreme forest hikers could have a higher subjective value for rough terrain compared to bird watchers or casual hikers. Accessibility could also have a more complex approach, as demonstrated in Paracchini *et al.*, 2014, where high value recreation areas could have both remoteness and urban neighborhood access values implemented in a matrix scale. The results of this analysis can be spatially shown as heterogeneous gradient values over a single land cover type (as compared to single values being applied to entire forest compartments or other planning units). Although forest compartment borders and delineations still show in the final results, the nature of distance, topographical and connectivity criteria add dynamic values to the results, which are mostly not related to the forest compartment spatial borders. The proposed method of assessing forest recreation potential can have some drawbacks, including uncertainty of the proposed criteria values and open-ended discussions on criteria importance for forest recreation preferences and uncertainty of accuracy of forest inventory data (which needs to be tested on field or by using remote sensing data). Aspects of recreational stress on ecosystems is overlooked in this version of the framework, especially in the case of topographical diversity, as too much recreational demand in diverse terrain areas could cause erosion processes. To further develop and implement the framework for local and regional scale assessments of forest recreation provision, expert and public surveys should be conducted to assess the subjective preferences and to achieve more accurate representations for criteria scaling, as opposed to only using literature sources. Criteria, such as, population density or distance from the population centers, should be added to have a full demand-supply flow of recreational potential. The framework from a GIS standpoint also allows to assess the potential trade-offs between various recreational groups and preferences, and trade-offs between forestry operations (by evaluating forest harvest provision services in the same area), where multiple recreation or harvest analysis maps are combined and analyzed in raster calculator or other tools.

Conclusions

1. At the current stage, the suggested approach offers a flexible way for preliminary assessment of recreational potential in forest areas.
2. Diversified criteria and inputs from expert or public sources are needed to increase the reliability of the approach, ensuring more accurate analysis results.
3. The subjectivity of recreational values is difficult to avoid during any related analysis, although forest planning can still include such results to support decision making processes in both forestry and recreational infrastructure planning operations.
4. The standpoint of multiple preference groups can be involved in such framework, by applying different sets of criteria for each type of recreational groups.

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THE EFFICIENCY OF FOREST DRAINAGE SYSTEM SEDIMENTATION PONDS IN THE CONTEXT OF WATER QUALITY

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Abstract
The establishment, maintenance and renovation of forest drainage systems are carried out to ensure the development of high quality forest stands and to secure access to forest resources, but it also poses a risk of erosion and increased discharge of suspended solids and nutrients associated with it. The aim of the study was to analyse the efficiency of standard-sized sedimentation ponds built by JSC 'Latvia's State Forests' for sediment and nutrient retention during and after drainage network maintenance. To assess the efficiency of standard-sized sedimentation ponds six study sites were established and various chemical and physical parameters were measured for three years to evaluate water quality and to estimate runoff of plant nutrients and suspended solids. Sampling was carried out before and during drainage network maintenance and during two years following it.
Despite the fact that some effect in reducing suspended solid export from catchments was observed, the results revealed insufficient efficiency of the sedimentation ponds in retaining plant nutrients and eroded matter during and after the drainage network maintenance. Retention of N_{tot}, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, $N\text{-}NH_4^+$ and DOC was ambiguous. It was concluded that other water protection structures should be considered or different parameters of sedimentation ponds should be used to improve the water quality exiting the drainage systems and entering waterbodies.
Key words: sedimentation pond; drainage system maintenance; nutrient export; total suspended solids.

Introduction

In the temperate and boreal regions around 15 million ha of paludified mineral soils and peatlands have been drained for forestry purposes, furthermore, about 10 million ha of them are located in countries of the Baltic Sea Region (Paavilainen & Päivänen, 1995).

Water availability is a major factor for site productivity (Gholz, Ewel, & Teskey, 1990). There is a strong relation between soil aeration, groundwater level and tree growth. High water level restricts seedling survival and tree growth. Subsequently, stands in such growth conditions have low productivity and are commonly understocked (Sarkkola, Hökkä, & Penttilä, 2004). Drainage of wetlands is one of the most effective measures in increasing the forest productivity. According to Sikström and Hökkä (2016), productivity of Scots pine after drainage network maintenance (DNM) increases by up to approx. 40 m^3 ha^{-1} during 20 years, on condition that nutrients are not limiting tree growth. An increase of productivity of fully stocked Scots pine stands as observed by Socha (2012) may increase up to 25%.

In Latvia, large-scale forest drainage activities were started in the second half of the 20th century. Nowadays there are more than 464,056 ha of drained area in state forests – the total length of the drainage network is 43,680 km. In Latvia, new ditches are currently only excavated within the existing drainage systems, but no new drainage systems are being built, primarily due to the reasons related to nature conservation. In Latvia, a large part of the forest drainage systems has already become ineffective due to deterioration and overgrowing of ditches and needs to be restored. Regular DNM should be carried out in order to ensure the efficiency of these systems. DNM involves cleaning of old ditches to their initial depth or digging supplementary ditches within the existing system, if necessary, or a combination of both methods. It is recommended to carry out DNM every 20-40 years to preserve appropriate growing conditions for the tree stands. Without drainage system restoring process, swamp formation processes may resume.

Despite the fact that DNM is needed to sustain the tree growth, it also poses a risk of erosion, as a result of which suspended particles, nutrients and heavy metals can enter the drainage systems and be further exported to water bodies. Organic material and suspended solids in drainage water are generally associated with nutrient losses from drained peatland forestry areas. As the sedimentation and eutrophication processes intensify, water quality may deteriorate; therefore, it is important to implement effective water protection structures and guidelines to improve the water management practices in forestry and water management.

The impact of ditch network maintenance on water quality is mainly described in Finnish scientific literature (Joensuu, 2002; Marttila & Kløve, 2010). There have been only a few studies on this topic in Latvia so far. The aim of this study was to analyse the efficiency of standard-sized sedimentation ponds built by JSC 'Latvia's State Forests' for sediment and nutrient retention during DNM.

Materials and Methods

The efficiency of sedimentation ponds was studied in six catchments in Latvia's State forests. Two study sites were located in Northern Kurzeme forestry (BU1 – 'Būšnieki 1', BU2 – 'Būšnieki 2'), one study area – in Southern Kurzeme forestry (VA – 'Vaiļi')

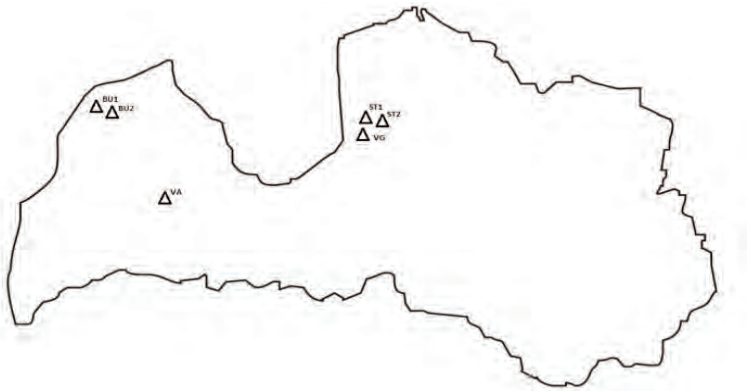

Figure 1. Location of the study sites in Latvia.

Table 1

General characteristics of the study sites

Study area	Coordinates (N; E)	Catchment area, ha	Dominant soil texture	Growing conditions, % of catchment area					Length of the sedimentation pond, m	Maintenance works finished
				Forests on dry mineral soils	Forests on wet mineral soils	Forests on wet peat soils	Forests on drained mineral soils	Forests on drained peat soils		
BU1	57.4354; 21.7011	76.1	Sandy loam	9			79	11	30 m	21.07.2012
BU2	57.43299; 21.70075	73.2	Sand	9			79	11	30 m	16.08.2012
VA	56.85576; 22.49577	448.2	Sand	5	7	5	80	2	50 m	15.09.2012
ST1	57.41015; 24.59164	272.1	Sand	18	1	1	9	70	50 m	11.05.2012
ST2	57.41046; 24.58986	92.6	Loam	37	9		21	33	50 m	10.04.2012
VG	57.29287; 24.55391	73.2	Sandy loam	52	30		17	1	30 m	01.06.2012

and three study areas – in Western Vidzeme forestry (ST1 – 'Stūrīši 1', ST2 – 'Stūrīši 2', VG – 'Vanagu gārša') (Figure 1). Catchment size of the study areas varied from 73.2 ha to 448.2 ha (Table 1). DNM was performed in the spring/summer of 2012.

Water quality sampling was carried out on the outlet ditch of each studied catchment where sedimentation pond was constructed. For reference, water samples were taken once before the maintenance works. After maintenance works were finished, water samples were taken twice a month until the end of October in 2012. In 2013 and 2014, water samples were taken twice a month in the study sites ST1, BU1 and VG, but in the study areas ST2, BU2 and VA – once a month from the beginning of May until the end of October. After the maintenance, water sampling was done in three points – at the inlet and outlet of the pond and in the pond itself. The samples were taken in 1.0 l polyethylene bottles directly from the ditches by carefully sinking the bottle below the water level.

In sites ST1, VG, BU1 simultaneously with water sampling, ditch profile (at water sampling locations) and stream velocity measurements were carried out to enable calculations of export of suspended solids and nutrients from the catchments.

To compare data statistically, the analysis of variance (*Anova*) in combination with *LSD* (*Least significant difference*) *post-hoc* test was conducted and standard errors were calculated. Different letters (a, ab, b) were used to indicate significant differences ($p \leq 0.05$) in the results. Sedimentation ponds were considered as effective if values significantly decreased ($p \leq 0.05$) after pond, comparing to the values before pond.

In Latvia, there are no threshold values to assess water quality in drainage systems, so results of the study are compared to Water Quality Standards for Priority Fish Waters by the Cabinet of Ministers of the Republic of Latvia.

Results and Discussion

Majority of published studies show that first-time drainage has a greater impact on runoff comparing to DNM (Åström, Aaltonen, & Koivusaari, 2001; Joensuu, Ahti, & Vuollekoski, 1999; Koivusalo *et al.*, 2008), especially regarding the concentrations of

suspended solids (Marttila & Kløve, 2010; Nieminen *et al*., 2010; Nieminen *et al*., 2017). At the same time, according to Ahti, Alasaarela & Ylitolonen (1995), Manninen (1995) and Manninen (1998), the effect on the concentration of suspended solids in the runoff of the initial ditching and DNM are similar.

In a study in Finland (Joensuu, 2002), a small decrease of total nitrogen concentrations was observed during the first years after ditch network maintenance; similar results were obtained in our study sites (Table 2; Table 3; Table 4; Table 5; Table 6; Table 7). On the contrary, earlier studies (Ahtiainen & Huttunen, 1999) ploughing and mounting to a mean level of 81.8 mg l–1 North Karelia Regional Environment Centre, P.O. Box 69, FIN-80101 Joensuu, University of Joensuu, Department of Biology, P.O. Box 111, FIN-80101 in 1986– 88, decreased to a level of 7.8 mg l–1 for 1989–91 and 4.5 mg l–1 for 1992–94. Total phosphorus concentration increased four-fold (142 µg l–1 reported that the total nitrogen concentrations increase after ditch maintenance.

$P\text{-}PO_4^{3-}$ concentrations in all research sites were generally low with small fluctuations over the years, except in site VA where relatively higher concentrations were observed during the first two years of sampling and during the third year before the sedimentation pond and in the pond itself.

In accordance with the Water Quality Standards for Priority Fish Waters (Cabinet of Ministers, 2002), the threshold value for total suspended solids is 25 mg L^{-1}. This value was exceeded in sites VG, ST1, ST2, BU2 in the first two sampling years. In site VA the concentrations of the suspended solids were high and exceeded the threshold value throughout all sampling period – although these results may have been influenced by prolonged renovation works that continued throughout all observation period.

In all sites $N\text{-}NO_3^-$ concentrations were higher in the renovation year and in the year after, but in general nitrate nitrogen values were low.

Overall, pH values in almost all sites fell within the interval of target values for Water Quality Standarts for Priority Fish waters – 6-9 (Cabinet of Ministers, 2002). In all study areas, pH values exceeded 6, except in the site VA in 2012. Comparing the pH values over the years, it has increased after DNM in all of the study sites, except in ST1 and VG. In the study by Joensuu (2002), the mean pH value increased by 0.6 immediately after renovation process, and it was still 0.3 units higher than during the pre-treatment period six years after DNM.

The reported decrease of DOC concentrations varied from 15% (Nieminen *et al*., 2010) to 30% (Hansen *et al*., 2013) during the first two years after DNM. In our study sites DOC concentrations have noticeably increased in the year subsequent to renovation, although in 2014 the concentrations declined again.

In contrast to the expected improvement in water quality by the construction of the sedimentation ponds, no statistically significant effect was detected in all research sites comparing observed water quality before and after the sedimentation ponds.

Comparing element concentrations over the years in site BU1, DOC concentrations in the year 2013 were significantly higher than in other sampling

Table 2

Mean element concentrations in sedimentation pond in forest drainage system 'BU1' on ditch N-23

Elements in water samples	Year	Before pond		In pond	After pond	
DOC ± SE, mg L^{-1}	2012	25.19 ± 2.22	a	24.65 ± 3.17	25.49 ± 3.34	a
	2013	35.72 ± 3.67	b	35.85 ± 3.75	35.10 ± 3.82	b
	2014	20.24 ± 1.29	a	20.33 ± 1.26	20.81 ± 1.38	a
N_{tot} ± SE, mg L^{-1}	2012	2.06 ± 0.45	a	1.47 ± 0.35	2.47 ± 0.73	a
	2013	0.58 ± 0.04	b	0.57 ± 0.04	0.58 ± 0.05	b
	2014	0.47 ± 0.05	b	0.49 ± 0.05	0.49 ± 0.05	b
$N\text{-}NO_3^-$ ± SE, mg L^{-1}	2012	0.25 ± 0.03	a	0.27 ± 0.06	0.27 ± 0.04	a
	2013	0.13 ± 0.03	b	0.20 ± 0.05	0.18 ± 0.05	ab
	2014	0.08 ± 0.03	b	0.09 ± 0.03	0.09 ± 0.03	b
pH ± SE	2012	7.88 ± 0.08	ab	7.90 ± 0.12	7.88 ± 0.12	ab
	2013	7.84 ± 0.12	b	7.98 ± 0.09	7.99 ± 0.07	ab
	2014	8.09 ± 0.09	ab	8.13 ± 0.08	8.11 ± 0.08	a
$P\text{-}PO_4^{3-}$ ± SE, mg L^{-1}	2012	0.01 ± 0		0.01 ± 0	0.02 ± 0	
	2013	0.06 ± 0.05		0.01 ± 0	0.01 ± 0	
	2014	<0.01		<0.01	0.01 ± 0	
TSS ± SE, mg L^{-1}	2012	22.34 ± 6.98		20.68 ± 10.83	24.13 ± 11.70	
	2013	18.37 ± 4.57		19.76 ± 7.99	26.76 ± 8.83	
	2014	17.69 ± 7.20		6.61 ± 1.78	8.22 ± 2.14	

Table 3

Mean element concentrations in sedimentation pond in forest drainage system 'BU2' on ditch N-6

Elements in water samples	Year	Before pond		In pond	After pond	
DOC ± SE, mg L^{-1}	2012	20.47 ± 2.00	a	18.90 ± 1.92	18.28 ± 1.86	a
	2013	39.97 ± 6.53	b	37.97 ± 6.43	36.34 ± 6.07	b
	2014	15.87 ± 1.53	a	16.38 ± 1.42	16.47 ± 1.27	a
N_{tot} ± SE, mg L^{-1}	2012	1.62 ± 0.23	a	1.51 ± 0.15	1.42 ± 0.32	a
	2013	0.57 ± 0.08	b	0.48 ± 0.04	0.46 ± 0.05	b
	2014	0.38 ± 0.05	b	0.36 ± 0.03	0.36 ± 0.02	b
$N\text{-}NO_3^-$ ± SE, mg L^{-1}	2012	0.13 ± 0.05		0.20 ± 0.06	0.24 ± 0.07	
	2013	0.15 ± 0.03		0.24 ± 0.07	0.13 ± 0.06	
	2014	0.11 ± 0.06		0.12 ± 0.06	0.13 ± 0.06	
pH ± SE	2012	8.02 ± 0.10		8.04 ± 0.08	7.98 ± 0.06	
	2013	8.22 ± 0.06		8.19 ± 0.07	8.21 ± 0.06	
	2014	8.18 ± 0.17		8.18 ± 0.12	8.13 ± 0.12	
$P\text{-}PO_4^{3-}$ ± SE, mg L^{-1}	2012	0.01 ± 0		<0.01	0.01 ± 0	
	2013	0.01 ± 0		0.01 ± 0	0.01 ± 0	
	2014	<0.01		<0.01	0.01 ± 0.01	
TSS ± SE, mg L^{-1}	2012	29.75 ± 9.17		9.10 ± 7.21	30.96 ± 14.18	
	2013	15.64 ± 4.33		9.25 ± 2.97	12.36 ± 5.41	
	2014	26.53 ± 7.37		3.15 ± 1.26	20.13 ± 16.14	

years, both before and after the sedimentation pond, while concentrations of N_{tot} in 2013 and 2014 were significantly lower than those in 2012 (Table 2).

In site BU1 concentrations of $N\text{-}NO_3^-$ before pond were significantly higher in 2012 comparing to 2013 and 2014, however significant differences after pond were observed between two initial years of the study and 2014. Mean pH value, $P\text{-}PO_4^{3-}$ and TSS concentrations did not differ significantly during the study years.

Comparing element concentrations in site BU2 over years, mean DOC concentrations in 2012 and 2014 were significantly lower than in 2013 both before and after the sedimentation pond. Mean N_{tot} concentrations in 2013 and 2014 were significantly lower than the respective values in 2012. The mean concentrations of other elements were not significantly different during sampling years, however mean DOC, N_{tot} and TSS concentrations generally had a tendency to decline, comparing before and after pond values (Table 3).

Table 4

Mean element concentrations in sedimentation pond in forest drainage system 'ST1' on ditch N-41

Elements in water samples	Year	Before pond		In pond	After pond	
DOC ± SE, mg L^{-1}	2012	24.89 ± 1.05	a	24.15 ± 1.12	24.73 ± 1.11	a
	2013	36.91 ± 3.63	b	37.05 ± 3.65	37.25 ± 3.71	b
	2014	26.35 ± 1.38	a	25.18 ± 1.63	24.96 ± 1.80	a
N_{tot} ± SE, mg L^{-1}	2012	2.21 ± 0.30	a	2.07 ± 0.30	2.55 ± 0.52	a
	2013	1.25 ± 0.22	b	1.29 ± 0.23	1.28 ± 0.23	b
	2014	1.25 ± 0.21	b	1.26 ± 0.22	1.26 ± 0.22	b
$N\text{-}NO_3^-$ ± SE, mg L^{-1}	2012	0.44 ± 0.12		0.54 ± 0.12	0.50 ± 0.12	
	2013	0.52 ± 0.24		0.54 ± 0.21	0.47 ± 0.19	
	2014	0.29 ± 0.11		0.30 ± 0.12	0.34 ± 0.12	
pH ± SE	2012	8.02 ± 0.07		8.02 ± 0.06	8.01 ± 0.06	
	2013	8.06 ± 0.11		8.06 ± 0.10	8.01 ± 0.09	
	2014	7.95 ± 0.09		7.99 ± 0.06	7.95 ± 0.07	
$P\text{-}PO_4^{3-}$ ± SE, mg L^{-1}	2012	0.01 ± 0		0.01 ± 0	0.01 ± 0	
	2013	0.01 ± 0		0.01 ± 0	0.01 ± 0	
	2014	0.01 ± 0		0.01 ± 0	0.01 ± 0	
TSS ± SE, mg L^{-1}	2012	43.38 ± 18.84	a	24.38 ± 13.18	37.87 ± 17.25	a
	2013	7.83 ± 2.82	b	63.34 ± 54.94	20.43 ± 17.39	b
	2014	9.04 ± 4.53	b	4.97 ± 3.05	4.56 ± 2.50	b

Table 5

Mean element concentrations in sedimentation pond in forest drainage system 'ST2' on ditch N-61

Elements in water samples	Year	Before pond		In pond	After pond	
DOC ± SE, mg L^{-1}	2012	17.80 ± 1.11	a	17.93 ± 1.18	19.35 ± 1.04	a
	2013	35.00 ± 5.69	b	35.98 ± 6.01	35.59 ± 5.92	b
	2014	20.05 ± 1.69	a	20.24 ± 1.77	20.78 ± 2.08	a
N_{tot} ± SE, mg L^{-1}	2012	3.08 ± 0.57	a	2.79 ± 0.43	3.76 ± 0.65	a
	2013	1.33 ± 0.35	b	1.27 ± 0.35	1.27 ± 0.31	b
	2014	1.01 ± 0.22	b	1.06 ± 0.25	1.07 ± 0.24	b
$N\text{-}NO_3^-$ ± SE, mg L^{-1}	2012	0.34 ± 0.10	a	0.29 ± 0.08	0.24 ± 0.06	ab
	2013	1.22 ± 0.58	b	1.29 ± 0.61	0.65 ± 0.35	ab
	2014	0.37 ± 0.14	b	0.37 ± 0.16	0.32 ± 0.17	b
pH ± SE	2012	7.92 ± 0.08		7.90 ± 0.07	7.88 ± 0.08	
	2013	7.78 ± 0.11		7.78 ± 0.10	7.75 ± 0.10	
	2014	8.01 ± 0.09		8.02 ± 0.09	8.00 ± 0.09	
$P\text{-}PO_4^{3-}$ ± SE, mg L^{-1}	2012	0.01 ± 0	ab	0.01 ± 0	0.01 ± 0	a
	2013	0.01 ± 0	ab	0.01 ± 0	0.01 ± 0	ab
	2014	<0.01	b	<0.01	0.01 ± 0	b
TSS ± SE, mg L^{-1}	2012	43.12 ± 17.31	ab	19.09 ± 5.37	85.81 ± 40.50	a
	2013	4.93 ± 1.79	b	2.75 ± 1.36	6.43 ± 4.28	b
	2014	0.89 ± 0.40	b	1.07 ± 0.47	2.33 ± 1.20	b

Table 6

Mean element concentrations in sedimentation pond in forest drainage system 'VA' on ditch N-5

Elements in water samples	Year	Before pond		In pond	After pond	
DOC ± SE, mg L^{-1}	2012	115.60 ± 16.73	a	112.80 ± 18.33	103.8 ± 14.12	ab
	2013	125.45 ± 18.04	a	113.24 ± 10.09	114.82 ± 10.46	a
	2014	91.05 ± 10.36	ab	70.16 ± 13.78	71.70 ± 12.33	b
N_{tot} ± SE, mg L^{-1}	2012	4.62 ± 0.89	a	4.72 ± 0.98	4.67 ± 1.37	a
	2013	2.60 ± 0.27	b	2.62 ± 0.22	2.75 ± 0.25	b
	2014	1.98 ± 0.33	b	1.61 ± 0.33	2.03 ± 0.31	b
$N\text{-}NO_3^-$ ± SE, mg L^{-1}	2012	0.83 ± 0.49		<LOD	0.77 ± 0.15	
	2013	0.39 ± 0.06		0.27 ± 0.09	0.63 ± 0.28	
	2014	0.13 ± 0.11		0.18 ± 0.09	0.68 ± 0.47	
pH ± SE	2012	5.77 ± 0.32	ab	5.39 ± 0.39	5.69 ± 0.34	a
	2013	6.29 ± 0.27	ab	6.33 ± 0.24	6.16 ± 0.26	ab
	2014	6.18 ± 0.43	ab	6.74 ± 0.42	6.73 ± 0.41	b
$P\text{-}PO_4^{3-}$ ± SE, mg L^{-1}	2012	0.31 ± 0.08	a	0.28 ± 0.03	0.25 ± 0.06	ab
	2013	0.18 ± 0.05	ab	0.23 ± 0.07	0.27 ± 0.10	a
	2014	0.14 ± 0.02	ab	0.11 ± 0.03	0.08 ± 0.02	b
TSS ± SE, mg L^{-1}	2012	887.64 ± 669.73	a	395.75 ± 241.23	702.64 ± 323.71	ab
	2013	38.67 ± 12.54	b	84.66 ± 41.58	95.63 ± 53.09	b
	2014	24.85 ± 8.16	b	26.67 ± 9.71	44.45 ± 21.57	b

In site ST1 observed mean DOC concentrations have similar tendencies as in previously described site – significantly higher values were observed in 2013, whereas N_{tot} and TSS concentrations were significantly higher in 2012. Although element concentration values before and after pond were not significantly different, generally declining tendencies of mean DOC and TSS concentrations were observed (Table 4).

In site ST2 results showed similar trends of mean DOC, N_{tot} and TSS concentrations as in site ST1 – significantly higher DOC values were observed in 2013, whereas N_{tot} and TSS concentrations were significantly higher in 2012. No declining trends of mean TSS concentrations were observed, comparing before and after pond values, while downward trends of $N\text{-}NO_3^-$ concentrations were observed, although not

Table 7

Mean element concentrations in sedimentation pond in forest drainage system 'VG' on ditch N-52

Elements in water samples	Year	Before pond		In pond	After pond	
DOC ± SE, mg L^{-1}	2012	22.15 ± 1.33	a	20.38 ± 1.59	21.91 ± 1.71	a
	2013	42.17 ± 4.42	b	41.72 ± 4.19	42.01 ± 4.24	b
	2014	20.87 ± 1.38	a	20.73 ± 1.36	20.66 ± 1.25	a
N_{tot} ± SE, mg L^{-1}	2012	2.76 ± 0.62	a	2.71 ± 0.37	2.06 ± 0.31	a
	2013	0.83 ± 0.11	b	0.8 ± 0.09	0.79 ± 0.08	b
	2014	0.72 ± 0.10	b	0.71 ± 0.1	0.71 ± 0.10	b
$N\text{-}NO_3^-$ ± SE, mg L^{-1}	2012	0.23 ± 0.03		0.2 ± 0.03	0.24 ± 0.04	
	2013	0.29 ± 0.11		0.21 ± 0.10	0.34 ± 0.15	
	2014	0.16 ± 0.05		0.15 ± 0.04	0.16 ± 0.05	
pH ± SE	2012	8.08 ± 0.10		8.09 ± 0.10	8.11 ± 0.09	
	2013	8.07 ± 0.08		8.06 ± 0.08	7.83 ± 0.16	
	2014	8.03 ± 0.11		8.04 ± 0.12	7.98 ± 0.18	
$P\text{-}PO_4^{3-}$ ± SE, mg L^{-1}	2012	0.01 ± 0	ab	0.01 ± 0	0.01 ± 0.01	a
	2013	0.01 ± 0	ab	0.01 ± 0	0.01 ± 0	ab
	2014	<0.01	b	<0.01	<0.01	b
TSS ± SE, mg L^{-1}	2012	84.23 ± 49.13		373.18 ± 212.97	72.07 ± 51.47	
	2013	23.75 ± 16.66		40.82 ± 34.69	14.47 ± 8.17	
	2014	8.12 ± 3.49		9.76 ± 3.46	7.85 ± 4.87	

statistically significant (Table 5).

Mean DOC concentrations were not significantly different comparing the sampling years in site VA, except notably lower concentration after the pond in 2014. At the same time, there was a downward trend comparing values before and after the pond. N_{tot} and TSS concentrations were significantly higher in 2012. A downward trend of other element concentrations, comparing values before and after the pond, were not noticeable (Table 6).

Tendencies of mean DOC and N_{tot} concentrations in site VG were similar to previously described sites (BU1, BU2, ST1, ST2) with DOC concentration significantly higher in 2013 and N_{tot} significantly

Table 8

Output of biogenic elements from BU1, ST1, VG catchment areas throughout the observation period, kg ha^{-1} per year

Elements	Year	BU1		ST1		VG	
		Before pond	After pond	Before pond	After pond	Before pond	After pond
N_{tot}	2012	1.14	1.05	0.16	0.24	0.08	0.07
	2013	1.37	1.27	0.20	0.29	0.10	0.08
	2014	1.34	1.29	0.27	0.32	0.10	0.90
TSS	2012	43.78	8.71	2.12	4.50	5.04	8.73
	2013	34.58	6.88	1.67	3.56	3.98	6.89
	2014	35.98	5.74	1.78	3.18	3.87	7.20
DOC	2012	23.77	<0.01	2.34	2.67	0.78	0.87
	2013	19.49	<0.01	1.92	2.19	0.64	0.71
	2014	21.18	<0.01	1.72	1.15	0.61	0.69
$N\text{-}NO_3^-$	2012	0.20	0.10	0.04	0.05	0.01	0.01
	2013	0.22	0.11	0.05	0.05	0.01	0.02
	2014	0.22	0.13	0.04	0.04	0.01	0.01
$P\text{-}PO_4^{3-}$	2012	0.02	0.01	<0.01	<0.01	<0.01	<0.01
	2013	0.02	0.01	<0.01	<0.01	<0.01	<0.01
	2014	0.01	0.01	<0.01	<0.01	<0.01	<0.01
$N\text{-}NH_4^+$	2012	0.05	0.05	0.01	0.01	<0.01	<0.01
	2013	0.05	0.06	0.01	0.01	<0.01	<0.01
	2014	0.05	0.05	0.01	0.01	<0.01	<0.01

higher in 2012. A downward trend comparing the TSS concentrations before and after pond was observed, although not statistically significant (Table 7).

Our results on the leaching of biogenic elements are comparable with the data from the Finnish scientific literature (Joensuu, 2002). In most cases the output of biogenic elements in Latvia are lower than in Finland, which can be explained by different soil composition – none of our research sites are located on deep peat soils.

Nieminen *et al*. (2017) synthesized the information on the DNM impact on water quality and runoff from different studies. Most of the reviewed studies showed significantly decreased DOC runoff after DNM. Comparing runoff data over the years in our study sites, DOC export has also decreased, however in site VG the efficiency of DOC retention in the sedimentation pond was lower than in the other sites (Table 8).

In the site BU1 the runoff values of most elements were lower after the pond, while the element values in sites ST1 and VG after the sedimentation pond were similar or, in some cases, even higher than before it. The efficiency of sediment and nutrient retention in BU1 site was higher than in sites ST1 and VG. Differences between sites can be explained by different conditions in catchment areas, and a very low amount of runoff during the sampling period, as in some months runoff close to 0 was observed.

A study by Joensuu (2002) observed that during summer (the low flow period), phosphorus concentrations were the highest. Although the role of a sedimentation pond is to detain and collect the flow of nutrients and suspended particles, in a study by Kløve (2000) it is mentioned that if the size of soil particles is large and water flow is small in the sedimentation pond, most elements will be detained, but small particles such as fine silt and clay possibly will not sediment in all cases.

Conclusions

1. Mean concentrations of suspended solids and biogenic elements gradually decrease over the years after the drainage system maintenance. The efficiency of sedimentation ponds is higher in reducing the concentration of suspended particles than in reducing the concentration of nutrients.
2. Sedimentation ponds have not achieved the expected efficiency to reduce the leaching of SS and biogenic elements. The use of other water protection structures such as peak flow control dams, surface runoff areas or different parameters of sedimentation ponds should be considered depending on the size and conditions in the catchment area.

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ECOLOGICAL QUALITY OF FRESHWATER LAKES AND THEIR MANAGEMENT APPLICATIONS IN URBAN TERRITORY

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Abstract
Freshwater lakes and rivers are habitats of variety of organisms and their populations giving great importance for freshwater ecosystems and providing water resources, food and recreational possibilities for humans. In spite of their fundamental importance to humans, freshwater lakes have been affected by anthropogenic disturbances, which have led to serious negative effects on the structure, functions and quality of these ecosystems. Lake ecosystems are dependent on inflow of water and supply of matter and energy from their catchment area. In studied lakes significant anthropogenic impact in loads of nutrients in their sediments and water was detected. This highlights the well-known problem of freshwaters in the World and in Europe – eutrophication, which can lead to increased productivity of water ecosystems – increased algae blooms, spreading of macrophytes and decreasing of oxygen content in water. Studied lake ecosystems show presence of human impact, not only by physiochemical parameters, but also by changes in biomass production, cyanobacterial algal blooms and overgrowing with macrophytes was observed. In order to improve water quality, appropriate management measures should be applied. We have analysed advantages and disadvantages of such measures as sediment removal, constructing of wetlands, cutting reeds and forming ecotones.
Key words: water quality, nutrient loads, lake ecosystems, eutrophication.

Introduction

Lakes are ecosystems that are localized in a basin, usually with rivers or channels feeding or draining it (Hairston *et al*., 2014). Relation between physical, biogeochemical and organismal processes in lakes can be studied to understand overall ecosystem quality and choose effective management. In the lake management, without conserving natural process, it is also important to employ existing and potential ecosystem services (Cramer, 2008; Hassall, 2014). Human activity can strongly influence aquatic ecosystems, and some activities have dramatically altered the fluxes of growth-limiting nutrients from the catchment area. Elevated availability of nutrients had negative effects to the quality of surface waters worldwide, indicating eutrophication (Smith, 2003). Eutrophication of water bodies leads to significant changes in the functions and quality of the aquatic ecosystems. Water bodies, which have been described to have strong eutrophication are usually surrounded by densely populated human settlements, agricultural lands with runoff containing nutrients used for fertilization, sewage drains which feed phosphorus used in household detergents etc. (Khan *et al*., 2005; Sorrano *et al*., 2015). Eutrophication causes predictable increases in the biomass of algae in waterbodies responding to changes in nutrient loadings and suspended material form catchment area (Smith, 2003). During algae blooms cyanobacterial dominance of phytoplankton has been reported, as well as similar trends of different types of waterbodies have been reported worldwide (Smith, 2003; Paerl *et al*., 2011). Experiments with N and P show importance of both of the nutrients (Klavins *et al*., 2002), but reduced nitrogen inputs in comparison to phosphorus may lead to growth of nitrogen-fixing cyanobacteria (Schindler *et al*., 2008). Without discussed eutrophication processes, effective management measures and restoration methods are important, also related to possible effects with climate change. Analysis of literature shows that the increase of temperature will affect the physical, chemical, and biological properties of lake ecosystems (Kļaviņš *et al*., 2008). These changes will lead to decrease in water quality (with likely increased abundance of noxious cyanobacteria) and for wildlife habitats (with changes in stratification regimes and primary production) (Brönmark *et al*., 2002; Vincent, 2009). Although it is expected that in northern lakes and rivers, productivity of water ecosystems may increase, but it will also have increased risks due to changes in water levels in the case of warming and periods of dry conditions (Cramer, 2008). Eutrophication induced increase of biomass production in waterbodies can lead to decrease of water depth, especially in dry conditions and if the hydrological regimes are changed. This may influence food chain in lakes, as suggested by a biomanipulation concept, where phytoplankton is eaten by zooplankton, which is then eaten by planktivorous fish, which, in turn, are eaten by piscivorous fish (Hansson *et al*., 2009). Typically, in water ecosystems where algae blooms occur the amount of zooplankton communities and predator fish is decreased and they have even more difficulties to hunt in these waters (low visibility) (Brönmark *et al*., 2002; Hansson *et al*., 2009). The trophic levels play important role in waterbodies (Hansson *et al*., 2009), but also the amount of macrophytes (also submerged) should be taken into account, due resuspension of particles from the sediment (P cycling

and decreased light penetration), and internal loads of nutrients. Two lakes in Latvia which coastline is urbanized and are inter-connected were studied. The aim of the following work is to characterize water quality, ecosystem functionality and analyse possible management actions.

Materials and Methods

Lake Balvu and Lake Pērkonu (Figure 1) is located in NE Latvia. Sampling points (in 2018) (Table 1) cover both lakes and rivers. Lakes are of Pleistocene glacial origin, they are connected and outflowing, indicating strong sedimentation rates in the particular watershed basin.

Sampling

The sampling of water was carried out in the 1 L PET bottle and stored in a cold storage. Some of the physico-chemical characteristics of water including water temperature, pH, dissolved oxygen were determined using HACH HQ40 portable multimeter.

Sampling of sediment cores, for analysis of nutrients (N, P), was performed in the central part of the lakes. Coring of sediments was done using a sediment sampler equipped with a 1.0 m long (d=5 cm) tube. Every sample was put into a non-transparent airtight plastic bucket with a lid and stored at constant temperature (+4 °C) to achieve *in situ* conditions during the storage. Sediments were dried at 105 °C before digestion.

Phytoplankton

Quantitative phytoplankton samples were fixed with 1% acidified Lugol's iodine solution. Phytoplankton counts were performed using LEICA DMI3000 inverted microscope. Individual biovolumes

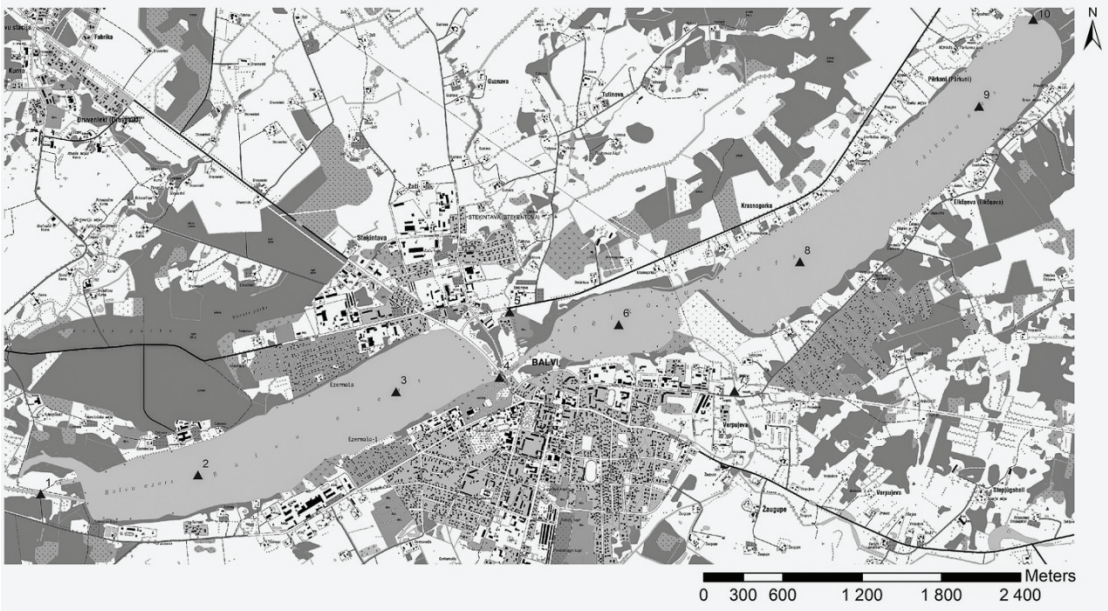

Figure 1. Location of sampling sites (1-10) in Balvu and Pērkonu Lakes.

Table 1

Sampling points in Lake Balvu and Lake Pērkonu

Sampling point No.	Latitude	Longitude
1	57.1277601	27.2058369
2	57.1289345	27.2259225
3	57.1343296	27.2498675
4	57.1345481	27.2615253
5	57.1382042	27.2630045
6	57.1372179	27.2766900
7	57.1337174	27.2904518
8	57.1412682	27.3000351
9	57.1511599	27.3230471
10	57.1563993	27.3302171

were calculated using appropriate geometric formulae according to their shapes and the mean dimensions of the organisms in the samples (Hillebrand *et al*., 1999). Biomass was estimated from biovolume, assuming unit specific gravity (APHA, 2005).

Nitrogen determination in lake sediments.

Approximately 0.5 grams of dry sample was transferred to a 250 mL digestion flask and 4 mL of 2.5% salicylic acid in sulfuric acid was added to the sample. The sample was left for 4 hours and afterwards was digested in a Kjeldahl digestion unit (behr Labor-Technik behrotest® K-12). After digestion 20 mL of distilled water was added to the sample to make a suspension. Afterwards the samples were distilled in a Kjeldahl distillation unit (behr Labor-Technik behrotest® S1), 25 mL of boric acid solution (c=20 g L^{-1}) was added to the distilled sample, 5 drops of methylred indicator was added and sample was titrated with 0.01 M H_2SO_4.

Phosphorus determination in lake sediments.

Sediments were dried at 105 °C before digestion. Approximately 500 mg of sample was weighed in a Teflon capsule and 9 mL of concentrated HNO_3 and 1 mL of 30% H_2O_2 was added to the sample. The capsule was sealed and placed in a microwave oven (Milestone Ethos Easy) and was digested at 200 °C and 49 bar pressure for 15 minutes. After digestion the sample was filtered through a filter paper, diluted up to 50 mL with distilled water and phosphorus concentration was determined with ICP-OES (Thermo Scientific iCAP 7000 series).

Determination of total nitrogen concentration in water

Total nitrogen was determined using a standardized Hach® Method 10071. One Total Nitrogen Persulphate Powder Pillow was added to each of two Total Nitrogen Hydroxide Reagent vials, 2 mL of sample was added to one vial, and 2 mL of distilled water was added to the other. Both vials were vigorously shaken for 30 seconds. Both the sample and blank were placed in a COD reactor for 30 minutes at 105 °C. Total Nitrogen Reagent A Powder Pillow was added to both sample and blank, the tubes were then shaken for 15 seconds. After 3 minutes Total Nitrogen Reagent B Powder was added to the sample and blank, tubes were then shaken for 15 seconds. After 2 minutes 2 mL of digested sample and blank were transferred to TN Reagent C vials, the vials were slowly inverted approximately 10 times for a complete recovery. After 5 minutes the sample was measured at 410 nm wavelength on a spectrophotometer (Hach-Lange DR2800).

Determination of total phosphorus concentration in water.

Total phosphorus was determined using a standardized Hach® Method 8190. Five mL of sample was pipetted in a test vial, one Total Potassium Persulphate Powder Pillow was added to the tube, shaken, and placed in a COD reactor at 150 °C and heated for 30 minutes. After digestion 2 mL of 1.54 *N* sodium hydroxide standard solution was added to the vial and shaken. Afterwards all the contents of one PhosVer3 powder pillow was added to the vial. The test tube was shaken for 10-15 seconds and measured after 8 minutes on a spectrophotometer (Hach-Lange DR2800).

Results and Discussion

Lake Balvu (Figure 1) is located in NE Latvia with an area – 1.68 km^2 and average depth – 2.2 m (max – 3.9 m) and catchment area, including Bolupe River – 248 km^2. Perkonu Lake is located in NE Latvia

Table 2

Concentrations (mg l^{-1}) of nutrients (N, P) in Lakes Balvu and Pērkonu

Sampling point No.	March		May		July		September		November	
	N, mg l^{-1}	P, mg l^{-1}	N, mg l^{-1}	P, mg l^{-1}	N, mg l^{-1}	P, mg l^{-1}	N, mg l^{-1}	P, mg l^{-1}	N, mg l^{-1}	P, mg l^{-1}
1	0.88	0.089	0.65	0.070	3.43	0.233	2.11	0.089	0.97	0.071
2	0.9	0.071	0.62	0.062	2.85	0.161	1.34	0.126	0.91	0.103
3	0.85	0.094	1.08	0.068	1.48	0.21	1.39	0.102	0.92	0.116
4	1.00	0.086	0.79	0.069	1.07	0.109	2.13	0.109	0.83	0.084
5	0.95	0.071	1.15	0.13	0.88	0.392	0.437	0.118	0.9	0.136
6	1.16	0.092	0.86	0.069	1.07	0.417	1.05	0.076	0.94	0.103
7	1.39	0.085	1.20	0.105	0.82	0.256	0.508	0.083	1.94	0.144
8	1.11	0.092	0.93	0.07	1.05	0.154	1.12	0.082	0.87	0.064
9	1.04	0.093	0.70	0.116	0.91	0.179	1.06	0.089	0.8	0.067
10	0.87	0.085	1.27	0.13	1.04	0.464	1.13	0.079	1.28	0.076

Table 3

Element composition and their relations of sediments in Lakes Balvu and Lake Pērkonu

Sampling point No.	N, %	P, g kg-1	N:P
9	1.08	0.99	11:1
8	1.20	1.21	10:1
6	1.43	0.96	15:1
3	0.59	0.90	7:1
2	0.91	1.29	7:1

with an area – 2.28 km^2 and average depth – 1.3 m (max – 3.0 m) with catchment area, including Bolupe River – 237.4 km^2 This hydrological system starts with Bolupe River which flows into Lake Pērkonu with average annual flow rate (Q) – 1.17 m^3 s^{-1}. Between both lakes there is a small extension of Lake Perkonu where River Žaugupe and River Pelnupe carries their water with average annual flow rate (Q) 0.10 m^3 s^{-1}and 0.12 m^3 s^{-1}, respectively. Tributaries with increased total catchment area lead to an increased flow from Lake Perkonu to Lake Balvu with in comparison to Bolupe River, with average annual flow rate – 1.50 m^3 s^{-1}. Finally, on Lake Balvu water locks with an average annual flow rate 1.57 m^3 s^{-1} are installed. This data shows that the water quality in Lake Balvu is dependent on the quality of Lake Pērkonu. Urbanized coastal area of both lakes and, especially of Lake Balvu can be influenced by anthropogenic factors (surface runoff, presence of sewage etc.). In the 60-ies of last century hydrological regime of Bolupe River was changed which lead to decreased water level of studied exoreic lakes by 1.5 m.

Analysed concentrations, distribution and seasonal changes of chemical ingredients indicate a strong impact of anthropogenic loads. The major problems of eutrophication in studied lakes are availability of phosphorus, lack of oxygen in winter and blooms of cyanobacteria in summer. Concentrations of nutrients (N, P) in Balvu and Pērkonu Lakes have similar seasonal pattern as other surface waterbodies in Latvia (Kļaviņš *et al*., 2002). Data shows big loads of nutrients from catchment area (tributaries of lakes), especially with P (Table 2; Figure 2). Although nutrients are important to provide biological processes in surface waters (Kļaviņš *et al*., 2002; Kļaviņš *et al*., 2011), reduced N inputs in studied lakes in comparison to P can lead to increased amount of nitrogen-fixing cyanobacteria as a response by the phytoplankton community to extreme seasonal nitrogen limitation and availability of P (Schindler *et al*., 2008). This phenomenon correlates with phytoplankton communities, where in Lake Balvu 89% of phytoplankton biomass consists of blue-green algae (*Cyanophyceae*), which is also described as important N fixing algae *(Aphanizomenon flosaquae)* (Beversdorf *et al*., 2013; Li *et al*., 2018). In Lake Perkonu, these algae are in small concentrations, but in extension of Pērkonu Lake increases to 30% of phytoplankton biomass. This can be as a response to loads of nutrients from Žaugupe and Pelnupe Rivers in this particular area as well as the low average depth of this extension which is less than 1 m.

One of key factors to describe loads of nutrients is also their ratio. In surface waterbodies, N:P ratio above 12 indicate P-limitation, while below 12 N-limitation accordingly (Kļaviņš *et al*., 2002; Sterner, 2011). Analysis of N:P ratio shows seasonal changes, and

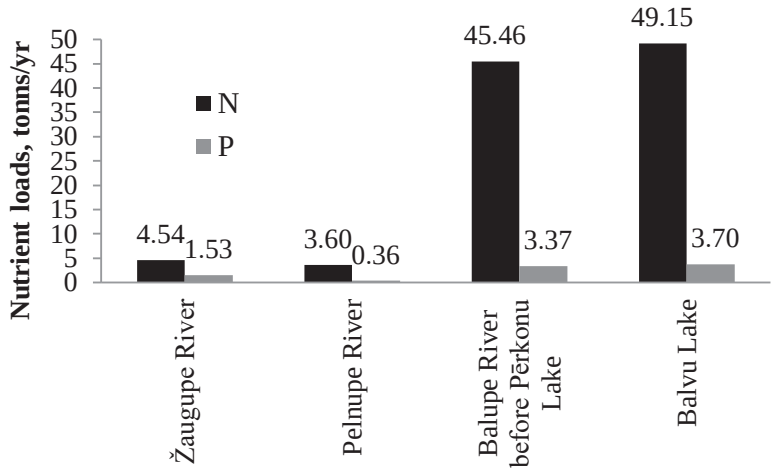

Figure 2. Estimated cumulative amount of nutrient flows in Lake Balvu and Lake Pērkonu.

in winter time it ranges from 9.04 to 16.35 with lowest values in Lake Balvu and in River Bolupe. The pattern of this ratio change, when nutrients are consumed by the producers of biomass, shows that in most cases N is the factor that limits the possible production of biomass. All tributaries indicate big P loads peaking in July despite the fact that nutrients are also actively used (N:P 2.24-17.70). Autumn season demonstrates an increase of N:P ratio, but it mostly happens because of dominated destruction and sedimentation processes in freshwater ecosystems. Lake Pērkonu is the first waterbody with slower water flow; therefore, first sedimentation processes dominate and can be evaluated by average depth of lakes and depth of accumulated sediments. Increased concentrations of nutrients, impact form urban areas and possibly warmer water which flows into Balvu Lake lead to even higher eutrophication acceleration. Increased eutrophication may lead to not only algae blooms, but also to overgrowing with macrophytes. Analysis of macrophyte coverage shows 15% for Lake Balvu, while Lake Perkonu coverage reaches 50%. These differences also can be explained with an average depth of lakes. Differences of approximately calculated loads (Figure 2) of nutrients show that the major part comes from tributaries of Lake Pērkonu. In Lake Balvu calculated loads from water flows show no or insignificant loads from the coastal area of this lake. A relatively small increase in nutrients in Balvu Lake also can be connected with previously described N fixing with biota, but loads from coastal area could not be seen in an outflow stream because of sedimentation processes in the lake. Also, there can be loads of nutrients with atmospheric deposition.

To better describe processes in studied lakes, also sediment analyses were done, including N, P concentrations in the upper sediment layer (Table 3). Upper layers of studied lakes indicate a strong impact of human actions in watershed basin and in coastal area of lakes with significantly increased proportion of allochthonous material (Purmalis *et al*., 2017). High N:P ratios typically are associated with agricultural runoff (Lanza-Espino *et al*., 2015), which correlates very well also with Lake Balvu and Pērkonu and their location in the studied hydrological cycle and catchment area. The upper part of sediments by N:P ratio in Lake Balvu significantly differs from Lake Pērkonu demonstrating that actual sources of sediments can be plankton and material carried from the coastal area and Lake Pērkonu whereas in last decades in Lake Pērkonu sediments are formed form allochthonous material and also partly form autochthonous material.

Lake Management Measures

The obtained data shows that studied lakes are eutrophic lakes with large loads of nutrients from the catchment area. There are risks that environmental events and their changes can lead to a decrease of water quality and lake ecosystem health. Therefore, the management of lakes (Cosgrove *et al*., 2015) in order to reduce anthropogenic impact is needed (Burlakovs *et al*., 2018). Measures that can be applied are various in their positive aspects as well as consequences. Firstly, it is important to reduce loads of nutrients from the catchment area. This can occur with revising of sewage system in urbanized territory and revising of applied agricultural practice in order to reduce nutrients in surface waters in catchment area of lakes. Secondly, installing wetland constructions (Ghermandi *et al*., 2010) on most important nutrient sources (Bolupe, Žaugupe, Pelnupe Rivers) can reduce amount of N and P carried with rivers by 40 – 60% (Vymazal, 2007). Thirdly, to stabilize or reduce amount of nutrients of lakes with cutting reeds (Köbbing *et al*., 2013), applying solid phase P-sorption products to sediments (Spears *et al*., 2013; Aalto *et al*., 2018; Rosińska *et al*., 2018) or by sediment removal (Van Wichelen *et al.*, 2007). Additional activities that can be applied are forming ecotones (Thorp *et al*., 2015) on the coastal area of lakes or even applying biomanipulation of trophic communities of lakes and oxygenation of water, especially in winter time and during blooms of blue-green algae (Jørgensen *et al*., 2005).

Advantages of revising the sewage system and applied agricultural practice could decrease annual amount of nutrients coming from the catchment area which is the most important source in studied lakes. In result, nutrients in lakes will be less available; however, success rate for these actions can be limited, because reduction of non-point sources is difficult (Schindler, 2012). Mentioned revision of these systems can be combined with constructed wetlands. Studies show (Vymazal, 2007; Ghermandi *et al*., 2010) that wetlands can be effectively used for removal of nutrients in water. Parameters of studied rivers (their location, flowrate) are suitable for applying wetlands. Disadvantages of this particular method are construction expenses and affected hydrological regime of streams, as well as a regular maintenance of wetlands is important. During the maintenance of wetlands collected reed biomass can be used as an energy source with possible annual biomass production 3.6 – 43 t per ha^{-1} (Vaičekonytė *et al*., 2013; Joensuu *et al*., 2013; Barz *et al*., 2013). Additional biomass for energy production can be reeds from lakes with average productivity ~ 5 t per ha^{-1} (Komulainen *et al*., 2008). Reeds can accumulate nutrients to produce their biomass and when removed from the lake, nutrients will be removed from cycling. Side-effects of this method are expenses of cutting reeds in lakes (in summer) while keeping healthy lake ecosystem could be applied only on particular lake sectors in order to cut everything (Rosińska *et*

al., 2017). Biomass production is connected with a vegetation period, but cutting in winter time, has less effect on removal of nutrients, because of storage of nutrients on their roots. From the energy production perspective – reed biomass harvested in winter (possible to cut all produced biomass above ice sheet), collected in vegetation season and stored for drying can be effectively used in winter time, when the demand for heat energy is the highest. Also, reeds can be used for different purposes.

Advantages of solid phase P-sorption for reducing the amount of P are immediate P removal from cycling in their way: water-sediments-water. These methods can be costly, they can reduce the depth of lake, affect or destroy benthic fauna and be as a source of chemical substances in lakes (Spears *et al*., 2013; Aalto *et al*., 2018; Rosińska *et al*., 2018). Therefore, more affordable (ecological scale) and more appropriate technology in studied lakes can be excavation of sediments. Excavated organic material can be used in agricultural applications (Stankevica *et al*., 2016) and accumulated nutrients will be removed from lake ecosystems and active element cycling. In order to keep benthic fauna, sediment removal should be done only partly (in more shallow parts of lakes and parts with high average depth of sediments, basically in both ends of Lake Pērkonu). Sediment removal applied in extension of Lake Perkonu can improve water quality and ecological status not only of Lake Pērkonu, but also Lake Balvu. Other kind of activity to reduce nutrient loads from coastal areas is forming terrestrial ecotones (Thorp *et al*., 2015), which can accumulate nutrients migrating to lake in order to provide their biomass production. For that purpose different plants and trees can be used, but this approach can be slow and could be difficult to evaluate real benefits. It can change also the landscape and in urban territories can be difficult to apply because of difficult harmonization with landowners of coastal area of lakes. To reduce resolving of already existing phosphorus into water from sediments in anoxic conditions, water oxygenation can be applied. This method will improve conditions in lakes in winter time as well as reduce solubilizing of P from sediments. The size of studied lakes could be challenging to apply oxygenation devices, but our studies indicate areas with the lowest oxygen content and can be applied more precisely, as well as movement of water masses can distribute oxygen from places where oxygenation was applied.

Conclusions

Freshwater lakes and rivers are habitats of variety of organisms and their populations are giving great importance for freshwater ecosystems, however, human actions can influence these ecosystems. In studied lakes, a significant anthropogenic impact in loads of nutrients was detected. If lakes as waterbodies are not affected by strong transformation, then other activities in their catchment area lead to decrease of their water level and accelerated eutrophication due to availability of nutrients can occur. Estimated loads of nutrients with existing water quality will not improve the lake ecological quality without appropriate management measures. Most effective measures in studied lakes could be sediment removal in certain parts of Lake Pērkonu as well as formation of wetlands on tributaries carrying highest loads of nutrients. Combining these methods with cutting reeds and revising a sewage system in urban territory (also surface runoff) may lead to improvements of water quality and decrease of algae blooms in summer time as well as improve oxygen availability in winter.

Acknowledgements

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DYNAMICS OF METEOROLOGICAL AND HYDROLOGICAL DROUGHTS IN THE AGRICULTURAL CATCHMENTS

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Abstract
The aim of the paper is to determine the relationship between meteorological drought and hydrological drought in the agricultural basin of the River Osa (northern Poland) in the years 1966-2015. Meteorological droughts appear as a result of insufficient amount or lack of atmospheric precipitation. As a consequence of meteorological droughts occurrences, there appear hydrological droughts which are characterized by low discharges of a river. Standardized Precipitation Index (SPI) and Standardized Runoff Index (SRI) indicators were used for the identification of droughts at various accumulation periods, i.e. 1, 3, 6, 9 and 12 months. In the years 1966-2015, there were identified from 63 (SPI-1) up to 10 meteorological droughts (SPI-12), while hydrological droughts – from 22 (SPI-1) to 8 (SPI-6, 9 and 12). The strongest relationship between the two kinds of droughts occurred in the periods of accumulation from 9 to 12 months. The values of the correlation coefficient between the meteorological and hydrological droughts were above 0.5 in those cases. Those indicators can be used for a system of early drought warning, which is of particular importance for crop production in agricultural areas. Long-lasting meteorological droughts contribute to increase of water intake for irrigation purposes, thus deepening the hydrological drought. As a consequence of the prolonged and intense hydrological drought, further irrigation may be impossible due to too low river discharges.
Key words: meteorological drought, hydrological drought, SPI, SRI, River Osa, Poland.

Introduction

According to the latest climate forecasts, the frequency of extreme weather conditions, and thus the occurrence of droughts is expected to increase (IPCC, 2013). As a consequence of further climate warming and changes in the spatial and seasonal distribution of atmospheric precipitation, changes in the hydrological regime of rivers and water resources take place. In the present climate, many regions of Poland often suffer from water shortage, especially during the vegetation season. In the future, this shortage may become even more serious which may result in limitations in the availability of water resources. In recent years, changes in the course of climate phenomena in Poland have been observed more and more frequently, which especially applies to the increase of air temperature (Tomczyk & Szyga-Pluta, 2018). Annual precipitation amounts in Poland only slightly change (slight increase), but what is important, major changes occur in seasonal and monthly precipitation patterns (Szwed, 2018).

An important problem is the impact of changing meteorological factors on the seasonal and long-term scale on the occurrence of meteorological and hydrological droughts. Relations between meteorological and hydrological droughts were the subject of research by various authors (Shukla & Wood, 2008; Lorenzo-Lacruz *et al*., 2013; Fendeková *et al*., 2018). Studies on the relationship between the courses of kinds of droughts, using various indicators, were conducted in Poland by Tokarczyk & Szalińska (2018), Somorowska (2009), Kubiak-Wójcicka & Bąk (2018). Kuśmierek-Tomaszewska *et al.* (2019) on the basis of meteorological and agricultural drought indicators determined shortages of precipitation in field crops production on agricultural areas.

The main aim of the paper is to analyze the course of meteorological and hydrological droughts and to assess their mutual relationship. The Osa agricultural catchment, located in northern Poland, was used for analysis. The increase in threat of meteorological drought results in an increase in hydrological drought, which is extremely important for agricultural areas and the volume of plant production, as well as the possibility of irrigation of these areas.

Materials and Methods

To determine the meteorological drought, the average monthly totals sums of precipitation obtained for 2 meteorological stations, i.e. Radzyń Chełmiński and Gardeja were used. In turn, hydrological characteristics were used for data on discharges of the River Osa in the Rogóźno profile. The location of the stations is shown in Figure 1. Meteorological and hydrological data were obtained from the Institute of Meteorology and Water Management - National Research Institute (*in Polish* IMGW-PIB). They cover the period from 1965 to 2015.

Meteorological droughts were identified on the basis of a standardised precipitation index (SPI). The SPI index was calculated for the meteorological station Radzyń Chełmiński. The SRI (Standardized Runoff Index) for the discharges of the River Osa recorded at gauging station Rogóźno was used to determine the hydrological drought. The values of the indices are calculated as standard deviation of atmospheric precipitation or discharge from the respective median value in the analysed multi-year period. The precipitation totals have been normalised with a function $f(P) = (P)^{1/3}$, and for the discharge sums the normalization function was a 2-parameter

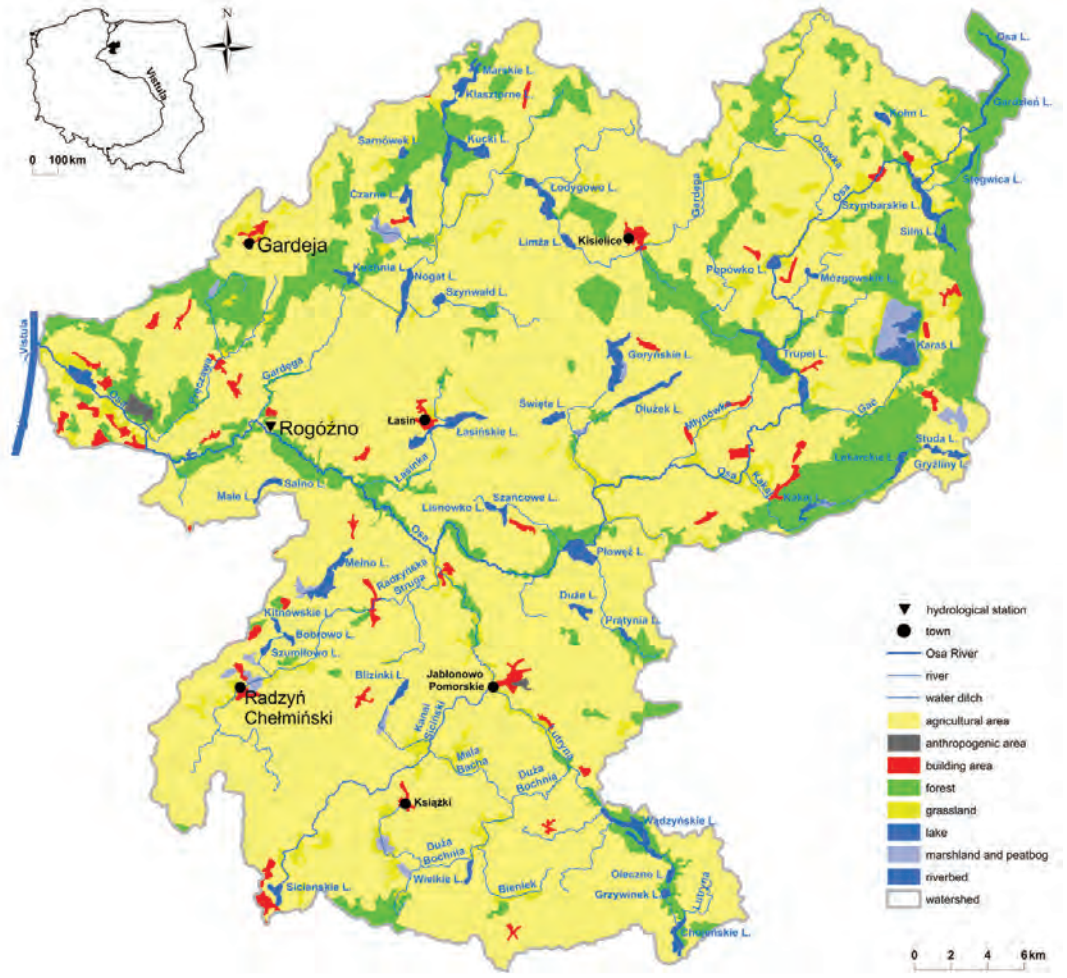

Figure 1. Land use in the River Osa basin on the basis of the Corine together with hydrological and meteorological stations.

logarithmic function (Bąk & Kubiak-Wójcicka, 2016, 2017). The drought intensity classification was carried out in accordance with Table 1.

The long-term (usually many months) period of small sums of rain or temporary lack of precipitation contributes to formation of the hydrological drought. The paper uses various sets of accumulated sums of precipitation and discharge, i.e. 1, 3, 6, 9 and 12 months. Previous studies have shown that short periods of accumulation are suitable for small catchments that react quickly to changes in meteorological conditions (Barker *et al.*, 2015). An important issue for agricultural areas is understanding the relationship between the course of meteorological drought and its impact on hydrological drought. The relationship between two droughts was presented with the use of the correlation coefficient r. The higher the correlation coefficient, the stronger the relation. According to the studies of other authors, a significant correlation between the course of both droughts occurs when $r > 0.5$.

The research area is the Osa catchment, whose total area is 1606.27 km^2. The Osa River is a second-order watercourse, the right tributary of the Vistula.

Table 1

Classification of drought intensity (McKee, Doesken, & Kleist, 1995)

SPI, SRI	Intensity of drought
< - 2.0	extremely dry
-1.99 to -1.5	severely dry
-1.49 to -1.0	moderately dry
-0.99 to 0.0	mild dry

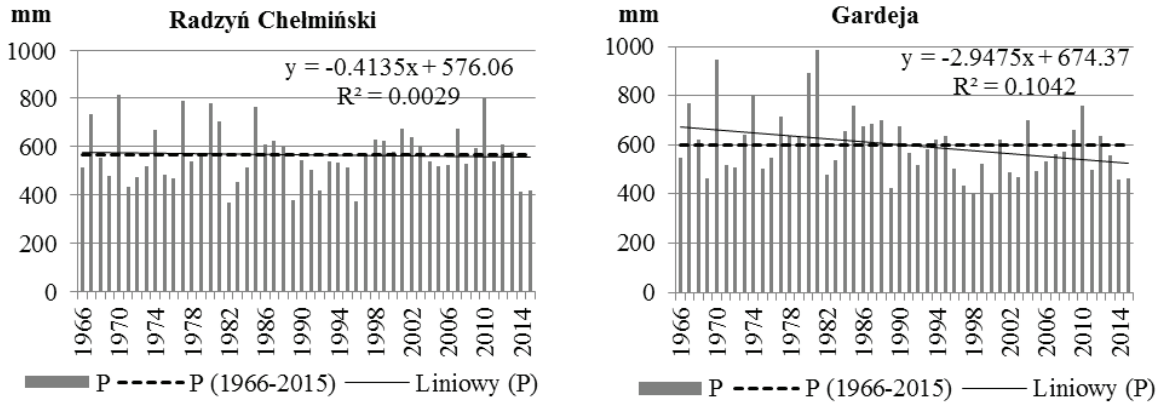

Figure 2. Multiannual course of average annual precipitation at meteorological stations Radzyń Chełmiński and Gardeja in the years 1966-2015.

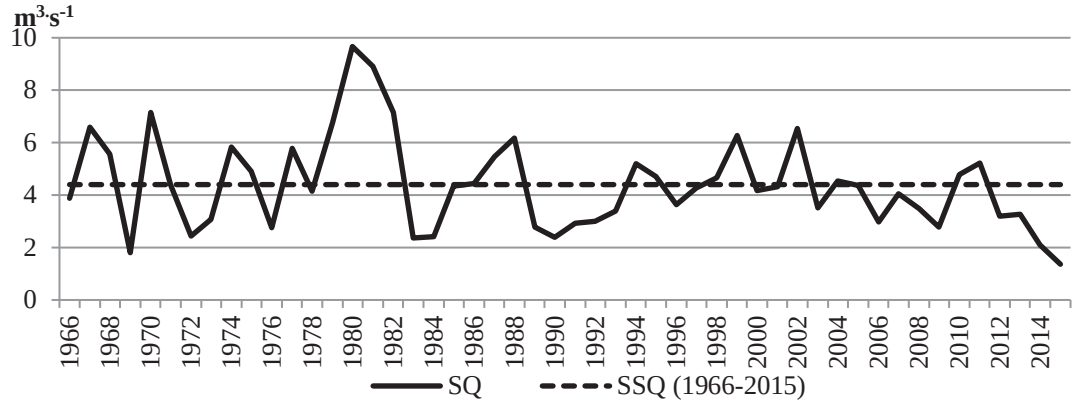

Figure 3. Average annual discharge of the Osa (SQ) at the background of multi-year discharge (SSQ) at hydrological station Rogóźno in the years 1966-2015.

The Osa originates from Lake Parkun and flows into the Vistula, north of Grudziądz. The length of the Osa River is 109.84 km. The most important tributaries of the Osa are the Lutryna and Gardęga rivers, which flow into the Osa below the hydrological station in Rogóźno (Figure 1). The hydrological station in Rogóźno closes the catchment area of 1135.11 km^2 (Atlas podziału hydrograficznego Polski, 2005). In terms of land use, arable land predominates, accounting for almost 70% of the catchment area. Forests occupy 14.4% of the catchment, meadows – 10% and swamps – 1.78% (Figure 1). Currently, there are 12 lakes greater than 100 ha in the Osa basin. The largest are the following lakes: Karaś, Trupel, Goryńskie, Kucki and Wądzyńskie.

Results and Discussion

During the analysed period of 1966-2015, the average atmospheric precipitation total at the meteorological station in Radzyń was 565.5 mm, while in Gardeja – 599.2 mm (Figure 2). These values are among the lowest in Poland. The analysis of annual precipitation totals at the Gardeja site presents a statistically significant downward trend, while the annual precipitation sums even at the Radzyń Chełmiński meteorological station. These results are in line with the studies carried out at various comparative periods by Czarnecka & Niedzgorska-Lencewicz (2012) and Szwed (2018). Precipitation during the vegetation season (April-September) in Radzyń accounted for 63% of whole year precipitation, while in Gardeja it was 60%. The lowest precipitation at the meteorological station in Radzyń was recorded in 1982 and at the Gardeja station in 2000. Low annual precipitation in these particular years occurred also in the entire Kuyavian-Pomeranian region (Kuśmierek-Tomaszewska *et al*., 2018).

The average long-term flow of the River Osa recorded at the Rogóźno hydrological station was 4.40 m^3 s^{-1}, which implies a specific discharge of 3.9 dm^3 s^{-1} km^{-2}. The specific discharge from the Osa catchment is one of the lowest in Poland. For the comparison, the average specific discharge from the entire Vistula basin in the period 1951-2015 was

Table 2

Parameters and indices of meteorological and hydrological drought in the years 1966-2015

	Total number of drought occurrences	Number of months with a drought (SPI or SRI <-1.0)	The longest drought span (months)	Maximum drought intensity
SPI-1	63	197	9 (I1989-IX1989)	-3.16 (I 1997)
SPI-3	42	215	19 (VI2014-XII2015)	-3.07 (I 1997)
SPI-6	42	205	24 (IX1991-VIII1993)	-2.96 (XII 1982)
SPI-9	13	224	35 (VIII1971-VI 1974)	-2.85 (VI 1996)
SPI-12	10	247	36 (X 1971-IX 1974)	-2.33 (V 2015)
SRI-1	22	206	29 (VIII 2013-XII 2015)	-2.42 (III 2015)
SRI-3	15	212	33 (IX 1982-V 1985)	-2.62 (V 2015)
SRI-6	8	256	48 (IV 1989-I 1994)	-2.80 (VIII 2015)
SRI-9	8	237	57 (V 1989-I 1994)	-2.84 (X 2015)
SRI-12	8	248	57 (VI 1989-II 1994)	-2.69 (XI 2015)

5.39 $dm^3\ s^{-1}\ km^{-2}$ (Kubiak-Wójcicka, 2019). The highest annual discharge of the Osa was recorded in 1980 and it was twice as high as the average value from the period 1966-2015. The lowest discharge occurred in 2015 and amounted to 1.36 $m^3\ s^{-1}$, which gave specific discharge of 1.2 $dm^3\ s^{-1}\ km^{-2}$. Throughout the period 1966-2015, there is a clear downward trend in the discharge. The annual distribution is dominated by the discharge in the cold half-year (October-March) – 57% over the discharge in summer (April-September), which accounted for 43% of the discharge during a year (Figure 3).Meteorological droughts in 1-month cumulative periods are characterized by the highest quantity (63), the shortest duration of the longest drought (9 months) and the highest intensity (-3.16) (Table 2). With the increase of the accumulation period, the number of meteorological droughts decreased (10 droughts for SPI-12) and the maximum intensity decreased (-2.33 for SPI-12). The maximum duration of the longest drought has extended and the number of months with meteorological droughts has increased. Hydrological droughts were characterized by a smaller number of events than meteorological droughts, especially in short periods of accumulation, i.e. from 1 to 3 months. In the longer period of accumulation (6-12 months), hydrological droughts were grouped, the number of months with a drought increased, and the duration of the longest drought increased. The most intense droughts in the Osa catchment were recorded in 2015. The hydrological drought, which took place in 2015 (SRI-1), covered all of Poland, and, in the Osa catchment, was one of the most severe (SPI / SRI <= – 2.0) and possibly the longest because it extended to 2016. 2015 was one of the driest years in terms of precipitation and temperature anomalies in Central Europe in the last 15 years (Fendekova *et al.*, 2018; Laaha *et al.*, 2017). The longest lasting hydrological droughts in the Osa catchment occurred in 1989-1994. The drought in those years became disastrous and covered almost the entire area of Poland (Łabędzki, 2007). The course of the drought in the individual accumulation periods is shown in Figure 4.

Correlation coefficients between SRI and SPI were the highest for the 9-month (February) and 12-month (May) cumulative period (0.76) (Table 3). The largest correlations between droughts occurred in the cold half-year (October-March) in periods of 6 and 9 months, and the correlation coefficient (r) was 0.65 and 0.67, respectively. The highest annual correlation coefficient was obtained for a period of 12 months (r=0.63), where r values are higher than 0.5 in all months, which indicates a high degree of dependence. The obtained results are consistent with the research of other authors. The high correlation coefficient between meteorological and hydrological droughts (annual r index above 0.5) was identified by Ljubenkov & Cindrić Kalin (2016) for the 6, 9 and 12-month accumulation periods for the rivers of Croatia. Higher correlation coefficients between droughts were obtained by Vicente-Serrano & López-Moreno (2005) for mountainous rivers in the Spanish Pyrenees, where fast surface runoff dominates in shorter time intervals, i.e. 1-2 months and Barker *et al.* (2015) for the rivers of England. Tokarczyk & Szalinska (2018) showed that the greatest correlations between SPI and SRI occurred in 12 to 24 months of accumulation for Prosna, while for Nysa Kłodzka in the accumulation periods from 18 to 24 months. In the case of large catchments, e.g. the Vistula basin, the greatest strength of the relationship was in longer periods of 18 and 24 accumulation (Kubiak-Wójcicka & Bąk, 2018). Relatively low values of correlation between droughts were recorded by Rimkus *et al.* (2013) in the basin of the Neman River. To a large extent, the impact of meteorological drought on

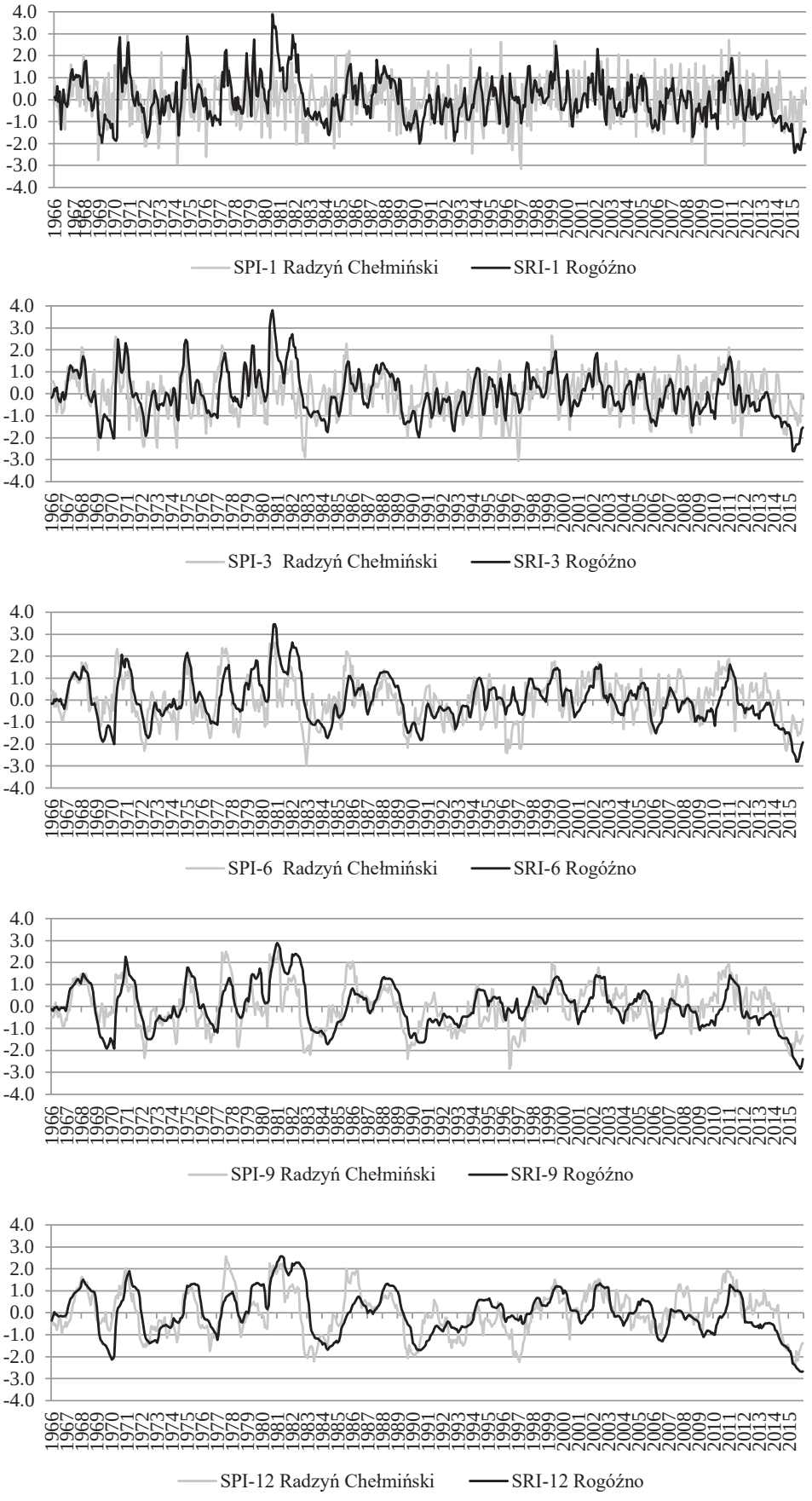

Figure 4. The course of indices SPI and SRI in various time scales in the years 1966-2015.

Table 3

The coefficient of correlation between meteorological drought and hydrological drought during a year

Months	1	2	3	4	5	6	7	8	9	10	11	12
SPI-1 vs SRI-1	0.14	0.16	0.30	0.29	0.21	*0.53*	0.52	0.29	0.17	0.26	0.39	0.32
SPI-3 vs SRI-3	0.42	0.38	0.29	0.37	0.39	0.36	0.53	*0.70*	0.53	0.42	0.50	0.54
SPI-6 vs SRI-6	0.57	0.62	0.64	0.54	0.40	0.37	0.47	0.55	0.57	0.65	*0.75*	0.69
SPI-9 vs SRI-9	0.69	*0.76*	0.72	0.66	0.60	0.53	0.50	0.48	0.47	0.57	0.60	0.68
SPI-12 vs SRI-12	0.62	0.66	0.69	0.73	*0.76*	0.70	0.63	0.59	0.54	0.52	0.50	0.57

hydrological drought is conditioned by the physical and geographical features of the catchment (geological structure, land use, catchment size).

The obtained results show that the Osa's agricultural catchment reacts quickly to the lack of atmospheric precipitation or insufficient amount of precipitation. During periods of meteorological drought in agricultural areas, irrigation is applied, which not only prevents crop decline, but it also allows to achieve a higher level of yields compared to the average without the use of this procedure (Żarski *et al.*, 2017). Hydrological droughts, which are the result of long-lasting meteorological droughts, additionally deepen due to increased water intake for the needs of irrigation. In the case of prolonged hydrological droughts, the possibility of land irrigation will be limited due to low flows in rivers. It is necessary to take measures to increase local water resources, as well as the use of technology that allows economical use of water for the needs of agricultural production.

Conclusions

The results obtained allowed to formulate the following conclusions:

1. meteorological droughts in the Osa basin in the years 1966-2015 are characterized by more events, intensity and a longer maximum duration than hydrological droughts;
2. with the increase of the accumulation period, the number of meteorological and hydrological droughts is reduced, while the total duration of droughts is increased, which results from the grouping of droughts in longer periods of accumulation, e.g. 9 and 12 months;
3. the relationship between meteorological and hydrological droughts is presented in the form of a correlation coefficient between the SPI and the SRI during the same accumulation periods;
4. the highest correlation coefficient between the SPI and the SRI was obtained for the 9 and 12-month accumulation periods (r=0.76);
5. the highest annual correlation coefficient was obtained for 12-month accumulation period (r=0.63); the r values are higher than 0.5 in all months;
6. hydrological droughts determined on the basis of the SRI indicator inform about water resources within the whole catchment;
7. SPI and SRI indicators can be used for monitoring and early warning against drought, which is crucial for agriculture, especially during the vegetation season.

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THE EXHAUSTION OF WATER RESOURCES IN THE KUYAVIAN-POMERANIAN VOIVODSHIP IN DROUGHT CONDITIONS IN 2015

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Abstract
The aim of the paper is to present the spatial diversity of water resources in the Kuyavian-Pomeranian Voivodship during the drought in 2015. The region's area is characterized by the lowest average annual precipitation in Poland, the lowest water resources and high water demand associated with intensive plant production. Hydrological research was carried out in September 2015 in 145 measurement points on various rivers. Despite the low precipitation recorded in August 2015 at the majority of meteorological stations, the volume of the specific discharge from the Kuyavian-Pomeranian region was characterized by high variability. The largest specific discharges were recorded for rivers located in the northern part of the region whose sources are located in the Pomeranian Lake District, i.e. Brda and Wda (over 2 $dm^3 s^{-1} km^{-2}$) and the Masurian Lake District (Drwęca over 1 $dm^3 s^{-1} km^{-2}$). The smallest specific discharges (less than 0.5 $dm^3 s^{-1} km^{-2}$) were recorded in the catchments located in the Kuyavian region (Tążyna, Zgłowiączka and Noteć) in the southern part of the Kuyavian-Pomeranian Voivodship and from the Osa River catchment. These areas are intensively used for agricultural purposes. The use of surface water resources as a potential source of irrigation water for crops can only be taken into account in connection with groundwater resources.
Key words: precipitation, specific discharge, water resources, the Kuyavian-Pomeranian Voivodship, Poland.

Introduction

The Kuyavian-Pomeranian Voivodship is located in the central part of Poland and covers an area of 17972 km^2, which is 5.7% of the area of Poland (GUS, 2018). In terms of land use, the Kuyavian-Pomeranian Voivodship belongs to the agricultural regions. The area of agricultural land takes 65.3% of the voivodship, while forest areas constitute 24.5%. The most favourable natural conditions for agricultural production are there in the districts of Inowrocław, Radziejów, Żnin, Aleksandrów as well as Toruń, Chełmno and Grudziądz. An important factor facilitating agricultural economy in these areas is favourable, flat terrain features. The Kuyavian-Pomeranian region is also distinctive due to one of the lowest annual precipitation sums and summer half-year, i.e. from April to September, precipitation sums in Poland (Bąk & Łabędzki, 2014; Bąk & Kubiak-Wójcicka, 2017; Łabędzki & Ostrowski, 2018; Kubiak-Wójcicka & Bąk, 2018). In terms of surface water resources, the Kuyavian-Pomeranian region, and in particular its southern part, is the area with the largest water deficiency in Poland (Gutry-Korycka *et al.*, 2014; Bartczak, Glazik, & Tyszkowski, 2014). One of the methods to compensate for the negative water balance is to supplement atmospheric precipitation by irrigation and use of ground retention resources. Irrigation requires sustaining an adequate amount of water supplied to the crops. The use of ground retention resources is based on local water resources – natural or appropriately increased by agrotechnical measures, as well as by properly operated drainage devices (Przybyła *et al.*, 2008). Water deficiencies are particularly grievous during the growing season, which affects the volume of agricultural production (Żarski *et al.*, 2013; Kuśmierek-Tomaszewska *et al.*, 2018). In 2015, the Kuyavian-Pomeranian Voivodship took the second place in Poland in terms of the area of agricultural land used for the cropping of ground vegetables (245.33 km^2 according to GUS data). The highest percentage of farms cropping vegetables are in the districts of Inowrocław, Radziejów and Włocławek (Rudnicki & Kluba, 2014).

The paper characterizes the volume of precipitation and air temperature in the Kuyavian-Pomeranian Voivodship, as well as conducts the analysis of surface water resources. Particular attention has been paid to whether surface water resources are able to protect agricultural areas from the negative effects of drought and to mitigate the damage to agriculture caused by the lack or insufficient amount of precipitation. These activities are of great importance in the planning, preparation and undertaking the activities aimed at avoiding or reducing the negative effects of drought (Łabędzki & Bąk, 2014).

The aim of this study is to present the spatial diversity of the specific discharge in the watercourses of the Kuyavian-Pomeranian Voivodship during the drought in 2015. The analysis was based on meteorological and hydrological data from the Institute of Meteorology and Water Management – National Research Institute (*in Polish* IMGW-PIB) and on own field research. The obtained results will allow to determine whether water intake from nearby rivers is possible for the purpose of irrigating agricultural areas during a period of small sums of precipitation in the vegetation season.

Materials and Methods

To characterise the meteorological conditions in the Kuyavian-Pomeranian Voivodship, daily sums of precipitation from 11 meteorological stations located within the administrative boundaries of the

voivodship were used. For 5 of them, annual averages and maximum air temperatures are presented. The data on daily discharge of major rivers in 2015 was used to assess the water resources of the Kuyavian-Pomeranian region. In total, the data for 9 rivers where regular hydrological observations are carried out was analysed. Both meteorological and hydrological data come from the Institute of Meteorology and Water Management – National Research Institute.

The hydrological observations of the IMGW-PIB were supplemented by own field studies, which were carried out in September 2015. The choice of measurement dates resulted from the long-term period with low precipitation (June-August) and its potential impact on water resources in river basins. In total, hydrological observations and measurements were collected at 145 points in various watercourses located throughout the Kuyavian-Pomeranian Voivodship. The measurements included watercourses with small catchments, whose areas ranged from 30 km^2 to 600 km^2, and which are not covered by the standard monitoring system by the IMGW-PIB. Based on the results of discharge measurements, specific discharges were calculated. The specific discharge from a catchment area was calculated as the quotient of the average discharge and the catchment area, which made it possible to compare water resources of various rivers of the region. On the basis of the obtained values, a map of specific discharges during the hydrological drought was made.

Results and Discussion

The factor strongly influencing the size of the runoff and the river regime features are precipitation and air temperature. In 2015, the annual sums of precipitation in the Kuyavian-Pomeranian Voivodship were diversified in both spatial and temporal terms. The lowest precipitation during the year was recorded in Płock (319 mm), while the highest – in Nowy Jasiniec (436.7 mm) (Table 1). In Toruń, the annual precipitation was 379.4 mm, which constituted only 70% of the long-term standard for 1981-2010 (GUS, 2018).

During the year, the lowest precipitation occurred in February in the majority of the area of the Kuyavian-Pomeranian Voivodship, and in its southern part – in August (Figure 1). Monthly precipitation on most meteorological stations did not exceed 20 mm, and in case of some of them didn't even reach 10 mm. In Toruń, the precipitation total in August was 3.9 mm. A lower value, i.e. 2.7 mm, was only recorded in August 1984. That monthly precipitation accounted for only 1% of the annual sum in 2015, and compared to the long-term average it was less than 6% (Raport o stanie środowiska w województwie kujawsko-pomorskim w 2015 roku, 2016). At most meteorological stations, the highest precipitation was recorded in July. The exception was the highest monthly precipitation recorded in September at the Nowy Jasiniec meteorological station.

The year 2015 in the Kuyavian-Pomeranian Voivodship was much warmer than the multi-year average. The average annual air temperature at selected meteorological stations ranged from 9.3 °C in Chrząstowo to 9.9 °C in Toruń. In relation to the long-term average from 1981 to 2010, in Toruń it was 1.4 °C warmer. By far the warmest month in terms of average monthly air temperature at all meteorological stations

Table 1

Average annual air temperature and total precipitation on selected meteorological stations in 2015 (on the basis of data from the IMGW-PIB)

Meteorological station	Longitude	Latitude	Average air temperature in °C (max/month)	Annual total precipitation (mm)	Maximal precipitation in a year	Minimal precipitation
Bydgoszcz-Szwederowo (A)	17° 59' E	53° 05'N	-	320.2	65.5 (VII)	5.3 (II)
Chrząstowo (B)	17° 35' E	53° 11' N	9.3 (35.9/VIII)	365.7	57.3 (VII)	5.8 (II)
Głodowo (C)	19° 14' E	52° 50' N	9.4 (35.8/VIII)	362.4	76.9 (VII)	6.5 (VIII)
Grudziądz (D)	18° 43' E	53° 26' N	-	369.8	55.8 (VII)	6.8 (II)
Janowiec Wielkopolski (E)	17° 29' E	52° 46' N	-	408.7	81.7 (VII)	16.1 (II)
Kołuda Wielka (F)	18° 09' E	52° 44' N	9.7 (35.7/VIII)	398.1	107.4 (VII)	6.9 (VIII)
Nowy Jasiniec (G)	18° 02' E	53° 21' N	-	436.7	62.1 (IX)	7.7 (II)
Pakość (H)	18° 05' E	52° 48' N	-	348.0	84.5 (VII)	9.8 (II)
Płock (I)	19° 43' E	52° 35' N	9.8 (36.5/VIII)	319.0	58.6 (VII)	3.0 (II)
Śliwice (J)	18° 11' E	53° 42' N	-	396.6	62.9 (VII)	2.1 (II)
Toruń (K)	18° 35' E	53° 02' N	9.9 (36.2/VII)	379.4	98.5 (VII)	3.9 (VIII)

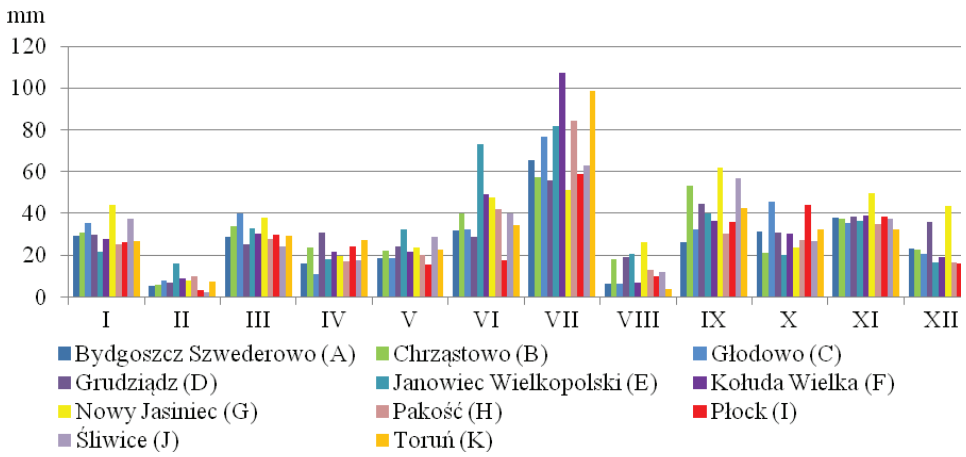

Figure 1. Average monthly precipitation in 2015 at selected meteorological stations (based on the data from the IMGW-PIB).

was August. The average monthly air temperature in August exceeded 20 °C (Figure 2). At all stations, except for Toruń, this month also recorded absolute annual maximum temperatures, which ranged from 35.7 °C in Kołuda Wielka to 36.5 °C in Płock. In Toruń, the annual maximum of 36.2 °C was recorded in July, while in August the maximum temperature was slightly lower and amounted to 36.1 °C.

It should therefore be stated that in 2015 the prevailing area of the province was very dry or dry in relation to the long-term period both in terms of precipitation totals and air temperature.

Low precipitation totals in the first half of 2015 and increasing air temperature in subsequent months contributed to creation areas of soil drought in the Kuyavian-Pomeranian Voivodship. According to the reports prepared on the basis of the climatic water balance and posted on the website of the Agricultural Drought Monitoring System (www.susza.iung.pulawy.pl) run by the Institute of Soil Science and Plant Cultivation – State Research Institute in Puławy, soil drought began to arise as early as in the third decade of June.

The Kuyavian-Pomeranian Voivodship in comparison with other regions of Poland is characterized by low water abundance, as evidenced by the smallest average specific discharge (below 4 $dm^3\ s^{-1}\ km^{-2}$) (Gutry-Korycka *et al.*, 2014). In the area of Kuyavia and some river basins, e.g. Zgłowiączka, the specific discharge was even lower and totalled below 2.5 $dm^3\ s^{-1}\ km^{-2}$ (Bartczak, Glazik, & Tyszkowski, 2014). The main hydrographic axis of the region is the Vistula River, which in the Kuyavian-Pomeranian region is a transit river. The average specific discharge for the entire Vistula basin in the years 1951-2015 totalled 5.4 $dm^3\ s^{-1}\ km^{-2}$ (Kubiak-Wójcicka, 2019). In 2015, the average specific discharge of the Vistula River was lower than the average for the multi-year period and ranged 3.56 $dm^3\ s^{-1}\ km^{-2}$ in Toruń. The highest specific discharge values were recorded in February (4.64 $dm^3\ s^{-1}\ km^{-2}$), while the lowest were recorded in September (1.26 $dm^3\ s^{-1}\ km^{-2}$) (Table 2).

The rivers Brda and Wda (northern part of the province) are characterized by the largest water abundance in the region. Their average specific

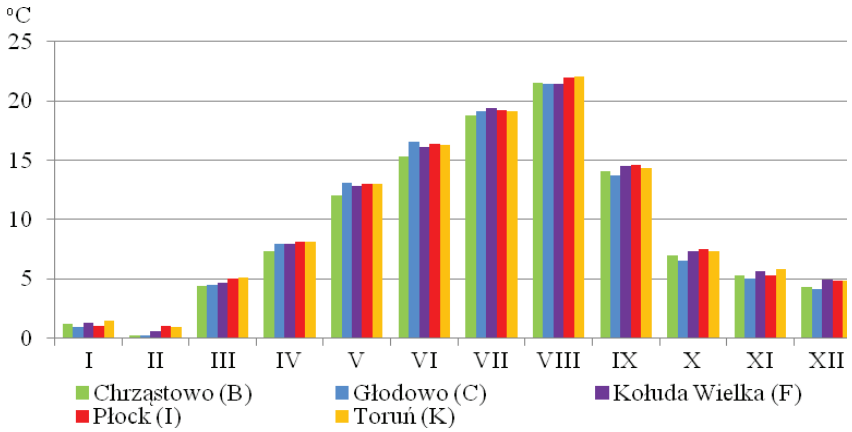

Figure 2. Average monthly air temperature in 2015 at selected meteorological stations.

Table 2

Average, maximum and minimum specific discharge in 2015 at selected hydrological stations (own calculations on the base of the data from the IMGW-PIB)

No.	River	Hydrological station	Catchment area (km^2)	Maximum specific discharge ($dm^3 \cdot s^{-1} \cdot km^{-2}$)	Average specific discharge ($dm^3 \cdot s^{-1} \cdot km^{-2}$)	Minimum specific discharge ($dm^3 \cdot s^{-1} \cdot km^{-2}$)
1	Vistula	Toruń	180390.67	9.04	3.56	1.26
2	Wda	Krąplewice	2025.83	6.27	4.02	2.75
3	Drwęca	Brodnica	3539.83	5.54	3.02	1.29
4	Drwęca	Elgiszewo	5019.48	5.56	2.62	1.14
5	Brda	Tuchola	2477.16	10.17	5.90	3.46
6	Brda	Smukała	4455.19	8.37	4.44	2.27
7	Osa	Rogóźno	1135.11	2.45	1.36	0.36
8	Noteć	Pakość	2356.20	1.95	1.26	0.59
9	Zgłowiączka	Włocławek-Ruda	1491.82	1.40	0.53	0.12
10	Mień	Lipno	230.65	3.21	1.24	0.56
11	Tążyna	Otłoczynek	431.20	0.83	0.21	0.03

discharges in 2015 were over 4 $dm^3\ s^{-1}\ km^{-2}$. The lowest average specific discharge in Poland occurred in the southern part of the Kuyavian-Pomeranian Voivodship. The smallest water abundance characterise the rivers Tążyna and Mień, for which the average annual specific discharge in 2015 amounted to 0.21 $dm^3\ s^{-1}\ km^{-2}$ and 0.53 $dm^3\ s^{-1}\ km^{-2}$, respectively. The seasonal distribution shows a clear differentiation of low specific discharges (Figure 3). The highest low specific discharges were recorded in winter and spring months, while the lowest – in the summer months, with extremely low specific discharges in August and September. The lowest monthly low specific discharges in August and September resulted from very low precipitation in August (below 20 mm) and relatively high air temperatures (above 20 °C).

Observations and hydrological measurements have shown the spatial range of the hydrological drought in 2015 and the regional variability of water resources (Figure 4). Areas with the lowest specific discharge (<0.1 $dm^3\ s^{-1}\ km^{-2}$) cover the upper parts of the Kuyavian river basins (Zgłowiączka, tributaries of the Noteć), of Chełmińskie Lake District (Fryba, Struga Toruńska, Górny Canal, Struga Wąbrzeska) and fragments of the Krajna Upland and Świecie Upland. In the case of small watercourses, which are fed with shallow circulation water, drying of riverbeds took place. The issue of lack of water in riverbeds also pertained to larger rivers flowing through the lakes. In the period of high air temperatures, evaporation from surface of water increased considerably. There was a significant decrease of the water level in the lakes. As a result of this phenomenon, the beds of some rivers, e.g. Gardęga below Lake Nogat, Struga Toruńska below Lake Mlewieckie and Szumionka below Lake Gwiazda were dry. Extremely low discharge of 1.4 $dm^3\ s^{-1}$ occurred in Zgłowiączka below Lake Głuszyńskie. The process of disappearance of discharge and drying of river beds began in some rivers already in May (08/05/2015), e.g. in Struga Toruńska

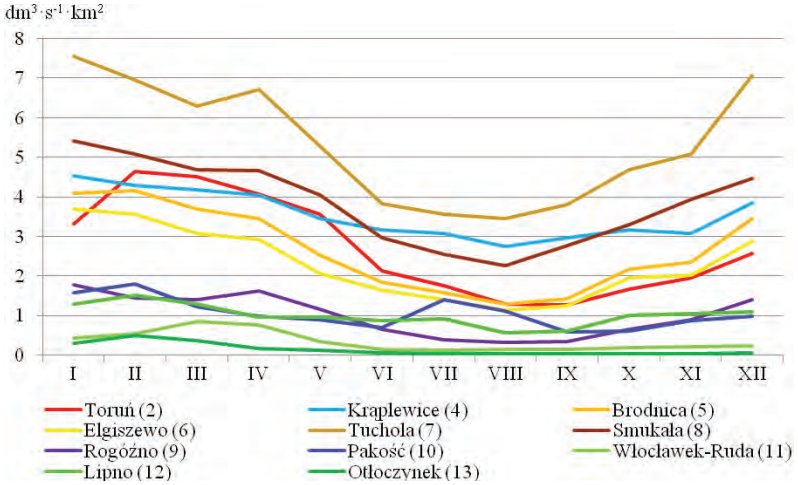

Figure 3. Lowest specific discharges in 2015 (on the base of the data from the IMGW-PIB).

Figure 4. Map of the lowest low specific discharges ($dm^3 s^{-1} km^{-2}$) during hydrological drought in September 2015 (Legend: 1. Points of hydrological observations and measurements in 2015; 2. Meteorological stations; 3. Hydrological stations; 4. Lines of identical specific discharge; 5. Border of conties; 6. Lakes and rivers; 7 Forests; 8. Urban area; 9. Cities).

below Lake Mlewieckie and lasted until mid-October (Sobota, 2016). In connection with the hydrological drought, the large lakes through which Struga Toruńska flows – Wielądzkie, Płużnickie, Wieczno Północne and Wieczno Południowe - have become endorheic (Solarczyk, Napiórkowski & Dembowska, 2017). During the hydrological drought the runoff in rivers is formed by an underground inflow. The ability to supply underground water to a deeper water-bearing system of rivers depends, among others on the range of the aquifer and the extent to which the valleys and riverbeds have cut into the surrounding land. During the drought, the largest specific discharges were recorded in the estuary sections of rivers flowing from the upland areas, as well as fragments of the sand region of the north-western part of the province (Bory Tucholskie). Runoff over 1.5 $dm^3 s^{-1} km^{-2}$ occurred in the lower parts of catchments of the Brynica (eastern part of the province), Mień, Struga Zielona, Osa, and in catchments of the Sępolenka and Kamionka. In the catchments of Czerska Struga, Bielska Struga and left bank Brda tributaries, the specific discharge was the highest in the province and exceeded the value of 2.0 $dm^3 s^{-1} km^{-2}$.

The spatial distribution of specific discharges determined during the hydrological drought in 2015 is to a large extent similar to the distribution of the lines determining the lowest from low specific discharges for the period 1951-1970 (Stachy, 1979). The highest specific discharges occur in the north-western part of the voivodship, in the upper part of the Brda basin. The deep deficit of water resources covers the area of the upper part of the Noteć basin and the Zgłowiączka basin. In the majority of the Kuyavian-Pomeranian Voivodship, specific discharges in 2015 were lower than specific discharges determined for the period 1951-1970. A particularly unfavourable phenomenon aggravating the deficiency of water resources occurred in 2015 in the southern and south-western part of the province (Kuyavia). The phenomenon of soil drought and hydrological drought, covering areas with very favourable features for agricultural production, affects the yield of plants, especially root crops and vegetables harvested in the autumn.

Table 3

Crop yields, root crops and vegetables (dt ha^{-1}) in 2015 over the period 2010-2017 (own calculations according to data from the GUS)

Type of crop	Average crop in 2010-2017	Crop in 2015	% of 2015 crops related to the period 2010-2017
Total cereals	41.9	39.6	94.5
Corn for grain	63.6	47.4	74.6
Potatoes	257	250	97.3
Sugar beets	585	472	80.6
Ground carrots	381	347	91.1
Ground beetroot	316	273	86.3
Ground onion	247	241	97.5
Ground cabbage	415	365	87.9
Ground cauliflower	180	157	87.3
Ground cucumbers	145	130	89.7
Tomatoes	335	326	97.2
Other ground vegetables*	135	126	93.1
Edible leguminous	26.8	25.2	94.0

* parsley, leeks, celery, radishes, lettuce and others.

The year 2015 belonged to dry years in the majority of the whole vegetation period throughout Poland (Kuchar *et al*., 2017). Problems with drought in 2015 in many regions of Poland appeared already in the spring. Significant shortages of precipitation were observed in winter and early spring (Łabędzki & Bąk, 2015). In 2015, when there were unfavorable conditions for plant growth, the yields of all types of crops decreased (Table 3). The yields of sugar beet and certain types of vegetables were particularly low. Higher losses in sugar beet yields are also caused by the lack of possibility of sprinkling irrigation the fields due to the large acreage these plants occupy. In the case of vegetables, water shortages in the ground could be replenished in some part of the area with sprinklers. Such treatments could have contributed to stopping the decline in total yields in the Kuyavian-Pomeranian Voivodship. Irrigation of plants in Poland is interventional, supplementing periodic water shortages (Żarski *et al*., 2013). The use of irrigation will increase, which results from the necessity to ensure the stability of plant production and to meet the increasingly high quality requirements (Stachowski & Markiewicz, 2011).

Conclusions

1. long-term persistence of meteorological drought in 2015 contributed to the reduction of water resources in the Kuyavian-Pomeranian Voivodship, which resulted in extremely low specific discharges. A significant reduction of water resources occurred first of all in the central parts of the plains and moraine plateaus, in intensively exploited agricultural areas and having the most favourable conditions for agriculture.
2. the highest values of specific discharge were recorded in the northern part of the Kuyavian-Pomeranian Voivodship (the upper Brda River basin) and in the edge zones of the uplands and river valleys of the main Vistula tributaries.
3. the lowest specific discharges were recorded in the southern areas of the Kuyavian-Pomeranian Voivodship, intensively used for agriculture, in which the areas designated for the cultivation of ground vegetables are among the largest in Poland.
4. in the case of droughts occurring in summer periods, yields of root crops, in particular sugar beet and certain vegetables (cauliflower, cabbage, beetroot), have decreased. Obtaining crops at a satisfactory level during long periods with no or little precipitation is associated with the need to apply irrigation. As a consequence of this type of treatment, there is an additional depletion of water resources within the catchment, further decreasing the low flows in rivers, and even their total disappearance.
5. in the period of meteorological droughts, as it was the case in 2015, in a large part of the area there are limited possibilities of surface water intake for irrigation purposes. The use of surface water resources as a potential source of irrigation water for crops can only be taken into account in connection with groundwater resources.

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THE CHANGE OF ANTHROPOGENIC LANDSCAPE IN LITHUANIAN RESORTS

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Abstract
Resorts in the Republic of Lithuania are residential areas with natural healing factors (mineral water, healing mud, health-friendly climates, recreational areas and water bodies) and a special infrastructure enabling them to use these factors. Currently, there are 4 resorts in the country: Birštonas, Druskininkai, Neringa and Palanga.
The purpose of this article is to carry out an analysis of the anthropogenic landscape of the resorts of the Republic of Lithuania in 2007-2018. During the preparation of the article, the following scientific methods were used: literature analysis, determination and evaluation of the current situation, grouping method, comparison method, analytical and statistical analysis methods, logical analysis, graphical method.
The analysis showed that the anthropogenic landscape of the three resorts increased: in Druskininkai – by 362.65 ha or 18.17%, in Neringa – by 113.43 ha or 52.78%, in Palanga – by 190.74 or 15.09%. The anthropogenic landscape of Birštonas has decreased by 41.11 ha or 5.03%.
Over the past decades, with the intensification of anthropogenesis and its accompanying urbanization, the importance of the natural environment has become more and more understood, and landscape research, which is associated with the assessment of naturalness and its problems, is becoming more and more relevant.
Key words: resort, landscape, anthropogenic landscape.

Introduction

According to the European Convention (European, 2000), the landscape is an important component of the quality of life for people everywhere, which expresses cultural heritage and natural diversity. The convention states that the landscape is a human perceived area, whose character is the result of the action and interaction of natural and/or human factors.

Countries ratifying the European Landscape Convention (ELC) agree to identify their landscapes, analyse their characteristics and assess the landscapes taking into account the values designated to them by the population (Herlin, 2016).

In the resolution 'On Approving the Description of the Landscape Policies of the Republic of Lithuania' approved by the Government of the Republic of Lithuania, the landscape is defined as the territorial component of the natural and/or anthropogenic components of the earth's surface, which is related to the material, energy and communication links. This is a territory, whose nature was determined by natural and/or anthropogenic factors and their interaction (Lietuvos, 2004).

Landscape is a complicated polyfunctional, constantly evolving system, altered or otherwise influenced by human beings (Skorupskas, 2004).

According to D. Veteikis, M. Jankauskaitė (2004), the landscape is mainly analyzed as a result of the interaction between nature and man. The quality of the landscape is influenced by the natural, economic and other activities of a person.

Landscape is a constantly changing and evolving system; therefore, the emergence of new landscape components, qualitative and quantitative changes is constantly taking place. The interaction of nature and human activity is changing landscape.

Anthropogenic landscape is a highly altered landscape of human activity (Ellis *et al*., 2006). People constantly change their surroundings. The environment can be changed directly and indirectly (Binford, Lee, & Townsendt, 2004).

Article relevance. Human activity is more or less noticeable throughout the landscape. Paving of roads, construction of buildings and extraction of mineral deposits, development of landfills have an impact on the landscape, but this is often a disadvantage for the environment (Bastian & Bernhardt, 1993). The environment, with anthropogenic factors, is filled with artificial, often disharmonious, technogenic derivatives that destroy the internal relations of natural landscape systems. Thus, in order to balance the internal structure of natural and anthropogenic areas, to determine the guidelines for the protection of the landscape, the assessment of the degree of artificiality/naturalness of the components of the earth's surface are of particular relevance (Jukna & Veteikis, 2011).

E. Piškinaitė and D. Veteikis (2014) also emphasize the importance of landscape research, noting that over the past decades, with the intensification of anthropogenization and its accompanying urbanization, the importance of the natural environment has become increasingly understood, and therefore landscape research related to the assessment of naturalness and the problems created are becoming more and more alert (Piškinaitė & Veteikis, 2014).

The object of this article is the anthropogenic landscape of the resorts of the Republic of Lithuania.

The aim is to carry out an analysis of the changes in the anthropogenic landscape of the resorts of the Republic of Lithuania during the period between the years 2007 and 2018.

Tasks to be solved:

1. To describe the current state of the landscape of the resorts.

2. To analyze the components of anthropogenic landscape of Birštonas, Druskininkai, Neringa municipalities, Palanga city, and their changes.

3. To study the change of anthropogenic landscape area in Lithuanian resorts during the period between the years 2007 and 2018.

Materials and Methods

Comparative, analytical as well as statistical and logical analysis methods were used for the research.

The article analyzed Lithuanian and foreign scientific literature.

The land fund statistics of the Republic of Lithuania (Nacionalinė žemės, 2007-2018), graphically depicted in figures, were used for the fulfilment of the research of the Lithuanian resorts anthropogenic landscape change for the years 2007-2018.

During the analysis the Lithuanian resorts statistics were compared with the Republic of Lithuania.

Results and Discussion

Analysis of the current situation. Resorts, which have natural healing factors (mineral water, healing mud, health-friendly climate, recreational areas and water bodies), and special infrastructure, which make it possible to use these factors for treatment, prophylaxis and rest, are considered as resorts in Lithuania. Currently there are 4 resorts: Birštonas, Druskininkai, Neringa and Palanga. There are also 9 resort areas (similar requirements apply to resorts, but there may not be special infrastructures for treatment).

Birštonas is a beautiful sanatorium treatment, wellness, tourism and entertainment center, a curative and resorting natural and cultural heritage resort of sustainable territorial development (Birštono, 2007).

In 1992, Nemunas Loops Regional Park was established – one of the largest regional parks in the country, covering over 25 thousand ha of land, which aims to preserve the unique landscape formed by the river Nemunas. 82% of the territory of Birštonas municipality is located in the Nemunas Loops Regional Park. There are 18 operating water wells and many inactive ones in the resort.

The total area of the municipality is 12171.76 ha. In 2018, the largest part of it was covered by forests – 47.87% (5827.24 ha) and agricultural land (4376.88 ha or 35.96%). The roads accounted for the smallest part – 1.92% (233.10 ha).

In 2018, water bodies occupied 737.98 ha (6.06%). Area of wetlands during 2007-2018 decreased by 36.43 ha or 57.17% and in 2018 occupied an area of 27.29 ha.

Druskininkai is an international year-round mineral water, mud and climate therapy resort, which is a city in southern Lithuania, 120 km from the capital Vilnius.

It is a richly nature-rewarded resort that has been valued for centuries for its natural and healing resources. It is the largest resort located in the south of the country, which combines the peace of the forests and modern resort therapies (Druskininkų, 2016).

In the resort, there is a picturesque landscape of the Raigardas Valley, which is currently recognized as a landscape reserve and which is distinguished by pure water springs and flat fields. The spectacular street village of Švendubrė, located 5 km from Druskininkai, is famous not only for its old streets, but also for a wonderful hill called the Black Mountain, old country homesteads of ethnographic Dzūkija region and the famous 'Devil Stone' in Švendubrė village, a geological monument.

Druskininkai municipality area covers 45301.20 hectares. The largest share of the municipality in 2018 took forests (31430.21 ha or 69.38%), the smallest – roads (759.71 ha or 1.68%).

Area of water bodies during the period between the years 2007 and 2018 increased by 279.04 ha or 25.46%. During the mentioned period, the area of wetlands decreased by 260.04 ha or by 40.26%.

Neringa is a resort located in the Curonian Spit, between the Baltic Sea and the Curonian Lagoon (western coast). It is the longest (about 50 km) and the most distant city in Lithuania (Neringa, 2018).

The municipality of Neringa occupies 13883.65 ha and makes up 2.66% of the territory of Klaipėda County. In 2018, the largest area of the municipality was occupied by forests – 7132.72 ha (51.37%), the smallest – by agricultural land – 20.27 ha (0.15%). In the municipality, the waters made up 35.27 percent and occupied 4897.16 ha. The area of wetlands during the period between the years 2007 and 2018 decreased by 20.90 ha (84.96%) and by 2018 occupied 3.70 ha.

Neringa has 6 parks and 4 squares occupying about 17.05 ha.

The landscape of the Curonian Spit is the cultural landscape formed in the sand dune during the 19th century based on human ecological wisdom, great physical effort and financial expenses (Bučas, 2007).

A special feature of this municipality is that its entire territory as far back as the 1960s was declared as the Landscape Reserve, in 1966, – as Landscape Reserve with a special regime, and in 1991, it was assigned to the established Curonian Spit National Park. In addition, on November 29, 2000, the Curonian Spit as a unique site with an exceptional cultural landscape, decided by the UNESCO World Heritage

Committee, was listed on the World Heritage List as a group of cultural landscapes (Urbanistika, 2012).

Palanga resort is located in the northwest of Lithuania, in the territory of Klaipėda County. The city borders the Republic of Latvia in the north, the Kretinga and Klaipėda districts in the east, and the Baltic Sea in the west. It is one of the largest Lithuanian resorts and tourist centers, already half way through the second century of recreational activities (Palangos, 2017).

The city municipality occupies an area of 7918.80 ha and makes up 1.52% of the Klaipėda County territory. In 2018, the largest part of the municipality consisted of forests (39.36%), the smallest – of roads (2.80%). In the municipality, water bodies occupied 228.80 ha and amounted to 2.89% of the analyzed territory's area. In 2018, wetlands occupied 32.35 ha. Since 2007 their area increased by 10.91 ha (50.89%).

Palanga resort on the Baltic seaside extends about 24 km. The modern Palanga resort is the result of the formation of a seaside settlement, port, town, city in the historical space (Jankauskaitė, 2016).

The northern part of Palanga belongs to the Seaside Regional Park, in which the Plazė Nature Reserve, the Nemirseta Landscape Reserve, part of the Šaipiai Landscape Reserve and a small part of the Karklė Marine Reserve are located. In the municipality, there is the Būtingė Geomorphological Reserve, the Būtingė Bird Mire Ornithological Reserve and the natural monument Būtingė Oak.

Nemirseta, which is incorporated into the Conservation Area of the Seaside Regional Park, is distinguished by the landscape characteristic to the Lithuanian seaside: a sandy protective beachfront coffin and large vegetation typical only for the Lithuanian seaside. From the old dunes, there are magnificent views of the new ones, below which is the sea.

Anthropogenic component change. Landscape changes such as new roads and buildings, changes in the agricultural and forestry network, the loss of elements of the traditional agricultural landscape, new solitary trees, and new roadside slopes have been associated with political driving forces (Hersperger & Burgi, 2010).

Anthropogenic areas include: built-up areas, roads, damaged land. In 2007-2018, the area of roads in *Birštonas resort* decreased by 29.22 ha or 11.14% and in 2018 occupied 233.10 ha (Figure 1).

The reason for the decline in road area was the fact that by 2015 data from theoretical calculations were inaccurate and cadastral measurements started in 2015, where data on road occupied areas are annually adjusted. At present in Lithuania, 50% of the cadastral measurements of road areas are carried out, including the Kaunas County, where Birštonas is located. Thus, the decrease of road areas is conditional.

In the Republic of Lithuania in 2007-2018, for the above reasons, the area of roads decreased by 26692.50 ha (20.20%).

In 2018, the built up area occupied 530.73 ha. During the analyzed period, the area decreased by 7.11 ha or 1.32%. A decrease was relative, since in 2015 the geographical information system and data bank were supplemented with new data and spatial data on land plots, buildings, addresses, engineering networks, forests, etc. were updated.

In 2007-2018, the area of damaged territories in Birštonas decreased by 4.78 ha (29.15%) and by 2018 occupied 11.62 ha. Illegal landfills, garbage dumps, and special waste disposal sites were eliminated in Birštonas within the framework of European Union directives and regulations.

The analysis of anthropogenic components in the municipality of Birštonas showed that the area of roads and built-up areas decreased relatively due to the measurements and data correction, damaged land decreased due to the European Union waste management policy.

In 2007, the anthropogenic landscape made up 6.71% of the total area of Birštonas and occupied 816.56 ha (Figure 2).

During the analyzed period, the anthropogenic landscape of Birštonas decreased by 41.11 ha or 5.03%.

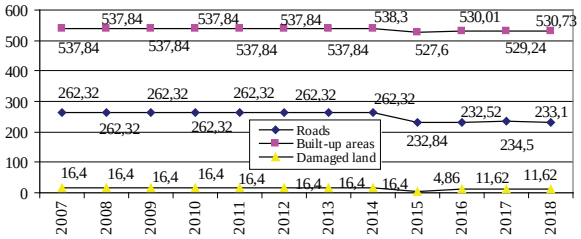

Figure 1. Changes in anthropogenic landscape components of the Birštonas municipality in hectares during the period between the years 2007 and 2018 (Nacionalinė, 2007-2018), (Created by the author of the article).

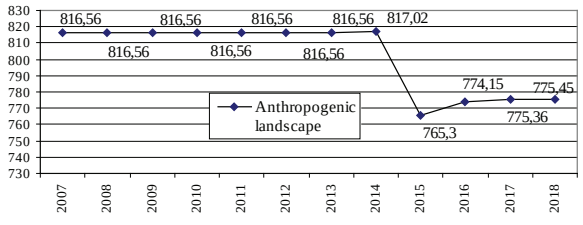

Figure 2. Anthropogenic landscape change in Birštonas in hectares during the years 2007 and 2018 (Nacionalinė, 2007-2018), (Created by the author of the article).

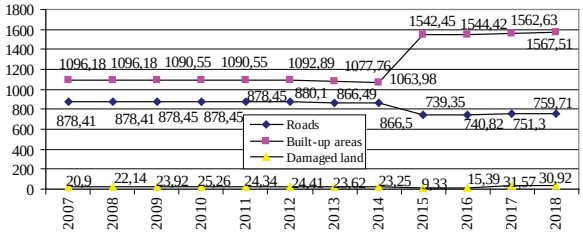

Figure 3. Changes in anthropogenic landscape components of the Druskininkai municipality in hectares during the period between the years 2007 and 2018 (Nacionalinė, 2007-2018), (Created by the author of the article).

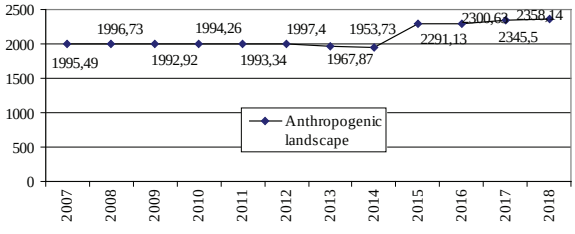

Figure 4. Anthropogenic landscape change in Druskininkai in hectares during the years 2007 and 2018 (Nacionalinė, 2007-2018), (Created by the author of the article).

The largest part of the landscape was made up of built-up territories (68.44%), the smallest part – by damaged land (1.50%).

In Druskininkai in 2018, roads accounted for 1.68% (759.71 ha). During the period between the years 2007 and 2018, the road area in the municipality has decreased by 118.70 ha or 13.51% (Figure 3). The reason for the decrease is the same as in Birštonas, i.e. cadastral measurements and refinement of data.

The area of the built-up territories in the resort during the analyzed period increased by 471.33 ha or 43.00% and in 2018 accounted for 3.46% of the Druskininkai resort area. The area has been growing due to the ongoing urban development.

The area of built-up territories in Lithuania during the decade increased by 57753.46 ha (32.07%). It follows that the development of these territories in Druskininkai is higher than the national average.

The area of damaged land has also increased. During the period between the years 2007 and 2018, the area increased by 10.02 ha (47.94%), when the area of damaged land during the analyzed period in Lithuania increased by 744.21 ha or 3.17%.

Damaged land in 2018 amounted to 0.05% of the municipality's territory. The development of municipal waste management infrastructure and the improvement of the development or creation of separate municipal waste collection capacities, influenced the development of the damaged area.

The analysis of the changes in the anthropogenic landscape components shows that the area of built-up territories and damaged area increased (43.00% and 47.94% respectively) and the area of roads has decreased by 13.51%.

In Druskininkai during the period between the years 2007 and 2018, the anthropogenic landscape increased by 362.65 ha (18.17%). In 2007, this landscape made up 4.40% of Druskininkai area, in 2018 – 5.21% (Figure 4).

The largest part of the anthropogenic landscape was occupied by the built-up territories (66.47%), the smallest – by damaged territories (1.31%).

In Neringa, the road area decreased by 0.30 ha (0.20%) during the period between the years 2007 and 2018 and in 2018 occupied 152.71 ha and amounted to 1.10% of the municipality's territory (Figure 5).

The built-up territories in Neringa municipality in 2018 occupied 173.65 ha comprising 1.25% of the municipality's area. In 2007-2018, the area of the built-up territory increased by 111.74 ha or 180.49%, with the country's average of 31.29%.

In Neringa municipality, the regulation of spatial planning, preservation of the natural landscape and illegal, arbitrary construction is particularly interspersed. In the course of various constructions, it is threatened to lose valuable and unique identity in the area.

In 2007-2010, there were no damaged lands in the municipality. In 2011, their area has already occupied

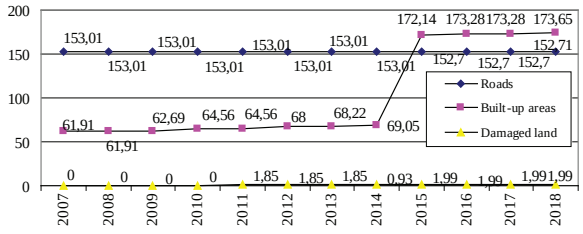

Figure 5. Changes in anthropogenic landscape components of the Neringa municipality in hectares during the period between the years 2007 and 2018 (Nacionalinė, 2007-2018), (Created by the author of the article).

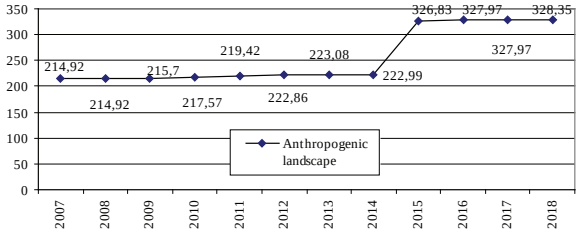

Figure 6. Anthropogenic landscape change in Neringa in hectares during the years 2007 and 2018 (Nacionalinė, 2007-2018), (Created by the author of the article).

1.85 ha. In 2018, the area under consideration increased and occupied 1.99 ha and amounted to 0.01% of the municipality's area. During the period between the years 2007 and 2018, the area increased by 1.99 ha.

After analyzing the components of the anthropogenic landscape of the municipality of Neringa, it has been established that the area of built-up territories (111.74 ha or 180.49%) and the damaged land (1.99 ha) increased and the road area (0.30 ha or 0.20%) decreased slightly. The area of roads decreased relatively, as several cadastral measurements were carried out, during which the area was refined.

In 2018, anthropogenic landscape of Neringa municipality made up 2.36% or 328.35 ha (Figure 6). During the period between the years 2007 and 2018, the area of the analyzed landscape increased by 113.43 ha or 52.78%.

The largest part of the anthropogenic landscape consists of built-up territories (52.88%) and roads (46.51%). Damaged land constitutes the smallest part of the anthropogenic landscape – 0.61%.

In 2018, the roads of the *Palanga city* municipality occupied 221.91 ha and amounted to 2.80% of the municipality's territory area (Figure 7).

For twelve years, the road area has increased by 13.36 ha or 6.41%. During the analyzed year, the development of road infrastructure was carried out, parking lots, etc. were erected in the municipality.

In the municipality, built-up territories in 2007-2018 increased by 208.28 ha or 20.42%. The area has been growing due to the intensification of constructions in the municipality. In Palanga, as in the municipality of Neringa, there are problems with illegal construction, as well as problems with violations related to construction projects.

In 2018, the built-up territories occupied the area of 1228.40 ha and amounted to 15.51% of the municipality territory.

Damaged land in the municipality in 2007 occupied 35.42 ha. Due to implemented European waste management directives and legal acts of the Republic of Lithuania, the area of damaged lands in the municipality has decreased by 30.90 ha or 87.24%. In 2018, the damaged area occupied 4.52 ha and amounted to 0.06% of the municipality area.

It was established that during the years 2007-2018 the areas of anthropogenic landscape components of Palanga city municipality were as follows: areas of roads (13.36 ha or 6.41%) and built-up territories (208.28 ha or 20.42%) increased, damaged land areas (30.90 ha or 87.24%) – decreased.

In 2007, the anthropogenic landscape of Palanga city municipality occupied 1264.09 ha and amounted to 15.96% of the municipality's area, in 2018 it occupied 1454.83 ha (18.37%) (Figure 8). During the period between the years 2007 and 2018 the area of anthropogenic landscapes increased by 190.74 ha or 15.09%. The area has been growing due to the development of built-up territories and road areas.

The built-up territories formed the largest part of the anthropogenic landscape of Palanga city municipality (84.44%). The damaged lands formed the smallest part (0.31%). Roads made up 15.25% of the anthropogenic area of the municipality.

After analyzing the changes in the anthropogenic landscape of the four resorts of the Republic of Lithuania, it is evident that the landscape area analyzed in the three resorts (Druskininkai, Neringa, Palanga) has increased. The biggest development in hectares was in the Druskininkai resort (362.65 ha). In these resorts were the most expanded areas of the built-up territories.

In the only Birštonas resort the area of anthropogenic landscape decreased (41.11 ha). From the analysis above, it is clear that this decrease is relative (due to the correction of the measurement data of areas).

Anthropogenic landscape in the Republic of Lithuania in 2007 accounted for 5.14%. During 2007-2018 its area increased by 9.47% and in 2018 amounted to 5.63% of the country's area. Thus, the development of anthropogenic landscapes in the resorts was more rapid in comparison with the increase in the total area of anthropogenic landscape

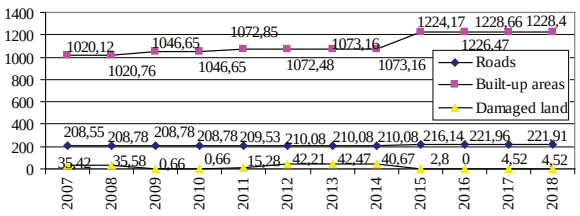

Figure 7. Changes in anthropogenic landscape components of the Palanga municipality in hectares during the period between the years 2007 and 2018 (Nacionalinė, 2007-2018), (Created by the author of the article).

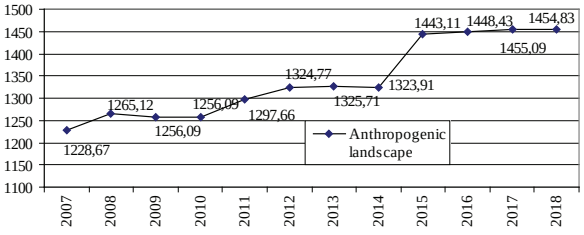

Figure 8. Anthropogenic landscape change in Palanga in hectares during the years 2007 and 2017 (Nacionalinė, 2007-2017), (Created by the author of the article).

in Lithuania: in Druskininkai – 362.65 ha or 13.17%, in Neringa – 113.43 ha or 52.78%), in Palanga – 190.74 ha or 15.09%.

It is argued that the protection of landscape diversity is as important as the protection of bio-diversity, in the world where an accelerating rate of technological change is forcing cultural landscapes to change in the direction of greater uniformity (Ermischer, 2007).

Urbanization processes show cycles of evolution that spread in different ways through space. Urbanized landscapes are highly dynamic, complex and multifunctional. Therefore, detailed inventories of landscape conditions and monitoring of change are urgently needed in order to obtain reliable data for sound decision-making (Antrop, 2004).

Landscape change is related to the development of anthropogenic components, the relationship between urbanized and natural areas. Knowing that anthropogenic processes reduce the natural resources, it is necessary to preserve the valuable landscapes of the Republic of Lithuania, including their resorts, their identity and to reduce the causes of negative change caused by anthropogenization; it is necessary to eliminate the factors that influence the negative landscape changes.

Conclusions

1. There are 4 resorts in Lithuania: Birštonas, Druskininkai, Neringa and Palanga. Birštonas is one of the oldest balneological resorts in Lithuania. Druskininkai is a mineral water, mud and climate therapy resort. Neringa is a resort located on the Curonian Spit, between the Baltic Sea and the Curonian Lagoon, famous for its unique landscape. Palanga is one of the largest Lithuanian resorts and tourist centers.
2. In Birštonas municipality, the area of roads (29.22 ha or 11.14%) and built-up territories (7.11 ha or 1.32%) declined relatively, due to measurements and data correction, damaged land (4.78 ha or 29.15%) – decreased because of the ongoing European Union waste management policy.
3. In Druskininkai, during the period between the years 2007 and 2018 the road area in the municipality has decreased by 118.70 ha or 13.51%. The area of built-up territories in the resort increased by 471.33 ha or 43.00%, while the damaged area increased by 10.02 ha or 47.94%.
4. In Neringa, the area of roads has decreased by 0.30 ha (0.20%). The area of the built-up territories has increased by 111.74 ha or 180.49%. The area of damaged land in 2007-2017 increased and occupied 1.99 ha.
5. In Palanga, the road area increased by 13.36 ha or 6.41%, the built-up area was 208.28 ha or 20.42%. The area of damaged land in the resort has decreased by 30.90 ha (87.24%).
6. During the period between the years 2007 and 2018 the area of the anthropogenic landscape in Druskininkai increased by 362.65 ha (18.17%), in Neringa – by 113.43 ha (52.78%), in Palanga – by 190.74 ha (15.09%). The area has been growing due to the development of built-up territories. The anthropogenic landscape of Birštonas has decreased relatively by 41.11 ha or 5.03%.
7. It was determined that the landscape area analyzed in the three resorts (Druskininkai, Neringa, Palanga) has increased. The biggest development in hectares was in the Druskininkai resort (362.65 ha). The most expanded areas of the built-up territories were in these resorts.

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EVALUATION OF LONG-TERM CHANGES MORPHOMETRY OF LAKE KISEZERS

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Abstract
This study is important to contribute morphometry researches and give an example of how to accomplish studies about lakes. The aim of the study is to use the latest technology to determine the morphometric parameters and their variability compared to the previous research results. Research focuses not only on local water body morphometry and bathymetry, and their influencing factors, but also deals with methodological issues regarding measurements of morphometric characteristics and data interpretation as well as state of the art visualization of results. On many occasions, there is a lack of research on morphometry of water bodies or they have taken place in the last century, which has led to the use of obsolete research methods in modern morphometry studies that do not produce the results of a high level of detail. The aim of the study is to use the latest technology to determine the morphometric parameters and their variability compared to the previous research results. The study consists of analysis of the literature on morphometry, methodology used in bathymetry studies, history of research, research methods used in the previous studies. The research object is Lake Kisezers including its morphometry, bathymetry, and influencing factors. The results of the study show that morphometric parameters of Kisezers differ from the results of previous studies. The results of the study confirm that Lake Kisezers is exposed to various influencing factors, mainly anthropogenic. The main factor influencing morphometry and hydrological regime in Kisezers is the water level fluctuations influaced by Riga Hydroelectric Power Plant.
Key words: Lake Kisezers, morphometry, bathymetry, water level fluctuations.

Introduction

The bathymetry and morphometrics are among the most important lake characterization indicators that provide necessary information on the status of a water body and its development in relation to its place and changes in the hydrological regime. The morphometric parameters of the lake are influenced by the location, origin, natural conditions, other water bodies and watercourses of the lake catchment area, as well as the anthropogenic impact (J.G. Tundisi & T.M. Tundisi, 2012). By interacting with these factors, a lake can change over a shorter or longer period of time (Slaucītājs, 1935). Hydrologic changes in the catchment area have a significant impact on the water body (Glazačeva, 2004). When determining changes in morphometry, it is possible to determine to what extent anthropogenic effects have altered the ecosystem of a lake (Agnieszka, Adam, & Kurzyca, 2011). Morphometry is a quantifiable parameter to assess how to use and manage a lake (J.G. Tundisi & T.M. Tundisi, 2012). The identification of bathymetry is important for depth monitoring and determination of changes in morphometry (Jawak & Luis, 2015). Determination of lake's depth is important to understand flows of nutrients and water body productivity (Leinerte, 1992).

Lake Kisezers is a component of a complex hydrological system where water level measurements have been carried out, in a long–term at several observation stations that allows to precisely evaluate water level fluctuations in the water body. There is inconsistent historical information on its morphometric characteristics available, which leads to the assumption that the available bathymetric map does not reflect the current situation. Perhaps the map used to calculate the morphometric characteristics of the published sources has been kept as a secret during the Soviet Union time and has not been published. When choosing Lake Kisezers as an object of the research, attention was also paid to the fact that Lake Kisezers is defined as a waterbody at risk in Latvian legislation (LVĢMC, 2014). In addition, Lake Kisezers is also referred to as the priority fish water. In order to set the ecological and chemical quality criteria for Lake Kisezers, it is necessary to identify its depths, as the average depth is a criterion after which lakes are classified according to their respective quality standards (Cabinet of Ministers …, 2004). Being in the city, Lake Kisezers is an important recreational object, but it is also a subject to strong anthropogenic effects, such as wastewater discharges, where chemical compounds accelerate eutrophication processes.

Studies of morphometry in Latvian lakes started in the 20th century. Already in 1909, F. Ludwig performed a detailed morphometric description of several lakes in the vicinity of Riga (Kokorīte, 2007), with a total of 29 lakes (Spuris, 1968). The research of national significance in the 1920s – 1930s has been developed (number of lakes, areas, general limnologic surveys) by V. Ozoliņš, V. Zāns, A. Kursītis, L. Slaucītājs, P. Stakle, P. Nomals, M. Galenieks (Cimdiņš, 2001). In the 1950s, H. Sizov conducted the study in 21 lakes. During this study bathymetry, morphometry

and classification of lakes have been done. The study has been unique because a boat has been used to measure the depth of water, rather than measurements taken from ice, as described in previous studies by authors (Сизов, 1959). In the 1950s, from 1943 until 1952 overall 20 Latvian lakes have been studied (Kumsāre, 1960; Cimdiņš, 2001). The methodology of Latvian research differs considerably from that of used in other countries. For example, bathymetry surveys have been conducted during the winter period measuring the depth of ice drilled pebbles instead of using an echo sounder. The measurement locations have been selected to cover the entire waterbody and represent its depth. The measurements were between 20 and 60 m apart. A. Tims was the first who studied Lake Kisezers (Slaucītājs, 1935). The results of our study differ substantially from the results obtained in 1882 by a hydrologist A. Tīms. The differences can be explained by lowering the water level of Lakes Lielais and Mazais Baltezers by 1.8 m due to the construction of the Gauja – Daugava Canal and the demolition of the mill of Bukulti (Slaucītājs, 1935). Analyzing the literature, it can be concluded that morphometry is usually determined from early 20th century map. There is a lack of information on studies in the late 20th and early 21st century. In Latvia, there has been no study on morphometry and bathymetry of lakes using the latest technologies such as (computer software and echo sounders).

When determining changes in morphometry, it is possible to estimate to what extent anthropogenic effects have altered the ecosystem of a lake (Agnieszka, Adam, & Kurzyca, 2011). Morphometry is quantifiable to assess how to use and manage a lake best (J.G. Tundisi & T.M. Tundisi, 2012). Morphometry describes the size of a waterbody and implies application of remote sensing, field, and chamber working methods. Nowadays, geographic information systems are widely used for the analysis of geospatial information (Gilberto, Goncalves, & Garcia, 2014). The accuracy of the morphometric measurements is determined by the scale of the cartographic material (Сизов, 1959), as well as the quality of the data of the waterbody and used equipment (Gilberto, Goncalves, & Garcia, 2014), the location of the waterbody, the purpose of further usage of the research results. The identification of bathymetry is important for depth monitoring and determination of changes in morphometry (Jawak & Luis, 2015). The bathymetric map is a source of several morphometric parameters that are measured. The newer and more qualitative data used to construct a bathymetric map, the more accurate the morphometric parameters are. Smaller intervals between the isobates provide a more detailed representation of the water body's bathymetry, which in turn gives more accurate results in morphometry studies. Overall, a higher degree of the bathymetric map may provide a more accurate determination of morphometric parameters (Hakanson, 1981).

Lake Kisezers is located on the seaside lowland, in the territory of Riga, in the Daugava river basin with lakes with a density of 0.038 lakes per km^2 (Tidriķis, 1995). This lake is the 10th largest lake in Latvia. The lake has three islands (Tidriķis, 1995). The lake is oblong-shaped with a scalloped shoreline and several shallow bays (Kačalova, 1984). The water body is located in the Kisezers – Jugla lake district, location shown in Figure 1. in the far part of the lagoon of Littorina (Kačalova, 1984). Lake Kisezers, together with Lake Jugla, is located in one valley formed by the former Daugava river. Lake Kisezers is a permeable river-type lake (Slaucītājs, 1935; Stiebriņš, 2011). It is connected with Lakes Mazais and Lielais Baltezers, Lake Jugla and is a part of the Daugava-Gauja hydrologic system. Geological research shows that Lake Kisezers, as well as Lake Jugla, Lielais and Mazais Baltezers were once a single waterbody – the Garciema Lagoon with inflow from both the Daugava and Gauja River. The description of Lake Kisezers in literature sources by 20th century is mainly based on Kačalova, Kumsāre and Kundziņš in the book 'The Great Lakes in the Neighborhood of Riga'. The results are described in the 5th Vol. (Kačalova, 1984), Vol. 2 of the Small Encyclopedia of the Latvian SSR (Pastors, 1968).

The gradual transformation of the hydrographic network of Riga and its neighborhood has been mainly driven by climate change. In the past, the hydrographic network changed only in natural processes, but after the city of Riga was established and expanded, the changes in the hydrographic network, among other things, also contributed to anthropogenic pressure (Stiebriņš, 2011).

According to the author's visual observations, it can be concluded that the channels have frequent and rapidly changing water level, flow rate, and direction. As a result of wind floods, the water level can rise by more than 2 m or decrease by more than 1 m. Due to the location of Lake Kisezers in a complex system, the lake is subject to anthropogenic and natural factors that affect the water body's morphometry and water level changes.

The aim of the study is to use the latest technology to determine the morphometric parameters and their variability compared to the previous research results. The following tasks were set for this study:

1. to develop a methodology for depth map design and fieldwork and evaluate its suitability for applications in future studies;
2. to collect depth data of Lake Kisezers in the fieldwork and develop Lake Kisezers bathymetric map based on the results of fieldwork, identify

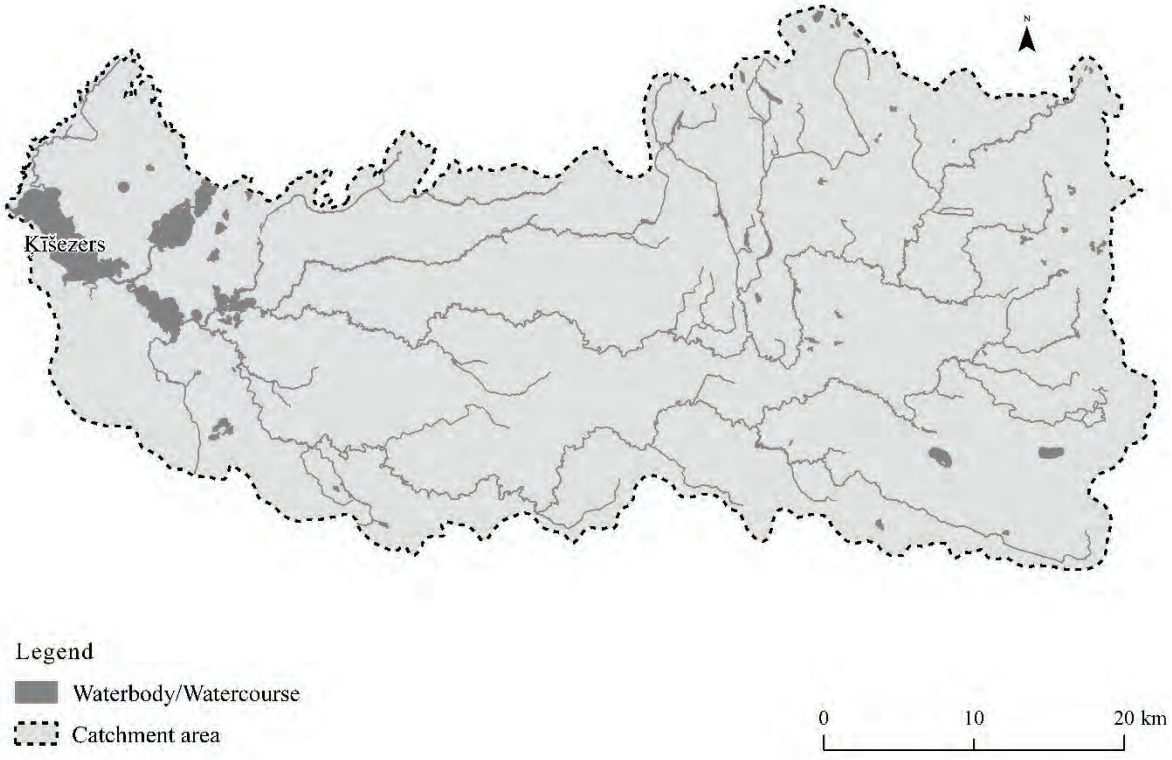

Figure 1. Study subject Lake Kisezers catchment area (For map construction used LVM GEO Map Browser free maps from The Latvian Geospatial Information Agency and Ģis Latvia 10.2).

water bodies morphometrical parameters and compare the results with the information found in the literature.

Materials and Methods

The study uses the data from the fieldwork in 2017, which includes the data on Lake Kisezers depth measurements, the mapping of the surface overgrowth, the data of the coastline decryption. The obtained data were used in the construction of the bathymetric map, and furthermore of calculate and determine morphometric parameters and the watercourse shoreline inspection has been done. The study summarizes the water level data of the observation stations 'Ķīšezers', 'Rīga', 'Daugavgrīva', 'Andrejosta', which were obtained from the Latvian Environment, Geology and Meteorology Centre Water level data is collected to assess how the water level between observation days changed and the data could be interconnected. Water level data to determine how fast the water level changes in the water body, which in turn alters all morphometric parameters.

Survey

The survey of Lake Kisezers was conducted on July 15, 16, 22, 23, 2017. The field works at Lake Kisezers were carried out in four days using a boat. In general, the depth measurements were made in about 50 h. The length of the depth measurements was influenced by the boat with a maximum speed of 25 to 30 km h^{-1}, the size of the waterbody, safety considerations (wave height, wind force, other floating craft). During the field work the estimation of the bathymetry of an embankment, the anthropogenic load was carried out by examining the shoreline of the water body and deciphering the changes and determining the location of the shoreline using GPS. Lake Kisezers was surveyed by moving around the perimeter of the lake with each circle away from the shore. Similarly, measurements can also be collected in the form of profiles (Sambuelli & Bava, 2011), but it is slower because the boat needs to turn around every time the water body is crossed. By moving around the perimeter of the lake, the data record reduces the chance of error, as the boat draft changes with uneven speed, resulting in errors and more complex and time – consuming data editing.

When looking at a waterbody, it is necessary to choose a suitable inventory (Hakanson, 1981). Lowrance Hook 5 GPS was used for the depth data recording during the survey. The results of this survey were converted into the required formats (shp), processed, and edited. From the processed data, a highly detailed bathymetric map with isobates of 1 m depth change and every 2 m depth change was constructed. A bathymetric map with isobathic every 2 m depth change was used for morphometric calculations. During the survey of Lake Kisezers, anthropogenic impacts near the shoreline were assessed.

For lake depth measurements and data acquisition, an engine equipped motorboat equipped with an echo sounder with a recording function and GPS is required. It is recommended to not take the record for more than a few hours, otherwise, the routes become too long and there is a greater chance that an error may occur in the echo record. The data from the Lake Kisezers survey takes 3.65 GB. For data recording, the echo sounder Lowrance Hook 5 with GPS and data recording function was used. Lake Kisezers was surveyed with a low – power motor boat for depth measurements Dulkan 400 with 7.45 kW Yamaha engine. The advantages of a low – power motorboat, in this case, are mainly fewer error areas requiring data editing. Such a boat is less damaging to the already significant anthropogenic load-bearing Lake Kisezers, due to its low fuel consumption, it produces fewer emissions.

The data from the fieldwork were processed, error areas have been edited, and corrections have been made in the immediate vicinity of the shoreline and in overgrown areas that may have hindered the echo rays, and thus depth information was read imprecisely. The depth measurements include a boat draft (Boiten, 2003), which is 25 cm in this case. The editing process included the conversion of each day's data, alignment to the water level of a given day, and addition of the echo proba draft (25 cm) to the results obtained. Depth measurements were all aligned to the average water level of 45.9 cm above sea level on the first day of observation (July 15). The results obtained for the second day of fieldwork were subtracted from 8.1 cm (53.8 cm). The results of the third field work day are added to 15.1 cm (30.8 cm). The results of the fourth day are added to 22.5 cm (23.4 cm).

A bathymetric map is constructed using field record data files in the sl2 format. Data records for each day are converted to shape file (shp) format using the MapCreator. Shp was edited and merged using ArcMap software of ESRI, summarized shp was converted to csv data format. Using ReefMaster card processing and interpolation tools, a bathymetric map with isobates every 1 and 2 m depth changes were constructed. ArcMap has been used in the final stages of creating a bathymetric card to design a map. In order to successfully create a bathymetric map, depth recording data in csv, shp, sl2 format, qualitatively marked coastline is required. The coastline can be used to determine the boundaries of the map interpolation. The analysis of the morphometric parameters was based on the literature analysis, which resulted in the determination of morphometric parameters, which can be calculated and determined for Lake Kisezers.

The morphometric parameters were determined in the study and are as follow: the total area of the lake and island, largest length (km) and the largest width (km), average width of the water body (km), maximum depth (m), average depth (m), shoreline length (km), shoreline development index, volume (m^3), relative depth, volume development, deflection angles.

Results and Discussion

Lake Kisezers is a lagoon lake of origin, formed by the interaction of complex natural conditions due to the development of the Baltic Sea stages, the influence of the Gauja and Daugava rivers. Nowadays, the lake is mainly influenced and changed by anthropogenic factors. For example, according to the literature, the natural depth of Lake Kisezers should be similar to other lakes in the Seaside Lowland, but the lake due to the complex conditions of formation and anthropogenic impact since the 13th century differs from other lakes in the Seaside Lowland. Due to its geographic location, Lake Kisezers is exposed to natural and anthropogenic factors that make the waterbody important object of studies. It is possible to simultaneously observe how the lake is affected by the catchment area, the Daugava River, Baltic Sea, City of Riga, Riga HPP and other anthropogenic effects, and to determine as in reality compared to the 20th century. The results of research have changed perspective on morphometry and hydrological regime of the 10th largest lake in Latvia.

Since the latest bathymetric map published in the literature reflects the situation in 1932s/1933s, the construction of a new bathymetric map describing the current situation was needed. So far no Lake Kisezers bathymetric map has been constructed based on data obtained using echo sounder. The literature and internet resources have been studied prior to the field work, their analysis has been performed, and indicative data on current bathymetry information of Lake Kisezers have been found. The data was obtained from the genesimaps.com, which contains an indicative depth map. The map indicates that the depth of Lake Kisezers in the area around Milgravis Canal is not as reflected in the 20th century bathymetric maps. The bathymetric map available at genesismaps.com cannot be used in this study due to unknown time of the map creation, water level in the lake at the time of measurements, wrongly marked coastline. The map can only be used to raise doubts as to whether the bathymetric map published so far is consistent with the current situation.

In the central part of Lake Kisezers, the depth is 4 – 4.5 m. The deepest places in Lake Kisezers were found in the immediate vicinity of Milgravis Canal and near the Jugla river in South. The deeper places are different from previous studies. They are formed as a result of sand dragging (Stiebriņš, 2011). Unfortunately, there is no information on the time of sand pumping. The

data used to constrain the bathymetric map include 1 876 073 points of depth measurement.

The fieldwork data is suitable for creating a bathymetric map with isobates every 1 m, but this map is not included in this article due to its size. The remarkable depth of the anthropogenic load has resulted in more than 15 m depth of sand in the deeper area. In the shore area near the depth of the shore, the shore reinforcement with piles and debris is observed, indicating the negative impact of the deepened area and the promotion of coastal erosion. The author's research results show that the maximum depth of 4.2 – 7 m as described in the literature is not true in Lake Kisezers any more. The previous information shows that Lake Kisezers deepest place was originally at the source of Milgravis Canal, where already during the L. Slaucītājs research the deepening of the anthropogenic load took place in the lake. Similarly, A. Tidriķis also points out that the deepest place was created by deepening Milgravis Canal, (Tidriķis, 1995). Thus, already in the beginning of the 20th century, the anthropogenic influence was the main influencing factor of the Lake Kisezers morphometry and bathymetry in the south area. The deepest place of the lake is 21.5 m. In the literature, it can be seen that the depth of the lake in the sand pumping sites exceeds 16 m (Stiebriņš, 2011). The study reflects the true depth of the area, the results show how deep the sand has actually been pumped out. It cannot be ruled out that rapid fluctuations in the water level have contributed to the leaching of the lake bed in these underwater quarries, resulting in areas deeper today than those planned by sand miners.

In the 20th century, L. Slaucītājs (Slaucītājs, 1935) described that the greatest depth of Lake Kisezers is 7 m. Information in other 20th century studies has not been reflected due to possible secrecy as Lake Kisezers was in close proximity to military complexes such as Suzi Base (National Armed …, 2010).

Lake Kisezers has three islands with a total area of 65921.4 m^2. The total area of the lake is 19.96 km^2. The size of the islands and the lake is different from the literature, which explains the location of the island and the shoreline of each lake. It is assumed that in the study, the coastline would be deciphered at its real location by using a shore-based survey of shore and boat, and ice. The islands occupy the total of 0.38% of the lake area. In the encyclopedia 'Riga' it is mentioned that the lake surface area/islands area ratio is 0.44% (Kačalova, Kumsāre, & Kundziņš, 1962). The numbers describing the length (7.7 km) and width (3.14 km) of the lake differ from the available literature. It may be that the respective numbers were incorrectly applied in previous studies. The mentioned length of 9 km in the literature is only possible if the line leaves the contour of the lake, which is incorrect and does not correspond to the methodological approach used nowadays, by pulling the line between the further north and south points of the lake. Due to the uneven bed, the lake volume calculations are complicated. The result proves that the volume of the lake is smaller than indicated in the literature, which most likely proves that the volume has been calculated using data when the lake has been already deepened, but the output data have not been made public. When comparing the highest water level (2.39 m, fixed in November 1969) and the water level during the author's bathymetric map design, the difference is 1.91 m. The result is 33793430 m^3 when calculating the volume according to the bathymetric survey data. By calculating the volume at the highest observed water level, the magnification at this water level can be up to 32229208.7 m^3. Any rapid water-level fluctuations are capable of significantly affecting the volume of Lake Kisezers, and can reach up to 66022638.3 m^3, which is 1/3 higher than the volume indicated in the literature. It is difficult to accurately calculate the volume of a sprat as, in Lake Kisezers, strong and long-duration winds of the Northwest and Southwest direction may cause water level slips to 20-30 cm, and this slip can last up to 10 days (Apsīte *et al.*, 2014). In the author's study, the volume of the body of water is calculated assuming that the mirror surface of Lake Kisezers is a non-tilted plane. For the first time, the lake has an average width of 2.2 km. The greatest depth is 21.5 m, which differs from the literature (Hmax is 4.2 to 7 m) approximately 3 to 5 times. The deepest point of the lake is found in one of the sand-pumping sites. An average depth of 1.99 m, which is less than the value of literature, indicates that the lake has become shallower since previous studies. The length of the shoreline is 38.44 km, which is significantly different from the 42.8 km mentioned in the literature. Differences can be explained by the changes caused by anthropogenic impact near the shoreline including (construction, shore reinforcement). The shore development index is 2.63, which indicates a complex coastline. For the first time, the lake has a Relative depth of 0.98% and volume development of 0.28, where the relative depth indicates the stratification (J.G. Tundisi & T.M. Tundisi, 2012). Summary in Table 1.

In Lake Kisezers, the annual water level fluctuations can be observed even up to 3.17 m, throughout the observation period from 1948 and onwards. Until 2017 the lowest observed water level fluctuation was 0.96 m, which indicates a rapid fluctuation of water level in Lake Kisezers. This results in difficulties to characterize the morphometry of this waterbody.

Both the largest volume and the largest area are occupied by a depth area of 2 – 4 m. After the bathymetric map with isobates every 1 m (map available on request), most areas are occupied by a

Table 1

Lake Kisezers morphometry summary from various researches

Morphometric parameter		Results	Tidriķis, 1995	Kačalova, Kumsāre & Kundziņš, 1962	Slaucītājs, 1935
f (km^2)	Area	16.96	17.38	17.38	17.88
S (km^2)	Island area	0.065	0	0	0.078
P (km)	Maximum width	3.14	3.60	3.60	3.55
L (km)	Length	7.70	8.90	8.90	8.94
Pv (m)	Mean width	2.20	0	0	0
Hvid (m)	Mean depth	1.99	2.40	3	2.40
Hmax (m)	Maximum depth	21.50	4.20	4.20	7.00
l (km)	Shoreline length	38.44	42.80	42.80	42.80
k	Shore development index	2.63	0	2.90	2.90
V (m^3)	Volume	33793429.62	42000000	40809000	40809000
Zr (%)	Relative depth	0.98	0	0	0
Q	Volume development	0.28	0	0	1.01

depth area of 3–4 m and a depth area of 2 – 3 m, which proves that the bathymetric map with isobates every 2 m (map available on request) provides the results that are relevant to the specification. It is mentioned that the largest area occupies a depth of 1 – 3 m (Kačalova, Kumsāre, & Kundziņš, 1962). So it can be concluded that sand mining did not take place before 1962.

Analyzing the changes in the lake coastline using historical cartographic materials, it was found that they are mainly influenced by eutrophication and anthropogenic impact. The greatest changes are seen in areas with the highest proportion of macrophytes and areas, where the anthropogenic load is observed (shore reinforcement, building, pier construction, other construction).

The main factor influencing the Kisezers morphometry and hydrological regime is the Riga HPP and its water level fluctuations, and the considerable flow rate in the Milgravis watercourse. This effect is particularly evident in volumetric and shoreline length changes.

Conclusions

1. Methodology for bathymetric map construction approves its suitability for lake survey repeatability. The research shows that using the latest technology, it is possible to perform high-level morphometry and bathymetry studies, which result in inaccurate data on the depth and dimensions of the waterbody.
2. During the study, it was shown that the bathymetry and morphometry of Lake Kisezers had changed significantly compared to the results of previous studies. Previous studies of the Lake Kisezers morphometry have occurred irregularly. Comparing the results of the previous studies with the results of this study, discrepancies can be observed, resulting in no fixed moment when sand quarries have been created in the lake. The differences in morphometric parameters obtained from the study can be explained by both climate change and anthropogenic effects. Water level changes, the time difference (seasonality) of parameters, such as high or low water level during the depth data measurements, inaccuracy when setting them, for example, marking waterfront shoreline, using obsolete data for calculations, resolution of the cartographic material used in the study.

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IDENTIFICATION OF WET AREAS IN AGRICULTURAL LANDS USING REMOTE SENSING DATA

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Abstract
Wet areas in agricultural lands are usually not fully or properly managed due to problematic accessibility by heavy machinery and are associated with lower crop yields. There are neither studies regarding spatial distribution of wet agricultural areas in Latvia nor large scale soil maps. Being aware of these wet areas, it would be possible to plan actions for effective management of these areas, starting with a scale of landscape. A geographic information system model could serve as an assistant for decision-making, such as, a direct support for the management of amelioration systems, change of land use and management patterns or granting support payments.
Remote sensing data like Sentinel-2 satellite images and LiDAR (Light detecting and ranging) technology can be used to identify local wet areas. The focus of this article is to evaluate different remote sensing indices and methods that can be used to identify wet areas in agricultural lands using open access data and software. From 52 indices, which were analysed with soil moisture field measurements in 33 sample plots, only two of them showed statistical significance in linear regression model ($p<0.05$): normalized height model in resolution of 25 meters ($r^2=0.45$) and visible blue spectral band in April ($r^2=0.39$). Results from this study help to focus on different aspects of remote sensing data usage and methodology for future improvements in order to fully implement LiDAR and Sentinel-2 data for identification of wet areas in agricultural lands.
Key words: Remote Sensing, GIS, LiDAR, Sentinel-2, agricultural lands.

Introduction

Last 50 years have marked significant increase in food growing and production, also in human population, which is predicted to be about 9 billion people in the middle of this century, but the limit is reached where, on global scale, agricultural lands could be expanded at the same rate as demand for the food. This situation leads to a question: how to sustainably produce the amount of food needed (Godfray *et al.*, 2010; Tilman *et al.*, 2002)? H. Godfray and M. Tester highlights in their studies that the best way to address future challenges in agriculture globally is a proper way of land use and management locally, while the knowledge of both farmers and policy makers is one of the key factors (Godfray *et al.*, 2010; Tester & Langridge, 2010).

Soil is one of the most important resources in agriculture – it provides plants with water and nutrients, serves as a habitat for organisms and a place for water storage, supply and purification (Mitchell & Soga, 2005). Wet and poorly drained soils are important for biodiversity (Plantureux, Peeters, & McCracken, 2005), but also are one of the limiting factors to efficiently manage agricultural lands, forests and similar fields (Pearsall, 1950). Information about these areas and their spatial distribution helps to improve the quality of land management and to avoid operational problems, negative environmental impact and additional financial costs (Christensen *et al.*, 1996). Soil science has been widely studied in Latvia, soil classification system has been developed, many books published and agricultural lands mapped in the Soviet times, but there is neither actual information and comprehensive materials on the spatial distribution of soil moisture in Latvia nor large-scale soil maps (Kasparinskis & Kārkliņš, 2018).

As technologies develop, more and more new data sources are used in soil studies. Various remote sensing tools, such as terrain models from laser scanning data, multi-spectrum satellite images, specific modelling tools and hydrological models are used for soil spatial modelling and condition determination worldwide (Minasny & McBratney, 2016). The hydrological conditions may be influenced by many factors and their interaction, but one of the most important factor is the surface topography – both groundwater and surface water flows almost always coincide with the direction and steepness of the slope, following potential energy of gravity of the Earth (Burt & Butcher, 1986; Zinko *et al.*, 2005).

The LiDAR (Light Detecting and Ranging), technology rapidly evolving nowadays, provides more and more possibilities for analysing an area or a study object. LiDAR is similar to a radar, only pulsing light signals are emitted and detected instead of radio waves (Schwarz, 2010). Laser scanning can be performed from different type of machinery, both from airborne (aircrafts, drones, etc.) and terrestrial (cars, rovers, stands, etc.), but almost all of the LiDAR system consists of four main components: a laser, scanner and optics, photodetector, and navigation and positioning system. The operating principle is simple – a laser beam is transmitted to a reflecting surface and the receiving equipment measures the time it returns to the source, in combination with the GPS receiver and the IMU sensor, it is possible to determine the exact relative distance (reflection point) for each light beam (Bellian *et al.*, 2004). LiDAR

Table 1

Characteristics of study sites

Name	Coordinates	Area (ha)	Sample plots	Description of wet conditions
Skriveri1	56.691385, 25.137438	17.6	9	In terrain depressions water accumulates seasonally, in two separate wet areas land is not managed
Skriveri2	56.694682, 25.144385	7.2	6	In terrain depression water accumulates on a long-term basis, land management is difficult (ploughing)
Skriveri3	56.696242, 25.129931	20.2	6	In terrain depression water accumulates on a long-term basis, land management is difficult (ploughing)
Pure1	57.041472, 22.913811	6.7	6	In terrain depression water accumulates seasonally, in wet area land is not managed
Pure2	57.043572, 22.882180	5.8	6	In the river valley water accumulates seasonally, land management is difficult (mowing)
Stende	57.210798, 22.559618	2.1	6	In whole area water accumulates on a long-term basis, land is not managed, partially created drainage system

technology can provide several thousand individual measurements every second, but the number of measurements and their accuracy vary depending on performance and technical parameters of each component. The more accurate and denser the point cloud, the higher quality of the output data and the post-processing capabilities, but for the user it also means higher costs for the equipment, so it is important to choose the appropriate technical specifications for the intended purpose (Dassot *et al*., 2011). The accuracy of high-resolution data in the lower layers can also be significantly affected by vegetation density and swelling, which can hold most laser beams to from reaching ground surface (Moskal *et al.*, 2009).

Similar to LiDAR, another evolving and modern remote sensing data type is multispectral imagery from Sentinel-2 satellites. The main advantage of the use of satellites is temporal resolution, as scenes are available relatively often and long-term monitoring of the site is possible (Alparone *et al*., 2004). Optical satellite sensors capture the electromagnetic beams of the Sun reflected from the Earth's surface within the range of visible light and infrared light, mostly panchromatic, black-and-white or multispectral scenes, producing coloured images from combination of different wavelengths (Deilami & Hashim, 2011). The Sentinel-2 program consists of 2 multispectral satellites operating at the time. Their orbits are synchronized with the movement of the Sun relative to Earth, thereby achieving repeated satellite overflights relative to specific points on Earth at the same time of the day. Such an orbit is essential for reading long-term and constant measurements. The images of different spectral channels are available within a resolution of 10, 20 and 60 meters. The visible lights and close-range infrared scenes are available at a resolution of 10 meters (Drusch *et al.*, 2012).

The aim of this study is to evaluate different indicators from LiDAR point clouds and Sentinel-2 multispectral images using GIS algorithms to process raw data and obtain comparable values to the field data.

Materials and Methods

The study was conducted at six sites in the central part of Latvia, where LiDAR data was available in the year 2018. Study sites were selected according to the survey of the owners where some of the area, seasonally or long-term, is difficult for the land management due to wet conditions or water accumulation. For field work, the boundaries of the study sites were marked by the natural and rural block boundaries, where each site includes both an area with optimal water regime for agriculture and wet area where the land management is difficult. For each optimal and wet area 3 random points were generated, making in total 39 sampling plots (Table 1).

Field Measurements were collected in November 2018. Each sample point was probed with a soil probe (with a maximum depth of 115 cm and the following indicators were identified: an occurrence and depth of reductimorphic colours, depth of groundwater (if reached) and granulometric composition for comparison with old (USSR) soil maps. In addition, soil moisture was measured with *Eijelkamp Penetrologger ThetaProbe* over a two-day period, under similar weather conditions (cloudy days without rain), so that no rapid changes in soil moisture could happen and data would be comparable (Vereecken *et al.*, 2008). Later on, soil sub-type after Taxonomy of Latvia soils was determined (Kārkliņš *et al*., 2009) and various indices from cartographic materials were defined: soil granulometric composition and sub-type from old soil maps (40 years and older); quaternary sediments and density of an amelioration network.

LiDAR point cloud data for this study is acquired from Latvian Geospatial Information Agency with a minimum point density at least 1.5 points per m^2,

average horizontal point error is 0.36 meters and vertical accuracy 0.12 meters. Each point cloud data covers 1 km^2 wide area and is already pre-classified. For each study site digital elevation models (DEM) were created from 4 to 12 raw data cells (1-2 central cell containing study area and buffer zone) for precise hydrological runoff modelling. Digital elevation model was created in GRASS GIS 7.4.2 application where point clouds in *.las* format were imported (using only ground surface class from point cloud data), empty cells filled with *r.fillnulls* tool (using *bicubic* method), point clouds were merged with *r.patch* tool and DEM was exported in 2, 5, 10 and 25 meter resolutions in *GTiff* format for further processing in QGIS 3.4.3. In addition, DEM with a resolution of 2 meters was processed in WhiteboxGIS 3.4 where with a tool *Burn Streams at Roads* ditches were smoothened for regular stream network (simulating culverts under the roads). In QGIS, a digital elevation model in all resolutions was processed with several SAGA GIS tools. Using a *Relative heights and slope* tool a normalized height model was made, which shows differences in local topography (Böhner & Selige, 2006) more clearly. Terrain depressions were filled with a *Fill sinks* tool (a raster map of depression depth was generated by extracting original DEM from filled), the depression map shows areas in the terrain where water could accumulate (Wang & Liu, 2006). Using a *Slope, Aspect, Curvature* tool steepness of the slope was calculated. As a slope of the surface increases, the risk of water accumulation decreases, but water accumulation increases at the bottom of the slope, especially if a negative relief is formed on which the water flows from the surrounding area (Beven & Germann, 1982). The catchment area (with *Catchment area* tool) shows the size of the area from which each cell receives surface water runoff, which allows to distinguish smooth water flows in the terrain model from the highest to the lowest point (O'Callaghan & Mark, 1984). Using *SAGA Wetness Index* and *Topographic Wetness Index (TWI)* tools two wetness indexes were modelled. As the end result of both models are indexes without set values, a *Raster normalization* tool (in a scale 1 to 10) was used for comparison both models and study areas. TWI in different studies have shown good results to determine moisture conditions in different areas, but it is not suited for flat areas and resolutions of digital elevation model higher than 25 meters (Case *et al*., 2005; Sørensen & Seibert, 2007). Topographic wetness index simulates the water flow as a thin layer moving from cell to cell, whereas SAGA index algorithms focus on the vertical cell distances relative to adjacent water objects and streams (Böhner *et al*., 2001).

Sentinel-2 multispectral imagery data for this study is acquired from European Space Agency using all available bands at best spatial resolution of 10 meters: (B2) visible blue spectral band, (B3) visible green spectral band, (B4) visible red spectral band and (B8) near infrared spectral band (Immitzer, Vuolo, & Atzberger, 2016). Although imagery from Sentinel-2 is available regularly, most of the scenes are covered with clouds, especially in spring and autumn seasons. Normalized Difference Vegetation Index (NDVI) is calculated from near infrared spectral band (NIR) and visible red spectral band (VIS) mathematically in Formula 1 (Pettorelli *et al.*, 2005):

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)} \quad (1)$$

To combine processed layers in GIS with field data, a *Point sampling tool* in QGIS was used for statistics of sample points. In total, 52 indices were generated (32 from LiDAR point clouds and 20 from Sentinel-2 multispectral imagery). The soil moisture measurements (%) were selected as the best parameter from field work for data comparison. Pearson's correlation coefficient was calculated for each data pair, then the indices with best results were used in a linear regression model for determination of statistical significance in the program R. In addition, all quantitative data was analysed by principal component analysis (PCA) in PC-Ord 5.0.

Results and Discussion

Among the surveyed 39 sample plots, only in 8 plots soil sub-types today coincide with the USSR soil maps. Results suggest that old soil maps nowadays serve as an approximate informative material. Soil sub-type and granulometric composition are influenced by time (soil processes), scale of map and methodology. The main differences between USSR soil maps and the results from field works are the higher proportion of podzolification process and lower soil moisture conditions.

After selecting indices with higher correlation coefficients and statistical significance in a linear regression model ($p<0.05$) only two of the GIS based parameters show connection between measurements of soil moisture: a normalized height model in resolution of 25 meters ($r^2=0.45$) and visible blue spectral band in April ($r^2=0.39$), yet the correlation between data is not high. Normalized height in resolution of 25 meters shows that this is suitable scale to analyse study sites at corresponding areas. The noise of high-resolution data does not interfere, yet local elevations and depressions are still visible and show the best correlation with surveyed wet areas on fields.

Different studies show that from indicators like a slope, SAGA wetness index and NDVI it is possible to get high-quality results for identification soil moisture

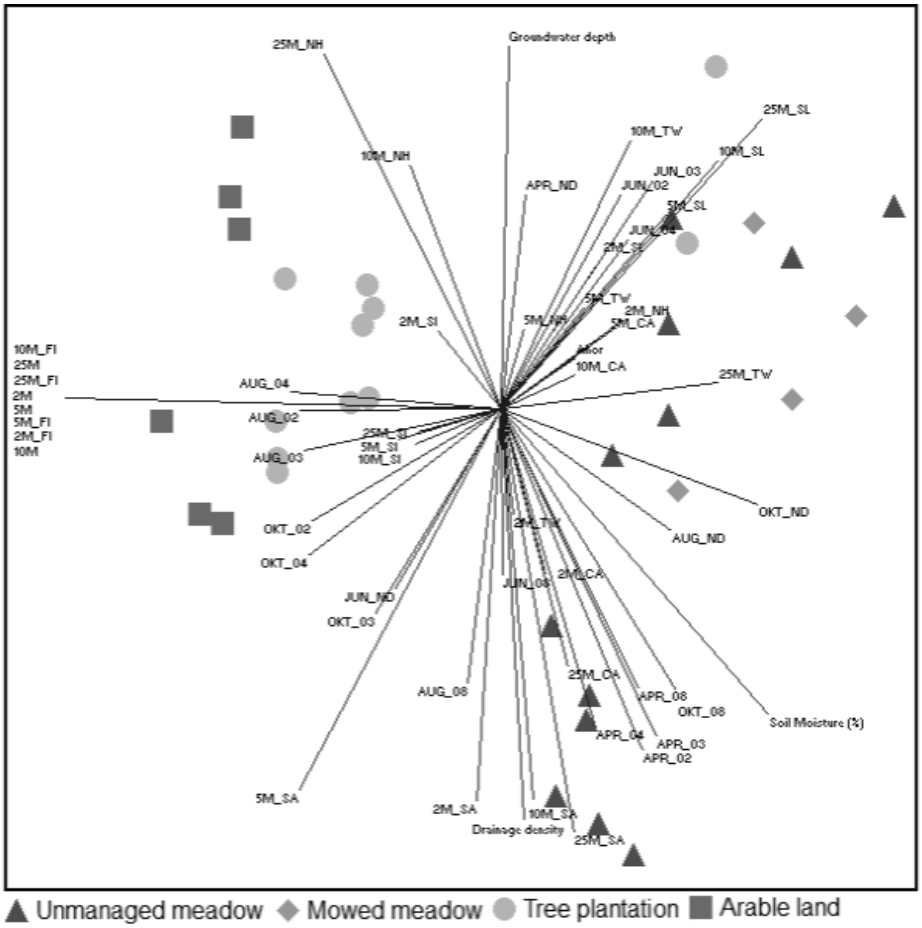

Figure 1. Quantitative measurements from GIS models and field work in principal component analysis.

in forestry (Ivanovs & Lupikis, 2018) and agriculture (McCoy, Asner, & Graves, 2011), but the methodology of sampling points and field measurements should be corrected. At this moment, the results are significantly affected by each study site and their local conditions. In other studies, Compound Topographic Index (CTI) (Higginbottom *et al.*, 2018), Soil Wetness Index (SWI) (Murphy, Ogilvie, & Arp, 2009) from LiDAR data, and Empirical Standardized Soil Moisture Index (ESSMI) (Carrão *et al.*, 2016) from multispectral satellite imagery that could be used for developing current research show good results at high-resolution soil wetness mapping.

Results from principal component analysis show similarities with linear regression models. First of all, there is a close negative relationship between soil moisture and normalized height models (higher in 25 m and lower in 10 m resolutions) meaning that lowest areas in a local terrain also can show wet areas. Results show that the raw data in summer months is not appropriate for soil moisture identification as different crops show different values. Data should be analysed (classified) by the type of crops and usually there is not visible water accumulation on the fields, whereas the best correlation is in scenes from April and October before and after active vegetation period. Results show the time frame on which imagery data it would be necessary to focus on to develop this research (Figure 1).

Results of this study suggest that there is much to implement for future development of this research. First of all, implementing more study sites and more sample plots in each study site is necessary for objective data analysis; secondly, focusing on the percentage of soil moisture as the main indicator of wet areas, using more measurements in every sample plot and calculating average; thirdly, expanding research and calculating specific moisture indexes, which have shown good results in other studies: Compound Topographic Index (CTI), Soil Wetness Index (SWI) and Empirical Standardized Soil Moisture Index (ESSMI).

Conclusions

To use old soil maps, developed more than 40 years ago, in order to get an overview about soil wetness conditions is inappropriate. Soil sub-types over the time have changed, mainly reduced humidity

conditions have been observed. As technologies like LiDAR and satellite imagery are rapidly developing, different studies show that it is possible to define wet areas with high accuracy.

The results from this study are not as high as expected and other studies have shown, but two of calculated indices show statistically significant results and with better study site and sample plot design it should be possible to obtain better results for usage in wet soil prediction models.

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ANALYSIS OF DIFFERENT APPROACHES TO REAL ESTATE APPRAISAL

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Abstract
The traditional valuation of real estate in the field of civil engineering did not include the uncertainty of human behaviour, which cannot be explained by the traditional approach. There are different valuation methods for real estate appraisal, which are basically classified into three groups as a classic, statistical and advanced. In this article, we estimated the different housing price models using the sample of 37 residential apartments in Riga, Latvia, October 2018. In order to evaluate if there is a possible association between the variables involved in relation to the property price, the analytical data were analysed by correlation analysis, analysis of variance (ANOVA), regression analysis, covariance analysis (ANCOVA), principal component analysis (PCA) and cluster analysis. The models estimation results show that using ANCOVA models for the prices forecasting the model fitting to data is less than 58%. The preliminary results of this study suggest that the estimated properties can be distributed in 4 groups, depending on number of rooms, area and age. In addition, the decision tree was created based on algorithms (J48) and a preliminary definition of the best rules was made. The decision tree presents an accuracy of 84% with 31 accepted instances for a total of 37 currently classified instances.
Key words: regression analysis, civil engineering, fuzzy logic, decision tree, appraisal real estate.

Introduction

Real estate appraisals are very important and are especially necessary for asset valuation, property taxes, insurance estimates, sales or rent transactions, risk analysis, estate planning, litigation and are relevant to government or investor decision making. Housing prices depend not only on various economic indices but also on the impact of other factors such as natural disasters, wars, market speculation, environmental variables (Aderibigbe & Chi, 2018). There are different valuation methods for real estate appraisal (Yeh & Hsu, 2018), however, in some types of real estate appraisals, a problem arises in determining real estate values.

For example, using the method of linear or nonlinear multiple regression, the problem of multicollinearity is actual, when predictor variables in the model are correlated with other predictor variables (Wheeler & Tiefelsdorf, 2005). (Dantas *et al.*, 2007) clarifies that there may be a problem of price estimation in real estate in the case of the use of traditional econometric methods, because the results tend to be biased, inefficient or inconsistent, given the neglect of spatial effects in the data. The same authors proposed a study considering the use of spatial econometrics. In this study, it was concluded that positive spatial autocorrelation in the data, although the negotiations of real estate purchase does not occur independently, as considered in the model of hedonic prices, there is an interaction between these prices, so that a negotiation of a real estate/apartment for a high price will generate a growing influence on the prices of neighbouring properties.

On the other hand (Wheeler *et al.*, 2014), it makes clear that in the case of spatial structure choice, this affects the interpretation of the parameters for the variables with which it is correlated, that is, it is also a type of multicollinearity. Therefore, the noncritical use of spatial econometrics may cause problems in the interpretation of individual parameters. Another possible solution would be to weaken multicollinearity by constructing Bayesian models that use variable coefficient processes to model non-constant linear relationships between variables (Gargallo, Miguel, & Salvador, 2017). According to (Yeh & Hsu, 2018) the traditional statistical method, basically, the type and measure of the variable define the most suitable model for use. The traditional valuation model is based on the hedonic model to estimate housing prices (Gargallo, Miguel, & Salvador, 2017).

On the other hand, the advanced method (Smętek & Trawiński, 2011) is related to fuzzy logic (Zadeh, 1978), artificial intelligence, decision tree allied to artificial learning algorithms (Eibe, Hall, & Witten, 2016). Although there is a limited number of studies on fuzzy logic for the real estate industry, there is a strong tendency for improvements related to the process of knowledge representation through fuzzy logic, supported by computational tools (Hüllermeier, 2015). In this case, when there are scattered data, the fuzzy model demonstrates a capacity for analytical compatibility with the problem (Zadeh, 1978). Moreover, fuzzy logic contemplates the subjectivities of the variables involved, the imprecision and uncertainty of human expression. Fuzzy logic is due to the need to consider subjective, ambiguous, and imprecise aspects that are difficult to measure to determine the value of a property. Nevertheless, the use of fuzzy logic is an alternative, there are observed factors that may be slowing the progress of this implementation in the area of real estate valuation. This fact is related to the number of fuzzy rules generated by the model. These rules grow geometrically, directly proportional to the number of attributes selected for

property valuation. However, this does not seem to be a problem, but a solution.

In this way and without losing the scientific character of the traditional evaluation, the proposal follows with the help of the decision tree allied to the algorithms of artificial learning. Accordingly (Eibe, Hall, & Witten, 2016), the association generates rules that describe the most relevant patterns present in the data. These rules are composed of precedents and consequents, this choice of rules promotes a discovery of patterns of behaviour. This behaviour will indicate that the proposed fuzzy model will present behaviour in the data processing of the two groups, and standard deviation and deviation percentage within a similar range. Therefore, there are some situations in practice where the option to adopt the hedonic method, so to speak, binary logic is not always the best solution to determine the market value of a property. Because there is a possibility of appearance of disagreement in the fullness of estimating some real estate prices. In addition, each country has different cultural and socio-economic structures. This particularity results in the difficulty of defining a world standard. But from this, possible price misunderstandings should be avoided.

Thus, an important point was the definition of real estate value determined by the International Council of Evaluation Standards (IVSC), whose definition reaches international acceptance. In addition, the need to seek a more palpable solution to the process of evaluating buildings is exacerbated by daring projects. In addition, changes in the construction production chain, including products, suppliers, materials and a process can significantly improve environmental efficiency and the economy during construction used in life cycle assessment (Surgelas, Marques, & Rodrigues, 2010). Thus, according to Baumane (2011) to implement an evaluation process, the object of this evaluation must be clearly defined, then choose the evaluation method. This research advances in the study of the problem and seeks an alternative for the forecasting of prices in the evaluation of real estate. Although there is a traditional method and literature deals with such techniques, there is controversy over which one would bring the best performance and with a greater degree of facility and clarity. Therefore, this controversy is due to the difficulty in finding adequate predictors because they often do not fit into the binary model.

The aim of the article is estimating different housing price models using the sample of 37 residential apartments in Riga, Latvia, October 2018 in order to evaluate if there is a possible association between the variables involved in relation to the property price. Furthermore, this article is part of the thesis in progress and is structured in 3 step: – Step 1, sample collection and statistical treatment based on binary logic. – Step 2, decision tree, and step 3, a creation of the fuzzy model with analysis validation of the results.

In the first step, the present study opted for the hedonic method to estimate apartments' prices, since this model is the technique most used by civil engineering professionals. Due to the emergence of multicollinearity, we have chosen to find more adequate regression models that relate the response variables to the variables involved in the property valuation analysis. Thus, property prices based on the physical characteristics and location of the property were analysed through correlation analysis, ANOVA analysis, regression analysis, covariance analysis (ANCOVA), analysis of major components (PCA) and cluster analysis. To evaluate the market price of the appraised apartment. In order to evaluate the price forecasting accuracy, the following three distance metrics are used: root mean squared error (RMSE), mean absolute error (MAE) and mean absolute percent error (MAPE). While both MAE and RMSE are simply measures of discrepancies between the predicted values and the actual observations, MAPE measures scaled discrepancies at each time interval (Ahn *et al.*, 2012). Finally, a decision tree based on algorithms and preliminary definition of the best rules (Tobergte & Curtis, 2013) was created. The hedonic model was used in this research to estimate housing prices, since this method is considered the most used (Gargallo, Miguel, & Salvador, 2017) and incorporated in the international standards of evaluation (IVS) and in the European evaluation standards (EVS) as an approach that estimates a market value. This method has been criticized due to the problems of multicollinearity in the estimation of the parameters, which are due to the very similar characteristics of the houses in the same area, which makes it difficult to estimate the regression coefficients (Bárcena *et al.*, 2014).

Materials and Methods

This article is related to improvements in the real estate valuation process. In this first step the different housing price models are estimated using the sample of 37 residential apartments in Riga, Latvia, October 2018 in order to evaluate if there is a possible association between the variables involved in relation to the price of the property. The selection of random samples occurred through a direct comparison of market data of similar elements in relation to the intrinsic and extrinsic characteristics of the property, and availability in the worldwide computer network. As for the research structure, the variables that are, in principle, relevant for explaining the formation of values and the supposed relations between them and the dependent variable are chosen. In relation to the quality of the data surveyed, this study opted

for: Latvian Government Office, http://liaa.gov.lv/en/business-latvia/real-estate-market-research; Colliers International Group Inc. State Land Service; The Real Estate Company, http://www.arcoreal.lv/en; others, such as https://city24.lv, and experience of own researcher in the formation of value. In this first step stage, the present study opted for the hedonistic method to estimate housing prices, since this model is the technique most used by civil engineering professionals. Based on existing theories, acquired knowledge, common sense and other attributes, the dependent variable *Y* is housing price (EUR m^{-2}) and following factors or independent variables were chosen: an area (m^2), apparent age (new(1), renew(2), old(3)), apartment conservation (new(1), renew(2), old(3)), building conservation (new(1), renew(2), old(3)), number of rooms (2) or (3), car parking (inside build(1), outside build(2), no parking(3)), sunlight = insolation (direct(1), not direct(2)), heating inside the building (individual(1), share(2)), environmental variable or park_river (near(1), far(2)).

The research design consists of the following steps:

1. check the qualitative factors significance for housing price by one-way ANOVA model,
2. check the quantitative factor of area (m^2) significance for housing price by simple regression analysis,
3. check the ordinal scale factors multicollinearity by Spearman correlation analysis,
4. check both the quantitative factor of area (m^2) and qualitative factors significance for housing price by ANCOVA model,
5. get the new uncorrelated principal components from correlated factors by PCA,
6. using the new uncorrelated principal components check the housing price model significance by regression analysis,
7. evaluate the price forecasting accuracy using mean absolute percent error (MAPE),
8. define similar groups of real estates by cluster analysis,
9. check the housing price model using the decision tree model based on algorithms (J48-data mining algorithms) and define the best association rules.

The present study uses the variable price (Y) and area logarithmic transformation to avoid possible misunderstandings in the results. The decision to transform dependent variable into *LnY* is made to test the dependent variable *Y* in the absolute term (Euro m^{-2}), to change in the relative term (%). This is because the use of logarithms of dependent or independent variables may allow nonlinear relations between the explained variable and the explanatory variables. Thus, estimates using logs are less sensitive to unequal (or extreme) observations because of the considerable narrowing that may occur in the amplitude of variable values. Thus, the test result may indicate whether to reject or not to reject the null hypothesis that the data comes from a normally distributed population.

Results and Discussion

The limitations of this model are presented, by different models of housing prices were found using samples from 37 residential apartments in Riga, Latvia. To determine if any of the differences between the means for different price groups, at the 1st stage the one-way ANOVA was made, show, that the factors such as apparent age, apartment conservation, building conservation, car parking, sunlight (insolation), heating inside the building and environmental variable are significant with P=95%, but the factor like the number of rooms is significant with P=85%, for the models, where dependent variable is Y or LnY. At the 2nd stage the simple regression analysis was made to check if the area factor is significant or not for the housing price using logarithmic transformation. As a result, it was concluded that the area factor is significant with P=95%, but the determination coefficient R^2=10.2% shows, that the model cannot be used for price forecasting. From previous data analysis it can be concluded, that all factors are significant, but the one-factor models are not enough for price estimation. So, the next step is the model transformation or additional factors should be putted to the model. At the 3rd stage the factors such as apparent age, apartment conservation, building conservation, number of rooms, car parking, sunlight or (insolation), heating inside the building and environmental variable were checked to the problem of multicollinearity using Spearman correlation analysis (Table 1). All factors correlate among themselves, except rooms, so there is the problem of multicollinearity and it is not possible to put these factors together, except rooms, at the same model.

At the 4th stage the quantitative factor of area (m^2) and two qualitative factors and its interaction effect significance for housing price by ANCOVA model were checked, where one of the qualitative factors is number of rooms (Table 2). The best model includes the factors of area (m^2), number of rooms, apparent age, interaction effects of number of rooms × apparent age and area (m^2) × apparent age, but the determination coefficient R^2=58% show, that model canno't be used for price forecasting. The decision is that: the best model is Y: Area + Room + Age + Room × Age + Area × Age or LnY: LnArea + Room + Age + Room × Age + LnArea × Age.

Figure 1 illustrates the ANCOVA graphical analysis, for example, the price: rooms + age shows

Table 1

Spearman rho, correlation analysis

variables	age	consv ap	consv build	rooms	parking_1	insolation	park_river
consv ap	0.822 0.000	–	–	–	–	–	–
consv build	0.507 0.001	0.697 0.000	–	–	–	–	–
rooms	0.180 0.285	-0.067 0.692	-0.239 0.154	–	–	–	–
parking_1	0.870 0.000	0.819 0.000	0.456 0.005	0.153 0.367	–	–	–
insolation	0.064 0.707	0.143 0.397	0.291 0.081	-0.175 0.299	0.072 0.671	–	–
park_river	0.198 0.240	0.358 0.029	0.291 0.081	-0.175 0.299	0.175 0.301	0.630 0.000	–
heating	0.470 0.003	0.469 0.003	0.436 0.007	-0.017 0.920	0.388 0.018	0.549 0.000	0.549 0.000

Cell Contents: Spearman rho
P-Value

Table 2

The ANCOVA analysis

Model	Area	Room	Age	Room × Age	Area × Room	Area × Age	Determination coefficient (%)
Y: Area + Room + Age + Room × Age + Area × Room + Area × Age	0.584	0.346	0.010	0.000	0.614	0.017	58.61
Y: Area + Room + Age + Room × Age + Area × Age	0.748	0.065	0.009	0.000	–	0.015	58.21
LnY: LnArea + Room + Age + Room × Age + LnArea × Room + LnArea × Age	0.573	0.747	0.078	0.005	0.815	0.084	53.11
LnY: LnArea + Room + Age + Room × Age + LnArea × Age	0.599	0.155	0.051	0.004	–	0.057	53.01
Y: Area + Room + Parking + Room × Parking + Area × Room + Area × Parking	0.311	0.715	0.330	0.431	0.491	0.470	30.10
Y: Area + Room + Parking	0.274	0.709	0.047	–	–	–	24.52
LnY: LnArea + Room + Parking + Room × Parking + LnArea × Room + LnArea × Parking	0.432	0.917	0.334	0.395	0.851	0.370	33.73
LnY: LnArea + Room + Parking	0.266	0.637	0.033	–	–	–	27.43

that for an apartment with 2 and 3 rooms and with a new age (1) the price of the apartment will decrease as the number of rooms increases. However, for an apartment in the renovated situation (2) the process is reversed. Thus, for an apartment with 3 renovated rooms the price of this property reaches a reasonable amount compared to the apartment with 2 renovated rooms. And in the situation where both are old (3) the price difference is not much different.

At the 5th stage the Principal Component Analysis (PCA) was made for correlated 8 factors of apparent age, apartment conservation, building conservation, number of rooms, car parking, sunlight, heating inside the building and environmental variable to get new uncorrelated principal components PC for the next regression analysis. The total explained data variance, using 4 new uncorrelated factors is 81.4% (Table 3). The first PC can be explained as *comfortability* factor, which is highly correlated to the factors of car parking, apparent age and apartment conservation. The second PC can be explained as *insolation* factor, which is highly correlated to the factor of sunlight (or

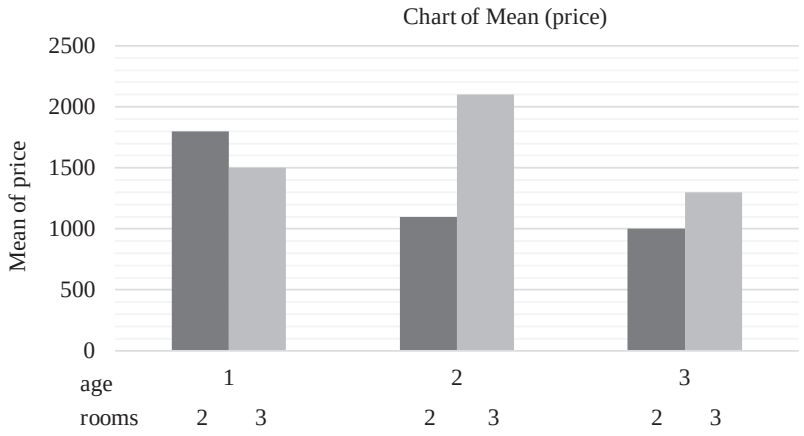

Figure 1. ANCOVA analysis graphs.

Table 3

PCA analysis – Sorted Rotated Factor Loadings and Communalities

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
parking_1	0.941	0.000	0.000	0.000	0.000	0.000	0.000	0.000
age	0.892	0.000	0.000	0.000	0.000	0.000	0.000	0.000
consv ap	0.803	0.000	0.000	0.000	0.000	0.000	0.000	0.000
insolation	0.000	0.916	0.000	0.000	0.000	0.000	0.000	0.000
rooms	0.000	0.000	0.986	0.000	0.000	0.000	0.000	0.000
park_river	0.000	0.000	0.000	0.907	0.000	0.000	0.000	0.000
consv build	0.410	0.000	0.000	0.000	-0.874	0.000	0.000	0.000
heating	0.000	0.000	0.000	0.000	0.000	-0.867	0.000	0.000
Variance	2.5998	1.0428	1.0372	1.0325	1.0282.	0.9523	0.1571	0.1501
% Var	0.325	0.130	0.130	0.129	0.129	0.119	0.020	0.019
CumulativeVar	0.325	0.455	0.685	0.814	–	–	–	–

Table 4

Factor Score Coefficients - Formulas to calculate new uncorrelated factors

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
age	0.472	0.066	-0.081	-0.031	0.220	0.135	-0.782	2.084
consv ap	0.205	0.062	-0.008	-0.085	0.153	0.087	2.423	-0.332
consv build	-0.297	-0.108	0.164	0.035	-1.366	0.118	-0.675	-0.093
rooms	-0.139	0.056	1.068	0.097	-0.242	0.062	0.236	-0.161
parking_1	0.647	0.043	-0.080	-0.035	0.247	0.125	-1.019	-1.574
insolation	0.064	1.319	0.048	-0.388	0.121	0.324	0.318	0.225
park_river	-0.072	-0.372	0.079	1.316	-0.043	0.233	-0.483	0.066
heating	-0.186	-0.271	-0.036	-0.205	0.112	-1.384	0.098	-0.253

Factor 1: parking_1, age and consv_ap (comfortability) = 0.472×age + 0.205×consv_ap – 0.297×consv_build - 0.139×rooms + 0.647×parking_1 + 0.064×insolation – 0.072×park_river – 0.186×heating;

Factor 2: insolation = 0.066×age + 0.062×consv_ap – 0.108×consv_build + 0.056×rooms + 0.043×parking_1 + 1.319×insolation – 0.372×park_river - 0.271×heating;

Factor 3: rooms = – 0.081×age – 0.008×consv_ap + 0.164×consv_build + 1.068×rooms - 0.080×parking_1 + 0.048×insolation + 0.079×park_river - 0.036×heating;

Factor 4: park_river = – 0.031×age - 0.085×consv_ap + 0.035×consv_build + 0.097×rooms - 0.035×parking_1 – 0.388×insolation + 1.316×park_river - 0.205×heating.

Table 5

Summary Model description and determination coefficient R^2

Models	R^2 (%)
• Three-factors ANCOVA	------
Y: area + room + age + rooms×age + area×age	58.21
LnY: LnArea + rooms + age + rooms×age + LnArea×age	53.01
• Two-factors ANCOVA	------
Y: area + parking_1	24.18
LnY: LnArea + parking_1	26.92
• Two-way ANOVA	------
Y: rooms + parking_1	21.59
LnY: rooms + parking_1	24.53
• Regression models with PCA	------
Price (Y): F1 + F2 + F3 +F4	29.98
LnPrice (LnY): F1 + F2 + F3 +F4	34.47
Price (Y): area + F1 + F2 + F4	29.79
LnPrice (LnY): LnArea + F1 + F2 + F4	34.87

insolation), the third PC can be explained as *rooms' factor*, which is highly correlated to the factor of number of rooms and the fourth PC can be explained as *environmental factor*, which is highly correlated to the factor of park_river. And the formulas to calculate new uncorrelated factors are shown in (Table 4).

At the 6th stage the multiple regression models were analysed with new four uncorrelated PC (comfortability, insolation, rooms and environment) and fifth factor of area. To avoid the problem of multicollinearity, the Pearson correlation analysis was made and concluded, that area factor is correlated with rooms' PC (r=0.755). Thus, the following 4 models were analysed:

- *LnY* or *Y* (housing price) depending on comfortability, insolation, rooms and environment,
- *LnY* or *Y* (housing price) depending on area, comfortability, insolation and environment,

but the determination coefficient for all models is less than 35% and canno't be used for price forecasting.

Moreover, the table 5 shows the following a summary for ANCOVA; two-way ANOVA; Regression analysis with PCA. The decision model description: the most appropriate model is:

Models: Price Y: area + room + age + room×age + area×age with determination coefficient R^2 (58%).

The Regression Equation results:

rooms	age	equation
2	1	price = 739 + 17.2 area
2	2	price = 2213 – 23.83 area
2	**3**	**price = 430 + 12.58 area**
3	1	price = 277 + 17.2 area
3	2	price = 4069 – 23.83 area
3	3	price = 295 + 12.58 area

At the 7th stage the price forecasting accuracy using mean absolute percent error (1) was made.

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left(\frac{Y_t - \bar{Y}_t}{Y_t}\right)^2 x\ 100 \qquad (1)$$

For model forecasting evaluation MAPE = 10%, and according (Ahn *et al*., 2012) it means that on average the difference between actual and theoretical model is 10% (reasonable and within the normality of this case study). Then, at this stage of the analysis, it is possible to propose an example to quantify the value of the square meter of the appraised apartment.

At the 8th stage similar groups of real estates, using factors of area, room and age were found by cluster analysis for 37 real estates: 1st cluster consists of real estates with average area in 88.9 m^2, 3 rooms and age renew (2) or old (3); 2nd cluster consists of real estates with average area in 70.8 m^2, 3 rooms and age new (1) or renew (2); 3rd cluster consists of real estates with average area in 54.5 m^2, 2 rooms and age new (1) or renew (2); 4th cluster consists of real estates with average area in 41.2 m^2, 2 rooms and age renew (2) or old (3).

At the last stage the similar groups a decision tree based on algorithms (J48) and preliminary definition of the 10 best and the association rules were preliminarily chosen by algorithmic 'apriori' with accordance 83.78% (84%):

1. Price_category=1 16 → park_river=2 16 <conf: (1)> lift: (1.48) lev: (0.14) [5] conv: (5.19)
2. Price_ category=1 16 → heating=2 16 <conf: (1)> lift: (1.32) lev: (0.11) [3] conv: (3.89)
3. heating=2 Price_ category=1 16 → park_river=2 16 <conf: (1)> lift: (1.48) lev: (0.14) [5] conv: (5.19)

4. par_river=2 Price_ category=1 16 → heating=2 16 <conf: (1)> lift: (1.32) lev: (0.11) [3] conv: (3.89)
5. Price_ category=1 16 → park_river=2 16 heating =2 16 <conf: (1)> lift: (1.61) lev: (0.16) [6] conv: (6.05)
6. parking_1=3 heating=2 15 → age=3 15 <conf: (1)> lift: (2.18) lev: (0.22) [8] conv: (8.11)
7. insolation=2 Price_category=1 15 → park_river=2 15 <conf: (1)> lift: (1.48) lev: (0.13) [4] conv: (4.86)
8. insolation=2 Price_category=1 15 → heating=2 15 <conf: (1)> lift: (1.32) lev: (0.1) [3] conv: (3.65)
9. insolation=2 heating=2 Price_category=1 15 → park_river=2 15 <conf: (1)> lift: (1.48) lev: (0.13) [4] conv: (4.85)
10. insolation=2 park_river=2 Price_category=1 15 → heating=2 15 <conf: (1)> lift: (1.32) lev: (0.1) [3] conv: (3.65)

Conclusions

The limitations of this model are presented by different models of housing prices that were found using samples from 37 residential apartments in Riga, Latvia. This study found the existence of an association between the variables involved in relation to the price of the property. Then, after the entire analysis process as the result the most appropriate ANCOVA model was defined, where three factors (property area in m^2, number of rooms, property age as old, renew or new) and two factors interactions effect (number of rooms × property age and property area × property age) are included in the model. The estimation of the model shows that the coefficient of determination R^2 is 58% of the price change was explained by the property price forecast using the factors included in the model. The preliminary results of this study suggest that the estimated properties can be distributed by 4 groups: renew or old properties with average area 88.9 m^2 and 3 rooms; new or renew properties with average area 70.8 m^2 and 3 rooms; new or renew properties with average area 54.5 m^2 and 2 rooms; renew or old properties with average area 41.2 m^2 and 2 rooms. The association rules were generated by the algorithm that preliminarily listed 10 best rules. The decision tree presents an accuracy of 84% with 31 accepted instances for a total of 37 currently classified instances, and finally, the third and final step is to establish a fuzzy logic model using the 10 best association rules created by the *apriori* algorithm. algorithms for learning/data mining), according to the results of the regression equation described above. In order of hand, the purpose of this article is to estimate the different models of the price of housing and, for example, if you have an apartment with rooms = 2 and age = 3 and area = 45 m^2, then the theoretical price is $Y = 430 + 12.58 \times 45m^2$. In step 1, it is possible to say that of this estimated value (Y) there is an acceptable margin of 10% for negotiating the apartment. And finally, the relationship involving human behavior in the valuation of the property will be applied in the last step 3 and will approach the Fuzzy Logic to estimate the market price of the apartment and thus compare with the values obtained in the traditional binary technique. The quality of the evaluation will depend on the quality of the information available to prepare it.

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GEOPARKS IN CULTURAL AND LANDSCAPE PRESERVATION CONTEXT

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Abstract
Society aims to develop frames for recognizing important geological and geomorphological sites and features or landscapes within their national and even transnational boundaries. Earth heritage sites educate the general public and preserve cultural and environmental matters. New trends of sustainable development, importance of site conservation are demanding that landforms and landscapes, rocks, minerals, fossils, soils should be protected legally, as they give understanding about the evolution of Mother Earth in local and regional context to generations. The Geopark concept was developed in cooperation with UNESCO and followed a large number of requests to UNESCO from all over the world, from geological institutions and geoscientists and non-governmental organizations, and it became extremely popular and influential to preserve those geological heritage areas, nowadays still recognized only nationally or not at all. This paper aims to give comprehensive overview of existing geoparks in the Baltic Sea Region, as well as analyze aspiring geoparks and unpublished initiatives of potential geopark (Livonia and Vooremaa) eventual establishment in frames of cultural and landscape preservation context. Criteria, requirements and earlier studies are given in context. The geoparks should mainly contain cultural and educational purpose while targeting the least possible damage in preservational aspect.
Key words: geoparks, natural heritage, industrial heritage, Swedish Institute, landscape aesthetics, landscape didactics.

Introduction

The UNESCO headquarters in Paris held an important meeting on February 13, 2004 to work on 'Operational Guidelines for National Geoparks seeking UNESCO's assistance'. Then 'UNESCO Network of National Geoparks' was born (Ólafsdóttir & Dowling, 2014; Sinnyovsky, 2014). It creates a unified platform for collaboration among experts and practitioners in order to preserve and popularize for wider audience geological heritage matters under the powers of UNESCO. Common values are shared by various participants all over the world. Strategy and best practices are shared and developed for the preservational context including the landscape and cultural issues. Sustainable preservation of the geological and geomorphological heritage has a crosspoint with preservation of industrial heritage as well where the mining regions are situated. Geological and geomorphological monuments very often have a cultural value from immemorial times as objects being treated in folklore and thus becoming cultural monuments of nationwide importance (Wójtowicz *et al.*, 2011; Fassoulas & Zouros, 2010; Azman *et al.*, 2010). Since United Nations Conference on Environment and Development held in Rio de Janeiro, 1992, the Agenda of Science for Environment and Development into the 21st Century was accepted. UNESCO, the United Nations Organisation for Education, Science and Culture set two frameworks: the World Heritage Convention and bilateral cooperation through Division of Earth Science activities. World Heritage Committee identifies and monitors places to be put on the World Heritage List. Criteria are extremely strict: 'universal value areas of conservation of geological and threatened species'. Just to name a few, Grand Canyon, the Hawaii Volcanoes, Yosemite-National Park, the Aeolian Islands in Italy, Lake Baikal, the Kamchatka Volcanoes and many others (more than 800) are recognized on the World Heritage List. The World Heritage List will have up to 1500 sites (cultural plus natural). On the other hand, the Geopark concept was developed on request of geological institutions and geoscientists as well as non-governmental organizations, pinpointing the need for additional category that helps preventing and popularizing geological and geomorphological, natural and sinergical cultural values. Promoting regional sustainable development, research and training, educational values are of the paramount importance in the concept (Fassoulas *et al.*, 2007).

Geodiversity – the one of pillars for the geopark existence and creation shall be used for scientific, educational, as well as tourism, providing precious resource and requiring efficient exploitation for production of socio-economic benefits (Ruban, 2017). Geoparks may contain ancient cultural objects as well as areas of economic and industrial activities; therefore, it is important to raise awareness of the society living there and the people coming there as of recreational and educational needs. Stakeholder

active involvement is crucial (Brown *et al*., 2012). Since United Nations Conference on Environment and Development, stakeholders such as decision makers, scientists, planners, and the general public have all approved the need for comprehensive approach for saving the heritage in context of sustainable environment, economics and culture values. Holistic approach would incorporate protection of geological heritage with economic renewal and education / research promotion. It was already recognized in 1991 with Digne Declaration that was the first widely – recognised statement of the background to geoconservation. Rome International Conference on Geoconservation in 1996 and the European Association for Conservation of the Geological Heritage (ProGEO) proposed that UNESCO should create geological heritage preservation places as Geosphere Reserves. UNESCO has developed this proposal (Ólafsdóttir & Dowling, 2014; Sinnyovsky, 2011) and new internationally recognised label 'UNESCO Geopark' was born, destined to become synonymous to environmental protection and development. The idea was to add around 20 recognized geopark areas around the world each year. According to UNESCO, today there are 140 Global Geoparks in 38 countries (UNESCO Global Geoparks, 2017).The Division of Earth Sciences of UNESCO taking initiatives together with International Union of Geological Sciences (IUGS) and authorities (governments) added the idioms of 'geotopes', 'geosites', or general geological heritage. Relationship among people and earth history is in the center of the paradygm of geoparks. Geoparks do not add additional protection status to existing areas: however, they help earth history sites or areas to be used as for sustainable economy promotion in concert with tourism and educational promotion. It gives additional input for preservation of the cultural and landscape heritage intangible values (Jones, 2018; Azman *et al*., 2010; Bujdosó *et al*., 2015).

This paper aims to give comprehensive overview of existing geoparks in the Baltic Sea Region, as well as analyze aspiring geoparks and unpublished initiatives of potential geopark (Livonia and Vooremaa) eventual establishment in frames of cultural and landscape preservation context.

Existing Geoparks in the Baltic Sea Region

Odsherred Unesco Global Geopark (Denmark)

Geological heritage of Denmark's only UNESCO Global Geopark: Odsherred, is mainly made up of glacial structures formed approx. 17,000 years ago. Three very distinct end moraines: Odsherred Arches form the core of Geopark. The complex of mentioned structures, surrounding depressions and meltwater represent a classical geomorphological example of a glacial landform that is considered unique by glaciologists and geologists all over the world (Odsherred UNESCO Global Geopark, 2017).

Rokua Unesco Global Geopark (Finland)

Rokua UNESCO Global Geopark is in Northern Finland. Geosite has several impressive bedrock sites, representing the main development stages of the Fennoscandian bedrock area. Diverse range of landscape forms formed during retreating glacier are consisting of varied mosaic of lots of geological formations, such as drumlins, hummocky moraines, terminal moraines, esker ridges, kettle holes, ancient shorelines, dunes, ravines and bogs. In addition to the geology, the areas are also connected by the prehistory of the people who followed the withdrawal of the ice sheet and sea (Rokua UNESCO Global Gerpark, 2017).

Muskauer Faltenbogen / Łuk Mużakowa Unesco Global Geopark (Germany & Poland)

The Muskauer Faltenbogen / Łuk Mużakowa UNESCO Global Geopark is a German-Polish transnational Geopark. The main objects and most scenic are push moraines in Europe: the Muskau Arch, created during earlier Quaternary European ice ages around 340,000 years ago. Later deep valley with numerous meanders and terraces formed. The area has numerous occurrences of lignite, dunes and cold iron-sulphate-mineral springs. Successions of sand, gravel, clay, and lignite beds of Tertiary age deformed by the load of the glacier may be found and seen here as well (Muskauer Faltenbogen / Łuk Mużakowa UNESCO Global Geopark, 2017).

Harz, Braunschweiger Land Unesco Global Geopark Unesco Global Geopark (Germany)

These are part of Harz Mountains composed of Palaeozoic sediments and magmatic rocks – 'Braunschweiger Land' is famous for its fossil-rich sediments of the Mesozoic and Tertiary periods. Intensive mining and research happened at least 1,000 years while numerous deposits of iron ore, brown coal, salt and oil were discovered under salt diapirs. The essence is 'Golden Square Mile', consisting of the close contact between the Variscan bedrock and the precipitous Mesozoic overlying rock, with many reference outcrops providing uniqueness (Harz, Braunschweiger Land UNESCO Global Geopark UNESCO Global Geopark, 2017).

Aspiring Geoparks

In Baltic region, there are 4 geoparks that have not been registered as UNESCO Geoparks yet, but are already registered as non-profit organizations in their countries.

Salpausselkä geopark

The aspiring Salpausselkä Geopark is situated in southern Finland. Salpausselkä Geopark project was started in 2017, by Lahti University of Applied Sciences and The Geological Survey of Finland,

assisting Metsähallitus Natural Heritage Services; in cooperation with municipalities forming the area of aspiring geopark (Asikkala, Heinola, Hollola, Kärkölä, Lahti, Padasjoki and Sysmä), with the support of EU. Ice-marginal formations with their eskers are the best – known geological features of Finland – formed of sand and gravel by glacial meltwater at the end of the last ice age 12000 – 11000 years ago they nowadays provide the City of Lahti and other municipalities of the region with good quality groundwater and, of course, geologically tells us the history of complex ice retreat.

North-West Estonian Geopark

According to Raukas (2010), North – West Estonian Geopark was formally founded in June 1, 2010 and covers Harku, Keila, Padise Nõva, Noarootsi communes as well as Paldiski town. The most monumental landform and the central geological value of the park is the North-Estonian Klint. Good preconditions for the formation of waterfalls exist in the mouths of rivers in the given area, due to intensive erossion, more than 6 meters high and around 70 meters wide Keila – Joa waterfall must be mentioned as the most important object of this type in the park. The rocks of the klint contain abundant skeletal fragments of trilobite, echinoderms, brachiopods (Raukas, 2010). Neugrund Meteorite Crater, formed in Early Cambrian some 535 million years ago, is probably one of the best-preserved marine impact structures in the World Ocean and the only one of those where most morphological units are visible and easily accessible. Also, it must be mentioned as a very significant geological object (Suuroja & Suuroja, 2010). Numerous Neugrund breccia boulders are found in the central and southern parts of Osmussaar island, carried here from the circular ridges of the crater by continental glacier. The most remarkable of these are megaboulders Skarvan and the Osmussaar Twins on the western coast of the island (Raukas, 2010). The biggest erratic boulder in the entire North European glaciation area, called Toodrikivi (volume over 1000 cubic meters) rests on the seabed near the Osmusaare isle (Raukas, 2010). Additionally, this area is interesting from the historical point of view due to its reach military history. The islands of Pakri were used as a practice bombing range of the Soviet army, Pakri Peninsula had the strongest concentration of the military units of the former Soviet Union in Estonia, where the nuclear reactors of the Submarine Training Centre, two nuclear missile bases and military harbours were located (Raukas, 2010). Signs of any activity of this geopark today were not found during the research.

Saarte geopark

Aspiring Saarte geopark is located in western Estonia on Saaremaa Island and surrounding smaller islets. The main geological value here is Kaali meteorite crater: one of the most important places of morphogenetic interest in Europe (Raukas & Stankowski, 2010). This object consists of the main crater surrounded by eight secondary craters forrmed as the result of a small meteorite shower. This meteorite shower is one of very rare cosmic catastrophes of this magnitude that took place in Europe in historical time (Raukas & Stankowski, 2010). Limestone cliffs of Gotland-West Estonian Klint, reach in fossils representing the biota of the Paleobaltic sea during the Sillurian period is another significant geological value of aspiring geopark (Märss & Soesoo, 2007). The most magnifient glacial landform here is the West - Saaremaa Upland – a huge end moraine height, composed mainly of till and rising 20 – 35 metres above surroundings (Raukas, 2010). The island has a rich flora and fauna and numerous architectural monuments such as medieval churches and Kuressaare Castle. The first try to get membership of the European Geopark Network and therefore also of Global Geopark Network was made by Saarte geopark at the end of 2013. In July 2014 a 2 – member delegation from the European Geopark Network and Global Geopark Network visited Saarte Geopark. Delegation got familiarized with the Saarte Geopark during their visit that lasted 3 days, application was differed and no information about the way foreward was found during the research.

Northern Vidzeme Geopark

Northern Vidzeme Geopark is founded as a non-profit organization in 2009, development of geopark in the territory of Burtnieki, Mazsalaca, Nauksheni and Rujiena counties and joining the UNESCO Geopark program was defined as the main aim of organization. The main geological values justify the formation of geopark: there are Devonian sandstone outcrops, cliffs and caves. Characteristic glacial relief forms, erratic boulders as well as a unique testimony of ice age, such as the largest settlement in Northern Europe must be mentioned as other valuable objects of aspiring geopark. Geopark is taking part in some local activities, while no information was found about attempts to submit an application to join Global Geoparks Network.

Initially there were strong ideas about creating **Livonia Geopark** (Figure 1), a cross-border Estonian – Latvian geopark with geotourism attractions: spectacular Devonian sandstone outcrops on river banks (incl. geoheritage sites in the Gauja national park), large mire areas along the Latvian - Estonian border. In an area of this prospective Livonia geopark operates the **Northern Vidzeme Geopark** (at present it is engaged only in some local activities).

Vooremaa Geopark, Eastern Estonia

A prospective **Vooremaa Geopark** (Figure 1) (by now the local parish authorities have agreed to

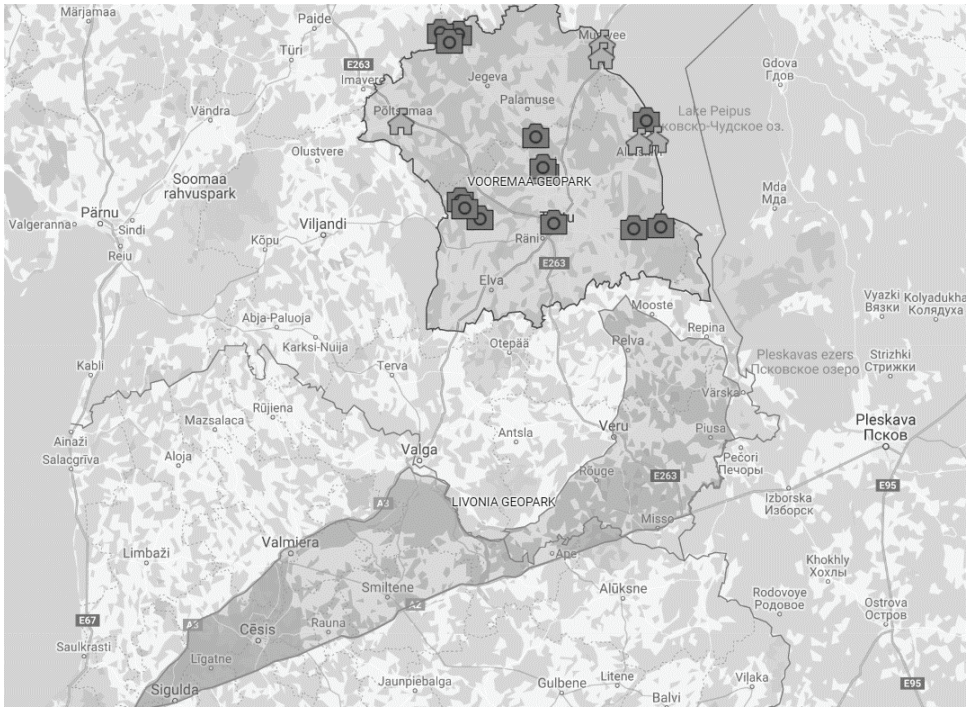

Figure 1. Geographical distribution of Vooremaa and Livonia perspective geoparks and marked geosites (author courtesy on base map of GOOGLE).

establish the Vooremaa geopark in the territory of Tartu and Jõgeva counties in February 2015). Main geotourism attractions of the Vooremaa geopark are: large mires (Endla, Alam-Pedja, Emajõe-Suursoo) of various genesis and on different development stages adjacent to the Vooremaa drumlin field; settlements of Russian Old Believers along the coast of Lake Peipsi (Starover, 2019). The Ice Age Centre at Äksi (Ice Age Centre, 2019) could be used as a headquarter for the Vooremaa Geopark. The local community leaders of Tartu and Jõgeva counties have recently agreed upon establishing the Vooremaa geopark by Spring 2016. Geologist Heikki Bauert introduced the Geopark idea in Jõgeva and Tartu counties, and Aivar Soop, the Rural Municipality Mayor, develops and leads the initiative. According to the plan, the Geopark will be created across Jõgeva and Tartu counties (Loomisel olev geopark, 2019).

'Terra Kukkersiana' geopark, northeastern Estonia could be planned as a prospective **Kukersite Geopark** (no public activities yet). It would be established in the Ida – Virumaa county, Northeastern Estonia. Main geotourism attractions should be kukersite oil shale (geology, mining, utilization) field sites (underground museum and water attractions in flooded mines are already opened for recreation); the North Estonian Klint – exposing Lower Cambrian to Middle Ordovician siliclastic to carbonate successions; Kuremäe Convent; Narva Castle (Narva museum, 2019) and other cultural and geo – objects.

Results and Discussion

Criteria and requirements

According to Global Geoparks Network (2014), Geopark is an area that has clearly defined boundaries and is large enough to promote sustainable economic and cultural development of the local community. The general focus of the geopark concept is the geological heritage and geodiversity, presence of impressive and internationally significant geological objects, important from the point of view of science, rarity, education and/or aesthetics, is essential for the establishment of the geopark (Azman *et al*., 2010) while the presence of such kind of objects alone is not enough. The establishment of a Geopark should be developed through a bottom-up process coming from a local community and local political leaders. Furthermore, political support must include the provision of necessary financial resources (Bujdosó *et al*., 2015). The Geopark should have professional management structures and be able to deliver policy and action for sustainable development across the territory where it is located, that is one of its main strategic objectives. The aim of the Geopark is to improve living condition of local population and quality of the surrounding environment (Azman *et al*., 2010). Very important objective of geopark is to strengthen identification of the population with their area and to stimulate the 'pride of place', which in turn produces strong local support for the protection of geological heritage. Educational function of Geopark

as well is of very high significance, it must provide and organize support for the communication of geoscientific knowledge to the general public through establishment of museums, educational centers, trails, publishing of popular literature, maps, providing modern communication media, etc. (Ólafsdóttir & Dowling, 2014). Geopark is not a specific category of protected area or landscape, branding of area as Geopark does not affect the legal status of the land, however, the authorities responsible for the Geopark must ensure enough protection of included geological values in accordance with local traditions and legislative obligations (Fassoulas *et al*., 2007).

Geoparks under the assistance of UNESCO shall incorporate multiple things such as: 1) preserve geological heritage (conservation) for future generations; 2) ensure sustainable tourism; 3) educate broader audience and promote research.

As we described above – an intention and options for creating several new geoparks (aspiring and perspective) in the Baltic Sea Region in the context of geological landscape, culture, mining industry development, aesthetics is higly topical. Moreover, they will provide the socio-economic development perspectives and didactics tool for landscape learning.

World Heritage Convention and the Man and Biosphere (MAB) Reserve programme must be respected to be complementary within IUGS-IGU-UNESCO Task Force 'GEOSEE'. It must have well-defined limits that have a large enough surface also for local economic development. It may not be solely of geological-palaeontological significance but also include cultural, archaeological, historical and ecological values (Wójtowicz *et al*., 2011; Fassoulas & Zouros, 2010; Azman *et al*., 2010). So in fact it means that Geopark itself has to provide sustainable development goals for local (regional) communities and on top serve as education on the environment, research training in various disciplines of the Earth Sciences, supplement natural environment and sustainable development policies.

Conclusions

Geopark has several main tasks to fulfill when organized and approved: preserve geological heritage (conservation), educate broad public on landscape aesthetics (landscape educational didactics) and ensure sustainable development (socioeconomic and tourism aspects). In this paper, we talk about aspiring geoparks that have closest intentions and opportunities to become geoparks in foreseeable future as well as perspective ones that still are only in conceptual ideas not discussed in broader public. However, as we see from regional planning documents about infrastructure plans in far future, very often good ideas are forgotten and not implemented. Therefore, it is important to raise up the scientific and public audiences with conceptual frames of forgotten issues. The main recommendations are that 1) geoparks must be strongly incorporated in strategic documents and affirmed in UNESCO and GEOSEE; 2) this area should have distinct borders in nature with concrete defined properties of geological, landscape, cultural significance; 3) terrains and landscape units should be complementary – it may not be defined as a geopark if only separate geosites characteristics (e.g., paleontological, geomorphological or cultural specified etc.) are relevant – with that said it must have a complex uniqueness that is easy to be explained for broader public; 4) an action plan for business, education and implementation in other strategic documents should exist. This must provide additional supplementary income (tangible and/or untangible) for the local population and attract private equity in future.

Acknowledgements

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URBAN HYDROLOGY RESEARCH FUNDAMENTALS FOR WASTE MANAGEMENT PRACTICES

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Abstract
The urbanization and increasing growth of planet's population accumulates significant volume of disposed waste as well as increases risks on human health and environmental safety. Landfill systems are the dynamic, living in space and time, potentially harmful entities that must be managed in as careful and smart way as possible. There are many studies related to landfill emissions such as leachates and methane. However, there is a need for advanced understanding of landfill hydrological regime and risks related to climate change and associated changes of hydrological cycle. The comprehensive studies about the urban hydrology are available; however, application to landfill management is fragmentary and inconsistent in several aspects. Landfill in long term has an impact on hydrological cycle. The heterogeneous land surface is one of aspects; however, there are still unanswered questions about the urban environment impact on water balance components. The aim of this study is to describe fundamentals of landfill hydrology in urban hydrological response unit context as well as evaluate the potential risks to environment and human health related to landfill geomorphology and hydrological balance in temporal climate conditions. The landfill hydrological cycle has similarities with urban hydrological cycle; however, there are additional components related to landfill specification, e.g., irrigation or leachate recirculation as well as total produced leachate.
Key words: urban hydrological response unit, solid waste, landfill water balance, Swedish Institute, biological degradation.

Introduction

The landfills are systems with mixed contaminants and approximate aftercare period from 200 till 500 years. During aftercare period there are risks to contaminate environment especially groundwater (Belevi & Baccini, 1989). The landfills are identified as important source of groundwater contamination with organic and nonorganic pollutants (Fatta *et al*., 2002; Li *et al*., 2008; Alslaibi *et al*., 2011; Regadío *et al*., 2012; Li *et al*., 2014). The aquafer contamination with leachate is serious environmental issue not only in developing countries, for example Morocco (Smahi *et al*., 2013), Malaysia (Zawawia *et al*., 2012), India (Gunjan *et al*., 2012), but also in the USA where approximately 75% of the landfills have negative impact on groundwater quality (Jones-Lee & Lee, 1993). Similar results are found in Denmark and other countries. As presented in Figure 1, there are 453 closed landfills in Latvia (LVGMC, 2019). Potential contamination risk is in 335 closed landfills as well as significant contamination is identified in 37 landfills. There is a need for advanced knowledge about

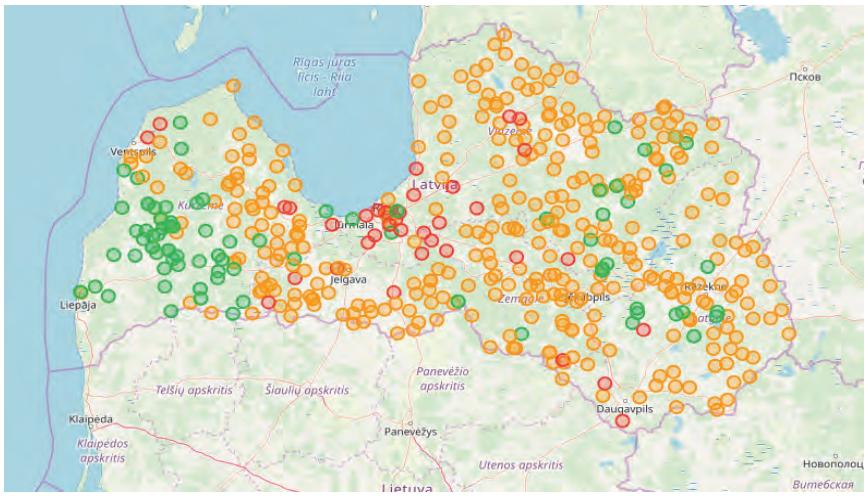

Figure 1. The location of closed landfills in Latvia where: red – contaminated site; yellow – potentially contaminated site; green – remediated site.

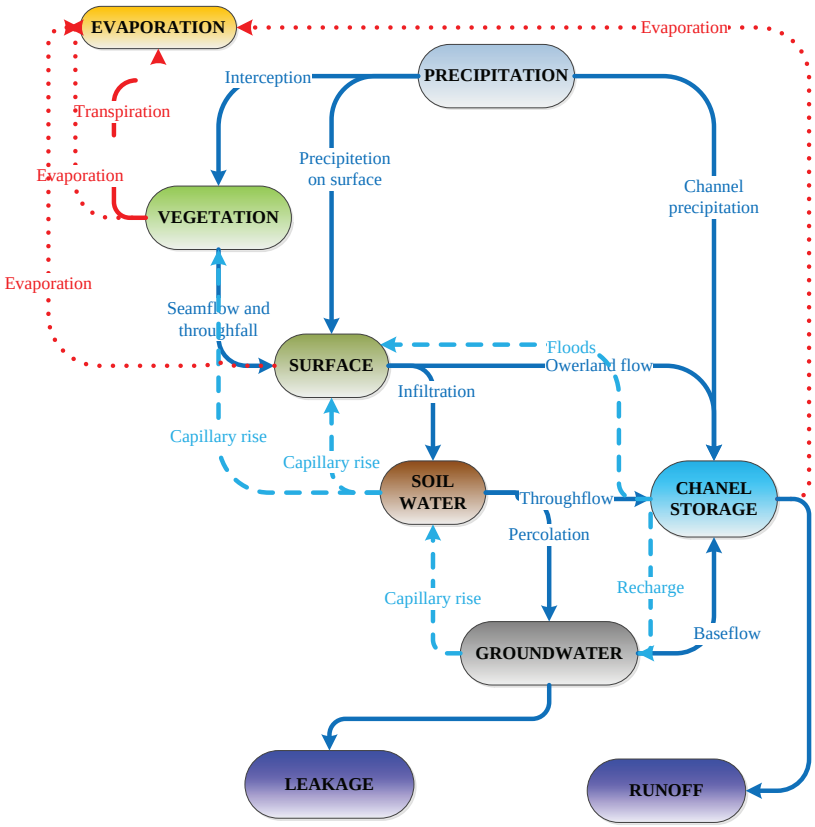

Figure 2. The hydrological cycle of natural catchment area (author courtesy according Ward & Robinson, 2000).

landfill hydrology with the aim to develop and apply groundwater contamination mitigation measures and aquafers protection strategies.

Landfill as any urban environment changes hydrological regime and in long term has an impact on hydrological cycle. The heterogeneous land surface changes hydrological regime and impacts a hydrological cycle, but there are still unanswered questions about the urban environment impact on water balance components (Van de Ven, 1990). In the natural hydrological cycle, there are three general components (Figure 2) such as precipitations, evapotranspiration and run-off which are influenced by interception, infiltration, geomorphology, velocity etc.

The urban hydrological cycle has some components, but they are modified (Figure 3). To evaluate water balance in urbanized catchment area, proportion of waterproof surface is used (Carle *et al.*, 2005, 2008; Zhou *et al.*, 2010; Mitchell *et al.*, 2003; Lhomme *et al.*, 2004; Ogden *et al.*, 2011; Xiao *et al.*, 2007). The precipitation is one of the main components of hydrological cycle and the impact of urban environment on precipitation is investigated in some studies (Taha, 1997; Shepherd *et al.*, 2002; Shepherd, 2006) and the main conclusion is that urbanization impact on precipitation is with a local effect. There is strong evidence of urbanization impact on evapotranspiration. However, there is a need for additional studies (Cheng *et al.*, 2011). Due to lack of vegetation in urban areas, the total evapotranspiration is lower than in rural areas (Taha, 1997; Chen *et al.*, 2009). The vegetation in urban environment has a larger spatial diversity and there is a need for new technologies and modelling approaches to investigate this phenomenon. The water retention in natural areas is in the range from 0.5 to 15 mm. However, in urban areas water retention is from 0.2 mm to 3.2 mm (Marsalek *et al.*, 2007). The main indicator of hydrological balance change is roughness of surface, and it is one of the main research objects in hydrological analysis (Arnold & Gibbons, 1996; Shuster *et al.*, 2005; Zhou *et al.*, 2010; Jacobson, 2011). The rain water and waste water collection are components of urban hydrological cycle and are developed to protect urban areas from floods and provide safe environment for humans (Delleur, 2003; Egodawatta *et al.*, 2013). The impact of urbanization on groundwater levels is investigated in many studies (Appleyard 1995; Changming *et al.*, 2001; Schirmer *et al.*, 2012). In the urbanized environment the natural recharge of groundwater is transformed in new forms (Foster, 1990): 1) waterproof surfaces disturb direct groundwater recharge and deplete groundwater resources; 2) the urbanization increases

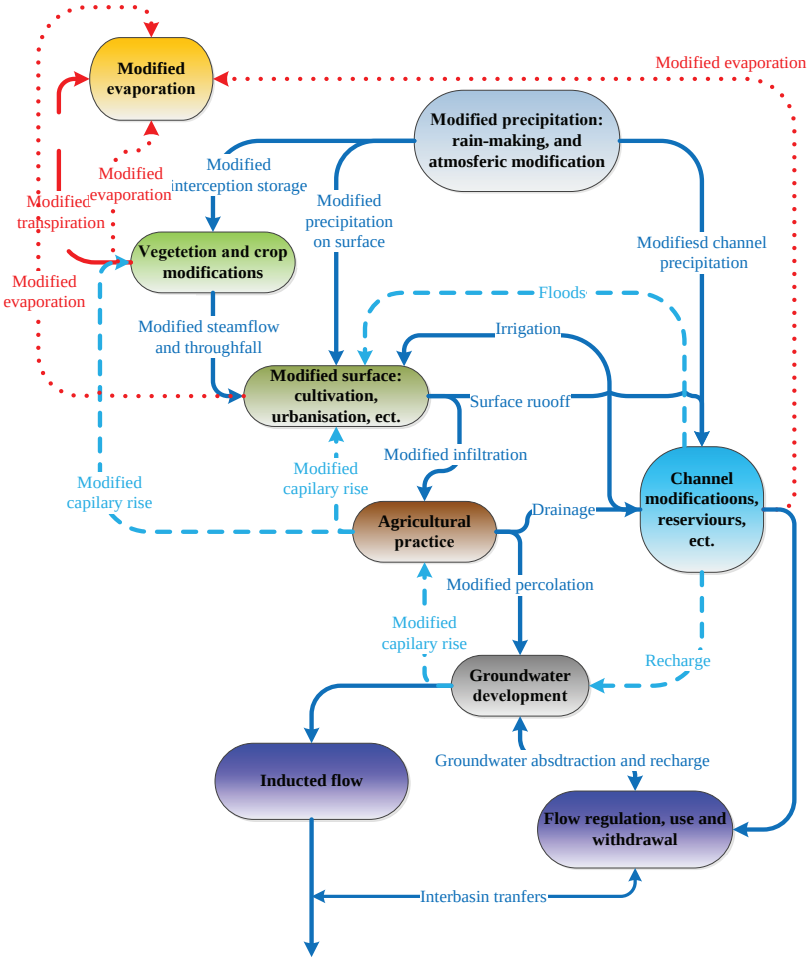

Figure 3. The hydrological cycle of urban catchment area (Ward & Robinson, 2000).

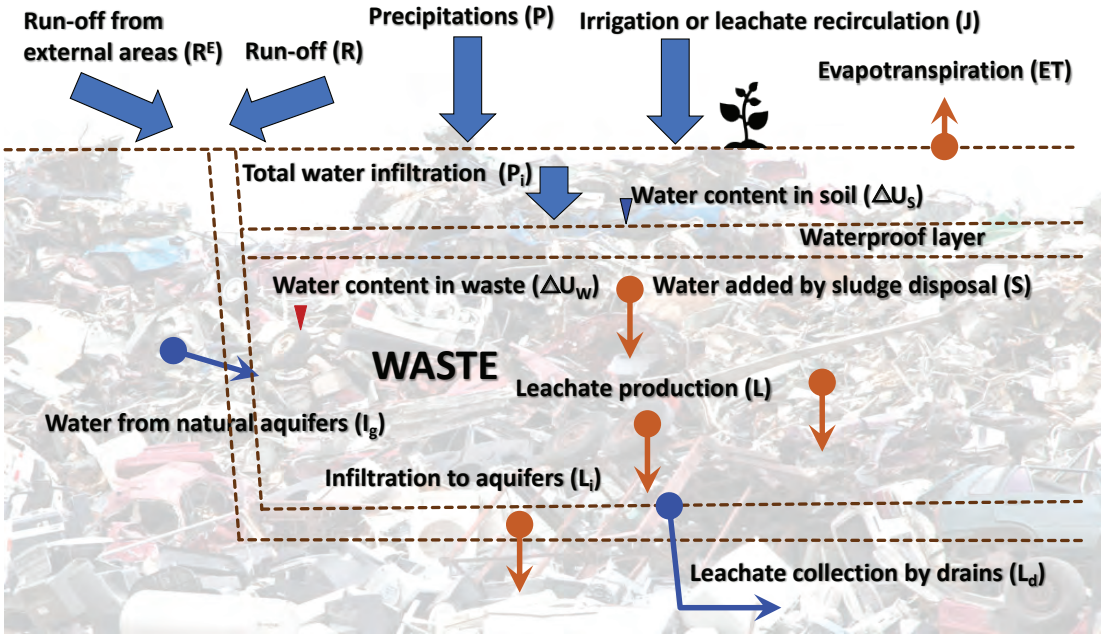

Figure 4. Landfill hydrological cycle conceptual scheme.

groundwater recharge associated with infiltration from anthropogenic systems (Lerner, 2002). In urbanized areas, the land surface is covered by waterproof surfaces where infiltration is close to zero (Leopold, 1968). The proportion of waterproof surfaces variates from 50% in residential areas to 90% in industrial areas (Foster, 1990). The aim of this study is to describe fundamentals of landfill hydrology in urban hydrological response unit context as well as evaluate the potential risks to environment and human health related to landfill geomorphology and hydrological balance in temporal climate conditions. The main tasks are: first, to investigate and describe water balance in landfills, second, divide environmental risk groups according to landfill geomorphology and hydrological balance, hydrological cycle components by landfill groups.

Materials and Methods

Landfill conceptual hydrological cycle is presented in Figure 4. The precipitation (P) is the same as in urban and natural areas. Additionally to precipitations, there is water of irrigation or leachate recirculation (J). The evapotranspiration (ET) in landfill is related to vegetation and mostly landfill areas are covered by grass and in some cases covered by bushes and even trees. Surface run-off (R) in landfill area is lower than in urban areas but higher than in natural areas. Run-off from external areas (R^E) is not acceptable but in some cases can be issued by geomorphological conditions. The water content in soil (U_S) is part of water balance equation 1:

$$Pi = P+J+R^E-R-ET\pm \Delta U_S \quad (1)$$

Where: Pi – water infiltrated in waste (mm); P – precipitation (mm); J – water of irrigation or leachate recirculation (mm); R^E – Run-off from external areas (mm); R – Surface run-off (mm); ET evapotranspiration (mm); U_S water content in soil (mm).

Landfill hydrological balance has additional components: water added by sludge disposal (S), water production or consumption by biological degradation of organic matter (b), total leachate production (L) see equation 2:

$$L=Pi+S+Ig\pm\Delta U_w+b; \quad (2)$$

Where: L – total leachate production (mm); S – water added by sludge disposal (mm); Ig – water from natural aquifers; U_W – water content in waste (mm); b – water production or consumption by biological degradation of organic matter.

Water content in waste is related to waste source and climate condition during waste disposal. The landfill water balance components such as water infiltration from natural aquifers, external run-off and leachate infiltration in natural aquifers are critical components of landfill water balance related to environmental risks.

Results and Discussion

The potential risks to human health and environment are related to leachate infiltration in aquifers. The landfills in Latvia were divided in three groups by landfill conditions and developed conceptual hydrological balance for each of groups using available information accessible in Latvia State Forest geographical information systems (LVM, 2019). The first group is landfills with controlled area and low risk of leachate infiltration in natural aquifers as presented in Figure 5.

The second group of landfills is closed and recovered, but the soil layer is associated with medium environmental risks (Figure 6). There is lack of surface run-off collection system as well as identified

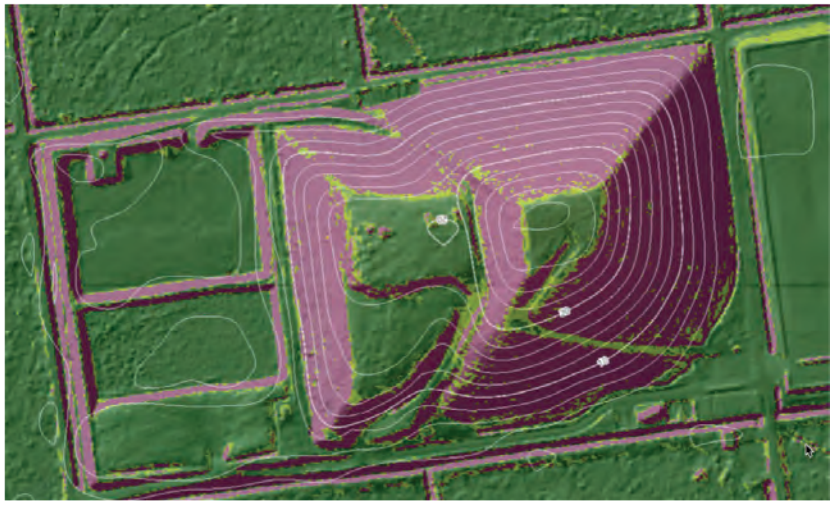

Figure 5. Landfill with low environmental risks.

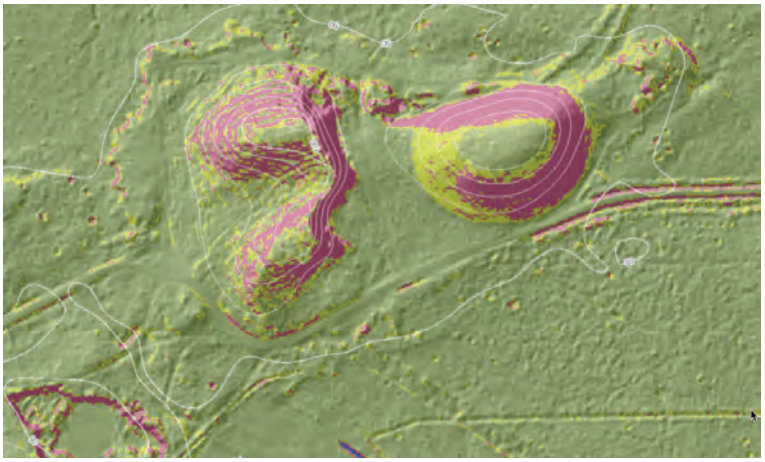

Figure 6. Landfill with medium environmental risks.

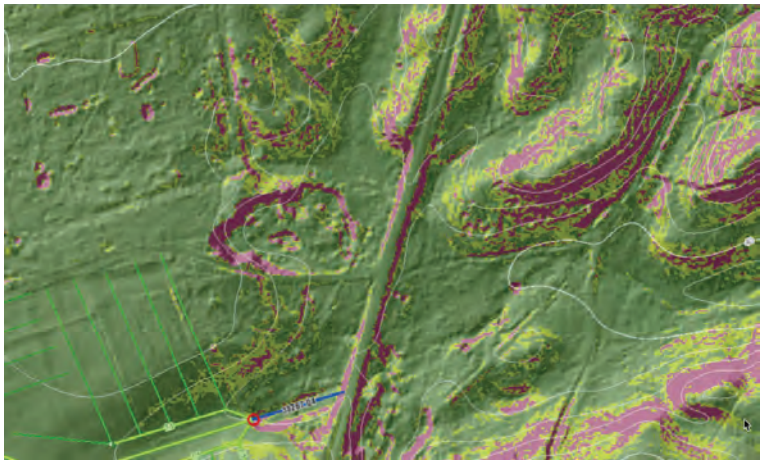

Figure 7. Landfill with high environmental risks.

Table 1

The hydrological cycle components by landfill group

Component of landfill hydrological balance	Low risk group	Medium risk group	High risk group
Water of irrigation or leachate recirculation (J)	J≥0	J=0	J=0
Run-off from external areas (R^E)	$R^E \leq 0$	R^E=0	R^E>0
Water infiltrated in waste (Pi)	Pi=0	Pi=0	Pi>0
Water from natural aquifers (Ig)	Ig=0	Ig≥	Ig>0
Leachate infiltrated in natural aquifers (Li)	Li =0	Li>0	Li>0
Leachate collected by drainage system (Ld)	Ld>0	Ld=0	Ld=0
Water added by sludge disposal (S)	S≥0	S=0	S=0

risks related to water infiltration in waste from natural aquifers and leachate infiltration into natural aquifers.

The third group of landfills has high environmental risks and includes landfills developed in abandoned sand or gravel mining areas where run-off is not collected and additional run-off from external areas infiltrates in waste body. This type of landfills is characterized with small amount of waste, but high risks of leachate infiltration in natural aquifers.

The analysis of hydrological components by groups is presented in Table 1. Low risk group of landfills has a leachate recirculation system. The water exchange between waste body and natural aquafers is close to 0. The clean run-off water from landfill

is collected and delivered to the closest water body. In the medium risk group of landfills, there is probability of water exchange between waste body and natural aquafers, but normally it is close to zero. The risks of environment contamination are related to leachate generated by biological degradation of organic matter.

The high environmental risk group of landfills is characterized by positive external run-off, positive infiltration from natural aquifers and leachate infiltration in natural aquifers where contamination migrates to the closest water body and is transported to the Baltic Sea.

Conclusions

The landfill hydrological cycle has similarities with an urban hydrological cycle; however, there are additional components of hydrological cycle components related to landfill specification, such as water of irrigation or leachate recirculation and total produced leachate.

There are medium or high environmental risks related to closed landfills, and there is a need for additional investigation using GIS and hydrological modelling tools to mitigate contamination of groundwater and deep aquifers.

More studies are needed and modelling elaborated in order to diminish the discharges of contaminated groundwater and greenhouse gasses out of urban areas including contaminated and potentially contaminated sites and landfills.

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BEHAVIOUR OF TIMBER PORTAL FRAME DEPENDING ON ROTATIONAL STIFFNESS OF KNEE JOINT

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Abstract
In this article, the topic under discussion is the development of deformations in semi-rigid knee joints made of dowel type fasteners and consequences expected regarding overall deformations of timber portal frame structure. The use of semi-rigid connection resolves the problem of transportation, but development of small rotation in connection reduces the stiffness of the connection that becomes significant during service life. It is assumed that the rotational stiffness modulus K_{φ} (kNm·rad^{-1}) is the relevant characteristic of semi-rigid connection. Timber portal frame structure (span 30 m) designed with dowel type fasteners located around two circles has been subjected to different loading trials by using Dlubal software (RFEM). Results of a numerical study of portal frame model demonstrate the importance of characteristics of semi-rigid knee joints for design. It is found that developing deformations in the semi-rigid knee connection produce up to 90% bigger vertical displacement at an apex point and 96% bigger horizontal displacement comparing with the rigid knee joint model.
Key words: semi-rigid timber connection, numerical study.

Introduction

During recent decades timber portal frame structures have become at the forefront more often when one chooses structural form for the design industrial building. Portal frame structure requires a shorter assembly time in comparison with a column-truss type frame. Portal frame forms a geometrically stable structure if knee joints are rigid, i.e., fasteners used are able to avoid the rotational movement between column and rafter elements. Knee joints of timber portal frames may be executed as glued finger joints or semi-rigid connections made by mechanical fasteners. From a static point of view, glued knee joints are safer representing clear conformity with a traditional model accepted for structural design of three hinged frames. Yet the limitations for sizes of prefabricated units due to transportation conditions take down an overall area of the use of these portal frames. The use of a semi-rigid connection enables us to avoid the problems regarding limitations of transportation, as in this case knee joint between column and rafter elements may be assembled at the building site, and transportable units are separate column and rafter elements. At the same time design assumptions for portal frames made with mechanical fasteners in the knee joints are more complex; moreover, they contain some unexplored details. In the knee joint made with mechanical fasteners the force transferring mechanism from the rafter to column element is significantly distinctive from the glued one. The single rafter units of a portal frame are usually enclosed by two glulam column elements. Bending moment created by external load is transferred step-by-step – wood-fasteners-wood. The procedure is followed by larger or smaller change of angle between the rafter and column, i.e., increase of rotational movement of connected elements. The rotation between timber elements in connection is increased due to deformations of mechanical fasteners, as well as by fastener's embedment action into wood. The result in this type of knee joint falls into class of semi-rigid connections. Rotational displacement in knee connection may affect the global behaviour of portal frame significantly under design loads (Figure 1, a).

The rigidity of connection may be characterized by the rotational stiffness K_{φ} (kNm·rad^{-1}) expressed by the value of bending moment value per one radian of angle change between connected elements. In Eurocode 5 (European committee for standardization, 2008) slip modulus K_{ser} for connections is defined representing the axial displacements between connected elements loaded in tension or compression. It is doubtful that deformation of knee joint may be expressed correctly using linear slip modulus K_{ser} (Fokkens, 2017). It is found from the results of previous experiments (Ozola & Fabriciuss, 2019) that K_{φ} value is in the range from $35 \cdot Md - 75 \cdot M_d$ kNm·rad^{-1} (M_d – moment capacity of connection).

Firstly, an examination of the force and stress distribution in the joint area, including the calculation method, was presented by Racher (Timber Engineering (1995). During the last decades investigations on behaviour of timber portal frames with semi-rigid knee joints were carried out by many researchers. Analysing behavior of semi-rigid connection in the two storey orthogonal frame, Leichti concluded that the moments at the connection may be expressed as the function of stiffness properties (Leichti *et al*., 2000). Bouchair et al. developed a two-dimensional finite element model of dowelled joint confirming the fact that the geometrical centre of the dowels can be used as a mechanical rotational centre of the joint (Bouchair, Racher, & Bocquet, 2007), and underlying need for criterion also regarding stresses interaction between the shear and the tension perpendicular to the grain. Scheibmair

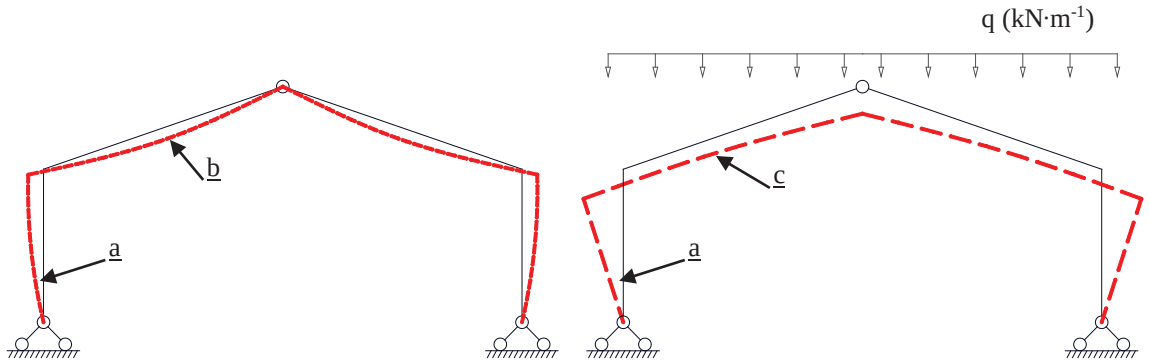

Figure 1. Portal frame model; a – ideal design shape of portal frame; b – assumed initial deviation in the geometry for a frame; c – deformed shape under load.

and Quenneville proposed moment connection with fully threaded screws inserted at 60 degrees to the load (Scheibmair & Quenneville, 2010). Morris and Quenneville executed a test programme of portal frame knee joint realising the moment redistribution on two pin portal frame model (Morris & Quenneville, 2010). Gehloff et al. proposed the use of reinforcement to prevent splitting of timber through edge lines (Gehloff, Closen, & Lam, 2010). Completed study of semi-rigid knee joints of timber portal frames was presented by Porteous and Kermani resulting with methodology for determination of connection's design capacity (Porteous & Kermani, 2013). Nevertheless, experimental results (Ozola & Fabriciuss, 2019) show that a huge rotation can be found at the connection under external loads and cannot be ignored when one is designing a semi-rigid connection. In addition, it is noteworthy, that most of the experimental investigations under short-term static loading were carried out.

In the current study, the classic model for structural analysis of portal frame (Figure 1) is supplemented with additional effects due to anticipated rotational displacements in semi-rigid knee joints (Schweigler, Bader, & Hochreiner, 2018), as well as taking into account the initial imperfections of the form defined by Eurocode 5 (European committee for standardization, 2008).

Duration of load effect is a very important issue for timber structures with dowel-type fasteners. The prognosis of effect from a long-term loading is unclear, because of many different factors, such as moisture content, stress level (as a ratio to capacity), temperature, a variation of wood density and many others, affecting the structural phenomena.

The aim of the study is to assess the effects of deformations of semi-rigid connection to internal forces and displacements of structure.

Materials and Methods

In this study, the model of timber portal frame with semi-rigid knee joint has been tested using Dlubal software (RFEM). Research was carried out in the Latvia University of Life Science and Technologies, Faculty of Environment and Civil Engineering during March, 2019. A portal frame structure was designed by built-up columns made of glue laminated tapered timber elements and of single rafter elements. The initial design of a portal frame under a design load 12.7 kN·m^{-1} was carried out assuming completely rigid knee joints. The span of a portal frame is 30 m, apex height – 14.5 m, the slope of rafter elements – 19 °. Vertical design load q_d=12.7 kN·m^{-1} attached to rafters represents a combination of permanent selfweight and medium-term snow load. Wind pressure is not taken into account in this study because its influence on longterm behaviour of knee joints may be assessed as insignificant. Cross section sizes of column at the knee joint are 2×200×1600 mm, but at the column base 2×200×600 mm. Rafter cross section sizes are 300×1600 mm at the knee joint and 300×800 mm at apex point (Figure 2). Strength class of glue laminated timber is GL24h.

Knee joint was designed with dowel type fasteners located around two circles. The radius of an external circle is r_{max}=640 mm, and 26 fasteners are arranged around the circle taking into account the limitations for distances between fasteners according to Eurocode 5 (European committee for standardization, 2008); see Figure 3. Radius of an internal circle is r_i=400 mm and 16 fasteners are located around that. Bolts M24 (grade 8.8) were used as fasteners.

Assumptions for engineering modelling of a semi-rigid connection have been discussed in detail by researchers (Hochreiner *et al.*, 2016), (Ormarsson, Dahlblom, & Nygaard, 2010). Before numerical analysis of a frame in deformed state, the design capacity was calculated for moment-resisting knee joint assuming fully rigid knee joint. Theoretical moment capacity (M_d) was found according to the methodology developed for dowelled frame corner design (Timber Engineering, 1995). In Figure 3 the exact solution of a knee joint of portal frame chosen

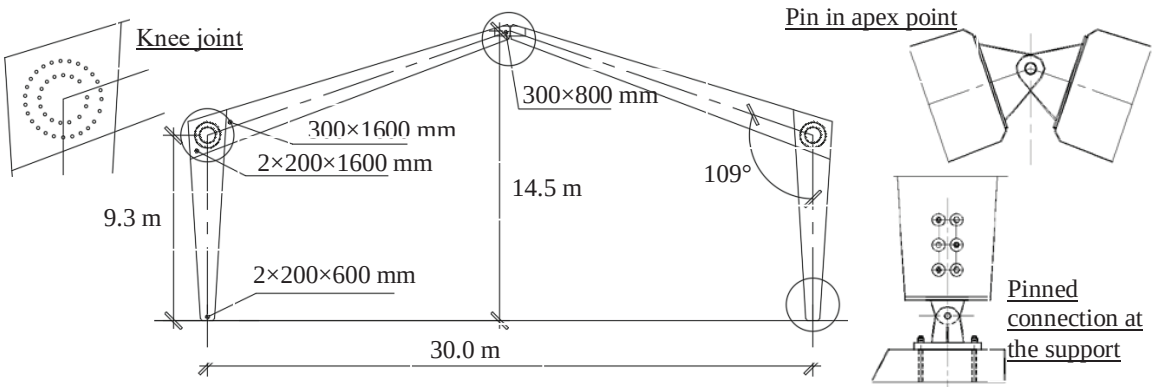

Figure 2. Timber portal frame structure.

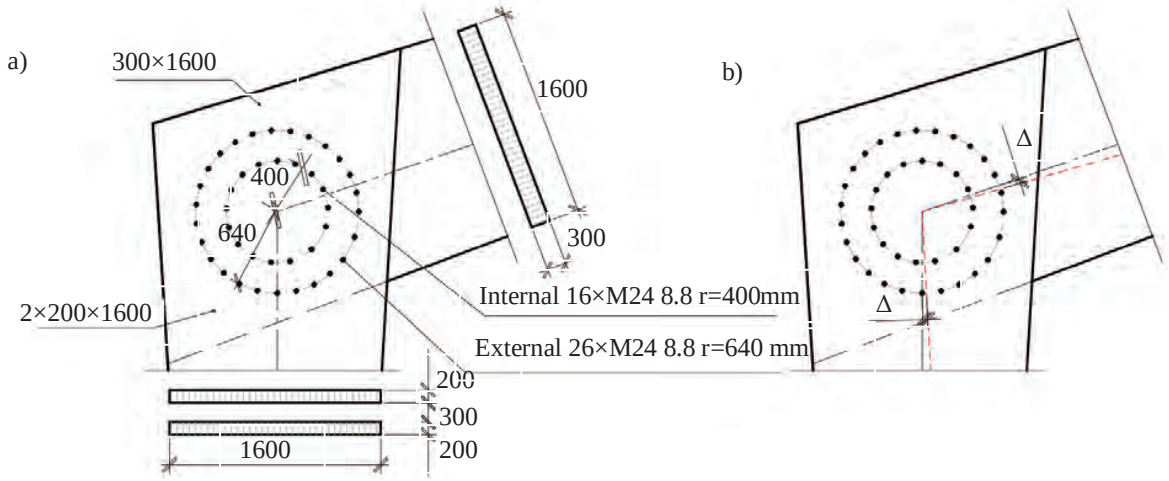

Figure 3. Solution of semi-rigid knee joint: a - connection design; b - rotational movement in connection.

for analysis is shown. In keeping with diameters of circles around which dowels are placed, design moment capacity of knee joint is 936 kN·m. Using existing static equilibrium equations for three hinged frames corresponding horizontal and vertical reactions were found, which led to relevant symmetrically distributed vertical design load value q_d=12.7 kN·m^{-1} to be attached to the frame rafter.

Rotational stiffness values assigned for analysis based on a logical assumption on displacements expected in the knee joint due to the following action effects were found:

- free displacement of bolt in hole (due to allowance 1 mm),
- deformation of bolts in bending,
- embedment of bolt into wood (up to 1 mm proposed).

The bending moment values per radian of an angle of rafter's and column's axis rotation correspondingly to expected displacement values Δ_1=1 mm, Δ_2=1.5 mm and Δ_3=2 mm were assigned as rotational stiffness modulus 320·M_d, 213·M_d, 160·M_d (see Table 1). For the design of an original model knee joint rotational stiffness was assumed $K_\varphi = \infty$ kNm·rad^{-1}.

First, the distributed vertical load q_d= 12.7 kN·m^{-1} was attached to the portal frame structure. A knee joint stiffness was defined as infinity K_φ=∞. This model of the system was used as reference one for the next trials of the numerical test when internal forces and point displacements were calculated assuming a deformed shape of the design model.

Second, a model of an imperfect shape was introduced and similar steps of static analysis were carried out. Increased displacements and internal forces were found when an imperfect shape of the system was introduced in an input data. See values of internal forces and displacements in Table 1.

Results and Discussion

Results of numerical analysis show that displacement of an apex point changes significantly by changing the knee joint stiffness values (Figure 4). Similar results were gained in previous investigation (Malo & Stamatopoulos, 2016). Assuming a rigid knee joint (K_φ=∞), a vertical displacement of an apex point may be prognosticated of 68.9 mm. Introducing semi-rigidity constant as a knee joint parameter, the apex point displacements take values in the range from

Table 1

Displacements of deformed shape portal frame nodes and internal forces

Rotational stiffness assumed kN·m·rad10^{-3}	Horizontal displacement of a knee point Δ_1 mm	Vertical displacement of a knee point Δ_2 mm	Vertical displacement of an apex point Δ_3 mm	Moment capacity of a knee joint kN·m	Axial force in column at a knee joint kN·m	Shear force in rafter section at a knee joint kN·m
Original three hinged model with rigid knee joints						
∞	-0.3	23.1	-68.9	936.64	-192.71	149.38
Deformed shape model assuming semi-rigidity (rotation) effects in knee joints						
∞	-0.3	23.1	-68.9	945.5	-192.78	150.22
320·M_d	-0.3	33.6	-99.3	949.5	-192.78	150.59
213·M_d	-0.3	38.8	-114.5	951.6	-192.78	150.78
160·M_d	-0.3	44.1	-129.6	953.6	-192.79	150.97
Deformed shape model assuming semi-rigidity (rotation) effects in knee joints + imperfect shape						
∞	-0.3	23.1	-70.4	945.6	-192.76	150.22
320·M_d	-0.3	34.6	-101.4	951.7	-192.79	150.74
213·M_d	-0.3	39.9	-116.1	954.1	-192.80	150.99
160·M_d	-0.3	45.3	-131.2	956.1	-192.81	151.18

99.3 mm to 129.6 mm (Table 1). It is clear that stiffness of connection significantly affects deformations of the portal frame. Deformations in the semi-rigid knee joint promote an increase in portal frame deformations up to 88% referring to a traditional design model with a rigid connection (Table 2). When geometric imperfections of shape are introduced additionally, the displacement of the apex point increases by 2 – 3%.

The moment capacity of the knee connection calculated for the original portal frame model is 936.64 kN·m (connection design bearing capacity). Taking into account expected deformations in the knee joint under the action of an external load, the bending in the knee joint increases up to 945.5 kN·m comparing with the rigid connection design, and from 949.5 to 953.6 kN·m by a semi-rigid design. Introducing effects of the model imperfections, the bending moment increases in a range of 951.7 to 956.1 kN·m. An average bending moment increase is about 2% (Figure 5) comparing with a rigid connection design (Table 2). The effects of geometric shape imperfections cause an additional moment increase of 0.1 – 0.3% (Figure 5). From the

Table 2

Comparison of displacements and internal forces in system with semi-rigid knee joint referring to traditional model (%)

Rotational stiffness assumed kN·m·rad10^{-3}	Horizontal displacement of a knee point	Vertical displacement of a knee point	Vertical displacement of an apex point	Moment capacity of a knee joint	Axial force in the column at a knee joint	Shear force in a rafter section at a knee joint
Deformed shape model assuming semi-rigidity (rotation) effects in knee joints						
∞	0	0	0	0.9	0	0.6
320·M_d	0	45.5	44.1	1.4	0	0.8
213·M_d	0	68.0	66.2	1.6	0	0.9
160·M_d	0	90.9	88.1	1.8	0	1.1
Deformed shape model assuming semi-rigidity (rotation) effects in knee joints + imperfect shape						
∞	0	0	2.2	1.0	0	0.6
320·M_d	0	49.8	47.2	1.6	0	0.9
213·M_d	0	72.7	68.5	1.9	0	1.1
160·M_d	0	96.1	90.4	2.1	0.1	1.2

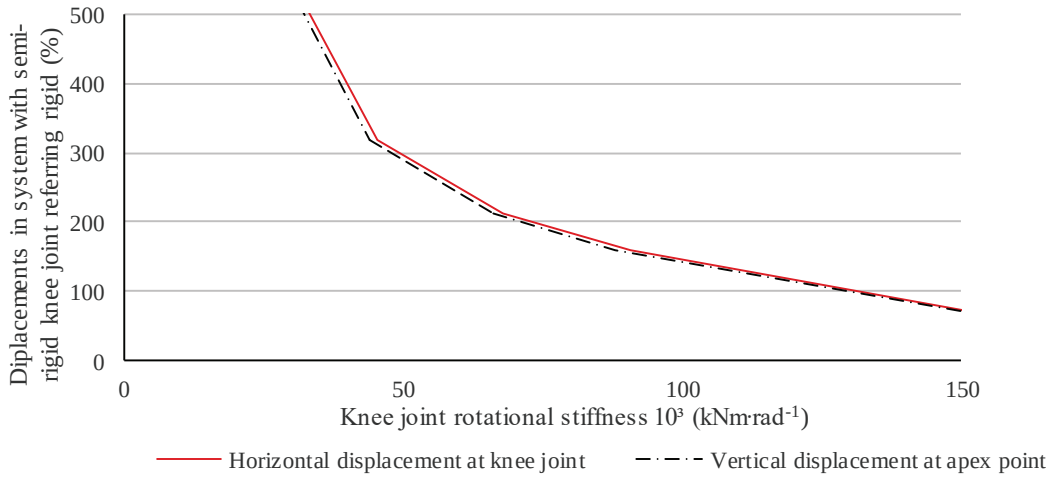

Figure 4. Apex point displacement depending on rotational stiffness of a knee joint.

results can be seen that a huge impact was from the external load that deformed the portal frame structure and increased influence if rotational stiffness in the connection were lower. Otherwise, the influence of imperfect shape was smaller (20 times smaller than from the external loading) and not directly related with knee joint connection stiffness.

Axial compression force value in the column at the section around knee joint is 192.71 kN when the rigidity withstands. Introducing a possible rotational displacement of a semi-rigid knee joint and an effect from the imperfect shape, axial force value changes up to 192.81 kN (0.1%).

Shear force at the rafter section around knee joint according to original design is 149.38 kN. Taking into account semi-rigidity effect, shear force values change from 0.8% to 1.1%. Also, introducing the imperfect shape parameters, shear force changes in the range from 0.9% to 1.2%.

In this study, the level of significance of influence of connection stiffness (characterized by so called spring constant) to overall deformation of a structure is found. Overall results show small differences among internal forces but significant ones regarding the movement of a knee joint and apex point. Vertical displacement of an apex point may reach up to portion of 1/200 of the span of a portal frame. This is a warning that there is a possibility that some of serviceability limit states might take place. General limitation for apex point displacement may be assumed in the range of L/400 up to L/300 where L is a distance between support axis (span). Moreover, development of plastic deformations embedding bolts into wood, as well as creep of wood material will be additional effects actual during the service life and leading to an increase of overall deformations of a portal frame.

Note that the effect of friction between planes of timber elements was neglected in the current research.

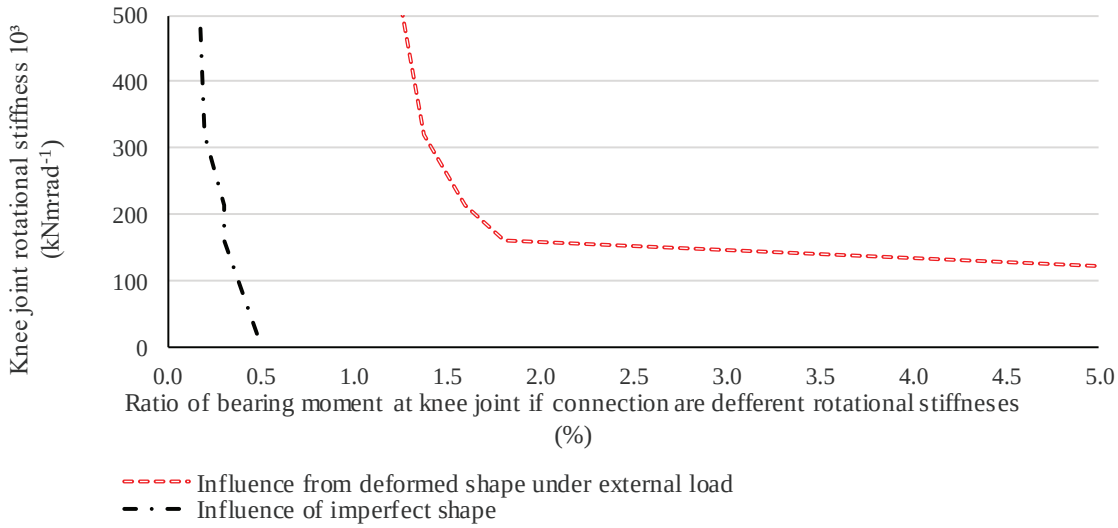

Figure 5. Influence of bearing moments according to timber portal frame knee joint stiffness.

Normally friction reduces rotational displacement of elements connected at the knee joint. But friction effect can't be assessed as longterm phenomena due to possible dimensional changes of timber under the influence of changing moisture content when contact surfaces may be interrupted.

Conclusions

Design assumptions for knee joints notably affect system's deformations under the external load, as well as internal force values. Developing deformations in the semi-rigid knee connection produce up to 90% bigger vertical displacement at an apex point and 96% bigger horizontal displacement at knee joint comparing with the rigid knee joint model.

Influence of semi-rigid behaviour of knee joint to values of internal forces is negligible. It is expected that bending moment increases of about 2% comparing with the traditional model.

Also, it is worthwhile to note that the portal frame behaviour under long-term loading may result to more unfavourable effects regarding increasing deformations.

Noticeable is the fact that semi-rigid rotational stiffness is directly dependant on the distance from a connection middle point and fasteners in external circle and moment capacity of the connection. It means that stiffness of semi-rigid connection will increase if the distance from the middle point until fasteners in external point will increase and overall moment capacity of connection will not decrease.

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THERMAL CONDUCTIVITY OF EXPERIMENTAL WALL CONSTRUCTIONS OF RENEWABLE INSULATING MATERIALS

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Abstract
Global scale environmental problems and economic issues are the main aspects what point out exigency to do research in the construction of renewable building materials. Renewable building materials are those materials that can be regenerated quickly enough and in theory, their production could be carbon-neutral. In order to evaluate the thermal efficiency of renewable materials in the framework systems of building envelope structures, test samples were made with the filling of renewable materials. The aim of the work is to find out the thermal conductivity coefficient of these natural composites and to compare them. Different size test samples were created for determination of thermal conductivity coefficient: 1.type as reference value: (width x height x depth) 290 x 290 x 30 mm; 2.type as experimental construction value (imitation of real wall construction): (width x height x depth) 980 x 980 x (165; 250; 345) mm. In this research as renewable insulating materials were used: maple leaves, legume (*Galega orientalis*), the composition of hemp shives (*Bialobrzeskie*) and sapropel with lime. A renewable insulating materials (also known as eco-thermal insulating) as alternative building materials discussed in this research work meets the requirements of the normative documents of the Republic of Latvia on sustainable construction principles. The analysis of results indicates significant difference among investigated materials – 0.040 W $m^{-1}K^{-1}$ lowest obtained value of thermal conductivity coefficient.
Key words: renewable insulating materials, thermal conductivity coefficient.

Introduction

Each eco-thermal insulating material has different properties but it shares the ecological origin of the inhabitants of heat-insulated premises providing a healthy environment for their health (RB&B EKOmateriāli, 2012).

Renewable materials contain natural fibres (e.g., jute, flax, hemp, cotton, cellulose), and have many positive properties: low thermal conductivity, low density, good specific tensile strength (Korjenic *et al*., 2011; Zach *et al*., 2013; Ku *et al*., 2011). The natural fibre materials have less impact on the nature (Korjenic *et al*., 2011; Papadopoulos, 2005; Visockis *et al*., 2016). Also, renewable building materiāls have lower embodied energy than conventional building materials (Myers, Fuller, & Crawford, 2012).

The publication compares the eco-insulation properties of monolithic and bulk maple tree leafs, hemp shives with sapropel binder, bulk legume (*Galega orientalis*) (Kolosovs & Rizkovs, 2016). These eco-source materials in the territory of Latvia can be obtained in huge quantities by providing ecosystem insulation manufacturers with work for many years and allowing economically justified industrialization of innovative ecosystem insulation production. Innovative eco-thermal insulation materials studied in the publication can be reused for different purposes. Eco-thermal insulation material originally purposed for the insulation of buildings, but after it served as a substrate for the cultivation of ecologically pure plants and finally was used as a fertilizer for increasing soil fertility by a completely recycling it in the environment. Production of innovative eco-thermal insulation materials consumes a minimum amount of materials, equipment and energy for the production technological process (Organiskais mēslojums dārzam, 2017).

Concept of evaluation of the thermal efficiency of renewable materials in the framework systems of building envelope structures was based on thermal conductivity coefficient comparison of 1.type (reference) and 2.type (experimental construction) samples. Proposed assumption: the concept must highlight the difference between methods of determination of thermal conductivity coefficient and scale factor influence on results. The method of determination of the thermal conductivity coefficient for the reference sample equates to the ideal working conditions, without any side influences contrariwise 2.type sample, there were turbulent cold air flow, heat flux and scale factor at the same time (building site conditions).The assumption for a scale factor influence: as the size of the test sample increases, also different deviation increases, so the thermal conductivity coefficient must alternate.

From previously defined conditions, the aim of the work is to find out the thermal conductivity coefficient of these natural composites at different sample types and working conditions and to compare them.

Materials and Methods

The following basic materials as fillers were used for preparation of testing samples: hempshives variety *Bialobrzeskie*, lime, maple leaves, legume (*Galega orientalis*).Testing sampleswere created for thermal conductivity coefficient determination in two different dimensions: 290x290x30 mm (for testing with device NETZSCH HFM 436 Lambda – as a reference value);

large scale samples (for testing in climate chamber Welltech YTH-1000Z/07-394B) 980x980 mm and with different thicknesses –345 mm for hemp shives mix with limeand sapropel, 165 mm for maple leaves; 250 mm for legume (*Galega orientalis*). The sample moisture measurements were carried out using Greisinger GMH-3830 Material moisture meter for general moisture assessment. The measurements were made in an ambient air temperature of ~ 25 °C.

Sample preparation of hemp shives mix with limeand sapropel: natural raw materials were obtained from different local companies. Sapropel was obtained from Ubagova Lake in Makoņkalns rural territory of Rezekne municipality, where LATPOWER Ltd is operating. Hemp shives were obtained from Latgale Agricultural Science Centre Ltd and processed in flax pre-treatment workshop in Preili (Pleiksnis *et al*., 2016). Hemp shives, sapropel, lime and water were mixed in a mixer to reach a plastic homogeneous mass. The mixture was packed in a wooden frame and sealed to obtain an optimum density of about 152 kg m^{-3}. The thickness of the sample was selected on the basic theoretical calculations and according to the Latvian Building code LBN 002-15. In previous studies, the optimal mass ratio of sapropel and hemp shives was determined 3:1. Binder mass is sapropel with additional water. Wooden frame was used as a mould and was filled with wet mixture of hemp shives and lime. Lime was added 5% of expected dry mass of mixture of hemp shives and lime. Wooden mould was kept vertically at filling process and mixture was filled at several steps. Sample was dried 168 hours in a natural way and 336 hours forced drying at 50 °C. The moisture of sample was measured at different depths – from 20 mm until 140 mm.

Sample preparation of maple leaves were harvested in Ludza Town Park. They were stored in bags to make sure for their long life. Experimental sample construction: a particle board box was created in size: width x height x depth 980 x 980 x 165 mm.

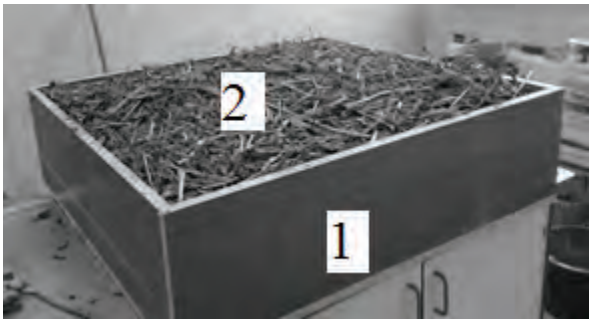

Figure 1. Test sample of 2.type as experimental construction. 1 – a particle board frame in size: width x height x depth 980 x 980 x 200 mm; 2 – renewable insulating material.

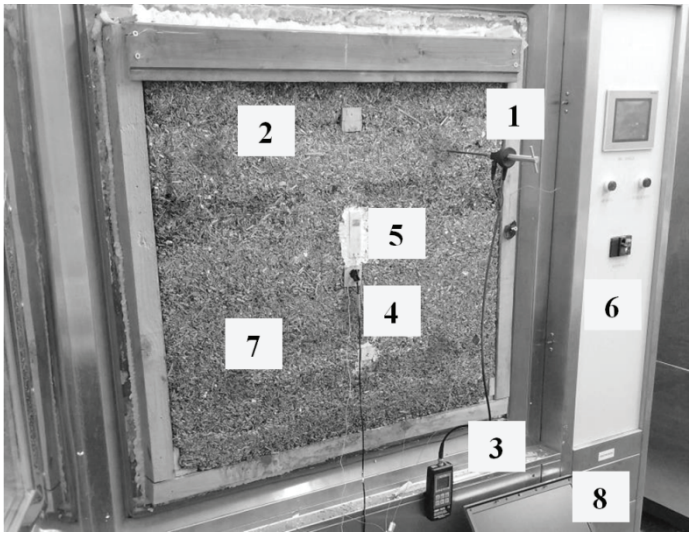

Figure 2. The testing process of thermal conductivity coefficient determination of experimental construction. 1 – moisture measurement device (injection probe Greisinger GSF 40); 2 – location of measurement points where the probe was injected in different depths; 3 – Greisinger GMH-3830 Material moisture meter; 4 and 5 – heat flux and temperature sensors; 6 – environmental chamber; 7 – test sample of 2.type (experimental construction);8 – data logger.

The particle board box was kept vertically at the filling process and filled with maple leaves at several steps. Mass of maple leaves was previously calculated for box volume to reach exact material density (ρ=30 to 40 kg m^{-3}). No additives were used for leaves. Sample was dried before filling 168 hours in a natural way and 336 hours forced drying at 50 °C. The moisture of sample was measured at different depths – from 20 mm until 140 mm.

Sample preparation of legume (*Galega orientalis*) – a particle board box was created in size: width x height x depth 980 x 980 x 250 mm. The particle board box creates a mould that was filled with legume at several steps. The particle board box was kept horizontally at the filling process. No additives were used to the legume. The sample was dried before filling 168 hours in a natural way and 336 hours forced drying at 50 °C. The moisture of sample was measured at different depths – from 20 mm until 140 mm. Apparent density of mixture about 45 kg m^{-3} was obtained. The moisture of sample was measured at different depths – from 20 mm until 140 mm.

The sample moisture measurements for all types of samples were carried out using Greisinger GMH-3830 Material moisture meter combined with an injection probe GSF 40.

The reference value of the thermal conductivity coefficient of samples was determined by using the NETZSCH HFM 436 Lambda device for 1.type (290 x 290 x 30 mm) samples, but for large samples – heat flux, temperature sensors and a mathematical calculation were applied. Equation of heat conductivity coefficient:

$$\lambda = \frac{qd}{T_1 - T_2} \quad (1)$$

where:

λ – heat conductivity coefficient, $Wm^{-1}K^{-1}$
q – heat flux, Wm^{-2}
d – thickness of sample, m
T_1 – temperature of room (positive),°C
T_2 – temperature of climate chamber (negative),°C

For thermal conductivity coefficient calculations assumption was used: the horizontal line (as general direction trend of the line) of temperatures and heat flux characterizes a stable period at the appropriate temperature difference.

Results and Discussion

A common feature for all graphs: all measurements were started when the experimental sample was installed and climate chamber was switched on; graphs are divided into periods of time which represent the status of the process; oblique position lines (as a general direction trend of the line) represent an alteration in the process; data of horizontal line (also as a general direction trend of the line) of temperatures and heat flux were used for thermal conductivity coefficient calculations. Slight positive temperature increase can be explained by the room temperature increasing because the climate chamber releases heat

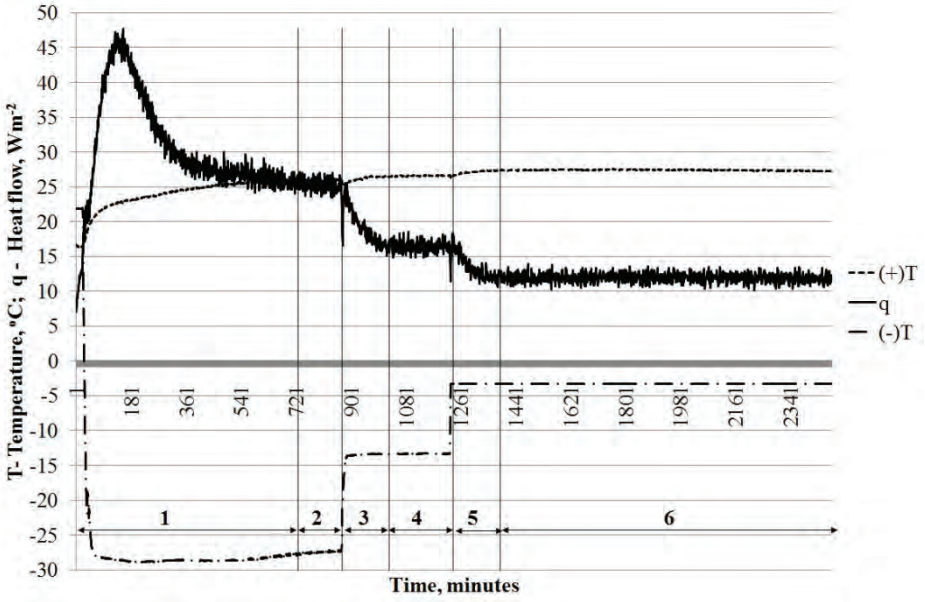

Figure 3. Maple leave sample, thickness 165 mm. Value of heat flux depending on differences of temperatures. Horizontal axis: Time – minutes, sampling rate – 1 sample each minute. Vertical axis: (+)T – positive room temperature, °C; (-)T – negative chamber temperature, °C; q – heat flux, W m^{-2} (only positive values). Temperature and heat flux values have the same scale. 1, 2, 3, 4, 5, 6 – time periods of change and stability for temperature and heat flux.

in the room. The negative temperature line represents the operation of the climate chamber.

Test results of maple leaves eco heat insulation, were used sample thickness 165 mm (Figure 3). Moisture content was measured before heat conductivity coefficient determination was carried out. Moisture of leaves from 7.4 to 9% was obtained. Measurements and calculation have been executed at different negative temperatures (-27 °C, -13 °C, -3.5 °C).

Description of Figure 3: 1 – period 0 to 770 minutes, period duration 770 minutes; switching on the climate chamber, adaptation of the heat flux sensor at specific temperatures; the rapid increase in heat flux would be explained by the initial state of the sample. 2 – period 770 to 900 minutes, period duration 130 minutes; (+)T and (-)T temperatures and q – heat flux period may be considered as stable and valid for calculations; calculated thermal conductivity coefficient 0.079 W m^{-1} K^{-1} at DT=52 K, (+)T 25 °C, (-)T -27 °C, q=25 W m^{-2}; 3 – period 900 to 1050 minutes, equalization period duration 150 minutes; switching negative temperatures in the climate chamber (increasing to -13 °C); 4 – period 1050 to 1240 minutes, period duration 190 minutes; (+)T and (-)T temperatures and q – heat flux period may be considered as stable and valid for calculations, calculated thermal conductivity coefficient 0.072 W m^{-1} K^{-1} at DT=39 K, (+)T 26 °C, (-)T -13 °C, q=17 W m^{-2}; 5 – period 1240 to 1420 minutes, equalization period duration 220 minutes; switching the negative temperature in the climate chamber to -3.5 °C; 6 – period 1420 to 2340 minutes, period duration 920 minutes; (+)T and (-)T temperatures and q – heat flux period may be considered as stable and valid for calculations, calculated thermal conductivity coefficient 0.070 W m^{-1} K^{-1} at DT=30.5 K, (+)T 27 °C, (-)T -3.5 °C, q=13 W m^{-2}. Thermal conductivity coefficient reference value of maple leave sample was 0.046 W m^{-1} K^{-1}.

General observation of maple leaf samples tests results: As the difference in temperatures decreases, the heat flux and the calculated thermal conductivity coefficient also decreases. An average time of 185 minutes (3 hours and 5 minutes) is needed to equalize the heat flux in a sample of 165 mm thick leaves (0.89 mm per minute).

Test results of legume (*Galega orientalis*), showed sample thickness 250 mm (Figure 4). Moisture content was measured before the thermal conductivity coefficient determination was carried out. Moisture of leaves from 6.5 to 8.5% was obtained. Measurements and calculations have been executed at different negative temperatures (-23 °C, -15 °C, -9 °C). Description of Figure 4: 1 – period 0 to 150 minutes, period duration 150 minutes; switching on the climate chamber, adaptation of the heat flux sensor at specific temperatures; 2 – period 150 to 370 minutes, period duration 220 minutes; (+)T and (-)T temperatures and q – heat flux period may be considered as stable and valid for calculations; calculated thermal conductivity coefficient 0.063 W m^{-1} K^{-1} at DT=40 K,

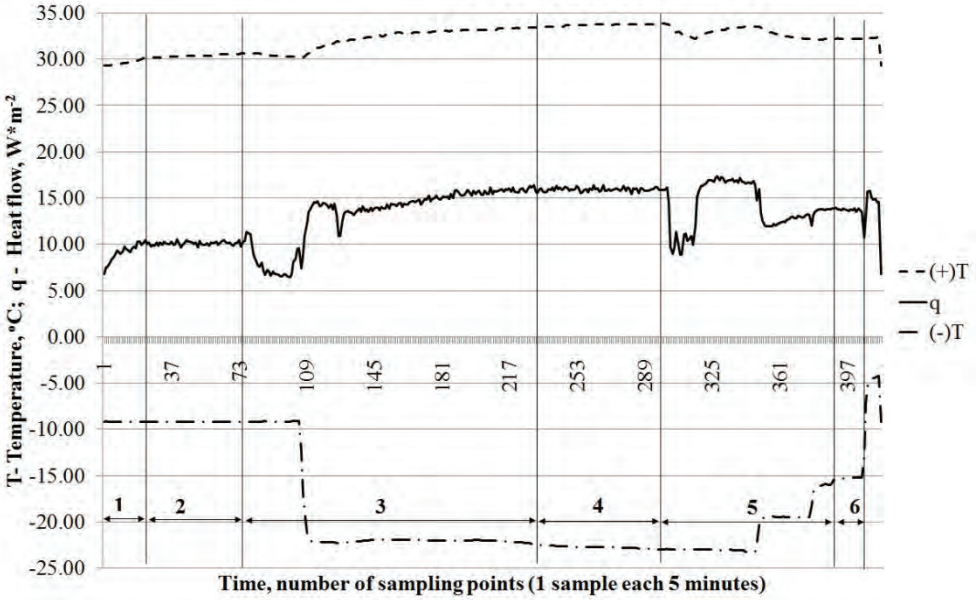

Figure 4. Legume (*Galega orientalis*) sample, thickness 250 mm. Value of heat flux depending on differences of temperatures. Horizontal axis: Time – minutes, sampling rate – 1 sample each minute. Vertical axis: (+)T – positive room temperature, °C; (-)T – negative chamber temperature, °C; q – heat flux, W m^{-2} (only positive values). Temperature and heat flux values have the same scale. 1, 2, 3, 4, 5, 6 time periods of change and stability for temperature and heat flux.

Table 1

Thermal conductivity of renewable materials

Materials	Thermal conductivity value, W m^{-1} K^{-1}		Density, kg $^{m-3}$
	1.type – reference	2.type (average value)	
Maple leaves	0.046	0.074	30.0 to 40.0
Legume (Galega orientalis)	0.040	0.069	45.0
Sapropel and hemp shives mixture	0.052	0.145	152.0 to 183.0
NatuHemp – hemp fibre (Black, 2019)	0.039	-	30.0
Thermafleece CosyWool – sheep's wool (Eden, 2019)	0.039	-	31.0
Straw bale (Costes *et al*., 2017)	-	0.062 to 0.079	60.0 to 125.0

(+)T 31 °C, (-)T -9 °C, q=10 W m^{-2}; 3 – period 370 to 1165 minutes, equalization period duration 795 minutes; switching negative temperatures in the climate chamber (decreasing to -23 °C); 4 – period 1165 to 1485 minutes, period duration 320 minutes; (+)T and (-)T temperatures and q – heat flux period may be considered as stable and valid for calculations, calculated thermal conductivity coefficient 0.073 W m^{-1} K^{-1} at DT=57 K, (+)T 33 °C, (-)T -23 °C, q=16.5 W m^{-2}; 5 – period 1485 to 1950 minutes, equalization period duration 465 minutes; switching the negative temperature in the climate chamber to -15.5 °C; 6 – period 1950 to 2030 minutes, period duration 80 minutes; (+)T and (-)T temperatures and q -heat flux period may be considered as stable and valid for calculations, calculated thermal conductivity coefficient 0.071 W m^{-1} K^{-1} at DT=47.5 K, (+)T 32 °C, (-)T -15.5 °C, q=13.5 W m^{-2}. Data sampling rate were: 1 sample every 5 minutes.

Thermal conductivity coefficient reference value of legume sample was 0.040 W m^{-1} K^{-1}.

Description of sapropel and hemp shives mixture results (not shown in the figure): 1 – period 0 to 815 minutes, period duration 815 minutes; switching on the climate chamber, adaptation of the heat flux sensor at specific temperatures; 2 – period 815 to 965 minutes, period duration 150 minutes; (+)T and (-)T temperatures and q – heat flux period may be considered as stable and valid for calculations; calculated thermal conductivity coefficient 0.145 W m^{-1} K^{-1} at DT=54.5 K, (+)T 27.5 °C, (-)T -27 °C, q=23 W m^{-2}. Thermal conductivity coefficient reference value of sapropel and hemp shives mixture was 0.049 to 0.054 W m^{-1} K^{-1}.

The value of the thermal conductivity coefficient obtained from the 2.type sample differs significantly from the reference value indicating the influence of the side effects. It points out the need to further investigate this issue. The data in Table 1 clearly show the difference between small samples (1.type samples, reference values) and large scale experimental samples (2.type samples). As mentioned in the literature (Costes *et al*., 2017) a quite significant influence on thermal conductivity has material density and fibre orientation (perpendicular or parallel to heat flux). As it was mentioned at the introduction and expected the testing conditions, scale factor via sample manufacturing technology and also a difference in density among samples, lead to the dissimilarity of thermal conductivity coefficient even for the sample of the same material. It is unexplored which of these factors do the most impact on obtained values. Also, for further investigations, the following variables must be included into account – density, humidity, fibre orientation and method of sample preparation.

Conclusions

1. Obtained results of thermal conductivity coefficient from reference samples (290 x 290 x 30 mm) are always better than large scale sample value. These points out the need to do further study of large-scale samples. It also points out the need to assess the variation of this nature in the design.
2. Experimental samples show the following trend: reference samples have lower values of bulk density and lower thermal conductivity coefficient, large samples have larger bulk density and also higher thermal conductivity coefficient values (leaves ρ=30 to 40 kg m^{-3}; leaves λ=0.046 to 0.074 W m^{-1} K^{-1}; legume ρ=45 to 50 kg m^{-3}; legume λ=0.040 to 0.069 W m^{-1} K^{-1}).
3. The values of the thermal conductivity coefficient obtained from renewable materials show a relatively sufficient competitive potential for materials on the market of building materials.

Considering that the actual working conditions of building envelope structures are going to be close to the 2.type test and based on the obtained values, the renewable materials mentioned in the article are not recommended to be used as thermal insulation materials without changing the application technology. Otherwise, it leads to the disproportionate thickness of building envelope structures (depends on local normative).

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ASSESSMENT OF LAND USE CHANGE SCENARIO TO INCREASE PRIMARY PRODUCTIVITY FUNCTION AT LOCAL SCALE

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Abstract
The global population has begun to rise exponentially; therefore, the demand for bioresources including food and fibre is increasing. An increasing demand for food and fibre necessitates more sustainable use of natural resources especially for soilbased ecosystem services. In this context, Functional Land Management was developed to optimize agricultural soilbased ecosystem services to meet both agricultural and environmental targets simultaneously. The aim of the research is to evaluate unmanaged agricultural land use change impact on primary productivity function in three parishes in Latvia by using Functional Land Management framework.
Evaluation of primary productivity function was accomplished for both sectors agriculture and forestry by using profit and working hours as a proxyindicators. Production of vegetables and perennial plantations have higher supply of primary productivity function comparing to other land uses.
Land use changes affect all soil functions that we expect from our land, especially primary productivity function. After applying land use changes, an increase in profit is higher in Liezere parish for both areas on mineral soils (7.1%) and areas on organic soils (5.2%); while an increase in working hours is higher in Usma parish: 36.6% in areas on mineral soils and 1.0% increase in areas on organic soils.
Shortterm benefits are received from agricultural land, while forest land provides long-term return which increases over time but can only be obtained after reaching the age of felling. Before applying land use changes or changes in management practices we have to consider other soil function and national commitments.
Key words: Functional Land Management, soil functions, agricultural land, forestry land, policy, production.

Introduction

The global population has begun to rise exponentially. In 2017, there were 7.6 billion people. The latest forecast shows that the world population will exceed 8.5 billion people by 2030 and 9.7 billion by 2050 (UN, 2017). This increases the demand for bioresources including food and fibre. This, in turn, necessitates more sustainable use of natural resources especially for soil-based ecosystem services.

Soil basically is non-renewable resource and provides many ecological and social functions (Mueller *et al*., 2010) and the key soil function 'food and biomass production' must be maintained sustainably (Blum, 1993). Therefore, the EU has established a framework for the protection of soil and the preservation of its capacity to perform environmental, socio-economic and cultural functions, namely biomass production, nutrient and water storage, filtering and transformation, carbon sequestration, the provision of a biodiversity pool, as well as a physical and cultural environment for humans, a source of raw materials and an archive of geological and archaeological heritage (EC, 2006).

In this context, multifunctional soil-based framework, called Functional Land Management (FLM), is developed to quantify the supply and demand of five soil functions, such as primary productivity, carbon sequestration and regulation, water purification and regulation, the provision and cycling of nutrients, and the provision of habitats for biodiversity (Schulte *et al*., 2014). Framework aims to optimize agricultural soil-based ecosystem services to meet both agricultural and environmental targets simultaneously. The performance of each soil function depends on land use and soil properties (Coyle *et al*., 2016). Coyle *et al*., (2016) expanded FLM framework by developing conceptual models for assessment of supply of each soil function, including the interrelation of land use and dominant soil property. In Ireland, wetness is the dominant soil property. Using results of conceptual models, soil matrix was created. Those soil matric can be used to show changes in suite of soil functions after implementations of various policy measures. Further framework was used to explore different scenarios for meeting agronomic and environmental objectives simultaneously (Valujeva *et al.*, 2016).

In Latvia, bioresources have a pivotal role to provide economic growth; therefore, Latvian Bioeconomy Strategy until 2030 was developed (LIBRA2030, 2017). One of the main opportunities for development of economy in Latvia is sustainable and efficient use of natural resources. Sustainable development of traditional bioeconomy sectors includes social, economic and environmental dimensions and also requires sustainable soil management. There are three main targets for development of traditional bioeconomy sectors, namely agriculture and forestry:

1. To increase a value added from agriculture and forestry sectors from EUR 2.33 billion in 2016 to EUR 3.8 billion in 2030;
2. To increase a value of bioeconomy production exports from EUR 4.26 billion in 2016 to at least EUR 9 billion in 2030;
3. To provide employment for at least 128,000 inhabitants.

Current research is limited to primary productivity function. The aim of the research is to evaluate unmanaged agricultural land use change impact on primary productivity function in three parishes in Latvia by using Functional Land Management framework. The main tasks of the research are 1) to quantify supply and demand of primary productivity function in three parishes in Latvia; 2) to identify possible pathways how to improve performance of primary productivity function. The object of the study is agricultural and forestry land in Latvia.

Materials and Methods

FLM in Latvia

FLM framework was adapted for Latvia. Data of agricultural land use and farming systems from the State Land Service, the Rural Support Service, Agricultural Data Centre, data of soil type and properties from digitized historical soil maps and land reclamation, and data of forest from the State Forest Service were collected within the project 'Evaluation of the land use optimization opportunities within the Latvian climate policy framework' (Nipers, 2019). Data collected within project was used to create land use and dominant soil property matrix by Valujeva *et al*., (in preparation). The land use of Latvia was divided into agricultural land and forestry land. Agricultural land had subdivisions, such as grain, oilseed, pulses (GOP), vegetables, perennial plantations, other crops, no crops, grasslands, not cultivated agricultural land and overgrown agricultural land, while forestry land had been divided into managed coniferous forests and managed deciduous forests, and natural coniferous forests and natural deciduous forests. In Latvia, management of organic soils is responsible for 50% of direct N2O emissions (NIR, 2018); therefore, the carbon content in soil was chosen as the main characteristic for soil properties.

Methodology for quantification of supply of and demand for primary productivity function

Within the project evaluation of socio-economic impact was accomplished for both sectors agriculture and forestry. Proxy-indicator for economic component was profit, but for social component - working hours. Profit for agriculture was a function of sold products, direct payments, and production costs including amortisation, while for forestry appreciation instead of profit was used. Average data of period 2014-2016 was used for determining profit per hectare. Appreciation per year was a multiplication of stock growth per year and a profit per m3 of wood in the end of production cycle. Workplaces were evaluated as a necessary hourly labour input per hectare per year for both agriculture and forestry. Profit and working hours were set per hectare. Methodology for quantification of profit and working hours were adapted for land use and soil property by Valujeva *et al*., (in preparation). Tabular index approach developed by Greiner *et al*., (2018) was used to create indicator from two indexes (profit and working hours) Valujeva *et al*., (in preparation). Gradient of 5 classes where 1 is low and 10 is high was used for mapping. In the study, quantification of supply of primary productivity function was done in polygon level for three parishes in Latvia.

Demand for primary productivity function is framed by regional and national planning documents, namely Development Programme of Kurzeme Planning Region for 2014-2020; Development Programme of Zemgale Planning Region for 2014-2020; Development Programme of Vidzeme Planning Region for 2014-2020; Latvia Bioeconomy Strategy 2030; National Development Plan of Latvia for 2014-2020; Sustainable Development Strategy of Latvia until 2030. Calculation of demand for each municipality in accordance to targets framed by Bioeconomy Strategy are accomplished by Valujeva *et al*., (in preparation). Indicator was created from target for value added from agriculture and forestry sectors and unemployment rate (Valujeva *et al*., in preparation).

Case studies

In the study, the methodology developed by (Nipers, 2019) and expanded by (Valujeva *et al*., in preparation) was used to quantify the supply and demand in three different parishes of Latvia, namely Usma, Zalenieki, Liezere. Distribution of land uses in relation to soil carbon content for each parish was shown in Table 1. Usma parish is located in North-West part of Latvia in Ventspils municipality; the land area is 219.35 km^2, population was 527 inhabitants and unemployment rate was 5.7% (SRDA, 2016) in 2018. In Usma parish, 62% of total area is covered by forests, 7% of total area is used for agricultural purposes and 25% of agricultural land in Usma parish is not cultivated or overgrown (Table 1). In Usma, 25% of agricultural and forestry land is located on organic soils. Zalenieki parish is located in Jelgava municipality; the land area is 122.16 km^2, population was 1,486 inhabitants and unemployment rate was 3.9% (SRDA, 2016) in 2018. The main land use in Zalenieki parish is agricultural land which covers 71% of total area and 0.6% of agricultural land is not cultivated or overgrown, but only 14% of total area

Table 1

Areas of land use in Usma, Zalenieki, Liezere parishes

Land use	Usma parish, ha		Zalenieki parish, ha		Liezere parish, ha	
	Mineral soil	Organic soil	Mineral soil	Organic soil	Mineral soil	Organic soil
GOP	131.0	9.4	7,514.0	0.1	490.0	66.8
Vegetables	6.0	0.0	80.0	0	1.0	0
Perennial plantations	1.0	0	26.0	0	13.0	0
Other crops	172.0	18.0	766.0	0	1,110.0	138.0
No crops	280.7	44.9	209.4	0	659.1	228.2
Grassland	371.0	54.0	54.0	1.0	2,147.0	287.0
Not cultivated agricultural land	242.0	70.0	42.0	0	218.0	49.0
Overgrown agricultural land	42.0	17.0	8.0	0	583.0	84.0
Managed coniferous forest	7,315.0	1,945.5	551.99	33.4	3,666.8	954.38
Managed deciduous forest	1,133.2	1,027.6	901.8	152.9	7,000	1,807.2
Natural coniferous forest	1,187.2	481.1	63.7	0	8.6	0
Natural deciduous forest	258.0	135.0	26.5	0.3	4.0	0
Total	11,139.1	3,802.5	10,243.39	187.7	15,900.5	3,614.58

Source: authors' calculations based on Nipers, (2019).

is covered by forests (Table 1). In Zalenieki, 2% of agricultural and forestry land is located on organic soils. Liezere parish is located in North-East part of Latvia in Madona municipality; the land area is 254.70 km^2, population was 1,285 inhabitants and unemployment rate was 7.20% (SRDA, 2016) in 2018. 53% of total area in Liezere parish is covered by forests, 24% is agricultural land and 15% of agricultural land is not cultivated or overgrown (Table 1). In Liezere, 19% of agricultural and forestry land is located on organic soils.

Scenarios

In the study, the land use change scenario impact on primary productivity function was explored. The land use changes included the return of not cultivated and overgrown agricultural land to agricultural production depending on soil quality rate: soil quality points less than 25 means that it is more suitable for forestry; soils with a quality rate in the range between 25 and 38 points is suitable for grass production; soil with quality points in the range from 38 to 77 is suitable for crop production. The scenario included the following land use changes: 1) the land use change from not cultivated and overgrown areas on mineral soils with soil quality points less than 25 to managed coniferous forests on mineral soils; 2) the land use changes from not cultivated and overgrown areas on organic soils to managed coniferous forests on organic soils; 3) the land use changes from not cultivated and overgrown areas on mineral soils with soil quality points in the range from 25 to 38 to grassland on mineral soil; 4) not cultivated and overgrown areas with soil quality points in the range from 38 to 77 on mineral soils were equally distributed between GOP, vegetables, perennial plantations, and other crops on mineral soils.

Results and Discussion

National demand for primary productivity in Latvia is framed by Latvia Bioeconomy Strategy 2030. There is no demand at municipality level, but Valujeva *et al*., (in preparation) has divided national target into regional targets depending on regional GDP target, share of agriculture, forestry, fisheries and unemployment rate at municipality level. The demand for primary productivity function is higher in Usma and Zalenieki, but lower in Liezere.

Supply of primary productivity function, with proxy-indicators profit and working hours, strongly relates to the land use and soil class. A higher supply of primary productivity function is in Zalenieki parish, while the supply of primary productivity function in Usma and Liezere parishes is distribution between low and high supply (Figure 1). Areas with low supply are not cultivated and overgrown agricultural land, and no crop areas which means that those areas are not used to produce goods for market or there is no available information. Total area with low supply of primary productivity function in Usma is 2,662 ha, in Zalenieki 270 ha, but in Liezere 3,054 ha.

Table 2 shows that GOP and vegetables grown on mineral soils have higher profits in Zalenieki compared to Usma and Liezere. Comparing perennial plantations on mineral soils in all parishes: the profit in Zalenieki is EUR 75,400 per year, which is 50% more than in Liezere and 26 times more than in Usma. Profit from other crops is the highest in Liezere, where it

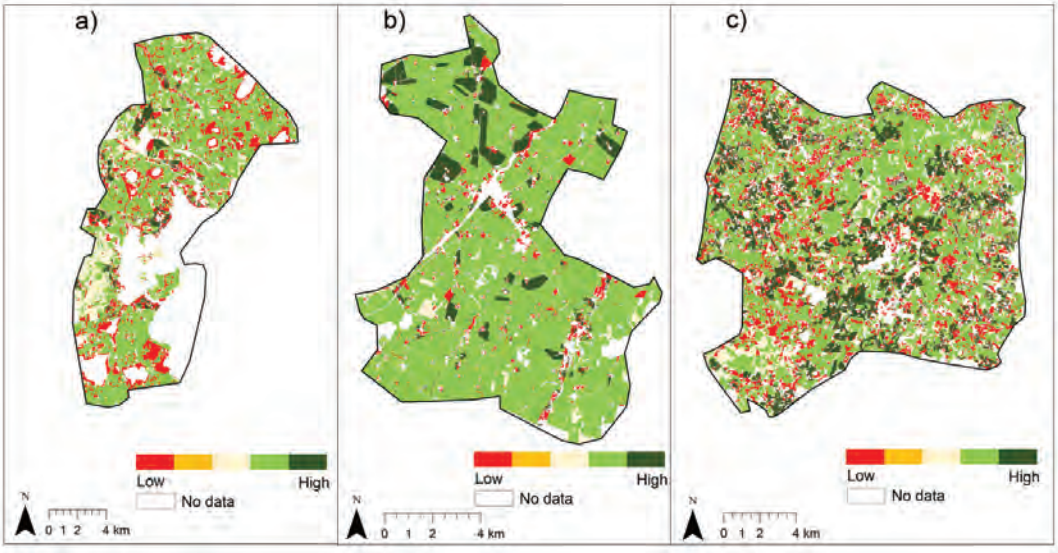

Figure 1. Supply of primary productivity function: a) Usma parish; b) Zalenieki parish; c) Liezere parish.

Source: authors' construction based on Nipers, (2019) and Valujeva *et al*., (in preparation).

reaches EUR 333,000 per year, while in Zalenieki the profit is almost EUR 300,000 per year, but in Usma the profit is about 6.4 times smaller than in Liezere.

The highest profit in managed coniferous forests is observed in the parish, where the forest canopy predominates: the profit in Usma is EUR 1,975,050 per year which exceeds the profit in Liezere by almost one million and which is 13 times more than in Zalenieki where the agricultural land predominates. In managed decidious forest, higher profit is observed in Liezere (EUR 1,050,000 per year), while in other parishes the profit exceeds EUR 100,000 per year. Natural coniferous forests have the highest profit in Usma: the profit is reaching EUR 160,272 per year. The profit from natural decidious forests in Usma is EUR 19,350 per year, while in Zalenieki the profit is only EUR 133 per year, but in Liezere there are no natural decidious forests.

Table 3 shows that GOP, vegetables, and perennial plantations grown on mineral soils have higher

Table 2

Profit in EUR per year for land use and soil class combinations in Usma, Zalenieki and Liezere parishes

Land use	Usma parish		Zalenieki parish		Liezere parish	
	Mineral soil	Organic soil	Mineral soil	Organic soil	Mineral soil	Organic soil
GOP	9,170	141	**525,980**	2	34,300	1,002
Vegetables	8,700	0	**116,000**	0	1,450	0
Perennial plantations	2,900	0	**75,400**	0	37,700	0
Other crops	51,600	3,600	229,800	0	**333,000**	27,600
No crops	0	0	0	0	0	0
Grassland	37,100	3,780	5,400	70	**214,700**	20,090
Not cultivated agricultural land	0	0	0	0	0	0
Overgrown agricultural land	0	0	0	0	0	0
Managed coniferous forest	**1,975,050**	157,586	149,037	2,705	990,036	77,305
Managed deciduous forest	169,980	46,242	135,270	6,881	**1,050,000**	81,324
Natural coniferous forest	**160,272**	19,485	8,600	0	1,161	0
Natural deciduous forest	**19,350**	3,038	133	7	0	0
Total	2,434,122	233,871	1,245,619	9,664	2,662,347	207,321

Source: authors' calculations based on Nipers, (2019) and Valujeva *et al*., (in preparation).

Table 3

Working hours EUR per year for land use and soil class combinations in Usma, Zalenieki and Liezere parishes

Land use	Usma parish		Zalenieki parish		Liezere parish	
	Mineral soil	Organic soil	Mineral soil	Organic soil	Mineral soil	Organic soil
GOP	3,275	235	**187,850**	3	12,250	1,670
Vegetables	3,000	0	**40,000**	0	500	0
Perennial plantations	600	0	**15,600**	0	7,800	0
Other crops	26,660	2,790	118,730	0	**172,050**	21,390
No crops	0	0	0	0	0	0
Grassland	11,130	1,620	1,620	30	**64,410**	8,610
Not cultivated agricultural land	0	0	0	0	0	0
Overgrown agricultural land	0	0	0	0	0	0
Managed coniferous forest	**21,945**	1,751	1,656	30	11,000	859
Managed deciduous forest	3,400	925	2,705	138	**21,000**	1,626
Natural coniferous forest	**2,374**	289	127	0	17	0
Natural deciduous forest	**516**	81	53	0	8	0
Total	72,900	7,690	368,342	200	289,036	34,155

Source: authors' calculations based on Nipers, (2019) and Valujeva *et al*., (in preparation).

working hours in Zalenieki compared to Usma and Liezere. A managed coniferous forest, natural coniferous forest, and natural deciduous forest on mineral soils provide higher working hours in Usma parish, while other crops, grassland and managed deciduous forest provide higher working hours in Liezere. Higher working hours from areas on organic soils are observed in Liezere parish (EUR 34,155 per year): compared to Usma (EUR 7,690 per year) and Zalenieki (EUR 200 per year) (Table 3).

Improvements in supply of primary productivity

Firstly, not cultivated and overgrown agricultural land on mineral soils with soil quality points less than 25 on mineral soils are transferred to managed coniferous forests on mineral soils, because biomass production in intensively managed forests is on average 26% higher than in unmanaged forests (Karttunen *et al*., 2018) and higher potential for biomass production is shown by coniferous stands (Nord-Larsen and Pretzsch, 2017). Secondly, not cultivated and overgrown agricultural land on organic soils is transferred to managed coniferous forests on organic soils, because afforestation of well-drained organic soils increases biomass production (Weslien *et al*., 2009), also this measure increases carbon sequestration in the soil, which is another soil function which we expect from our soils although we are not investigating that in this study. Thirdly, not cultivated and overgrown agricultural land on mineral soils with soil quality points in the range from 25 to 38 are transferred to grassland. Fourthly, not cultivated and overgrown agricultural land with soil quality points in the range from 38 to 77 on mineral soils is equally distributed between GOP, vegetables, perennial plantations, and other crops on mineral soils.

After applying land use changes to areas on mineral soils, the increase in profit is 5.6%. A higher increase in profit is observed in Liezere parish (7.1%), while lower increase in profit is in Zalenieki parish (2.2%), but the increase in Usma parish is 5.6% (Figure 2). An increase in the supply of primary productivity function on organic soils is on average 4.0%. A higher increase is observed in Liezere (5.2%), but a lower increase is observed in Usma (3.0%). In Zalenieki, there are no not cultivated or overgrown agricultural land on organic soils. A higher increase in working hours after land use changes on mineral soils is in Usma (36.6%) and Liezere (7.6%), but in Zalenieki the increase is only 2.0% (Figure 2). An increase in working hours after land use changes on organic soils from not cultivated and overgrown to managed forests is in the range from 0.4% in Liezere to 1.0% in Usma.

Food and fibre is not the only social demand for our land that we expect. We also expect carbon storage and regulation, nutrient cycling, water purification and provision of habitat for biodiversity (Schulte *et al*., 2014). Therefore, before applying land use changes or changes in management practices we have to consider other soil function and national commitments. Climate-smart land management is a key to achieve socio-economic and environmental targets; therefore, further research is necessary to explore how these land use changes affect other soil functions, namely climate function and biodiversity.

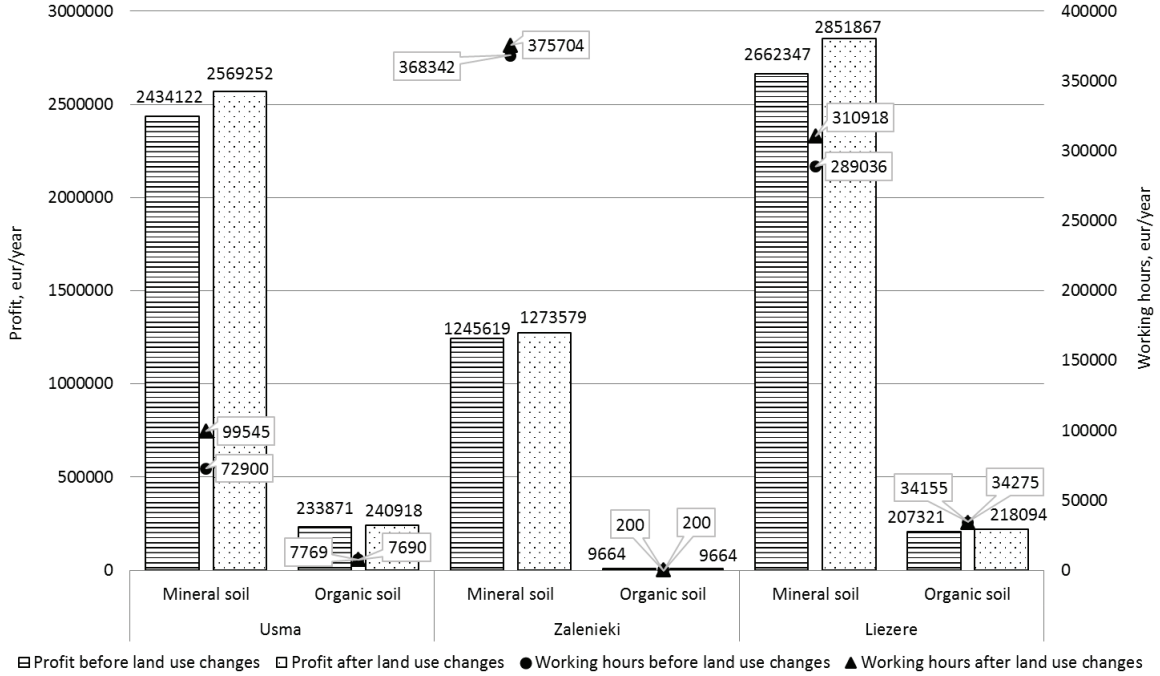

Figure 2. Profit and working hours before and after applying land use changes in Usma, Zalenieki and Liezere parishes.

Source: authors' construction.

Conclusions

Soil is non-renewable resource and provides food and biomass production for society. Also, it provides many other ecological and social functions like water purification, habitat for biodiversity, nutrient cycling, and carbon sequestration and regulation. Therefore, protection of soils and the preservation of its capacity to perform socio-economic and ecological functions is necessary.

Land use changes affect all soil functions that we expect from our land, especially primary productivity function. Higher profit and working hours are observed from areas on mineral soils. Short-term benefits are received from agricultural land, while forest land provides a long-term return which increases over time but can only be obtained after a reaching the age of felling. Before applying land use changes or changes in management practices we have to consider other soil function and national commitments.

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THE PIG FEEDING AND NITROGEN ASSOCIATED GASEOUS EMISSIONS IN LATVIA

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Abstract
The research paper focuses on description of the pig (*Sus scrofa domestica*) farming tendencies in Latvia with the scope to give feeding characteristics in relation to emission outcome. In the recent years the concentration of pigs in farms with a herd size more than 10,000 has increased. With increase of the large farms the average feed consumption is more affected by one operator. Efficient utilization of nutrients content in feeding is crucial to meet environmental goals. It is one of the steps to achieve Nutrient Use Efficiency. There is relationship between crude protein and reduction of reactive nitrogen. Feed content not only affects excreted nitrogen, but also pH of manure and total ammoniacal nitrogen. It is complex abatement measure to quantify reduction of the emission because of impact of various environmental factors. In Latvia, the most common are sows cross breeds (Yorkshire × Landrace) and on January 1, 2019 the biggest group accounted was fattening pigs with average dry feed consumption per day from 0.33 kg (liveweight from 5 to 6 kg) up to 3.6 kg (liveweight from 80 to 120 kg) with crude protein value from 163.5 g to 155.3 g per 1 kg feed dry matter. Excreted nitrogen (N_{ex}) was calculated for these groups of pigs less than suggested values in guidelines for emission calculation. The highest calculated total NH_3 emission is from fattening pigs group with liveweight from 55 to 90 kg although the highest calculated N_{ex} is for lactating sows. NO_x also calculates as NO_2 and the highest value was 3.23 g per one lactating sow.
Key words: pig feed, nutrient content, reactive nitrogen, crude protein, manure management.

Introduction

The demand for food production altered the land-based cycle of nitrogen causing harm for human health, environment and economics. Improvement of nutrient use in animal production is one of the key actions to achieve Nutrient Use Efficiency. The negative effects of abundance of nitrogen not only affects water quality and biodiversity, but also decreases the air quality including increased global warming effect by more reactive gas than CO_2 – N_2O (Sutton *et al.*, 2013). Reduction of the emissions is in scope of the EU National Emission Ceiling Directive (Directive 2016/2284/EU). Traditionally the aim of pig (*Sus scrofa domestica*) breeder is to achieve high increase in liveweight of pigs and reproduction rates with minimum feed consumption and low feed costs. Excessively high levels of dry matter, protein, minerals and other nutrients in doses of pig feed increases water consumption, manure and urine output. Non-digested nutrients enter the ecosystem increasing environmental impact described previously.

As pigs are monogastrics, digestion of all nutrients takes place mainly in the endemic process. The main energy amount for pigs is protein, fat, starch and fibre. Minerals and vitamins are also important to ensure physiological processes. There are many researches investigating the effect of adaptation of feeding strategies to reduce nitrogen loss by manure. Sajeev *et al.* have published a meta-analysis discussing the potential of crude protein (CP) adjustment to meet the aim of ammonia (NH_3) reduction for cattle and pigs. Fourteen published works were used to determine the effect of reduction CP on NH_3 and total ammoniacal nitrogen (TAN). The conclusions show that there is a relationship between CP and NH_3. There is on average 11 ± 6% reduction of NH_3 per %-point of CP (Sajeev *et al*., 2017). Canth *et al*. research includes experimental data on growing pig after reduce of CP level. Two way experiment where performed. Measurements made in metabolism cages and farm level (housing type – slatted floor compartment). Initial CP level was 16.5% and 14.5% which was reduced by 2% and 4% respectively. Reduced NH_3 emission was similar for both experiments with a little bit higher efficiency in farm level. About twice higher reduction level determined for 4% reduction of CP compared to 2% CP reduction. There was a positive effect on manure pH and TAN, which are also factors of reduced NH_3 emissions (Canh *et al*., 1998). The highest effect on NH_3 is described in the research by Portejoie *et al.* for barrows fresh slurry. Reduction of NH_3 emission was about 76% with much greater reduction of the CP because of high initial CP level (20%). The CP reduction was 8 CP % (Portejoie *et al*., 2004). The results of researches are various because of differences in methodology and impact of environmental factors. Reduction of NH_3 emission depends on lowering level of CP with coefficient of determination 0.53 (Sajeev *et al*., 2017). An alteration of CP is not the only way to impact NH_3 emissions from manure. Increasing the non – starch polysaccharides by 100 g can lower pH of the slurry by 0.12 units according to the research of Jha and Berrocoso (Jha & Berrocoso, 2016).

The aim of the study is to estimate the current effect of feeding strategies of Latvian pig production, its tendencies and estimate impact on greenhouse gasses (GHG) and ammonia emissions for the purpose

to assess options to optimize feed composition for reduction of gaseous emissions.

Materials and Methods

Statistical data of the number of pigs in Latvia are based on data collection of the Agricultural Data Centre (Agricultural data centre, 2019). Pig numbers are represented in groups according to the herd size. Surveys about pig feeding on pig holdings with more than 1000 pigs have been carried out in cooperation with the Latvian Association of Pig Growers (n=5) during 2015-2018. Recipes have also been obtained from main pig feed producers (n=5). For analyses average data is used and represents the major tendency of pig feeding strategies. Emission in relevance to reactive nitrogen is evaluated theoretically.

The main factor that influences excreted nitrogen (N_{ex}) is the diet of the livestock. Input – output measurements or balance method was used for estimating N_{ex} by pigs assuming that the amounts of N_{ex} in faeces and urine is equal to the total amounts of feed N consumed minus the amounts of N in the pigs product. Equation (1) was used to calculate annual N excretion rate.

$$N_{ex} = N_{intake} \cdot (1 - N_{retention}),$$
kg N animal^{-1} year^{-1} (1)

The annual total nitrogen intake per pigs is calculated by Equation 2. Values fraction of annual N intake that is retained by pigs ($N_{retention}$) for the study is adopted from in-depth analyses of country reports on nitrogen excretion factors of livestock (Šebek *et al*., 2014).

$$N_{intake} = \frac{GE}{18.45} \cdot \left(\frac{CP}{6.25}\right),$$
kg N animal^{-1} year^{-1} (2)

In Equation (2) gross energy intake of the animal (GE, MJ animal^{-1} day^{-1}), conversion factor for dietary GE per kg of dry matter (18.45 MJ kg^{-1}) are used. This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock. CP in diet (%) and conversion from kg of dietary protein to kg of dietary N, kg feed protein (kg N)$^{-1}$ – 6.25 are also used in Equation 2.

Equation 3 was used to calculate gross energy intake by pigs using energy intake for maintenance and growth of pigs (ME, MJ animal^{-1} day^{-1}) and digestible energy of gross energy of pigs (DE, %).

$$GE = \frac{ME}{DE}, \text{ MJ animal}^{-1} \text{ day}^{-1} \quad (3)$$

Intergovernmental Panel on Climate Change Guidelines methodology 2006 and emission factors were used to estimate N_2O emissions from manure management of pigs (Intergovernmental …, 2006). Feed digestibility was obtained from the catalogue of forage digestibility and chemical analysis study under 2009-2014 EEA Grants Programme National Climate Policy and financial support for the project 'Agricultural sector GHG emissions calculation methods and data analysis with the modelling tool development, integrating climate change' (Degola, Trūpa, & Aplociņa, 2016). Ammonia emissions are calculated using European Monitoring and Evaluation Programme and European Environment Agency Guidebook 2016 Tier 2 approach. Emission coefficients used are default (European Environmental Agency, 2016).

It is assumed for calculations that pigs are housed all year with slurry manure management system. Emissions are calculated for one animal unit per defined pig group per year.

Results and Discussion

When the term protein is used in pig production, we immediately understand that it is a protein that is complete, or that in which essential amino acids are in certain ratio, so that animals achieve positive yields. Pigs have 5 major essential amino acids - lysine, methionine + cysteine, threonine, tryptophan and valine. Each amino acid performs a specific function, so it is important to control their contents and ratio. In practice, when drawing up feed doses for fattening pigs the following amino acid ratios are used:

- lysine – 1.00;
- methionine + cysteine – 0.56;
- threonine – 0.63;
- tryptophan – 0.18;
- valine – 0.58.

In pig feeding, it is important to respect not only the ratio of amino acids, but also their ratio to the maintenance energy (ME). This is important because if there is no adequate energy supply, protein use will not be efficient and overall metabolic processes may be disrupted. In practice, it is important to control the energy to lysine ratio (Table 1).

Table 1

Maintenance energy / lysine ratio for fattening pigs

Animal liveweight, kg	10 – 30	30 – 60	60 – 90	90 – 120
Lysine: ME	0.93	0.80	0.64	0.52
Digestible lysine: ME	0.82	0.70	0.55	0.44

In practice, the following amount of fat in the feed dose is maintained:

- 2.0 – 2.6% for pregnant sows;
- 3.5 – 4.5% for lactating sows;

Table 2

Change in number of pigs by herd size

Pig holding groups	Number of pigs by year							
	2011	2012	2013	2014	2015	2016	2017	2018
1 – 9	6,122	3,794	3,560	7,205	7,171	9,174	11,798	10,539
10 – 50	14,628	11,710	11,925	10,729	9,330	10,074	10,695	9,554
51 – 100	7,334	5,865	5,797	5,041	4,367	3,484	3,762	3,108
101 – 500	17,894	14,465	10,134	7,429	6,714	9,798	6,198	6,121
501 – 1,000	12,876	5,664	6,841	9,439	9,066	6,097	5,148	3,737
1,001 – 5,000	46,692	57,495	43,032	58,809	55,247	36,020	36,642	33,884
5,001 – 10,000	66,533	60,170	48,721	48,186	69,455	48,781	52,490	52,095
> 10,000	158,685	151,318	181,239	171,989	167,507	204,266	203,997	202,465

- 7.0 – 10.0% for suckling piglets;
- 5.0 – 6.0% for separated piglets;
- 3.0 – 4.0% for fattening pigs up to 30 kg;
- 2.5 – 3.0% for fattening pigs (30 – 60 kg);
- 2.0 – 2.5% for fattening pigs (60 – 115 kg).

A significant energy source in pig nutrition is starch. The main source of starch is the cereals included in the feed dose. In the Baltic region, the main used cereals are barley, wheat and triticale. The starch in pig feed on average is between 40% and 55%. The level of starch in feed is determined by the proportion of cereals and, as it will be higher, the higher the level of starch. The soybeans contain a large amount of protein required in the pig feed dose, but in the pig feed production practice, the fat and protein components are added separately. It is convenient for diversification of feed to meet the required protein and fat levels according to each age group of pigs.

It is also important for pig health and good digestive tract function to control the amount of neutral detergent fibres (NDF) in feed. Crude fibre makes animals feel sate, they are peaceful, stress level, aggression and cannibalism is decreased. This is particularly important for groups of pregnant sows and for the final fattening period, when NDF should be planed 13.0 – 14.5%. Crude fibres are mainly contained in compound shells of feed materials. A high percentage of NDF is in feed with high concentration of barley, rapeseed and dried beet grasses in feed.

The total number of pigs in Latvia on July 1, 2018 was 321,748. The number of pigs in Latvia is fluctuating, affected by the economic situation in Latvia and Europe, diseases, feed costs and other conditions.

There is a tendency to increase of small pigs holdings (1 – 9 pigs) by 2018, while the number of pigs in those holdings is small, approximately 3.2% of the total number of pigs (Table 2). In Latvia, 90% of total number of pigs is concentrated in large holdings, with more than 1,000 pigs in the herd (Table 2). These holdings are modern and use diversified feeding strategies with balanced protein, vitamin, mineral and other additives content.

In Latvia, the most common are cross breeds (Yorkshire×Landrace) – 44.3% and Landrace – 35.4% sows according to Agricultural data centre pig recording data (Figure 1).

Pig catering on these holdings is complete and provides pigs with all the necessary nutrients. Growers

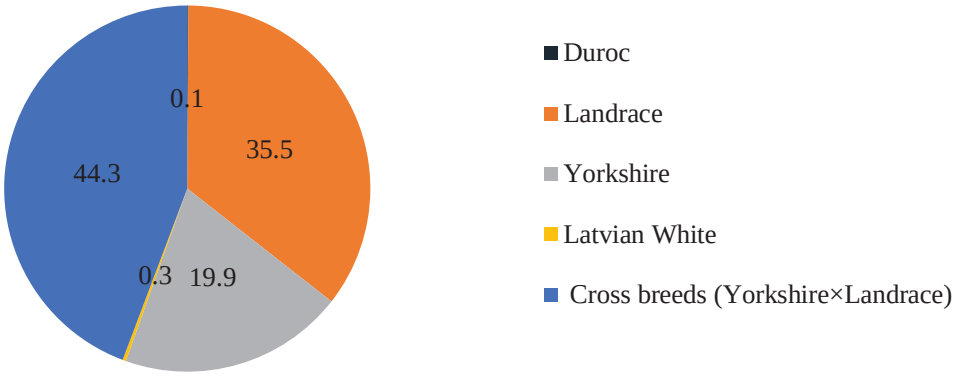

Figure 1. Distribution of sow breeds according to Agricultural data centre pig recording (%).

Table 3

Average feed nutrient content in 1 kg of feed dry matter

Nutrients	Pregnant sows	Lactating sows	Piglets, 8 – 15 kg	Pigs, 15 – 30 kg	Pigs, 30-60 kg	Pigs, 55 – 90 kg
Maintenance energy, MJ	12.4	13.3	13.5	12.9	12.8	12.8
Crude protein, g	133.2	150.2	163.5	179.3	165.3	155.3
Digestible protein (%)	74.9	81.4	84.4	82.3	80.6	79.5
Starch, g	470.0	457.3	454.9	429.5	454.4	471.5
Fat, g	24.9	44.3	35.6	27.6	22.9	22.9
Lysine, g	7.1	9.8	13.7	12.8	11.1	9.9
Digestible lysine, g	5.8	8.8	12.6	11.6	9.7	8.6
Digestible met.+ Cist., g	4.3	6.0	7.2	7.4	5.3	5.0
Digestible met., g	2.0	2.8	3.5	3.6	2.6	2.4
Digestible threonine, g	3.9	5.5	8.0	7.4	6.0	5.5
Digestible tryptophan, g	1.1	1.8	2.0	1.9	1.7	1.6
Digestible valine ,g	4.6	4.6	5.0	4.7	4.5	4.8
Ca, g	6.6	7.8	8.2	7.8	6.9	6.2
P, g	4.8	4.9	5.0	5.5	4.8	4.7
Digestible P, g	2.1	2.5	2.7	2.8	2.1	2.1
Crude fibres, g	41.2	32.4	26.4	34.7	36.1	36.4
Neutral detergent fibre, g	150.0	120.0	80.0	100.0	140.0	145.0

cooperate with foreign counterparts and consultation firms. Different additives are used to balance feed. The average content of nutrients in feed for groups of different liveweights is shown in Table 3. Average CP for all pig groups is 157.8 g per kg of feed or 15.8%. The highest CP content is on average 17.9% and it is typical for pigs in growing period with liveweight 15 – 30 kg.

There are completed feed producers for pigs as 'LRS Musa'. Feed materials: wheat (*Triticum*), barley (*Hordeum vulgare*), triticale (*Triticosecale*), maize (*Zea mays*), pea (*Pisum*) bran, rye (*Secale*) bran, soya bean (*Glycine max*), rapeseed (*Brassica napus*), dried sugar beet (*Beta vulgaris*) chips, sunflower (*Helianthus annuus*) cake, sugar beet molasses, plant oil, minerals, amino acid and vitamin additives,

Table 4

Average daily consumption of dry matter and total protein of feed per pig

Group of pigs	Feed dry matter, kg	Crude protein in dry matter, g
Lactating sows (liveweight from 180 up to 300 kg)	1.53 + 0.41 per piglet (6.0 – 8 kg)	901 – 1,202
Sows after lactation, in 30 – 35 day period (liveweight from 180 up to 280 kg)	2.70 – 3.15	360 – 420
Pregnant sows (liveweight from 180 up to 200 kg):		
pregnancy period 0 – 35 days	1.80 – 2.25	240 – 300
pregnancy period 30 – 85 days	2.25 – 2.70	300 – 360
pregnancy period 85 – 115 days	3.10 – 3.60	413 – 480
Fattening pigs		
liveweight from 5 up to 6 kg	0.33	54
liveweight from 10 up to 18 kg	0.94	169
liveweight from 30 up to 60 kg	1.25	207
liveweight from 60 up to 80 kg	2.70	420
liveweight from 80 up to 120 kg	2.70 – 3.60	440 – 587

Table 5

Breakdown of pig number per group according to Agricultural Data centre pig recordings for January 1, 2019

Pig group	Pig number	% of total pig number
Total pig number	302,800	100.0
Sows	22,398	7.4
Boars	431	0.1
Fattening pigs	138,763	45.8
Piglets	45,609	15.1
Weaning piglets	82,946	27.3
Gilts	4,627	1.6
Growing pigs	8,026	2.7

mycotoxins binders. In feed recipes of these producers cereal amount are at 66 – 85% and soya, sunflower sprouts or rapeseed from 5 – 18%, depending on the demand of specific age group of pigs. Other feed companies also produce complete feed for pigs, such as 'Dobeles Dzirnavnieks', 'Straume', 'Baltic Feed' and other. However, the largest proportion of big holdings prepare feed themselves, using their own grown or purchased grains, rapeseed, soya and sunflower sprouts or cakes, bran, vegetable oil. Mineral, vitamin and amino acid additives are used for feed material on the demand of specific age group of pigs.

The feed consumption has been calculated (Table 4) for the dry feeding, which may also be diluted with water. It is complete, assuming that the dry matter in feed is 88%. Daily the highest consumption of CP is for lactating sows and finishing pigs (80 – 120 kg) because of high consumption of the feed.

In accordance with Agricultural data centre pig recordings for January 1, 2019 the biggest group is fattening pigs (45.8%) and weaning piglets – 27.3% (Table 5).

Pigs on small holdings from 1 to 9 pigs in the herd may consume higher quantities of feed, as the feed may sometimes be unbalanced by nutrient (not only forage, but also scraps of food, root crops and other compounds are used as feed materials). As a general rule, pigs are kept for their own consumption and do not affect the average use of feed in Latvia.

Calculated emission according to N_{ex} is summarized in Table 6. The highest total NH_3 emissions (12.81 kg) are from lactating sow with piglets due to highest N_{ex}. The same is for other nitrogen gaseous emissions (N_2O, NO_x). Calculated N_{ex} meet the requirements defined by Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs (European Commission, 2017). Values of N_{ex} in BAT are given for two groups: sows with piglets (till 25 kg) and fattening pigs (25 – 105 kg).

Comparing changes of pig feeding in the time scale, there is a decrease in the nitrogen emissions. According to pig feeding norms (Latvietis, 1998), calculated N_{ex} for a pregnant sow is 15.98 kg animal^{-1} year^{-1}. That is by 19% less than calculated N_{ex} and

Table 6

Emissions affected by nutrient content of pig feed

Pollutants	Pig groups					
	Pregnant sow	Lactating sow with piglets	Pig, 8 – 15 kg	Pig, 15 – 30 kg	Pig, 30 – 60 kg	Pig, 55 – 90 kg
N_{ex}, kg	12.91	28.04	2.08	5.19	6.38	14.72
N_{ex}, kg (European Commission, 2017)	21.00 – 32.00			7.00 – 13.10		
NH_3 (housing), kg	2.41	5.24	0.50	1.24	1.52	3.50
NH_3 (storage), kg	1.26	2.75	0.19	0.47	0.58	1.34
NH_3 (application), kg	2.22	4.82	0.46	1.14	1.40	3.23
Total NH_3, kg	5.89	12.81	1.15	2.85	3.50	8.07
NO_x (as NO_2), g	2.44	5.31	0.37	0.91	1.12	2.58
N_2O, g	101.42	220.34	16.35	40.80	50.12	115.63

emissions of NH_3, NO_x, N_2O according to represented data in this paper. The CP difference for a pregnant sow is about 0.7 CP%. There is greater difference (35% of reduction) for lactating sows with piglets with reduced CP by 3.5 CP%.

Calculated data shows that there is a need to revise used N_{ex} because of increasing impact of big pig holding share in pig production structure. For this moment in Latvia's Informative Inventory Report 1990 – 2017 (Skrebele *et al*., 2019) used N_{ex} is 14 kg head^{-1} year^{-1} for fattening pig, so in comparison with calculated data the weighted average should be lower. The same tendencies can be seen in other countries inventories, for example, Estonia where N_{ex} is 10.6 kg head^{-1} year^{-1} (Kohv *et al*., 2019). Decreased N_{ex} would decrease nitrogen associated gaseous emissions.

Development of feeding plans with decreased CP is an acceptable way to reduce pig production impact on environment because lower emissions can be reached. The lowest bar defined by BAT is still not reached in all farms in the country. There is still a possibility to reduce total with nitrogen associated gaseous emissions by pig feed planning.

Conclusions

More pigs in Latvia are concentrated in big holdings (>10,000). These pig producers use varied feed recipes and according to the used average data of feed composition calculated N_{ex} meet the requirements defined by European Commission. Low excreted nitrogen results in lower emissions of NH_3, N_2O and NO_x. Lactating sows emits highest emissions due to enclosure of piglets to calculation. Calculated excreted nitrogen values according to research of pig feeding and consequently N_2O end NH_3 emissions are less than calculated by using assumptions of the pig feeding norms published in 1998. That shows that there is a positive trend to reduce emissions by feed planning for pigs with reduced crude protein.

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BIASING A STAGED FUEL INJECTION SYSTEM OF A SINGLE CYLINDER FOUR STROKE GASOLINE ENGINE

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Abstract
This paper investigates the effect of fuel bias between the primary and secondary injectors of a staged fuel injection system on the performance of a high output single cylinder spark-ignited internal combustion engine. It is known that staged fuel injection systems are widely used in motorsports applications where high engine speeds are coupled with high power output, therefore, the aim of this study is to evaluate the effect of a secondary fuel injector installed on a Honda CRF450R single cylinder four-stroke gasoline engine. The said engine was equipped with a programmable Performance Electronics PE3-SP0 control unit and a secondary fuel injector identical to that of OE. Power measurements were carried out on a Dynojet-200ix chassis dynamometer in four different modes with altered fuel proportion between injectors, with each measurement being repeated three times. Ambient conditions were monitored with Performance Electronics Pe3Monitor software and the fuel map was adjusted to produce a stable air-fuel ratio. The results were averaged and compared numerically and by coefficient of correlation. It was observed that the data as obtained from the chassis dynamometer software SportDyno 4 contains a lot of noise, both mechanical and electrical in nature, and the changes in power output are highly dependent on engine and equipment temperature. The best results were obtained by using both injectors with fuel proportion biased to the front of the system.
Key words: electronic fuel injection system, port injection, volumetric efficiency, chassis dynamometer.

Introduction

Since the early experiments with electronic fuel injection on gasoline engines as means of improving the fuel efficiency, emissions, and power output, it has been observed that said system poses several important advantages over its predecessors, for instance, fuel efficiency. Sophisticated fuel injector design allows the fuel to be metered only by the injection pulse width (Knapp & Lembke, 1985) leading to more accurate dosing. It was very early understood that fuel injection must be carried out under low pressure to promote evaporation. Unfortunately, when injected at such conditions, the fuel breaks up not only into vapor but also liquid fuel droplets of which some are deposited on the walls and create a fuel film (Almkvist & Eriksson, 1993). However, velocity in the induction system has a significant effect on the transport and vaporization of fuel spray, as well as on the evaporation of wall deposits (Nagaishi *et al*., 1989). It was then found that fuel vaporization can be accelerated by breaking the flow into very fine droplets (Zhao, Lai, & Harrington, 1995). For this reason, high pressure injection was developed, where it was also found that high pressure fuel spray producing fine droplets minimizes soot emissions (Karl *et al*., 1997). Although a lot of research was done on GDI (Gasoline Direct Injection) where the fuel is injected directly into the combustion chamber, later developments of HCCI (Homogeneous Charge Compression Ignition) systems found that port injection is highly preferable in applications requiring different fuel atomization strategies combined with low production cost (Cao *et al*., 2005). Around the same time a different port injection strategy was tested mainly in motorsports – staged injection, consisting of a primary (downstream) and secondary (upstream) injector. On single cylinder or individual throttle body engines the secondary injector would most often be placed upstream of the throttle valve where earlier studies show that droplet size is the determining factor in their path around it – larger droplets will tend to deposit on the throttle valve surface while smaller droplets will tend to follow the air stream around it (Nogi *et al*., 1988). The secondary injector would only be deployed at engine speeds and loads with sufficiently high intake velocity under high injection pressure as to minimize the likelihood of fuel deposition. It was discovered that in order to burn the deposited fuel film, it must be vaporized by heat conduction from the walls (Hendricks *et al*., 1993). Advantage could be taken from what little deposition remained as it cooled the intake runner walls while evaporating. Thus, the injected fuel itself increases the density of mixture entering the cylinder leading to higher volumetric efficiency (Sarkar, Manivannan, & Ramesh, 2003). These advantages are mostly employed in motorsports. However, knowing that motorsports is the area of technical break-through where the limits of our technology are pushed further, some examples have been known to exist among road use motorcycles. The aim of this study is to evaluate the effect of a secondary fuel injector installed on the single cylinder four-stroke gasoline engine of a Honda CRF450R off-road motorcycle.

Materials and Methods

The object of investigation is the electronic fuel injection system of a Honda CRF450R motorcycle equipped with a secondary fuel injector identical to that of OE. The location of the secondary injector was chosen 76 mm upstream of the primary (OE)

injector (Figure 1) due to packaging restraints. The power measurements were carried out in 2018, on DynoJet 200-ix eddy-current chassis dynamometer in Riga. The technical parameters of the used engine and dynamometer are given in Table 1. Four different fuel injection modes were chosen for comparison (Table 2) where the total amount of fuel injected remains unchanged, but the proportion of it is biased between the primary and secondary injectors where the maximum allowed fuel bias as dictated by the engine control unit is 65% towards either of the injectors. The fuel is supplied via electric pump with a constant pressure of approximately 3.5 – 4 bar. The amount of injected fuel is defined as the injector open time in milliseconds during each injection cycle. In order to evaluate the repeatability of the power measurements, the power delivery in each mode was measured three consecutive times resulting in a total of 12 measurements.

The Performance Electronics PE3-SP0 engine control unit is also programmed to multiply the injector open time values in fuel map with coefficients based on water and intake air temperatures. Since both of these parameters directly influence not only the amount of injected fuel but also the development of intake charge mixture, which in turn directly influences the

Table 1

Technical parameters

Honda CRF450R engine	Number of cylinders	1
	Capacity	449 cm^3
	Bore	96.0 mm
	Stroke	62.1 mm
	Fuel delivery	Gasoline EFI, 46mm throttle body
	Compression ratio	13.8:1
	Valvetrain	SOHC, four valves per cylinder
	Cooling strategy	Liquid cooled
DynoJet 200-ix dynamometer	Type	Chassis dynamometer
	Absorber	Eddy current
	Maximum power rating	750 hp
	Maximum speed	320 km h^{-1}
	Maximum wheelbase	2134 mm
	Sensors	Air temp., humidity, barometer, lambda

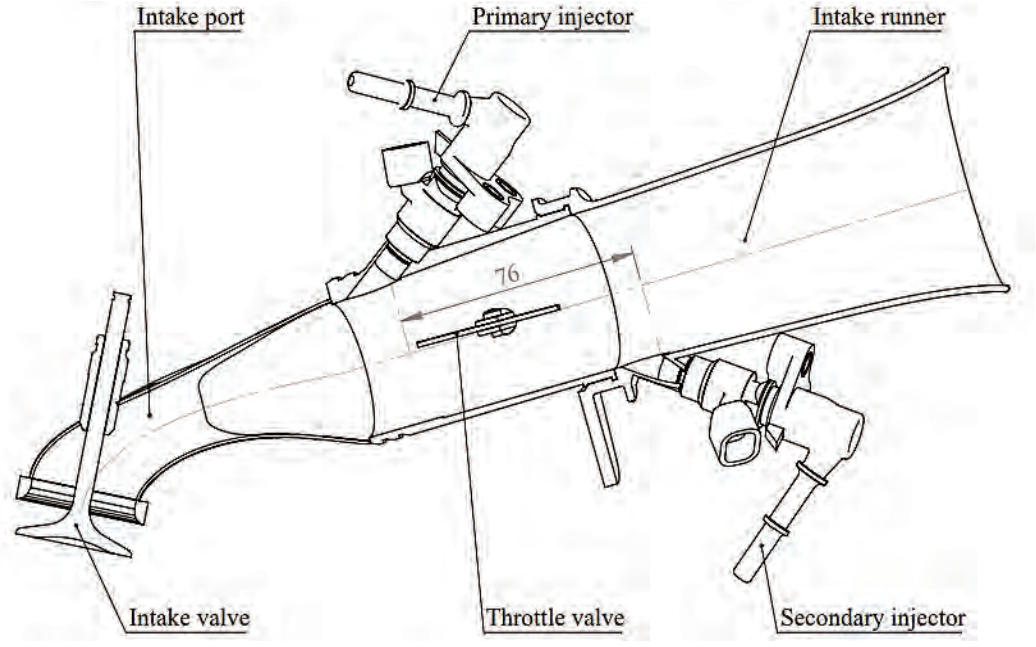

Figure 1. Staged fuel injection system layout.

Table 2

Injected fuel bias as tested in each mode

Configuration	Injected fuel bias	
	Primary injector	Secondary injector
Baseline	100%	0%
Mode 1	65%	35%
Mode 2	50%	50%
Mode 3	35%	65%

Table 3

Controlled parameters

Parameters	Range of values
Engine speed range	4,500 – 10,000 min^{-1}
Engine rotational acceleration	340 – 360 min^{-1} sec^{-1}
Intake air temperature	20 – 21 °C
Water temperature	80 – 82 °C
Air-fuel ratio (AFR)	12.5 – 13.5
Tire pressure	2.0 – 2.1 bar

power output, it is essential to control them during the measurements. This is done by connecting the engine control unit with a laptop via ethernet cable where the temperature values as read from the built-in sensors on the engine are displayed on the online screen of Pe3Monitor software. All the controlled parameters of the experiment are listed in Table 3.

The data is exported from SportDyno 4 software as mechanical power (hp) reading at a given engine speed in revolutions per minute. Since the DynoJet 200-ix dynamometer and the internal combustion engine themselves are prone to repeatability errors associated with noise, both mechanical and electrical in nature (vibration, static electricity, grounding, etc.), the exported data is very unstable and is not usable without pre-processing i.e., the data points are not aligned and therefore cannot be compared on a single horizontal axis. In order to align the data points, formula (1) is used to round the engine speed values v_i to the nearest integer V_i with the interval 100 min^{-1}.

$$V_i = 100\lfloor\frac{v_i}{100}\rfloor \quad (1)$$

Average power P_j at engine speed V_j is further calculated from the measured power P_i data points corresponding with equal engine speeds V_i according to equation (2), where the number of identical engine speeds V_i after rounding according to equation (1) is denoted by n.

$$P_j(V_j) = \frac{1}{n}\sum P_i(V_i) \quad (2)$$

The torque T_j can then be back-calculated in Newton-meters from mechanical power P_j using equation (3).

$$T_j(V_j) = \frac{P_j(V_j)\cdot V_j}{7120.756} \quad (3)$$

Results and Discussion

The results calculated after averaging the data against the nearest engine speed integers according to equations (1 and 2) are given in Table 4. Coefficient of correlation is then used to evaluate the agreement between the repeated measurements in each mode. The resulting coefficients of correlation are shown in Table 5.

It is visible that the agreement of data or repeatability in each mode is noticeably higher between two specific runs, meaning that one of the three consecutive runs or measurements tends to deviate from the other two. Such runs are Baseline – Run 1, Mode 1 – Run 2, Mode 2 – Run 1 and Mode 3 – Run 1. This could be explained by variations in coolant and oil temperatures due to the runs being executed in a consecutive manner – one after the other with inconsistent cool-down times where the temperature of the intake system and combustion chamber is influencing the fuel evaporation rate, intake charge density and volumetric efficiency

Table 4

Aligned results

Configuration	Average torque, Nm	Average power, hp
Baseline – Run 1	46.81	46.96
Baseline – Run 2	44.85	45.12
Baseline – Run 3	44.38	44.65
Mode 1 – Run 1	44.96	45.21
Mode 1 – Run 2	44.31	44.60
Mode 1 – Run 3	44.60	44.87
Mode 2 – Run 1	46.01	46.20
Mode 2 – Run 2	44.84	45.09
Mode 2 – Run 3	44.30	44.59
Mode 3 – Run 1	45.36	45.59
Mode 3 – Run 2	44.52	44.81
Mode 3 – Run 3	44.25	44.54

Table 5

Coefficients of correlation

Configuration	Runs 1 & 2	Runs 1 & 3	Runs 2 & 3
Baseline	0.9931	0.9862	0.9972
Mode 1	0.9967	0.9992	0.9980
Mode 2	0.9944	0.9893	0.9981
Mode 3	0.9957	0.9939	0.9976

Table 6

Averaged results

Interval	4,500 – 6,000 min^{-1}		6,100 – 8,000 min^{-1}		8,100 – 10,000 min^{-1}	
Config.	Average torque, Nm	Average power, hp	Average torque, Nm	Average power, hp	Average torque, Nm	Average power, hp
Baseline	39.78 ± 0.29	29.59 ± 0.22	49.55 ± 0.38	49.14 ± 0.38	45.62 ± 0.15	57.74 ± 0.18
Mode 1	39.73 ± 0.34	29.54 ± 0.25	49.72 ± 0.46	49.30 ± 0.45	45.85 ± 0.16	58.03 ± 0.31
Mode 2	39.68 ± 0.29	29.50 ± 0.22	49.33 ± 0.36	48.92 ± 0.36	45.75 ± 0.13	57.89 ± 0.16
Mode 3	39.31 ± 0.20	29.22 ± 0.15	49.16 ± 0.24	48.75 ± 0.23	45.64 ± 0.11	57.77 ± 0.14

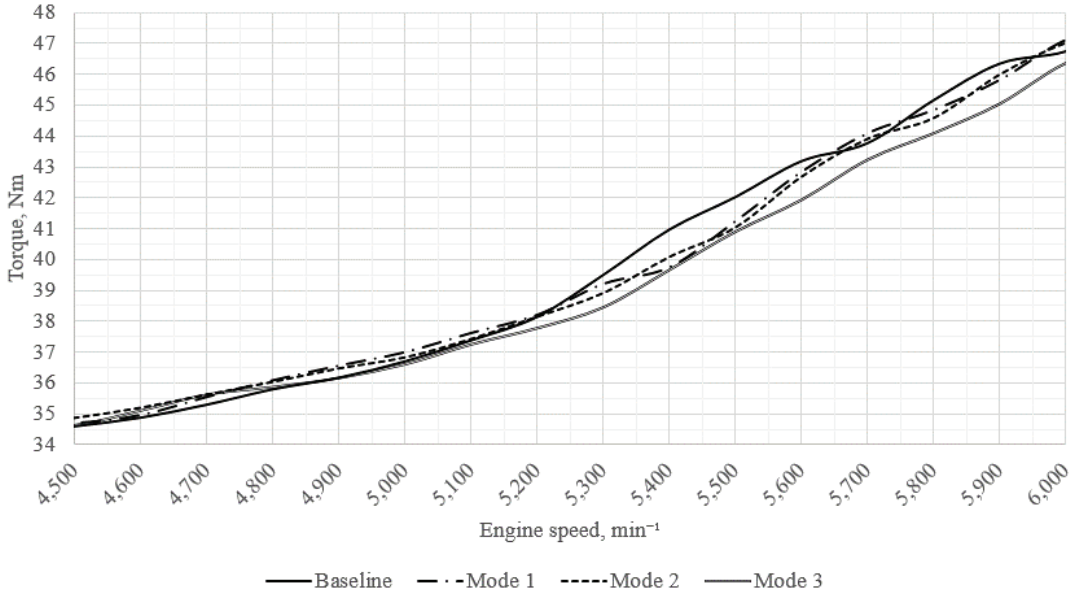

Figure 2. Torque comparison at low engine speeds.

(Sarkar, Manivannan, & Ramesh, 2003). To increase the credibility of this study, the mentioned data sets are discarded. The results are brought to the final summation by averaging the two remaining data sets in each mode. Table 6 shows average torque, split by three engine speed intervals – low speed (4,500 – 6,000 min^{-1}), medium speed (6,100 – 8,000 min^{-1}) and high speed (8,100 – 10,000 min^{-1}). The torque values are expressed as averages between repeated runs supplemented with standard error of mean.

Figure 2 indicates the tendency of increasing low speed torque loss when secondary injector is used (Mode 1, Mode 2 and Mode 3). The highest averaged torque – 39.78 Nm is produced in baseline test, using only the primary injector. This could be attributed to an insufficient intake velocity, leading to increased fuel deposition on the walls of the intake system (Nagaishi *et al*., 1989).

Figure 3 shows slight improvements of medium engine speed torque with the fuel injection biased to the front (Mode 1), meaning that only slightly more fuel can be injected from the secondary injector compared with the baseline (single injector) test until it starts to deposit on the induction system walls without evaporating, as represented by Mode 2 and Mode 3 curves.

Figure 4 shows the tendency of the previously described phenomena becoming less pronounced as the engine speed is increased higher. This could be explained by accelerated evaporation of the fuel deposits due to a higher intake velocity, meaning that at some point the engine speed could be high enough

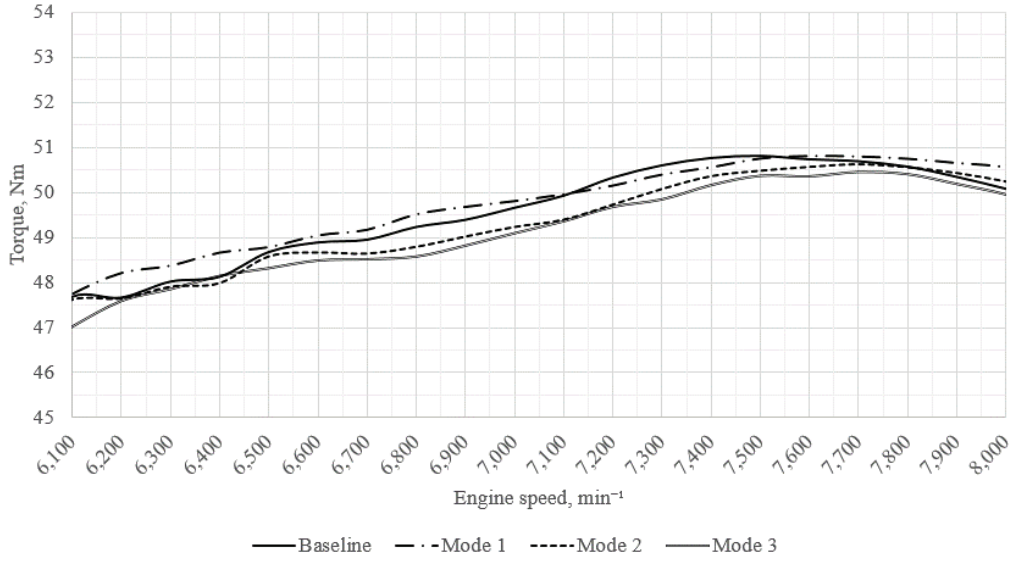

Figure 3. Torque comparison at medium engine speeds.

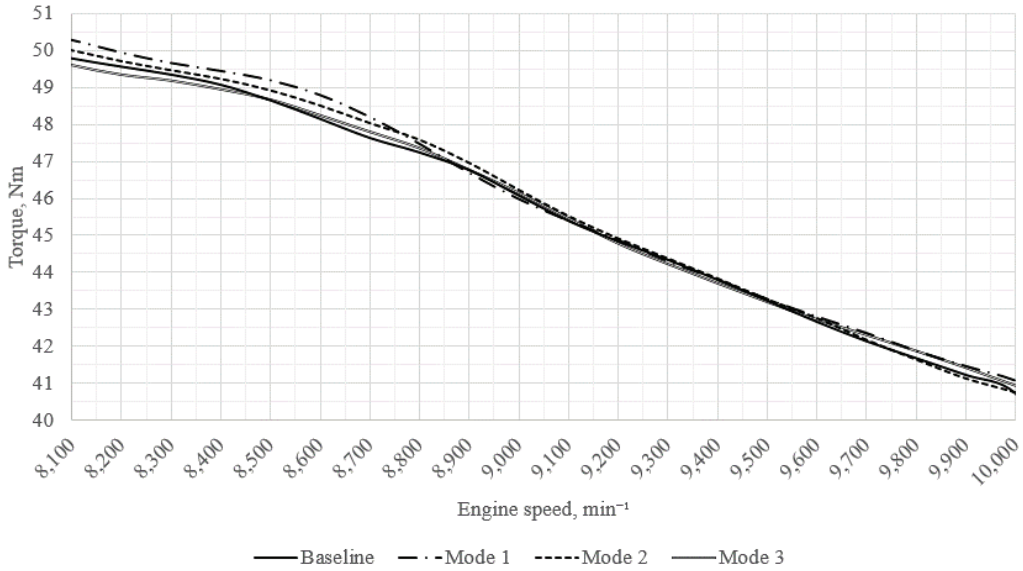

Figure 4. Torque comparison at high engine speeds.

so that biasing the injected fuel more towards the secondary injector becomes beneficial. In the case of the engine used in this study, the said point falls off the operating speed range.

Conclusions

1. Staged fuel injection systems in gasoline engines are used when high output and high engine speeds are required, where the aim of the secondary fuel injector is to aid in cooling the intake runner, while increasing the volumetric efficiency and the rate of fuel evaporation. The possible benefits in this case are lower fuel consumption, lower emissions and higher efficiency.
2. In the engine speed interval 4,500 – 6,000 min^{-1}, the best results (39.78 Nm, 29.59 hp) were achieved by using only the primary injector. At medium engine speed between 6,100 and 8,000 min^{-1}, the best results – 49.72 Nm (+0.34%) and 49.30 hp (+0.33%) were achieved by fuel bias 65% on the primary and 35% on the secondary injector. At high engine speeds from 8,100 to 10,000 min^{-1}, the best results were also achieved by fuel bias 65% on the primary and 35% on the secondary injector – 45.85 Nm (+0.50%) and 58.03 hp (+0.60%).
3. The measurements conducted on DynoJet 200-ix chassis dynamometer show a relatively low credibility as the calculated error (0.11 – 0.46 Nm and 0.12 – 0.45 hp) exceeds the differences between test modes (0.02 – 0.45 Nm and 0.03 – 0.38 hp). This could be attributed to changes in engine and possibly equipment temperatures. To increase the credibility of this study, the experiment should be repeated on engine dynamometer under tighter control of engine temperature and ambient conditions.

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REVIEW OF COOLING SOLUTIONS FOR COMPACT ELECTRONIC DEVICES

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Abstract
Nowadays, with the rapid development of robotics and automation, there is a need for more powerful, more compact data processing equipment that also emits more heat. Various electronics cooling solutions are already in use, others are in development. Each cooling solution has its advantages and disadvantages. Active cooling usually dissipates heat more efficiently, but passive cooling is more reliable, especially when the electrical system is exposed to aggressive environmental influences. The possibility of using graphene in the manufacture of electrical equipment components is widely studied. Graphene could significantly improve the efficiency of passive cooling because its thermal conductivity is much better than copper.
Key words: cooling system; electronics cooling; thermal management; heat dissipation.

Introduction

The use of electronic devices in agricultural production facilities is increasing. The amount of data processed for automated equipment is increasing significantly and is expected to increase further in the near future. Increased data processing requires appropriate requirements to cooling of processor in compact enclosures. There are also other electronics components that emit significant amounts of heat. In order to avoid overheating of the electronic component, it is necessary to use appropriate heat dissipating systems. Most of electronic components must not exceed 120 °C operating temperatures. Various technical solutions are available for cooling electronic components. Usually air convection cooling is used. If the electronic circuit is covered with a compound, conductive cooling is provided. Cooling quality depends on thermal conductivity of the compound resin. This study discusses both traditional and innovative solutions and evaluates the application possibilities for achieving positive results. The aim of the work is to find an effective technology for cooling compact electronic devices.

Heat Transfer Fundamentals

The rate at which heat is conducted through a material is proportional to the area normal to the heat flow and to the temperature gradient along the heat flow path. For a one-dimensional, steady state, the rate of the heat flow is expressed by Fourier's equation:

$$Q = kA\frac{\Delta T}{L}, \quad (1)$$

where k – thermal conductivity, W (m K)$^{-1;}$
Q – rate of heat flow, W;
A – contact area, m^2;
L – distance of heat flow, m;
ΔT – temperature difference, K.

Thermal conductivity of a material can be defined as the rate of heat transfer through a unit thickness of the material per unit area and per unit temperature difference. The thermal conductivity of a material is a measure of the ability of the material to conduct heat. A high value for thermal conductivity indicates that the material is a good heat conductor, and a low value indicates that the material is a poor heat conductor or insulator. The thermal conductivities of some common materials at room temperature are given in Table 1.

Table 1
The thermal conductivities of some materials at room temperature (Cengel, 2008)

Material	Thermal conductivity k, W (m K)$^{-1}$
Diamond	2300
Silver	429
Copper	401
Gold	317
Aluminium	237
Iron	80.2
Mercury	8.54
Water	0.613
Air	0.026

Pure crystals and metals have the highest thermal conductivities, and gases and insulating materials the lowest. Liquid metals such as mercury and sodium have high thermal conductivities and are very suitable for use in applications where a high heat transfer rate to a liquid is desired. The lattice component of thermal conductivity strongly depends on the way the molecules are arranged. For example, diamond, which is a highly ordered crystalline solid, has the highest known thermal conductivity 2300 W (m K)$^{-1}$ at room temperature. Composite materials made of diamond and copper with the thermal conductivity of 768 W (m K)$^{-1}$ can be prepared by pressureless infiltration (Jia *et al.*, 2019; Parashchuk, 2016). Despite their higher price, diamond/copper heat sinks are used in the cooling of sensitive electronic components such

as power diode lasers because of the excellent thermal conductivity of diamond.

Another inherent thermal property of a material is its thermal resistance R [K W^{-1}], as defined in Equation 2.

$$R = \frac{\Delta T}{Q} \quad (2)$$

Thermal resistance is a material property to resist a heat flow when there is a temperature difference between two faces of the material (Cengel, 2008; Digestibility & Diets, 2007; Welty *et al*., 2007). It may be associated with the conduction of heat. The thermal resistance concept is widely used in practice because it is intuitively easy to understand and it has proven to be a powerful tool in the solution of a wide range of heat transfer problems.

Although the process of convection is very complex, the rate of convection heat transfer is observed to be proportional to the temperature difference and is conveniently expressed by Newton's law of cooling as:

$$\acute{q}_{conv} = h(T_s - T_f) \quad (3)$$

or

$$\acute{Q}_{conv} = hA_s(T_s - T_f), \quad (4)$$

where $\acute{q}_{conv}$ – convective heat flux, W m^{-2};
h – heat transfer coefficient, W $(m^2 K)^{-1}$;
T_s – temperature of the solid surface, K;
T_f – temperature of the surrounding fluid, K;
$\acute{Q}_{conv}$ – heat transfer rate, W;
A_s – contact area of heat transfer surface, m^2 (Cengel, 2008; Welty *et al*., 2007).

Convection heat transfer coefficient h depends on the conditions in the boundary layer, which are influenced by the surface geometry, the nature of the fluid motion, and an assortment of fluid thermodynamic and transport properties as shown in Table 2.

Convection with fluid phase change can provide more effective heat transfer coefficient values than forced convection in liquids or gases.

Cooling solutions for compact electronic devices

Smartphones, tablets, and other similar mobile devices are becoming more multifunctional and capable of handling higher data traffic in less time. The more compact the device becomes, the more difficult it is to create a suitable cooling system so that it does not overheat. The cost of the thermal management hardware must be small compared to the overall system cost (Fujitsu Laboratories Ltd, 2015; Pelonis, 2014). Different cooling technologies are being researched to find suitable for compact electrical equipment.

Passive air cooling

Most of today's compact electrical appliances use passive air cooling. Passive cooling uses natural convection and heat dissipation by utilizing a heat spreader or a heat sink to maximize the radiation and convection heat transfer modes (SimScale, 2019). Convection type heat transfer is often combined with conduction. Heatsinks are used for heating components, which help to dissipate heat in the ambient air. Often, the hot component is placed in a sealed housing where the air circulation flow rate is very low, so the machine can overheat for a longer period of time (Ahmadi *et al*., 2015; Mehrtash & Tari, 2013; Sidik *et al*., 2017). Passive air cooling can be used to cool low-heat parts. For more efficient heat dissipation, thermal bridges or heat pipes of copper, aluminum or other material with good thermal conductivity may be used. Copper and aluminum not only conduct heat well, but also electricity, so the thermal bridges can be supplemented with silicone pads that provide electrical insulation. If the heat has to be transferred from a solid body to another solid body, then the thermal interface materials must be used for direct contact to fill the air gaps. The main advantages of passive cooling are energy efficiency and low cost.

Active air cooling

The heating components are usually equipped with heatsinks that increase the area of the heat transfer surface.

Table 2

Typical values of the convection heat transfer coefficient (Cengel, 2008; Niezgoda-Zelasko & Zelasko, 2014)

Process		Heat transfer coefficient h, W $(m^2 K)^{-1}$
Free convection	Gases	2–25
	Liquids	50–1000
Forced convection	Gases	25–250
	Liquids	100–20 000
Convection with phase change	Boiling or condensation	2500–100 000

Table 3

Solid materials and fluid compatibility (LYTRON, 2019)

Solid material	Heat transfer fluid			
	Tap water	Glycols	Deionized Water	Dielectric Fluids (Fluorinert, PAO)
Copper	x	x		x
Aluminium		x		x
Stainless Steel	x	x	x	x

The fan creates a turbulent airflow that cools the heatsink and removes heat. Different types of fans can be integrated into electronics, such as computer cases, or are attached to CPUs, hard drives or chipsets, to maintain thermal conditions and reduce failure risk (SimScale, 2019). Over time, dust is sucked into the cooling system inlet ducts and pollutes the interior of the unit, covers the components, and decreases cooling efficiency. There are cases of dust clogging the fan causing overheating of the electrical equipment (Angelini *et al*., 2017; Park, Lee, 2017; Shi *et al*., 2017). This type of cooling is not applicable to closed systems that need to be operated under aggressive environmental conditions – wet, dusty and corrosive gases. Different filters are used to purify the intake air, but they reduce cooling efficiency. Filters should also be cleaned regularly. Cyclone technology for dust removal from the air can be used instead of filters (Galins *et al*., 2018). The fan generates noise. A higher flow velocity results in a better heat transfer, but larger noise (Gui *et al*., 2017). To reduce noise, feedback link can be used to control the fan speed depending on the required cooling intensity. Active cooling spends extra electricity, resulting in higher costs compared to passive cooling. Air cooling is limited by specific heat. To dissipate large amounts of power, a large mass flow rate is needed.

Passive cooling with liquid heat transfer fluid

Heat from the hot components is dissipated in the environment by convection. This technology is already used for cooling high power transformers. The transformer windings are located in a dielectric fluid that provides both insulation and winding cooling. Mineral oil, silicone fluid, synthetic or natural esters can be used as a dielectric fluid (CIGRE, 2010; Nadolny & Dombek, 2017; Njombog Tanteh *et al*., 2014). Experimental studies indicate that the cooling capacity of the alternative liquid worsens with aging due to the exponential decrease of the viscosity with temperature (Ortiz *et al*., 2018). Heat transfer efficiency is greatly influenced by the thermal conductivity, specific thermal conductivity, viscosity and expansion coefficient of the heat carrier. As the liquid heats up, the viscosity decreases, thereby increasing the fluid flow rate and cooling efficiency. Convection can be combined with conduction. For example, the heat from the processor is transferred to the heatsink (conduction), but further away from the heatsink to the liquid heat transfer fluid (convection). For more efficient conduction heat transfer, thermal bridges with high thermal conductivity can be used.

Active cooling with liquid heat transfer fluid

The heat transfer fluid such as water, oil, tosol or ester is supplied to the hot component using a circulation pump. The heating component is fitted with a collector or heat transfer tube through which the heat transfer fluid flows and transfers heat to the radiator or heat exchanger where it is dissipated or further transferred. The system is used with high-power heating components when a large amount of heat is released in one place, for example, cooling a CO_2 laser lamp or copper mirrors etc. This technology is also suitable for the cooling of semiconductor processors, rectifiers and transistors (Hidalgo, 2016). Liquid cooling is able to achieve better heat transfer at much lower mass flow rates than air cooling. A lower flow velocity results in a lower noise. Water is one of the best heat transfer fluids due to its specific heat. Antifreeze is added to water to lower the freezing point of the water-based liquid and increase its boiling point. Ethanol serves to depress the freezing point of water below zero -32 °C (Mohapatra, 2006). For a product to be reliable, heat transfer requires the selection of compatible solid materials and heat transfer fluid to avoid corrosion as shown in Table 3.

Heat pipes are usually made of copper or aluminium. Most cooling systems are compatible with water or glycol/water solutions but require special plumbing for compatibility with deionized water or a dielectric fluid such as polyalphaolefin (PAO). Nanofluids are another type of fluids considered as a working fluid of forced liquid heat transfer. The nanofluids may contain small solid particles of diamond, graphene, copper, Al_2O_3, SiO_2 etc. (Kiseev & Sazhin, 2019; Languri *et al*., 2018; Wang *et al*., 2019). Research confirms that adding particles improve thermal conductivity.

Thermoelectric cooling

Thermoelectric cooling technology (TEC) uses semiconductor-based electronic component – Peltier module that functions as a small heat pump. Heat flows through semiconductor from one face to another. The electric current simultaneously cools one face and heats

the opposite face. A simple thermoelectric cooling system consists of two ceramic plates of p-type and n-type semiconductor materials between the plates. TEC can be used for precise temperature control of compact electrical equipment if refrigerants are not desirable. Improvement of thermoelectric cooling has been studied in many articles (Cai *et al*., 2019; Enescu & Virjoghe, 2014; Lu *et al*., 2018; Sajid *et al*., 2017; Wang *et al*., 2017; Yang *et al*., 2017; Zhao & Tan, 2014), but there are still various drawbacks to this technology. The use of Peltier elements is limited by the low energy efficiency of this element. The warm side heats up more than the cool side is cooled and the extra energy is required for the Peltier element to function. In order to cool down the Pelter element's hot side, active cooling is required, which complicates the use of technology.

Phase Change Materials (PCMs)

Phase Change Materials are materials whose phase change, from solid to liquid, and liquid to solid, are used to store and release heat. During melting, the material absorbs large amounts of heat from the environment. When the temperature drops, the material solidifies and releases heat (Advanced Cooling Technologies, 2019; Global E Systems, n.d.). Liquid-gas phase changes are impractical for thermal storage because large volumes or high pressures are required to store the materials in their gas phase. If the technology was previously used only for large electrical appliances such as a refrigerator, then today, this solution can take up very little space (Fok *et al*., 2010; Ganatra *et al*., 2018; Kaito *et al*., 2015; Setoh *et al*., 2010; Xie *et al*., 2019). Fujitsu has developed a loop heat pipe less than 1 mm thick that can be added to small, thin electronics. The heat pipe is a heat-transfer device that consists of an evaporator that absorbs heat from the heat source and a condenser that dissipates that heat away. Heat transfer fluid is encapsulated inside this closed loop as a coolant (Fujitsu Laboratories Ltd, 2015). The thin loop heat pipe can be installed on a heat-generating component, such as a central processing unit CPU or graphics processing unit GPU. Thicker PCM copper sheets are more effective for the thermal design. The technology used by Fujitsu works without a compressor and a pump. It does not increase the overall energy consumption of the device in order to diffuse heat.

Thermal interface materials

Thermal interface materials are used between two solid components to enhance the heat transfer efficiency. With increasing demands for better heat transfer, more efficient thermal interface materials are being developed. Thermal grease (also called thermal paste or heat sink compound) is used to eliminate air gaps from the interface area in order to maximize heat transfer. Grease 'dry-out' occurs due to the separation of the filler from the polymer matrix at elevated temperatures. This results in increased thermal resistance of the material (Gowda, 2007). The most effective (and most expensive) pastes consist almost entirely of liquid metal, usually a variation of the alloy galinstan, and have thermal conductivities in excess of 13 W (m K)$^{-1}$ (Meng *et al*., 2018; Roy *et al*., 2015; Zhang *et al*., 2019). These are difficult to apply evenly and have the greatest risk of causing malfunction due to spillage. These pastes contain gallium, which is highly corrosive to aluminium and cannot be used on aluminium heat sinks.

Thermal pads can be used for less heat generating components when electric insulation is important.

Future technologies for cooling compact electrical appliances

Graphene is a one-atom-thick layer of carbon atoms arranged in a hexagonal lattice. It is the thinnest compound known at one atom thick, strong with good thermal and electrical conductivity at room temperature. Researchers all over the world continue to constantly investigate and patent graphene to learn its various properties and possible applications, which include: transistors; computer chips; antennas, supercapacitors etc. (Su & Zhang, 2018; Yue *et al*., 2019). Single layer graphene has a thermal conductivity above 2000 W (m K)$^{-1}$ (Balandin, 2011). Thermal management of compact electronics could greatly benefit from graphene's ability to dissipate heat and optimize electronic function. Graphene's heat conductivity can be used in many ways, including thermal interface materials, thermal greases, heat spreaders, graphene-based nanocomposites etc.

Results and Discussion

The review of the methods, techniques, and technical solutions for the cooling of electronic circuit components has led to some noteworthy knowledge that will help effectively proceed with this important issue of the safety of electronic components. As a result of the research, the latest technologies of cooling of electronic components have been identified, which will significantly increase the cooling efficiency by removing heat directly from the heating surfaces. The heat transfer types discussed in the article are summarized in Figure 1 and Figure 2.

Today, the most innovative cooling system is with the conductive heat transfer, using graphene technology. This technique is still in the research phase and is starting to come into practice. The widespread use of these technologies will be expected in the next decade, as is the case with supermagnets and super capacitors today.

One of the most advanced is a conductive heat transfer solution using a heat collector with a passive heat pump based on a change in the physical state of

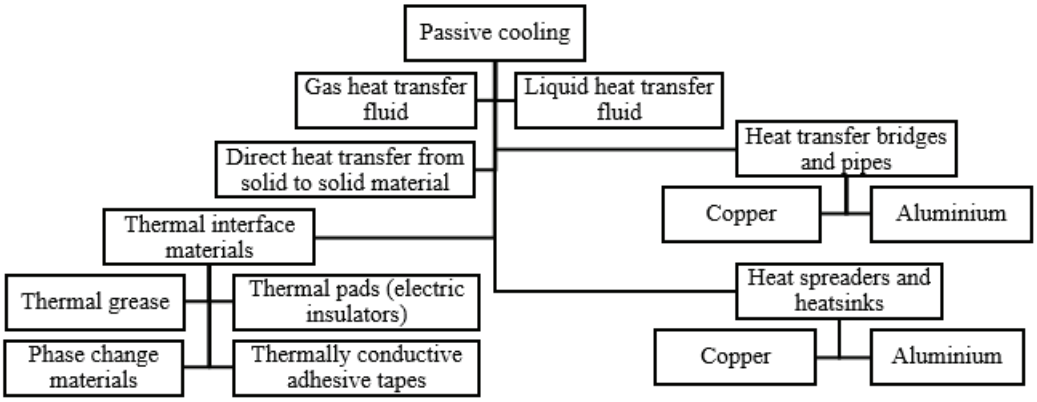

Figure 1. Types of passive cooling.

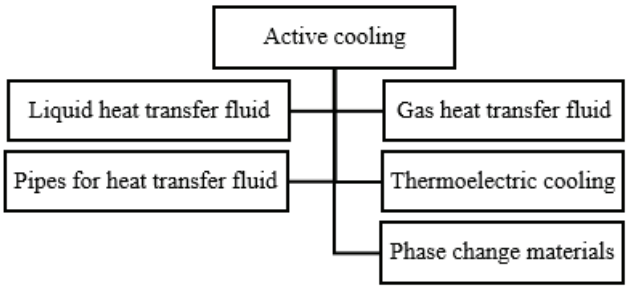

Figure 2. Types of active cooling.

the substance, a technology that has been used for a long time and successfully in renewable energy, in tube-type vacuum solar collectors.

Technically the simplest are passive convective cooling solutions, if the spreading heat capacity is small – some watts; thus no special solutions are needed. With expandable heat output, the heatsink dimensions - the area of the active surface and the mass – increases significantly, and there is a need to think about more efficient cooling techniques. The most common is convective active cooling with a fan. This cooling technique is not convenient, because there are moving mechanical parts and noise. There are also wear parts that collect and accumulate dust and pollute the electronics board. If dust filters are polluted, electronic elements can overheat.

The most reliable type of cooling is direct heat transfer. The electronic element is attached directly to the cooler or to the metal casing of the appliance using heat conducting grease or a thermal pad. Such technical solutions are widely used for electronic circuits in automotive, aviation and military industries.

Considering the previously mentioned, it will be necessary to select the most economically and technically suitable cooling technique for electronic components for each task. It may not be the most innovative, but one that provides the necessary results.

Conclusions

1. An overview of the cooling technology of electronic components confirms that several new and advanced technologies are currently available in parallel with the well-known technologies, which use heat pumps based on the change of the physical state of the heat transfer fluid, nanofluid technologies for heat transfer, and can provide efficient cooling at the compact technical performance.
2. At the moment, the latest heat transfer technology is based on the use of nano-carbon technologies, using graphene as a thermal transfer bridge. The graphene's thermal conductivity (above 2000 W $(m\ K)^{-1}$) is considerably higher than that of copper (401 W $(m\ K)^{-1}$). This technology is expected to be widely used in the near future.
3. The choice of the cooling system for electronic components should be based primarily on technical and economic considerations, guaranteeing the safety of electronics, so the use of traditional cooling technologies will not decrease, but the introduction of advanced technologies will be determined by market demand and customer solvency.

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EFFECT OF SALT TREATMENT ON YIELD AND QUALITY OF FROZEN COD LOINS

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Abstract
Study has been performed in fish processing plant 'X' with an aim of on purpose to investigating the influence of salt treatment on yield and quality of frozen cod loins. Samples were soaked in 0.8, 1.2, 10% NaCl concentrations in brine before being frozen. In this study, the cod loin's weight loss during refrigeration, defrosting and cooking was calculated and sensory analysis was carried out. It was found that the soaking in brines affected higher weight of cod loins after freezing. In the control group it decreased by 1.14%, but the S0.8, S1.2 and S10 groups had the weight gain, respectively 3.41, 4.72 and +4.78%. Although after the defrosting and cooking the control group had the lowest weight losses, considering the losses of all operations, it was found that the largest weight loss was in the control group and in the S0.8 group, respectively 31.19% and 31.29%, while the lowest in the S1.2 and S10 groups – 30.49 and 30.06% ($p<0.05$), respectively. Salt treatment did not affect the taste and odor, but improved the cod loin's texture properties. Based on these results, salt treatment is considered as an effective way to improve the yield and quality of frozen cod loins.
Key words: cod, salt treatment, production yields, sensory properties.

Introduction

One of the most important factors in improving food safety and competitiveness is its quality and stability. Consumers are interested in the ability of each company to organize their activities in order to market high quality products. Food quality is characterized by nutritional, physiological, safety and energy values. Modern food quality is not only nutritional and energy value, but also food safety.

The quality of fish meat is influenced by various factors: fish species, physiological state, catch method, processing technology and etc. (Andriejauskienė & Liorančas, 2011). The market is demanding meat, which is characterized by acceptable sensory properties, technological and culinary characteristics. In many European countries, the meat market is overcrowded, and various ways of improving its quality and competitiveness are sought (Jukna, Jukna, & Šimkus, 2003). High quality raw material enables processors to produce high quality and competitive fish products. Fish processing occupies an important place among other factors affecting quality. The final quality of the fish product will depend on how the refrigeration, freezing and other processing processes are carried out (Čiulevičius, 1987).

Whole fish with a protective coating (scales, skin) will stay much longer under the same conditions than fillets. Additional protection is required to protect the fillet and improve its technological properties. Freezing is one of the most employed methods used for preserving fresh fish and seafood products. However, in the frozen state of fish, physical, chemical and enzymatic changes are able to appear eventually rendering the tissue to an undesirable state (Abraha *et al*., 2018). Pourshamsian, Ghomi & Nikoo (2012) reported that taste, color and texture are some of the quality deterioration factors that occur in food during frozen storage. Freezing rate, thawing methods, and temperature fluctuations are main factors which affect the extent of fish product quality loss. Freezing maintains the product fresh and extends shelf life for a long time. This depends on several factors, such as initial condition of fish and time elapsed between harvest and freezing. These factors can influence protein denaturation and texture defect can occur (Yerlikaya & Gokoglu, 2010). In frozen fish process protein denaturation might occur. Once protein is denatured, muscle texture, water holding capacity, color and flavor of frozen fish and fish products are affected, since muscle protein is the main contributor to the characteristic textural properties (Sriket, Benjakul, & Visessanguan, 2017).

Nowadays, the interest in brine's ability to improve the quality of whole muscle beef, pork and poultry products is increasing (Harikedua & Mireles DeWitt, 2017). During the salt treatment, a thin layer of denaturated proteins is obtained on the surface of the fillet, which protects it from the external factors, reduces drying during freezing and weight loss during defrosting (Valtýsdóttir *et al.*, 2010, 2011). Low brine concentration typically has less than 5% NaCl and is used just to impact muscle protein functionality without altering flavor/appearance. Low brine concentration also reduces drip loss during storage and cooking-loss, improves juiciness and extends shelf life by inhibiting bacterial activity (Robbins *et al*., 2002; Parsons *et al.*, 2011; Sen *et al*., 2005; Rowe *et al*., 2009). Low concentration saline brines do not stop, but only slow down microbial activity (U.S. Department of Health and Human Services, 2011). Slight treatment with salt has a positive effect on the activity of enzymes in meat (transglutaminase, etc.). Salt releases water, which is later used to form the texture of fish meat (Ramirez *et al*., 2002). Qiancheng (2008) argues that the quality

of fish fillets can be improved by salt treatment. This improves water-binding and sensory properties. Thus, the aim of this study was to investigate the influence of salt treatment on yield and quality of frozen cod loins.

Materials and Methods

The study was performed in the fish processing plant 'X' which is specializing in the processing of fresh and frozen Atlantic cod (*Gadus Morhua*) from the North Sea. Above-mentioned company meets all hygiene, sanitary and environmental requirements. For this study cod loins were cut from the middle section of fattest part of the fillet. The loin size ranged from 75 to 90 g. Four research groups of 15 samples each were used for the study. The control group were cod loins without treatment. The second group (S0.8) soaked in 0.8% NaCl solution (1 h 30 min); the third group (S1.2) soaked in 1.2% NaCl solution (1 h 30 min); the fourth group (S10) soaked in 10% NaCl solution (5 min). The treatment was done in ice-water baths at tempetrature of +1 °C and afterwards all loins were frozen, packed in cartons lined with plastic bag and stored for one week at -20 °C. Throughout the test, control of the weight of the cod loins was performed to determine weight loss during freezing, dry defrosting and cooking. Defrosting loss was determined by the weight loss of the sample over 24 hours holding it in special bags of mesh at + 4 °C (Honikel, 1998). The salt content in defrosted loins was determined by Mohr method. The cooking loss was determined by Shilling's (1966) method of weighing the loin sample before cooking and after. Cooking was done in a circulating water bath for 30 min at 70 °C (Howgate, 2010). After this heat treatment, the sensory analysis of the products was performed according to the requirements of LST ISO 8589:2010 and sensory profiles were established. Samples were evaluated according to taste, smell and texture (Table 1). The intensity of each property of the product was evaluated and from these data, a mathematical statistical profile was used to form a profile of the sensory characteristics of each product. A group of 6 assessors participated in the sensory proficiency test. The assessors were selected and trained to work in accordance with LST ISO 8586-1.

Results and Discussion

The study results revealed that salt concentration did not exceed 1% (Table 2). Naturally, the salt content in cod meat ranges from 0.4 to 0.9%, because cod lives in salty waters, so it already has a slight amount of salt. (Waterman, 2001; Esaiassen *et al*., 2004; Roe *et al*., 2013). However, we can see that the control group had the lowest amount of salt (0.19%).

Normal weight loss during freezing is up to 2.5% for fish and other seafood (Johnston *et al*., 1994) and during defrosting in open air – up to 5% (Archer, Edmonds, & George, 2008). As it can be seen from the results of the study in Table 3, the weight of cod loins

Table 1

Sensory properties and descriptions

Properties	Scale	Description
Total odor intensity	Low – intense	Intensity of general smell
Cooked fish smell	Low – intense	Intensity of smell characteristics of cooked loins
Hardness	Low – high	Feature defining the force needed to bite the sample
Fibrousness	Low – high	Evaluation of individual fibers in the sample which are felt while chewing
Chewingness	Low – high	Number of bites and / or duration required to chew bite
Juiciness	Low – high	The product's ability to extract juice by chewing
Total flavor intensity	Low – high	Intensity of general sense of taste
Intensity of cooked fish flavor	Low – high	Intensity of cooked fish flavor
Saltiness	Low – high	Intensity of the salty sense

Statistical analysis of results was performed using SPSS statistical software, version 20.0.

Table 2

Concentrations of NaCl in cod loins

Groups	NaCl %
Control	0.19 ± 0.05
S0.8	0.29 ± 0.06
S1.2	0.61 ± 0.08
S10	0.70 ± 0.07

Data on weight loss during refrigeration, defrosting and cooking are presented in Table 3.

Table 3

Production yields during technological processes (g)

Sample	Technological processes					
	Before salt treatment /before freezing	After salt treatment /after freezing	Before defrosting	After defrosting	Before cooking	After cooking
Control	87.67	86.67	85.80	79.32	79.32	61.47
Yields (%)	– 1.14%		– 7.55%		– 22.50%	
S0.8	78.33	81.00	80.09	71.93	71.93	54.30
Yields (%)	+3.41%		– 10.19%		– 24.51%	
S1.2	84.67	88.67	87.06	77.42	77.42	58.73
Yields (%)	+4.72%		– 11.07%		– 24.14%	
S10	83.67	87.67	86.75	79.46	79.46	58.45
Yields (%)	+4.78%		– 8.40%		– 26.44%	

in the control group decreased by 1.14% ($p<0.05$) after freezing. The S0.8, S1.2 and S10 groups had the largest weight gains – 3.41, 4.72 and +4.78% ($p<0.05$), respectively.

After defrosting, the weight loss of all groups exceeded 5%, although the control group had the lowest weight loss during defrosting, which was 7.55% ($p<0.05$).

After cooking, the smallest weight loss was in the control and the highest in the S10 group because treated loins had less weight losses in previous processes, so this means that if there is more moisture in the fish, the loss during cooking is higher.

Taking into account the weight loss of all groups (Figure 1), all technological processes show that the largest weight loss was in the control group and in the S0.8 group – 31.19% and 31.29%, respectively, while the lowest in the S1.2 and S10 group – 30.49 and 30.06% ($p<0.05$), respectively.

For the sensory analysis, the samples were grouped into control and treated groups. There were no significant differences between the groups in the sensory profiles of the smell and taste (Figure 2) in this study.

As regards the sensory profiles of the texture (Figure 3), it was found that hardness, fibrousness and chewiness were most pronounced in the control group ($p<0.05$). Based on the results of the sensory evaluation, we found that soaking in salt brines had a positive effect on the sample properties. The best sensory profiles were in the S1.2 and S10 study groups: they were more tender, less fibrous, with better chewiness and more juicy ($p<0.05$).

In this study, the salt treatment increased higher yields and sensory quality. Esaiassenet *et al.* (2004) got similar results and found that the intensity of the attributes - cod smell, cod taste, glossiness, juiciness, flakiness and whiteness – were higher in the brined products compared with non-brined. Later Esaiassene, Østli & Joensen (2005) studied the effect of phosphate, salt, glucose, ascorbate and starch on yield, sensory quality and consumers liking,

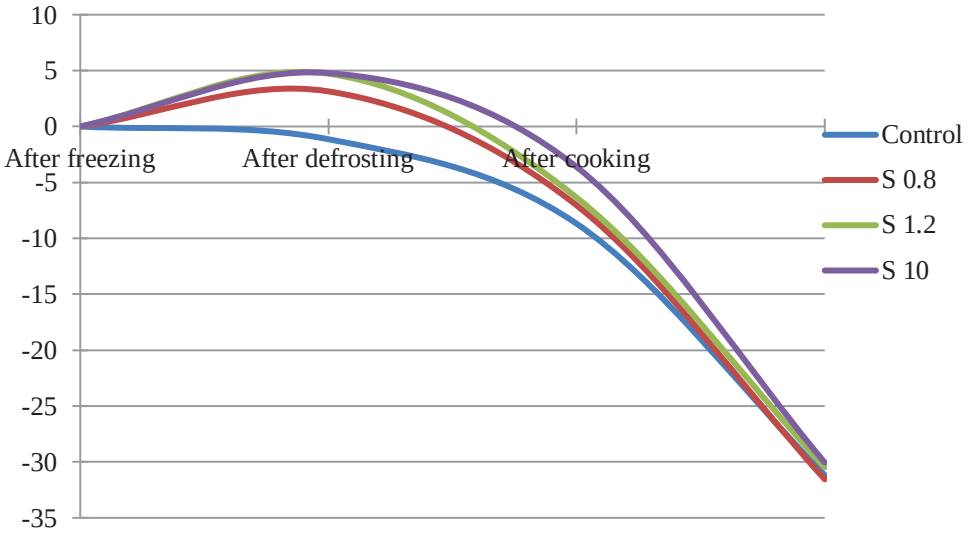

Figure 1. Total weight loss during cod's processing, %.

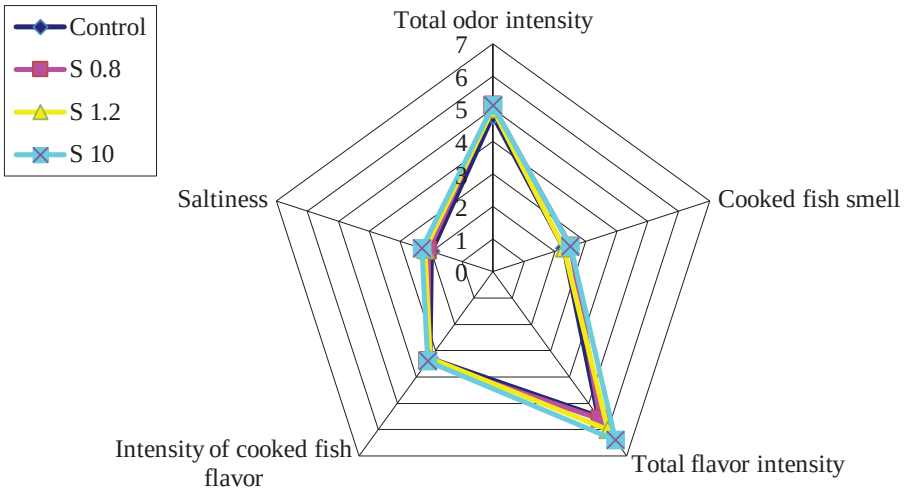

Figure 2. Smell and flavor sensory profile.

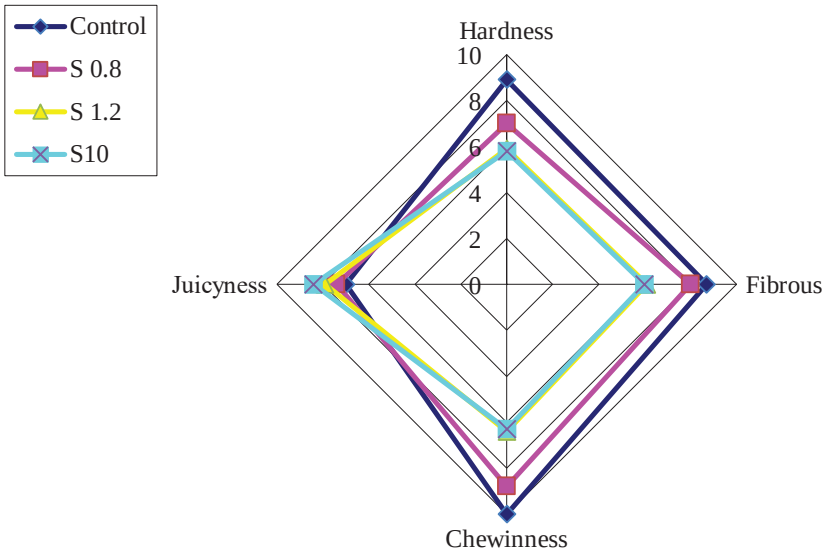

Figure 3. Sensory texture's profile.

and found that salt was the variable with the highest pronounced effect on yield, followed by triphosphate, glucose, starch and sodium ascorbate. Consequently, sensory analyses showed that the intensity of the sensory attributes – cod taste, cod smell, juiciness, whiteness and glossiness – could be heightened by brining, while the intensities of old/stale taste and smell could be lowered. However, there are other ways of increasing yield and quality but they use salt injections with additives, which obtain different results. Qiancheng's (2008) study showed that a combination of fresh protein isolate with salt injected into saithe and kept frozen resulted in lower cooking losses than only a salt injection. Thus, Thorarinsdottir *et al*. (2004) found that injection with salt had higher cooking yield compared to the mixture of protein and salt injection into cod fillets, which were kept frozen. These differences might occur because different salt concentrations were used in studies mentioned above. Summarizing, it is clear that brining considerably enhances the yields and sensory properties of frozen and thawed cod fillets.

Conclusions

Based on the results of the research, it can be stated that salt treatment at the time of refrigeration increases the yield in range of 3.41 to 4.78%.

Although the weight loss of the study groups is higher during defrosting and cooking, however, the data obtained from all technological processes indicate that soaking cod loins in salt brines reduces the total weight loss during freezing, thawing and cooking.

Soaking in low concentration brine does not affect the taste and smell but improves the texture of the samples.

Therefore, the salt treatment for cod loin is an effective way to improve its weight and sensory quality.

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EVALUATION OF A HEADSPACE SOLID–PHASE MICROEXTRACTION WITH DIFFERENT FIBRES FOR VOLATILE COMPOUND DETERMINATION IN SPECIALTY COFFEE BREWS

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Abstract
The aroma of coffee is the main quality factor. Compounds with floral, fruity, citrus and sometimes fermented aroma notes are defined as high quality characteristics for the specialty coffee brew. Commercial coffees mostly are at medium roast and the aroma profile is focused on balanced chocolate, caramel, toasted bread and almond bitterness aroma notes. These sensory characteristics set the focus for volatile compound profile analysis by Headspace solid-phase microextraction (HS-SPME). The most popular fibres for commercial coffee aroma profile analysis are DVB/CAR/PDMS, CAR/PDMS, PDMS/DVB and PA. There is limited research done about specialty coffee aroma profile and evaluation of more suitable fibres for solid-phase microextraction. The aim of the research is to evaluate the aroma composition of specialty coffee brews using different SPME fibres. Results demonstrated that CAR/PDMS fibre, compared to other fibres, can extract significantly more volatile compounds with higher peak areas in all chemical compound groups, except phenols. The CAR/PDMS was the only fibre which could detect all 17 important volatile compounds for specialty coffee. In conclusion, from the given research evidence, CAR/PDMS fibre is suggested as the most suitable SPME fibre coating for volatile compound extraction for specialty coffee brew import. The result provides evidence for improved specialty coffee aroma profile analysis by SPME.
Key words: specialty coffee, volatile compounds, SPME, fibre coating.

Introduction

HS–SPME is a simple, rapid but sensitive method for volatile compound extraction from food products and beverages (Chen, Chiang, & Chung, 2019). There are commercially available 7 SPME coatings: polydimethylsiloxane (PDMS), polyacrylate (PA), carboxen/polydimethylsiloxane (CAR/PDMS), polydimethylsiloxane/divinylbenzene (PDMS/DVB), carbowax/divinylbenzene (CW/DVB), carbowax/template resin (CW/TR) and divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) (Spietelun *et al*., 2010). It is important to evaluate SPME coatings, extraction and desorption technique for a specific product (Chen, Chiang, & Chung, 2019). The most popular fibres for commercial coffee aroma profile analysis are DVB/CAR/PDMS, CAR/PDMS, PDMS/DVB and PA. The DVB/CAR/PDMS fibre was selected for Mestdagh et al. (2014) study about the kinetics of coffee aroma extraction and Lee, Kim, & Lee (2017) study for coffee brew volatile compound profile determination of reversed coffee grinding and roasting process. The PDMS/DVB fibre was confirmed in Roberts, Pollien, & Milo (2000) research as the most suitable SPME fibre coating for wider range coffee volatile compound extraction. Petisca et al. (2012) study suggested CAR/PDMS as a beneficial SPME fibre coating for coffee furan compound detections. The CAR/PDMS fibre also was chosen by Kim et al. (2018) for the prediction of key aroma compounds in differently roasted coffee samples. Commercial coffees aroma profile is focused on balanced chocolate, caramel, toasted bread and almond bitterness aroma notes. These sensory characteristics set the focus for volatile compound profile by HS-SPME. Specialty coffee focus is on highlighting specific aroma and flavour notes from coffee by high–quality standards. From niche product specialty coffee has become a whole industry. Specialty coffee is defined as high quality coffee (Donnet, Weatherspoon, & Hoehn, 2008; Lee, Bonn, & Cho, 2013). Compounds with floral, fruity, citrus and sometimes fermented aroma notes are compared as high quality characteristics for the coffee brew (Fassio *et al*., 2017; Piccino *et al*., 2014; Poltronieri & Rossi, 2016; Silveira *et al*., 2016).There is limited research done about specialty coffee aroma profile and evaluation of more suitable fibres for solid phase microextraction. The aim of the research is to evaluate the volatile composition of specialty coffee brews using different SPME fibres.

Materials and Methods

Coffee samples

Five samples of coffee *(Coffea arabica L.)* beans were collected from two different coffee roasteries in Latvia. The main characteristics of the coffee samples are summarized in Table 1. Natural processing method was applied for Honduras_1, Kenya, Columbia, Ethiopia coffee samples, and anaerobic processing method – Honduras_2. All coffees are roasted at light–medium roast level and rated as specialty coffees: specialty coffee grade applies if the total specialty cup quality score is 80 points or above (Donnet, Weatherspoon, & Hoehn, 2008; Silveira *et al*., 2016). Both roasters, according to The World Coffee Research Sensory Lexicon (2017), gave sensory characteristic

Table 1

Main characteristics of the samples

Sample name	Roastery	Origin	Roasting level	Sensory description from roasters
Honduras_1	roastery 1	Honduras	light–medium	dark plum, grapes, red pepper, toffee (caramel)
Kenya	roastery 1	Kenya	light–medium	blackberry, red pepper, roses, dark chocolate
Columbia	roastery 1	Columbia	light–medium	pineapple, dried apricot, elderflower
Ethiopia	roastery 2	Ethiopia	light–medium	lime, jasmine, chocolate cream, cherry brandy
Honduras_2	roastery 2	Honduras	light–medium	dried fruits, passion fruit, melon, kombucha

descriptions and the descriptions are also stated on the specialty coffee label as sensory guidelines for consumers.

Brewing method

Coffee beans were immediately ground and prepared by French Press brewing technique (150 mL of 93 °C water (Neptunas/Lithuania) was added to 16 g of coarse grind coffee, with extraction time: 4 minutes). Each sample after brewing was immediately analysed. All brewed coffee samples were prepared in duplicates.

Headspace Volatile Compound Extraction by SPME

Aroma compounds were extracted by solid phase microextraction (SPME). The coffee extract samples (5 mL) were transferred to 20 mL glass container. Extraction parameters: extraction temperature +50 ± 1 °C; incubation time: 4 minutes; extraction time: 7 minutes. In the research four different fibres were used: divinylbenzene/ carboxen/ polydimethylsiloxane(DVB/CAR/PDMS), carboxen/ polydimethylsiloxane (CAR/PDMS), polydimethylsiloxane/ divinylbenzene (PDMS/DVB) and polyacrylate (PA). All fibres were purchased from Supelco (Bellefonte, PA, USA).

HS–SPME–GC–MS chromatographic parameters

'Perkin Elmer Clarus 500' chromatograph with mass spectrometer and 'Elite–Waw ETR' (60 mx 0,25mm internal diameter; DF 0.25 column) were used for gas chromatography method. Injection parameters: desorption time – 15 minutes; temperature +250°C. Working conditions were as follows: injector 250 °C; transfer line to MSD 260 °C; oven temperature start 40 °C, hold 7 min, programmed from 40 – 160 °C at 6 °C min^{-1} hold 10 min, and from 160 – 210 °C at 10 °C min^{-1}, hold 15 min. The column initial flow rate of 1 mL min^{-1} was held using helium as carrier gas. The outlet split 1:2 and between 40 and 300 mass–to–charge ratios were scanned. As a quantitative measure, the share in the total GC peak area for each compound is given. The compounds were identified using mass spectral database 'Nist98'(Gloess *et al*., 2013; Steen *et al*., 2017).

Statistical analysis

The data were express as mean. Analysis of variance was performed, and the significant differences were stated if $p<0.05$. The data were analysed with Microsoft Office Excel 2013.Principal component analysis (PCA) was used for reduction of variables to a smaller set called components. The first principal component demonstrates the highest variability, followed by second component with less variability. PCA was performed including volatile profile of all tested coffees. Data were treated using SPSS 23 software.

Results and Discussion

Evaluation of coffee volatile compound chemical groups, detected with different SPME fibres

From 16 chemical compound groups, 76 compounds were detected (compounds are summarized by their chemical groups in Table 2). CAR/PDMS fibre extracted significantly more volatile compounds compared to other fibres and showed the highest peak areas in all chemical compound groups, except for phenols. CAR/PDMS has shown lack of extracting phenol compounds from ground coffee also in Akiyama et al. (2007) study. The phenol compounds as 4–vinylguaiacol or 4–ethyl–2–methoxyphenol are not common compounds in specialty coffee aroma profile because of the smoky, spicy unpleasant aroma notes and increasing concentration is only detected in medium–dark roasted coffees (Dorfner *et al*., 2003; Yang *et al*., 2016). Roberts, Pollien, & Milo, (2000) research also reports CAR/PDMS fibre as the most suitable for small molecule extraction as 2–methylpropanal, acetaldehyde and organic acid as acetic acid and propionic acid extraction. The CAR has a large surface area with different range pores (micro– and macro–pores), which allows extracting also trace level volatile compound, compared to DVB with limited micropores (Chen, Chiang, & Chung, 2019; Salum *et al*., 2017). The results also confirm this statement because using DVB/CAR/PDMS and CAR/PDMS fibre volatile compounds showed a higher peak area range compared to PDMS/DVB. DVB/CAR/PDMS fibre is the most commonly chosen fibre for aroma analysis of coffee brews. However, these studies used distilled water for coffee extraction (Caporaso *et al*., 2018; Mestdagh *et al*., 2014). It is known that distilled water cannot extract beneficial

Table 2

Chemical compound groups extracted from coffee brews using four different SPME fibres

No.	Chemical compound groups (number of compounds)	GC–MS peak area (number of compounds)			
		DVB/CAR/PDMS fibre	CAR/PDMS fibre	PDMS/DVB fibre	PA fibre
1.	Alcohols (7)		5.68E + 07^{a} (3)	2.89E + 07^{c} (3)	3.01E + 07^{b} (3)
2.	Aldehydes(11)	3.18E + 08^{b} (3)	9.61E + 08^{a} (8)	2.39E + 08^{c} (6)	3.07E + 07 (5)
3.	Alkanes (2)	6.37E + 06^{b} (1)	2.89E + 07^{a} (1)		
4.	Ketones (9)	6.71E + 07^{b} (4)	2.95E + 08^{a} (7)	4.17E + 07 (2)	4.32E + 05^{c} (1)
5.	Amides (1)		9.61E + 07 (1)		
6.	Esters (8)	7.09E + 07^{b} (5)	3.19E + 08^{a} (6)	1.53E + 07^{c} (1)	
7.	Furans (6)	4.09E + 08^{b} (5)	1.43E + 09^{a} (6)	3.97E + 08^{c} (4)	8.46E + 07 (3)
8.	Organic acids (10)	1.90E + 07^{c} (4)	3.07E + 08^{a} (3)	1.02E + 07 (5)	3.02E + 07^{b} (2)
9.	Oxides (1)	1.12E + 07 (1)	1.02E + 08^{a} (1)	1.69E + 07^{c} (1)	1.01E + 08^{b} (1)
10.	Phenols (3)		4.77E + 05^{c} (1)	3.50E + 06^{b} (1)	3.72E + 06^{a} (1)
11.	Pyrazines (9)	7.96E + 06 (1)	1.13E + 08^{a} (7)	4.10E + 07^{b} (6)	
12.	Pyridine (1)	2.37E + 07^{b} (1)	7.03E + 07^{a} (1)	2.47E + 06 (1)	
13.	Pyrimidine (2)	3.33E + 07^{b} (1)	8.07E + 07^{a} (1)	4.67E + 06^{c} (1)	5.10E + 05 (1)
14.	Pyrroles (2)	1.20E + 07^{c} (2)	5.21E + 07^{a} (2)	2.87E + 07^{b} (1)	
15.	Sulfur containing compounds (2)		1.77E + 07^{a} (1)	2.59E + 06^{b} (1)	
16.	Terpenes (2)		1.56E + 07^{a} (1)	3.41E + 06^{b} (2)	
Total compounds (76)		9.79E + 08^{b} (28)	3.94E + 09^{a} (50)	8.33E + 08^{c} (35)	2.81E + 08 (17)

Different letters (a–c) in the same row indicate significant differences ($p<0.05$) in GC–MS peak area.

aroma and flavour compounds because of the lack of minerals like calcium or magnesium (Hendon, Colonna–Dashwood, & Colonna–Dashwood, 2014). From this point of view, DVB/CAR/PDMS fibre suitability for coffee brew aroma extractions was not proven.

The PA fibre was able to extract only 17 volatile compounds from 8 chemical compound groups, showing the lowest total compound peak area, but the advantage of current fibre is the extraction of phenols with a higher peak area. It has been reported that fibre coatings with polar and non–polar materials are more efficient for polar compound extraction from samples with polar matrix composition. It could be one of the reasons why using PA fibre alkanes, amides, esters, pyrazines, pyridines, pyrroles, sulphur containing compounds and terpenes were not detected. Chen, Chiang, & Chung, (2019) study also confirmed that using PA fibre compounds as ketones, pyrazines, sulphur containing compounds were not detected. The DVB/CAR/PDMS, CAR/PDMS and PDMS/DVB fibres are bipolar and the results confirm their ability to extract wider composition of volatile compounds (Mestdagh *et al*., 2014; Spietelun *et al*., 2010).

Important volatile compounds in specialty coffee brew

It is noted that from approximately 950 coffee volatile compounds only 20 can significantly influence the aroma and flavour profile. These 20 compounds are mostly detected in specialty coffees (Kim *et al*., 2018; Laukaleja & Kruma, 2018). In this study, using CAR/PDMS fibre 17 important specialty coffee volatile compounds were detected: DVB/CAR/PDMS detected 15, PDMS/DVB detected 13 and PA fibre only detected 6 compounds. A higher peak area of volatile compounds was detected using CAR/PDMS and DVB/CAR/ PDMS fibres (the results are illustrated in Table 3). Both fibres detected a significantly higher peak area for 2,6–dimethyl–4–thiopyrone (caramel aroma notes), 2–methylfuran (roasted coffee aroma notes). The CAR/PDMS fibre is suggested for detection of compounds with low boiling point, especially aldehydes (Salum *et al*., 2017). In this research, the CAR/PDMS was the only fibre which could extract acetaldehyde (fruity aroma notes) and had a higher peak area for 3–methylbutanal (fruity), 2–methylpropanal (roasted, sweet almond aroma notes). The overall volatile compound profile in this research corroborates with Wei et al. (2017) aroma analysis using CAR/PDMS fibre; the furan and aldehyde compound peak areas were similar and proportional. Petisca et al. (2012) study reports supporting evidence that CAR/PDMS is the most efficient for furan compound extraction from coffee. The DVB/CAR/PDMS was the only

Table 3

Identified important volatile compounds in specialty coffee brews using four different SPME fibres

No.	Compounds	GC–MS peak area (x10^8)				Compound sensory description
		DVB/CAR/ PDMS	CAR/ PDMS	PDMS/ DVB	PA	
1.	1–(2–Furanylmethyl)–1H–pyrrole	19.64^b	48.81^a	7.08^c		savoury, vegetables
2.	2,3-Pentanedione	5.01				buttery
3.	2,6–Dimethyl–4–thiopyrone	56.01^b	127.43^a	33.73^c	5.01	caramel
4.	5–Methyl–2–furancarboxaldehyde	35.85^b	73.31^a	20.29^c	10.35	caramel
5.	2–Furanmethanol	60.46^a		42.15^b	3.66^c	floral
6.	Furfuryl acetate	27.37^b	34.29^a	11.89^c	3.06	floral, fruity
7.	3–Methyl–butanal	7.14^b	12.39^a	6.57^c	0.86	fruity
8.	1–(2–Furanyl), ethanone	7.85^a	3.29^b			nutty
9.	2–(Methoxymethyl)furan	95.72^a	34.00^b	2.93		nutty, ground coffee–like
10.	2–Methylfuran	73.77^b	164.31^a	27.06^c	6.86	roasted almond, coffee
11.	Furfural	14.57^b	16.84^a	5.16^c		caramel
12.	2–Methylpropanal		3.98^a	3.28^b		roasted sweet almond
13.	2.5–Dimethylpyrazine	7.96^a	5.48^b	3.56^c		roasted
14.	Ethyl–pyrazine	16.63^b	32.29^a	9.35^c		chocolate–peanut, nutty
15.	4–Methyl–pyrimidine		18.20			popcorn
16.	Acetaldehyde		6.15			fruity
17.	Furfurylformate	19.64^b	48.81^a	7.08^c		malt, fruity

Different letters (a–c) in the same row indicate significant differences ($p<0.05$) in GC–MS peak area.

fibre which could detect 2,3-pentanedione (buttery aroma notes) in coffee brews and showed the highest peak area for 2–furanmethanol (floral aroma notes), 2–(methoxymethyl) furan (nutty, ground coffee like aroma notes), 2,5–dimethylpyrazine (roasted aroma notes) compounds.

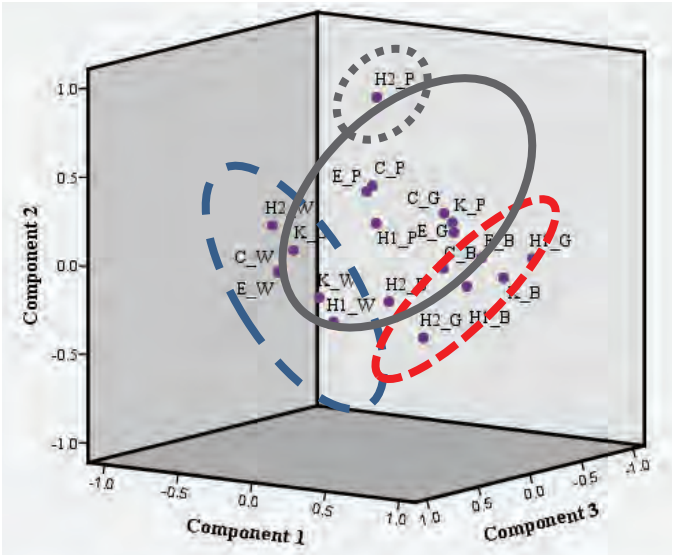

Figure 1. Component Plot in Rotated Space by principal component analysis (PCA). Code names: E_W – Ethiopia PA fibre; C_W – Columbia PA fibre; H1_W – Honduras_1 PA fibre; H2_W – Honduras_2 PA fibre; K_W – Kenya PA fibre; E_P – Ethiopia PDMS/DVB fibre; C_P – Columbia PDMS/DVB fibre; H1_P – Honduras_1 PDMS/DVB fibre; H2_P – Honduras_2 PDMS/DVB fibre; K_P – Kenya PDMS/DVB fibre; E_B – Ethiopia CAR/PDMS fibre; C_B – Columbia CAR/PDMS fibre; H1_B – Honduras_1 CAR/PDMS fibre; H2_B – Honduras_2 CAR/PDMS fibre; K_B – Kenya CAR/PDMS fibre; E_G – Ethiopia DVB/CAR/PDMS fibre; C_G – Columbia DVB/CAR/PDMS fibre; H1_G – Honduras_1 DVB/CAR/PDMS fibre; H2_G – Honduras_2 DVB/CAR/PDMS fibre; K_G – Kenya DVB/CAR/PDMS fibre.

This study result disproves Bressanello et al. (2017) and Gloess et al. (2013) researches; they reported a positive correlation between sensory (cupping) results and important coffee volatile compounds determined by HS–SPME using PDMS/DVB. Ribeiro et al. (2009) using PDMS/DVB fibre for prediction of sensory properties of Brazilian *Coffea arabica L.* roasted coffees concluded the importance of the method for future alternative coffee beverage quality monitoring.

PCA of the specialty coffee brews with different fibres

The Principal component analysis reduced variables in components and the first two components represented 83.84% of total variance. In the score plot, coffee samples extracted with Carboxen/PDMS (CAR/PDMS) and Divinylbenzene/Carboxen/PDMS (DVB/CAR/PDMS) were classified in one principal component showing the highest content of the most important coffee volatiles (Figure 1). In separate principal components, samples extracted with polyacrylate (PA) and Polydimethylsiloxane/Divinylbenzene (PDMS/DVB) fibre were classified. Due to the specific volatile profile, Honduras_2 samples were classified differently – the sample extracted with Carboxen/PDMS was classified together with other coffee samples extracted with Polydimethylsiloxane/Divinylbenzene (PDMS/DVB), and the Honduras_2 sample, extracted with Polydimethylsiloxane/Divinylbenzene (PDMS/DVB), was classified separately from all tested samples. The results can be explained by the applied processing method. Honduras_2 was the only coffee sample with different processing method (anaerobic), while for the other four coffees natural processing method was applied. Natural process method allows the coffee cherries to dry in the sun, while in anaerobic process coffee cherries are washed and coffee beans are afterwards sealed in fermentation tanks. During the anaerobic process coffee develops the fermented aroma and flavour notes (Geromel *et al.*, 2008; Taveira *et al.*, 2015).

The Principal component analysis allowed to reduce data of coffee volatiles in principal components, and results confirmed the importance of SPME fibre coating selection for analysis of coffee volatile profile, because samples were classified based on fibre coating, not the origin of coffees.

Conclusions

The results demonstrated that CAR/PDMS, compared to other fibres, was able to extract significantly more volatile compounds with higher peak areas in all chemical compound groups, except phenols. The CAR/PDMS was the only fibre which could detect all 17 important volatile compounds for specialty coffee. The PA fibre showed the largest phenol peak area but could only detect 6 from 17 important volatile compounds. This research disproves previous reports, showing that PDMS/DVB and DVB/CAR/PDMS fibres detect a wider and higher concentration of coffee volatile compounds compared to CAR/PDMS fibre. The result provides evidence for specialty coffee aroma profile analysis by SPME.

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INTRODUCTION OF SMART PACKAGING SYSTEMS IN THE MARKET OF LATVIA – ATTITUDES OF MANUFACTURERS AND RETAILERS

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Abstract
Perfect packaging exists in nature – examples include banana peel (*Musa sapientum fixa cortices L.*) and eggshell (*Ovi testa L.*), together with the many smart materials and systems that control plant and biological functions. Smart packaging is a type of packaging, which in addition to performing the four basic functions of packaging such as protection, communication, convenience and containment, also offers several additional functionalities depending on the type of product. Changes in consumer preference for safe food have led to innovation in packaging technology. The market for smart packaging systems has a promising future by integrating them into packaging materials. For food retailers, smart packaging is a huge development in helping to reduce food waste. The aim of this study was to assess the awareness and attitudes of food manufacturers and retailers to the introduction of smart packaging systems into the Latvian market. A survey reflected knowledge about active and intelligent packaging and its possible introduction into the Latvian market. Ten manufacturers and ten food retailers from different regions in Latvia answered 16 questions, including how well they were informed about smart packaging and how much consumers would be willing to pay for it. In addition, the food manufacturer and food retailer confidence in the impact of smart packaging on a product storage quality was analyzed. The results revealed that manufacturers and retailers in Latvia have a poor understanding of the new opportunities which could be offered by using technologies of smart packaging.
Key words: smart packaging, manufacturers, food retail, shelf life.

Introduction

Packaging is a crucial part of any advanced integrated product supply system. The main advantage is not just to preserve product's integrity and features starting with the production line and ending with the consumer impact on health and safety, but also to accelerate production and distribution and improve storage options (Robertson, 2006). Recently, huge strides have been made in the packaging technology development and application of new products and processes. Packaging is an essential bit of food processing and preservation, and it vastly influences the product's shelf-life. The material of the package can modify the product by physical and chemical alterations because of the particle migration into the nourishment. In case of food, it is vital to control the quality and safety of it during shipment and storage and extend the shelf-life of the goods (Dobrucka & Cierpiszewski, 2014). The container accounts for the protection of the food from the medium, shielding it from physical, chemical and microbiological factors such as moisture, light, oxygen or microbial contamination that could influence the nature of the goods (Moldovan & Pantea, 2015).

Some additional functionality could be to retain the integrity of a product and inhibit food decomposition, improve product properties such as appearance, flavour, smell, etc., respond actively to variations in product and package conditions, deliver product information, product history or state to the user, indicate seal integrity, or confirm product authenticity (Yam, Takhistov, & Miltz, 2005).

'Smartness' of the packaging is a general term that incorporates a number of functionalities, depending on the product being bundled, including food, beverage, pharmaceutical, household products etc. Representatives of modern and expected functional 'smartness' would be in packages that:

- Maintain wholeness and actively stop food decomposition (shelf-life),
- Improve product characteristics (e.g. appearance, flavour, fragrance etc.),
- Respond actively to variations in product or package circumstances,
- Deliver product information, product history or state to the user,
- Help with the preparation and designate seal integrity,
- Verify the product's authenticity and prevent theft (Siegrist, 2008).

Smart packaging can already be found on the shelves, and many other active and intelligent packaging ideas are under development (Kuswandi *et al.*, 2011). The central cause of tremendous progress that can be seen in the field of food packaging is the rise of nanotechnologies, which shapes nanometer-scale materials of industrial and experimental significance. By introducing nanotechnologies, scientists have addressed the food nature, security and stability concerns (Sharma *et al.*, 2017). The use of anti-microbial technologies and oxygen scavenging active food packaging systems, for example, sorbate-releasing low-density polyethylene (LDPE) film for cheese, has the capability to prolong the shelf-life of perishable foods while simultaneously improving its quality by decreasing the necessity of preservatives (O' Callaghan & Kerry, 2016). In intelligent packaging, the container function turns on and off in response to

shifting outer/inner states and can involve a message to the customer or end user as to the condition of the product (Ghaani *et al*., 2016).

The tendency in food packaging methods is the outcome of consumer preferences towards mildly processed foods with an improved shelf-life and convenience (Dobrucka & Cierpiszewski, 2014). Furthermore, the recent trend of retail systems and evolving lifestyle are the incentives for the progression of original and innovative packaging techniques without compromising the safety and quality characteristics of the goods (Dainelli *et al*., 2008). A major boost for fresh food packaging methods is the advancing issues of foodborne microbial flashes which oblige the practice of packaging with antimicrobial effect along with the retention of food quality (Appendinia & Hotchtkiss, 2002). Alterations in packaging started in the shape of metallic containers, adjustable packaging, electrically operated packaging machinery, aluminum foil, aseptic packaging and flexographic printing (Brody, Strupinsky, & Kline, 2008). The emerging novelties in the packaging business will strengthen the economy by enhancing food protection, quality and by decreasing product losses (Mehmet, 2015).

One of the most debated topics is the ability to track packed products. New methods have been developed to assure the traceability during the entire journey of the goods from manufacturers to market suppliers (Ghaani *et al*., 2016). New electronic devices have been developed so that they can be attached to the package showing different properties, such as, heat, time of storage, a span of delivery, etc. These tracking systems certainly do not come for free, but the lack of them is an immense mistake for the producers. The main data that must be provided is the batch number of the fresh materials, the manufacturer ID and the biodegradability of the materials. In tracking systems, a significant part is performed by the labels that can include indicators that provide information for the customers, for example, branding and identification of the product (Moldovan & Pantea, 2015). The aim of this study was to assess the awareness and attitudes of food manufacturers and retailers to the introduction of smart packaging systems into the Latvian market.

Materials and Methods

The analysis is based on a survey with two types of respondents: food retailers and food manufacturers. To participate in the survey, the top 10 Latvian food retailers were selected, based on their revenue in 2017 (data obtained from LFFC (Latvian Federation of Food Companies)). The chosen companies cover all the major Latvian regions: Riga (5 companies), Zemgale (1), Vidzeme (2), Latgale (1), Kurzeme (1). The second survey with similar questions was carried out with 10 different food manufacturers in Riga (6 companies), Zemgale (1), Vidzeme (1), Kurzeme (1), whose goods are distributed to the retail chains of Latvia (product group - packaged food products). The manufacturers were selected from those who provide perishable products (e.g dairy, fruits) and have their products on the shelves of all top 10 retailers. The methodology of the questionnaire was used to accomplish the research objective. For each of the 16 carefully chosen questions, the answers were either multiple-choice or interviewee produced response. The survey was issued to respondents using an online survey website VisiDati.lv. The number of respondents by sex were: 14 female and 6 male respondents. Most respondents (16) were between the ages of 35 and 50, 3 were between the ages of 25 and 35, and 1 was over 50 years old. In response to their educational status, the preponderance of those who participated in the survey indicated that they had a master's or a bachelor's degree – 18; 2 respondents held a professional degree. The qualitative method was used in the survey. During the questionnaire, the participants were encouraged to respond to the questions fully. If they needed clarification, some additional information was given to ensure that the respondent fully comprehends the question.

Results and Discussion

The survey provided an opportunity to analyse respondents' answers in order to clarify the manufacturer and retailer attitudes and knowledge regarding smart packaging. Smart packaging adds extra value to the consumer, shipping facilities, and companies that produce the above-mentioned products. For example, smart packaging can include tabs that indicate the freshness of an item, extend the shelf-life of a product, track shipping progress, and improve the protection of the products it is carrying. Smart packaging can help with a better supply management of retail, compliance complications, inventory management, and increase the protection of products during shipment (Marsh & Bugusu, 2007). Smart packaging is not something new for Latvian manufacturers and retailers. However, the term 'smart packaging' was familiar to 8 retailers, but 2 manufacturers had never heard of it before.

Retailers always try to ensure surveillance of their goods, as the monitoring can reduce the amount or eliminate product discrepancies and faked products. Retailers can accomplish these tasks, they can reduce or minimize the write-off of discarded or crashed products if they use smart packaging (Phalgun, Nagendra, & Shivakumarb, 2016). If a retailer chooses to forget such smart packaging solutions, they lose an option to regulate, and to control and minimize the write-off of spoiled items. 7 retailers consider smart

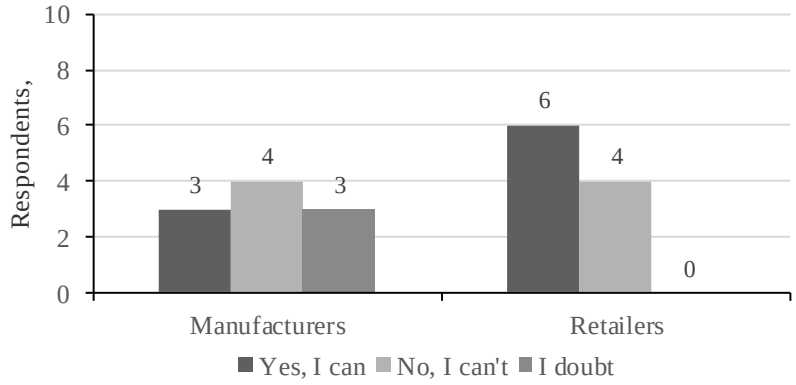

Figure 1. Respondents' ability to differentiate between active and intelligent packaging.

packaging as one of the correct decisions while 3 retailers answered with 'definitely no'. The response of this group reflects the answer to the question about the understanding of the term 'smart packaging'. 6 manufacturers, as one of the many criteria for evaluating the packaging, answered – 'yes, certainly', 4 gave a negative answer, 2 of the manufacturers chose 'definitely no' and 2 – 'do not care at all' answers. The difference of opinions of manufacturer respondents can be described as an inability to control the storage of packaged products delivered to the retailer. The retailer cannot ensure control of each item displayed on the shelf in the store.

Smart packaging is a relatively recent invention which has a lot of room for improvement. Modern technologies, which help in communication with consumers, such as printed electronics and the internet, are being exploited more and, therefore, rapid development of intelligent packaging can be observed (Seckin & Yener, 2015). However, there are inevitable obstacles for such accelerated development. For example, some smart packaging is not cost-effective to produce. Another obstacle is the way smart packaging affects legislation. Sustainability is an extra barrier since some of these technologies are challenging to recycle. And finally – timing, there are not many examples of proven success of it. Nonetheless, there exists stable and reproducible proof that smart packaging is a commercial success (Muizniece-Brasava & Kirse, 2018). Figure 1 shows that 6 retailers can distinguish between active and intelligent packaging. An inverse measure of results was obtained from manufacturers. It is important to note that 7 manufacturers cannot distinguish term differences, out of which 3 doubt the ability to distinguish types of smart packages.

Only 1 out of both groups' respondents use smart packaging in their own production facilities (Figure 2) and this is a very low level currently for smart packaging products. The smart packaging industry is heavily divided, as both large and small-to-medium-sized enterprises continue to focus on narrow, one-off solutions, which prevents the planned implementation of smart packaging. The wide array of participants from infrastructure providers to packages, from brands to retailers themselves have prevented smart packaging introduction into the market.

5 manufacturers and 4 retailers answered that they try to introduce smart packaging in the production process. On the other hand, almost half respondents: 4 manufacturers and 5 retailers answered that they do not plan to integrate smart packaging into their own production process. Firstly, the reason could be the non-cost-effectiveness of the final product, because the shelf price level is one of the indicators of a product's demand. With the introduction of nanomaterials, the

Figure 2. The use of smart packaging in production by respondents.

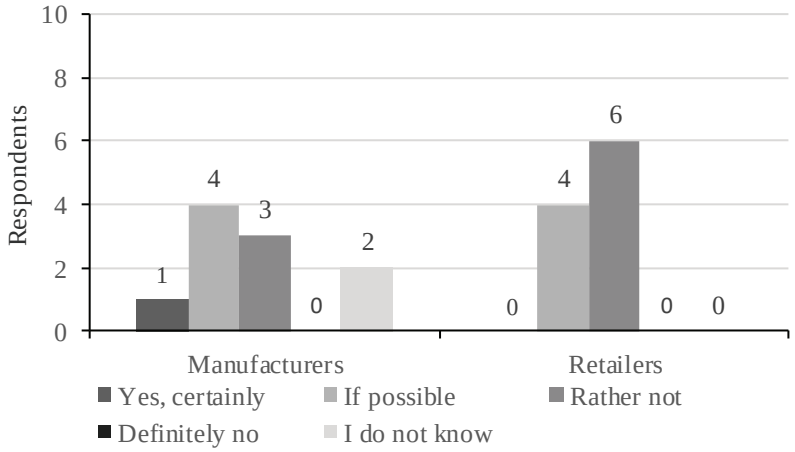

Figure 3. Respondents' readiness to pay more for smart packaging.

food industry will transform as never before. The 21st century customers have witnessed an accelerated improvement in approval of nanomaterial-based food packaging due to the implementation of smart packaging. Smart materials will advance the existing storage systems while smart packaging will extend shelf life (Phalgun, Nagendra, & Shivakumarb, 2016). Smart packaging provides consumers with extra information, communicates with retailers and manufacturers.

In Figure 3, you can see the respondents' opinions about readiness to pay a little more for smart packaging.

Most of the respondents among manufacturers and retailers are not ready to pay more for smart packaging. From the manufacturers' side, a stable position is not indicated; this may depend on the level of change in the cost price of the finished product. Retailers have a more comprehensive position. It depends on the implementation system in the production and sales process of the product in smart packaging (Carbone *et al*., 2016). Not all respondents are ready to pay more for smart packaging. Manufacturers must convey to the buyer that the smart packaging will be superior compared to equivalent competitors' products.

In Figure 4, manufacturers' opinion is divided into two parts where one half does not want to pay more for smart packaging and the other half of manufacturers are ready to pay up to 10% more.

Retailers have another position and they are ready to pay more for smart packaging. 3 retailers are ready to pay up to 5% more and 4 are ready to pay up to 10% more. Such difference in the answers reflects the difference in the conditions of the possibility of conveying smart packaging to the end customer. The first criterion among manufacturers is the choice over which channel the product will be sold – directly to the final customers or to the distribution channel where price increase will be perceived very negatively. There are multiple advantages for the retailer who can offer smart packaging on its shelves for the end customers. Smart packaging can help with a better supply chain management, compliance complications, managing inventory, and increase the security of products in the shipment process. Additionally, perishable items and fresh products can be continuously monitored for freshness and potential condition issues. In today's world, we are continuing to see increasing numbers of faked products, ranging from wine to high-end clothing, to big-name sports apparel. With smart

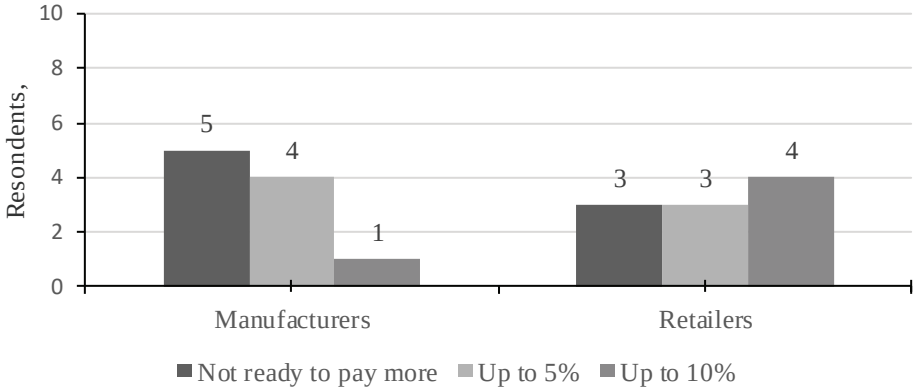

Figure 4. Number of respondents willing to pay more for smart packaging.

packaging, retailers can constantly keep close tabs on inventory, shipments, and where things come from and go to (Seckin & Yener, 2015).

When asked whether respondents believed that smart packaging would give food products an advantage over equivalent competitors' products without smart packaging, 6 manufacturers answered – yes, certainly. However, the opinion of retailers is divided: 5 of them were sure that smart packaging would give a superiority while the other 5 gave the answer – rather not. Questionnaire respondents were asked to analyse smart packaging also from the marketing position. 8 manufacturers believe that smart packaging can give the advantage for marketing and only 2 are unsure of it. The main retailers in the Latvian market do not have a single vision, 5 are sure that smart packaging is one of the marketing tools and 5 believe that this is a modern trend and, therefore, an integral part of the development of packaged products.

For food retailers, smart packaging is a huge development in helping to lessen food waste. We all know that most of our food products come stamped with a 'sell-by' date or 'best before' seal. Are these helpful guides? Perhaps, but they are nowhere near foolproof and are riddled with uncertainties and potential errors. This leads to massive amounts of food waste for both retailers and consumers, which in return can hurt the environment. Intelligent packaging can help reduce these common issues and deter large amounts of wasted food throughout the world (O' Callaghan & Kerry, 2016).

Smart packaging also offers opportunities in the area of theft protection. Products with RFID (radio frequency identification) transponders integrated into the packaging can always be tracked. This not only helps to prevent theft from stores, but it also supports manufacturers with supply chain management, transport, and logistics. Products can be traced along the entire value chain, at the factory, in the warehouse (inventory management, goods in and out, etc.), and during transit to stores and end-users (location of goods) (Dobrucka & Cierpiszewski, 2014).

Due to the demand for quickly prepared and ready-to-eat 'fresh' food products, with the delivery from centralized processing, as well as globalization of food business, major challenges for food safety and quality have arisen. Contemporary foodborne microbial upsurges are encouraging a search for innovative ways to restrain microbial growth in the foods whilst sustaining quality, safety and freshness (Biji *et al*., 2015). The first option is to utilize packaging to provide an enlarged margin of safety and quality. The following generation of food packaging may add materials with antimicrobial qualities. These packaging technologies could become the reason for the shelf-life extension of foods and could lessen the danger of pathogens. Antimicrobial polymers may gain use in other food-related industries (Majid *et al*., 2016). A very important point can be made around the purpose that both respondent groups expect from smart packaging in the production process and on the shelf itself. Manufacturer respondents answered: 2 were for protecting food against deterioration, 2 were for ensuring easy and convenient use, none were for the informing the consumer about the content of the food and 6 were for all the previously mentioned purposes. Most of the respondents want to receive as much information about product conditions as possible. Retailer respondents noted only two important criteria: 6 were for protecting food against deterioration and 4 were for informing the consumer about the content of the food.

Interesting differences can be deducted by analysing questions on the priority when choosing

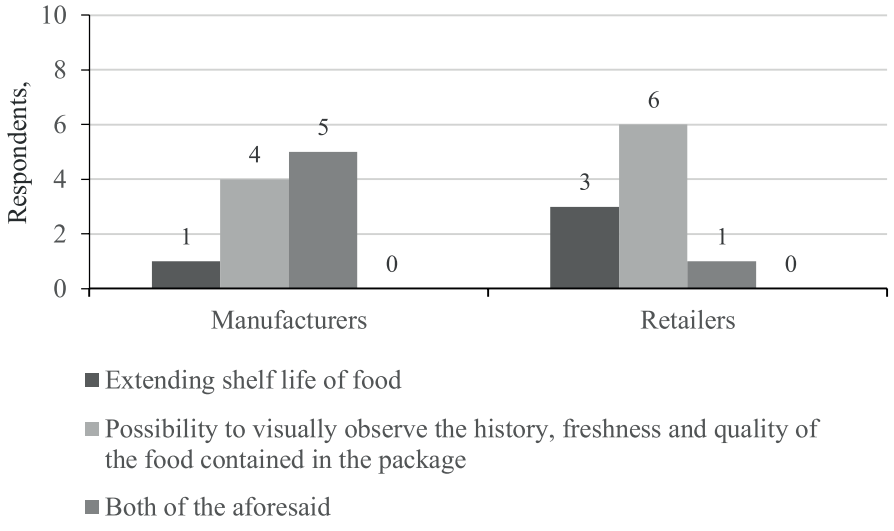

Figure 5. Respondents' expectations from smart packaging.

a package for products. 5 manufacturers consider that the most important criterion in smart packaging is environmental requirements (nature-friendly, recycling options), however, only 1 retailer voted for this criterion. The answer about requirements for packaging safety in direct contact with food was supported by 3 manufacturers and 5 retailers. The second important criterion for retailer respondents was product and packaging compatibility for longer sales times (quality, etc.), voted by 4 of them, and only by 2 manufacturers. Criteria of significance on the expectation from smart packaging are shown in Figure 5.

An insignificant part of manufacturers, 1, answered per criterion extending shelf life and 3 retailers answered the same. 4 manufacturers and 6 retailers voted for the possibility to visually observe the history, freshness and quality of the food contained in the package. 5 manufacturers voted for both criteria and only 1 retailer voted for both criteria. Survey reflects the direction of each group where we can trace the desire of manufacturers when using smart packaging technologies to receive maximum of what can be offered by this technology. But retailers want to solve clearly defined tasks.

An important section in this survey after all questioning was to provide an answer on the following topic: what should be done to promote the positive attitude of society towards smart packaging. 5 manufacturers versus 4 retailers answered that customers should be educated through advertising. A similar ratio in the responses (5 versus 4) was given to the idea to offer product within price promotion and only 2 retailer respondents considered that the sales or promotion should be done only with trusted product brands.

The state of food items frequently relies upon their perishability. Perishable foods need a cool environment to preserve quality and freshness throughout transit and storage. By controlling the extent to which perishable foods face degradation promoting factors (like oxygen, light) both manufacturers and retailers are able to manage their perishability. The shape and the material of the food container play a crucial and decisive role in food quality and shelf-life. Packaging chiefly affects the barrier features to create an irrefutable food environment (Singh, Wani, & Langowski, 2017).

Conclusions

1. According to the survey results, top 10 food retailers and food manufacturers in Latvia have little understanding of the new opportunities which could be unveiled by using technologies of smart packaging. The numerous listed benefits and respondent expectations from smart packaging result in the belief that both groups are open to new trends, ready to try them, study them and are prepared to pay for smart packaging.
2. The upside potential is large, as smart packaging is posed to solve numerous weighty business issues from stock-outs to counterfeiting to product spoilage to customer satisfaction, communication and retention.
3. Smart packaging is organizing around a set of few applications, which are driving supply chain efficiency, followed closely by product integrity and customer engagement.
4. The results proved that the crucial factors for the manufacturers and retailers are the quality, the efficient use, and the ability to control storage time, which, in turn, are what the smart packaging offers.
5. Packaging manufacturers have an opportunity to move away from purely price-based competition, increase customer loyalty, and offer their customers real, long-term added value. To achieve this, it is fundamental for packaging manufacturers to design and develop new products and services and work with their customers to bring them to market.

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DETERMINATION OF ORGANIC ACIDS IN HONEY SAMPLES FROM LATVIAN MARKET BY HIGH-PERFORMANCE LIQUID CHROMATOGRAPHY

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Abstract
Honey is a naturally sweet product, which is produced by honeybees (*Apis mellifera*). Honey is a natural source of antioxidants and has been known to mankind since ancient times. Honey contains approximately 200 different compounds. Organic acids can be used as an indicator to detect the freshness, authenticity and acidity of honey. The aim of this research was to determine and quantify organic acids such as oxalic, L-tartaric, D-quinic, L-malic, L-ascorbic, citric, fumaric and succinic in honey samples from Latvian market u sing high-performance liquid chromatography. The chromatographic separation of organic acids was carried out with PerkinElmer C18 (4.6 mm × 250 mm I.D, particle size 5 mm) analytical column at the temperature of 35 °C in wavelength at 210 nm. The obtained results showed that the analysed honey samples contain L-tartaric, D-quinic, L-malic, L-ascorbic, citric, fumaric and succinic acids. The concentration of these acids was found to be variable. Oxalic acid was not detected in the analysed honey samples. L-tartaric acid was the main acid in all analysed honey samples.
Key words: honey, organic acids, high-performance liquid chromatography.

Introduction

Honey has been used in traditional medicine since ancient times due to its nutritional value and therapeutic effect (Conti *et al.*, 2018). Honey is a complex natural mixture, which mostly consists of carbohydrates, but it also contains around of 200 components such as enzymes, amino acids, organic acids, vitamins, phenolic compounds and minerals. The qualitative and quantitative content of chemical compounds, organoleptic properties of honey depend on many factors such as floral origin, geographical and climate conditions (Da Silva *et al*., 2016).

The content of organic acids in honey is approximately 0.5% of the fresh weight of honey (Mato *et al.*, 2003). Despite their low quantity, organic acids play an important role to many properties of honey such as organoleptic, physical and chemical (Chakir *et al.*, 2016; Aljohar *et al.*, 2018). Organic acids can also be used as indicators to detect the freshness and authenticity of honey (Tezcan *et al.*, 2011). It has been reported that organic acids are the contributors to antibacterial and antioxidant activities in honey (Alonso-Torre *et al.*, 2006).

Organic acids such as acetic, citric, formic, glutaric, fumaric, succinic, D-gluconic, oxalic, D-glucuronic, L-malic, propionic, D-quinic, L-tartaric and many others are present in honey (Mato *et al.*, 2003; Nozal *et al.*, 2003; Tezcan *et al.*, 2011). The prevailing organic acid in honey is gluconic acid. Gluconic acid is synthesized from glucose oxidase, which honeybees supply during the ripening process. As predominant organic acid, gluconic acid is present in all types of honey. The quantity of gluconic acid depends on the activity of glucose oxidase (Karabagias *et al.*, 2014). Citric acid also has been found in all types of honey. The concentration of citric acid can be used to distinguish floral honey from honeydew. The content of citric acid in floral honey is noteworthy lower than in honeydew honey (Mato *et al*., 2003; Da Silva *et al*., 2016). Some organic acids can be used to detect the authenticity of honey, for example, 2-methoxybutanedionic and 4-hydroxy-3-methyl-*trans*-2-pentenedioic acids mostly prevail in honey, which is harvested in New Zealand (Shamsudin *et al*., 2019).

It has been reported that organic acids such as oxalic, lactic and formic can be used as an effective treatment against ectoparasitic mite (*Varroa)*. It has been stated as a very serious problem in apiculture in Europe and the USA (Norain Sajid *et al*., 2019). The use of synthetic pesticides can negatively affect human health, that is why the organic acids are used as a treatment to the infestation (Bogdanov *et al*., 2002). It has been found out that the concentration of formic acid in honey can be elevated as it is used as a treatment against the ectoparasitic mite (Matysiak, Balcerzak, & Michalski, 2018).

Organic acids can be used as indicators of aerobic or anaerobic fermentation in honey. These organic acids, which occur in honey during fermentation process, can negatively affect the quality of honey (Boussaid *et al*., 2018).

The qualitative and quantitative content of honey can be dependent on many factors. Mostly it depends on botanical origin, geographical and environmental conditions. Also, the duration of storage can impact the content of organic acids.

The aim of this research was to determine and quantify organic acids such as oxalic, L-tartaric, D-quinic, L-malic, L-ascorbic, citric, fumaric and succinic in honey samples from Latvian market using high-performance liquid chromatography.

Materials and Methods

Experiments were carried out at the laboratories

of the Department of Chemistry, the Faculty of Food Technology at the Latvia University of Life Sciences and Technologies. The object of the research was nine multifloral honey samples, which were purchased from Latvian market. Four honey samples HEU1, HEU2, HEU3, HEU4 were commercially available and bought from distributors. The information on the product labels marked the samples HEU1, HEU2, HEU3, HEU4 as blends of honey from the European Union and non-European Union countries. The production year of the four honey samples was not shown on the product labels. Another five honey samples HLV1, HLV2, HLV3, HLV4, HLV5 were bought directly from Latvian beekeepers. These honey samples were collected in different regions of Latvia in the year of 2018. The honey sample HLV1 was collected from beehives in the northern part of Latvia (Vidzeme). The samples HLV2, HLV3 were harvested from beehives in the central part of Latvia (Zemgale). The samples HLV4, HLV5 were collected from beehives placed in the southern part of Latvia (Latgale).

Determination of organic acids

Preparation of standard solution: analytical standard-grade oxalic, L-tartaric, D-quinic, L-malic, L-ascorbic, citric, fumaric and succinic acids were purchased from Flukaä and Sigma-Aldrich. The mixture of 0.0500 ± 0.0001 g oxalic, 0.1000 ± 0.0001 g L-tartaric, 0.1000 ± 0.0001 g D-quinic, 0.1000 ± 0.0001 g L-malic, 0.0500 ± 0.0001 g L-ascorbic, 0.1000 ± 0.0001 g citric, 0.0205 ± 0.0001 g fumaric and 0.2000 ± 0.0001 g succinic acids was weighted in 50 mL volumetric flask with narrow neck, slowly dissolved in a small portion of deionized water and filled with deionized water till the mark and mixed.

Sample preparation: honey samples were diluted to 50% (w/v) with deionized water, homogenized, and centrifuged (Pro-Research, Centurion Scientific Ltd.) for 10 minutes at 3200 rpm.

Detection of organic acids: chromatographic analysis was carried out using a Shimadzu LC-20 Prominence liquid chromatograph, (Shimadzu USA Manufacturing Inc, Canby, USA), detector DAD SPD-M20A, Solvent Delivery Unit LC-20AD, Column Oven CTO-20A, Autosampler SIL-20A, System Controller CBM-20A and data system LCsolution software. The analytical column PerkinElmer C18 (4.6 mm ´ 250 mm I.D., particle size 5 mm) and temperature of column +35 °C were used for separation of organic acids in wavelength at 210 nm. All analyses of the samples were carried out in gradient conditions. The mixture of acetonitrile (HPLC grade) and 0.05 M KH_2PO_4 (1:99) was used as the mobile phase. Starting flow rate was 1.25 mL min^{-1}. Injection volume was 10 mL. The retention times in the analysed honey samples were compared with the retention times of standards to determine organic acids in the samples.

Statistical analysis

The determination of organic acids was carried out in triplicate. The mean ± standard deviations were used to express the obtained data of this study. The calculations were carried out using Microsoft Office Excel 2016.

Results and Discussion

The obtained results of the study showed that organic acids such as L-malic, L-ascorbic, citric, fumaric and succinic acids were not detected in all analysed honey samples (Tables 1, 2). Oxalic acid was the only organic acid, which was not detected in the honey samples. L-tartaric acid was present in all analysed samples. The determined concentration of L-tartaric acid was very high in all samples. The amount of this acid ranged from 0.508 to 0.698 g 100 g^{-1}. The highest concentration of this acid was found in the sample HLV1, but the lowest concentration of L-tartaric acid was found in the sample HLV3. The concentration of L-tartaric acid could be variable, as the samples were harvested from different floral origin and different regions.

D-quinic acid also was detected in the analysed samples. The range of the acid was from 0.002 to 0.447 g 100 g^{-1}. The highest concentration of D-quinic acid was found in the sample HLV4. The lowest concentration of this acid quantified in the sample HEU4. It has been previously reported (Shamsudin *et al.*, 2019) that a high concentration of D-quinic acid could indicate that the sample HLV4 could be *Erica* sp. honey.

Succinic acid was present in seven of nine honey samples (HLV1, HLV2, HLV3, HLV4, HLV5, HEU2, HEU3). The detected concentration of succinic acid ranged from 0.003 to 0.139 g 100 g^{-1}. The highest concentration was found in the sample HLV5. It was found that the concentration of succinic acid in floral honeys from different cities of Santa Catarina state in Brazil ranged from 0.013 to 0.096 g 100 g^{-1}. The highest content of succinic acid was found in bracatinga honeydew honey, where it ranged from 0.484 to 0.672 g 100 g^{-1} (Brugnerotto *et al*., 2019). The high concentration of succinic acid was found to be characteristic of *Quercus* sp. honey (Mato *et al*., 2003).

L-ascorbic acid, which is well known as an antioxidant compound, also was found in the analysed honey samples. The concentration of the acid was lower than the concentration of L-tartaric, D-quinic and succinic acids. The detected content of L-ascorbic acid in the analysed samples ranged from 0.001 to 0.020 g 100 g^{-1}. Among all analysed samples, the sample HLV1 exhibited the highest concentration of L-ascorbic acid. The presence of L-ascorbic acid

Table 1

Oxalic, L-tartaric, D-quinic and L-malic acid content in the analysed honey samples

Sample	Oxalic acid, g 100 g^{-1}	L-tartaric acid, g 100 g^{-1}	D-quinic acid, g 100 g^{-1}	L-malic acid, g 100 g^{-1}
HLV1	ND	0.698 ± 0.04	0.029 ± 0.01	0.012 ± 0.02
HLV2	ND	0.608 ± 0.03	0.268 ± 0.02	ND
HLV3	ND	0.508 ± 0.02	0.221 ± 0.02	0.040 ± 0.001
HLV4	ND	0.627 ± 0.03	0.447 ± 0.03	ND
HLV5	ND	0.624 ± 0.03	0.245 ± 0.02	ND
HEU1	ND	0.611 ± 0.02	0.002 ± 0.001	0.017 ± 0.02
HEU2	ND	0.636 ± 0.03	0.006 ± 0.001	0.060 ± 0.005
HEU3	ND	0.666 ± 0.02	0.018 ± 0.010	ND
HEU4	ND	0.583 ± 0.03	0.004 ± 0.001	0.015 ± 0.03

ND – not detected

Table 2

L-ascorbic, citric, fumaric and succinic acid content in the analysed honey samples

Sample	L-ascorbic acid, g 100 g^{-1}	Citric acid, g 100 g^{-1}	Fumaric acid g 100 g^{-1}	Succinic acid, g 100 g^{-1}
HLV1	0.020 ± 0.005	0.028 ± 0.002	0.001 ± 0.0005	0.011 ± 0.04
HLV2	0.007 ± 0.01	0.015 ± 0.003	0.001 ± 0.0002	0.024 ± 0.02
HLV3	0.001 ± 0.02	0.012 ± 0.002	ND	0.012 ± 0.002
HLV4	0.005 ± 0.002	0.043 ± 0.02	0.001 ± 0.0002	0.087 ± 0.003
HLV5	0.006 ± 0.003	0.092 ± 0.03	ND	0.139 ± 0.05
HEU1	0.004 ± 0.001	0.011 ± 0.002	ND	ND
HEU2	0.001 ± 0.0001	ND	ND	0.017 ± 0.003
HEU3	0.008 ± 0.0005	0.030 ± 0.02	0.001 ± 0.0003	0.003 ± 0.0005
HEU4	ND	0.014 ± 0.005	ND	ND

ND – not detected

and its content in honey could be dependent on many factors such as floral sources and geographical origin (Moniruzzaman *et al.*, 2013; Strelec *et al.*, 2018). It was reported that the content of L-ascorbic acid in Romanian honeydew honey was up to 0.013 g 100 g^{-1}, but in Polish honeydew honey it was up to 0.014 g 100 g^{-1} (Chis *et al.*, 2016), but the highest concentration of L-ascorbic acid was found in thyme honey, where the concentration was up to 0.057 g 100 g^{-1} (León-Ruiz *et al.*, 2011).

The presence of citric acid was found in eight of nine honey samples. The content of citric acid in those honey samples ranged from 0.001 to 0.092 g 100 g^{-1}. The highest concentration of citric acid was quantified in the sample HLV5, which was higher than it was found in multifloral honeys from the north-western Spain. The amount of citric acid in the Spanish honeys ranged from 0.007 to 0.014 g 100 g^{-1} (Mato *et al*., 2006). According to other authors, the highest concentration of citric acid was common in honeydew honey (Suárez-Luque *et al*., 2002; Serra Bonvehí, Bentanol Manzanares, & Santos Vilar, 2004).

L-malic and fumaric acids were not found in all analysed samples. The highest concentration of L-malic acid was found in the commercially available honey sample HEU2, where it was 0.060 g 100 g^{-1}. The content of fumaric acid in the honey samples was not found higher than 0.001 g 100 g^{-1}. It had been reported that L-malic and fumaric acids were detected in honey in small quantities (Mato *et al*., 1998; Serra Bonvehí, Bentanol Manzanares, & Santos Vilar, 2004; Mato *et al*., 2006; Tezcan *et al*., 2011).

The observed results (Tables 1, 2) showed that there was a variability in the presence of organic acids in honeys. Comparing the analysed honey samples obtained from Latvian beekeepers to commercially available honey samples, which were the blends of honeys from the European Union and non-European Union countries, the honey samples harvested from Latvian beehives were richer of organic acids. Other authors (Suárez-Luque *et al.*, 2002; Matysiak, Balcerzak, & Michalski, 2018) previously had reported that the content of organic acids were variable. The content of organic acids in honey was dependent on many factors such as floral source, the type of honey, geographical conditions (Siddiqui *et al*., 2017). Also, the duration of storage could induce a decrease in the concentrations of organic acids in honey.

Conclusions

The obtained results of this research showed that honey is a natural source of organic acids. The concentrations and presence of analysed organic acids varied in each honey sample. Honey samples, which were purchased from Latvian beekeepers, had a higher diversity of analysed organic acids than the honey samples from the European Union and non-European Union countries. Even the concentration of analysed organic acids was found to be higher in honeys from Latvia than in honeys, which consisted of honeys produced in the European Union and non-European Union countries.

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PRELIMINARY STUDY OF BOVINE COLOSTRUM QUALITY IN LATVIA

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Abstract
Bovine colostrum is a mammary gland secret which, due to its high immunoglobulin concentration, is necessary for the transfer of passive immunity to the calf, preventing diseases caused by microbial infections in the newborn ruminants. Colostrum, however, may contain pathogens and can be an infection transmitter, affecting morbidity and mortality rates of calves in the farms. Total plate count and immunoglobulin concentration are two main factors affecting colostrum quality, therefore the aim of the study was to analyse Latvian dairy herd colostrum quality.
Colostrum was collected from Holstein Black cows within the first six hours after calving, lactation period of animals ranged from 1st to 4th lactation. Colostrum samples (n=51, 50 mL) were collected from December 2018 to February 2019. Immunoglobulin concentration (n=51) was defined by colostrometer (COLOSTROMETER^{tm} Biogenics, USA), total solids content by optical refractometer (Model BX, UK). *Staphylococcus* spp. colony–forming unit (CFU) (LVS EN ISO 6888-1+A1:2007), the presence of *Listeria* spp. (LVS EN ISO 11290-1+A1:2007) and *Salmonella* spp. (LVS EN ISO 6579-1:2017) were examined in the colostrum samples (n=20). Despite the high immunoglobulin concentration in the analysed samples, our research findings demonstrate suboptimal colostrum quality received by calves. That indicates the necessity for regular colostrum quality control and better management practise providing on the farm.
Key words: bovine colostrum, immunoglobulins, *Staphylococcus* spp., *Listeria* spp.

Introduction

Bovine colostrum is a mammary gland secret which, due to its high immunoglobulin (Ig) content, is necessary for the transfer of passive immunity to the calf, preventing diseases caused by microbial infections in the newborn ruminants. It is crucial for newborns to ensure adequate immunoglobulin concentration in the blood during the first 12 to 36 hours (Hernández-Castellano *et al.*, 2015). The highest concentration of biologically active compounds in colostrum is collected at the first milking after calving (Hurley & Theil, 2011). According to Sacerdote *et al.* (2013), maximum Ig concentration in colostrum is in the first four hours after parturition, and six hours according to Borad & Singh (2018) data. Latvian researchers' results (Eihvalde, Kairisa, & Zagorska, 2012) confirmed that the lactation period influences immunoglobulin concentration, but the difference was not significant.

Contaminated colostrum, however, may contain pathogens and can be an infectious disease transmitter, affecting morbidity and mortality rates of animals in the farms (Stewart *et al.*, 2005; Morales-delaNuez *et al.*, 2011; Mohammed *et al.*, 2018). Bovine milk contains complex microbiota that affects quality and safety of the product. Total plate count in raw milk from healthy bovine can range from 10^3 to 10^5 CFU mL^{-1} (Porcellato *et al.*, 2018).

Colostrum microbiological contamination can occur in different ways: milk can be contaminated with commensal bacteria from the teat skin, epithelial lining of teat canal, or via the lactiferous duct while it is being excreted; or due to the contamination of milk during production, collection, processing, handling, distribution and storage (Alegbeleye *et al.*, 2018).

Staphylococcus spp., *Streptococcus spp.*, *Bacillus spp.*, *Micrococcus spp.*, *Corynebacterium spp.* and sometimes coliforms, are common bovine commensal bacteria (Alegbeleye *et al.*, 2018; Curone *et al.*, 2018). Some pathogens such as *Salmonella* spp., *Staphylococcus aureus*, *Listeria monocytogenes*, *Campylobacter jejuni*, pathogenic *Escherichia coli* (Stewart *et al.*, 2005; Elizondo-Salazar, Jayarao, & Heinrichs, 2010) may be excreted into milk if they are localized in the mammary gland or associated lymph nodes due to systemic disease (Alegbeleye *et al.*, 2018). Total plate count and Ig concentration are two main factors affecting colostrum quality, therefore the aim of the study was to analyse Latvian dairy herd colostrum quality.

Materials and Methods

Colostrum was collected from Holstein Black cows within the first six hours after calving. Analysed animals lactation ranged from 1st to 4th (see Table 1). Before calving (>49 days) 'Cepravin dry cow' (LTD MSD, Netherlands) was used. Active component of 'Cepravin dry cow' is cephalonium.

Colostrum samples (n=51, 50 mL) were collected at conventional farm 'X', located in Zemgale, from December 2018 to February 2019. Colostrum samples were collected according to LVS EN ISO 707:2011 Milk and milk products – Guidance on sampling. Samples were used at 20 °C for detection of Ig and total solid content immediately after collection (Baltrukova, Zagorska, & Eihvalde, 2019).

Samples for microbiological analysis immediately after collection were frozen (-19 ± 1 °C, 30 min) and delivered to the laboratory, stored for up to 30 days.

Table 1

The characteristics of analysed bovine colostrum samples

Lactation period	Number of samples	Period
1st Lactation	21	18.12.2018 – 17.02.2019
2nd Lactation	15	12.12.2018 – 12.02.2019
3rd Lactation	10	16.12.2018 – 17.02.2019
4th Lactation	5	23.12.2018 – 10.02.2019

The research was carried out at the Institute of Food Safety, Animal Health and Environment 'BIOR' at Food and Environmental Microbiology laboratory. Before microbiological tests, samples were removed from freezer, defrosted and homogenized in a water bath (45 ± 2 °C), after that samples preparation followed, according to: LVS EN ISO 6887-1:2017 'Microbiology of food and animal feeding stuffs – Preparation of test samples, initial suspension and decimal dilutions for microbiological examination – Part 1: General rules for the preparation of the initial suspension and decimal dilutions' and LVS EN ISO 6887-5:2011 'Microbiology of food and animal feeding stuffs – Preparation of test samples, initial suspension and decimal dilutions for microbiological examination – Part 5: Specific rules for the preparation of milk and milk products'.

Colostrometer (COLOSTROMETER^{tm} Biogenics, USA) was used for Ig concentration determination, which is expressed as mg mL^{-1}. Percentage of total solids in colostrum (n=51) was measured using an optical refractometer (Model BX, UK) with a range of 0 to 34% Brix.

In colostrum samples (n=20) *Staphylococcus* spp. CFU mL^{-1} was examined according to LVS EN ISO 6888-1+A1:2007 Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of coagulase-positive staphylococci (*Staphylococcus aureus* and other species) – Part 1: Technique using Baird-Parker agar medium; medium used for microorganism isolation was B-P agar, MSA (Mannitol Salt Agar), TSA (Tryptic Soy Agar). Presence of *Listeria* spp. was examined according to 11290-1+A1:2007 Microbiology of the food chain – Horizontal method for the detection and enumeration of *Listeria monocytogenes* and of *Listeria* spp. – Part 1: Detection method; medium used for microorganism isolation was Half-Frazer broth, Frazer broth, ALOA (Agar Listeria acc. to Ottaviani & Agosti) agar, Blood agar. The presence of *Salmonella* spp. was detected according to LVS EN ISO 6579-1:2017 Microbiology of the food chain – Horizontal method for the detection, enumeration and serotyping of *Salmonella* – Part 1: Detection of *Salmonella* spp.; medium used for microorganism isolation was BPW (Buffered peptone water), RVS (Rappaport-Vassiliadis Soy Peptone) broth, MKTTn (Muller-Kauffmann Tetrathionate-Novobiocin) broth, XLD (Xylose Lysine Deoxycholate) agar, Salmonella Chromogenic agar, Nutrient agar.

Isolated cultures (see Table 2) were identified using MALDI-TOF autoflex speed (Bruker, Germany) in Collection of Microorganism Culture of the Laboratory at the Institute of Food Safety, Animal Health and Environment 'BIOR'. For culture identifications Blood agar, Nutrient agar and TSA were used. All mediums in this study were purchased from 'Biolife' (Italy).

Descriptive statistics were used for data analysis, Duncan's test was calculated. The difference was considered statistically significant if $p<0.05$.

Results and Discussion

Immunoglobulin concentration (mainly IgG and IgM) is considered as one of the most important immune variables (Hernández-Castellano *et al.*, 2015). Ig level in bovine colostrum varies considerably in different studies: 15 – 180 mg mL^{-1} (Borad & Singh 2018), 1.4 – 204 mg mL^{-1} (Dunn *et al*., 2017), 1.8 – 200.2 mg mL^{-1} (Morrill *et al.*, 2012), 60 – 100 mg mL^{-1} (Sanchez *et al.*, 2004). According to the findings by Lago *et al.* (2018), high-quality colostrum contains more than 50 mg mL^{-1} of Ig, providing calves with passive immunity.

In the analysed colostrum samples, Ig concentrations varied from 39 to 150 mg mL^{-1} (Table 2). In the present study, mean Ig concentration (90.29 ± 3.33 mg mL^{-1}) was similar to the results obtained by Yaylak, Yavuz, & Özkaya (2017) – 91.00 ± 4.48 mg mL^{-1} and it was higher than reported by Morrill *et al.* (2015) – 72.91 ± 33.53 mg mL^{-1}. Comparing immunoglobulin concentration among lactation period, a significant difference ($p<0.05$) was established, the highest Ig concentration observed in colostrum obtained from cows after the 3rd calving, all samples contained ≥89 mg mL^{-1} Ig and ≥25% Brix. In the current study, the 1st lactation cows had higher Ig level (92.28 ± 4.44 mg mL^{-1}) than the 2nd lactation cows (77.20 ± 5.94 mg mL^{-1}), that corresponds to the results by Yaylak, Yavuz, & Özkaya (2017) – 94.1 ± 6.82 mg mL^{-1} and 88.03 ± 5.66 mg mL^{-1}, respectively.

Table 2

Ig and total solids concentration in bovine colostrum

Parameter	Quantity of samples, %	mean	SD	minimum	maximum
Mean analysed bovine colostrum sample					
Ig (mg mL^{-1})	100.0	90.29^{b}	3.33	39	150
Brix (%)		25.04^{B}	0.48	19	32
1st Lactation					
Ig (mg mL^{-1})	41.2	92.28^{b}	4.44	53	121
Brix (%)		25.29^{B}	0.66	19	32
2nd Lactation					
Ig (mg mL^{-1})	29.4	77.20^{d}	5.94	40	118
Brix (%)		22.80^{C}	0.73	20	30
3rd Lactation					
Ig (mg mL^{-1})	19.6	109.40^{a}	5.82	89	150
Brix (%)		28.60^{A}	0.76	25	32
4th Lactation					
Ig (mg mL^{-1})	9.8	83.00^{ac}	12.26	39	112
Brix (%)		23.6^{C}	0.93	21	26

Duncan's test: different letters (a–d, A–C) in the column indicate significant difference among samples ($p<0.05$).

Total solids content in colostrum varied from 19 to 32%. Mean concentration was 25.04 ± 0.48%, which is higher than reported by Lago *et al.* (2018) – 20.3 ± 2.9%, by Morrill *et al.* (2015) – 21.24% ± 4.43%, by Quigley *et al.* (2013) – 23.8% ± 3.5% and lower than the value reported by Yaylak, Yavuz, & Özkaya (2017) – 26.61 ± 0.84%.

Quigley *et al.* (2013) recommended 21% Brix solids content to be considered as the breakpoint for high-quality bovine colostrum, which corresponds to Ig concentration of ≥50 mg mL^{-1} in colostrum. Morrill *et al.* (2015) specified Ig concentration of ≥50 mg mL^{-1} in colostrum exactly for Holstein Black breed, analysed in the current research. Based on these recommendations, only in 3.9% colostrum samples Ig concentrations were lower than 50 mg mL^{-1}, but other 96.1% samples contained more than 53 mg mL^{-1} Ig. In comparison, Lago *et al.* (2018) showed 80% (n=53) sample quality conformity, Morrill *et al.* (2012) reported 70.6% (n=827) and Dunn *et al.* (2017) – 56% (n=1239).

Ig concentration was moderately positively correlated (r=0.76) with solids content % Brix (Figure 1). Morrill *et al.* (2015) reported similar results, e.g. r=0.79, results by Yaylak, Yavuz, & Özkaya (2017) reported r=0.70.

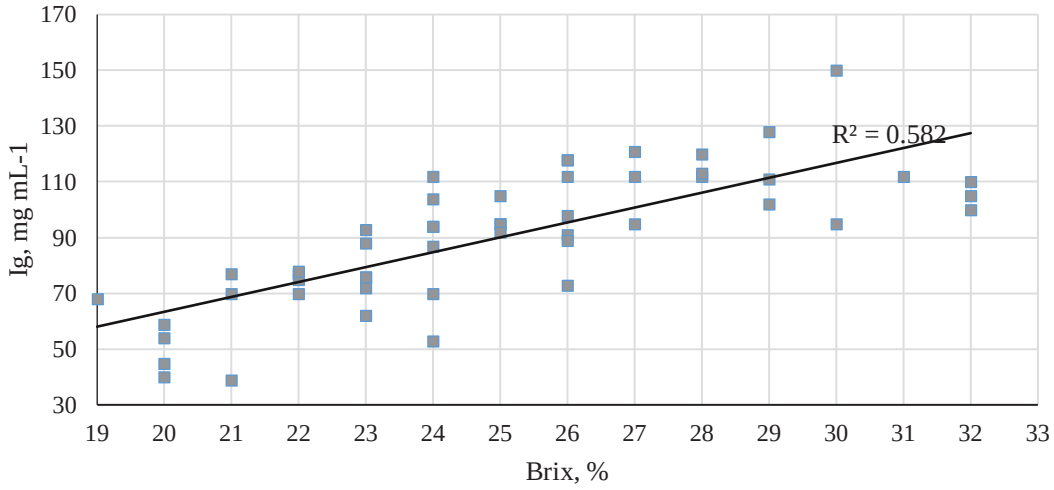

Figure 1. Correlation among solids content % Brix and Ig concentration in colostrum samples (n=51).

Table 2

Bacteria species isolated from analysed bovine colostrum samples (n=20)

Microorganisms	Species	Number of samples
Listeria spp.	*L. innocua*	5
Staphylococcus spp.	*S. aureus*	1
	S. epidermidis	5
	S. haemolyticus	4
	S. capitis	3
	S. chromogenes	4
	S. cohnii	1
	S. xylosus	1
Enterococcus spp.	*E. feacium*	4
	E. feacalis	4
Bacillus spp.	*B. clausii*	1
Macrococcus spp.	*M. caseolyticus*	1

Microbiological quality of colostrum is a very important factor, which can have a significant effect on calf health. Our previous study showed poor microbiological quality of obtained colostrum due to high total plate count 5.65 $\log_{10}$ CFU mL^{-1} (Baltrukova, Zagorska, & Eihvalde, 2019). Previous studies (Dunn *et al.*, 2017) detected a wide range of pathogens in colostrum, therefore in the current study samples were examined for *Listeria* spp. (*L.monocytogenes*), *Salmonella* spp. presence and *Staphylococcus* spp. count (Table 2). They are considered the most common pathogens in bovine milk, that increase newborn calves mortality rate, as well as, it could be dangerous for humans if raw colostrum has been consumed without thermal treatment (Stewart *et al.*, 2005; Alegbeleye *et al.*, 2018; Mohammed *et al.*, 2018).

In this study, *Salmonella* spp. and *Listeria monocytogenes* presence was not detected in any of the analysed colostrum samples. *Listeria* spp. was isolated from 25% of colostrum samples and identified as *L. innocua*; it is one of the non-pathogenic *Listeria* species, which is common in habitat and may contaminate farm environment, animal feed and water (Osman *et al.*, 2014).

Two *Enterococcus* species were found on Blood agar and TSA: four colostrum samples contained *E. feacium* and the same number of samples contained *E. faecalis*; onBlood Agar *Bacillus clausii* and in TSA M*acrococcus caseolyticus* were detected.

Despite the 'Cepravin dry cow' use before calving, in the current study coagulase-negative *Staphylococcus* was the most common microorganism in bovine colostrum (Figure 2), which represents 100% of isolated microorganisms. Other studies showed similar results – *Staphylococcus* spp. were among the most frequent of the isolated bacteria in 57.7% (Fecteau *et al.*, 2002) and 47.9% (Garedew *et al.*, 2015) of cases. Coagulase-negative *Staphylococcus* species such as *S. epidermidis*, *S. haemolyticus*, *S. capitis*, *S. chromogenes*, *S. cohnii*, *S. xylosus* were identified in all analysed colostrum samples. The number of microorganisms varied from 10^2 to 10^4 CFU mL^{-1}, and all samples contained more than one *Staphylococcus* specie. The number of microorganisms of the most frequently identified *S. epidermidis* and *S. haemolyticus* species varied from 10^2 to 10^3 CFU mL^{-1}, but the least common *S. cohnii* varied from 10^1 to 10^2 CFU mL^{-1}, *S. xylosus* below 10^1 CFU mL^{-1}. *S. epidermidis* and *S. haemolyticus* are normal inhabitants of bovine skin and mucous membranes, but their strains show resistance to various antibiotics that may decrease curing effect of cow mastitis (Susan, Obansa, & Anthony, 2014). *S. epidermidis* and *S. aureus,* isolated from milk samples in cows (Da Silva Chagas *et al.*, 2017) and sheep (Vasil *et al.*, 2017) with mastitis, have a role in biofilm production at different surfaces (milking and other equipment). Biofilms are a major form of microbial growth, they are considered to be responsible for the high resistance of microorganisms to sanitizers, allowing pathogenic and spoilage bacteria to survive the sanitization process (Flach *et al.*, 2014).

S. chromogenes was detected in three samples and the numbers ranged from 10^1 to 10^5 CFU mL^{-1}. One colostrum sample contained *S. aureus* $4.0 \cdot 10^2$ CFU mL^{-1} that did not exceed incremental norms ($<5.0 \cdot 10^2$ CFU mL^{-1}). *S. aureus*, *S. chromogenes, E. feacalis, E. feacium* are drug resistant (Susan, Obansa & Anthonomy, 2014; Garedew *et al.*, 2015) mastitis causative agents, which can be found in colostrum from diseased bovines (Alegbeleye *et al.*, 2018).

Summarizing study results can be concluded that some measures should be applied for improving colostrum quality, as a significant part of identified

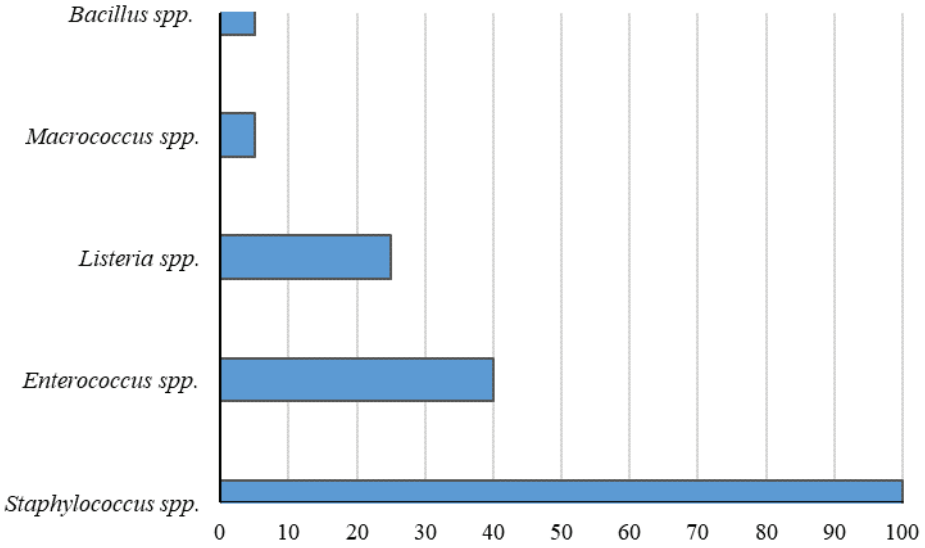

Figure 2. Distribution of isolated microorganism genus in bovine colostrum samples (%).

microorganisms are pathogenic, antibiotic resistant, and biofilm producing species (Susan, Obansa, & Anthonomy, 2014; Da Silva Chagas *et al.*, 2017; Vasil *et al.*, 2017). Enhanced animal health and hygienic conditions on dairy farms can minimize colostrum bacterial contamination (Alegbeleye *et al.*, 2018). One more possible solution for minimizing bacterial contamination of colostrum and decreasing calf mortality rate is heat treatment. The results of a study by Elizondo-Salazar, Jayarao, & Heinrichs (2010) indicate that heat treatment of bovine colostrum at 60 °C for 30 to 60 min may be used as an optimal regime to observe a less denaturation in IgG concentration and a significant decrease in plate count in samples (Elizondo-Salazar, Jayarao, & Heinrichs, 2010). That confirms the study by Malmuthuge *et al.* (2015) which showed that heat treatment of colostrum could serve as an effective method for reducing pathogen exposure to newborn calves. Further researches are needed to obtain high quality colostrum andexplaining interaction among immunoglobulins (class, concentration) and specific pathogens. Thermal treatment importance for colostrum quality should be evaluated as well.

Conclusions

According to Ig concentration and total solids content, analysed colostrum samples belong to high-quality colostrum group.

In the current study improper microbiological quality of analysed colostrum was highlighted, still *Staphylococcus* genus was the most frequently identified in the analysed samples. Pathogen Staphylococcus specie – S. aureus was determined in one colostrum sample. *L. innocua* was identified in 25% of analysed colostrum samples. *Salmonella* spp. and *L. monocytogenes* were not detected.

Despite high immunoglobulin concentration in the analysed samples, our research findings demonstrate suboptimal colostrum quality received by calves. That indicates the necessity for regular colostrum quality control and better management practise providing on the farm.

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HEALTH STATUS OF GENE FOND DONOR COWS OF LATVIAN NATIVE BREEDS LATVIAN BROWN AND LATVIAN BLUE

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Abstract
The preservation of local animal breeds is a topical theme in recent years. Latvian Brown (LB) and Latvian Blue (LZ) cow breeds are exhausting and must be preserved. It can be performed by the use of multiple ovulation and embryo transfer (MOET). The difficulties exist in choosing the gene-fond (GF) cows as donors caused by the small number of animals. Twenty-three cows were intended for donor cow's role from different herds until September 2018, and twenty of them were accepted. Anamnesis, clinical examination, blood morphology (13 parameters) and biochemical indices (19 parameters) were analyzed before MO induction. Three cows were rejected because of ovarian cysts or pyometra, negative energy balance (NEB) (glucose < 2.3 mmol L^{-1} simultaneously with elevated ß-hydroxybutyric acid > 1.4 mmol L^{-1}) and elevated ($p<0.05$) number of leukocytes (28.20 x10^9 L^{-1}). More than 52.6% of cows had a repeated artificial insemination before the last parturition, and 5.3% of cows had lifeless offspring in the last parturition. The 1st and 2nd lactation cows were healthier than older cows ($p<0.05$). The amount of albumins, cholesterol, triglycerides and Na, K, P, Cl, Mg was significantly different in donors with and without successfully obtained embryos ($p<0.05$). In conclusion, not only acceptable clinical health but also the cow metabolic status is a decisive factor for success of MOET.
Key words: native breed, gene fond cow, health status.

Introduction

Cow fertility is influenced by a combination of factors. The main ones are related to animal genetics, management and climatic conditions. Complex interactions of these factors make it difficult to determine the exact reason for decline of fertility. Nonetheless, the main causes that have a negative impact on dairy cows' fertility and offspring are identified by scientists. The assessment of the impact of one factor of reproductive performance may be highly confounded. Reproduction can be affected by individual and herd level factors with effects on reproduction including the cow age, season, diseases, nutrition, body condition, environment, herd management decisions, the intensity and accuracy of heat detection, and the use of management programs. Such reasons as poor nutrition, management and environmental factors are often not evaluated in studies for the decline in fertility although they have a significant impact on the reproductive performance. Are metabolic demands for production and reproduction reaching a biological or management limit? Are genetic selection criteria for fertility optimized? These are important and warrant valid questions (LeBlanc, 2010).

Nutrition plays a critical role in the regulation of cow fertility. Cows that have metabolic disorders and/or gynecological problems are more likely to have lower conception rates and to be culled due to fertility problems (Roche, 2006). Body condition score (BCS) is used to monitor nutritional and health status of cows during their productive cycle. Body condition score at different stages of lactation correlated with improved fertility: genetic correlations between BCS and pregnancy in 63 days after the start of breeding season ranged from 0.29 to 0.42. (Berry *et al*., 2003). Cows in low BCS at calving or that suffer excess BCS loss early postpartum are less likely to ovulate. They have a reduced submission rate to artificial insemination and conception rate to the first service. They also have an increased likelihood for pregnancy loss and increased calving to conception interval (Roche, 2006; Roche *et al*., 2009; Ribeiro *et al*., 2016). This can partly be attributed to impaired oocyte competence associated with a low BCS (1.5-2.5; 5-point scale) (Snijders *et al*., 2000). Fertility in cows that are over conditioned at calving (BCS≥3; 5-point scale) tend to have greater fat mobilization, and therefore a more severe negative energy balance (NEB) in early postpartum period than in cows with an optimum BCS at calving (Roche *et al*., 2009). Changes in BCS during the transition period affected non-esterified fatty acids (NEFA) and ß-hydroxybutyric (BHB) concentration as well as fertility and occurrence of health problems during the lactation (Roche *et al*., 2018; Barletta *et al*., 2017). A successful reproduction depends on the ovulation of an oocyte capable of undergoing fertilization and subsequent embryo and fetal development. As demonstrated in inhibitor studies, subsequent embryo development is significantly influenced by lipolysis and b-oxidation within the maturing cumulus-oocitoocytelexes (COCs) (Dunning, Russell, & Robker, 2014). Metabolic changes in blood serum may be reflected in the biochemical composition of follicular fluid and could indirectly influence oocyte quality. The study to examine the biochemical composition of follicular fluid harvested from different-sized follicles and its relationship with that of blood serum in dairy cattle founded the significant correlation between the composition of serum and follicular fluid for ions

(sodium, potassium and chloride) and metabolites (glucose, β-hydroxybutyrate (β-OHB), lactate, urea, total protein, triglycerides, non-esterified fatty acids and total cholesterol). Leroy, 2004, detected that follicular fluid concentrations of glucose, β-OHB and total cholesterol increased from small to large follicles and decreased for potassium, chloride, lactate, urea and triglycerides. The present study suggests that the oocyte and the granulosa cells of dairy cows grow and mature in a biochemical environment that changes from small to large follicles. The significant correlation between the composition of serum and follicular fluid for the above-mentioned metabolites suggests that metabolic changes in serum level will be reflected in the follicular fluid and, therefore, may affect the quality of both the oocyte and the granulosa cells (Leroy *et al*., 2004). The biochemical serum changes observed in dairy cattle during NEB early postpartum period are well reflected in the follicular fluid of the dominant follicle, this exposing the granulosa cells and maturing oocyte (Leroy *et al*., 2008). Shabankareh, Kor, Hajarian, 2013, examined the influence of the corpus luteum on metabolite composition of follicular fluid (FF), harvested from different-sized follicles and the relationship between metabolite composition of FF to blood serum in dairy cows. The results showed that serum concentration of glucose, cholesterol and triglyceride was significantly different ($p \leq 0.05$) in FF from follicles of different size categories.

Walsh, Williams, & Evans, 2011, consider the following points to have the greatest negative impact on fertility and that they need to be prioritized in efforts to ameliorate the problem. Firstly, NEB should be minimized and any infection on the postpartum uterus should be resolved. Secondly, expression and detection of estrus should be performed and followed by insemination with high quality semen (day 0). Thirdly, ovulation and fertilization of a high quality oocyte (day 1) should happen. Fourthly, an early increase in progesterone secretion from the corpus luteum (days 3-7) should follow. Fifthly, the uterine endometrium must produce an early and appropriate environment to stimulate embryo development (days 6-13). This leads to sixthly that is adequate quantities of interferon-tau (days 14-18) produced by a large embryos that provides signals for maternal recognition of pregnancy (days 16-18) due to decrease of uterine prostaglandin secretion (Walsh, Williams, & Evans, 2011).

Studies focused on investigation the effects of uterus inflammatory diseases before cow breeding on fertilization and embryo development were provided. Reduced cleavage of potential zygotes, reduced survival of zygotes to the morula stage, impaired development to early stages of conceptus elongation, an increased pregnancy loss, and consequently, reduced pregnancy and calving per breeding (Ribeiro *et al*., 2016) were reported.

In order to preserve Latvian Brown (LB) and Latvian Blue (LZ) native cow breeds by using multiple ovulation and embryo transfer (MOET), the project *BioReproLV* was started by the Faculty of Veterinary Medicine, Latvia University of Life Sciences and Technologies. The Latvian Brown (LB) and Latvian Blue (LZ) dairy cows are the native cattle breeds and characteristic to Latvia exclusively. During last years, the number of these animals has decreased continuously. Since LB and LZ breeds are national wealth, responsibility of the government and related institutions is to take care of preservation, rational use and further development of these breeds. That is why the best animals of the population have been selected, based on their origin and productivity, and approved as gene fond (GF) animals. By data available of Animal Breeders Association of Latvia, in 2013, only 123 LB cows were confirmed as GF animals, and about 300 LZ cows in 2015-2018.

Selection of gene-fond (GF) animals, included in the project *BioReproLV,* is performed by pedigree experts and partners of the project Animal Breeders Association of Latvia. Although GF animals are of superior genetical value, it is also necessary to be in adequate health status to get good response to MO and embryos of adequate quality.

The problem is that many of the GF animals are housed on small farms without calculated feeding ration. Many of farmers owning GF animals do not have appropriate level of knowledge relevant to the cow physiology, feeding, sanitary conditions, and breeding. It was clear that in natural conditions these GF animals and native breeds in Latvia would die out despite of having some governmental programs and support.

The aim of this study is to detect the health status in 23 GF donor cows intended for MOET.

Materials and Methods

Twenty-three GF cows were intended as donor cows from different herds during 2017 and 2018, and 20 of them were included to be donor cows. Because of small number of animals no further differentiation between breeds was performed in interpretation of results. Short anamnesis of recent health disorders and clinical symptoms, age, number of lactations were collected from owners. An investigation of health status was performed before induction of MO. The general clinical examination (pulse, respiratory rate, rectal temperature, rumination, consistence of feces), and evaluation of reproductive tract as well as the body condition score (BCS) were performed. Blood samples were collected to establish such parameters as blood morphology (red blood cells

(RBC)), hemoglobin (Hgb), hematocrit (PCV), mean corpuscular volume (MCV), mean corpuscular Hgb (MCH), mean corpuscular Hgb concentration (MCHC), white blood cells (WBC), platelets (PLT), band neutrophils (St), segmented neutrophils (Sg), eosinophils (Eo), lymphocytes (Ly), monocytes (Mo)) and biochemical analysis (alanine aminotransferase (ALT), aspartate aminotransferase (AST), gamma glutamyl-transferase (GGT), alkaline phosphatase (ALP), lactate dehydrogenase (LDH), urea, creatinine (CREA), total protein (TP), albumin, sodium (Na), potassium (K), calcium (Ca), phosphorus (P), chloride (Cl), magnesium (Mg), cholesterol (CHOL), triglycerides (TRG)). Blood morphological and biochemical analyses were performed in accredited laboratories – 'Centrālā Laboratorija' (LVS EN ISO 15189:2013; LATAK-M-434-04-2011) and Food safety, Animal Health and Environment Institute 'BIOR' (LVS EN ISO/IEC 17025:2005; LVS EN ISO 15189:2013). Express tests were performed on the farm to detect the concentration of glucose (Glc) and ß-hydroxybutyric acid (BHB) in the cows' blood using *FreeStyle Optium Neo*. Reference values were adapted from Latimer, Duncan & Prasses, 2011 and Kaneko, Harvey, & Bruss, 2018. Blood samples were taken from the caudal vein applying venipuncture. The area of puncture was cleaned with 70% ethanol before sampling. Blood samples were collected in 5 mL vacutainers containing clot activator, and in 3 mL vacutainers containing ethylenediaminetetraacetic acid (EDTA) (for blood morphology and biochemistry, respectively). Blood samples were cooled immediately and stored in +4 °C till delivery to laboratory. Express tests were performed using fresh blood immediately after obtaining.

Statistical parameters of data such as mean values and the standard deviation, two independent samples t-test were calculated using *R Commander Version 2.4-1* (*RStudio*).

Results and Discussion

There are many important factors to be considered for successful MOET in a cow (Mikkola, 2017; Marie, 1999). A good herd and individual cow reproductive health (Kohrama & Poorhamdollaha, 2012), appropriate metabolic status (Gabriel & Reuben, 2014), age, successful parturition, optimal indices of artificial insemination (AI) in a herd and individual cow, welfare and housing conditions (Abdelattya *et al*., 2018), kind of protocol (Barusellia *et al*., 2011) and medicines to induce MO (Mikkola & Taponen, 2017), embryo flushing method, staff qualification and experience – these and many other common and individual factors are important for successful MOET.

No recent health disorders or clinical symptoms in GF donor cows were observed by the owners. Many of GF animals are in age, they live on small farms without calculated feeding ration, but nutrition plays a critical role in the regulation of cow fertility (LeBlanc, 2010). Many of these small private farm owners do not have appropriate education regarding the cow physiology, feeding and sanitary. These conditions could be the reason for reproductive inaccuracies and MOET failure.

More than 52.6% of cows had repeated artificial insemination before the last parturition, and 5.3% of cows had lifeless offspring in the last parturition. The reasons had not been established neither by the owners nor local vets.

The average age of donors was 6.6 ± 3.61 years. The oldest cow was 15 years old and had 13 lactations. Superovulation success depends on the cow's age because the amount of gonadotropin responsive follicles decreases with the age (Malhi *et al*., 2008). Only 4 or 21.1% were primiparous cows, 10 cows or 52.6% were older than the third lactation, but 15.9% of cows had more than 7 lactations.

No inaccuracies regarding the general health parameters were detected in all intended cows. Due to the results of reproductive tract examination, 20 GF cows were accepted as donors. Initially, there were 23 GF cows intended for MOET, but 3 cows were rejected because of ovarian cysts or pyometra, negative energy balance (Glc above 2.3 mmol L^{-1} simultaneously with elevated BHB above 1.4 mmol L^{-1}).

The average BCS was 3.0 ± 0.50 points, the range was from 1 to 4.5 points, where 1 point denotes very thin, and 5 points denote an excessively fat cow. Cows in low BCS at calving, or that suffer excess BCS have impaired fertility (Berry, Roshe, & Coffey, 2007; Roche, 2006; Roche *et al*., 2009; Snijders *et al*., 2000). Changes in BCS during three weeks prepartum until three weeks postpartum affected NEFA and BHB concentrations, fertility, and occurrence of health problems during the lactation (Barletta *et al*., 2017).

Blood morphological parameters (Table 1) were basically in reference ranges except one cow had a slightly elevated WBC (13.10 $x10^9$ L^{-1}), and one had a significantly ($p<0.05$) elevated WBC (28.20 $x10^9$ L^{-1}), but it was not related to the reproductive system disorders clinically; anyway, this cow was rejected. Also, MCV and MCHC were elevated in two oldest cows, and it was not related to any clinical signs of illness. Elevated St and Sg were in cows which were rejected to be the donor cows.

Primiparous cows had more RBC and MCHC in comparison with multiparous cows ($p<0.05$) and elevated Sg which could be evidence of subacute or chronic inflammation process. Despite of the fact that parameters were in reference ranges, multiparous cow had more Htc, St and Ly ($p<0.05$), and it proves that older cow group cows had cows chronic inflammation

Table 1

Blood morphological parameters in intended cow for MOET (compared in three categories: primiparous versus multiparous cows, cows which had embryos versus the ones who did not have and cows accepted for a donor role versus those denied)

Parameters	Primiparous cows (n=3)	Multiparous cows (n=17)	Cows which had embryos (n=9)	Cows which did not have embryos (n=11)	Accepted for a donor role (n=20)	Denied for a donor role (n=3)
RBC (10^{12} g L^{-1})	6.3 ± 0.12*	5.9 ± 0.62	6.00 ± 0.66	6.0 ± 0.55	6.0 ± 0.60	6.1 ± 0.44
Hbg (g dL^{-1})	10.0 ± 0.15	10.0 ± 1.05	9.73 ± 1.00	10.1 ± 0.92	10.0 ± 1.01	10.2 ± 0.32
Htc (%)	26.4 ± 2.47	29.8 ± 3.32*	29.70 ± 4.24	29.0 ± 2.95	29.2 ± 3.63	29.5 ± 0.32
MCV (fL)	41.6 ± 3.22	50.4 ± 4.34*	49.72 ± 5.77	48.5 ± 5.04	48.9 ± 5.52	49.0 ± 3.16
MCH (pg)	15.8 ± 0.34	16.9 ± 1.72	16.24 ± 1.54	16.9 ± 1.63	16.7 ± 1.63	16.9 ± 16.87
MCHC (g dL^{-1})	38.2 ± 3.66*	32.6 ± 4.85	30.35 ± 6.45	35.1 ± 3.34*	33.4 ± 5.38	34.6 ± 1.42
WBC (10^9 L^{-1})	7.6 ± 0.11	8.3 ± 2.16	9.35 ± 2.30	9.3 ± 5.95	8.1 ± 2.10	18.6 ± 10.17*
PLT (10^9 L^{-1})	401 ± 239.7	378 ± 140.8	464 ± 157.9*	349 ± 150.9	363 ± 148.9	531 ± 179.2*
St (%)	0.3 ± 0.49	2.4 ± 1.73*	2.20 ± 1.63	1.9 ± 1.82	2.0 ± 1.84	2.0 ± 1.05
Sg (%)	51.3 ± 6.34*	35.5 ± 8.24	32.50 ± 11.32	40.9 ± 7.82*	37.6 ± 10.26	42.5 ± 4.74*
Eo (%)	8.3 ± 4.17	8.0 ± 8.06	12.5 ± 10.57*	5.6 ± 3.26	8.5 ± 7.90*	5.0 ± 0.01
Ly (%)	34.0 ± 3.05	48.3 ± 7.79*	44.83 ± 10.53	46.5 ± 8.15	46.5 ± 9.30	41.5 ± 3.69
Mo (%)	5.1 ± 3.77	6.3 ± 2.93	7.67 ± 3.60*	5.2 ± 2.42	5.7 ± 3.17	8.5 ± 0.53*

*$p<0.05$

process and it could impair embryo harvest. In cows which had no embryos this parameter was closely to upper physiological value or elevated. Cows denied for donor role had elevated WBC ($p<0.05$).

A traditional way to establish cow's internal health and metabolic status is evaluating of blood biochemical parameters (Table 2). It was proved by former investigations that embryo size and quality depend on the level of Glc in blood (Son *et al*., 2012). In our study, primiparous cows had a higher level of Glc (3.3 ± 0.71 mmol L^{-1}) in comparison with multiparous (2.7 ± 0.58 mmol L^{-1}) cows ($p<0.05$). In cows which were accepted for a donor role, the level of Glc was significantly higher than in the rejected cows (3.0 ± 0.68 and 2.5 ± 0.05 mmol L^{-1}, respectively). Regarding the harvest of embryos from all cows together, the difference of Glc did not differ significantly (2.8 ± 0.43; 2.9 ± 0.76 mmol L^{-1}, respectively, $p>0.05$), but the level of BHB was significantly higher in cows with poor harvest of embryos (1.2 ± 0.45; 0.67 ± 0.21 mmol L^{-1}, respectively, $p<0.001$).

Fertility in cows that are over conditioned at calving (BCS≥3; 5-point scale) tend to have greater fat mobilization, and therefore a more severe NEB in postpartum period than cows with an optimum BCS at calving (Roche *et al*., 2009).

A multiparous cow had an impaired liver health (GGT, ALAT, ASAT, LDH together), and those parameters differed from primiparous cow results significantly ($p<0.05$).

T-test for independent samples of blood biochemical parameters in cows with good expression of MO and cows with a poor reaction to medicines inducing MO was conducted. In cows with a good MO expression there was more RBC (6.2 ± 0.61 and 5.7 ± 0.42 x10^{12} g L^{-1}, respectively), Alb (32.7 ± 4.95 and 29.8 ± 2.07 g L^{-1}, respectively). They were better provided with Cl, Mg and had optimal CHOL (4.5 ± 1.4 vs 3.9 ± 0.85 (mmol L^{-1}). Significant correlations were also observed by Leroy, 2004, for total cholesterol and large follicles in cow ovaries ($r=0.42$; $p<0.05$).

Conclusions

1. Despite the genetic value and such parameters as acceptable anamnesis, age, the number of lactations and results of general clinical examination of GF cows are not enough to accept GF animal as a donor.
2. Results of reproductive tract examination and BCS are the very first signals to accept or reject GF animal as a donor. Non acceptable results of reproductive tract examination and BCS can also be useful signals not to perform on-farm express tests and any further laboratory tests.
3. On-farm express tests are useful tools to make decision for further laboratory tests or specific treatment of animal before accepting it as a donor.
4. Results of hematology and biochemistry are the very last parameters to accept or reject GF animal as a donor. These results allow to foresee the

Table 2

Results of blood biochemical parameters in cows intended for MOET (compared in three categories: primiparous versus multiparous cows, cows which had embryos versus cows which did not have and cows accepted for a donor role versus those denied)

Parameters	Primiparous cows (n=3)	Multiparous cows (n=17)	Cows which had embryos (n=9)	Cows which did not have embryos (n=11)	Accepted for a donor role (n=20)	Denied for a donor role (n=3)
ALAT (U L^{-1})	31.1 ± 2.36	33.9 ± 10.77*	31.0 ± 14.20	34.6 ± 6.69	32.8 ± 10.23	38.0 ± 5.27
ASAT (U L^{-1})	99.8 ± 21.16*	79.5 ± 16.53	78.3 ± 21.23	85.2 ± 17.27	8.3 ± 19.92	79.5 ± 3.69
GGT (U L^{-1})	21.1 ± 5.30	33.1 ± 8.15*	30.5 ± 7.78	31.3 ± 9.62	3.5 ± 8.69	35.0 ± 10.54
ALP (U L^{-1})	145.5 ± 133.97*	45.1 ± 14.72	52.5 ± 18.24	66.5 ± 80.23	64.7 ± 69.97*	38.5 ± 6.85
LDH (U L^{-1})	1941 ± 659.7*	1063 ± 208.0*	1003 ± 270.3	1335 ± 515.7	1244 ± 495.7	1022 ± 19.5
UREA (mmol L^{-1})	5.1 ± 1.62*	3.5 ± 1.60	3.9 ± 1.85	3.7 ± 1.63	3.5 ± 1.56	5.6 ± 1.74*
CREA (mmol L^{-1})	35.9 ± 35.37	78.5 ± 16.25*	71.9 ± 11.57	74.4 ± 28.15	74.4 ± 25.00	67.1 ± 2.58
TP (g L^{-1})	73.2 ± 1.52	74.7 ± 5.66	75.5 ± 7.67	73.9 ± 3.36	74.4 ± 5.54	75.0 ± 0.00
Alb (g L^{-1})	37.8 ± 4.99*	30.7 ± 3.13	29.2 ± 3.29	33.3 ± 4.20*	31.8 ± 4.59	32.5 ± 1.58
Na (mmol L^{-1})	145.0 ± 0.85*	140.5 ± 2.08	140.0 ± 2.35	141.8 ± 2.46	140.9 ± 2.51	144.0 ± 0.00
K (mmol L^{-1})	5.0 ± 0.58	5.3 ± 0.40	5.4 ± 0.55*	5.2 ± 0.36	5.2 ± 0.44	5.6 ± 0.21*
Ca (mmol L^{-1})	2.3 ± 0.16	2.4 ± 0.15	2.4 ± 0.21	2.4 ± 0.12	2.4 ± 0.16	2.5 ± 0.06
P (mmol L^{-1})	1.7 ± 0.26	2.1 ± 0.28*	2.2 ± 0.32*	2.0 ± 0.28	2.0 ± 0.33	2.1 ± 0.02
Cl (mmol L^{-1})	98.3 ± 0.98	98.7 ± 2.00	99.2 ± 1.37	98.3 ± 2.03	98.5 ± 1.95	99.5 ± 0.53
Mg (mmol L^{-1})	1.3 ± 0.27*	1.0 ± 0.09	1.0 ± 0.09	1.0 ± 0.18	1.0 ± 0.17	1.0 ± 0.01
CHOL (mmol L^{-1})	3.9 ± 0.00	4.4 ± 1.43	4.0 ± 1.43	4.7 ± 1.31*	4.4 ± 1.48	4.4 ± 0.54
TRG (mmol L^{-1})	0.1 ± 0.00	0.2 ± 0.05*	0.2 ± 0.07	0.2 ± 0.04	0.2 ± 0.05*	0.1 ± 0.04
Glc (mmol L^{-1})	3.3 ± 0.71*	2.7 ± 0.58	2.8 ± 0.43	2.9.0 ± 0.76	3.0 ± 0.68*	2.5 ± 0.05
BHB (mmol L^{-1})	1.0 ± 0.55	0.9 ± 0.40	0.7 ± 0.21	1.2 ± 0.45*	0.8 ± 0.35	1.7 ± 0.26*

*$p<0.05$

animal response to MO and the possible outcome of embryos.

5. Not only good health, but also cow metabolic status is a decisive factor for MOET.

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THE EFFECT OF DIETARY β-GLUCANS SUPPLEMENTS ON THE HAEMATOLOGICAL PARAMETERS OF THE SEA TROUT

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Abstract
In recent years, the effective immunostimulating properties of β-glucans have been widely proven not only in mammals, but also in aquatic animals. The aim of this study was to determine the effect of dietary β-glucan supplements on the percentage of individual types of leukocytes and the haematocrit of the sea trout (*Salmo trutta* L.). Investigations were performed at the state fish farm 'Tome', hatchery 'Pelči' of the Institute of Food Safety, Animal Health and Environment 'BIOR', during a six month period (September 2018 – February 2019). On the basis of feeding with immunostimulant diets, a total of 15 000 sea trout were assigned into five groups. For blood collection healthy fish were randomly selected once a month, five 5 individuals from each group. Blood smears were made to determine the leukocyte differential count. Sampling was done once a month (September 2018 – January 2019) (n=125). Haematocrit was determined by the standard microhaematocrit method. Sampling was done once a month (January 2019 – February 2019) (n=50). We concluded that the dietary β-glucan supplements can improve the haematocrit level and effect the percentage of individual types of leukocytes of the sea trout, stimulation of the preparation for parr-smolt transformation.
Key words: Sea trout, β-glucans, haematology, leukocytes, haematocrit.

Introduction

In the last few years, indiscriminate abuse use of antibiotics to prevent and treat bacterial diseases has induced the emergence of several resistant pathogens in aquaculture. Therefore, it is necessary to select suitable ways to control outbreaks of diseases (Vivekanandhan *et al*., 2002; Meena *et al*., 2013) as soon as possible. Natural immunostimulants are one of the options to improve resistance to disease in fish and enhance immune response at time of stress (Meena *et al*., 2013; Vallejos-Vidal *et al*., 2016; Thompson, 2017).

β-glucans, especially derived from the cell of baker's yeast *Saccharomyces cerevisiae* are the most commonly used immunostimulants in aquaculture (Thompson, 2017). Beta-glucans are carbohydrates consisting of linked glucose molecules, which are naturally occurring in the cell walls of cereals, bacteria, fungi with significantly differing macromolecular structure depending on the source (Volman *et al*., 2008). Beta-glucans can increase the innate defence mechanisms of fish by enhancing phagocytic, antimicrobial and cytotoxic functions of macrophages and leukocytes (Cárdenas-Reyna *et al*., 2017; Thompson, 2017), increased complement and lysozyme activity, and enhanced antibody response (Thompson, 2017).

The biological product 'BGN-2' used in this study (BGN-2) has been developed by 'JP Biotechnology' (Latvia) using our own patented technological process. BGN-2 mainly consists of *Saccharomyces cerevisiae* yeast derivatives obtained in the process of production of ethanol from grain. It contains two main biologically active components: free β-glucans and nucleotides. Along with free β-glucans and nucleotides BGN-2 contains amino acids, peptides and polypeptides, as well as free mannan and B vitamins.

For many decades the sea trout (*Salmo trutta* L.) have been reared in Latvia to improve natural salmonid sources (Birzaks, 2014; Rutkovska & Medne, 2018). According to data from International council for the Exploration of the Sea (International council for the Exploration of the Sea, 2018) total number of reared sea trout smolts released in the Baltic Sea in 2017 was 3 804 000. Latvia released 224 000 sea trout smolts in 2017, somewhat less than in 2016 (308 000), but more than the last ten-year average (168 000).

Researchers have showed that immunostimulation with β-glucans can be used to improve growth of the Baltic salmon (*Salmo salar*) under industrial conditions in Latvia (Medne & Savicka, 2003), but there is no data about the influence to the haematological parameters of sea trout, namely percentage of individual types of leukocytes and the haematocrit. The aim of this study is to determine the effect of dietary β-glucan supplements on the percentage of individual types of leukocytes and the haematocrit of the sea trout.

Materials and Methods

Experimental fish and husbandry

Investigations were performed at the state fish farm 'Tome', hatchery 'Pelči' of the Institute of Food Safety, Animal Health and Environment 'BIOR'. Fish hatchery 'Pelči' is located in the drainage basins of the river Venta, Latvia (56°55'16.3" N 21°58'28.6" E). At the farming trial 15 000 farmed sea trout juveniles were randomly distributed into five 1.8 m^3 tanks (n=3000 in each tank), containing 1.2 m^3 of water in flow-through rearing system.

The average initial body weight of the sea trout was 2.3 ± 0.30 g

Fish were allowed to acclimate to the new housing conditions for 14 days. Health of the fish was regularly assessed. Careful netting and handling were implemented to minimize stress.

Fish diet and preparation of feed

The fish were fed commercial feed without supplements prior to the start of the trial.

Fish diet consisted of pelleted commercial feed mixed with two different quantities of β-glucans (Angel Yeast, China) and two different quantities of BGN-2, administered 20 times a day by the automatic fish feeder at approximately 2% of body weight per day. The control feed was β-glucan-free.

Commercial feed was thoroughly mixed with β-glucan supplement powder and rapeseed (*Brassica napus*) oil. The pellets were dried in a ventilated room for 1 h and then placed in the fish feeder. Diets were prepared shortly in advance and were distributed over a 4 day period. Every four days a new diet was prepared in order to ensure freshness and quality.

The five feeding diet groups were:

(1) Fish (n=3000) controls were represented by commercial pellets and 20 mL rapeseed oil (control group);
(2) Fish (n=3000) fed a mix composed of 1 g of β-glucans in 1 kg of commercial pellets and 20 mL rapeseed oil (1 g kg^{-1} β-glucans);
(3) Fish (n=3000) fed mix composed of 3 g of β-glucans in 1 kg of commercial pellets and 20 mL rapeseed oil (3 g kg^{-1} β-glucans);
(4) Fish (n=3000) fed mix composed of 6 g of BGN-2 in 1 kg of commercial pellets and 20 mL rapeseed oil (6 g kg^{-1} BGN-2);
(5) Fish (n=3000) fed mix composed of 14 g of BGN-2 in 1 kg of commercial pellets and 20 mL rapeseed oil (14 g kg^{-1} BGN-2).

Blood collection, cell staining and microscopy

For blood sample collection healthy fish were randomly selected once a month (n=5 individuals from each group), from September 2018 to January 2019 for blood smears (n=125) and from January 2019 to February 2019 for hematocrit (n=50). Blood samples were collected from the caudal vein of fish with a heparinized syringe (according to the Republic of Latvia Cabinet Regulation No. 1, adopted 8 January 2019, Regulation of the Protection of Animals Used for Scientific Purposes).

Blood smears were made to determine the leukocyte differential count. Blood smears were stained with MGG Quick Stain (Bio-Optica, Milano) according to manufacturer's instructions. This method of manually determining leukocyte differential count was selected because nucleated red blood cells (RBC) prevent accurate enumeration using automated analysis (Hrubec, Cardinale, & Smith, 2000). The following cell types were identified: lymphocytes, neutrophils, monocytes, eosinophils and basophils (Lehmann & Sturenberg, 1981; Изергина, Изергин, & Изергин, 2014).

Microscopic examination of blood smears was carried out using a light microscope BRESSER TFM-201/301 Science Infinity at magnification 400× and 1 000× and counting 100 – 200 leukocytes (Изергина, Изергин, & Изергин, 2014).

Haematocrit or packed cell volume was determined by the standard microhaematocrit method and expressed in percentage. Blood samples were loaded into standard capillary tubes, spun in a microhaematocrit centrifuge for 5 min and measured on a microcapillary reader. Due to the small size of fish, the haematocrit was taken starting from January, as it was not possible to collect enough blood for analysis.

Statistical analysis

For statistical analysis of all obtained data Microsoft Office 365 MS Excel was used. Haematological values are represented by means ± standard error (SE). The significance was determined by the t-test; p value < 0.05 was used to estimate the level of statistical significance for differences.

Results and Discussion

Differential leukocyte counts were characterized by predominance of lymphocytes (Table 1). Three types of leukocytes, namely lymphocytes, neutrophils and eosinophils were identified in the circulating blood of sea trout. The differential leukocyte count, like other haematological characteristics, is dependent on the fish species, age, sex, the cycle of sexual maturity, season of the year, different methods of rearing, feed quality, pathogens and stress and health condition (Modra, Svobodova, & Kolafova, 1998; Ivanc *et al.*, 2005; ReyVázquez & Guerrero, 2007; Lone *et al.*, 2012; Fazio, 2019). Also, the study of fish leukocytes plays an important role in monitoring of water pollution (Modra, Svobodova, & Kolafova, 1998). Haematological parameters are important characteristics of the physiological status of fish (Fazio, 2019), but the analyses are not widely used in fish medicine due to the lack of reference intervals (Modra, Svobodova, & Kolafova, 1998; Barcellos *et al.*, 2003; Lone *et al.*, 2012).

Dietary β-glucan supplements are a potential immunostimulant for fish (Petit & Wiegertjes, 2016) thought to affect the number of circulating leukocytes (Baunly *et al.*, 1996); however, according to our study, it did not affect leukocyte differential count significantly. There was no statistically significant difference between the groups with supplements compared to the control group (Table 1), but significant differences were observed in level of neutrophils (diet 3 g kg^{-1} β-glucans) and eosinophils (diet 1 g kg^{-1}

Table 1

Peripheral blood leukocyte differential counts from sea trout

Parameters	September	October	November	December	January
Control group					
Lymphocytes (%)	97.3±1.20[a]	92.0±2.31[a]	93.7±2.31[a]	92.3±2.60[a]	97.3±2.85[a]
Neutrophils (%)	2.7±1.20[a]	7.7±2.03[a]	5.7±2.19[a]	7.3±1.20[a]	2.7±0.88[a]
Eosinophils (%)	0.0±0.00[a]	0.3±0.33[a]	0.7±0.67[a]	0.3±0.33[a]	0.0±0.00[a]
Diet 1 g kg^{-1} β-glucans					
Lymphocytes (%)	97.0±1.53[a]	97.7±1.45[a]	96.0±0.67[a]	99.0±0.67[a]	98.7±1.15[a]
Neutrophils (%)	2.7±1.20[a]	2.3±1.45[a]	3.7±0.88[a]	1.0±0.58[a]	1.3±0.33[b]
Eosinophils (%)	0.3±0.33[a]	0.0±0.00[a]	0.3±0.33[a]	0.0±0.00[a]	0.0±0.00[a]
Diet 3 g kg^{-1} β-glucans					
Lymphocytes (%)	96.0±2.08[a]	92.0±2.08[a]	97.0±2.96[a]	85.7±1.20[a]	95.3±2.52[a]
Neutrophils (%)	4.0±2.08[a]	7.3±2.19[a]	3.0±2.52[a]	13.7±0.67[a]	4.0±0.58[a]
Eosinophils (%)	0.0±0.00[a]	0.7±0.33[a]	0.0±0.00[a]	0.7±0.67[a]	0.7±0.67[b]
Diet 6 g kg^{-1} BGN-2					
Lymphocytes (%)	93.7±0.88[a]	98.7±0.67[a]	98.3±0.67[a]	96.0±0.33[a]	94.3±0.33[a]
Neutrophils (%)	6.0±1.00[a]	1.3±0.67[a]	1.7±0.33 [a]	4.0±1.15[a]	5.7±1.45[a]
Eosinophils (%)	0.3±0.33[a]	0.0±0.00[a]	0.0±0.00 [a]	0.0±0.00[a]	0.0±0.00[a]
Diet 14 g kg^{-1} BGN-2					
Lymphocytes (%)	95.0±1.73[a]	93.3±2.33[a]	94.3±2.33[a]	97.3±2.03[a]	94.7±1.76[a]
Neutrophils (%)	4.7±1.76[a]	6.3±2.19[a]	5.7±1.76[a]	2.7±1.45[a]	5.3±0.88[a]
Eosinophils (%)	0.3±0.33[a]	0.3±0.33[a]	0.0±0.00[a]	0.0±0.00[a]	0.0±0.00[a]

a and b means in the same row with different letters are significantly different ($p < 0.05$)

β-glucans) compared to the other diet groups at the end of experiment.

The highest percentage of lymphocytes was found in the 1 g kg^{-1} β-glucans group 99.0 ± 0.67 in December, also high percentage was observed in January (98.7 ± 1.15). The lowest percentages of lymphocytes were found in the 3 g kg^{-1} β-glucans group in December and October (85.7 ± 1.20 and 92.0 ± 2.08, respectively).

The highest percentage of neutrophils (13.7 ± 0.67) was found in the 3 g kg^{-1} β-glucans group in December whereas the lowest value was in the 1 g kg^{-1} β-glucans group in December, and it was 1.0 ± 0.58.

At the end of the experiment (in January) we observed that the percentage of lymphocytes and neutrophils changed in the 6 g kg^{-1} BGN-2 group (94.3 ± 0.33 and 5.7 ± 1.45) and in the 14 g kg^{-1} BGN-2 group (94.7 ± 1.76 and 5.3 ± 0.88) compared to other groups. The percentage of neutrophils became higher, but it was lower for lymphocytes. This indicates that the fish begin preparing for parr-smolt transformation (Изергина, Изергин, & Изергин, 2014). Researchers have reported a similar pattern in the Atlantic salmon parr (Pettersen *et al*., 2005).

Eosinophils were sporadic in all groups during all the feeding period, with the highest mean value of 0.7 ± 0.67 found in the 3 g kg^{-1} β-glucans in October, December and January. Also, in the control group high percentage of eosinophils was detected once in November, when it was 0.7 ± 0.67.

Basophils and monocytes were not found in any of the fish examined. It has also been reported that no basophils have been found in salmonids (Modra, Svobodova, & Kolafova, 1998; Rutkovska & Medne, 2012). Also, there is evidence that monocytes, basophilic and eosinophilic granulocytes very occasionally occur in the head kidney and in peripheral blood of rainbow trout (*Oncorhynchus mykiss*) (Lehmann & Sturenberg, 1981).

Haematological parameters such as haematocrit, haemoglobin, number of erythrocytes and white blood cells are indicators in toxicity studies on aquatic animals (Barcellos *et al*., 2003). Mean haematocrit level (Table 2) was found significantly increased in January in the 6 g kg^{-1} BGN-2 and 14 g kg^{-1} BGN-2 groups compared to the control group – 33.8 ± 5.25 and 33.0 ± 5.00. The highest haematocrit level was observed in February in 6 g kg^{-1} BGN-2 group, but the

Table 2

The peripheral blood haematocrit

	Control group	1 g kg^{-1} β-glucans	3 g kg^{-1} β-glucans	6 g kg^{-1} BGN-2	14 g kg^{-1} BGN-2
January	27.8±6.20[a]	26.5±3.50[a]	30.1±3.95[a]	33.8±5.25[b]	33.0±5.00[b]
February	31.5±2.09[a]	29.6±5.40[a]	30.6±5.50[a]	34.9±3.45[a]	29.8±2.09[a]

a and b means in the same row with different letters are significantly different ($p < 0.05$)

lowest percentages were found in January in the 1 g kg^{-1} β-glucans group.

From our point of view, the β-glucans provide stability and integrity of the haematological parameters of sea trout and thus protect them during stressful conditions. The better haematological alterations appeared for sea trout fed the 6 g kg^{-1} BGN-2 diet, when fish showed an increase in the haematocrit and in the number of neutrophils, which probably represent the activation of protective mechanisms.

Conclusions

Present results corroborate that dietary supplementation with β-glucans (specifically BGN-2 at 6 g kg^{-1}) would be beneficial for sea trout, resulting in an increase in the main haematological parameters and stimulation of the preparation for parr-smolt transformation.

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STEM CELL THERAPY IN THE TREATMENT OF BILATERAL ELBOW JOINT OSTEOARTHRITIS IN DOG

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Abstract
The aim of this pilot study was to assess whether a single mesenchymal stem cell intra-articular injection in the osteoarthritic joint gives a therapeutic effect. This trial study was made in order to better manage and structure further study on more dogs. Single injections of 3 million mesenchymal stem cell intra-articular injections were made bilaterally in the osteoarthritic elbow joints. The dog was examined before and after monthly stem cell therapy using stance analyser scales to determine the static weight of each limb. Weight balance between forelegs improved, but not significantly ($p>0.05$). A radiographic examination was made for both elbow joints before stem cell therapy and the second and fifth month thereafter. Calculations of sub-trochlear sclerosis in percentage were made using mediolateral projections. Sub-trochlear sclerosis in percentage significantly decreased ($p<0.05$) after stem cell therapy in both legs.
Key words: stem cells, osteoarthritis, canine, elbow joint.

Introduction

Osteoarthritis (OA) is one of the most commonly diagnosed joint diseases in both humans and dogs. The prevalence of osteoarthritis in dogs is reported in the literature with conflicting values. Estimates have ranged from 6.6% based on primary-care data, to 20% based on referral data in the United Kingdom dog population. Assessment from North America report age specific prevalence values ranging from 20% in dogs older than 1 year up to 80% in dogs older than 8 years, based on radiological and clinical examination data from referral settings (O'Neill *et al*., 2018). Among dogs over one year of age, almost one out of every five has some degree of OA. Additionally, the morbidity in OA increases with age, and about 95% of OA cases occur in dogs over five years with dogs older than 10 years accounting for 50% of canine OA cases (Luo *et al.*, 2018). OA is a common clinical disease in dogs affecting several tissues, including joint cartilage, subchondral bone, synovial membrane, and tendons (Luo *et al.*, 2018). This musculoskeletal disease is related to chronic pain, lameness, loss of joint function and mobility, functional disability and reduced quality of life (Comblain *et al*., 2017). Pain results in both local and distant deterioration of the musculoskeletal system as a result of decreased and altered mobility (Cachon *et al*., 2018). OA induces joint swelling, pain, deformation, and effusions (Luo *et al*., 2018). The joint capsule also experiences a fibrotic redevelopment process, which becomes clinically apparent through the restricted mobility of the joint (Neumann & Lauenstein-Bosse, 2018). OA is characterized by a gradual loss of cartilage and results in the development of osteophytes at the margins of the joints. The articular cartilage is damaged by a complex interaction of genetic, metabolic, biochemical and biomechanical factors, followed by activation of inflammatory responses involving the synovium, subchondral bone and cartilage. Pro-inflammatory cytokines and chemokines are plentiful in OA (Di Marzo *et al*., 2017).

Canine elbow dysplasia (CED) is the most common developmental disease of the elbow joint and results in forelimb lameness in medium and large breed, juvenile and adult dogs. CED is a syndrome, which consists of several conditions, including elbow joint incongruity (INC), ununited anconeal process (UAP), fragmentation of the medial coronoid process (FCP) of the ulna also named as coronoid dysplasia and osteochondritis dissecans (OCD) of the medial part of the humeral condyle. These conditions can occur as single traits or in combination and each can cause irreversible elbow OA (Theyse, 2018). Radiographic hallmarks of cartilage pathology include mainly joint space narrowing, subchondral sclerosis, subchondral cysts, osteophyte formation, and chronic inflammation of ligaments (Luo *et al*., 2018). The radiological findings of the elbow joints are according to the severity (size) of the presence of osteophytes and/or the presence of abnormalities reflecting the primary lesions UAP, OCD, FCP or Medial Coronoid Disease (MCD) and/or INC according to the International Elbow Working Group (IEWG) update in 2010. Grading elbow dysplasia according to the IEWG: Grade 0 – Normal elbow joint, no evidence of INC, sclerosis or arthrosis. Grade 1 – mild arthrosis; sclerosis of the base of the coronoid processes but trabecular pattern still visible, presence of osteophytes < 2 mm. Grade 2 – moderate arthrosis and suspect primary lesion; step between radius and ulna 3 – 5 mm (INC), indirect signs for other primary lesion (UAP, FCP/MCD, OCD), presence of osteophytes 2 – 5 mm, obvious sclerosis (no trabecular pattern) of the base of the coronoid processes. Grade 3 – severe arthrosis and evident primary lesion; presence of osteophytes > 5 mm; step between radius and ulna > 5 mm (obvious INC), obvious presence of a primary lesion (UAP, FCP/CD, OCD) (Hazewinkel, 2018).

Articular cartilage is a highly specialised tissue with shock absorber function and enabling synovial joints to articulate with low frictional forces. Due to its avascular, aneural and alymphatic state, it has a limited repair potential (Goldberg *et al*., 2017).

Because of ineffective healing of chondral defects, there is a need to develop therapies to restore articular cartilage to near normal (Counsel *et al.*, 2015). The best treatment of OA is focused on blocking the catabolic activity of cartilage and enhancing regeneration of normal cartilage. At the moment, therapies for the OA is focused on the reduction of pain and discomfort, prevention of further degeneration and improvement on functional movement. The most common treatment of OA is symptomatic and involves use of nonsteroidal anti-inflammatory drugs (NSAIDs), analgesics, and chondro-protectants, but it provides no disease-modifying effect (Yun, Ku, & Kwon, 2016). There is a growing interest in regenerative medicine: cell therapy, where cells are injected directly into the blood or into tissues. Stem cells are cells that have the ability to divide and transform into many different cell types in the body. Stem cells can be categorised as pluripotent and multipotent were pluripotent stem cells are harvested from embryonic sources and can develop into any type of cell in the body. Multipotent stem cells are taken from adults and can divide and develop into a more limited range of cell types. When stem cells divide, the new cells can either stay as stem cells or they can cultivate into a new type of cell with a more specific function (Goldberg *et al*., 2017). In early stages of life, each of these organs has a population of stem cells, called adult stem cells, that have roles in replenishing damaged cells by self-renewal and a unique ability to form the particular cell type it resides in. With age, the supply of these self-renewing stem cells significantly decreases by tenfold from new born to teenage years and again by teenage to old age (Hansen *et al*., 2018). For instance, adult stem cells isolated from various sources, mainly bone marrow (BM) and adipose tissue (AT) derived stem cells, have been widely used for the treatment of different animal diseases. They have the potential to differentiate into numerous cell types such as osteoblasts, adipocytes, cardiomyocytes, chondrocytes, hepatocytes, and brain cells (Sultana *et al.*, 2018). The use of AT derived stem cells has gained popularity as alternative to BM derived stem cells (Balolong *et al.*, 2016). Mesenchymal stem cell (MSC) is present in all tissues and organs. Their primary function is the replacement of dead cells in the physiological cell renewal processes. Besides, they may also replace dead cells in pathological situations, such as inflammation, ischemia or trauma. The MSC have the natural ability for multipotency, being capable of generating new cells of tissues derived from this germ layer. These cells, by action of hormones and growth factors, acquire morphophysiological aspects pertinent to their location within the body. According to the signalling factors that the MSC are exposed, different decisions may be taken, where the main ones are those that are involved in proliferation and cellular differentiation. The MSC capture and send molecular signals, which change the niche, either by modulating the immune system as providing mechanisms for tissue repair effectors, involving since activation of cell homing, cell apoptosis, induction of the formation of new blood vessels, and the healing process (Markoski, 2016). Other important features of MSCs are their anti-inflammatory and immuno-suppressive abilities enabling them to significantly attenuate the immune responses in the host. These cells along with soluble bioactive compounds are then able to inhibit the activation of T lymphocytes, B lymphocytes, and natural killer cells. Because of this important property, MSCs can be used in allogeneic treatment where the cells from one donor dog can be used to treat other dogs. In this regard, adult stem cell therapy, in the form of MSCs, has recently provided a new paradigm for treating chronic arthritic dogs from symptom management to stimulating regeneration of bones and cartilage, resulting in considerable improvements in quality of life. MSCs were able to aggregate, multiply, and bridge injured tissue by forming vasculature-controlled chondrocytes for cartilage formation and osteoblast for bone formation (Hansen *et al*., 2018). Intra-articular injection holds several potential advantages, including reduced recovery time and cost (Counsel *et al*., 2015). In veterinary medicine, the number of animals already treated provides a substantial basis for assessing the effectiveness of cell therapy in the treatment of a large number of diseases. However, in general, the therapeutic issues involving the use of stem cells to regenerate tissue still have not been fully understood (Markoski, 2016).

The aim of this pilot study was to assess whether a single mesenchymal stem cell intra articular injection in the osteoarthritic joint gives a therapeutic effect. And if it does, then in the near future conduct a more complex study, with more examinations and observations on more dogs to better evaluate therapeutic effect of this type of treatment.

Materials and Methods

The research was carried out at a small animal veterinary clinic of the Latvia University of Life Sciences and Technologies from April to September, 2018. The research was done on one 4 year old dog with bilateral elbow joint dysplasia (ED) and OA. The dog was constantly lame and stiff on both forelegs. The symptoms were more pronounced on the left foreleg. According to the dog owner, lameness and stiffness was observed from the age of 3 months. At the age of

5 months a radiographic examination was made and ED diagnosed with primary lesions UAP and INC, and signs of OA – osteophytes and subtrochlear sclerosis. At the age of 6 months, an athrotomy was made, anconeal process removed and dynamic, proximal ulna osteotomy was performed to the right elbow joint. The owner of the animal voluntarily agreed to participate in the study.

The research plan was to make examinations before stem cell therapy and repeat examinations once a month for five months. For the first month, the dog was examined on a 'ReHab KRUUSE E1061' stance analyser. The stance analyzer measures the distribution of body weight on each limb when standing and may allow for subtle differences to be seen between the outcomes of various surgical procedures and allow assessment of progression of the disease or recovery over time (Wilson, 2018). Five measurements were recorded. For sedation, Butorphanol 0.4 mg kg^{-1} intravenous (i.v.) injections were made as a pre-medication and slow propofol i.v. injection made until the palpebral reflex disappeared. Radiographic examination for both elbow joints was made. A mediolateral projection was made positioning the dog in lateral recumbency as well as a craniocaudal projection made positioning the dog in ventral recumbency. After radiographic examination, the injection site preparation and stem cell intra-articular injection was made in both elbow joints. The 'CaniCell' stem-cell product from the company 'MEDREGO' containing 3 million cells was used. The lateral site of the elbow was clipped (clipper blade 40#). Preparation of the injection site was made by using alcohol and chlorhexidine swabs. The tube with the stem cells was manually defrosted and transferred to a sterile syringe. An intra-articular injection of aspirated joint fluid (~1.0 mL) was then made to the elbow joint and the syringe was removed from the needle (the needle was kept in the joint). The syringe with the stem cell product was added to the needle and cells injected into the joint. The syringe with needle was removed from the joint and a slight massage on the injection site was made. The same procedure was repeated for the other elbow.

For the second, fourth and fifth visit, the dog was examined on the stance analyser. Each time five measurements were recorded. For the third and sixth visit, the dog was examined on the stance analyser and radiographic examination for mediolateral and ventrodorsal projections for both elbow joints were made. The dog was obedient and calm, so radiographic examination was made without sedation.

Statistical analysis

For every stance analyser examination, five measurement records were made. By using descriptive statistics, average values for each leg were determined from five measurements taken each time. These were used to calculate the weight difference between left and right foreleg as well as the weight difference between both forelegs and hind-legs. Graphs were made from the data obtained. Covariance analysis using a 95% significance level was used to statistically estimate the monthly data.

To evaluate radiographic examinations, measurements of subtrochlear sclerosis (STS) were made using measurement of STS as a % of the distance between 2 standardized radiographic landmarks (% STS) (Smith *et al*., 2009). Each flexed mediolateral projection was assessed for presence of STS. When present, STS was quantified as a percentage of the length between 2 fixed points. To measure % STS, a line was created perpendicular to the most caudal margin of the ulnar proximal metaphyseal cortex and to the most proximo-caudal aspect of the radial head (Y). The STS caudal border which constituted a subjective radiographic assessment of the junction between sclerotic and normal trabecular bone pattern, was created along line to most proximo-caudal aspect of the radial head (X). The distance X was expressed as a percentage of the total distance Y. The % STS was calculated as 100(X/Y) (Fitzpatrick *et al*., 2009).

The data obtained was displayed in graphs. Covariance analysis using a 95% significance level was used to statistically estimate the data over the months.

Results and Discussion

Comparison of monthly weight shows that the difference between forelegs decreases. There is no significant change in the statistical analysis of the data ($p>0.05$). Representing the data in the graph (Figure 1), there is a downward linear trend. Weight symmetry between forelegs equalize, which shows a slight (though not significant) improvement.

Weight difference in percentage between forelegs and hind legs before stem cell injection was 12%, after one month 19%, after two months 23%, after three months 10%, after fore month 11% and five months after stem cell therapy it was 20%. Comparing monthly weight difference between forelegs and hind legs there is no significant change in the statistical analysis of the data ($p>0.05$).

Stance analyser is a simple and good way to evaluate distribution of body weight on each limb at a stand; thus it can be determined on which limb it is more painful to lean on, and in movement, it will show like lameness. With this examination it can be evaluated if pain reduces in time after therapy. Results of this study shows a slight improvement in forelimb weight symmetry and it means that the legs are less painful. Previous studies show that the stem cell treatment resulted in pain and functional improvement. Based

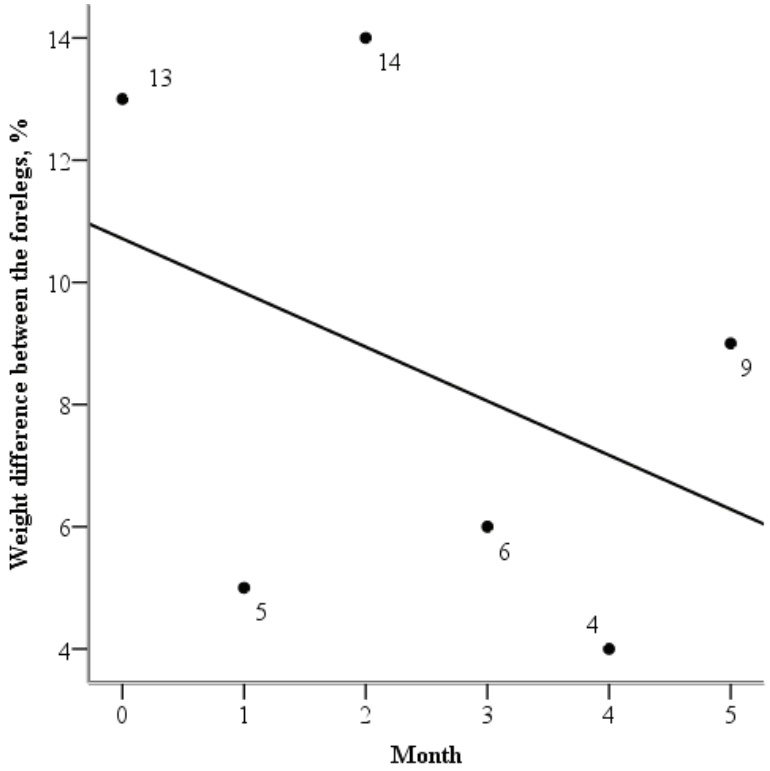

Figure 1. Weight difference between the right and left forelegs in months.

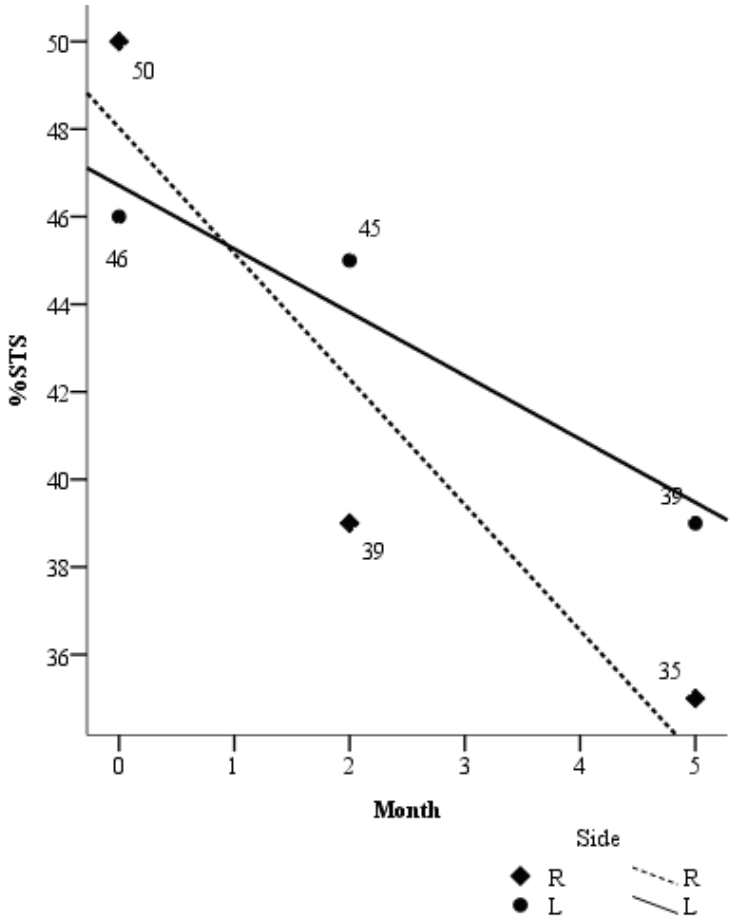

Figure 2. Right (R) and left (L) elbow %STS in months.

on the owner evaluations, the stem cell intraarticular injection had a significant effect on the dog's lameness during walking without any further medication for at least a one-year period (Huguenin *et al*., 2016; Kriston-Pál *et al*., 2017). Because the dog had bilateral elbow joint ostesteoarthritis and treatment was made on both elbow joints, results on the stance analyser are not seen well. In the basic study, dogs with unilateral elbow osteoarthritis should be definitely selected.

Evaluating % STS changes in the right elbow joint in months acquires that STS reduced from 50% to 35% and in the left elbow joint it reduced from 46% to 39% (Figure 2). The results of the statistical analysis show a significant change in % STS compared in months ($p=0.044$).

First radiological findings of elbow OA is STS and osteophytes. The stages of severity of elbow dysplasia developed by IEWG are determined by radiographic assessment of the presence of STS, the size of the osteophytes height, INC distance and the presence of primary pathology (UAP, FCP / MCD, OCD). In this study measurements of % STS were made. After stem cell therapy % STS significantly ($p<0.05$) decreased in both elbows. Reduction of STS is one of disease modifying effects. Previous studies show similar acknowledgement, stem cell treatment gives a disease modifying effect that stimulates regeneration of bones and cartilage, resulting in considerable improvements in life quality (Hansen *et al*., 2018; Huguenin *et al*., 2016). To evaluate % STS importance better, in the basic study, it is necessary to observe it in a control group in elbow joints without osteoarthritis and without treatment. It is mentioned in other research, clinical importance of % STS remains unknown (Smith *et al*., 2009).

Conclusions

1. Comparison of monthly distribution of body weight on each limb using stance analyser, weight symmetry between forelegs equalize, which shows a slight, but not significant, changes.
2. Comparing monthly weight difference between forelegs and hind legs there are no significant changes.
3. In radiographs evaluating %STS changes in elbow joints in months acquires that %STS significantly decreased. This may indicate that inflammation in the joint reduces, but at the moment there is no information that %STS correlates with severity of OA and stage of the disease.
4. Taking into account the results obtained in the pilot study, it is worth to perform the basic study on more dogs including more examinations, assessments, and animal owner questionnaires to better and more thoroughly evaluate changes after stem cell therapy.

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THERMOGRAPHIC SKIN EVALUATION AFTER THE USE OF ELECTROSURGICAL DEVICES AND SCALPEL MADE INCISIONS IN RABBITS

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Abstract
The purpose of using electrosurgical devices in veterinary practice is to reduce bleeding during the cut increasing temperature locally, causing coagulation and apoptosis of proteins. There is a lack of data on the extent and depth of these thermal damages and whether these effects on the different tissues are the same. Because of that, the aim of this study was to investigate which of the different electrosurgical devices causes highest heating effect on the skin tissue of rabbits (*Oryctolagus cuniculus*). The research was carried out at the Latvia University of Life Sciences and Technologies, Faculty of Veterinary Medicine. It included 50 rabbits, on average 2 years old, clinically healthy, with similar weight and condition. We formed five experimental groups: skin tissue cut with CO_2 laser (n=10), an electrocoagulator (n=10), a tissue welding device (n=10), a radiofrequency apparatus (n=10) and a scalpel as control group (n=10). In order to evaluate the thermal effects of electrosurgical instruments on tissues, we performed contactless thermography. There were taken 3 images for each animal, totally 150 skin thermo-gramms. From the obtained results we conclude that the most pronounced thermal effect on rabbit's skin was caused with laser and an electrocoagulator. All electrosurgical devices caused a significantly higher ($p<0.01$) increase in skin temperature compared to a surgical scalpel at the moment of tissue incision. During the study, it was found that the gentlest electrosurgical devices used on rabbit skin tissue was a radiofrequency device.
Key words: Laser, electrocoagulator, tissue welding device, radiofrequency.

Introduction

For centuries, doctors and scientists have been trying to find the most effective and at the same time the gentlest type of tissue incision that would provide a qualitative surgeon's work during surgery, while reducing the amount of tissue damage, the frequency of complications and the tissue healing period. Classical surgical scalpels do not always meet the requirements of modern veterinary medicine. This is why other types of tissue incision, known and approbated in human medicine, are becoming more common in veterinary practice. Various electrosurgical devices mentioned in the literature were widely introduced in human medicine only at the beginning of this century and still are considered to be an integral part of modern surgery worldwide (Vogt, 2008; Taheri *et al*., 2014).

Electrosurgery is conducting of the high frequency current through tissue to achieve a specific surgical effect. Heat generation and thermal tissue damage are the cause of the obtained electrosurgery effect. The only variable that determines the ultimate current effect on the tissue is the depth of affected tissue and the rate of heating (Taheri *et al*., 2014; Haneke, 2015).

In veterinary medicine, the most frequent purpose of using electrosurgical devices is to cut tissue during surgical manipulations and to reduce bleeding, causing coagulation. The ability of these electrical devices is to interrupt tissue interactions incising them in the place of the most intense impact, as well as the ability to act on them thermally, causing protein coagulation. Some electro-surgical biophysical mechanisms are more or less studied, but the full effect of these technologies on different tissues is unknown. It has been investigated that during their exposure to tissues, the temperature increases locally, causing coagulation and apoptosis of proteins (Tobias & Johnston, 2012; Haneke, 2015), but there is a lack of data on the extent and depth of these thermal damages. It is also not known whether these effects on the different tissues of the body are the same and how they affect the regeneration processes.

In human medicine are studies with different electrosurgical devices where thermal effect on the skin is investigated using thermographic examination. Schneider and co-authors have investigated ultrasonic scalpels and monopolar electrocautery thermal effect on the skin of neck. The main conclusion was thermographic examination. Schneider and co-authors have investigated ultrasonic is superior to monopolar electrocautery for skin incisions in neck dissection (Schneider *et al.*, 2018)

There are different electrosurgical devices such as electrocoagulator, laser, tissue welding and radio frequency devices. Tissue incision by electrocoagulator is achieved by heating the tissue to the boiling point, causes a rapid explosion of water in the cell and protein denaturation, which leads to cutting the tissue (Wall & Gertners, 2008; Taheri *et al*., 2014). Thermal effect of electrocoagulator on the tissue depends on the energy level, the duration of application and the biological properties of the tissues (Beriat *et al.*, 2012; Tobias & Johnston, 2012; Haneke, 2015).

Laser impact is based on the emission of photons. Photon is the basic unit of light and electromagnetic radiation. Two types of photon emissions are distinguished – spontaneous (eg. sunlight) and stimulated. Stimulated photons emit monochromatic and synchronous light waves – lasers (Wall & Gertners, 2008). Laser causes thermal damage,

necrosis and carbonization not only on the damaged bone tissue, but also on the surrounding soft tissues (Saeed & Mahmood, 2011).

The hypothesis about the effect of the tissue welding device is based on the denaturation of the albumin, collagen and elastin in the walls of the blood vessels. Tissue cells are exposed to the electrical current and incised. (Патон, 2011; Tobias & Johnston, 2012). Using a tissue welding device, the tissue surface can reach up to +100 °C high temperature and the surrounding tissue is traumatized at a distance of 1mm from the cutting site. D. Eberli and his co-authors during prostatectomy surgery found that surrounding tissues were heated to +75 – 85 °C The tissue at a distance of 1.7 mm to 2.7 mm from the wound is heated to almost +45 °C, which is critical and it causes thermal injury in the tissue (Eberli *et al*., 2009; Tobias & Johnston, 2012).

The basic principles of the radio frequency device are significantly different from other electronic devices. During exposure to radio frequency device, the tissue becomes an object which radio waves flow through. By using radio frequency current, the temperature of the internal structures of the cells increases, intracellular fluid is lost and protein denaturation occurs (Tobias & Johnston, 2012; Haneke, 2015) The narrow range of radio frequency waves ensures reduced heating of surrounding tissues (Vogt, 2008; Taheri *et al*., 2014). Radio waves during surgical manipulation can almost completely prevent thermal damage (Haneke, 2015).

Overall thermal damage occurs when the heat is applied to the tissues faster than they are able to absorb and disperse it. The severity of the damage depends on the temperature of the heat source, the conductivity of the tissues and the duration of contact. Temperatures above +45 °C can cause coagulation necrosis and irreversible skin damage. There is a transition zone around the burn site where the damage is potentially reversible. Around it is hyperaemia, where tissue damage is minimal and healing processes occur (Beriat *et al.*, 2012; Pereira *et al.*, 2012).

Based on the lack of information on the thermal effects of electrosurgical devices, the aim of this research was to investigate which of the different electrosurgical devices caused the highest heating effect on the skin tissue in rabbits *(Oryctolagus cuniculus*).

Materials and Methods

The research was carried out at the Faculty of Veterinary Medicine, Latvia University of Life Sciences and Technologies. An experiment started in 2015 and was completed in 2018. It included 50 rabbits, on average 2 years old, clinically healthy, with similar weight (about 3.5 kg) and condition. We formed five experimental groups of animals, whose skin incision was made by CO_2 laser 'Aesculight' (n=10), an electrocoagulator 'EK-300M1 MAC' (n=10), a tissue welding device 'BOVA ARC 250' (n=10) and a radiofrequency apparatus (n=10), as well as a control group (n=10) where the incision was made by a scalpel. We have received permit from the Food and Veterinary Service to work with experimental animals (No 75).

In the state of general anaesthesia, during surgery a skin incision was made by one of each instruments included in this study according to group of rabbits. To avoid discomfort during surgery, first anaesthesia was injected intramusculary. As soon as the animal reached the sleep state, it was connected to the inhalation anaesthesia device and monitoring sensors. At the beginning of the operation, analgesic medicament was injected intramuscularly with 24-hour effect. The re-injection of analgesics and antibiotics was evaluated by animal behaviour and physiological parameters.

In order to evaluate the thermal effects of electrosurgical instruments on tissues, we performed contactless thermography with the *Flir-i3* thermograph during exposure. The temperature range checked by thermograph is -20 °C to +300 °C. During the surgery thermography was performed by placing the thermograph at a distance of 7 cm from the cut site; 3 images were taken for each animal, totally 150 skin thermos-gramms. The thermographic changes of obtained images were analysed using a special computer program 'FLIR QuicReport 1.2 SP2', which allows analysis to be performed within ± 0.01 °C error.

Statistical analysis of the obtained temperature indicators was performed with the help of program Excel2016, calculating the mean, standard deviation, minimal value and maximal value for each group. In the result section standard deviation is marked using ± symbol. In order to evaluate the differences in the average temperature of the groups, we used the Student's t-test with α=0.05.

Results and Discussion

Thermography was performed to evaluate heating effect of the skin during exposure to assess and compare data of each surgical electrical device. There were obtained 30 thermo-gramms for each study group, totally 150 images.

The analysis of the obtained thermos-gramms showed that the use of laser caused the highest thermal effect, which reached a maximum of +255.7 °C and was not lower than +197.1 °C. According to the use of electrocoagulator, we found that in the site of skin incisions there was also a very high temperature above +130 °C in some measurements. Regarding other electrical devices used in this research, the tissue heating above +100 °C (which is known to be a boiling temperature) was not detected in both, during the use

Table 1

Thermal values (°C) of skin during incision with different electrical devices and surgical scalpel

Electrosurgical devices	Mean	Standard deviation	Minimal Value	Maximal value
Laser	255.7	18.34	197.1	270.2
Radio frequency devices	57.5	16.83	38.3	93.0
Electrocoagulator	93.5	29.76	36.3	136.2
Tissue welding device	66.2	11.59	41.3	86.8
Surgical scalpel	35.4	1.15	33.0	37.6

Table 2

Comparison of tissue temperature data after the use of different electrosurgical device with Student's t-test

Electrosurgical devices		p-values
Laser	Radio frequency device	5.049×10^{-46}
	Electrocoagulator	1.395×10^{-29}
	Tissue welding device	8.943×10^{-43}
	Surgical scalpel	2.709×10^{-33}
Radio frequency device	Electrocoagulator	6.594×10^{-7}
	Tissue welding device	0.024
	Surgical scalpel	6.263×10^{-8}
Electrocoagulator	Tissue welding device	3.608×10^{-5}
	Surgical scalpel	1.381×10^{-11}
Tissue welding device	Surgical scalpel	5.868×10^{-15}

of radio frequency devices (maximal value +93 °C) and the tissue welding device (+86.8 °C). From all of the electrosurgery devices the radiofrequency device had the lowest thermal effect (57.5 ± 16.83 °C) on the skin tissue. In the control group, the skin tissue was not heated at all. We found that the upper surface temperature of the skin when it was incised by scalpel was +35.4 °C or even slightly below the physiological limit (+33 °C). Such a slight drop in temperature can be explained by the preparation procedure of the surgery area.

Generally, all electrosurgical devices heated the tissues above +45 °C. According to other authors research results, this is the limit value of thermal critical point of tissue trauma (Tobias & Johnston, 2012). We found out that the widest range of temperature changes were obtained after the incisions made with electrocoagulator, where the average values fluctuating within almost +30 °C. This can be explained because of basic operating principles of these devices, as a rapid increase in temperature above +100 °C is achieved. Adjacent cells are minimally affected if heating reaches up to a limit of +100 °C. However, protein coagulation and subsequent coagulation necrosis cannot be excluded if the temperature may exceed +45 °C. The average values of the temperature changes caused by the radio frequency devices (57.5 ± 16.83 °C) and the tissue welding device (66.2 ± 11.59 °C) also shows that we can expect coagulation necrosis in further tissue examination (Tobias & Johnston, 2012).

During the study, it was also important to compare which of the electrosurgical devices heats the tissue significantly more than others. Among all electrosurgical devices, the laser caused the greatest increase in temperature during tissue incision, which proved to be significant ($p<0.01$) compared with other devices. Changes in temperature during tissue incision also differed significantly between tissue welding device and electrocoagulator ($p=3.608 \times 10^{-5}$). When using electrocoagulator, the heating effect on the skin was significantly higher. The difference in temperature changes between the radio frequency devices and the tissue welding device was significant, but with a lowes p-value (p=0.024). The gentlest electrosurgical devices used on rabbit skin tissue was a radio frequency device that had the lowest heating effect on the tissues, average 57.5 ± 16.83 °C. Though making a tissue incision by scalpel, the wound temperature was significantly lower ($p<0.01$) than performing the same procedure by electrosurgical device.

Most authors in their studies had described thermal changes in tissue caused by the use of electrosurgical devices (Eberli *et al*., 2009; Saeed & Mahmood,

2011; Tobias & Johnston, 2012). Our study shows that various electrosurgical devices have a significant thermal effect on tissues that can cause pathological thermal skin damage, which encourages for future investigation according to tissue morphological changes caused by different electrosurgical devices.

Conclusions

1. The highest thermal effect on the rabbit skin during surgical incisions was caused using a laser (up to +270.2 °C) and an electrocoagulant (+136.2 °C).
2. All electrosurgical devices caused a significantly higher ($p<0.01$) increase in skin temperature compared to a surgical scalpel at the time of tissue incision.
3. During the study, it was found that the gentlest electrosurgical devices used on rabbit skin tissue was a radio frequency device that had the lowest heating effect on the tissues, average 57.5 ± 16.83 °C.

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HISTOPATHOLOGICAL CHANGES IN LIVER OF ELKS WITH *PARAFASCIOLOPSIS FASCIOLAEMORPHA* INVASION

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Abstract
Parafasciolopsosis is a parasitological disease which is caused by the liver fluke *Parafasciolopsis fasciolaemorpha.* This parasite which belongs to herbivores often causes invasion in elks (*Alces alces*). The aim of our study was to diagnose the parasite and investigate what kind of histopathological changes it caused in the liver tissue. The study took place in Latvia University of Life Sciences and Technologies, Faculty of Veterinary Medicine, Laboratory of Comparative Pathology and Laboratory of Parasitology. During the study from 2017 to 2018 we collected liver samples and faeces from 46 felled elks of different age and gender, from all over Latvia. Ten grams of faeces were examined for trematode eggs by sedimentation method and a section of liver was examined for the presence of flukes and the histological structure of the liver. In this study *Parafasciolopsis fasciolaemorpha* were found in 11 samples of liver from 46 elks, with invasion extensity of 24%. The histopathological examination of the liver samples revealed fibrosis, proliferation of bile ducts, pericholangitis, calcerous deposits in bile ducts and other notable histological changes in the liver tissue that can cause hepatic trematodes.
Key words: Parafasciolopsosis, *Alces alces*, hepatic trematode, liver tissue, faeces.

Introduction

Parafasciolopsosis is a parasitological disease caused by the liver fluke *Parafasciolopsis fasciolaemorpha* from the family *Fasciolidae*. It is a typical parasite of elks (*Alces alces*): however, the fluke has also been recorded in roe deer (*Capreolus capreolus*), bison (*Bison bonasus*) and other ruminants (Filip, Pyziel, & Demiaszkiewicz, 2016).

The agent was first diagnosed in 1932 in Eastern Europe (Filip & Demiaszkiewicz, 2016). Nowadays the disease is prevalent in central Europe as well as in the eastern and southern parts (Filip, Pyziel, & Demiaszkiewicz, 2016). Scientific publications show that the invasion is a topical issue in Poland, Hungary, Belarus, and Russia (Eckert *et al*., 2005; Filip, Pyziel, & Demiaszkiewicz, 2016). There are no international reports about the situation in the Baltic States.

This hepatic trematode has been diagnosed at the Faculty of Veterinary Medicine since 1970 by laboratory testing of liver samples from hunted elks. The epizootic data about parafasciolopsosis in Latvia present that elks are infected throughout the country (Bergmane *et al*., 2017). Therefore, research about parasite induced pathological changes in liver tissue and pathogenesis of the disease is topical. Due to the harmful effects of parasites, the infected elks have a growth disorder that is an important factor in the process of obtaining high-quality hunting trophies (Bergmane *et al*., 2017).

A mature fluke is lancet-like 3-7 mm in length and 1.0 – 2.5 mm in width (Eckert *et al*., 2005). The parasite locates in the bile ducts of the liver, and also in the duodenum and pancreas when the invasion is extremely intensive. An invasion can cause anemia, reduce body weight and productivity, growth inhibition in young animals and significant illnesses which may lead to falls (Filip, Pyziel, & Demiaszkiewicz, 2016).

The life cycle of the parasite is typical for the *Fasciolidae* family, which is mediated by an intermediate host – aquatic snail (Eckert *et al*., 2005; Filip *et al*., 2016). Animals infest after eating metacercaria, an invasive larvae usually found in water or on plants near water reservoirs (Eckert *et al*., 2005).

A juvenile fluke penetrates the wall of the duodenum and migrates to the liver where it matures. Liver damage and haemorrhage resulting in necrosis is associated with the migration of immature flukes through the liver. Adult flukes reside in the bile ducts where they produce eggs and cause cholangitis. As a result, the liver becomes enlarged, has multiple cavities filled with dark brown liquid, trematodes and eggs (Filip, Pyziel, & Demiaszkiewicz, 2016; Taylor, Coop, & Wall, 2016; Zachary, 2017).

Taking into account the actuality of parafasciolopsosis in Latvia, the aim of our study was to diagnose the parasite and investigate what kind of histopathological changes it caused in the liver tissue.

Materials and Methods

The research took place in Latvia University of Life Sciences and Technologies, Faculty of Veterinary Medicine, Laboratory of Comparative Pathology and Laboratory of Parasitology during the hunting seasons 2017 and 2018 (October – December). Liver samples from 46 felled elks and 34 faecal samples from the same elks of different age and gender, which were hunted in accordance with legislative acts, were included in this research. The samples, collected from all over Latvia, after examination results were divided into two groups: one was the negative group – 35 samples and the other was the positive group – 11 samples invaded with *Parafasciolopsis fasciolaemorpha.* The negative group was defined as a control group. Samples of liver

and faeces collected from the rectum were transported refrigerated to the laboratory for further examination.

Several methods have been used for parasitological examination of the faecal samples. Ten grams of faeces were examined for the presence of trematode eggs by sedimentation method (Zajac & Conboy, 2006). McMasters method was applied for qualitative testing of the presence of other helminthes eggs base of gastrointestinal nematode (Bowman, 2013). The Baermann test was used to isolate larvae from faecal samples, mostly to diagnose lungworm infections (Zajac & Conboy, 2006). The rate of infestation of animals was estimated by calculating the invasion extension. Considering that faecal samples were not collected from all 46 elks, the samples from the liver also were examined for the presence of flukes by the clinical examination where flukes were found in parenchyma filled in multiple cavities and ducts and visually as lancet like organisms (Filip, Pyziel, & Demiaszkiewicz, 2016).

The samples of liver for histological examination were fixed in 10% formalin solution until processing into paraffin blocks. For the histological tissue visualization samples were prepared by standard Hematoxylin and Eosin (H&E) staining method and later examined under a light microscope in 100, 200 and 400 time magnification to evaluate microscopic tissue changes such as fibrous tissue formation, bile duct changes, etc. (Zachary, 2017).

Results and Discussion

The first task of this research was to find appearance of parasites during parasitological examination. Results of the coprological studies show that from 34 investigated faecal samples *Parafasciolopsis fasciolaemorpha* was detected in eight samples with invasion extension of 24%.

The results of the 46 liver clinical examinations show 11 positive cases – eight from the same elks, which have positive faecal samples, two samples with the negative faecal examination and one without the faecal examination. In general, our study shows that *Parafasciolopsis fasciolaemorpha* were found in 11 samples from 46 elks, with invasion extensity 24%.

Higher prevalence of parafasciolopsosis is reported by researchers from Poland, where it is widespread. Several studies have found that the extent of the infestation of parafasciolopsosis reaches 69% – 100% (Filip, Demiaszkiewicz, 2016; Filip *et al*., 2016). In contrast, in other studies carried out in North America (Bildfell *et al*., 2007; James & Maskey, 2011) and Norway (Davidson *et al*., 2015), where the elk population is dense, trematode *Parafasciolopsis fasciolaemorpha* was not detected. In a study conducted in Lithuania in 2007 to detect internal parasitic fauna of elks, trematode *Parafasciolopsis fasciolaemorpha* was not detected, though *Fasciola hepatica* was detected (Davidson *et al*., 2014; Aukštikalniene *et al*., 2007; Bildfell *et al*., 2007; James & Maskey, 2011).

For more appropriate evaluation of invasion extension of elk parasitosis in Latvia future investigation will be performed.

According to coprology study results, other parasites were found such as *Trichostrongylus* spp. with invasion extensity 88%, *Trichuris* spp. – 73%, *Strongyloides* spp. – 35%, *Protostrongylus* spp. – 27%, *Moniezia* spp. – 12% and *Paramphistomum* spp. – 6%. The fact that nematodes are more frequent than the presence of trematodes of *Cervidae* also is confirmed by other studies in Lithuania (Aukštikalniene, Bukelskis, & Kašetaite, 2007), in Poland (Filip & Demiaszkiewicz, 2016) and in Norway (Davidson *et al*., 2015), where scientists found that the most common nematode of elks was *Trichuris* spp. and of deers – *Strongyloides* spp.

The histopathological examination of the positive samples from the liver with *Parafasciolopsis fasciolaemorpha* invasion revealed proliferation of interlobular connective tissue detected as interlobular fibrosis, which surrounds liver lobules, vessels and bile ducts – was found in all positive cases, as well as biliary hyperplasia. For the control group the quantity of interlobular bile ducts located in the portal area average was three to five, while for the positive samples the number was greater by ten. Inflammatory cell infiltration of macrophages and neutrophils were seen in portal areas and around bile ducts, indicating pericholangitis. Some of the bile ducts were complete with calcerous deposits that can cause biliary obstruction. Previously named pathological changes in liver more improved dilatation of bile ducts (Filip, Pyziel, & Demiaszkiewicz, 2016).

Such pathological changes in the liver are also described by other hepatic trematodes: *Fasciola hepatica, Fasciola gigantica* and *Fascioloides magna* (McGavin, Carlton, & Zachary, 2001; Smith, 2015; Taylor, Coop, & Wall, 2016; Zachary, 2017). Mature flukes remain in the larger bile ducts and are the reason for cholangitis. Inflamatory infiltrate of neutrophils and macrophages is often found (Zachary, 2017). Normally interlobular connective tissue is poor and difficult to see (Eurell & Froppier, 2006), as it was for the control group. Interestingly, that with *Fasciola hepatica* infection duct calcify is characteristic to cattle but not sheep (Smith, 2015). The fact that calcium sediment is typical of parafasciolopsosis invasion in the bile ducts is confirmed by case report from Poland where it is mentioned that such deposits may completely block the bile duct (Filip, Pyziel, & Demiaszkiewicz, 2016). The researches show that bile duct obstruction can lead to extrahepatic cholestasis (McGavin, Carlton, & Zachary, 2001). Such changes

were not detected in this research. *Fasciolides magna* is characterized by the formation of a black pigment, which is not detected in other flukes (Zachary, 2017).

Further studies are necessary to better understand the influence of the parasite not only on the liver but also on other tissues in the body.

Conclusions

The results of the research show that *Parafasciolopsis fasciolaemorpha* was found with invasion extensity 24%. Histological examination of the liver samples invaded with Parafasciolopsis fasciolaemorpha showed typical chronic cholangial changes similar to cases of other hepatic trematodes invasion.

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ISOLATION OF CELLULOLYTIC BACTERIAL STRAINS FROM *RANGIFER TARANDUS* RUMEN MICROFLORA

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Abstract
The feature of the microorganisms of rumen microbiocenosis is the ability to form a number of digestive enzymes, including cellulases, which allows ruminants use the energy of feeds rich in fiber. Microorganisms that are promising as a source of cellulases, biodestructors of toxins having antagonistic properties against pathogens for creating probiotic feed additives, both for reindeer and for other livestock, were isolated from the reindeer rumen. The aim of the study was to create a collection of microorganisms that are promising for creating a biopreparation.
As a result, collections of 63 associations of microorganisms decomposing cellulose and carboxymethylcellulose were created, their morphology and cultural properties were described. It was found that the amount of cellulose degradation was 44 – 62% in the 4 most active isolates (No 14, 15, 21 and 26). The obtained data allowed to make a conclusion about the ability of bacterial strains isolated from the rumen to synthesize cellulolytic enzymes carrying out cellulose biodegradation, which allows them to gain a competitive advantage in the rumen of the reindeer diets with an abundance of cellulose. Isolates No 14 and 15 showed high antagonistic activity to *Fusarium sporotrichioides*, and isolate No 15 and 16 showed high antagonistic activity to *Fusarium oxysporum.* Isolate No 15 showed a wider antifungal activity compared to other isolates. Among all isolated strains, this bacterial isolate is represented as having a large spectrum of activities, including both high cellulolytic and high antifingal activity.
Key words: cellulolytic bacteria, *Rangifer tarandus*, rumen bacterial community, Russian Arctic.

Introduction

The absorption of plant feed in reindeer (*Rangifer tarandus*) occurs, as in other ruminants, due to enzymes produced by rumen symbiotic microorganisms. The rumen of reindeer is known to be inhabited by bacteria, archaea, fungi, and protozoa. Most of the bacterial rumen symbionts assigned to the *Firmicutes* (Mathiesen *et al*., 2005; Sundset *et al*., 2009).

Reindeer is one of the special animals that live in conditions of poor diet, a significant part of which is lichens. The bacteria of the phylum *Bacteroidetes*, *Actinobacteria* and *Proteobacteria* were found in the *Rangifer tarandus* rumen community in a lesser extent. In a minor amount representatives of phylum *Tenericutes* and *Fusobacteria*, *Acidobacteria*, *Cyanobacteria* were found in the reindeer's rumen (Ilina *et al*., 2018). In the summer-autumn period, the basis of the reindeer diet is plants – cereals, sedges, willow leaves, dwarf birch trees and the proportion of lichens does not exceed 15%. In the winter-spring period, the share of lichens in the diet of reindeer increases to 70%, and the remaining 30% are residues of green plants, mosses, and various impurities (Orpin, 1985). Such a diet is dangerous because of the high amounts of usnic acid found in lichens, which is toxic to animals (Guo *et al*., 2008). In addition, lichens are producers of other harmful metabolites, in particular, mycotoxins (Tolpysheva, 2014).Thus, a community of microorganisms adapted to high quantities of lichens metabolites and having celulolytic properties should have been formed in the rumen of a reindeer. That is why the isolation of microorganisms from the rumen of reindeer is promising for the search for microorganisms with high cellulolytic activity and able to become part of probiotic.

Probiotics are living microorganisms whose use has a positive effect on many functions of the body (Hadieva *et al*., 2018). One of the important properties required for probiotics in ruminants is the decomposition of cellulose; therefore, the isolation of highly active bacterial strains with cellulolytic activity from reindeer's rumen is promising for creating biopreparations for cattle. The aim of the study was to create a collection of microorganisms that are promising for creating a biopreparation.

Materials and Methods

Four samples of fresh reindeer's rumen liquid from Yamalo-Nenets (a healthy calf and an adult animal) and Nenets Autonomous districts (samples from a healthy adult male and female) were received in the laboratory. Samples of rumen liquid (1 ml) each were sown on liquid nutrient medium (0.5 l meat peptone broth, 0.5 l distilled water, 0.5% chalk, filter paper (2-3 strips)) in a 10 ml and cultured at 37 °C under aerobic conditions. Not later than 5 days, decomposition of the filter paper was observed (Tepper, Shilnikova, & Pereverzeva, 1993). Cellulose-decomposing associations were determined by the presence of lysis zones of filter paper at the end of the experiment. Selected associations were cultivated on carboxymethylcellulose medium (5 g l^{-1} carboxymethylcellulose, 0.1 g l^{-1} malt extract, 0.04 g l^{-1} yeast extract and 2 g l^{-1} $CaCO_3$ (Ngangi *et al*., 2013)) for the determination of cellulose degrading bacteria in associations.

A total of 63 isolates decomposed carboxymethylcellulose (determined by the presence of lysis zones carboxymethylcellulose) in aerobic conditions were isolated. Then their ability to decompose cellulose (filter paper) was evaluated.

The method for evaluation cellulolytic activity of selected isolates according to Henderson, Horvat and Block in the Churlis modification (Churlis, 1958; Tarakanov, 2006) is based on determining the difference in cellulose weight (filter paper) before and after its incubation with the liquid culture of microorganisms *in vitro*. The liquid culture of the isolated associations (1ml) in duplicate was introduced in 9 ml per tube with a filter, dried to constant weight at the temperature of 104-106 °C and medium (NaH_2PO_4 – 2041.6 mg l^{-1}, $NaHCO_3$ – 2041.6 mg l^{-1}, KCl – 262.4 mg l^{-1}, KJ – 28.03 mg l^{-1}, NaCl – 262.4 mg l^{-1}, $MgSO_4$ – 8.5 mg l^{-1}, $FeSO_4$ * $7H_2O$ – 31.2 mg l^{-1}, $MnSO_4$ – 15.6 mg l^{-1}, $CuSO_4$ * $5H_2O$ – 1.6 mg l^{-1}, $ZnSO_4$ * $7H_2O$ – 0.47 mg l^{-1}, $CoSO_4$ – 0.7 mg l^{-1}, $Na_2P_4O_7$ * $10H_2O$ – 0.07 mg l^{-1}, $CrCl_2$ * $5H_2O$ – 0.16 mg l^{-1}, K_2CrO_4 – 0.08 mg l^{-1}, $NaAsO_3$ – 0.13 mg l^{-1}, glucose 500 mg l^{-1}, urea 840 mg l^{-1}, distilled water – 1 l), in duplicate. It was kept in a thermostat for up to 2 weeks at the temperature of 37 °C. Then, the filter was removed, washed and dried to constant weight at the temperature of 104 – 106 °C. Filters were weighed and the amount of decomposed cellulose in the sample was calculated (Tepper, Shilnikova, & Pereverzeva, 1993).

Themost active cellulolytic isolates were tested for antagonistic activity against *Escherichia coli* and the fungi *Fusarium oxysporum* and *Fusarium oxydans*.

The culture of antagonist strain was mixed with a 20% agarose nutrient medium (1 ml of culture per 200 ml of medium) and evenly poured into Petri dishes, after solidification of the medium, wells were made into it, into which 200 µl of culture of the isolates were poured. Petri dishes were cultivated in a thermostat at 37 °C for *E. coli*, at 30 °C for *Fusarium sp*. during the day in three replications for each strain. Antagonistic activity was determined by the presence/ absence of the growth zone / growth retardation in the antagonist strain. The zone was measured in order to determine the degree of activity of the strain.

Results and Discussion

All selected isolates had a similar morphology: whitish colonies with a diameter of 0.1-1 mm on the medium with carboxymethylcellulose. Two associations (No 7 and 46) had a yellow color. Microscopy of the sample showed the presence of several cell types in the samples, which were similar between the samples: small cocci (diplococci, streptococci), small rods, large clostridial rods. A total of 63 isolates decomposed cellulose in aerobic conditions were isolate. Then their ability to decompose cellulose (filter paper) was evaluated. It was found that 10 of 63 isolates had the high ability to degrade filter paper. The results are presented in Table 1. The isolates No 14, 15, 21, and 26 turned out to be the most active, decomposing 44 – 62% of the original cellulose according to Henderson, Horvat and Block method in the Churlis modification.

Table 1

Determination of cellulolytic activity of isolated isolates by the method of Henderson, Horvath and Blok in the modification of Churlis

Isolate No.	Cellulose loss		The amount of decomposed cellulose, %
	mg	%	
7	80	4.0	4.0
	80	4.0	
14	880	44.0	44.0
	880	44.0	
15	950	47.5	47.8
	960	48.0	
21	1100	55.0	56.8
	1170	58.5	
24	360	18.0	17.8
	350	17.5	
26	1240	62.0	62.0
	1240	62.0	
37	190	10.0	9.5
	180	9.0	
46	120	6.0	6.0
	110	6.0	
51	210	11.0	10.0
	180	9.0	
58	540	27.0	25.5
	480	24.0	
Control*	0	0	0
	0	0	

* control – without inoculum

The obtained data allowed to make a conclusion about the ability of bacterial strains isolated from the rumen to synthesize cellulolytic enzymes carrying out cellulose biodegradation, which probably allows them to gain a competitive advantage in the rumen of the reindeer consuming diets with an abundance of fiber. The most active cellulolytic isolates No 14, 15, 21 & 26 were tested for antagonistic activity against *Escherichia coli* and the mycotoxin-producing fungi *Fusarium oxysporum* and *Fusarium sporotrichioides*. The results are presented in Table 2 and Figure 1.

Table 2

Determination of antagonistic activity in isolated isolates by the method of 'wells', mm

Isolate No.	*Escherichia coli*	*Fusarium sporotrichioides*	*Fusarium oxysporum*
14	1 ± 0.04	40 ± 2.7	10 ± 0.8
15	2 ± 0.09	50 ± 3.0	50 ± 3.4
21	-*	-	-
26	-	-	50 ± 2.4

* antagonism was absent.

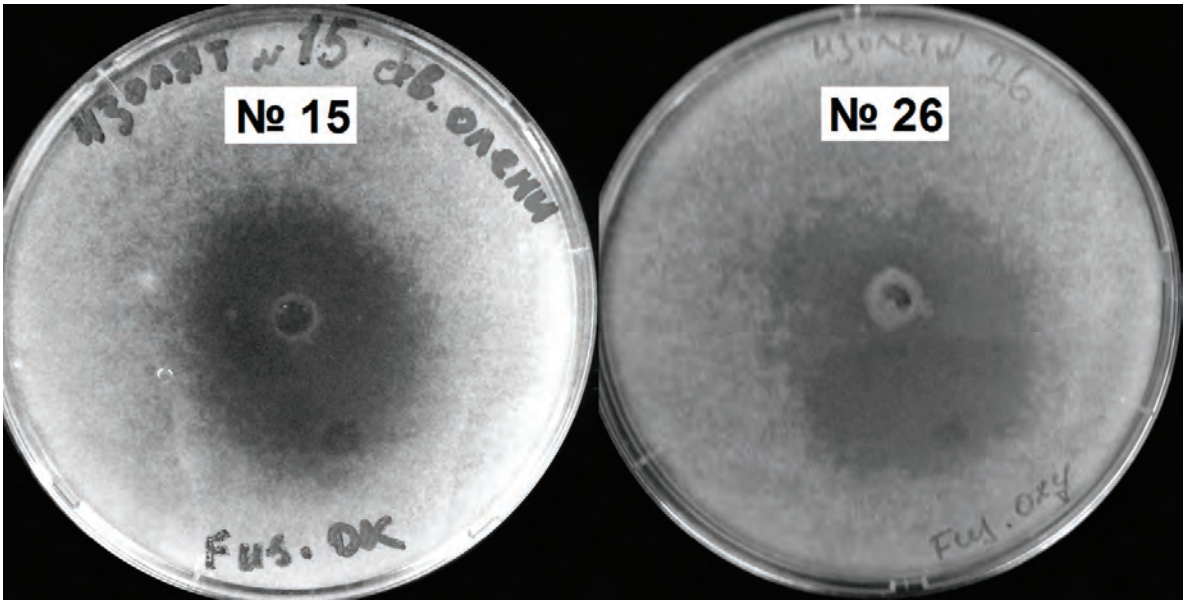

Figure 1. Antagonistic activity of strains isolated from the rumen of reindeer No 15 and No 26 against *Fusarium oxysporum.*

The antagonistic activity of bacterial isolates in our experiments was different. It was manifested differently in relation to micromycetes and bacteria: there was practically no antagonism towards *Escherichia coli*, whereas isolates No 15 and 26 showed high antagonism to *Fusarium oxysporum* (50 ± 3.4 and 50 ± 2.4 mm, respectively), and isolates No 14 and 15 showed high antagonism to *Fusarium sporotrichioides* (40 ± 2.7 and 50 ± 3.0 mm, respectively). The obtained results confirm the presence of antimicrobial substances in the culture fluids. Isolate No 15 showed a wider antifungal activity compared to other isolates. This is due to the different spectrum of antimicrobial and antifungal substances produced by these bacteria. Among all isolated strains, this bacterial isolate is represented as having a large spectrum of activities, including both high cellulolytic and high antifingal activity.

Conclusions

The obtained data allowed us to make a conclusion about the ability of bacterial strains isolated from the rumen to synthesize cellulolytic enzymes carrying out cellulose biodegradation, which allows them to gain a competitive advantage in the rumen of the reindeer diets with an abundance of cellulose. The presence of antimicrobial substances produced by cellulolytic bacteria also gives them an advantage among other microorganisms in the reindeer rumen. Among the 4 most active cellulose-decomposing bacterial isolates, strain No 15 was the most effective. This strain had a high cellulolytic and antagonistic activity against two species of mycotoxin-producing fungi of the genus *Fusarium*.

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