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Viesturs Melecis

Coping with the Impacts of Urban Heat Islands: reducing vulnerabilities and building resilience to the impacts of climate change in cities in a global change context

1. Introduction

The urban heat island (UHI) effect can be defined as higher temperatures within urban areas compared to their surroundings; however, elevated temperature effects are combined with changes in precipitation patterns, climate extremes as well as impacts of air pollution in urban areas (Oke, 1982; Ward et al., 2016). Differences in solar radiation heating in urban areas is a primary factor increasing the air temperature and surface temperature in urban areas, especially around roads, commercial and industrial territories, if compared with the average temperature of green space and residential areas (Synnefa, et al., 2008; Santamouris, et al., 2011). The urban heat island effect is a result of growth of urban areas (urbanization), structural and land cover changes, as well as industrialization (Rizwan et al., 2008), created by changes of heat absorbing surfaces, anthropogenic heat production, development of specific air circulation patterns (e.g. street canyons) and other factors (Stewart and Oke, 2012; Hirano et al., 2016). The effect is a reality for every urban area independent of its size and geographic location, but for megacities, especially those located in warm climate zones, the manifestation is significantly greater (Stewart and Oke, 2012; Ramamurthy and Sangobanwo 2016).

The most important negative consequences of UHI are related to increased temperatures in urban territories, and especially higher risks of heat waves and their effects (including increased mortality and morbidity of urban inhabitants), human discomfort, increased energy consumption during summer time (however reduced during winters), impaired air and water quality (Gartland, 2010) and other adverse impacts (Hsieh and Huang 2016). Heat waves is one of the major risk factors of UHI as they can affect human health resulting in exhaustion, dehydration, circulatory disorders, and potentially death (Gartland, 2010; Wolf et al., 2009; Buchin et al., 2016). Heat waves primarily pose a danger to vulnerable individuals, such as elderly people, the very young and those with social or physical impairments (Rebetez et al., 2009).

Climate warming contributes to the increase of UHI effects due to increased average temperatures and potentially decreased precipitation, and thus aggravated impacts (Paulina et al., 2015). The summer heat load due to climate change most likely will result in the increase of heat waves in many areas, and they will have higher intensities and longer duration (IPCC, 2013).

Urban heat islands depend not only on the character of physical processes, but also on urban planning approaches (Yang et al., 2016). There exists a strong relationship between the UHI effect and urban configuration (Hsieh et al., 2010). The wind and thermal regime of the cities depends on the land-cover and land-use character of the urban territory (Gago et al., 2013). Urban heat island effect reduction can be achieved as a result of increased evapotranspiration: as the vegetation cover releases latent heat and at the same time reduces the amount of energy available for heating, green areas can potentially cool the surrounding area (Peng et al., 2012; Ali et al., 2016). The natural process of tree transpiration lowers temperature (Gartland, 2010). The green cover of vegetation also reduces the intensity of direct solar exposure and helps to transfer the received solar radiation into latent heat. Water bodies are another feature that can help to reduce thermal load due to a transpiration effect and higher specific heat (Liu and Weng, 2008). The heat island effect can also be reduced by decreasing anthropogenic heat (Emmanuel, 2005).

Strategies of urban heat island mitigation and adaptation to it through urban planning can be considered as a main tool to achieve adverse impact reduction, especially with regard to the climate change and urban sprawl effects (Gartland, 2010; Stewart and Oke, 2012; Wand et al., 2016). An increase in the percentage of green areas and in the vegetation fraction reduces the thermal pressure that city dwellers face. Thus, urban planners should take into account the impacts of UHI for future cities, and work on the possible solutions to mitigate theme in existing cities (Peng et al., 2012).

2. The Vulnerability of Cities to Climatic Changes

Vulnerability describes physical, social, economic, environmental and institutional structures and processes that determine a system's or object's susceptibility as well as coping and adaptation capacities regarding the way that it reacts to dangers, such as the effects climatic changes (Birkmann et al., 2013). Vulnerability is therefore made up of exposure, sensitivity and adaptive capacity (Birkmann, 2008; Bohle and Glade, 2001; Bohle and Glade, 2008; Cardona, 2005; Turner et al., 2003). The vulnerability concept of the IPCC also includes these three components (IPCC 2007).

Exposure describes to what extent humans, natural assets or material goods are located in places endangered by climatic changes and their consequences. Exposure may be considered directly or indirectly, for example when delimiting study areas for a possible vulnerability analysis. In addition, some approachesuse the share of the exposed population or area as a variable for the vulnerability analysis (Birkmann et al., 2012; Turner et al., 2003).

Sensitivity is the degree to which people, natural assets or material goods react to climatic changes and their effects (GTZ, 2004; Riegel et al., 2013). Since a significant change of the exposure would require a change of location, climate change adaptation measures usually aim at reducing sensitivity, i.e. at adapting people, natural assets and material goods to climate change through organizational, structural or other measures (Riegel et al., 2013).

The adaptive capacity describes the ability to handle the negative effects of climatic changes by taking opportunities as they arise and reducing the effects through anticipatory and precautionary action (McGill and Ayyub, 2007). The adaptive capacity depends on factors such as public opinion, political will formation, and human and financial resources (Riegel et al., 2013). This can refer to strategies such as using air-conditioning or irrigated landscaping to cool the areas surrounding neighborhoods and places of residence. It also includes behavioral adaptations, such as spending time indoors during heatwaves or making use of offers of assistance in an emergency (Chow et al., 2012).

Hence a system is vulnerable if it is susceptible to the negative effects of climatic changes and unable to cope with them. Conversely, this means that the vulnerability of a system, region, municipality or household is lower the larger its coping and adaptive capacity is (Smith et al., 2001).

Numerous definitions of ‘vulnerability’ agree that the term primarily refers to the social or “internal” side of climate impact. This means that the concept of vulnerability provides a counterbalance to the idea that catastrophes and risks are primarily the result of environmental change and natural events. The concept and its application show that not only is the stress of climatic changes or extreme weather events, such as heat stress, responsible for problems and risks, but that the sensitivity, the coping capacity and the adaptive capacity of a society or system decide whether an environmental change or natural event becomes a risk or even a disaster (Birkmann et al., 2013).

In contrast, the “external” side of climate impacts is primarily connected to natural hazards and the direct changes of the climate. However, it must be noted that in natural hazards research, the exposure to climate changes and natural hazards is also partially considered as its own factor that must to some extent be determined independently of vulnerability (UN/ISDR, 2011).

While vulnerability analyses usually focus on environmental disorders on exposed systems and societies, De Graaf et al. point out that in practice, “the exposed system may amplify, attenuate, and create stresses and disturbances” (2007: p. 166). There is a relation between human practices and the vulnerability of complex systems such as ecosystems; for example when environmental management practices reduce the coping capacity of ecosystems, making them more vulnerable to external forces like fires and hurricanes (De Graaf et al. 2007; Scheffer et al., 2001). This means that it makes no sense to create a synthetic division between environmental threats and human vulnerability. Human and environmental systems are closely linked, and such a distinction prevents a full understanding of the complex interplay between them (De Graaf et al. 2007).

Climate impact research connects the term ‘vulnerability’ more strongly with aspects of the effects of climatic changes. For example, the IPCC states in its fourth assessment report that the vulnerability depends on the type, extent and speed of the climatic change as well as on the fluctuations that the system is exposed to, its sensitivity regarding these changes and its adaptive capacity (IPCC, 2007a). Accordingly, climate change research focuses intensively on the direct effects of climate change in relation to vulnerability (cf. Zebisch et al. 2005). In the IPCC special report SREX (IPCC, 2012), some integration of the perspectives of natural risk research on the one hand and climate impact research on the other hand has already occurred. It particularly stresses the concept of social vulnerability and makes clear that exposure can also be studied as its own dimension in addition to vulnerability (IPCC, 2012).

Despite the difficulties of developing a shared approach of vulnerability that covers all aspects, the concept of vulnerability with the different research focuses – social, environmental, economic – has contributed significantly to the understanding of climate change as a complex problem of human-environment interaction rather than purely physical events (Birkmann, 2008).

In the risk glossary of United Nations University, Thywissen (2006) states: “vulnerability is a dynamic, intrinsic feature of any community (or household, region, state, infrastructure or any other element at risk) that comprises a multitude of components. The extent to which it is revealed is determined by the severity of the event.” Therefore, vulnerability is not a fixed variable, but is influenced by the actions of the people affected. For example, if the hazard potential rises, so does vulnerability; through better prevention of dangers, vulnerability can be reduced (Fleischhauer, 2004).

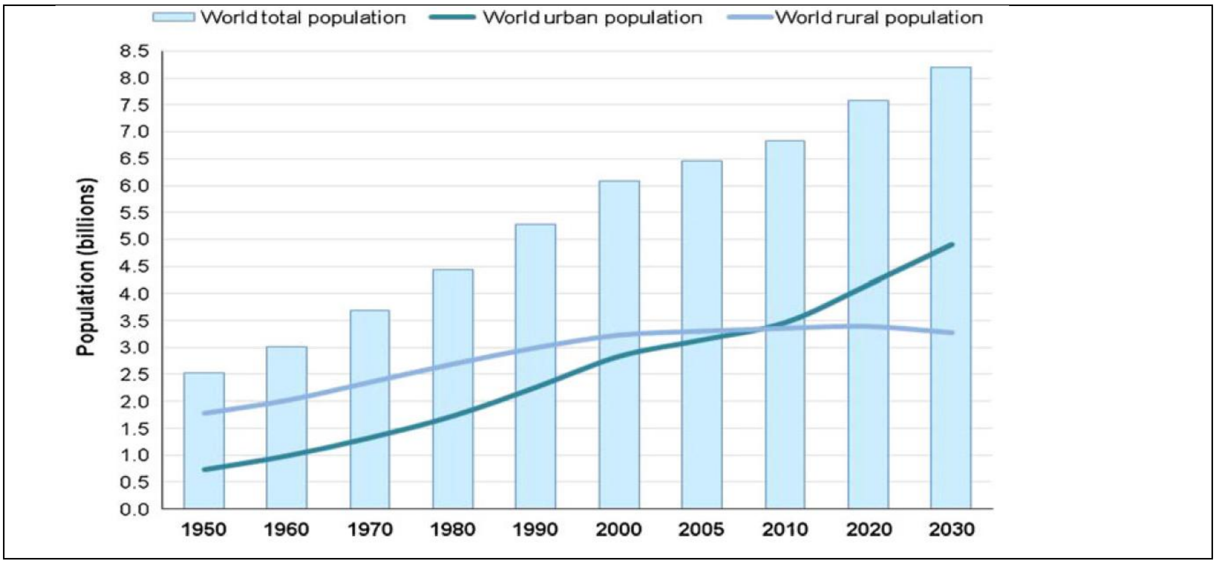
The future development of vulnerability is particularly important in the context of global warming. The Intergovernmental Panel on Climate Change (IPCC) reports 2007 that heat waves increased toward the end of the 20th century and are expected to continue to rise in frequency, intensity, and duration on a global scale, which in turn leads is likely to increase heat-related morbidity and mortality as well. Chow et al. note that “maximum temperature is one of the most important components in the physical exposure to heat vulnerability” (2012: p. 289).

The increasing mean temperature is projected to lead to more precipitation in winter but drier summers in many areas, resulting in water resources become more changeable. For example, the Rhine supplies large parts of western Germany and the Netherlands with water relatively consistently, which is largely due to snowmelt from Switzerland usually occurring in June (De Graaf et al.; 2007; Ven, 1996). As global warming causes an earlier snowmelt, the water flow becomes less consistent and the chance of water shortages in summer increases (De Graaf et al., 2007).

Cities and urban areas in particular are affected by such developments. Colten (2006) states that the dependency on technological systems and higher population concentrations make cities more vulnerable to the impact of extreme events than rural areas, in which disruptions occur at a much smaller scale.

In 2011, about fifty percent of the world’s population lives in urban areas, and according to the OECD this share is increasing yearly and will reach 60% by 2030 (OECD, 2008; table from Hallegatte and Corfee-Morlot, 2011: p. 1). In addition, the urban population in developing countries is expected to grow at roughly twice the rate of that in developed countries from 2005–2030. As they contribute significantly to the national GDP, cities constitute the economic center for every nation. The high population density coupled with the valuable infrastructure in cities often make them economic, social, and cultural hubs that have disproportionately high impact on the environment, which in turn means they are especially vulnerable to the effects of climate change (Hallegatte and Corfee-Morlot, 2011).

Table 1: World population trends – urban-rural breakdown. Source: Hallegatte and Corfee-Morlot, 2011



Hallegatte and Corfee-Morlat (2011) list the Eurpoena heatwave of 2003 as an example of an extreme weather event as an example of the sorts of extremes that are likely to become more frequent as a result of climate change. Such events have led to a greater awareness of heat-related mortality. Umbrella organizations and international organizations have started providing assistance to cities, and cities learning from one another and sharing their experiences by providing guides and report on how to include climate change vulnerability in urban planning (e.g., World Bank 2008; UNFCCC 2009) (Hallegatte and Corfee-Morlot, 2011). In cities, the negative health effects of heat waves constitute a significant problem that is only expected to increase with further global warming (Klein Rosenthal et al. 2014; Knowlton et al., 2007). According to Chow et al., “changes in surface conditions accompanying rapid urbanization profoundly changed the local landscape, demography, and ecosystem, with potential consequences for heat vulnerability” (2012: p. 290). Common heat-related causes of death are cardiovascular or respiratory distress (Hallegatte and Corfee-Morlot, 2011; Hoshiko et al., 2010; Klein Rosenthal et al., 2014). Reid et al. stress that “although understanding vulnerability to heat at the individual biomedical level is important”, there are also several factors beyond the individual level, such as place, that “contribute to differing levels of risk” and whose understanding is vital for discovering preventive solutions (2009: p. 1730). Thus, cities should locate vulnerable groups – since not all people are at equal health risk – so as to target their resources as efficiently as possible. This will also enable the development of heat emergency plans (Reid et al., 2009).

Chow et al. identify those “lacking in economic assets and access to public support systems, with diminished physical or cognitive capacities to respond to warnings and missing strong and enduring social support systems” as the groups most vulnerable to hazardous events as they are least able to adapt (2012: p. 288). For example, in the United States “the capacity to respond to hazards has been linked to racial and ethnic status, income level, gender, age, migration status, and housing tenure” (Chow et al., 2012: p. 288). Including both biomedical and social indicators into their vulnerability assessment of Georgetown County, South Carolina, Cutter et al. (2000) found no overlap between the “areas of the highest biophysical vulnerability” and the “areas of the highest social vulnerability”, and concluded that places that “combined medium levels of biophysical vulnerability with medium to high levels of social vulnerability" were the most vulnerable ones (cited in Chow et al., 2012: p. 289). This is in line with several prior smaller studies that linked physical exposure with social vulnerability to heat stress (cf. Harlan et al., 2006), and "socioeconomic status and urban vegetation with heat stress" (Chow et al., 2012: p. 288, referring to Jenerette et al., 2007, cf. also Reid et al., 2009). In Phoenix, Arizona, social inequalities regarding heat exposure are strong:

> *"Given the importance of irrigated vegetation in UHI mitigation, Jenerette et al. (2007) used a path model to examine social determinants of surface temperature and vegetation patterns: well-off Phoenicians used superior social and economic status to maintain low-density housing units with much irrigated vegetation to reduce heat stress."* (Chow et al., 2012: p. 289)

Risk factors for vulnerability to heat stress have been identified by several studies. Vulnerable groups include those over the age of 65, "people with pre-existing cardiovascular and/or respiratory illnesses", young children, obese people, and "those using medications that impede thermoregulation" (Klein Rosenthal et al., 2014: p. 45).

According to Hallegatte and Corfee-Morlot (2011), it is vital that local actors understand what future climate change risks their region faces and identify the causes of urban vulnerability. A better understanding of the drivers of climate change impacts is needed for local authorities to effectively communicate with "decision makers, to mobilize political will, to assess adaptation options and to design cost-effective and timely responses" (Hallegatte and Corfee-Morlot, 2011: p. 2). Climate change scientists, impact experts, and local and national decision makers need to communicate in order to generate the foundation of knowledge required for effective adaptation management strategies (Hallegatte and Corfee-Morlot, 2011). This foundation of knowledge must include a clear identification of particularly vulnerable areas (Chow et al., 2012).

With the development of climate adaptation plans, cities can better identify the locations and population groups at greatest risk if they come to a better understanding of "the causes of intra-urban spatial heterogeneity of […] premature deaths" caused by heat stress (Klein Rosenthal et al., 2014: p. 45). This will also be helpful in the pursuit for adaptable exposures (Klein Rosenthal et al., 2014). Suitable measures can be "policies to improve social cohesion and integration within neighborhoods via widespread dissemination of heat-stress mitigation information" (Chow et al., 2012: p. 300). Since vulnerability varies over space and time and is unequal across different demographic segments, heat mitigation measures have to be tailored to the vulnerable groups (Chow et al., 2012).

Since both the full consequences of climate change and future technology are uncertain, there can be no holistic pre-made solutions (De Graaf et al., 2007). Instead, experimenting is necessary, which is why De Graaf et al. consider transition management a promising approach. Transition management seeks to reduce vulnerability by effecting a gradual societal transformation. The process is comparatively slow – typically taking a generation or more – and comprises a series of "small-scale experiments aimed at sustainable system innovation" (De Graaf et al., 2007: p. 170). These transition experiments do not so much seek to optimize existing infrastructure as to develop innovative systems (De Graaf et al., 2007). Note, however, that there is the possibility of climate tipping points that could lead to relatively rapid changes (Lenton, 2013), and these might call for more significant governance and management changes (Serrao-Neumann et al., 2016).

In order to deal with uncertainty effectively, it is important to understand the vulnerability of a system, which is not static: A stable, well-functioning system today may become more vulnerable in the future if it fails to adjust to new developments (De Graaf et al., 2007). Cannon et al. (2002) therefore argue that vulnerability assessment must include a predictive quality "and conceptualize what could occur to an identifiable population in case of a future disaster" (De Graaf et al., 2007: p. 166). This means that vulnerability needs to consider to what extent communities and societies are capable of adapting to unclear upcoming developments (De Graaf et al., 2007).

Despite the uncertainty of the exact size and nature of future challenges, solutions must be developed for long time horizons while spatial and financial resources must be set aside to allow for future adaptations (De Graaf et al., 2007). Ideally, such adaptations will not only limit the direct and indirect impacts of climate change, but also come with co-benefits, e.g. by being advantageous for either ecosystem services or energy security and water security (Hallegatte and Corfee-Morlot, 2011).

The damage potential made possible by vulnerability are diverse. **Damage potential** describes the entirety of possible damages caused by a hazard and refers to the total of all values within a reference area (Fleischhauer, 2004). The following table shows exemplary indicators of damage potentials that are related to different forms of vulnerability and, to an extent, make it measurable.

Approach for differentiating between vulnerabilities		
Vulnerability	**Damage potentials**	**Selection of indicators**
Economic vulnerability	- Damages to real estate, movable goods or technical systems - Disruptions/failures of work, production or delivery	- Type of usage - Usage density - Height of material values - Infrastructure dependence
Functional vulnerability	- Damages to technical infrastructures - Damage to social infrastructure - Supply failures (electricity etc.) or insufficient supply	- Critical infrastructure - Alternative ways of supply - Number and importance of the sensitive social institutions (daycare centers, nursing homes, hospitals, rescue services)
Social vulnerability	- Damage to persons	- Number of people in the catchment area (residents, workers, visitors etc.) - Demographic composition (share of persons with limited mobility, e.g. elderly people, children, sick person etc.)
Environmental vulnerability	- Damage to natural assets	- Number and value of natural assets to be protected (water, ground,

		wildlife etc.)
Immaterial vulnerability	- Damage to cultural assets - Political and psychological effects	- Measuring immaterial vulnerability quantitatively is difficult. Only qualitative indicators (e.g. cultural significance, environmental justice) can be used.

Sources:
BBK, Bundesamt für Bevölkerungsschutz und Katastrophenhilfe (ed.) [2010] Methode für die Risikoanalyse im Bevölkerungsschutz. Wissenschaftsforum Band 8. Bonn
Riegel, C. [2005] Verwundbarkeit von Gemeinden: Kommunale Risikomanagementkonzepte in Deutschland und Guatemala. Diplomarbeit an der Fakultät Raumplanung der Universität Dortmund.

The IPCC (2001) has made a list of **categories of determinants of the adaptive capacity of society:**

- The range of available technological options for adaptation.
- The availability of resources and their distribution across the population.
- The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed.
- The stock of human capital including education and personal security.
- The stock of social capital including the definition of property rights.
- The system’s access to risk spreading processes.
- The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers themselves.
- The public’s perceived attribution of the source of stress and the significance of exposure to its local manifestations.

3. The empirical evidence: a comparison of the impacts of urban heat islands in a set of cities (for this a small survey will be performed,
identifying the numbers of days heat waves have affected the cities over the past 5 to 10 years, provided the data is available (5 pages)

4. Methods for mitigating UHI

There have been a range of studies investigating methods to mitigate the UHI effect and a number of recent reviews into mitigation of the UHI effect (Gago et al., 2013; Kleerekoper et al., 2012; Rizwan et al., 2008). Fundamentally, they are based on reducing the air temperature through increasing albedo or increasing evapotranspiration.

4.1 Reflective colouring

The simplest method proposed for mitigating the UHI effect and producing local cooling is based on colouring surfaces to reflect heat (Rosenzweig et al., 2006; Santamouris, 2014; Yang et al., 2015). The UHI is a result of heat being absorbed by the surfaces that dominate the urban environment and then being radiated out. Reflective surfaces are designed to increase the albedo of cities. Instead to absorbing the solar radiation reflective surfaces reflect much of it back, thus reducing the localised heating effect. These methods are relatively straightforward and cheap to implement, and can be as simple as painting surfaces, roofs etc. (Yang et al., 2015) However, the mitigation impacts are not always clear. Modelling and empirical studies suggest that reflective surfaces could have significant cooling impact in surfaces, and that this could translate into cooling of several degrees (Yang et al., 2015 and references therein). However, some studies have noted that reflective surfaces in isolation can actually increase temperatures. Hence, such approaches have to be strategic and relatively wide-spread, as well as highly context specific (Yang et al., 2015). Hence, there is often a requirement to impose rules over roof and wall coverings, which may not always be acceptable. Importantly, such approaches have few other benefits.

4.2 Urban Design

It has been suggested that urban design and the resulting airflow can exacerbate or mitigate the UHI effect. The types of building, building material used and the morphology of the buildings can all influence local heating or cooling. It has been suggested that alternative materials such as cool pavements can mitigate the heating effect (Santamouris, 2013). Also, the layout of buildings can create shade and change airflows to help cool urban areas. Ensuring that there are high ratios of street width to street height (Kleerekoper et al., 2012) or ensuring more randomness in the arrangement of taller building (Gago et al., 2013) can reduce the heating effect. Although these approaches imply a more strategic approrach, they require substantial intervention by planners and designers. Implementing new materials on pavements could be costly, and is only really practical as pavements are replaced. Specifying urban form has to take into account a range of factors, not least economic pressures. Adjusting urban form to mitigate the UHI effect is unlikely to be a top priority in urban planning and design.

4.3 Urban greening: trees, green roofs, green walls, green space

An alternative to reflective colouring is the use of urban greening (Bowler et al., 2010). Trees and other plants transpire water, which evaporate resulting in cooling of the surrounding air. At the same time, larger trees create shade resulting in cooler ground areas. Trees have long been identified as a method to cool cities (Lanza and Stone, 2016). More recently, the possibility of green roofs and green walls has been highlighted for their cooling effects (Coutts et al., 2013a; Kolokotsa et al., 2013; Rosenzweig et al., 2006). The cooling effect of large greenspaces, such as parks or urban forests, has also been studied (Feyisa et al., 2014; Gago et al., 2013; Kleerekoper et al., 2012; Rosenzweig et al., 2006).

Although the cooling effects of trees and green areas are well-established there are a number of important considerations for them to be effective. Type of vegetation (Lanza and Stone,

2016) and placing of the greenery is important (Coutts et al., 2013a). Importantly, these urban greening approaches require ongoing maintenance and water and they can become less effective during drought conditions, often when they are most needed (A. Coutts et al., 2014; Coutts et al., 2013a; Kleerekoper et al., 2012). Hence, in areas likely to suffer drought they need to be highly resistant, or replacing them can be very costly. Note, however, that such greenery has a range of multiple benefits, particularly around amenity, water management and energy consumption (Berardi et al., 2014; Bowler et al., 2010; Coutts et al., 2013a; Serrao-Neumann et al., 2015).

4.4 Water

Water features are known to reduce air temperatures around them through evaporation. Thus, urban streams and lakes have the potential to cool urban areas (A. M. Coutts et al., 2014; Hathway and Sharples, 2012; Kleerekoper et al., 2012). However, the effects are not straightforward and some studies have suggested that water bodies can actually maintain or increase temperatures at some times during the day (Steeneveld et al., 2014). The latent heat capacity of water maintains a more even temperature and thus diurnal variations are less noticeable. At the same time water features will be prone to drought, which is most likely to be when they are most needed (A. M. Coutts et al., 2014). However, water features provide a range of other benefits, such as amenity, and if designed as part of a wider strategy might provide flood mitigation or other benefits (A. M. Coutts et al., 2014; Coutts et al., 2013b).

4.5 Green and blue infrastructure

Building on the possibility of both greenspace and water to provide a cooling effect, strategically planned green areas and water features can be used to mitigate UHI. This combines the benefits of urban greening and water with the more strategic approach of urban design and planning. The concept of green infrastructure extends beyond a local one-off approach and implies a planned and strategic combination of a range of trees, flora and greenspaces (Matthews et al., 2015). Similarly, blue infrastructure implies the strategic use of water (Hathway and Sharples, 2012). Note that in both cases the infrastructure is designed to perform a range of functions, with cooling being one (Matthews et al., 2015). A more strategic approach can help address some of the issues around one-off interventions, including combining greenspace with water sensitive urban design and ensuring maximum impacts of water and greenery as well as the most efficient use of resources. At the same time, it allows for consideration of trade-offs and multiple benefits in a more strategic approach. Importantly, green and blue infrastructure can make use of existing water features and greenspace, and seek to combine a range of different technologies and interventions.

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THE DYNAMICS OF PINE FOREST VEGETATION AS AN INDICATOR OF CLIMATE CHANGE AND EUTROPHICATION IN THE INTEGRATED MONITORING STATIONS IN LATVIA

The aim of this research was to study the changes in vegetation as an indicator of eutrophication processes in pine forests during the period of 12 years. Integrated Monitoring data collected in pine stands in two different regions of the country were used. The data set of the research includes species composition and abundance in four vegetation layers (tree, shrub, ground and bottom). Analysis of species frequencies and ordination of vegetation data was carried out. Ellenberg indicator values were used to explain vegetation dynamics.

There is a significant temporal gradient in vegetation dynamics from light nutrient poor and species poor forests to more nutrient rich, species more diverse and closed forests during 12 years period. The gradient is more pronounced in the Coastal Lowland than in the Vidzeme Upland. Relationships between vegetation dynamics and changes in Ellenberg indicator values can be interpreted both as natural forest ageing and slight eutrophication but it is not possible to separate both influences based on the present data of 12 years period.

Key words: pine forest, vegetation, Ellenberg indicator values, eutrophication.

INTRODUCTION

Intensive observations of vegetation in the Integrated Monitoring sites are of high value in the characterization of the transformation processes of pine forests (indicatorspecies, deposition critical loads, etc.). Such investigations give an insight into the temporal dynamics of species' frequencies and abundances, and reflects precisely the rate of eutrophication process.

In Latvia, vegetation ruderalisation, graminification, and fruticification are the processes that indicate the transformation of pine forest stands under the influence of man (Laiviņš, 1998), namely, the slow gradual eutrophication of forests. Similar processes of forest environment eutrophication are refered to in other boreonemoral regions, based on long term observations of species composition (Falkengren-Grerup, 1986, 1989; Kuhn et al. 1987; Thimonier et al. 1992, 1995; Bobbink et al. 1998).The main reason for the transformation of pine stands is anthropogenic influence, the amelioration of wet forests in particular. Presumably, environmental dynamics has also influenced the floristic composition of pine forests: the increase of air temperatures (climate warming) and atmospheric deposition (the maximum being in the 60-80ies of the last century).

Climate change induces several processes in boreal forests, for example, a decline in growth and health of dominant tree species, increases the area burned by fire, increases the infestation of insects (Volney and Fleming, 2000; Soja et al. 2007), however, two factors, namely climate change and air pollution, act together and produce combined effects to forest ecosystems (Bytnerowicz et al., 2007). Climate warming influences resources of nutrients: there is a positive relationship between nitrogen mineralisation and soil temperature (Luxmoore et al., 1993). Consequently, not only air pollution but also climate warming can stimulate eutrophication of forests.

In Latvia three integrated monitoring sites are established in pine stands in two different regions of the country. The aim of this research was to study the changes in vegetation and environmental factors and to characterize the regional differences in pine stand transformation processes of the pine forests in Latvia during the period of 12 years.

MATERIALS AND METHODS

The study area

There are two integrated monitoring stations in Latvia – Taurene (located in the Vidzeme Upland) with one site (located in the basin of the forest stream falling into Lake Taurene), and Rucava (located in the Coastal Lowland) with two sites – Brušviti and Peši that are located in the basin of the Vārnupīte River. All the three sites are established in pine stands representative for a region in 1993.

Brušviti site is located in an 84 year-old pine *Pinus sylvestris* stand with separate birches *Betula pendula* classified as *Vaccinio vitis-idaea-Pinetum* var. *Calluna vulgaris* community. *Vaccinium vitis-idaea, Calluna vulgaris, Empetrum nigrum, Deschampsia flexuosa,* and *Melampyrum pratense* dominate in ground layer and *Pleurozium schreberii, Dicranum polysetum, D. scoparium, Cladina rangiferina,* etc, dominate in moss layer.

Peši site is located in a 50 year-old pine *Pinus sylvestris* stand with separate spruces *Picea abies* classified as *Vaccinio myrtilli-Pinetum* var. *Deschampsia flexuosa* community. *Vaccinium myrtillus, V.vitis-idaea, Deschampsia flexuosa, Pteridium aquilinum,* and *Melampyrum pratense* dominate in ground layer and *Hylocomium splendens, Pleurozium schreberi, Dicranum polysetum,* etc, dominate in moss layer.

Taurene site is located in a 56 year-old pine *Pinus sylvestris* stand with separate spruces *Picea abies* and birches *Betula pendula* classified as *Vaccinio myrtilli-Pinetum* var. *typicum* community. *Vaccinium myrtillus, V.vitis-idaea,* and *Melampyrum pratense* dominate in ground layer and *Hylocomium splendens, Pleurozium schreberi, Dicranum polysetum* dominate in moss layer.

Species abundances depend on the type and intensity of natural and anthropogenic disturbances. In Rucava and in Taurene the pine stands are naturally formed. According to the information received from local people there has been a forest fire in Brušviti site in 1985. The consequences of the fire were still evident in 1993 – the trunks of pines were still black and there were soil patches denuded of vegetation in places, and substantial increment of *Calluna vulgaris* was observed.

An improvement cutting of the stand has been carried out in Peši site in 1989-1990 (shortly before establishing protection of the site in 1993). Therefore the stand has become thin in some places and along with better light conditions the abundance of light-demanding forest fringe species (*Vicia cassubica, Lathyrus sylvestris, Pteridium aquilinum, Calamagrostis arundinacea,* etc) has increased. Permanent plots were located on this site in order to avoid cutting passage corridors. No substantial natural or anthropogenic influence has been observed in Taurene site.

Sampling design and vegetation records

Intensive vegetation plots were established based on the existing experience (Anon., 1994; 1998; 2003; Brakenhielm, 1992; Kleemola, Soderman, 1993). Three plots of 30 x 30 m size (A, B, and C) were established in each of the monitoring sites. In each permanent plot one circular plot with a radius of 15 meters was established for tree layer records. Shrub layer was recorded in 10 circular plots (located randomly) with a radius of 1 m, and field and bottom layer records were made by point-square method (Лайвиня, 1983) in 25 0.5 x 0.5 m squares (located randomly). Species composition (trees, shrubs, herbs, mosses, lichens) and their cover in a three degree scale (1) cover of species is less than 1 %, 2) cover of species is 1 – 25 %, 3) cover of species exceeds 25 %) was recorded in 100 3 x 3 m squares (Fig.1). Vegetation records were carried out once in three years, the taxation of tree layer was done once in six years.

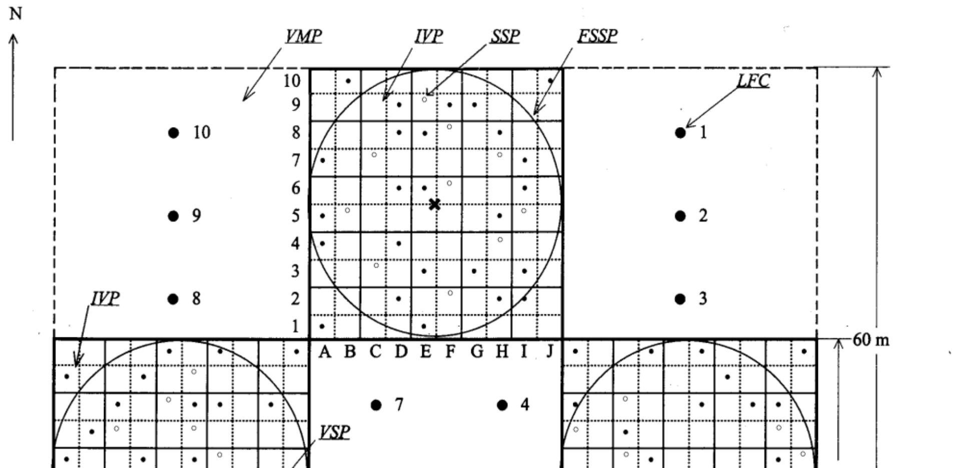


Fig.1. The sampling design of intensive vegetation monitoring. VMP- vegetation monitoring plot (30 x 30 m); FSSP – tree layer records' plot; IVP – flora mapping square (3 x 3 m); VSP – field and bottom layer record square (0.5 x 0.5 m); SSP – shrub layer records' plot (R = 1 m); LFC – litterfall box.

This work deals with the analysis of 12-year dynamics of the species composition and abundances in 3 x 3 m squares and point-squares of 0.25 m^2 (records were kept in 1994, 1997, 2000, 2003, and 2006).

Data analysis

Plant species indicator values (Ellenberg et al., 1992) were used to explain variation and dynamics of vegetation in the course of time. Ellenberg indicator values were calculated in two ways. To calculate values for each square (3 x 3 m), only species presence/absence was used. For the calculation of the mean value of a plot (30 x 30 m) the weighted values were calculated using the sum of the species' cover (cover was estimated onsite in a 3 degree scale).

Z_α criterion was used ($z_{0.05}$) to evaluate differences in the frequency of the species in the period from 1994 to 2006 (Arhipova, Bāliņa, 2003). Indicatorspecies analysis was performed to reveal the differences in species composition between all the monitoring sites (Dufrene, Legendre, 1997).

To reveal the inner diversity among the three monitoring sites a detrended correspondence analysis (Hill, Gausch, 1980) was performed using all 3 x 3 m squares (4500 in total) in one matrix (no downweighting of rare species was applied). Ordination axes were correlated with Ellenberg indicator values.

To reveal whether there are directed changes in vegetation at each site we followed the approach used by Nygaard and Ødegaard (1999). Ordination was performed separately for each monitoring site using all 3 x 3 m squares including all the observation years in one data set. Downweighting of rare species was applied at all sites with the exception of Taurene where species' diversity was the least and downweighting caused too strong an influence on the ordination of one species (*Pinus sylvestris*). DCA ordination plot scores for each year were analysed and the significance of changes was evaluated by the non-parametric Wilcoxon signed rank test.

Software packages SPSS for Windows and Pcord 4 (McCune and Mefford, 1999) were used for the analyses.

Nomenclature for vascular plants: Gavrilova, Šulcs, 1999; for mosses: Āboliņa, 2001; for lichens: Piterāns, 2001.

RESULTS AND DISCUSSION

The comparison of three monitoring sites

In total 96 species (vascular plants, mosses, and lichens) were recorded in three monitoring sites in 5 observation years. Floristic similarity of the Taurene site was 0.63 (Sørensen similarity index) both with the Peši site and Brušviti site, but both the latter were less similar to each other (Sørensen similarity index 0.49). From a species with high constancy only *Goodyera repens* was unique for Taurene. All other species recorded only at the Taurene site were sporadic (for example, *Juniperus communis, Poa pratensis*). The Peši and Brušviti sites had more unique species in comparison with Taurene. Constant species that were not present in Taurene but common in Brušviti or Peši were *Deschampsia flexuosa*, *Calamagrostis arundinacea*, *Scleropodium purum*, and *Empetrum nigrum*.

Indicatorspecies analysis (after Dufrene, Legendre, 1997) revealed several species that have significantly higher abundance in one site in comparison with the two other sites (Table 1).

Table 1

Indicatorspecies analysis (after Dufrene, Legendre, 1997)

for three monitoring sites in 1994

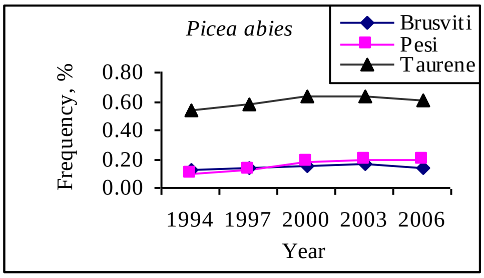
* T – Taurene, P – Peši, B - Brušviti

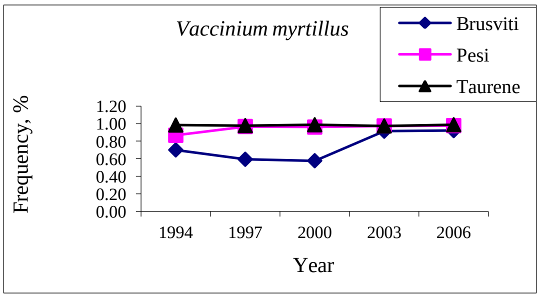
Species	**Constancy, %**			**Mean cover (in degrees)**			**Indicator -value**	**p**
	T*	**P**	**B**	**T**	**P**	**B**		
Taurene								
Hylocomium splendens	**100**	73	63	**2.6**	1.9	1.8	51.3	0.001
Picea abies	**54**	9	12	**2.2**	1.7	1.7	41.6	0.001
Dicranum polysetum	**96**	80	86	**1.4**	1.4	1.1	38.2	0.001
Vaccinium myrtillus	**98**	87	70	**2**	2.5	2.4	34.6	0.001
Festuca ovina	**13**	4	-	**1**	1.2	-	10	0.001
Peši								
Deschampsia flexuosa	-	**100**	41	-	**2.8**	1.2	85.1	0.001
Melampyrum pratense	76	**99**	83	1.4	**2.0**	1.3	47.5	0.001
Pleurozium schreberii	100	**100**	99	2.7	**2.9**	2.8	34.6	0.001
Trientalis europaea	2	**34**	-	1	**1.4**	-	32.6	0.001
Calluna vulgaris	-	**26**	-	-	**1.2**	-	26	0.001
Maianthemum bifolium	2	**23**	-	1	**1.2**	-	21.2	0.001
Quecus robur	5	**25**	2	1	**1**	1	19.8	0.001

Pteridium aquillinum	5	**24**	-	1.7	**1.6**	-	19.2	0.001
Ptilia crista-castrensis	28	**28**	-	1	**1.4**	-	16.5	0.001
Betula pendula	20	**32**	13	1	**1.2**	1.6	15.5	0.001
Luzula pilosa	29	**29**	-	1	**1.1**	-	15.2	0.001
Frangula alnus	2	**13**	-	1	**1.1**	-	11.1	0.001
Brušviti								
Calluna vulgaris	35	15	**97**	1.2	1.3	**2.1**	74.8	0.001
Empetrum nigrum	-	-	**30**	-	-	**1.3**	30.3	0.001
Dicranum scoparium	35	12	**48**	1	1	**1.2**	27.5	0.001
Cladina arbuscula	-	-	**4**	-	-	**1**	4	0.001
Vaccinium uliginosum	2	-	**4**	1.4	-	**1.7**	3	0.005

Changes in the frequency of species and Ellenberg indicator values

The dynamics of species' frequency between 1994 and 2006 was analysed. The statistical significance of changes was determined using z_{α} test (Arhipova, Bāliņa, 2003), the values are shown in Appendix 1. 12-year period is a very short time in a medium aged pine forest (41-80 years old). Nevertheless, during the period several vegetation transformation tendencies have been observed.





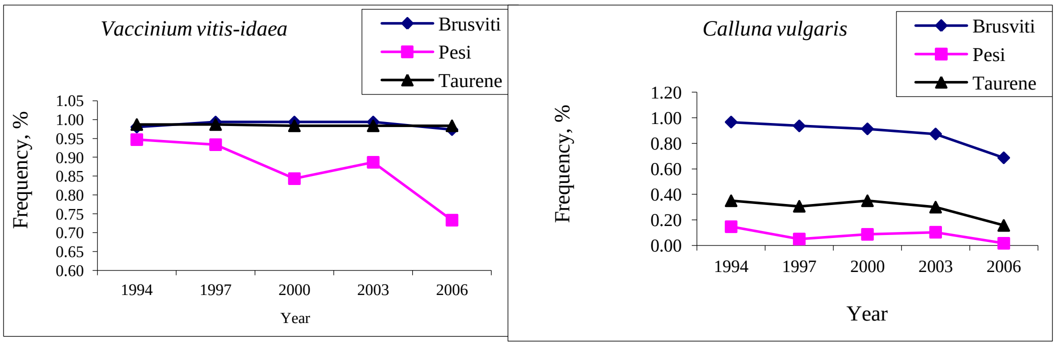
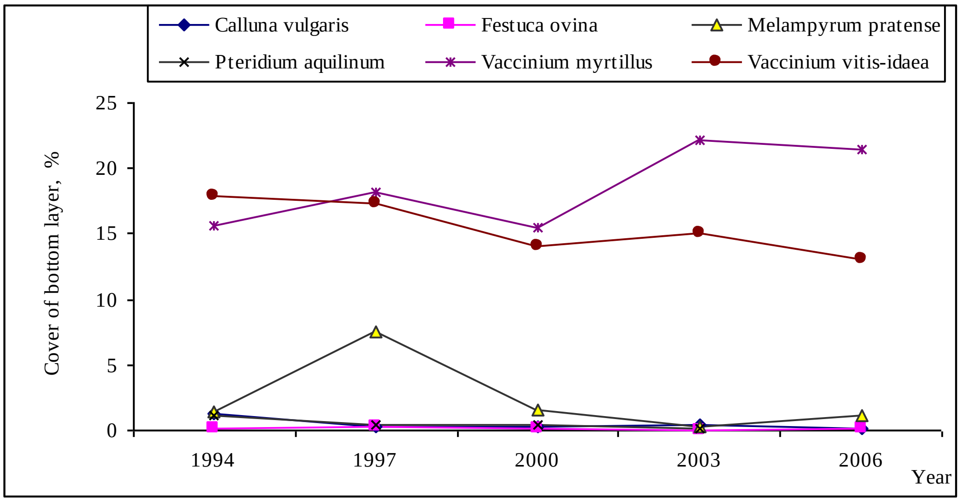
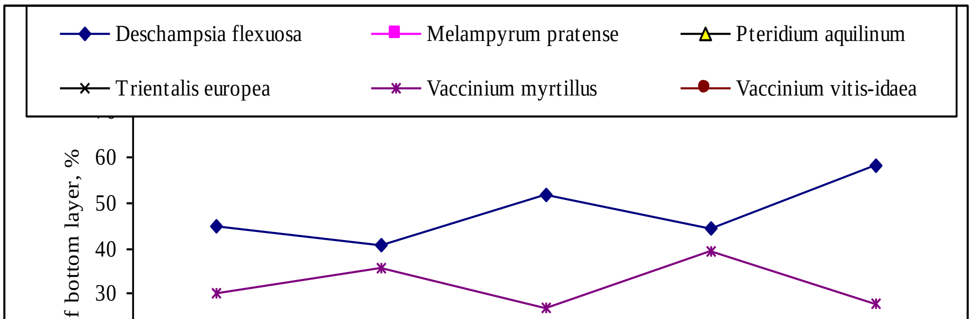


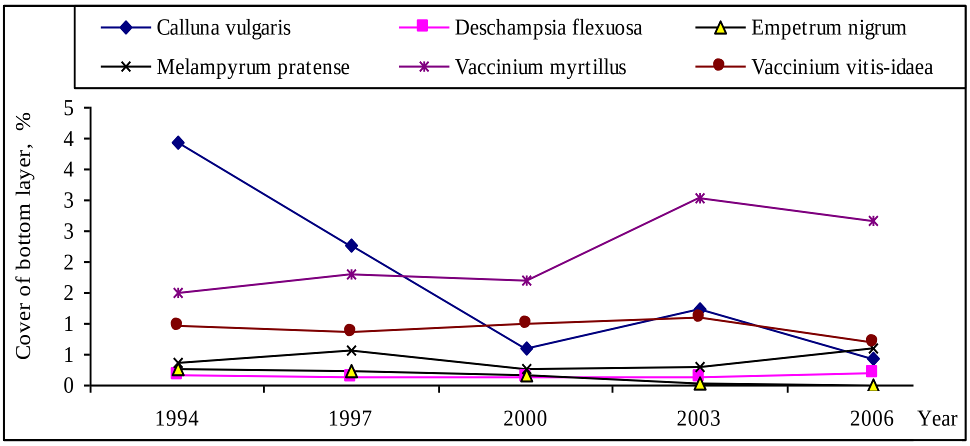
Fig.2. The dynamics of species' frequency in the integrated monitoring plots (calculated from the data on 3 x 3 m squares).



Taurene

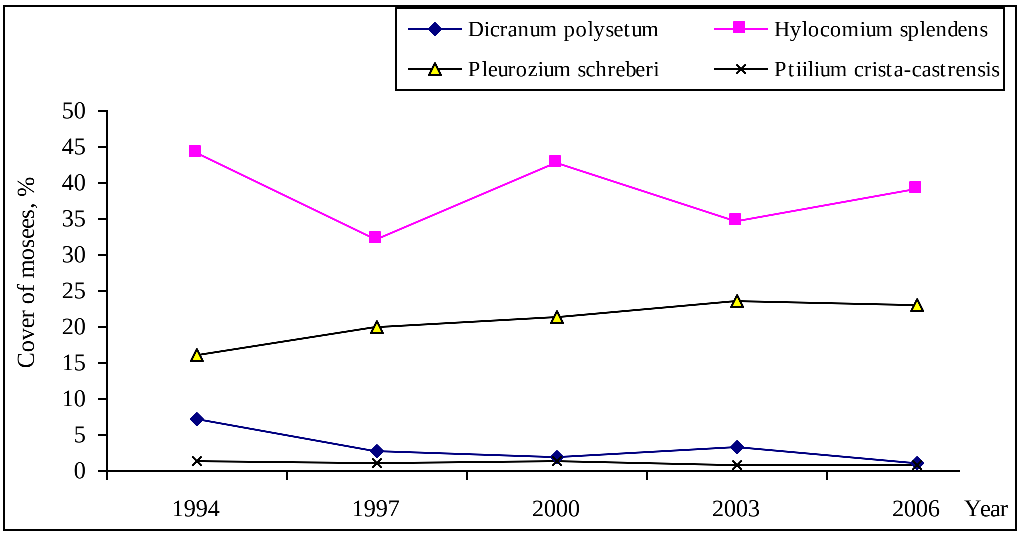


Peši

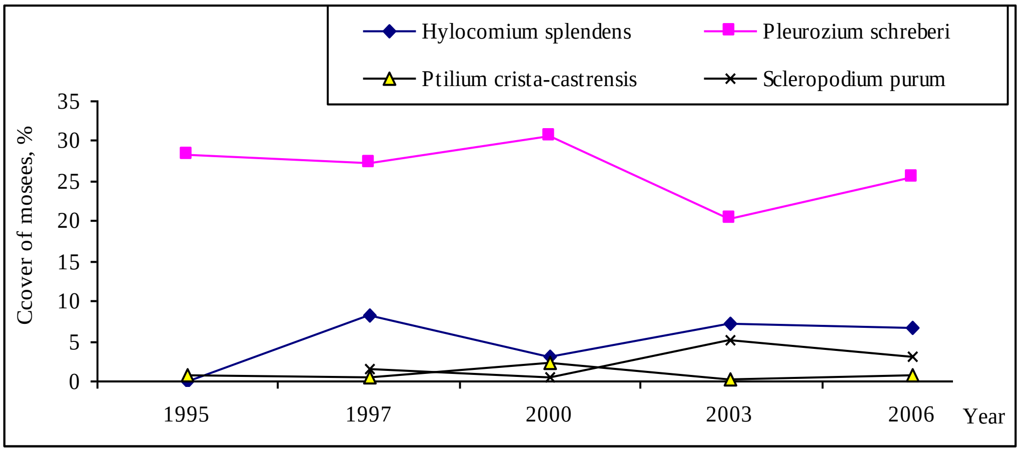


Brušviti

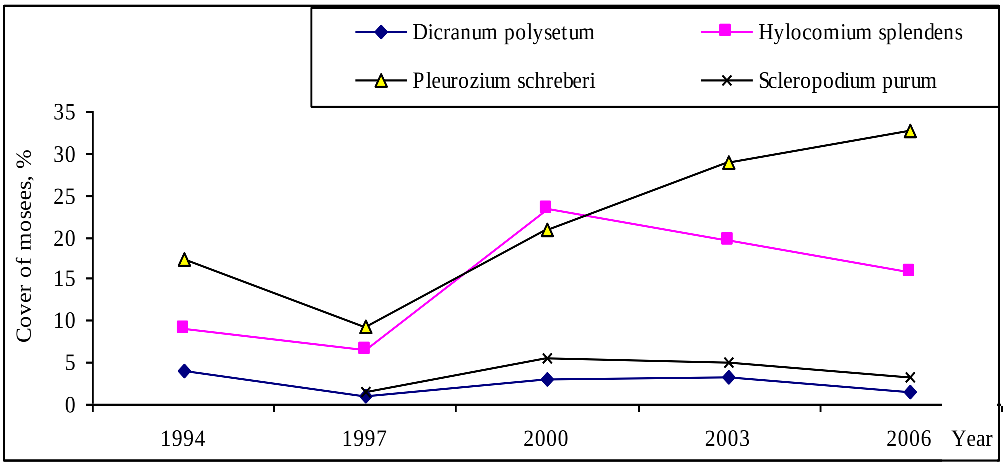
Fig.3. The dynamics of bottom layer species' cover in the integrated monitoring plots (calculated from the data on 0.25 m^2 squares).



Taurene



Peši



Brušviti

Fig.4. The dynamics of moss species' cover in the integrated monitoring plots (calculated from the data on 0.25 m^2 squares).

The proportion of *Picea abies* has increased in all plots, both in tree and shrub as well as in field layer (Fig.2). The increment is more expressed in the Peši and Taurene site than in the Brušviti site (Appendix 1). With the increasing role of spruce in forest, the stand light conditions become worse and abundance of light demanding species such as *Populus tremula* and *Betula pendula* decreases in shrub layer. They are replaced by *Frangula alnus* and *Sorbus aucuparia* that are characteristic of spruce forest shrub layer (Appendix 1).

Field and bottom layer enriches in *Vaccinium myrtillus, Maianthemum bifolium, Trientalis europaea, Hylocomium splendens, Brachythecium oedipodium* mostly on the expense of *Vaccinium vitis-idaea* and partially also *Melampyrum pratense* (Fig.2, 3).

The most conspicious was the invasion of oceanic temperate moss species *Scleropodium purum* in the monitoring sites of the Coastal Lowland (Brušviti, Peši). The number of occurences of this species (the total number of 3 x 3 m squares where it was recorded) has increased 12 times in Brušviti and 4 times in Peši in a period of 12 years.

The species composition and abundance in the field layer experienced rapid changes after the forest fire in Brušviti. Abundance of *Cladonia* species (*Cladina arbuscula, C. stellaris)* growing on soil and *Calluna vulgaris* decreased and *Deschampsia flexuosa* and *Vaccinium myrtillus* expanded in the field layer and *Hylocomium splendens* and *Dicranum polysetum* in the bottom layer.

Changes in Ellenberg indicator values were very slight. There was no significant temporal trend in temperature. The only significant trend was for moisture (positive) in the Peši site and for continentality (positive) in the Taurene site. The Brušviti site has been more dynamic, as five of the six Ellenberg indicator values have positive or negative significant trend (Table 2, 3).

Table 2

Mean Ellenberg indicator values (calculated as mean from plots A, B and C) in three integrated monitoring sites

Variable	Taurene					Peši					Brušviti				
	1994	1997	2000	2003	2006	1994	1997	2000	2003	2006	1994	1997	2000	2003	2006
Light	5.73	5.73	5.64	5.62	5.64	5.77	5.75	5.72	5.72	5.76	6.15	6.11	6.12	6.03	5.98

Temperature	3.24	3.28	3.21	3.10	3.11	3.75	3.73	3.75	3.71	3.86	3.38	3.54	3.41	3.42	3.46
Continentality	5.47	5.47	5.49	5.63	5.67	4.83	4.93	4.91	5.05	4.96	4.94	4.95	5.06	5.11	5.09
Moisture	4.21	4.27	4.31	4.26	4.22	4.45	4.46	4.55	4.54	4.56	4.23	4.29	4.24	4.22	4.21
Reaction	3.12	3.10	3.12	3.15	3.10	2.82	2.91	2.98	3.06	2.98	2.52	2.73	2.94	2.99	2.98
Nitrogen	2.07	1.97	2.05	2.09	2.11	2.54	2.60	2.69	2.68	2.65	1.74	1.81	1.85	1.93	2.00

Table 3

Trend statistics for Ellenberg indicator values (the Mann-Kendall test) (1994-2006)

Location	**Ellenberg's value**					
	Light	**Temperature**	**Continentality**	**Moisture**	**Reaction**	**Nitrogen**
Brušviti	**-1.96**	0.98	**1.95**	**-2.45**	**1.97**	**2.45**
p	0.025	0.163	0.025	0.007	0.025	0.007
Peši	-.076	0.25	1.47	**1.96**	**1.77**	0.98
p	0.224	0.400	0.071	0.025	0.039	0.164
Taurene	-1.57	-1.47	**2.27**	0.00	0.00	1.47
p	0.059	0.071	0.012	-	-	0.071

Changes in species' frequency correlate with the dynamics of Ellenberg indicator values. The most intensive changes in Ellenberg indicator values have taken place in Brušviti, and it can be explained by the recent fire event.

All the monitoring sites experience a slow increase in nitrogen and reaction figures. The indicators of this process are the increase in frequency of *Vaccinium myrtillus, Scleropodium purum,* and *Cirriphillum piliferum*, and the decrease in frequency of *Vaccinium* *vitis-idaea, Calluna vulgaris, Dicranum scoparium*. Common feature for all sites is also the decrease in light figures.

Moisture figures show an increasing trend in Peši (species as *Sphagnum capilifolium, Molinia caerulea,* and *Vaccinium uliginosum* increase) and a decreasing trend in Brušviti, although these sites are in a couple of kilometers distance from one another. A possible reason for the drying of upper soil layer could be the dense turf development of *Deschampsia flexuosa.* Such processes are observed in pine forests of Germany (Heinsdorf, 1967).

To conclude, oligotrophic and light demanding pine forest species have decreased in all the monitoring sites during the 12-year period. They are *Calluna vulgaris, Festuca ovina, Vaccinium vitis-idaea, Dicranum scoparium,* etc. The frequency of several mesotrophic species has increased, for example, *Picea abies, Vaccinium myrtillus, Maianthemum bifolim, Cirriphillum piliferum, Brachythecium oedipodium* (Fig. 3, 4.).

Changes in species' frequencies can be attributed both to eutrophication and natural aging of forest. An increase in *Maianthemum bifolium, Trientalis europaea, Hylocomium splendens,* and *Dicranum polysteum,* with the age of a stand is reported from the southern Finland pine forests (Nieppola, 1992). An increase in *Scleropodium purum, Picea abies,* and *Vaccinium myrtillus* in NE Germany from 1965 to 1998 is explained as the effect of natural eutrophication process of stand's development (Zerbes, Brande, 2003). All the mentioned species (with the exception of *Dicranum polysetum* that has decreased significantly) have increased in Taurene and Rucava. *Deschampsia flexuosa* is often reported to be an indicator of nitrogen deposition (Heinsdorf, 1967; Falkengren-Grerup, 1989, 1990; Hofmann et al., 1990; Tamm, 1991; Rodenkirchen, 1993; Brunet et al., 1998; Bobbink et al., 1998; van Dobben et al., 1999); this species has increased significantly in the Brušviti site. On the other hand, *Dicranum polysetum, Chamaerion angustifolium, Rubus idaeus,* and *Dryopteris carthusiana* are also the species reported as indicators of eutrophication (Mäkipää, 1994; Bobbink et al., 1998), however, in our case they do not show any significant increase in frequency.

DCA ordination separately for each site (using all 3 x 3 m squares from all the observation years) showed that overall vegetation heterogeneity was quite low – the length of gradient was less than 2 standard deviations in the ordinations of Peši and Taurene data sets and 2.8 standard deviations in the ordination of the Brušviti site. The ordination revealed both the inner heterogeneity among plots (in each site there were three plots: A, B, and C) and temporal vegetation dynamics. The ordination of Brušviti site is shown in Fig.5 for illustration.

In the Brušviti site the plot B was quite different from plots A and C – Ellenberg indicator values showed that it is less nutrient-rich, with less species' diversity and with better light conditions. DCA ordination of the Peši site showed that the inner heterogeneity of 30 x 30 m squares was not as pronounced as in the Brušviti site. Plots B and C were very similar to each other, but plot A differed a little in nutrient availability. DCA ordination of the Taurene site revealed the same pattern as in the Peši site. Two plots were quite similar (A and

B) but the C plot was different from others. It supported less dwarf shrubs (*Vaccinium vitis-idaea, V. myrtillus, Calluna vulgaris*) but more herbs which are less light-demanding but with higher requirements for nutrient availability (*Luzula pilosa, Pteridium aquilinum*). Light conditions were the best in plot B, but nutrient availability in plot C. For all the ordinations the first axis can be interpreted as nutrient gradient – the correlation of the first axis was the highest with Ellenberg indicator value of nitrogen (Table 4).

Temporal vegetation dynamics (expressed as the correlation between years of observation and ordination axes) was the most pronounced at the Brušviti site, less at the Peši site and very weak at the Taurene site. Nevertheless, there was significant displacement of squares along the first and second axis in all the sites and in the Peši site also along the third axis in the course of time (Table 5).

The displacement along axis was associated with increased nitrogen values and, in a smaller extent, with moisture, reaction, and species' diversity values and decreased light values along these axes in all the three sites (Table 4).

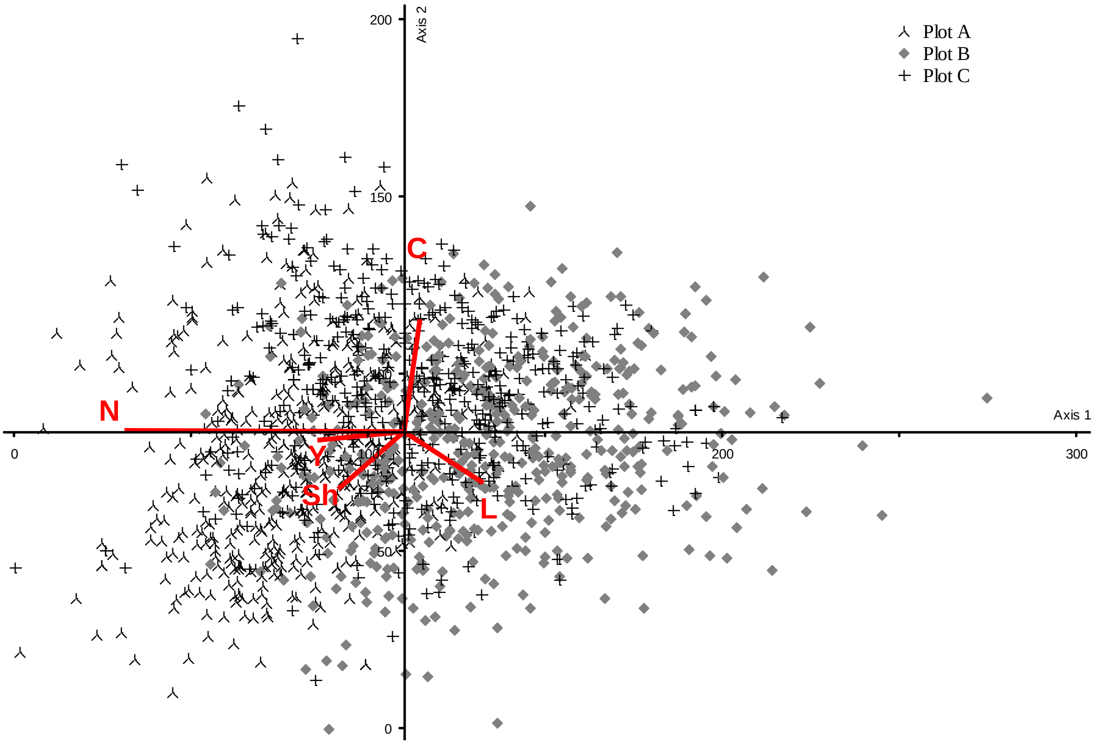


Fig. 5. DCA ordination of the Brušviti site (individual 3 x 3 m squares in all the observation years are used). Sh – Shannon-Wiener index, Y – observation year, Ellenberg indicator values: L – light, C – continentality, N – nitrogen.

Table 4

DCA ordination parameters and Spearman rank correlations with axes and site variables for three ordinations using 3 x 3 squares (for each site n = 1500; * p = 0.01)

Variables	**Brušviti**			**Peši**			**Taurene**		
	Axis 1	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Eigenvalue	0.13	0.09	0.07	0.09	0.08	0.07	0.17	0.12	0.11
Length of gradient	2.75	1.36	1.43	1.20	1.71	1.31	1.28	1.67	1.17
Total inertia	0.85			1.00			3.10		
r^2 between original and ordination space	0.60			0.39			0.43		
Correlations with axis									
Y – year of observation	**-0.40***	-0.14*	-0.22*	**0.27***	0.07*	0.27*	0.09*	**0.19***	-0.10*
Sh – Shannon index	-0.31*	**-0.37***	0.19*	0.24*	0.10*	-0.17*	0.05	-0.21*	0.04
Sp – number of species	**-0.31***	-0.14*	0.18*	0.11*	0.17*	-0.21*	0.28*	-0.08*	-0.01
L – light	**0.35***	-0.23*	0.07*	-0.21*	-0.08*	**0.32***	**-0.62***	**-0.40***	0.05
T – temperature	-0.01	-0.14*	0.12*	-0.04	**0.43***	-0.25*	-0.35*	-0.33*	-0.04
C – continentality	0.21*	**0.43***	-0.25*	-0.21*	0.06*	0.16*	0.28*	**0.36***	-0.22*
M – moisture	-0.19*	-0.26*	**0.28***	0.26*	-0.01	-0.21*	**0.43***	0.08*	-0.26*
R – reaction	**-0.29***	-0.25*	-0.22*	0.19*	0.12*	0.14*	**0.48***	0.11*	-0.04
N – nitrogen	**-0.69***	0.01	0.23*	**0.38***	0.24*	**-0.41***	**0.50***	0.12*	0.02

Table 5

Median change of the scores of squares in DCA ordination for three monitoring sites in different years (Wilcoxon signed rank test, n = 100 for each site)

DCA axis	Years	Brušviti			Peši			Taurene		
		change (in S.D.	Test statistics (Z)	P value	change (in S.D.	Test statistics (Z)	P value	change (in S.D.	Test statistics (Z)	P value
1	1994-1997	-0.23	-13.37	0.001	0.06	-6.40	0.001	-0.04	-4.22	0.001
1	1994-2000	-0.31	-13.98	0.001	0.15	-12.25	0.001	0.00	-0.42	0.670
1	1994-2003	-0.40	-14.83	0.001	0.15	-10.80	0.001	0.04	-2.62	0.009
1	1994-2006	-0.46	-14.87	0.001	0.19	-12.67	0.001	0.03	-2.16	0.031
2	1994-1997	-0.07	-6.23	0.001	0.05	-4.24	0.001	0.02	-2.73	0.006
2	1994-2000	-0.12	-9.71	0.001	0.05	-3.67	0.001	0.07	-6.65	0.001
2	1994-2003	-0.12	-8.73	0.001	0.06	-3.95	0.001	0.16	-6.31	0.001
2	1994-2006	-0.09	-6.97	0.001	0.06	-3.70	0.001	0.18	-6.07	0.001
3	1994-1997	0.00	-0.07	0.94	0.07	-7.48	0.001	0.00	-0.34	0.740
3	1994-2000	0.06	-5.79	0.001	0.09	-8.19	0.001	0.00	-1.14	0.260
3	1994-2003	0.13	-9.25	0.001	0.19	-11.92	0.001	-0.02	-3.23	0.001
3	1994-2006	0.12	-8.53	0.001	0.18	-12.76	0.001	-0.01	-2.05	0.041

Vegetation dynamics and environmental factors

The ordination revealed that there is a significant temporal gradient in vegetation dynamics during the 12-year period in pine forests. This gradient is more pronounced in Rucava than in Taurene and shows that forest vegetation changes from light- and nutrient-poor forests with low species' diversity to more nutrient-rich, species-diverse and closed forest with better moisture conditions. It is proved both by the changes in species' abundance in the course of time and by the changes of Ellenberg indicator values of nitrogen and reaction.

Tree and shrub layer is the least dynamic sinusia of forest community. A common feature is an increase in abundance of *Picea abies* and a decrease in *Pinus sylvestris*; it is more pronounced in Taurene and Peši than in Brušviti. Ground layer experiences gradual replacement of *Calluna vulgaris* and *Vaccinium vitis-idaea* by *Deschampsia flexuosa* in Brušviti, *Vaccinium myrtillus* in Taurene (*Deschampsia flexuosa* is not present at all), and both species in Peši.

However, it is hard to say whether the temporal gradient of vegetation observed in this research is caused by air pollution, climate warming, or it is the consequences of natural vegetation dynamics. There is a very slight increase in Ellenberg nitrogen figures in 12 years – from 0.04 degrees in Taurene to 0.26 degrees in Brušviti. This increment is even less than the spatial differences in mean nitrogen figures among the plots in the first observation year – mean nitrogen value vary among plots A, B, and C by 0.42 degrees in Brušviti, 0.26 degrees in Peši and 0.13 degrees in Taurene. Moreover, atmospheric nitrogen deposition that has been emphasized as the main factor of eutrophication in many studies (Falkengren-Grerup, 1986; Brunet et al., 1998; Kuhn et al. 1987, etc) has decreased both in Rucava and Taurene during the observation period (Terauda, Nikodemus, 2007). Eutrophication effect on boreal forest ground vegetation is reported from sites with about 15 to 40 kg $ha^{-1}y^{-1}$ of atmospheric deposition of nitrogen. These figures are only 5-10 kg N $ha^{-1}y^{-1}$ in Latvian monitoring sites. Some species do respond to such low amount of deposition, for example, *Deschampsia flexuosa* (Bobbink et al., 1998), but it seems that atmospheric nitrogen deposition in Latvian monitoring sites is still less than the critical load inducing substantial changes in forest vegetation. There are no precise data on critical nitrogen loads on boreal forests but it is assumed by expert judgment that it is about 10-15 kg N $ha^{-1}y^{-1}$(Bobbink et al., 1998). On the other hand, increase in soil reaction is reported to have an indirect positive effect (improved biological activity of the humus) on eutrophication process (Becker et al., 1992). In both monitoring stations in Latvia, an increase in Ellenberg reaction value has been observed.

Climate warming is reported to intensify the eutrophication process in boreal and temperate forests (Luxmoore et al., 1993; Bytnerowicz et al., 2007). In Latvia, climate has become warmer during the last centuries and especially during the last 60 years (Lizuma et al., 2007 (this issue)), thus the observed eutrophication of pine forests could also be explained by the influence of climate warming.

Forest spatial heterogeneity also is an important aspect in the interpretation of ordination results. In our data the first ordination axis correlated with factors governing both spatial (inner plot heterogeneity in edaphic conditions) and temporal (changes in years) differences inside each site. It is suggested that the axis with the highest eigenvalue is the most important in revealing ecological gradients in data (Jongman et al., 1995). The strongest correlation with the first axis was for Ellenberg values of edaphic factors such as nitrogen and reaction, and less close correlation was with the time scale. Therefore we can conclude that inner vegetation heterogeneity in plots is more pronounced than the directed changes in the course of time.

Our results are in accordance with the findings of other researchers. For example, Grandin (2004) has shown that with short time series (about 15 years) inner heterogeneity of vegetation plots can be of greater importance in the explanation of variance in ordination analysis than a temporal trend. Several authors emphasize that boreal forests are very heterogeneous on a small spatial scale because of a distinct microrelief and the patchy structure of vegetation (e.g., Grandin, 2004).

The pine forest ecosystems in both monitoring sites are still not mature. That means that natural vegetation dynamics toward a mature pine forest is taking place. As the natural changes in the vegetation of such forests lead to the same changes in flora and vegetation as eutrophication does (Becker et al., 1998), it is not possible to separate both influences in this research.

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Appendix 1. Values of z-test ($z_\alpha > z_{0.05} > 1.96$) for the differences in species' frequency between 1994 and 2006, (+) – species' frequency increases, (-) – species' frequency decreases.

Species	Monitoring site		
	Brušviti	Peši	Taurene
Trees and shrubs			
Betula pendula	0.24 (+)	1.91 (-)	**2.71 (-)**
Corylus avellana	-	0.45 (-)	-
Frangula alnus	-	**2.52 (+)**	0.92 (-)
Picea abies	0.72 (+)	**3.68 (+)**	1.74 (+)
Pinus sylvestris	1.09 (-)	0.34 (-)	1.66 (-)
Populus tremula	-	1.15 (-)	1.01 (-)

Quercus robur	0.26 (+)	1.64 (+)	0.40 (-)
Salix cinerea	-	1.42 (-)	1.01 (-)
Sorbus aucuparia	-	1.63 (+)	0.79 (+)
Herbs and dwarf shrubs			
Agrostis tenuis	-	1.15 (-)	1.01 (-)
Calamagrostis arundinacea	-	1.25 (-)	-
Calamagrostis epigeios	-	1.75 (-)	-
Calluna vulgaris	**9.10 (-)**	**5.84 (-)**	**5.47 (-)**
Carex ericetorum	-	1.01 (-)	1.01 (-)
Carex pilulifera	-	0.00	-
Chamaerion angustifolium	-	0.34 (-)	1.01 (+)
Convallaria majalis	-	1.42 (+)	-
Deschampsia flexuosa	**2.71 (+)**	-	-
Dryopteris carthusiana	-	0.82 (-)	**2.26 (-)**
Empetrum nigrum	1.28 (-)	0.00	-
Epipactis helleborine	-	0.00	-
Festuca ovina	-	**3.52 (-)**	**4.27 (-)**
Festuca rubra	-	1.42 (+)	-
Goodyera repens	-	-	**8.32 (+)**
Hieracium vulgatum	-	0.45 (-)	-
Lathyrus sylvestris	-	0.45 (-)	-
Luzula pilosa	-	**5.57 (-)**	**5.78 (-)**
Lycopodium annotinum	-	1.01 (+)	1.42 (-)
Lycopodium clavatum	-	2.56 (-)	-
Maianthemum bifolium	-	**9.32 (+)**	0.51 (+)
Melampyrum pratense	**5.15 (+)**	1.28 (-)	**6.79 (-)**

Molinia caerulea	-	1.15 (+)	-
Monotropa hypopitys	1.42 (-)	1.01 (-)	-
Orthilia secunda	-	1.01 (-)	-
Pteridium aquilinum	-	**3.32 (+)**	0.00
Pyrola chlorantha	-	1.91 (+)	-
Rubus idaeus	-	1.01(-)	-
Rumex acetosella	-	-	1.01 (+)
Solidago virgaurea	-	0.72 (-)	0.00
Trientalis europea	-	**8.37 (+)**	1.43 (-)
Vaccinium myrtillus	**6.90 (+)**	**5.04 (+)**	0.34 (+)
Vaccinium uliginosum	0.40 (+)	1.42 (+)	0.34 (-)
Vaccinium vitis-idaea	0.54 (-)	**7.16 (-)**	0.92 (-)
Vicia cassubica	-	1.01 (+)	-
Mosses and lichens			
Aulacomium palustre	**2.26 (+)**	**2.34 (-)**	0.58 (-)
Brachythecium oedipodium	**4.20 (+)**	**4.52 (+)**	**6.43 (+)**
Cirriphillum piliferum	**3.81 (+)**	**13.56 (+)**	**2.67 (+)**
Cladina arbuscula	**3.10 (-)**	-	-
Cladina rangiferina	0.16 (-)	1.01(-)	1.76 (-)
Cladina stellaris	**2.26 (-)**	-	-
Dicranum polysetum	0.00	**8.73 (-)**	**3.58 (-)**
Dicranum scoparium	**7.07 (-)**	**3.82 (-)**	**9.03 (-)**
Hylocomium splendens	**8.03 (+)**	1.83 (+)	0.00
Hypnum jutlandicum	**2.86 (+)**	-	-
Lophocolea heterophylla	-	-	1.01 (+)

Pleurozium schreberi	1.42 (+)	1.01 (-)	0.00
Pohlia nutans	-	-	1.01(-)
Polytrichum formosum	-	0.58 (-)	1.01 (+)
Polytrichum juniperinum	**3.04 (+)**	0.58 (+)	1.75(-)
Ptilidium ciliare	0.82 (-)	-	-
Ptilium cirsta-castrensis	1.75 (+)	**2.81 (-)**	**3.85 (+)**
Rhytidiadelphus triquetrus	-	1.01 (+)	1.01 (+)
Scleropodium purum	**13.58 (+)**	**6.40 (+)**	-
Sphagnum capilifolium	-	0.26 (+)	-
Sphagnum girgensohnii	-	-	1.01 (+)

Phenological Time-series in Latvia as Climate Change Indicators

In this study long-term time-series of phenological (timing of seasonal events) records are used to assess the impact of climate change on Latvia‘s nature.

Records were obtained for 1928-1939 and 1959-2004 from three observation points for the beginning of the flowering of the bird-cherry *Padus racemosa*, linden *Tilia cordat,* and the beginning of leaves’ colouring of the birch *Betula pendula.* For the period 1971-2000, data regarding leaf development, colouring of leaves, and leaves’ fall also were obtained for eight species (alder *Alnus incana*, aspen *Populus tremula*, red currant *Ribes rubrum*, maple *Acer platanoides*, dandelion *Taraxacum officinale*, ash *Fraxinus excelsior,* rowan *Sorbus aucuparia*, lilac *Syringa vulgaris)* at eight observation points.

The beginning of spring and summer phases have shifted by 4 days earlier over the last 50 years. The most recent changes were observed for early spring phases. The beginning of flowering of the alder *Alnus incana* has advanced by 1.1days per year (33 days during 1971-2000). The length of the growing season for birch *Betula pendula* and maple A*cer platanoides* has increased during the past 30years on average for 14 days.

Key words *phenology, climate change, phenological trends, time series, growing season.*

Introduction

Phenology is the study of the seasonal timing of biological events such as leaf unfolding, flowering of plants in spring, fruit ripening, leaf colour changing and fall in autumn as well as the annual migration of birds and animals, and timing of animal breeding (Lieth 1974, Koch 2005). Phenological information is important in monitoring all aspects of ecosystems in agricultural, medicine, forestry, and tourism and wildlife management (Beaubien and Hall-Beyer 2000). Phenology has deep and long-standing traditions as the study of plant and animal seasonal rhythms (Menzel 2000). As phenological rhythms are closely related to climate, phenological phases can play a role of climate change indicators. Phenology is probably the simplest and most cost effective means of observation of the effects of changes in temperature, consequently, phenology has become an important tool in the research of global climatic change (Koch 2005).

The origin of phenology can be traced back to ancient society, but the oldest existing (and still on-going) phenological monitoring record is in Japan: the flowering of a cherry tree has been observed and recorded since 705 A.D. In Europe the oldest time series is the ripening of a grape in France, dating back to 1370 (Koch 2005). In the Baltic States the longest phenological data series have been reconstructed for rye harvest, dating back to the 17th century in Estonia (Ahas 1999). In Latvia the first observations started in 1822.

Many studies in the entire world have shown significant changes of onset of phenological phases during the 20th century. For example, in Europe spring events such as leaf unfolding, have advanced on average by 6.3 days (-0.21 days per year), while autumn events, such as leaf colouring, have been delayed by 4.5 days (0.15 days per year). Altogether the average annual growing season has been prolonged by 10.8 days since the early 1960s (Menzel 2000). In western Canada, aspen poplar *Populus tremuloides* has shown a 26-day shift to earlier blooming over the last century (Beaubien and Freeland 2000). In Estonia, onset of spring has advanced for 8 days over the last 80 years with a faster change during the last 40 years (Ahas et al. 2000). In Lithuania phenological spring at the end of the 20th century started 8-16 days earlier than in the late 70-ties (Romanovskaja 2004).

This study investigates long-term phenological time series over the 20th century to assess the impact of climate change in Latvia.

Materials and Methods

Phenological Database

Phenological changes in Latvia during the last century are described using observation data collected by a volunteer network. Phenological data were taken from the annual *Calendar of Nature and History* (*Dabas un vēstures kalendārs) (*from 2005 *Nature and History)* and were digitized for the period of 1973-2006, from *Phenological Bulletins* (*Fenoloģiskais biļetens),* 1959 to 1972, and from *Phenological Booklets* (*Fenoloģiskais buklets),* 1927 to1939.

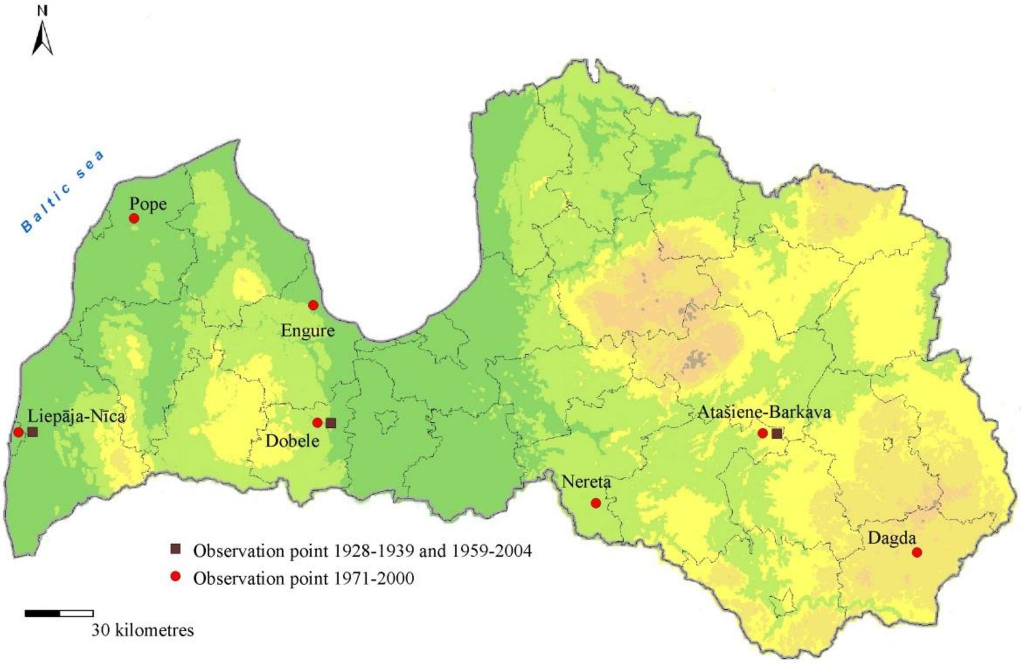

Fig. 1. *The Location of observation stations used in this study.*

The number of observation points varies from year to year and there are gaps in the data series as well. For this study we selected data from 8 observation points (Fig. 1); at three of these the data series of several observers from nearby points were combined: Aizpute–Snēpele, Atašiene–Barkava, Liepāja–Nīca.

For the periods 1928-1939 and 1959-2004, records were obtained from Dobele, Liepāja-Nīca and Atašiene-Barkava for the beginning of the flowering of the bird-cherry *Padus racemosa*, linden *Tilia cordata* and the beginning of leaf colouring of the birch *Betula pendula*.

Data for the beginning of leafing, flowering, colouring and fall of leaves for eight species: the alder *Alnus incana*, aspen *Populus tremula*, red currant *Ribes rubrum*, maple *Acer platanoides*, dandelion *Taraxacum officinale*, ash *Fraxinus excelsior*, rowan *Sorbus aucuparia*, lilac *Syringa vulgaris* and the growing season of the birch *Betula pendula* and maple *Acer platanoides* were available for a 30-year period (1971-2000).

The phenological dates given refer to the Julian day (day of the year). Climatic data for the years 1927-2004 are obtained from Latvian Environment, Geology and Meteorology Agency.

Methods

Taking into account the possibility of data subjectivity, data were manually checked and outliers were excluded from the data rows.

For the study of time series we used the following analytical tools-one factor regression, correlation analyses and non-parametric *Mann – Kendall* test analyses.

The main statistical parameter drawn from the regression analysis, the slope, indicates the mean temporal change (days per year) of the studied variable.

The Mann-Kendall test is a non-parametric test which does not require the data to be distributed normally. It is not sensitive to abrupt breaks due to inhomogeneous time series, which are characteristic for phenological records (Libiseller and Grimvall 2002).

The main idea of the Mann-Kendall test for trends is to determine the sign of all pair-wise differences between the consecutive elements of time series, while each of them is compared with all previous values of the time series. The test statistic is near zero when the number of positive and negative differences is more or less equal. There is an increasing trend if the test statistic is positive, i.e., the number of positive differences is significantly higher than the number of negative differences, and vice versa.

The result was considered to be statistically significant if the value of the normalised test statistic was +/- 2, with a p-value less than 0.001.

Results and Discussion

The long-term phenological time series for the beginning of flowering of the bird cherry *Padus racemosa*, linden *Tilia cordata* and the beginning of leaves' colouring of the birch *Betula pendula* during the periods 1928-1939 and 1959-2004 indicated negative trends.

The long-term average for the beginning of the flowering of the bird-cherry *Padus racemosa* was on May 13, the flowering of linden *Tilia cordata* on July 13, and the leaves' colouring of the birch *Betula pendula* on September 21.

The flowering phase has advanced by 1.6 days per decade for the bird cherry and 0.9 days per decade for the linden.

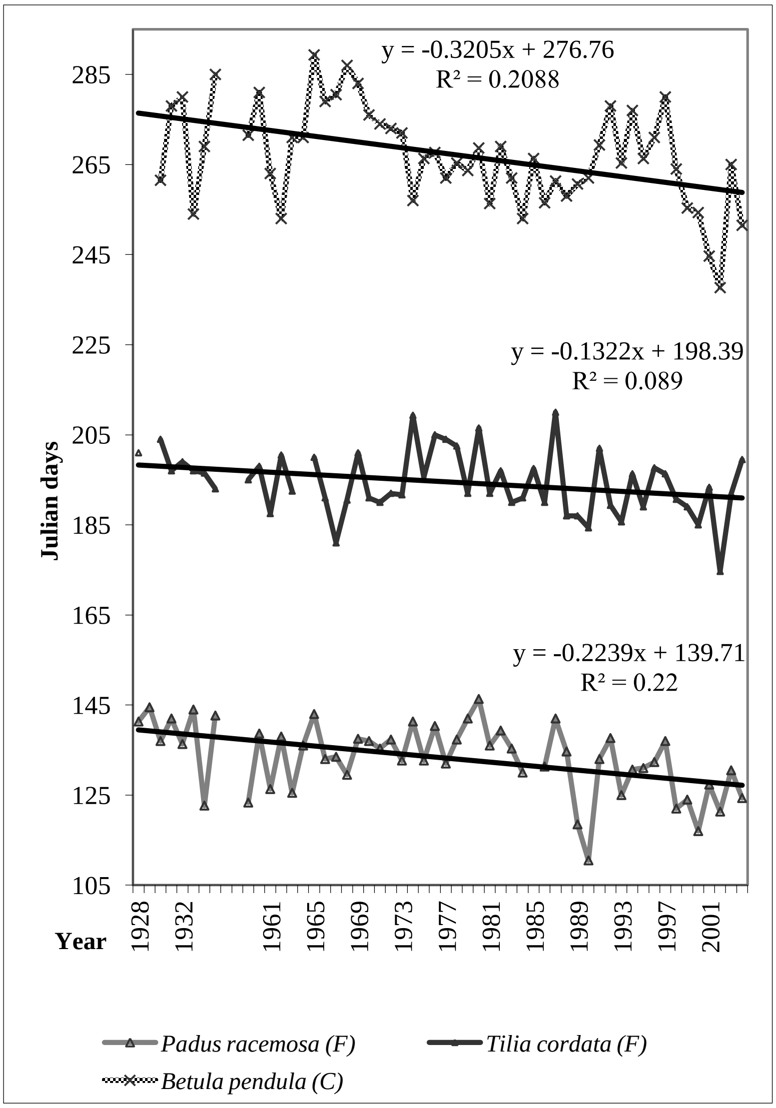

Fig. 2. *Long term phenological changes for the beginning of the flowering of the bird cherry Padus racemosa, linden Tilia cordata and the beginning of leaves' colouring of the birch Betula pendula during 1928-1939 and 1959-2004 for three stations.*

The autumn phases in Latvia start earlier by 2.8 days/decade, in contrast to Europe, where autumn phases start later. The *Mann-Kendall* test demonstrated that the trends of earlier onset of phenological phases are mostly statically significant and negative.

Table 1. *The Mann-Kendall test statistic for phenological changes*

Observation point	**Beginning of flowering** *Padus racemosa*		**Beginning of flowering** Tilia cordata		**Beginning of leave's colouring** *Betula pendula*	
	Normalised test statistic	p-value	Normalised test statistic	p-value	Normalised test statistic	p-value
Atašiene-Barkava	**-2.72**	**0.003**	-0.189	0.425	**-2.11**	0.017
Dobele	**-3.01**	**0.001**	-1.708	0.044	**-2.00**	0.022
Liepāja-Nīca	-1.65	0.049	**-2.547**	**0.005**	**-3.21**	**0.0007**

Significant statistics are marked in bold

The phenological appearance dates of the species differed by over 35 days in a year in spring and summer, 52 days in autumn.

In Dobele, which is situated in the southern-central part of Latvia, the average date of the beginning of the bird cherry flowering is April 20. The earliest date of the flowering of the bird cherry *Padus racemosa* was recorded in 1990 – the beginning of the flowering of bird cherries was 22 days earlier than on average. The latest date in the periods 1928-1939 and

1959-2004 was registered in 1987, on May 30 in Liepāja-Nīca observation point, located nearby the Baltic Sea coast.

The beginning of the flowering of the linden *Tilia cordata* is on average July 13, and the latest date recorded was in Atašiene–Barkava in 1974, when a linden flowered only on August 9 (28 days later than the average). In 1992 a linden flowered 21 days earlier than the average (Dobele, June 19).

The earliest date of leaves' colouring of the birch *Betula pendula* was August 17 in 2002 (Atašiene-Barkava), more than a month before the average. The latest date was October 20 in 1965 (Liepāja-Nīca).

The earliest extreme values of spring and autumn were all recorded during the last 15 years.

Since 1971, most of the changes have been observed for early spring phases, for example, the beginning of the flowering of the alder *Alnus incana* has advanced by 1.1days per year, 33 days for all the period (Table 2). For the red currant *Ribes rubrum*, the beginning of leaf unfolding has advanced by 5.6 days per decade, ripening by 3.5 days per decade.

***Table 2**. The average, latest and earliest phenological appearance dates and changes for eight species in the period 1971- 2000 (average values from eight observation points).*

Species	Phase	Average date	Earliest date	Latest date	Deviation (days/30year period)
Alder *Alnus incana*	F	25.03.	30.01.	27.04.	-33
Aspen *Populus tremula*	F	19.04.	23.02.	21.05.	-0,5
Red currant *Ribes rubrum*	L	27.04.	18.03.	19.05.	-16,9
Birch *Betula pendula*	L	01.05.	01.04.	21.05.	-15,9
Maple *Acer platanoides*	L	01.05.	01.04.	21.05.	-16,9
Birch *Betula pendula*	F	06.05.	12.04.	01.06.	-11,1
Red currant *Ribes rubrum*	F	09.05.	09.04	30.05.	-15,3
Maple *Acer platanoides*	F*	11.05.	03.04.	28.05.	-4,2
Dandelion *Taraxacum officinale*	F	11.05.	12.04.	03.06.	-12,3
Ash *Fraxinus excelsior*	L*	20.05.	04.05.	04.06.	-0,1
Rowan *Sorbus aucuparia*	F	27.05.	06.05.	22.06.	-8,7
Red currant *Ribes rubrum*	R	15.07.	23.06.	19.08.	-10,6
Maple *Acer platanoides*	C	19.09.	24.08.	15.10.	-1,3
Birch *Betula pendula*	C	20.09.	20.08.	25.10.	-1,8
Aspen *Populus tremula*	C	28.09.	01.09.	26.10.	-0,4
Maple *Acer platanoides*	LF	02.10.	06.09.	29.10.	1,3
Lilac *Syringa vulgaris*	C*	05.10.	31.08.	29.10.	-21,2
Birch *Betula pendula*	LF	05.10.	01.09.	10.11.	-2,45

Aspen *Populus tremula*	LF	08.10.	07.09.	29.10.	-0,03

F - beginning of flowering; L - beginning of leafing; R - advanced ripening; C - colouring of leaves; LF - leaves' fall; *1971-1987

The colouring of leaves of the studied plant species has advanced 1-2 days per 30 years, and leaves' fall has advanced 0.5-2.4 days for the whole period (except maple –1.3 days per 30 years).

For the studied period, the average length of the growing season, which was defined as the time between leaf onset and leaf fall, was 157 days for the birch *Betula pendula*, and 155 days for the maple *Acer platanoides*. On average the growing season for the maple and birch starts on May 1 and ends on October 5 and October 2, respectively. In comparison to European phenological gardens (1959-1999) it is evident that the growing season has prolonged by 10.8 days on average (Menzel 2000). At the same time Chmielewski and Rotzer (2001) noted that growing seasons end by 0.1 day per 10 years earlier in the Baltic region, 0.4 days per 10 years earlier in the British Isles, in contrast to Europe where the end of the growing season has retreated 2.4 days per 10 years.

Similar to the observations in Europe (Chmielewski and Rotzer 2002), in Latvia the earliest dates of leafing (the beginning of the growing season) were recorded in 1990, when the growing season for the birch and maple started on average 20 days earlier. The longest growing period in Latvia was recorded in 1994 for the birch (175 days), in 1989 for the maple (172 days), and the shortest in 1989 (138 days) and 1978/1979 (142 days), respectively (Fig.3.).

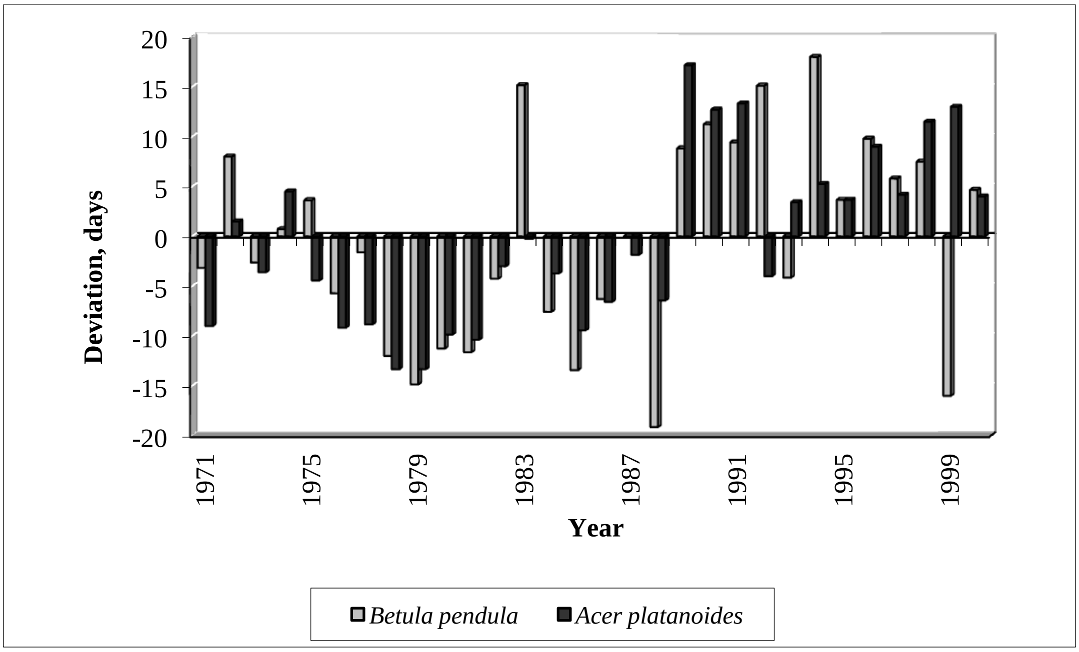

Fig. 3. The deviation of the average length of the growing season (1971-2000). Mean values for 8 observation sites.

In general, the trend of an increasing growing season is positive by 9.8 days (3.3 days per decade) on average for the birch *Betula pendula* and 18.5 days (6.2 days per decade) for the maple *Acer platanoides*, which is mostly due to the early onset of spring phases. For example, the beginning of the leafing of the birch *Betula pendula* has advanced by 16 days per 30 years. In our study, the greatest changes in the prolongation of the growing season occurred after 1988.

Phenological appearance dates are mainly induced by meteorological conditions, mostly by an increased temperature. Using data from the International Phenological Gardens for the period 1969–1998 across Europe, Chmielewski and Rotzer (2001) noted that a warming by 1°C in early spring (February–April) induced the beginning of the growing season 7 days earlier. Phenological studies in Europe (Menzel 2000, Ahas et al. 2002, Sparks 2000) have shown that spring phases have started earlier by about 8 days during the last 30 years.

In our study a strong correlation between spring phases and air temperature of the previous month were found. An increase in the mean air temperature in April by 1ºC, is associated with an earlier flowering of 2.6 days of the red current *Ribes rubrum* in May, and an earlier flowering of 3.4 days of the dandelion *Taraxacum officinale*. Linear regression analyses showed a strong negative correlation (R -0.79…-0.46) for earlier spring phase. For autumn phases a higher air temperature leads to a later autumn. Overall the found correlation coefficients for autumn phases and temperature are weaker.

The correlations showed that the influence of precipitation on phenological phases differs for seasons and species. Significant correlation coefficients are found for earlier species (for example, *Alnus incana*) of spring phases, but there is no linkage or it is very weak between the development of phenological phases and precipitation in summer and autumn. This fact could also be an indicator that precipitation is not a limiting factor for the development of phenological phases.

Table 3. *Correlation between phases and the average temperature of a previous month (T_{pm}) and precipitation (P_{pm})*

Species	**Phase**	**Average value**	**R** (T_{pm})	**R** (P_{pm})
Alder *Alnus incana*	F	25.03.	**-0,65**	**-0,47**
Aspen *Populus tremula*	F	19.04.	**-0,46**	-0,19
Red currant *Ribes rubrum*	L	27.04.	**-0,66**	-0,14
Birch *Betula pendula*	F	06.05.	**-0,67**	**0,30**
Red currant *Ribes rubrum*	F	09.05.	**-0,79**	0,20

Dandelion *Taraxacum officinale*	F	11.05.	**-0,74**	0,05
Rowan *Sorbus aucuparia*	F	27.05.	-0,06	-0,27
Red currant *Ribes rubrum*	R	15.07.	**-0,59**	0,08
Maple *Acer platanoides*	C	19.09.	**0,37**	-0,06
Birch *Betula pendula*	C	20.09.	**0,59**	-0,32
Aspen *Populus tremula*	C	28.09.	0,29	0,18
Aspen *Populus tremula*	LF	08.10.	**0,45**	0,07

F - beginning of flowering; L - beginning of leafing; R - advanced ripening; C - colouring of leaves; LF – leaves` fall. Most significant statistic are marked in bold

Conclusions

The results of linear regression analysis and the results of the Mann-Kendall test showed that spring and summer phases in Latvia occur on average 4 days earlier over the last 50 years. The most recent changes were observed for early spring phases; the beginning of the flowering of the alder *Alnus incana* is 1.1days per year earlier. The most significant shift has happened in the last 15 years.

This study showed that the colouring of leaves of the selected plant species has advanced 1-2 days per 30 years and leaves' fall 0.5-2.4 days for the whole period.

The length of the growing season, determined by the vegetation of birch and maple species, has increased by 9.8 days (3.3 days per decade) for the birch *Betula pendula* and 18.5 days (6.2 days per decade) for the maple *Acer platanoides.*

The study confirmed the relationship between temperature and the beginning of spring, summer, and autumn phenological phases. Spring phases are mainly induced by the temperature of the previous month, while the relationship with autumn phenological phases is weaker. A weak relationship was also discovered between precipitation and phenological phases, which indicates that precipitation in general is not a limiting factor for the beginning of phenological phases in Latvia.

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Long-term Assessment of Hydroecocystem of the River Salaca, North Vidzeme Biosphere Reserve, Latvia

The comparison of chemical and microbiological parameters of the River Salaca and quantitative and qualitative changes in bacterioplankton, phytoplankton and zoobenthos community since 1982 until now does not display substantial differences. The River Salaca is a stable ecosystem with high species diversity. Saprobity of the river corresponds to β-mesosaprobic level which is the background state for this type of big streams in Latvia. Cyanobacterial blooms during all the years of long-term assessment are observed in the outflow of the River Salaca due to the algal blooms in the origin of the river – the Lake Burtnieku.

The increasing growth of aquatic vegetation in recent years has been related to climatic factors – higher mean annual air temperatures and earlier springs. The absence and lowering of the ice cover during winters in recent years also causes changes in vegetation growth (a prolonged growing season).

Further investigations could enable the detection of the species which indicate climate change and the recognition of possible ecological impacts on the ecosystem of the River Salaca.

Key words: *the River Salaca, aquatic chemistry, bacterioplankton, phytoplankton, aquatic macrophytes, benthic invertebrates, saprobity.*

Introduction

The River Salaca (length 95 km) is situated in the North Vidzeme biosphere reserve (area 400 km^2), in the northern part of Latvia, in the eastern Baltic. It takes its origin from the eutrophic Lake Burtnieku (area 40 km^2) and flows in the Gulf of Rīga. The Salaca as the central watercourse combines all the impacts of the Salaca basin (3570 km). On the whole the river is little affected ecosystem, and an important salmon river not only for Latvia but also for the Baltic region.

However, the Salaca basin is variable in land use patterns, the number of inhabitants, and soil types. The dominance of podzolic soils is a typical feature of the River Salaca basin.

Forests and arable lands dominate the basin of the Salaca River and enclose the entire length of the river.

To retain the River Salaca as an unpolluted ecosystem with high biodiversity (the river is acknowledged as one of 150 most biologically diverse rivers in Europe) and to ensure a sustainable development of the river, long-term chemical and biological (plankton and benthos) surveys have been realised to assess the water quality and its changes.

Materials and Methods

Regular chemical and biological surveys of the Salaca River have been carried out during the period of vegetation since 1982 and are in progress until now. Regular sampling is carried out in three most characteristic sampling stations of the river. A non-regular sampling and assessment of macrophytes was carried out in eleven stretches on the entire length of the River Salaca (Fig. 1).

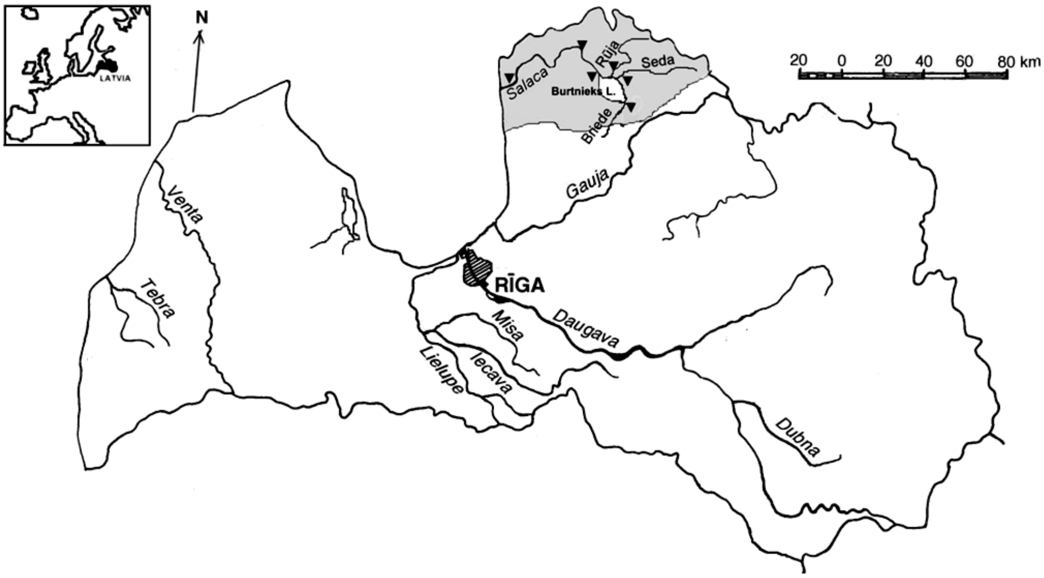

Fig. 1. The map of the basin of the River Salaca

The basic chemical data – COD, BOD_5, the level of nutrients and ionic composition in the water were analysed by standard methods (Standard Methods 1992; HACH 1992).

The total number of bacteria and the number of aerobic saprophytic bacteria in the water and sediment were assessed by applying the methods of freshwater microbiology (Standard Methods 1992).

For quantitative analyses phytoplankton samples were collected and examined according to standard methods (Standard Methods 1992). Phytoplankton samples were collected at 0.5 m depth with Ruttner type sampler and immediately fixed with the Lugol’s iodine solution. Phytoplankton taxa were identified and enumerated following the inverted microscope method of Utermőhl (1958). Algal biomass was established by means of the volume measure method comparing algal shapes of particular species and their individual volume. Live samples for qualitative species’ identification were taken with the help of 10 μm plankton net.

The studies of aquatic vegetation in the River Salaca have been performed during the vegetation period in 1986 and 2002 within 11 river stretches. The length of stretches was 1.5-17 km; it depends on the river bed material's homogeneity.

The macrophyte species, their frequency and coverage were estimated from a boat in 1986. Plant abundance was estimated according to the six-point scale established by Drudes (Anonymous 1975). Environmental variables of the each stretch, such as water depth, bottom material content, and stream velocity, were recorded. In 2002, the cover of submerged vegetation has been estimated for each stretch of river.

Samples of benthic macroinvertebrates were collected and analysed according to standard methods (Standard Methods 1992). Saprobic indices were calculated for zoobenthos communities according to Pantle and Buck (1955), modified for Latvian rivers (Cimdiņš *et al.* 1995).

Results

Long-term analyses of air temperature in the Salaca River basin show an increasing trend in annual mean air temperatures, especially the temperatures in spring months (Fig. 2).

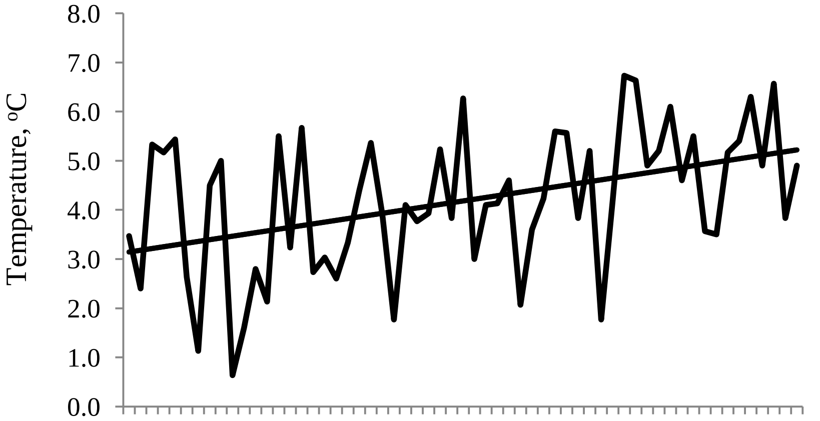

Fig. 2. Long-term trends of annual mean air temperatures in the basin of the River Salaca.

Trends of the long-term assessment of the River Salaca show an increase in water discharge in winter season and simultaneous decrease in water discharge in summer season (Fig. 3).

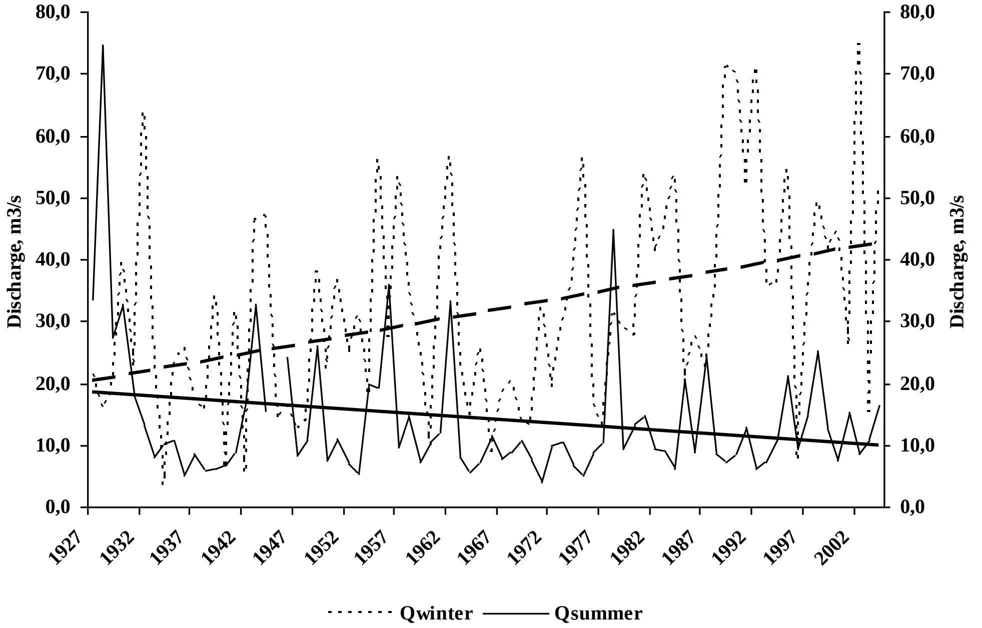

Fig. 3. Changes of the River Salaca discharge Q (m^3/s) during winter and summer seasons (mean monthly data from the sampling station Lagaste, 1927-2004).

The River Salaca, as the majority of surface waters in Latvia (35-44 %), belongs to the class of calcium group of hydrogencarbonates with a medium rate of mineralization (285.8 mg/l). The chemical composition of the upper part of the Salaca is determined by eutrophic Lake Burtnieku, the tributaries' basins of which are bogging-up (Briede *et al.* 1995), therefore the river's water is characterized by a comparatively high level of organic substances. Seasonal changes are typical of the River Salaca basin (Rodinov 1989), and a substantial difference in the main hydrochemical parameters – biogenous element concentrations, BOD_5, COD – has not been confirmed from 1982 to 2002 (Fig. 4).

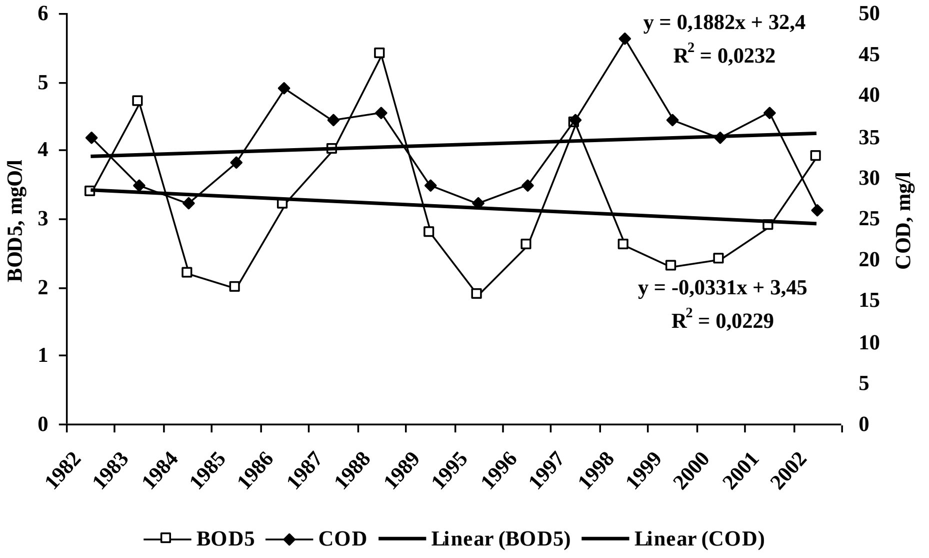

Fig. 4. Long term trends of BOD (mg/l) and COD (mg/l) observed in the outflow of the River Salaca.

In the outflow of the River Salaca a decrease in biogenic elements N and P was detected due to changes in land use patterns in the catchment area of Lake Burtnieku (Fig. 5).

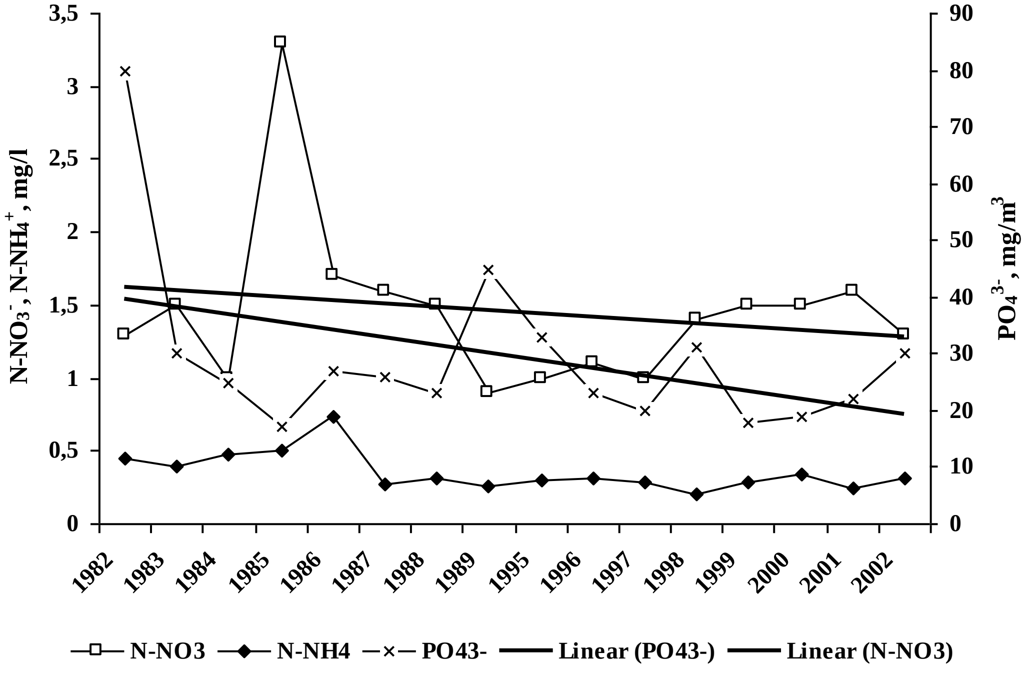

Fig. 5. Long term trends of biogenic elements (N, P) in the outflow of the River Salaca.

In general, in the water of the lower part of the River Salaca there are no marked trends of relevant decrease of $N\text{-}NO_3^-$ and $P\text{-}PO_4^{3-}$ (Fig. 6).

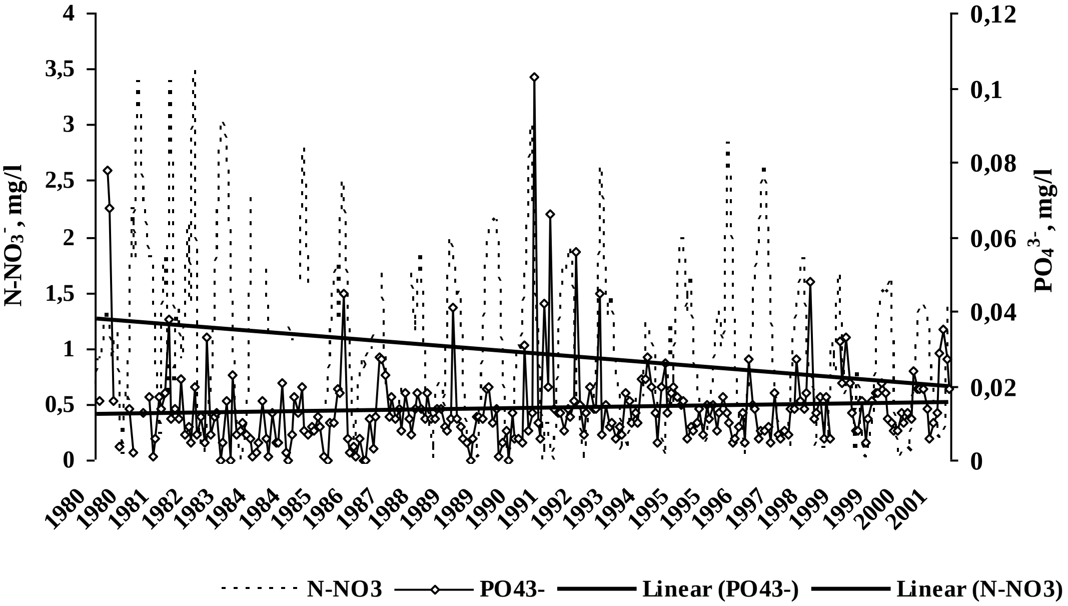

Fig. 6. Long term trends of the nutrients (mean monthly data, from LEGMA) in the lower Salaca.

Long-term observations show a minor decrease of COD in the lower Salaca (Fig. 7).

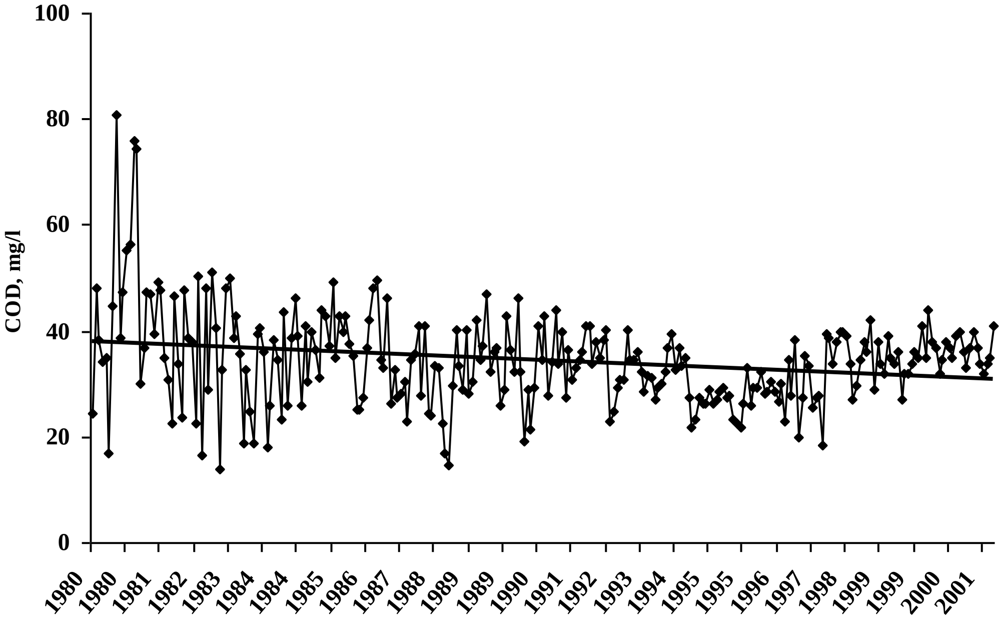

Fig. 7. Long term trends of COD in the lower Salaca (mean monthly data).

In the lower part the Salaca River, the water quality is better due to an increased stream velocity.

The investigations of microorganisms in the water and sediment of the Salaca that are carried out in the 80ies of the previous century reflect seasonal fluctuations typical of unaffected lotic systems (Melberga 1989).

The impact of the tributaries to the Salaca is insignificant, and an unsubstantial deviation from the background state typical of Latvian small streams (weekly polluted or *β*-mesosaprobic) was observed only in the upper and middle parts of the tributaries (Springe 1990). The number of aerobic heterotrophic bacteria (saprophytes) has not changed substantially in the water and sediment during the time period from 1995 to 2006 (Fig. 8, 9).

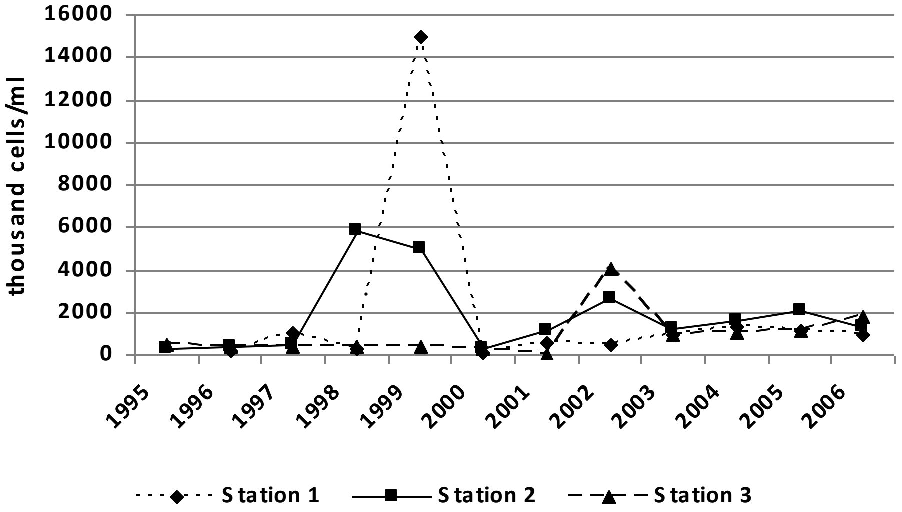

Fig. 8. The number of aerobic heterotrophic bacteria (saprophytes) in the water in the summer vegetation period from 1995 to 2006.

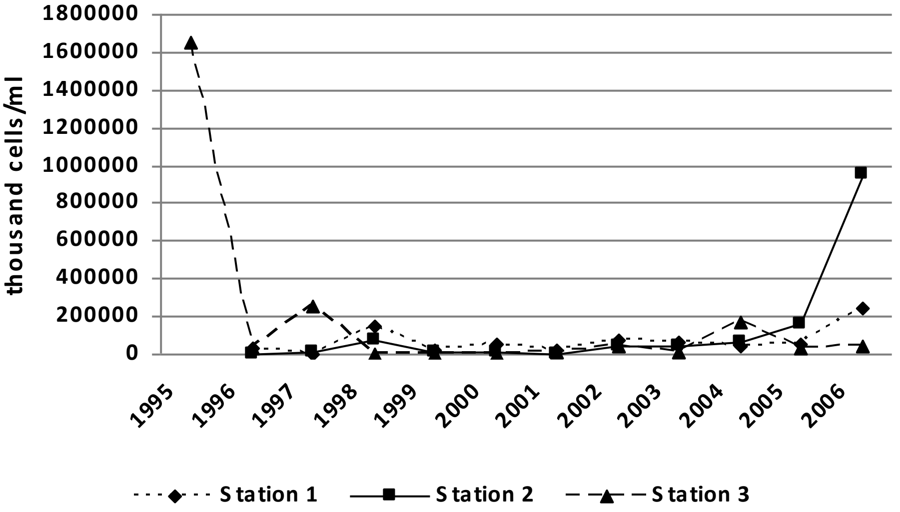

Fig. 9. The number of aerobic heterotrophic bacteria (saprophytes) in the sediment in the summer vegetation period from 1995 to 2006.

Phytoplankton in the upper part of the River Salaca indicates the eutrophic nature of Lake Burtnieku characterised by cyanobacterial (blue green algae) blooms (Fig.10).

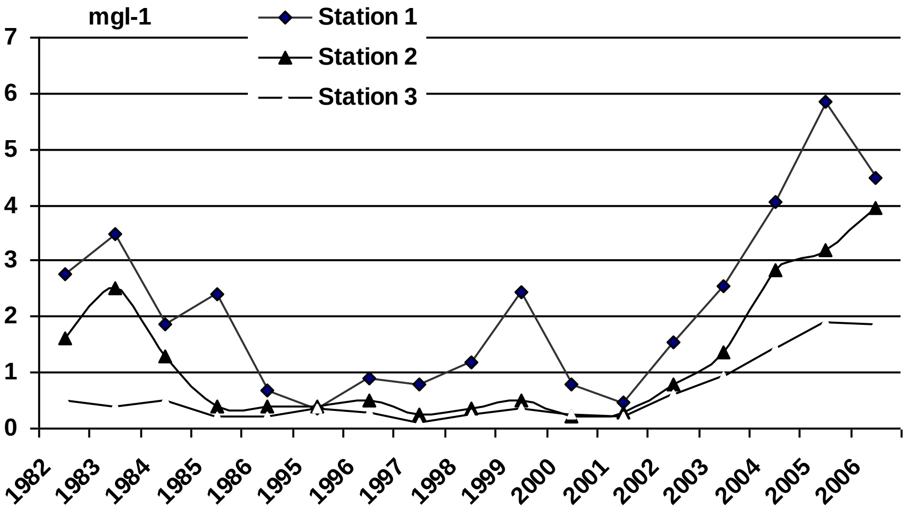

Fig. 10. Long term changes of phytoplankton (biomass mg/l) in the upper part of the Salaca River (outflow), the medium part, and the lower part.

In the outflow from Lake Burtnieku, Cyanobacteria, mainly *Microcystis* spp., *Anabaena* spp., and *Oscillatoria* spp., are building up the main phytoplankton biomass which decreases in the entire length of the river (Fig. 11).

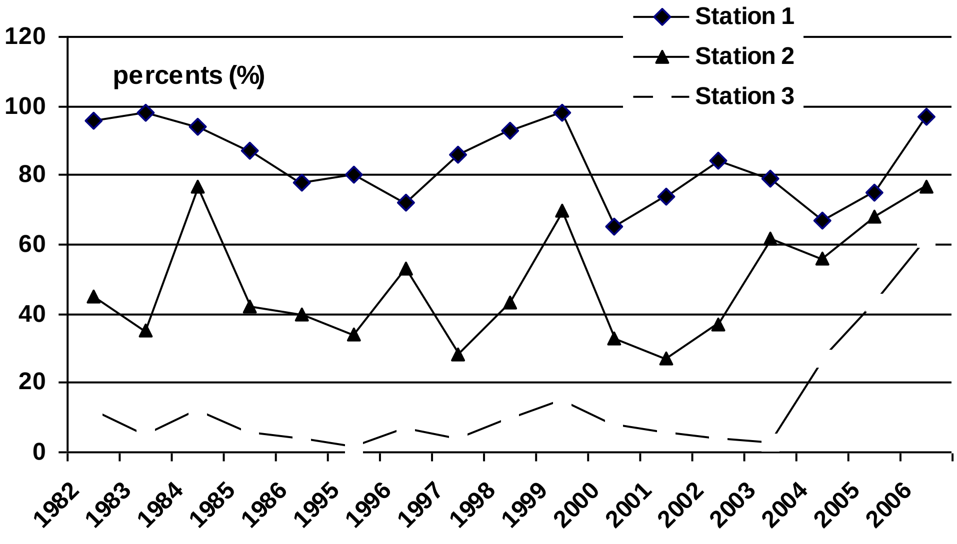

Fig. 11. The percentage of Cyanobacteria in phytoplankton biomass in the Salaca River sampling stations: the upper part (outflow), medium part and lower part.

According to the structure of periphytic and microphytobenthic communities, there are mosaic-like changes of habitats along the River Salaca causing an alternation in periphyton and phytobenthos communities (Druvietis 1997).

Inverse relationship between biomass of diatoms and Fe and Si ions was observed (Fig.12).

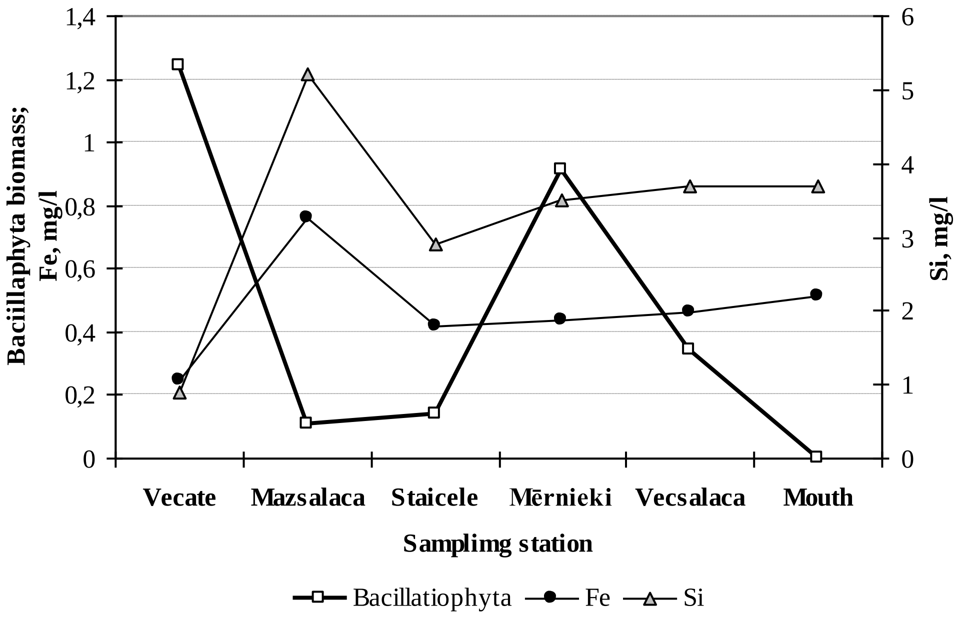

Fig. 12. Relationship between diatoms (bacillariophyta) and Fe and Si ions.

In total 42 different species were found on all the length of the river. In the macrophyte species composition of the River Salaca different emergent and helophyte species were dominant. Typical helophytes were *Schoenoplectus lacustris*, *Sagittaria sagittifolia*, and *Butomus umbellatus.* The most abundant emergent species were several *Potamogeton* species – *Potamogeton pectinatus, P. perfoliatus, P. praelongus, P. alpinus.* Nymphaeids were typical of the areas with a high total macrophyte cover.

In comparison to 1986, the total cover of macrophytes in 2002 in the river has obviously increased. Some stretches of the river were 80-90 % occupied by vegetation (Fig.13).

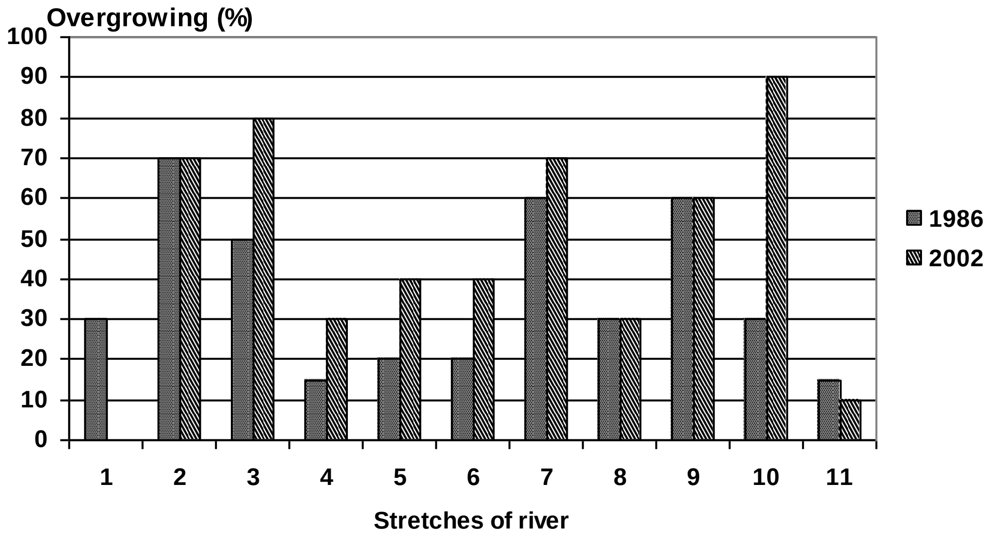

Fig. 13. Changes in the degree of overgrowing of the Salaca River.

The quantitative and qualitative changes in zoobenthos community since 1982 until now are insignificant (Kļaviņš *et al.* 2000), and it confirms the environmental stability of the Salaca.

The leading groups of zoobenthos are larvae of water insects, oligochaetes and molluscs. Zoobenthos communities of the station 1 (the outflow of the River Salaca) are dominated by colonies of invasive molluscs *Dreisena polymorpha* (54-89 % from the number of individuals per m^2). The colonies of this species appear to be a suitable haven for other benthic organisms. The long-term assessment approves a stability in the quantitative parameters of this population. The highest numbers of individuals are detected in Station 3 – the lower Salaca. This part of the river is characterised by high velocity of streams, as well as diversity of biotopes. As a result, this stretch of the River Salaca is characterised by high biodiversity of zoobenthos (157 species). These species are mainly reophyl species, characteristic of rhithral type streams. Zoobenthos is dominated by mayflies, cadissflies, stoneflies, dragonflies, beetles and their larvae, bugs, oligochaetes, and molluscs. The long-term assessment shows stability in the number of individuals in the outflow of the Salaca (Station 1) where benthic communities are dominated by limnophyl species characteristic of Lake Burtnieku (Fig.14).

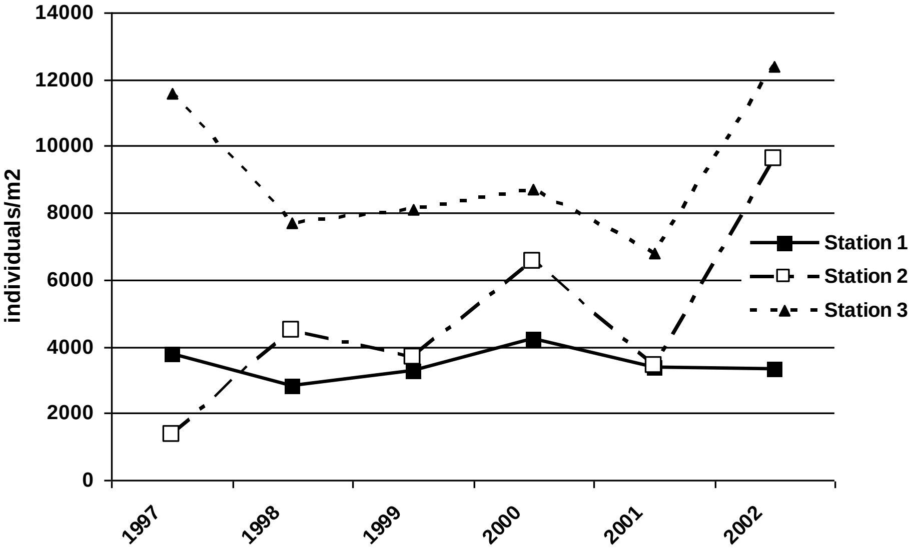

Fig.14. Numbers of individuals (individuals per m^2) of zoobenthos communities in the Salaca River.

The structure of zoobenthos community lake as bacterial community characterizes the Salaca as a *β*-mesosaprobic water-body (Fig.15).

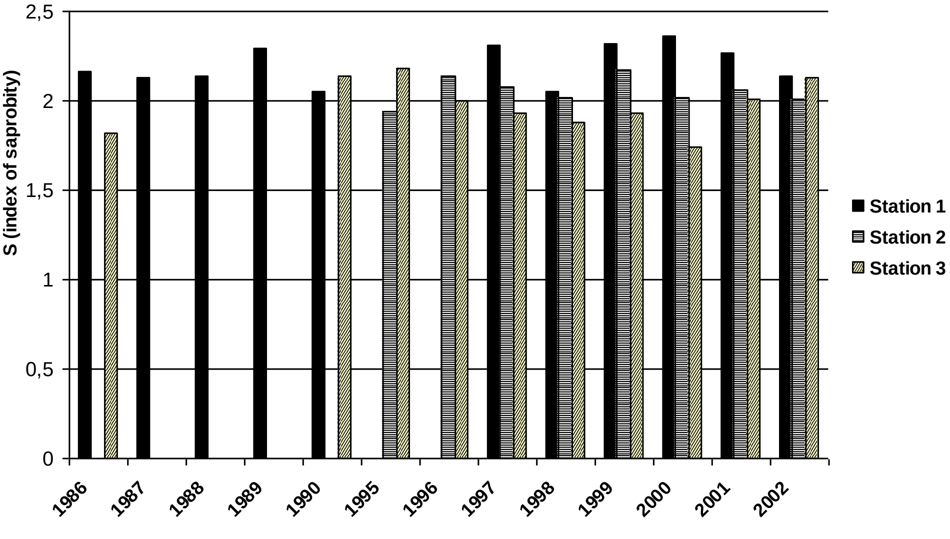

Fig. 15. The dynamics of saprobic indices of zoobenthos communities according to Pantle and Buck.

The comparison of chemical and bacteriological parameters of the River Salaca, as well as quantitative and qualitative changes in zoobenthos community since 1982 until now does not display a substantial difference. The River Salaca is a stable ecosystem with high species diversity and its saprobity corresponds to *β*-mesosaprobic level that is the background state for such river types in Latvia. However, the changes in land use patterns related to social and economical changes in Latvia since 1990 have resulted in lowered eutrophication (Briede 1995).

On the other hand, in the outflow of the Salaca River, cyanobacterial blooms are observed in all the years of assessment. According to literature (Moss *et al*. 2003), and contrary to expectations, warming did not increase the abundance of blue-green algae (cyanophytes).

The increasing growth of aquatic vegetation could be related to climatic factors – higher mean annual air temperatures and earlier springs. The absence and lowering of the ice cover during the winters in recent years also causes changes in vegetation growth (a prolonged growing season).

The fast macrophyte growth could affect fish resources in the Salaca, which is the most important wild salmon river in Latvia. The overgrowing will also affect recreational possibilities and biological diversity and create changes in landscape.

Further investigations must be focused on the analysis and understanding of the changes of the ecosystem of the River Salaca. It is likely that the intensive growth of aquatic vegetation is a result of climate warming during the previous years.

The future research aims must include the characterisation of ongoing changes in the vegetation structure of the river, especially for those stretches of the river where overgrowing is expected to increase. The weed clearance in the lower reach of the river in 2006 will permit the observation of the re-establishment of the vegetation.

Further investigations could enable the detection of the species which indicate climate change and the recognition of possible ecological impacts on the ecosystem of the River Salaca.

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