UNIVERSITY OF TARTU
DEPARTMENT OF GEOGRAPHY

PUBLICATIONES INSTITUTI GEOGRAPHICI UNIVERSITATIS TARTUENSIS
107

ESTONIA

GEOGRAPHICAL STUDIES
10

Editors:
Jüri Roosaare
Ülo Mander

Tartu 2008

TUNIS تونس

IGC 2008

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Building together our territories

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On the occasion
of the 31st International Geographical Congress

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Contents

Preface

The Estonian Geographical Society (founded on 15 November 1955) has long traditions of publishing selected scientific papers on the occasion of International Geographical Congresses. The first of these (Estonia..., 1972) was dedicated to the 22nd IGC in Canada. Geographers at the University of Tartu also recommenced the publishing of the results of their investigations in English in connection with international congresses (Publications..., 1964). Today these two publication series are merging, and it is our honour to introduce "ESTONIA. Geographical Studies 10", dedicated to the 31st International Geographical Congress (Tunis, August 12–15).

The aim of these proceedings is to present a snapshot of the activities of some Estonian geographers engaged in various projects, since contemporary geography is very broad and its applications quite interdisciplinary. According to the Congress' slogan – "*Building together our territories*" – the congress' "*issues present geography as a science that invites humankind to live intelligently with others and with its milieu*" (Hayder, 2007:4). We hope that the papers printed here can contribute to this ambition, both for physical landscapes and in order to exploit the mental landscapes of science.

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Editors

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LOCATING COMMUTING PATTERNS USING MOBILE POSITIONING DATA: DIFFERENCES IN MODELLED HOME AND WORK LOCATIONS

Rein Ahas, Siiri Silm, Erki Saluveer, Olle Järv, Margus Tiru, Anto Aasa

INTRODUCTION

The everyday mobility of human populations is a major cause of transportation demand and related carbon emissions. This is caused by the spatial distribution of society. Therefore it is important to investigate the location of homes and workplaces and to study related travel behaviour. This information is an important source for the development of sustainable planning models for the reduction of transportation demand in society. One of the new methods for the investigation of home and work locations is mobile positioning, which has also been called a social positioning method (Ahas & Mark, 2005). Mobile positioning is often considered to be a novel and exciting source of information in the investigation of social processes, while at the same time the number of published studies is small, because of problems concerning data acquisition and privacy issues.

This article aims to determine the location of home and workplaces in Estonia using passive mobile positioning data. We modelled home and work time anchor points using mobile positioning data, and compared the geographical distribution of homes and workplaces. Mobile positioning, coupled with the explosive growth in the number of phones, has rapidly emerged as an important tool for geographers. Mobile positioning means the tracing the location of handsets. The location of a handset is triangulated with the help of cellular antennae, other telephones or satellites. In terms of geographic surveys and applications, the most important distinctions lie between active and passive mobile positioning (Ahas et al., 2008). Active mobile positioning is the mobile tracking of the location of a specific handset using special queries. Passive mobile positioning data is secondary data that is stored in the memory files and logs of mobile operators. The location data is stored on the servers of service providers on numerous different occasions, e.g. handovers, billing memory or other services.

THEORETICAL FRAMEWORK

In order to analyse passive mobile positioning data, which consists of hundreds of location points recorded for every telephone (random ID, person) in Estonia, we need to establish a theoretical framework. Frequent use of certain mobile phones in constant locations offers us the possibility to learn about important or meaningful places for the particular phone (person) (Nurmi & Koolwaaij, 2006). To calculate such meaningful locations, we need a conceptual framework, which has been developed in travel behaviour research under the name of anchor points. Anchor points are locations where people regularly stay (Golledge & Gärling, 2001; Golledge & Stimson, 1997). "Common anchors" are significant places in the environment that are commonly recognized and used as key components of cognitive maps (Dijst, 1999). "Personalized anchors" are related to a person's activities, and they mark a specific workplace or home base (Golledge, 1990). In this study, we developed methodology for calculating personalised or personal anchor points of home and work time places for mobile telephone owners in Estonia. The calculated locations of home and work-time anchors were compared geographically.

DATA AND METHODS

In this study we use passive positioning data from EMT, Estonia's biggest mobile operator, for more than 500 000 active phone users in the network. The database contains the locations of all "calls out" (calls initiated by a respondent) with the precision of a Cell ID during a one-year period. EMT uses network hardware and positioning middleware from Ericsson Ltd: GPRS/EDGE and WCDMA/3G networks and MPS 9.0 mobile positioning platform. The entries for every outgoing call include: a) the time of the call; b) a random ID number for the phone; c) the cell ID. Because of privacy protection, we do not possess any personal information about the respondents, but only a randomly assigned ID. The data is gathered by Positium LBS, a company which has a contract regarding the use of LBS data with the 2 major mobile operators in Estonia.

To calculate anchor points, an 8-step model that determines the location of home, work-time location and secondary anchors for every ID was developed. This model was developed by Positium LBS (E. Saluveer and O. Järv), and is designed to work with huge databases in PostgreSQL database manager. The modelling calculated the location of more than 500 000 persons for every 12 months in the period 1.11.2006–31.10.2007. The average number of calls per month was 65.3 million; there were an average of 100–120 calls per ID per month.

In this study we analyse home anchors (the calculated location of respondents' home), work time anchors (the calculated place where respondents regularly spend time during working hours) and multifunctional anchors, which have a home and work-time anchor in the same location, as network cells are large (rural areas) or a person stays (works) at home regularly on workdays.

RESULTS

Distribution of homes and work time locations

The geographical distribution of modelled home locations follows the patterns of settlement in Estonia. Shown at county level as in Fig. 1, the distribution of homes is very similar to data in the Estonian population register: 38% in Harju, 12.6% in Tartu, Ida-Viru 8.0% and Pärnu county 6.5% of all Estonians (Table 1, Fig. 1). Tallinn, the capital of Estonia, has 68% of modelled homes in Harjumaa. The number of homes is higher near bigger cities; suburbanization is an ongoing process, especially in the Tallinn area.

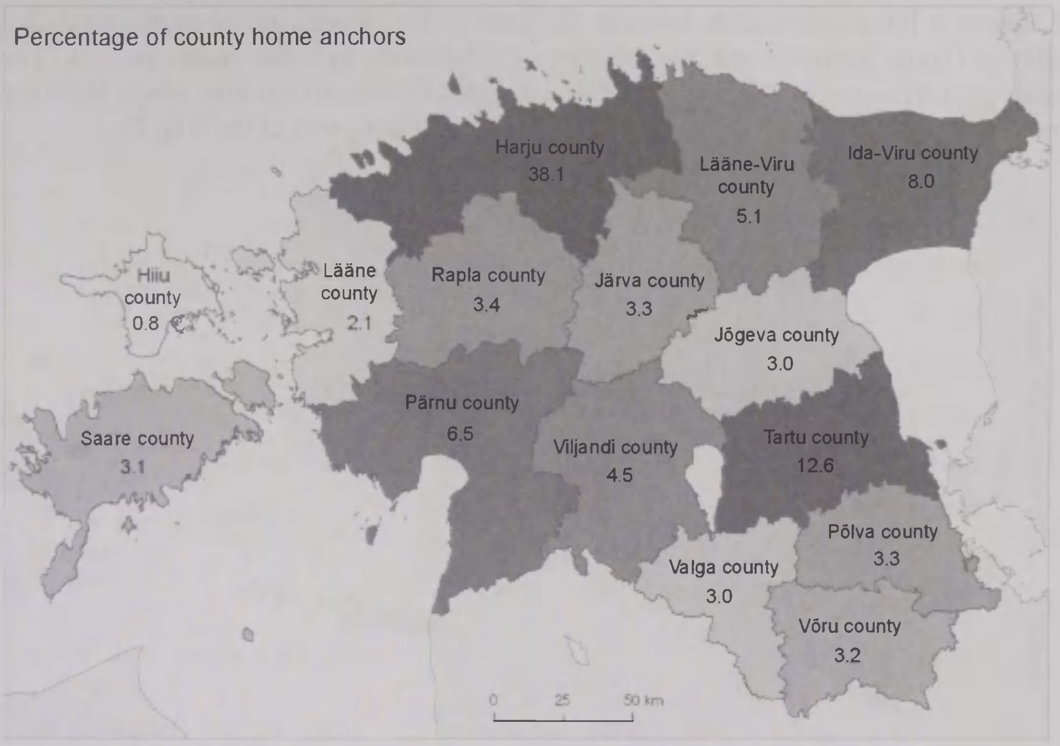

Fig. 1. Geographical distribution of modelled home anchor points in Estonian counties.

Table 1. Distribution of modelled home and work time locations (including multifunctional home and work-time anchors).

County	Home locations, No.	Home locations share by counties	Work-time locations No	Proportion of work time locations, by county
Harju county	307 349	38.1	316 439	39.2
Tartu county	101 274	12.6	102 932	12.7
Ida-Viru county	64 910	8.0	64 930	8.0
Pärnu county	52 040	6.5	51 949	6.4
Lääne-Viru county	40 983	5.1	40 351	5.0
Viljandi county	36 597	4.5	35 863	4.4
Rapla county	27 125	3.4	23 767	2.9
Põlva county	26 474	3.3	25 339	3.1
Järva county	26 434	3.3	25 436	3.2
Võru county	26 187	3.2	25 960	3.2
Saare county	24 837	3.1	24 602	3.0
Jõgeva county	24 557	3.0	23 642	2.9
Valga county	24 286	3.0	23 618	2.9
Lääne county	16 940	2.1	16 292	2.0
Hiiu county	6 490	0.8	6 351	0.8
Total	**806 483**	**100.0**	**807 471**	**100.0**

There is a linear correlation between the size of the municipalities in the modelled dataset (home anchors) and the number of inhabitants in those municipalities. The greatest differences occur in larger cities and in north-eastern Estonia, where there are more Russian speaking inhabitants and former Soviet industrial cities (Fig. 2).

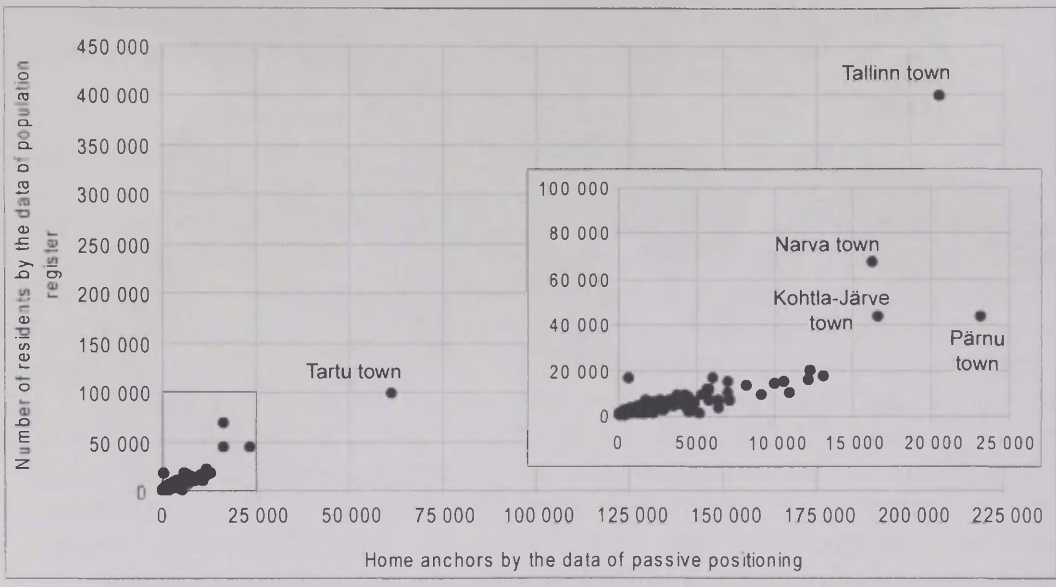

Fig. 2. Correlation between size of Estonian municipalities by modelled home anchors (mobile positioning data) and population register in 1.01.2007.

The distribution of modelled work time anchor points is also similar to the location of homes (presented here earlier) after the modelled data (Fig. 3) or the population register. The location of modelled work time anchors is a unique dataset for Estonia, as no single database with such statistics is available. Therefore it cannot be compared geographically.

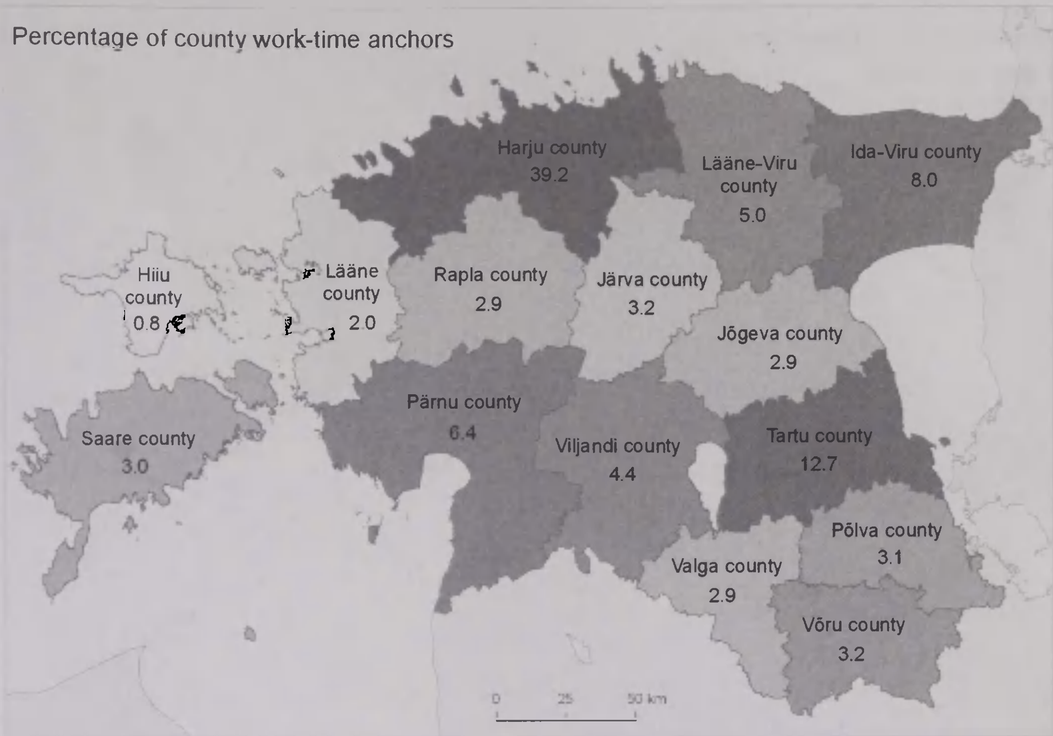

Fig. 3. Geographical distribution of modelled work-time anchor points in Estonian counties.

Differences in the geographical distribution of home and work-time anchors

Despite the general similarities in the distribution of modelled homes and work time places, there are geographical differences in the distribution of locations of modelled homes and work time anchors. Work-time anchors are more than modelled homes concentrated to cities with especial focus to bigger cities. For example, there are 207 979 home anchors and 231 558 work time anchors in Tallinn, 61 539 home anchors and 68 449 work time anchors in Tartu. The majority of cities have more work time anchors than homes. There is a greater number of work time anchors in most cities (Fig. 4; Table 2): Pärnu (3 414), Jõhvi (2 713), and Viljandi (2 078). Rakvere, Kuressaare, Rapla and Võru have 1000–2000 more work time anchors than homes, and some suburban communities in the Tallinn urban region, for instance Rae and Saue, also have a greater number of work time locations than homes. In smaller cities the difference between the number of modelled homes and work time locations is smaller, but is still noticeable.

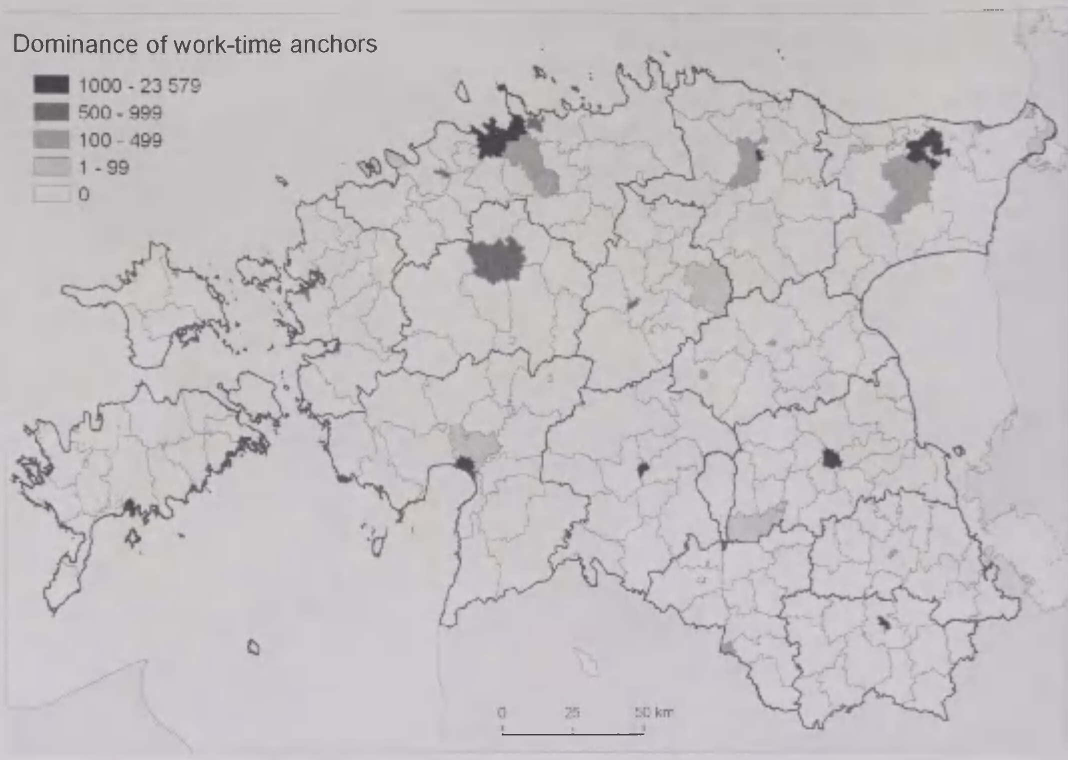

Fig. 4. The difference in the distribution of work time and home anchor points in Estonia; the dominance of work-time locations over homes.

Homes dominate over work time places in suburban regions near bigger cities, for instance the majority of municipalities near Tallinn. The number of home anchors is greater than work-time anchors in the following municipalities: Harku (3 009), Viimsi (2 467), Kohila (1 450), Saku (1 208) and Keila (1 156) (Fig. 5; Table 2). Areas where home anchors dominate over work-time anchors within the range of 500–1000 units are found in the hinterland of Tallinn, and near the cities of Tartu, Pärnu, Viljandi and Kuressaare. The difference between the number of home and work time anchors is smaller in the municipalities of South-Eastern Estonia.

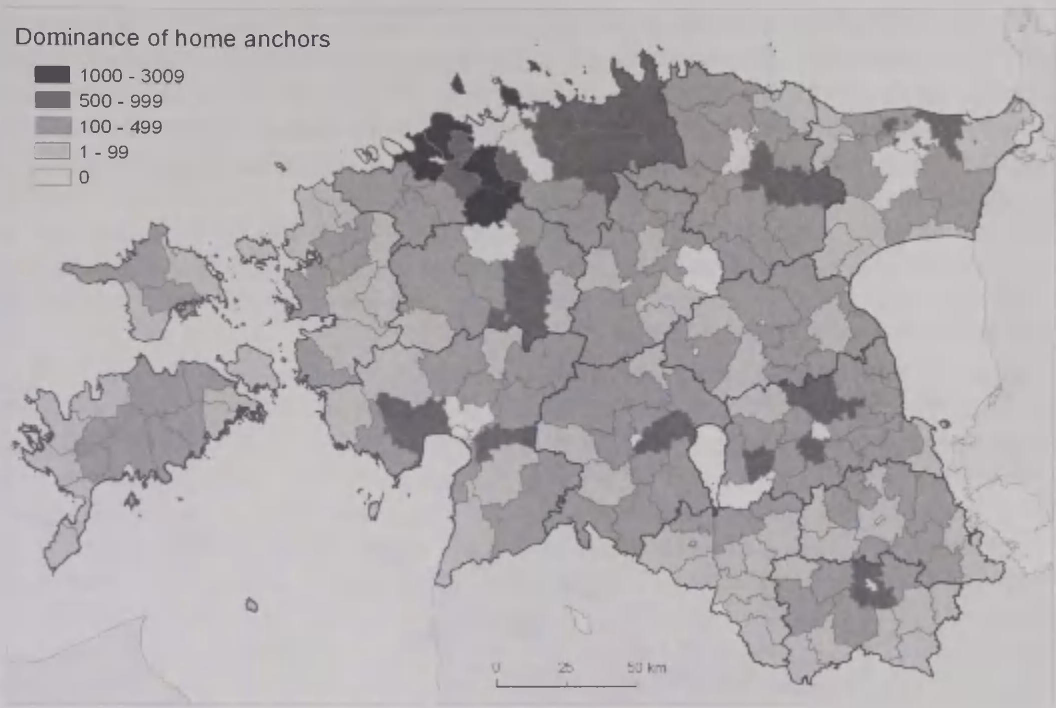

Fig. 5. The difference in the distribution of work-time and home anchor points in Estonia; the dominance of home locations over work-time places.

Table 2. Municipalities with the greatest difference in home and work-time anchor points in Estonia

No	Municipality	Dominance of work-time anchors	Municipality	Dominance of home anchors
1	Tallinn town	23 579	Harku parish	3 009
2	Tartu town	6 910	Viimsi parish	2 467
3	Pärnu town	3 414	Kohila parish	1 450
4	Jõhvi parish	2 713	Saku parish	1 208
5	Viljandi town	2 078	Keila parish	1 156
6	Rakvere town	1 688	Jõelähtme parish	984
7	Kuressaare town	1 535	Kohtla-Järve town	949
8	Võru town	1 180	Kuusalu parish	890
9	Keila town	582	Loksa town	890
10	Maardu town	569	Kehtna parish	890
11	Paide town	568	Kiili parish	832
12	Haapsalu town	536	Raasiku parish	756
13	Rapla parish	513	Ülenurme parish	725
14	Jõgeva town	485	Konguta parish	708
15	Põlva town	461	Tartu parish	678
16	Rae parish	332	Paikuse parish	668
17	Valga town	274	Anija parish	613
18	Põltsamaa town	232	Saue parish	576
19	Kärdla town	172	Saue town	570
20	Mäetaguse parish	154	Toila parish	570

The more detailed investigation of the proportion of home and work time anchors in the Tallinn urban region is presented in Fig. 6. There is a predominance of work places in cities: Keila (55%), Rapla (54%), Tallinn (53%) and Maardu (53%). Home anchor points dominate in the majority of municipalities in the Tallinn region. Differences rise, with up to 65% in distant rural municipalities such as Kernu, Nissi, Kohila and Aegviidu.

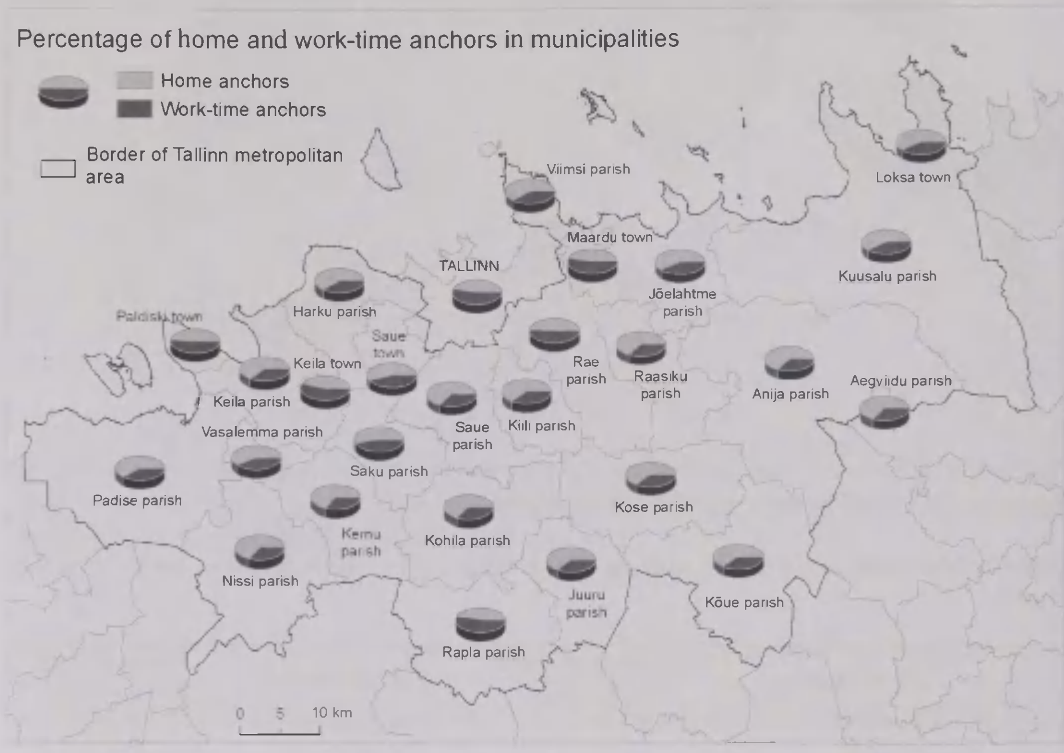

Fig. 6. Proportion of modelled home and work-time anchors in the urban region of Tallinn.

DISCUSSION AND CONCLUSIONS

The objective of this study was to compare the geographical location of homes and work time places in Estonia. For the analysis, we used a new method based on a passive mobile positioning database. We used an anonymous dataset from the largest Estonian mobile operator, EMT, which has more than 500 000 subscribers, more than 35% of the Estonian population. This method was selected as there is a need to develop a new methodology for population monitoring in rapidly developing countries such as Estonia. In Estonia there is ongoing rapid suburbanization near the largest cities (Tammaru et al., 200x). The population is also changing in rural areas and post-Soviet industrial cities in North-Eastern Estonia. Because of those rapid changes, the mobile positioning data can serve as an alternative source for population monitoring, since the population register is not functioning properly and the last census data (from 2000) is out of date.

Our results and the comparison with the population register data showed that the method we used to monitor the locations of homes and work time places was accurate. Modelled locations of homes and work-time places followed their logical distribution. The number of modelled work time locations was higher in cities. As we do not possess other sources that show geographical statistics of jobs, our discussions and comparisons with different databases showed that this result is correct. Jobs are concentrated in city centres.

Homes were mostly located in suburban regions near larger cities. This trend is also logical, as suburbanization is taking place quite rapidly in Estonia, and thousands of families have moved out of the city (Leetmaa et al., 200x). Our studies with new suburban settlement areas show that the inhabitants of these new suburbs are highly educated (Silm et al., 200x; Ahas et al., 2007a), and most of their jobs are located in the city centre. Therefore we can say that suburbanization is increasing the demand for transportation in Estonia. A second important result concerns the location of jobs still concentrated in cities. As homes move out of the cities and the labour market is more and more mobile throughout Estonia, there is a greater distance between home and work. Even if Estonian municipalities plan to create new workplaces in the suburbs, as has happened in the urban region of Tallinn, the highly qualified jobs are far from homes (Ahas et al., 2007b). It has also been noted in other western countries that more educated persons have a greater distance from home to work than persons with more menial jobs (Kwan, 2000). As our anonymous database does not include the social status of respondents, we cannot measure this relation with the current dataset, but by comparing suburbanization patterns in Estonia and level of education, we can assume that this is also the case with Estonian suburbanization (Tammaru & Leetmaa, 2007; Silm et al., 200x).

There are a number of issues to discuss concerning our unkonventional data and method. Our preliminary results concerning the study locations of homes and the comparison with the population register shows that our method is accurate. We also compared our personal activity spaces with those we modelled for 26 cases, and the results were reliable. There are problems with rural locations, where the mobile network is less dense and many home and work time anchor points are in the same network cell. This result is still usable and interesting, but it shows the level of precision of our method. There may be also a problem with the privacy and anonymity of data, which has to be handled properly, since the accuracy of future research depends on it. The preciseness and anonymity of today's data is not really a problem. In the near future, however, the quality of data will increase rapidly, as A-GPS telephones that have an accuracy of a few metres are in use in the EMT network since 2007. This is a milestone that makes the discussion of spatial privacy particularly important, and this may become an important discussion point for geographers in the near future.

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SEASONAL VARIABILITY OF HUMAN REPRODUCTION IN ESTONIA

Rein Ahas, Jüri Roosaare, Anneli Uusküla, Siiri Silm

INTRODUCTION

The impact of seasonal changes in the temperate climate zone is very extensive. The annual variance in air temperature exceeds 80°C in more continental areas, leading to changes in all organic and inorganic nature. The changes in the environment and nature as a whole are accompanied by seasonal changes in human activity. The physiological and behavioural aspects of the seasonality of human activity have been extensively studied, but there are nevertheless many questions to which no clear answer has been found. One of these questions concerns the characteristics of and reasons for the seasonality of births. The seasonal variance of births is clearly visible in most human populations. At the same time, unlike plants and animals, it is difficult to relate the seasonality of the birth of human beings to changes in seasonal environmental factors, since in the case of births, enigmatic differences occur in the seasonal variance models of different countries and time periods (Lam & Miron, 1996). It is probable that the seasonal rhythm of births is an adaptation with a certain meaning that has evolved in the course of evolution. Regrettably, today nobody has been fully capable of deciphering the key to this adaptation. The introduction to the issue can be accurately summarised with the following quote from Lam and Miron (1996): "*The seasonality of births mostly remains an unsolved puzzle in empirical demography. It is a puzzle that gives rise to thought-provoking questions for both the biological and behavioural study of births.*"

The objective of this article is to study the seasonal rhythm of Estonian births and the factors that impact it. This would help to achieve a better understanding of the seasonal changes taking place in society and also their reasons. For that purpose, the data on the birthdays of all of the 1.39 million residents of Estonia have been analysed, and this should yield better results than the more limited samples that are conventionally used for such studies.

In studying the seasonality of Estonia births, two important aspects must be taken into account. Firstly, Estonia is a small country with homogenous natural conditions, which should facilitate the investigation of births in the population. Secondly, major political and economic changes have taken place in Estonian society during the last century; the effect of these changes can be observed in the structure of the country's population. During the 20th century, Estonia has experienced two devastating wars, five entirely different political regimes, two Stalinist mass repressions, industrialisation and russification. These are aspects that make the database more uneven and more difficult to interpret, but at the same time might offer answers to the questions that have until now remained unanswered.

EARLIER STUDIES

The seasonal rhythm of births has been thoroughly studied by different authors. The issue is intriguing, as nobody has yet been capable of thoroughly determining the reason for the seasonality of births. A seasonal rhythm is characteristic of the life and breeding of many plants and animals. The continued role of seasonal timing which has retained its influence throughout the course of evolution indicates that it is an important aspect in the adaptation of organisms (Roenneberg & Aschoff, 1990). The advantage of seasonal timing may be that it helps species survive periods with unfavourable conditions, time the date of conception within the species, plan food supplies, increase resistance to diseases, and much more.

The seasonality of the births of human beings is not apparent when one examines individual cases, but in the case of larger statistical samples, the seasonal aspects of birth data become manifest. This has been studied quite thoroughly in various demographical, biological, phenological and epidemiological investigations conducted in different regions (Roenneberg & Aschoff, 1990; Lam & Miron, 1994; Udry & Morris, 1967; Ahas, 1999). The results of this research indicate that the seasonal rhythm of births has a certain geographical aspect. For example, the seasonal rhythm of births in Northern Europe (the maximum number of births being in spring) and in the United States (the maximum number of births being in summer and early autumn) is different, while the birth seasons in the Mediterranean countries, the Near East and Central America are quite similar (Lam & Miron, 1994). In the birth curves of the populations of the Northern and Southern hemispheres, a contrary pattern has been detected, which indirectly refers to the impact of the exterior environment deriving from the seasons (Cowgill, 1966). The seasonal rhythm of births in populations also changes over the course of time. The most extensive changes in the seasonality of births have been observed since the 1960s (Roenneberg & Aschoff, 1990). One frequently mentioned reason for this is that great social and economic changes have taken place in society (Lam & Miron, 1994; Ahas, 1999).

As mentioned above, the search for the reasons for the seasonality of births has been one of the central study objects of demographers and biologists ever since the mid 20th century. No direct correlation has been detected between the frequency of intercourse and the seasonality of births (Udry & Morris, 1967). The seasonality of births has most often been related to the impact of weather conditions (Cowgill, 1966; Roenneberg & Aschoff, 1990; Rojansky et al., 1992; Centola & Eberley, 1999), while the relations generally still remain weak, and more recent analyses do not offer any clear answers here, so that one could instead say that there are no proved relations (Lam & Miron, 1996).

It has been supposed that the external environment (temperature, photo period etc.) has an impact on the birth rate (conceptions) through hormonal composition, the quality of sperm or sexuality (Rojansky et al., 1992; Centola & Eberley, 1999; Rojansky et al., 2000). The key factor in seasonal variance might be melatonin, which might be involved in both spermatogenesis and folliculogenesis (Partonen, 1999). The fertility of men might depend seasonally on the quality of sperm, which varies greatly (Jorgens et al., 2001). The concentration of sperm and its spermatozoon content is generally lower in summer than it is in fall and winter (Spira, 1984; Gyllenborg et al., 1999). Less factors have been discovered between conceptions by women and environmental factors (Rojansky et al., 1992). However, a certain trend consisting in an increase in the probability of conception in the first half of June and December has been discovered (Smits, 1998).

Biological and physical mechanisms probably constitute another important set of factors influencing the seasonality of the birth rate. The mechanisms of the biological calendar (circannual clock) timing of life activity and procreation certainly fall into this category as well (Follett & Follett, 1981; Gwinner, 1986; Roenneberg & Aschoff, 1990). In the biological sense, a modern person no longer has any direct need (food, weather conditions) to time births seasonally, but certain physiological, endocrinological and immunological variables still indicate systematic seasonal variances (Roenneberg & Aschoff, 1990). It is possible that the reasons for this might lie in the continued functioning of the genetically encoded biological calendar. At the same time, regionally evolved human populations all over the world have become mixed up, and therefore the mechanisms of the biological calendar might also be confused.

Socio-economic-demographic factors could constitute a third set of factors conditioning the seasonal rhythm of births (Lam & Miron, 1991). The most outstanding of these are the aspects related to the type of production used by the society (agrarian, industrial or information society), as well as economic conditions and causes, aspects related to traditions and holidays (the Christmas and Midsummer Eve effect), phenomena related to getting married and planning a family, and phenomena related to social and political events (wars, political regimes, revolutions).

STUDY AREA

Natural conditions

Estonia is situated on the east coast of the Baltic Sea, at coordinates 57°30′–59°49′ N and 21°46′–28°13′ E. Estonia has a territory of 45 227 km^2.

Estonia's landscape is flat, with small differences in altitude. The average absolute altitude of the land is ca 50 m, and the highest point is located only 318 m above sea level. The alternation of uplands and plains with lowlands, basins and valleys is characteristic of the territory of Estonia. Dominating relief forms include moraine plains, bulges and drumlins formed during the Ice Age. Northern and Western Estonia have another characteristic trait, namely limestone plateaus.

Estonia's climate is transitory from maritime to continental; it is influenced by the Atlantic Ocean and the continent of Eurasia. Estonia's weather is most actively conditioned by the northern part of the Atlantic Ocean, the Gulf Stream and the Iceland minimum, which causes the Estonian climate to be much milder than is characteristic for this latitude. Four seasons are clearly distinguishable in Estonia. In summer the duration of daytime is more than 19 hours, while a short winter day lasts merely 6 hours. From the beginning of May to the end of July there is a time when the nights are not completely dark.

Overview of the historical events that have had an influence on population structure in respect of gender and age

Estonia's geopolitical situation on the border of the cultural spaces of the Eastern and Western part of Europe has also left an imprint on contemporary society. Conflicts, lines of demarcation, mixtures and synergies have come into being on the border of the Western and Russian cultural space. In this subchapter, the historical events (Table 1) that have most likely influenced the data used in this research have been examined. The database comprises all residents of Estonian who were alive as at 1.01.2001. These are people who have lived through the events that have taken place in Estonia during the 20th century, and it must be noted that this century has been quite turbulent.

Table 1. Outstanding political events of the 20th century

Event	Time
Russification	1885-1905
World War I	1914-1917
Independence war	1918-1920
Emigration	1924-1930
Independent Republic of Estonia	1918-1940
World War II	1941-1944
Leaving abroad	1939-1940
Massive arrests and deportations	1941-1949
Enforced industrialisation and collectivisation	1949-1950
Intensive growth of cities	1950-1970
Massive deaths in Soviet camps	1945-1959
Intensive russification	1970-1980
Migration from the Soviet Union	1950-1980
Regaining independence of Estonia	•1991
Construction of the Republic	1991-...
Years	1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000

During the last century, the Estonian population was influenced by numerous socio-political processes, which were expressed in both birth rate, death rate and migration. The most important event in the 19th century was the liberation from serfdom in 1816, which had a considerable impact on the lives of Estonian residents.

The principal factors influencing population processes during the first half of the 20th century were the two world wars, the German Occupation and the Soviet Occupation. Before World War II, the population was slightly above 1 million. The population scenery of Estonia during the first decades of the 20th century was influenced both by World War I (1914–1917), the War of Independence (1918–1920) and emigration caused by the difficult economic situation (1924–1930). To counterbalance this, some positive impact was brought about by the return home, during the years 1920–1922, of the Estonians who had been living in Russia. A devastating and much stronger impact than that of the events referred to above resulted from World War II (1941–1944), when 18.5% of the population died as a direct result of military activities (Kaufmann, 1967; Ainsaar, 1998). During the period of World War II, the population of Estonia also decreased due to emigration to Germany (1939–1940) and mobilisation into the German army (1943), as well as due to the activities of the occupation regime of the Soviet Union – mobilisation into the Red Army and evacuation to Russia. In addition, a large number of people, fearing the occupation, escaped to the West (mostly through Germany and Sweden).

The structure of the population and the behaviour of the society were also strongly influenced by the period of Stalinist repressions and collectivisation in the 1940s. In 1941 and 1947 massive deportations to Siberia, arrests and displacements of people took place. In these years, a total of 48 000 people died as a result of the activities of the Soviet regime (Palli, 1998).

Starting from the 1950s, the population of Estonia began to increase at a stable rate (immigration from the USSR, natural increase in population), reaching a level of over 1.5 million by 1990. During the 1950s, the Estonian population was influenced by migration from the east, conditioned by the needs of the country's developing industry; most of the immigrants were workers and their families, and people returning from Stalinist prison camps. From the 1950s to the 1970s, the intensive growth of cities played a considerable role, which was favoured by enforced collectivisation and the settlement of the aforementioned immigrants in the cities (Tammaru, 2002). The period after Estonia regained its independence (1991) can be characterised by a lack of economic stability and a continuous decrease in the permanent population as a consequence of both the diminishing natural increase in population and the reduction in the number of immigrants (Tammaru et al., 2004; Ainsaar, 1998).

On the basis of the data used in this research, a gender and age pyramid has been composed (Fig. 1), indicating the changes in birth and survival rates during the last century. The proportion of elderly women is traditionally remarkably larger, and the low periods caused by the wars also have an impact on the number of births in the following generations.

DATA

Air temperature

For the purpose of characterising the meteorological conditions of the years studied, the data concerning daily average temperatures recorded at Tartu Meteorological Station during the years 1900–1999, and the climatic seasons determined by J. Jaagus of the Institute of Geography (University of Tartu) on the basis of daily average temperatures have been used (Jaagus & Ahas, 2000), enabling us to describe the seasonal phenomena more accurately.

Fig. 1. The gender and age pyramid of people involved in the research (the vertical axis depicts years, the horizontal axis the number of men and women born in each respective year. The database includes 1.39 million people alive and residing in Estonia as of 1.01.2001.

In studying the relationship between conceptions and environmental factors, different values calculated on the basis of daily average temperatures (t°_{D}) were applied: average monthly temperatures, daily, monthly and yearly deviations in temperatures from the long-term average for the respective period, different moving average temperatures and cumulative sums of temperatures of months and seasons. The cumulative negative temperature (Σt°_{-D}, provided that t°_{-D}: $t^{\circ}_{D}<0$) of the cold season (1.10–31.03) and the deviations of daily average temperatures from the standard ($t^{\circ}_{D} - t^{\circ}_{N}$, where t°_{N} is the multi-annual daily average temperature) were also applied in the research.

Birth dates of residents

In analysing the seasonality of births, we used the Population Register database of the Ministry of Internal Affairs, which includes all data on the birth dates of permanent residents and citizens residing in Estonia as of 1.01.2001. The database includes a total of 1 387 939 people. In comparison, it could be pointed out that according to the data obtained from the official census conducted in 2000, the number of permanent residents of Estonia was 1 370 052 people. 90.9% of the residents of Estonia were born in Estonia, and 8.8% in a foreign country (Statistical Office of Estonia, 2000). 67% of residents are Estonians; the majority of the rest are Russians, Ukrainians, Byelorussians and residents of other ethnic origins who speak Russian (Statistical Office of Estonia, 2000). In this research, from the data recorded in the Population Register, we only used those personal identity codes that describe the gender and the birth date/month/year. No other data or identifications included in the register were used in this research. On the basis of the observed database, Estonian residents have an average of 3 800 birthdays a day. The birthdays are distributed unevenly: the lowest number of birthdays is from October 11 until October 31 – an average of 3 453 birthdays a day, and the greatest number of birthdays is from March 8 until March 28 – an average of 4 048 birthdays a day.

The data used in this research differ from those used in other similar research, because it encompasses all births, no matter what the person did in the future. The personal identity codes of living persons have been used, which, however, indicate only the birth dates of persons who are still living. The differences are probably not significant, although the hypothesis that the survival of a person does not depend on his or her birth date has been taken as the basis of this research paper. Some indications that the successfulness of survivors to some extent also depends on their birth dates have, however, been discovered (Doblhammer, 2002). Our hypothesis means that the fate of the Estonians who died massively in the battles of 1944 was not related to specific birth dates, but rather with years of birth, on which basis youngs men were drafted into the military.

Bias in database

In addition to historical events, birth dates are influenced by errors that occur at the time of their registration. In Fig. 2, the homogeneity of the database and the locations of possible errors have been indicated. The reasons for certain errors can be assumed or are known, while others remain inexplicable for the time being.

January 1 syndrome. The number of births registered on this day (5 928) by far exceeds the average, while the number of births on December 31 is below average (3 170). The reason for this is the registration of persons not having a birth date on January 1, and the registration of babies born on the last days of a year in the new year. This, in turn, has several reasons: firstly the desire to make children seemingly younger for having a later year of birth, which was motivated by the need to save children from having to serve in a foreign army that held control in Estonia, or to send their children to school later. This category is clearly distinguishable during the years of World War II (Fig. 2). Parents probably saved their children from the possible war by registering them as younger, because the issue of sending young men born in certain years to fight in the war was very relevant. Secondly, the registration of births during the holiday period was simply hampered, as offices were shut, etc.

The next date in terms of the number of births, which also stands out separately, is May 1 (4 734), which is then followed by a constant sequence starting from the number 4 366.

Much more complicated, however, are errors that lack any reasonable explanation. The most enigmatic circumstance is the regularity that is represented in the entire database, but is most clearly distinguishable during the 1920s and 1930s, consisting in the circumstance that on the 1st, 5th, 10th, 15th, 20th and 25th days of each month more births were registered than on neighbouring days (Fig. 2c and 2d). There is no reasonable explanation for this 5-day syndrome. It might be caused by some peculiarity of registration or record-keeping during this period, although it remains unclear how this could influence the dates of birth.

In the course of subsequent analyses, moving averages were used to reduce the impact of the errors referred to above.

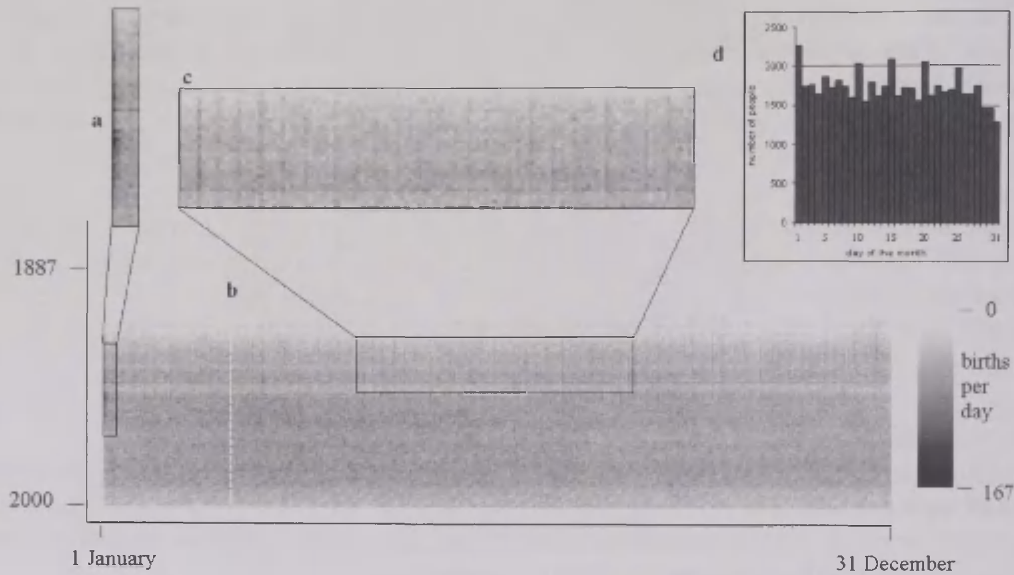

Fig. 2. Source data of the birthdays used in the research, represented in graphical form. Each pixel a_{ij} in the 366x114 raster image represents the number of births on the day i of the year j. The horizontal light stripes indicate the years of World War I and World War II. Some details have been given below: a) January 1 was a "favoured" birth date until the 1960s; b) February 29 occurs only once every four years; c) Darker vertical stripes (clearer in the summer periods of the 1920s and 1930s) indicate 5-day periods, which are not very clear, but still persistent; the reason for these is unknown; d) In the distribution of births between the dates during the period 1925–1934, there is a clear tendency for certain days (1, 5, 10, 15, 20, 25).

Preparation of data

The preparation of the data for the purpose of analysing seasonality was performed in stages together with interim analyses. All data and intermediate results were kept and processed in MS Excel worksheets.

1) In order to determine the seasonal variance of births and achieve a more precise analysis of relations between them, the dates of births were recalculated into theoretical dates of conception. For that purpose, 38 weeks, i.e. 266 days, was taken as the fixed duration of pregnancy (Roenneberg & Aschoff, 1990; Edwards, 1987). From hereon, only the conception values have been represented in this paper.
2) As the number of very old people is low, the 632 people born during the years 1887–1900, representing 0.05 per cent of the population, were left out of the calcu-

lations. Birthdays on February 29 in leap-years were also left out of the analysis (852 people, representing 0.06 per cent of the population). In addition, the conception data for the year 2000 were left out of consideration, because the data from that year were incomplete. Therefore the period under observation consists of the 1 383 314 residents of Estonia conceived during the years 1901–1999 who were alive as of 1 January 2001 (Fig. 2).

3) As the research focuses on seasonality, the database of conceptions in different years was standardised in order to analyse the results more efficiently. Firstly, the absolute figures of conceptions per day were converted into relative values by taking the total number of conceptions in each year to be 100 per cent. In this way, we obtained a percentage of conceptions per day and per month that enabled a comparison of different years. On average, 1/365 or 0.274% of conceptions have taken place on each day of the year, which is considered to be the standard value of conception. Next, deviation from the standard value, i.e. from the even distribution within a year corresponding to each day, was calculated, focusing on the totals of the deviations in the course of different periods. For example, in March, whose 31 days represent 8.5 % of the days in the calendar year, an average of 7.95% of the total annual number of conceptions takes place. The average total of deviations in the month of March is -0.55 %, which means that during the entire observation period an average of half a percent less are conceived. All days in March, except for March 24 and 31, have fewer conceptions than the standard value. In the deviations, the 5-day syndrome is also clearly visible.
4) In order to reduce the impact of noise and errors (birth dates January 1, May 1 etc.) included in the database, the data obtained was smoothed by applying a moving average. The application of a moving average is also justified by the fact that the conception date cannot actually be determined with absolute precision and without any errors. The estimated period of pregnancy is 40 weeks (280 days), starting from the first day of the last menstruation. The actual duration of pregnancy from conception to childbirth (266 days) is ~ 2 weeks shorter than the estimated duration of pregnancy, due to the maturation of the new ovum in the course of ~ 2 weeks after menstruation. In the case of 50% of women, childbirth takes place within ~ 1 week from the estimated partition date/pregnancy and in the case of 90% of women within ~ 2 weeks (Harrington & Campbell, 1993). For the purpose of reducing such influences when studying seasonality, a 27-day moving average was used to smooth the data.
5) In order to find a correlation between conceptions and monthly average air temperatures, the conception data was recalculated into monthly values and all the months were uniformed into 30-day periods.
6) In addition to the number of birth dates referred to above, the method of cumulative summing of births was also applied. For that purpose, the dates of reaching certain number of births (33.3%, 50%, 66.6%) were calculated for each year. Such cumulative sums of conceptions make it possible to analyse the threshold levels of certain phenomena and the dates when these are crossed as seasonal phenomena (Ahas & Aasa, 2003).

METHODS

For the analysis, MS Excel 2000 and Statistica 6.0 software was used. Taking into consideration that the amount of data under observation was very extensive, all of the indicators provided below may be considered to have a high statistical significance, and their minimal probable errors are not treated.

In analysing the periodicity of the data, the spectral analysis of the time series of the percentage of monthly conceptions was applied. According to the method applied (*the fast Fourier' transform*), the periods have been determined using the following formula: $T_i=N/i$; $i=1, 2, \ldots, N/2$; $N=1188$ (i.e. the number of months in 99 years). Consequently, the precise duration values of the period are in a way only formal.

In order to determine the different seasonal distribution types of conceptions, a cluster analysis was performed, where the data was grouped in years. The method applied (*K-means clustering*) makes it possible to find the best (with the largest difference from one other) grouping for each predetermined number of clusters (we used 2 to 4) and to choose from between such groupings that which is most easily interpretable. The grouping of data was also attempted with other methods (e.g. dendrogram and factor analysis), which also gave accurate results, but these were not as clear and readily interpretable.

RESULTS

Seasonality of conceptions

The number of conceptions in Estonia is not evenly distributed throughout the year. While having generalised the whole data of the period under observation (1901–1999), the daily proportion of conceptions is higher in summer and lower in winter. The period from the beginning of April to the end of August (Fig. 3) can be regarded as the high period of conceptions. The peaks emerge in mid-April and mid-June, between which there is a certain period of decline, with the lowest phase at the end of April and at the beginning of May. The lowest period of conceptions is in January and February; there are also smaller low periods in September and November.

The peak of conceptions in mid-April is characterised by its sharp increase starting from April 9 (0.276 percentage points) until it reaches its maximum on April 23 (0.285 percentage points), after which the proportion of conceptions declines quite abruptly (in 2 days) to the level preceding the increase (Fig. 3, point 2). In absolute figures, the average number of conceptions on April 9 is 3 814, while the average number of conceptions on April 23 is 3 947. It could be assumed that one reason for the abovementioned sharp changes could also be that the persons conceived in that period are born at the turn of the year, which is also expressed in the so-called January 1 syndrome affecting the database, as described above. This is actually not the case, as when calculating the average, the numerous births on January 1 are balanced by the low number of births on December 31. The only accountable impact of January 1 syndrome (to which the conceptions on April 10 correspond) on the moving average is a certain increase in the maximum value on April 23.

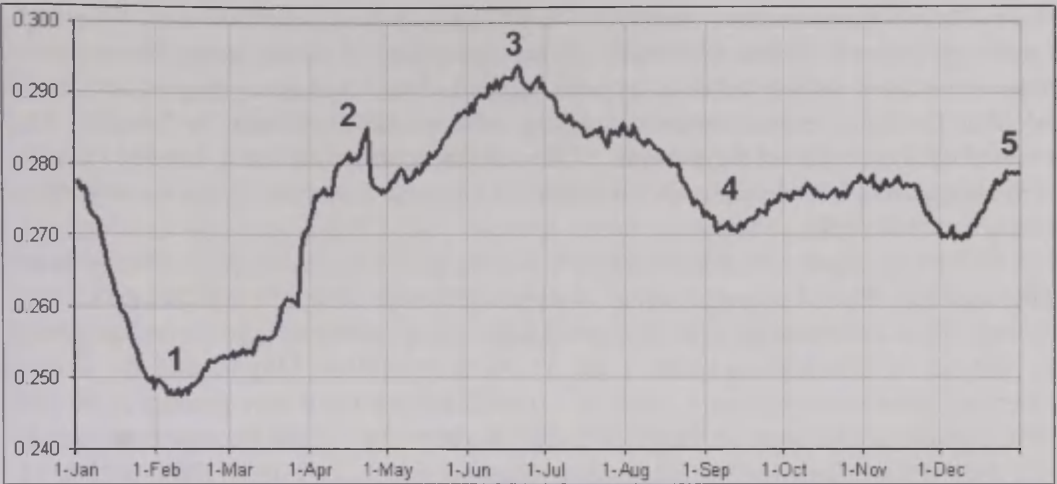

Fig. 3. The daily average number of conceptions of the population of Estonia expressed as a percentage of the annual total and smoothed with a 27-day moving average. The explanations of the periods marked with numbers are provided in the text.

The second peak of the high period of conceptions, with the high point around June 20, is more even in character; the daily proportion of conceptions rises smoothly from mid-May until mid-June, and thereafter declines until the second half of August (Fig. 3, point 3). No particularly sharp rise or decline could be pointed out. The maximum could be considered to be the period in mid-June, when the proportion of conceptions exceeds the threshold of 0.29 % over 23 days (June 9 – July 1). The observed peak of conceptions in June is also the period with the highest proportion of conceptions in the year. More than 4 050 people are conceived on peak days. The reasons for the increase in the number of conceptions in mid-June can be assumed to be both the higher temperatures and shorter nights, the holiday period and Midsummer Eve, which for Estonians is the most important summer holiday and period of festivities.

The summer peak in conceptions ends with a decline in August and September. By September 13, the average proportion of conceptions falls to the minimum level of 0.271%, which in numerical values is 3 742 conceptions a day (Fig. 3, point 4). Starting from September, the indicators of conceptions stay at the average annual level (0.2740%), and begin to decline again from the 3rd decade of November. The decrease in conceptions characteristic of the cold season is interrupted by a local rise in December. December 25–30 is a high period of conceptions, with the maximum of 3861 persons a day. This period is marked by point 5 in Fig. 3.

There is a low period of conceptions during the first months of each year, which is the coldest part of the winter (Fig. 3, point 1). This minimum period lasts until the end of March, during which the proportion of conceptions remains below average. There are no outstanding minimum low during the winter period, although the lowest values can be found in the period from February 5 to 13, when the number of conceptions is below 0.248 percentage points or 3 431 conceptions a day.

Seasonality of the cumulative sums of conceptions

For the purpose of a better evaluation of the seasonality of conceptions, the method of cumulative sums of conceptions is also applied. This method makes it possible to calculate the dates when a certain percentage of the number of births per year has been attained. In the course of the analysis, different thresholds were used, but only the date of attaining the 33.3% level has been indicated, because it best describes the winter and spring curve of births.

The date by which 1/3 of the total annual conceptions has taken place has fluctuated quite significantly in the period under observation (1901–1999): the difference between the minimum and maximum values is 42 days. As an average over the entire period, the number of conceptions reaches the 33.3% threshold on May 7, and the average difference between subsequent years is 5 days. This indicator was earliest in the year 1918 (April 13) and latest in 1945 (May 24). Both the year with the minimum and the year with the maximum value fall in the periods of wars (1917–1920, 1940–1946). The third period with larger fluctuations is in the period when Estonia regained its independence (1991–1993), when drastic changes once again took place in Estonian society. The birth rate during those periods was below average, and the large variance is also partly caused by this.

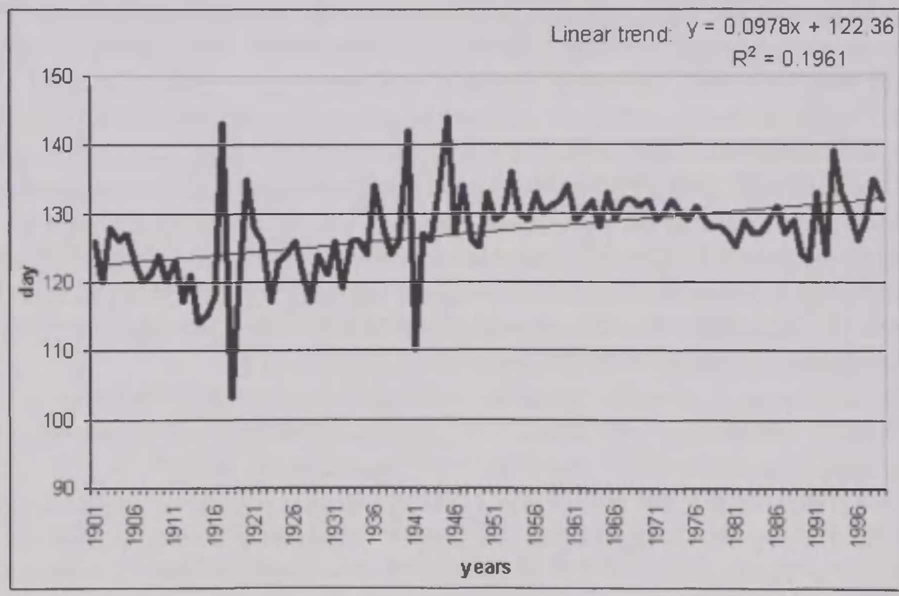

Fig. 4. The dates of reaching the 33.3% level of total annual conceptions and their linear trend.

In observing the general tendency of the years under consideration, it can be seen from Fig. 4 that the number of conceptions continuously reaches the level of 33.3% at a later time, which means that the proportional importance of the first third of the year has declined. Until the year 1943, the number of conceptions was generally earlier, and from that time on later than the average trend in the period as a whole. Deviation from the general trend can also be noted from the end of the 1970s, when the number of conceptions became earlier than in the preceding period, but does not reach the level of the first half of the century. The reason why the threshold of reaching the 33.3% level of conceptions has shifted to an earlier time could be a more even distribution of conceptions within the year, as well as a different type of seasonal distribution during the first and the second half of the century, which is described in further detail in the next chapter. The trend of reaching the 33.3% threshold of conceptions bears a visual resemblance to trends in temperature and plant phenology phenomena characteristic to Estonia, which indicates the impact of changes in climatic conditions.

Cycles occurring in the conception data

In addition to the fluctuations with seasonal characteristics, cyclical changes with a longer duration also occur in the conception data. The spectral analysis used for their characterisation revealed a 24.8-year cycle (Fig. 5) as most characteristic. This can be related to the impact of the wars (1918–1920 War of Independence; 1941–1944 World War II). As this period can contain only 4 such cycles, its occurrence is statistically insignificant.

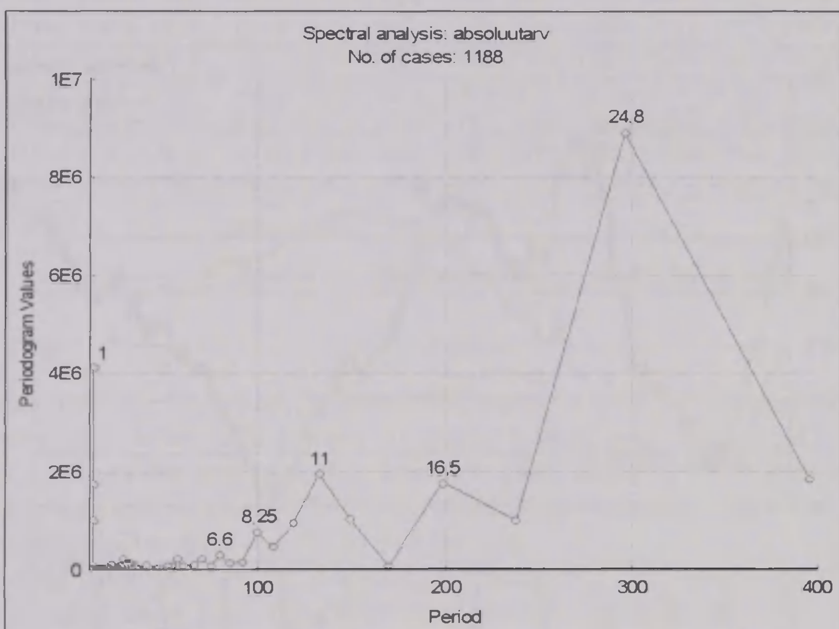

Fig. 5. Periodicity in the monthly values of conceptions: periods of 1–25 years. x-axis – months; the y-axis depicts the relative value of importance for the period under consideration. The periodogram values can be interpreted in terms of variance (the sums of squares) of the data at the respective frequency or period (STATISTICA Electronic Manual). The most outstanding cycles are provided, and their duration in years.

The data also comprises an 11-year cycle, which could be related to the activity of the sun, and a 16.5-year cycle, for which, however, there is no good explanation, but which is probably derived from the changes in the socio-political situation or from the NAO cycle. The 8-year NAO cycle is clearly distinguishable in various data from Estonia, and its influence might be presumed (Jevrejeva & Moore, 2001; Ahas et al., 2002).

The annual (seasonal) cycle of births, which was also examined above, becomes clearly evident. The importance of cycles within a year in the total variance of the time series is significantly lower. The 6-month cycle (warm and cold season) and 2.4-month cycle, which divides the year into five parts and is to some extent also noticeable in Fig. 3, could be pointed out.

Annual grouping

The comparison of the seasonal pattern of conceptions of specific years with the average (Fig. 3) and with each other indicates that the years are quite different. In order to ascertain in which way the years could be divided into groups and which years belong to which group, the years were divided into 2, 3 and 4 groups by using cluster analysis. The best results were obtained with clusterisation into two groups, which is examined in further detail below. Division into 3 or 4 groups only added new details, but did not change the main course of the interpretation.

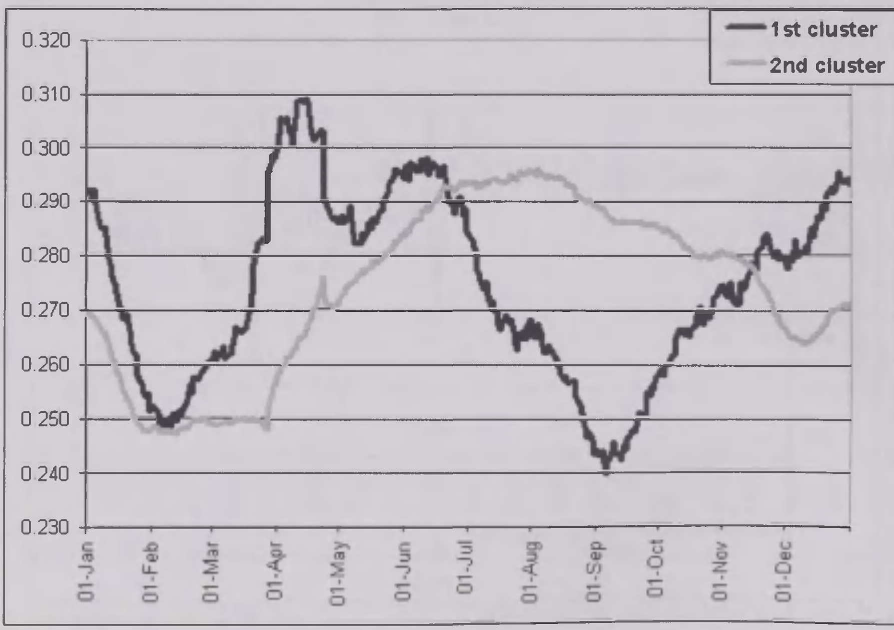

Fig. 6. Plot of means for two clusters. The 1st cluster describes the years of the agrarian type of conceptions (1901–1943); the 2nd cluster describes the years of the industrial type of conceptions (1944–1999).

The seasonal patterns of conceptions typical to the 2 clusters obtained (on the basis of the averages of the clusters) have been depicted in Fig. 6, and the elements of both clusters (years pertaining to one or another) in Table 2. From the table, it can be seen that cluster 1 mainly contains the years 1901–1943, and cluster 2 the years 1944–1999. There are also certain deviations in the division of the years. The years of cluster 1 comprise 19.4% and the years of cluster 80.6% of conceptions.

There are remarkable differences in the distribution of conceptions in the years belonging to cluster 1 and cluster 2 (Fig. 6).

Cluster 1 includes the earlier years (mostly 1901–1943), when the agrarian lifestyle had a stronger seasonal dynamic. In its seasonality, this type is considerably more complicated than the next cluster. The high periods of conceptions in cluster 1 are in spring and at the beginning of the summer, with a steep peak in mid-April (15.04), and less accentuated peaks in mid-June (4.06–15.06) and around the turn of the year. Clear minimum periods become evident in February and September.

Table 2. Members of each cluster

Cluster 1	Cluster 2
1901, 1902, 1903, 1904, 1905, 1906, 1907, 1908, 1909, 1910, 1911, 1912, 1913, 1914, 1915, 1916 1917, 1918, 1919, 1921, 1922, 1923, 1924, 1925, 1927, 1928, **1929**, 1930, 1931, 1932, 1933, 1935, **1938**, 1941, 1943	1920, 1926, 1934, 1936, 1937, 1939, 1940, 1942, 1944, 1945, 1946, 1947, 1948, 1949, 1950, **1951**, 1952, 1953, 1954, 1955, 1956, 1957, 1958, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1967, 1968, 1969 1970, 1971, 1972, 1973, 1974, **1975**, 1976, 1977, 1978, 1979, 1980, 1981, **1982**, 1983, 1984, **1985**, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999
35 members	64 members

Typical (closest to mean) years are marked in bold

Cluster 2 includes the later years (1944–1999), when there was a predominantly industrial (urbanised) lifestyle in Estonia. This type is more even throughout the year, and generally follows the tendency that there are more conceptions in periods with higher temperatures and vice versa. The only exception is the second maximum, which stands out at around Christmas and the turn of the year.

The principal differences in the seasonal distribution of conceptions between the clusters presumably arise from the differences between the type of society, which changed from agrarian to industrial in the course of the period under observation. These changes are also directly influenced by changes in the social and political regime and wars. Nevertheless, it is not possible to determine the exact reasons for the different seasonal rhythms of conceptions on the basis of this research. It can be assumed that in the agrarian society (cluster 1), conceptions were most strongly influenced by the warm period in summer and the stronger dependence of the organisation of life and the works from the seasons. People worked harder in summer, as it is the cultivation period, and rested more in winter.

In urbanised Estonia after World War II (cluster 2), the importance of the warm summer as the holiday period increased. This might have accelerated the growth in the number of conceptions in the summer months. In general, however, the "urbanised type" is more even throughout the year, primarily because the life of modern people is less directly influenced by nature and the related seasonality. Today the impact of various socio-economic factors (family planning, economic situation, societal influences etc.) has also increased, but their direct effect on the seasonal distribution of conceptions is more difficult to determine.

In dividing the database into 3 or 4 clusters, the main differences arise from the division of the first (agrarian) cluster type. The 2nd, industrial cluster type, which comprises 4/5 of all people, remains quite similar after such additional divisions.

Relations of conceptions with air temperature parameters

The most widespread opinion is that changes in the external environment deriving from the changing of the seasons directly or indirectly cause changes in conceptions (Cowgill, 1966; Ahas, 1999). Direct relations have been sought with air temperature, the length of day and night and the volume of radiation. In general, the curves describing the annual pattern of temperature and the seasonality of conceptions are obviously very similar (Fig. 7).

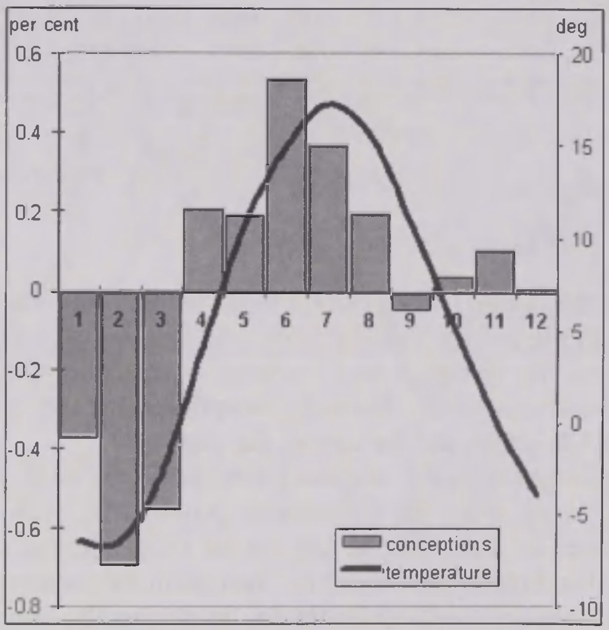

Fig. 7. Annual patterns of the deviations from the even distribution of conceptions and air temperatures in Estonia in the years 1901–1999.

Such a similarity leads us to ask whether there is a correlation between conceptions and air temperature. The result of the correlation analysis of the monthly average air temperatures and conceptions during the entire period observed in the research (Fig. 8) indicates a considerable correlation between the phenomena $r = 0.80$, $p<0.01$. As these points are approximate to a polynomial, one can presume that an even better relation could be found between those two indicators. At the same time, Fig. 8 still only confirms what is apparent from Fig. 7 – that the annual patterns of conceptions and air temperatures are similar.

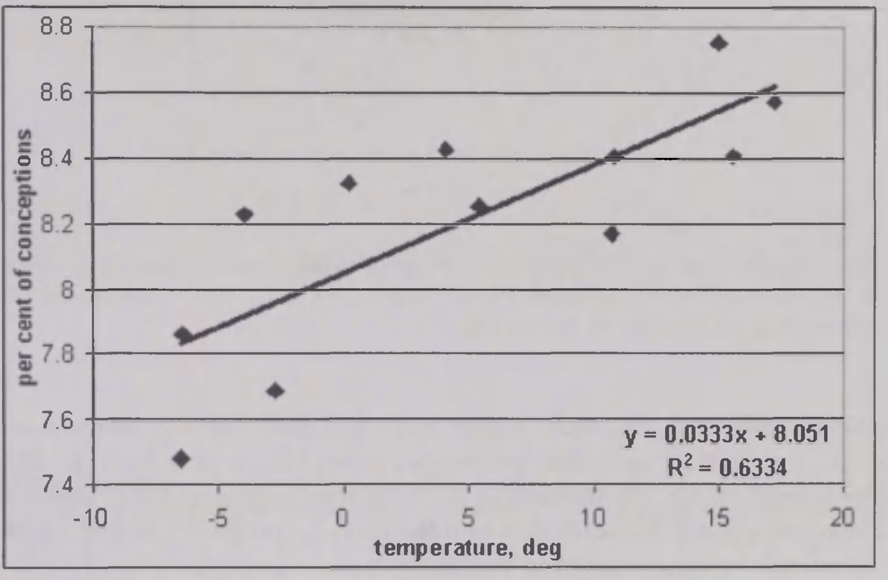

Fig. 8. The relation between the monthly average temperatures of the entire period and the percentage of conceptions in the same months (sequenced into 30-day periods).

In order to study the detected relation in further detail, we sought to answer the following question: are the temperature deviations (months that are warmer or colder than average) related to the deviations in the intensity of conceptions (number of conceptions over or below the average). Using this method, the data of each of the 1188 months included in the period were analysed. However, the results of the analysis of deviations in the temperature and in the monthly number of conceptions indicate that there is no relation between these two indicators (Fig. 9). Thus we can say that although both phenomena under observation have a generally similar seasonal pattern, there is probably no causal relationship between them.

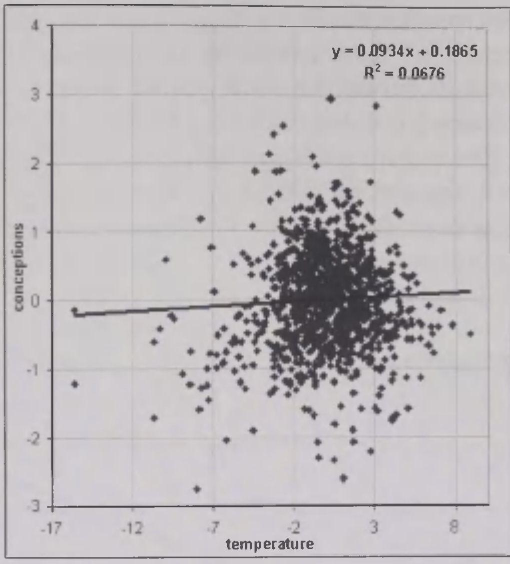

Fig. 9. Deviations in the average temperatures of specific months (horizontal axis) do not cause deviations in the number of conceptions (vertical axis) that take place in the respective months – there is no linear relation between them.

The analysis performed for each month indicated that slightly better correlations between air temperature and conceptions occur in March and July. In March the relation was positive, i.e. the increase in air temperature caused more conceptions. In July the relation with air temperature was negative, i.e. contrary. The correlations were neither improved by removing from the analysis wars and the regaining of independence as "socially bad years".

In searching for the closest possible relations between the number of conceptions and the indicators of air temperature, we took the period after World War II under closer observation (in order to preclude the influence of major social changes), which also more or less corresponds to the 2^{nd} cluster (Table 2). It turned out that slightly better correlations are obtained when one compares the date of reaching 33.3% of the number of conceptions with the cumulative sums of temperatures below zero in the winter (Fig. 10). Correlations reached the level of $r=0.34$ if one removes from the analysis the exceptional year 1993 (very low birth rate, very warm winter). In the contrary case, the relation would have declined to the level of $r=0.23$. In the latter case the cumulative of temperatures below zero in the winter described 11% of the dates of reaching 33.3% of the number of conceptions with relevance probability of $p<0.02$.

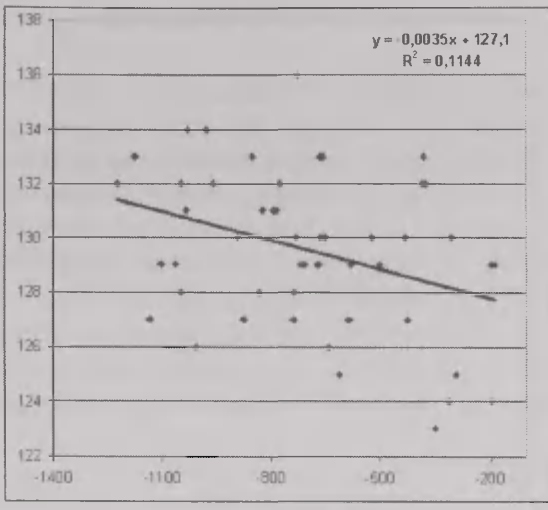

Fig. 10. The relation between the cumulative sums of negative air temperatures during the cold period (1.10–31.03) (horizontal axis) and the date of reaching 33.3% of the number of conceptions (vertical axis). The year 1993 was omitted as exceptional (very low birth rate, very warm winter).

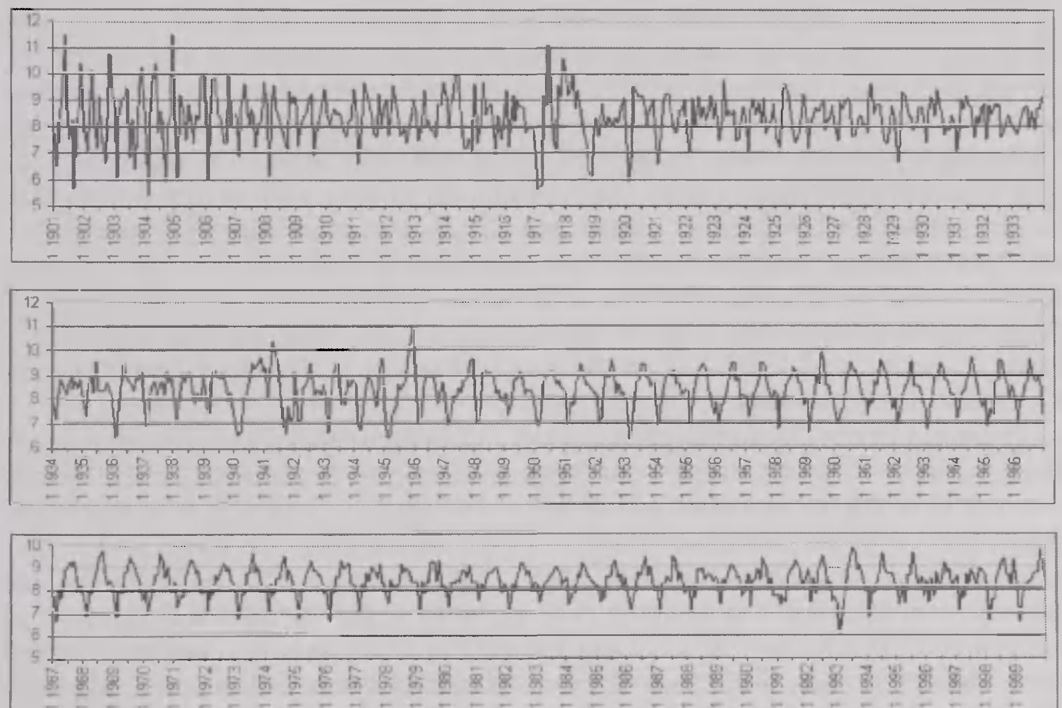

Fig. 11. Seasonal rhythm of conception dates of the Estonian population in the 20th century. The graph represents standardised values time series of the conceptions of the 1.39 million Estonians, with a one month step. The vertical axis depicts the monthly percentage.

DISCUSSION

The first matter that requires analysis and discussion is whether the studied conception dates represent seasonal phenomena. In general terms, seasonal phenomena are phenomena that can be described as having a specific seasonal rhythm that generally repeats year after year and is caused by the impact of the uneven distribution of sunlight deriving from the inclination of the axis of the Earth (the seasons).

The seasonality of Estonian conception data is proved by several aspects that have been mentioned in this research paper. The database is even more valuable because the analysis has been performed on the basis of the entire permanent population residing in Estonia as of 1.01.2001. As a result of the analysis of the data, two important aspects emerged, which support the claim that conception and subsequent births are seasonal phenomena:

1) The annual distribution curve of conceptions (Fig. 3) repeats year after year, and despite changing noticeably in the course of the century (Fig. 6), it still has fluent transitions during the entire past century (Fig. 11). The standardised variance of the whole database represented in Fig. 11 is probably the most expressive evidence of the seasonality of births.
2) The spectral analysis of the whole database clearly identifies the annual cycle as the most important aspect (Fig. 5). This is further proof of the seasonality of the birth data. Although the 24.8 year cycle is more emphasised on the relative scale of spectral analysis, this cannot actually be fully considered, as this is probably impacted by the wars, and the whole period only contains a maximum of 4 cycles.

Given the above, it can be ascertained quite firmly that we are facing a phenomenon that is repeating year after year. This means that the conception of human beings is a seasonal phenomenon. Actually, the conception and birth dates of human beings can also be called phenological, as seasonal organic phenomena are traditionally classified as 'phenological', while seasonal phenomena of inorganic nature (air, snow, water, soil) and society (society, economy, culture) are classified as 'seasonal'. Now we only need to clarify whether the annual variance of births is a biological or a social phenomenon. Today the term 'seasonality' is more frequently used in the literature. The seasonality of births is also proved by earlier research, an overview of which has been provided in the theoretical part of this paper.

If conception is a seasonal phenomenon, the next question would be what might cause the seasonality of conceptions. From phenology it is precisely known that the seasonality of the life processes of both plants and animals is most conditioned by the fluctuation of the temperature of the exterior environment and the photo period. As a result of extensive analysis, Lam and Miron (1996) have established certain relations between conceptions and temperature. For example, under certain conditions high air temperatures reduce the number of conceptions (the example of the southern states of the USA). At the same time, winter frost does not have a direct impact on conceptions. Also, the relations with temperature found to explain the summer conception maximums (the birth boom in spring) typical of Northern Europe were scarce.

In analysing our data, it became clear that the annual patterns of conceptions and air temperature are similar (Fig. 7 and 8). Certain relation (March – positive, July – negative) can be seen between the number of conceptions and the average air temperature of certain months.

The analysis of monthly values, however, indicates that deviations in air temperature do not condition deviations in the number of conceptions (Fig. 9). Nevertheless, the circumstance that a month with significantly higher/lower air temperature than the average does not condition a higher/lower rate of conceptions than the average does not necessarily mean that there is no relation between air temperature and conceptions. When one observes longer weather periods instead of a calendar month, which is a relatively random and short period, we can see that the relation between, for example, the cumulative sums of the temperatures below zero in the winter and the date of reaching 33.3% of annual conceptions is already reliable (Fig. 10). This relation describes 11% of the data, i.e. 22 springs, which is quite a good result in the context of this paper. Therefore the remaining 89% of the variance is conditioned by other reasons, including social, random and certainly also other biological reasons. We did not use the photo period (the duration of daytime) data in this research, although the duration of daytime is automatically comprised in the date included in the seasonal data.

In respect of the types of seasonality of conception throughout the world, Estonia is primarily similar to its neighbours in Northern Europe. The most characteristic feature for Northern Europe is the conception maximum in summer (June-July), the subsequent decline that lasts until a moderate increase in December, and the absolute minimum in winter (January-February). This is quite similar to the conception curve of Estonia given in Fig. 3 and with the Estonian conception data from the earlier period (1922–1929) that has been studied. The search for seasonality of conceptions characteristic to Estonia is slightly hindered by differences in the earlier or agrarian (1901–1943) and the modern or industrial (1944–2000) conception curves (Fig. 6) obtained as a result of the cluster analysis. The main difference in the earlier period is a significant decrease in conceptions during August and September. One explanation for this could be that harvesting work during the fall was the most important and intense working period of the year, and there was no rest at this time. The conception curve of the earlier period (cluster 1) also closely matches the conception curve of Estonia describing that period, which has been published earlier in the literature.

It would certainly be possible to explain the conception rhythms of countries that are similar to or different from ours on the basis of natural conditions and cultural traditions, but regrettably present knowledge, data and models do not make it possible to explain the relations and reasons completely.

CONCLUSIONS

In this research paper, we analysed the seasonality of Estonian birthdays and the conception dates calculated on the basis thereof. The distribution of the 1.39 million conception dates studied clearly indicates that we are dealing with a seasonal phenomenon, i.e. a phenomenon that repeats year after year. The number of conceptions is greatest in spring and summer (June-July), and smallest in winter (January-February).

The different temperature parameters studied in searching for the reasons for the seasonality of births did not yield good results. Certain parameters describe slightly more than 10% of the data, but no more substantial relations were discovered in the course of the research.

It could be assumed that as the daily average air temperatures do not have a direct impact on natural processes, the application of the physiologically more important minimum or maximum temperatures and temperature sums instead of average temperatures would give better results. In phenology, it is precisely such parameters that are used to identify relations and prepare models. Therefore, in future the seasonality of conceptions should be modelled in further detail by relating the physiologically outstanding factors of specific years with the birth data of the population. Success in research might also be achieved by performing the respective analysis in countries that have had greater social stability than Estonia.

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THE POLITICS OF NATURE ON THE BORDERLAND OF THE EUROPEAN UNION. THE CASE OF WATER IN NARVA–IVANGOROD

Jussi S. Jauhiainen

INTRODUCTION

In late 2007 the inhabitants of Narva, a town located in northeast Estonia by the border with Russia, learned that the local water provider Narva Vesi (a private municipal company in Narva) aimed to raise by half the price of the water they use (Rannajõe, 2007). Many inhabitants were infuriated and asked the local politicians to do something about it. The people could not understand why such an increase should take place. For the elderly, water had been very inexpensive, almost free, for most of their lives. Some recalled the days they shared a water system with the people on the other side of the river in Ivangorod. The residents of Narva wondered why the price of water across the river was much lower. Again, the elderly had lived most of their lives in one functional urban area that shared a common water infrastructure through which the inhabitants drank and used the same water. Many inhabitants in Narva pointed an accusing finger towards the national capital Tallinn and the European Union "capital" Brussels. This was done in the same way they used to blame Tallinn and Moscow for their water-related problems during the Soviet period.

Many elderly people and others in Narva are very local. They possess old Soviet documents that are no longer valid, but have neither Estonian nor Russian citizenship. They consider themselves the "true citizens" of Narva. Today, a majority (95%) of the inhabitants of Narva remain speakers of Russian, and only a minority (44%) are Estonian citizens (Statistic Estonia, 2008).

Before the increase, the price of water in Narva was curiously low in comparison to other Estonian municipalities. For example, the price for individual consumers was only a quarter of the price in some municipalities around the capital, Tallinn. The price for industries would not rise from the then current 1.71 euros per cubic meter, but for individuals the new price of water was to be 1.18 euros per cubic meter (Narva Vesi, 2008).

Like the inhabitants, the textile industrial company Kreenholm, which since the 19th century had been the largest private employer of the town, claimed that the rising water costs would substantially harm their business, which used a lot of water. Strong accusations flew between Narva Vesi and the Kreenholm factory. The issue of water also became politicized at the national level. As regards the earlier water price rise in Narva in 2006, Estonia's ombudsman Jõks argued in autumn 2007 that it had not followed the principles of a transparent democratic society (Taras, 2008). In addition, the national health authorities came to the conclusion that the water provided in Narva contained excessive amounts of certain chemical substances. They prohibited its sale for individual use, a decision that was strongly objected to by Narva Vesi (Mäekivi, 2007; Rand, 2007). By the beginning of 2008, Narva Vesi had still not been able to solve this problem. The national authorities fined them and continued to prohibit the sale of water by Narva Vesi (Masing, 2008). The local people were very confused – how could water that was once pure and almost free of charge have become seemingly undrinkable and much more expensive? The water issue became even more complex when the Kreenholm factory owners refused to pay the accumulated water bill. Instead, in November 2007, they sold all the property to a new Estonian enterprise before the property would have been seized (Purga, 2007). In early 2008, the new owners closed the activities of Kreenholm, leaving thousands without a job.

This article studies the politics of nature in the European Union borderland of Estonia. This borderland has been and is a complex and specific context (Jauhiainen, 2002). Well-known scholar of science and technology studies Bruno Latour (2004) argues that as regards nature, facts and values are inseparable. The positions of scientists, politicians and ordinary citizens are mixed, and none of them has a privileged position that cannot be criticised. This article does not contribute to the discussion about Latour's much-debated vision of new political ecology with assemblies of humans and nonhumans. It must, however, be acknowledged that politics and nature are inseparable and that both humans and nonhumans must be recognized in discussing issues related to water.

The case study methodology is used to analyze the politics and policies in regard to water in Narva–Ivangorod. Attention is paid to the transformation of water into a commodity over a long period and to the politics of water more generally. Water is a topic in which nature and politics are particularly combined in specific geographical contexts (Kaïka, 2005).

An appropriate method to approach the complexity of politics of nature in a particular context, here in Narva–Ivangorod, is case study with field practice and multiple research materials. The following viewpoints are presented as a further development of the notions of the case study method by social scientist Bent Flyvbjerg (2006). One can develop theoretical knowledge about complex and abstract issues, such as politics of nature, by engaging in practice and everyday activities of water-related issues. An intensive case study in a specific context obviously has peculiarities, but by conceptualizing research outcomes, one can generalize and develop theory. Nevertheless, the comparison of many cases indicates which aspects are common and which ones remain particular due to spatio-temporal circumstances. The usage of many materials balances the research and diminishes arguments based on a method or interpretation that is too narrow.

It is a common challenge for all case studies to be able, especially if written as an article and not as an extended monograph, to limit enough but not too much the empirical material, to indicate the evidence and to be able to summarize the key findings generally enough. In addition to earlier studies, the research material for this article consists of water-related documents from the Narva archives. These also include business reports by the local water company Narva Vesi. To go in-depth into the unwritten events of the recent past, nine thematic interviews with the key persons dealing with water-related issues in Narva and Ivangorod were conducted in 2005. In addition, the Estonian public media was monitored by browsing through the two largest Estonian newspapers regarding water issues in the Narva–Ivangorod area. The interviews were transcribed and cross-examined with the issues discussed in the media. The research also included several field visits to the Narva–Ivangorod area over several years.

WATER AND POLITICS OF NATURE

Water is a resource with particular biophysical, socio-cultural and spatial characteristics. Many economic, political, social and ecological issues are included in water, such as basic needs, everyday use, trade, management, safety, etc. (Finger et al., 2006). In recent theoretical discussions on nature and elements of nature, many scholars argue that one should overcome the dichotomy between the often essentialized and separated categories of society and nature. In the past ten years, there has been a discussion about "hybrids", intertwined socionatures (Castree & Macmillan, 2001; Ivakhiv, 2002; Braun, 2004; Swyngedouw, 2004; see also Latour, 2004). Water is an illustrative example that supports such a viewpoint of seeing society and nature as one interwoven complexity. From the constructionist point of view, nature as such cannot meaningfully exist without humans who give nature its meaning. Even if we take a different ontological standpoint, for example critical realism, nature and society cannot essentially be fully separated. To grasp the politics of such socionature(s) in practice, the case study method discussed above is a useful approach.

The transformation of wild and free water into regulated urban water weaves together the urban fabric and ecological, economic, social, and political networks. In this process, nature is metabolized and politicized (Swyngedouw & Kaïka, 2000). Such transformation and organization of water is a multifaceted process. Key scholar Eric Swyngedouw (1999), who has developed the idea of socionature as a hybrid by utilizing water as an example, writes, "*These* [water] *flows would narrate many interrelated tales: the story of social groups and classes, and the powerful socio-ecological processes that produce social spaces of privilege and exclusion, of participation and marginality, of chemical, physical and biological reactions and transformations, of the global hydrological cycle and global warming, of the capital, machinations and strategies of dam builders, of urban land developers, of the knowledge of the engineers, of the passage from river to urban reservoir, of the geo-political struggle between regions and nations.*"

A crucial issue in the politics of water is the transformation of water into an object. Such 'objectification' considers water as an economic good with an exchange value. This also indicates how water is an element of socio-nature. Such commodification (i.e. a substantial role in the pricing, measurement, distribution, etc. of water) adds new qualities and agents into the transformation and organization of water. The political-economic perspective underlines the importance of market incentives and private companies in such a transformation. This links water to the theories of ecological Marxism and ecological modernization (Davidson & Frickel 2004; see also Smith, 1984). The transformation of water is part of modernization contributing to industrialization and urbanization.

The measurement of the technical and economic efficiency of water supply systems becomes significant when the water provision becomes a business activity (Bakker, 2001). It is common to create comprehensive and manageable water networks based on economies of scale. In water supply, Bakker (2005) makes a distinction between the privatization, commercialization and commodification of water. *Commodification* is a process whereby goods formerly outside market spheres of existence enter the world of money. Water becomes exchangeable and saleable through the medium of money. This transformation of biophysical objects, such as water, takes place simultaneously in three spheres: discursive, material and socio-economic. Water is abstracted, valued and displaced in the discursive sphere. This means that water is separated from its ecological context. This means the separation of drinking water from a river by physical intervention and adaptation in the material sphere. In addition, price, charge, allocation and exchange methods as regard water are introduced in the socio-economic sphere. *Commercialization* requires the implementation of management practices supporting commercial principles (efficiency), methods (cost-benefit analysis), and objectives (profit-maximization). *Privatization* means a change from public to private ownership in the organization and practices of water supply. Bakker (2005), however, rightly observes that commodification is a contested, partial and transient [process] in which objects move in and out of and back and forth from their commodity status. Commodification often takes place through various events and socio-technical mediations, events and ruptures. The politics of nature consists of interconnected pieces. The transformation of water is not necessarily, and it is rarely, a linear process.

The debate over water policies (not in the sense of politics as regards the deeper ontological question of the essence of water as nature) has become one of utmost importance in the European Union, especially since the launching of the Water Framework Directive. This policy regulates the condition of natural waters in the territory of the European Union, for example by statutory naturalization of water bodies by environmental governance (Davidson & Frickel, 2004). In addition to this aim of providing a cleaner water-related environment by 2015, directly business and economic related issues of water have also emerged. Among these are the cost-related rationalization, privatization and marketization of water services (Kallis & de Groot, 2003). Increasingly, water is produced, distributed and exchanged primarily through the economic profit imperative (Bakker, 2001). However, environmental concerns are becoming increasingly important as part of this business logic.

CASE OF NARVA–IVANGOROD

Water has played and is now playing a fundamental role in the development of the area that today comprises the town of Narva in Estonia and the town of Ivangorod in Russia. For many centuries, these towns have formed a common functional area referred to as Narva–Ivangorod. Broader political changes have both brought these towns together and separated them. The water-related issues in Narva–Ivangorod over a longer period of time are briefly described below. Special emphasis is placed on water as politics of nature: how water becomes a commodity and how this commodity is transformed in different political and economic contexts.

The transformation of water until the early 20th century

Location by the Narva River was fundamental to the birth of Narva. A stronghold under the Danish Kingdom was established in 1256 by the river, not too far from the Baltic Sea. Such a location was important because of the trade between Central European regions and Russia and its predecessors. The Vikings had earlier already used the same river for their travels towards present-day Russia, and the area had been inhabited for a very long time. In 1345, Narva received town rights from the King of Denmark. The small town soon passed to the Teutonic and then to the Livonian knights, who possessed it until the mid-16th century. During the Livonian era, the Hermann stronghold was built next to the river (Eesti Entsüklopeedia, 2003). Narva gradually grew in importance. In 1492, Grand Prince of Muscovy Ivan III established a stronghold on the other side of the river to facilitate the Russians' access to the Baltic Sea and as protection against the expanding Western forces. Next to the stronghold there arose a settlement that became known as *Ивангород* (Ivangorod), 'the town of Ivan'. Occasionally there were hostilities across the river that was a line separating the two settlements. In fact, troops from the Russian side destroyed Narva several times.

In 1558, Narva and Ivangorod became a unified urban area of 5000–7000 inhabitants when Russian troops conquered Narva. Narva–Ivangorod became more important and competed in trade with the Hanseatic town of Tallinn. Sweden conquered the area in the latter half of the 16th century, and in the following century both the stronghold and the town developed in the Baroque style. In the beginning of the 18th century, the Russians attacked Narva, and their second attempt in 1704 was successful. Both Narva and its district Ivangorod were conquered, and Narva–Ivangorod lost its significance as a border town. Instead, the town was developed as a harbour to transport wood (Eesti Entsüklopeedia, 1994b). The 18th century marks the end of the premodern Narva–Ivangorod, characterized by their geopolitical location between the West and the East. Water in the form of the river was fundamental in the development of the settlement, because of trade and because the river also regulated traffic between Narva and Ivangorod. Water from the river and wells was obviously also used in everyday chores.

The 19th century was a period of modernization in Narva–Ivangorod. The first textile factory was established in 1819. A few years later it utilized the first steam-powered machine in Estonia. The town of a few thousand inhabitants began to grow when new textile factories were established. Kreenholm was founded in 1857, and it later became the largest textile factory in Europe. The factory brought various water-related innovations to Estonia, including several machines utilizing waterpower (Eesti Entsüklopeedia, 1994a). This modernization meant that the river water also received more complex roles than merely a medium of transport; water was also, for instance, an important source of energy.

In addition, during the late 19th century, complex drinking water and sewage water systems were organized in Narva–Ivangorod. In 1875 Town Councillor Vassily Petrov proposed to the Town Council the organization of water supply in Narva. Following the expansion of industry, by the 1870s the town's population had increased to 30 000, one third of whom lived within the town borders (Kihu, 1960). In his declaration to the Mayor (cited in Nikolayev, 1926), Councillor Petrov stated:

> *As we all know, water is a necessity nobody can live without, but the inhabitants of Narva suffer from an extreme shortage of water. Many are forced to carry river water home on their shoulders or borrow a bucketful of water from their neighbour. It is true that there is a person named Hartmann (and another, named Reihard), who carries water to houses, but he can hardly satisfy the townspeople's needs. People are often left several days without water, forced to use melted snow or rain water instead and wait until the water carrier shows mercy upon them after all their trouble, selling them a barrel of water for 15 to 25 kopeks. It has to be mentioned that water carriers demand additional money for liquor and if you don't tip them, you may spend another couple of days without any water at all. ... The Town Law states that it is the duty of the town council to attend to the well-being of the town, which among other things includes the installation of waterworks and taking care of fire-fighting measures according to articles 30 and 31 of the fire-safety regulations. Water supplies must be established and barrels of water kept in the attics. In accordance with its decisions of April 10, May 25 and June 9, 1874, the Town Council should allow an additional sum in the budget to buy 4 horses which could be given to the fire-fighting squad so that water could be carried to people for 15 kopeks a barrel. Such a measure would be a favour to the town and will be met by general approval.*

The letter indicates how water was connected to the economic sphere and was a commodity in this period of modernization. After voting, the Narva Town Council decided to negotiate with the Volunteer Fire Fighting Squad of Narva about water carrying in the case of fire and supplying the townspeople with water for a certain tax. It was decided by common consent to make a proposal to the Town Government to gather information about the ways and costs of installing waterworks in Narva. The government estimated the costs to be 15 000 Roubles for pump house installations, fitting pipes, tanks and public water taps, maintenance costs and incidental expenses. In addition, annual maintenance costs were estimated to be 1500 Roubles (Nikolayev, 1926).

The Town Council called out for persons interested in supplying the town with water and awaited proposals during the winter of 1875/1876. According to Councillor Petrov, because of the competition in water supply, the inhabitants of Narva had recently been served satisfactorily. However, later in spring 1875 Reihard stopped offering his services. Many people were forced to carry water from the river themselves or pay Hartmann's workers the double price for it. Other proposals to organize the water supply were sought, but these were not realized. Then the Government proposed that the Council should decide positively on the construction of waterworks as its own property. There were several persons with technical education in the government so the matter progressed smoothly (Nikolayev, 1926).

The landlords in Narva agreed to buy for households over a million buckets of water for a quarter of a kopek per bucket. After that it was decided to start the construction of the waterworks immediately. The amount of 25 000 roubles was allocated from the reserve fund, and up to 7000 from the surplus returns, in total 32 000 roubles. The fitting of pipes began on July 29, 1876, and by September 1876 the pipes had been fitted in eight streets, in the market places and in the suburbs of Narva. On September 28, 1876, the water was pumped into the tanks and the waterworks of Narva started functioning (Nikolayev, 1926). The water supply became permanent in the early 1880s (Андреева et al., 2001). By the end of the 19th century, the population of Narva was 30 000 people, comprising many nationalities, and the town was home to half of Estonia's industrial workers, of whom 5 400 worked at Kreenholm. The town continued to grow, and in 1913 45 000 people lived in greater Narva, including Ivangorod. The amount of workers at Kreenholm was over 10 000 (Eesti Entsüklopeedia, 1994). During the modernization period, the river water became commodified for use by people, industries and power stations.

Transformation of water from early to late 20th century

Estonia declared independence in 1918 and signed a peace treaty with Russia in 1920. Accordingly, Ivangorod (renamed *Jaanilinn* in Estonian) became a part of Estonia and Narva. Due to the poor relations between Estonia and Russia, economic activities in the Narva area declined, as did the population, which fell to 22 500. Later World War II broke out and the frontline between Estonia and Russia was located in Narva for a few months. The town was devastated: 98.2% of the buildings were practically destroyed, and the remaining buildings substantially damaged (Weiss-Wendt, 1997).

After the war, Estonia was incorporated into the Soviet Union and the damaged textile industries were reconstructed. The labour force was brought in from different parts of the Soviet Union, and Russian became the *lingua franca*. Ivangorod and Narva formed a common functional area, and connecting bridges were constructed across the river. Until the end of the 1950s, the water for the common water supply network was taken from the water station near the river bridge and purified using very basic methods (Андреева et al., 2001). The period from the 1950 to the 1990s transformed both the river and water usage. In 1957, a raw water purification plant was opened in Mustajõe, 20 km upriver from the town. The Narva sewage station was established soon after, and a year later, in 1967, it also treated half of the wastewater from Ivangorod. The other half went straight into the river untreated, creating environmental problems downstream.

The transformation of water to a quasi-commodity led to the necessity to measure infrastructure. Once a month the representatives of Narva and Ivangorod town water organizations together measured the processed quantities of drinking water and sewage (Malihhin & Tsvetkov, 2005). The water measurement instrument for Ivangorod was located in Narva. The amount of sewage delivered from Ivangorod to the Narva station was measured in Ivangorod using pipe instruments.

Even more significant was the development of specific industries related to water. In the late 1950s, a water power station was constructed on the Ivangorod side of the river. The river flow based on natural variation ended, and the riverbed at the local waterfall was dried. In order to regulate water quantity, a water reservoir with a dam was built upstream. In 1956, the reservoir reached its size of 191 km^2, in some parts reaching a depth of up to 15 meters, but was on average low. Regulated water flows were needed for growing textile production, and the new water power station for exploiting energy resources. In the nearby area in Estonia, the mining of oil shale was increased substantially. This material was transformed into energy in two power plants located by the river, one of which was opened in 1959 and the other in 1969. Both needed large quantities of water in this process.

The enhancement of water infrastructure brought about a need to manage the water network more comprehensively. The Narva Municipal Office for Water Supply and Sewage was organized in 1965 and modified in 1971 and 1984 under the Soviet Estonian general administration for water supply and sewage. By the end of the Soviet period, Ivangorod had 12 000 and Narva about 89 000 inhabitants living in a significant industrial urban area (Eesti Entsüklopeedia, 1994b). The complex water infrastructure spanned from dikes to channels, locks, pumps, and pipes. In addition to common everyday consumption of drinking water and extraction of wastewater, many uses and technologies were involved with the river water. Several local industries in Narva and Ivangorod had their own water bores. The network around the water extended spatially, including inhabitants, various local–regional political and economic interest groups, textile and other factories as well as naturalized environmental entities, etc.

Water was considered a commodity, but not significant as a direct resource for economic profit. Despite certain similarities with nationalized water industries and the state hydraulic paradigm of water management in Western Europe (Bakker, 2005), the Soviet regulatory system was much less concerned with cost recovery and social equity related to the means of the individual and collective consumer. For example, the inhabitants paid a small monthly fee regardless of the actual amount of water used. The water infrastructure was developed to supply the increasing demand of water to feed the five-year plans of the growing textile industry. Constructed water pipes foresaw the further expansion of the industrial use of water, in which the cost of providing water did not play a fundamental role. Again, there are some similarities to the Western European context, where the use of water infrastructure is promoted to its fullest capacity. The Soviet era ends this period characterized by high modernization.

Transformation of water from the late 20th century to today

The period following 1991, when Estonia regained its independence, is one in which various water-related material and human networks between Narva and Ivangorod disintegrated (see Jauhiainen & Pikner, 2008 from which this section is elaborated). The water supply and sewage infrastructures were shared and used equally by Narva and Ivangorod in 1991, despite the political separation between Estonia and Russia. Nevertheless, the reorganization of the water network soon began. In independent Estonia, water regulation was reorganized nationally and locally, bringing a new management approach to water. In 1992, Eesti Vesi was founded, which was an Estonian state-owned enterprise that also owned Narva Vesi. In 1993, Narva Vesi was transformed into a municipal enterprise located in Narva, and in 1995 it became a public limited company owned by the municipality (Narva Vesi, 2007).

Narva Vesi became a curious mixture of business and politics involving water. In the beginning, the increase in turnover and dividend distribution was not the target. In fact, only limited municipal investment was planned, and it was expected that aid would come from external sources such as the European Union. The local water prices in Narva and Ivangorod were first set by the company and then approved by the Narva Town Council (Rist, 2006). The price was kept low for individual and industrial users – mostly in order to gain political support for the ruling party. This economized budget of Narva Vesi reduced investments on infrastructure. The water price for Ivangorod was even lower, because the wholesale price did not have to include delivery infrastructure costs (Rist, 2005).

The delivery of drinking water to Ivangorod was regulated in Narva. The municipality of Ivangorod paid for the consumption and distribution of water on a monthly basis. Sewage from Narva and Ivangorod first went through the Narva purification station and was thereafter directed down the Narva River (Sizova & Sizov, 2000). The water organizations in respective towns held few annual meetings but had otherwise little cooperation, and even when they did, that only took place in practical matters.

Towards the second half of the 1990s, the water issue began to change substantially. Narva Vesi continued to distribute the water to Narva and Ivangorod. However, certain cost-related aspects were on the agenda on the Estonian side. New metering systems for water consumption were introduced in 1994–1995 throughout Estonia and especially in Narva. The inhabitants were motivated to install household water consumption meters, as they would thus pay less for water consumption. The Soviet-era daily per capita water consumption norms (300–400 litres) were about three times higher than actual consumption, which is why the water norm made household water bills high. In 1996–97, Narva Vesi implemented a European Union funded project to install water consumption meters to Narva households (Rist, 2005). The less wealthy Narva inhabitants got their meters through loans. The household water meters resulted in a decrease in actual water consumption and, subsequently, a decrease in the income of Narva Vesi, and thus created a need to raise the price of water. In addition, large amounts of water were lost by water pipe leaks and also by the purposeful stealing of water.

The rationalization and marketization of water services became new topics, under which the water networks developed in Narva–Ivangorod. In Ivangorod, water was paid for according to a fixed monthly fee subsidized by the Russian state authorities up to 50%. However, Narva Vesi raised the water price about nine times during the 1990s (Malihhin & Tsvetskov, 2005). The fastest price change took place in 1997–98, after which the cost tripled the standard price in Leningrad Oblast. Nevertheless, the Russian authorities continued to subsidize the water use in Ivangorod. Soon the municipality of Ivangorod became indebted to Narva Vesi because it and its inhabitants were unable to pay for "*the golden water of Narva*" (Tsvetskov, 2005).

Due to the Ivangorod's increasing debts, Narva Vesi implemented periodical cuts in 1997–1999, which involved not providing drinking water to Ivangorod or providing it for just a few hours per day and at low pressure. Narva Vesi informed the municipality of Ivangorod of the supply cuts in advance. The municipality further informed the inhabitants, so the people were able to collect reserve water in advance. In Ivangorod, there emerged various alternative ways to obtain drinking water by by-passing the water provided by Narva Vesi. Another result was that the sewage water from Ivangorod was largely channelled into the river without cleaning, which created annoyance in Estonia. This issue also received attention at the international level, because unclean sewage water eventually ended up in the Baltic Sea. The Town Council of Narva initially postponed the total closure of water delivery to Ivangorod. However, the decisive end took place in 1999, when the debts of Ivangorod to Narva Vesi had risen to over 1.2 million Euros. Water had become a commodity, although still with abstract and not fully payable exchange value.

The water issue also reached prominence in international politics, and was actively discussed in the national and international media. The main issue was the (non)payment of water by the municipality of Ivangorod (see Jauhiainen & Pikner, 2008). The government of Estonia even paid part (about 655 000 Euros) of Ivangorod's debts to Narva Vesi without broader consultation to avoid Ivangorod dumping sewage into the river (Estonian Ministry of Foreign Affairs, 1998). In interviews held in Narva in 2005, the debts of Ivangorod and the different economic systems between Estonia and Russia were mentioned as the main reasons to stop drinking water delivery and wastewater collection. In Ivangorod, the local authorities also referred to broader political reasons. Leningrad Oblast gradually paid the water debts to Narva Vesi in 2001–2004. The commodification of water during the 1990s included pricing issues, but, as Bakker (2005) has noticed regarding the OECD countries, there was no shift to market environmentalism in water supply management. The position of the environment (cost, nature) was weak, price competition was absent, and resource costs were insignificant on the water agenda.

Both Narva and Ivangorod improved the physical water infrastructure network in various ways during the 1990s, often separately. Narva Vesi headed towards water supply commercialization, and the Ivangorod municipality continued with state-subsidized water. The construction of new local water infrastructure in Ivangorod was half-finished by the time of the final water closure in January 1999, and a sewage station was opened in 2001.

In Narva, new infrastructure was built, and most artesian wells were closed down. Today almost all houses in Narva are equipped with a water measurement system, and the inhabitants of Narva pay for the amount of water they consume (Ers, 2000). However, the price of water has risen so much that the reduction in the use of water in the past ten years does not mean a reduction in the actual costs for the inhabitants. Regarding the sewage infrastructure in Narva, a new purification plant built in 1997–98 replaced the previous one in Mustajõe, and a new pipe from the Mustajõe River to Narva town was put into operation. Since 2002, the Mustajõe water station has been automated. Water quality is measured weekly, and technical control is conducted on a monthly basis. At the end of 2005, Narva Vesi opened a new sewage station that fully replaced the one dating from 1960. Funding mostly came from European Union sources, and Narva Vesi paid only a tenth of the investment.

Water consumption by inhabitants has diminished radically in both Narva and Ivangorod since the Soviet Union for various reasons. The population in Narva and Ivangorod has fallen by a quarter since 1989, and at present is about 77 000. The water consumption is about one-third of what the water infrastructure was designed for.

Therefore the water cycles are slower and pipes degrade faster (Tsvetskov, 2005). In addition, several industries using water have become bankrupt – Kreenholm as the latest significant case in the early 2008 – and the rising water costs lessen the use of water. Despite the rapid and substantial (46%) rise in water prices in 2008 (Narva Vesi, 2008), water costs in Narva are still below the Estonian average. In autumn 2007 the Prime Minister of Estonia, Andrus Ansip, expected that the water price would still rise substantially in towns in Estonia (Kalamees, 2007). The water industry in Narva is still mostly supply-based without competition, and local politics intervenes in price regulation in ways that are difficult to forecast. At the moment, Narva Vesi does not have a clear and transparent price regulation system. This was recently criticized by Estonian ombudsman Jõks, as presented in the introduction (Taras, 2007).

Narva Vesi has recently worked together with a consultancy firm to improve the water management system. The report indicates certain steps (e.g. efficiency criteria, outsourcing) that would pave the way for commercialization of the water supply (Business grain, 2002). However, as Bakker (2005) has observed regarding England and Wales, water companies remain vertically integrated monopolies, and full commodification and commercialization of water through market environmentalism has thus far remained incomplete. In addition, the privatization of Narva Vesi will be postponed until the next decade due to the requirements of European Union resource use.

While households and local industries are significant users of water, the large electrical power stations are the largest consumers, as they use water for cooling processes. Their industrial water originates from the river's water reservoir, goes through several cleaning phases in the electricity stations, and after use mostly returns to the reservoir. This complex issue would require a separate study. The use of water by these power stations has been diminishing because of the reduction in the mining of environmentally harmful oil shale. There is also thermal and alkaline waste from the electrical power stations and the Narva rubbish collection plant (Narva town, 2002). Despite the water economy, there are also several other negative environmental impacts in Narva, such as wastewater leaks into the river and environmental issues involving the water reservoir, which have not been very thoroughly discussed to date. The issues of controlling the nature of water, i.e. preventing flooding and reducing the quantity of harmful substances, have been on the agenda. However, Narva Vesi is currently experiencing serious challenges with the latter, according to the national health authorities (Masing, 2008). The abstraction of water from nature seems not to be fully possible, as these issues indicate. The role of the environment as a fully recognized, equal and legitimate participant in water-related issues has not yet been addressed in Narva–Ivangorod. The cases from Western Europe (see Bakker 2005; Kaïka, 2005) suggest that market environmentalism should be an upcoming issue in Narva–Ivangorod, but the specific transboundary context creates obstacles to this process.

CONCLUSIONS

Facts and values are mixed in the politics of nature, as the case of water in Narva–Ivangorod exemplifies. The reactions by the common people in late 2007 in Narva in regard to water – astonishment at the rapid price rise and scepticism regarding the quality of water – were quite correct, as they often are. The issue was and had throughout the inhabitants' lives been about the change in the *nature* of water. Instead of being *only* water – a free-flowing, liquid substance in the river between Narva and Ivangorod, in a single urban area that is connected by everyday activities – water had been extracted from nature and transformed into a commodity. Such a commodity was no longer a *natural* matter but it had a good economic value and political meaning. For the enterprises, the substance was called *industrial* water. As Castree (2003) has indicated, the transformation of a once free and later state-managed common good, such as water, into a measured, monetized, privatized and sellable good is a common phenomenon in Western societies. Increasingly, water is produced, distributed and exchanged primarily on the basis of the economic profit imperative (Bakker, 2001). However, such transformation from the use value of water to the exchange value often involves contradictions and conflicts. It is about the politics of nature in both a narrow and a broad sense.

In conclusion, three observations emerge from the Narva–Ivangorod case. First, instead of trying to separate nature from society or politics, the case indicates that water is socio-natural or politico-natural. The latter, clumsy term can be used in referring to both the political ontology of water and to the political practice that surrounds water. Second, by removing the nonhumans from the water-related processes – whether in the area of pipes, bacteria, chemical substances, the geological layer of the riverbed, or other nonhumans – one receives a very limited picture and twisted interpretation of a multitude of issues taking place in relation to water. Third, science is actively involved in politicizing water by tearing water from its *natural* element and by abstracting it into a seemingly apolitical substance.

A case study is a way to engage the reader, the researcher and the field into communication between each other and thus into processing various types of knowledge, whether explicit, implicit or tacit, about the issue in question. Case study is not the only method to study a complex topic such as water in the framework of environmental policy. Nevertheless, it facilitates the discussion between various materials, and by contextualizing both concepts and practices, it offers more than a single viewpoint.

The case shows that commodification is important in the transformation of transboundary water flows and infrastructure. The transformation is persistently diverse, and this diversity arises out of such multi-scalar relations (Castree, 2005). In the studied case, the shift first to the Soviet Union command economy and later to the (European Union) market economy and its water management policies were crucial changes that divided the transboundary area. Water became a measured and monetarized commodity. Rising water price, planned outsourcing, efficiency indicators, and a shift towards market environmentalism are general trends of the commodification and commercialization of local water services, which are also evident in Narva–Ivangorod.

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MODERN CRIMEA, ITS POPULATION AND THE SITUATION OF THE ESTONIANS RESIDING THERE

Ott Kurs

The present paper studies the population of the present day Crimea based on the materials personally collected in September 2001 and 2003 and June 2004 and more contemporary literature, and in particular the location and language use of the Estonians based on the 2001 census. The article is a continuation of the previous treatment of the subject (Kurs, 2002a).

LOCATION AND NATURAL CONDITIONS

The Crimean Peninsula is situated on the southernmost edge of Eastern Europe, between the 44 and 46 degrees north, i.e. approximately at the same geographic latitude as Southern France and Northern Italy. Thus, based on its geographic location, the Crimea could in a sense belong to the group of Mediterranean countries. This point of view is also justified as regards distances, as it is only 630 kilometres from the Crimea (Simferopol) to Istanbul – less than to Kiev, the capital of Ukraine (660 km). Also, the distance to Athens, the capital of Greece, is smaller (1130 km) than that to Moscow (1230 km), to which the Crimea was subordinated for approximately 300 years. And from Estonia it is about 1500–1600 kilometres to the Crimea.

Compared to the large peninsulas of the Mediterranean countries, the Crimea is quite small, with an area of 27 000 km^2, i.e. 20 times smaller than that of the Pyrenean or Balkan peninsula. In its exterior it is quite similar to the southern part of the Balkan peninsula – the Peloponnese – as both are connected to the mainland via a thin isthmus. Its relief differs from that of the Peloponnese by being clearly divided into two parts – a plain area and a mountainous area. The plain constitutes more than 60% of the area of the Crimea and encompasses its northern and central part. Specialists have distinguished 8 original landscape units in the plain area, and 39 in the mountainous area (Ена, 1960) that, based on similar traits, could be grouped into six zones, of which the two larger ones comprise the plain area and the three smaller ones the mountainous area (Багрова et al., 2001: 115). Moving from the Isthmus of Perekop, which connects the Crimea with the mainland, towards the south one can find the following landscape zones:

The northern and north-eastern part is a saline semi-desert with a continental climate which has retained relatively little of its original landscape. At present 50–70% of the land is cultivated and 20–30% is used as pasture. As a result of the overburdening of the pastures, desertified areas have expanded (Багрова et al., 2001: 116). The appearance of the landscape has changed most because of settlements with huge smoke-spewing chimneys and by the railways and highways connecting the settlements. Of towns and administrative centres, this zone includes Armyansk, Krasnoperekopsk, Rozdolne,[1] Pervomaiske, and the Dzhankoy and Nizhnohirskyi railway junctions. In the great zeal for transforming nature, the Northern Crimea channel extending to the eastern border of the Kerch Peninsula (402 km) was dug here, plus a series of branch channels reaching the foothills. The water of the Dnieper River which with the help of the channel was now steered to the Crimea and instead of having a beneficial effect, began to carry salts from the earth to the fields, thus destroying the soil's fertility. Hence today only 38% of the water in the Northern Crimea Channel is agriculturally useable (Багрова et al., 2001: 67). In addition to industrial waste, the soil has also been contaminated by the over-use of pesticides (Багрова et al., 2001: 116).

The majority of the plain part of the Crimea consists of a typical steppe which has now basically become covered with fields, gardens, vineyards and pastures. In its relief it is more varied than the semi-desert zone, being divided into the up to 179-metre-high Tarhankut peninsula in the west, the Central Crimea and the Kerch Peninsula with its wavy relief in the east. One half of the area of Tarhankut that has hot dry summers and soft winters, as well as dry valleys, is used for grain fields; pastures take up a third; the major city centres Eupatoria and Chornomorske are located on the coast. No less than 75% of the Central Crimea with its wavy relief, more rains and more severe winters has been cultivated, and is mainly covered by grain fields, vineyards, gardens and artificial crops. Human settlements are located in the river valleys. The following cities and administrative centres are located here: Saki, Krasnohvardiyske, Sovetske and Kirovske. Many mines and industrial enterprises have been established in the pastures of the Kerch dry steppe, which is rich in natural resources; 35% of the land has been cultivated (Багрова et al., 2001: 119). The east coast is the home of the industrial and transport centre Kerch; the district centre Lenine (former Yedi Quyu, meaning "seven wells") is located by the railway and near the channel.

The steppe area in the foothills, which has a damper and cooler climate, has been most strongly influenced by human activity. This area is home to the towns with the largest populations in the Crimea – Sevastopol and Simferopol, the former and present administrative centres of Bakhchisaray and Bilohirsk, the historic centres of Ancient Crimea and Albat (present Kuybysheve). During the Soviet period the military and military industry heavily polluted Sevastopol and Simferopol.

The Crimea mountain zone south of the foothills is the area with the most rainfall and forests and the least human settlement. Nevertheless, the area has many tourist routes. The steep south slope is mainly covered by pine forests at elevations of 400 and 900 metres; some of these forests are protected.

Between the steep south slope and the Black Sea lies a zone with sub Mediterranean climate (Багрова et al., 2001: 51–52) and relatively small area (875 km^2), but very varied (Ена et al., 2000: 7) landscape. In July the temperatures are between 23–24.5°C, in January 2–4°C; there are 230–260 warm days per year (Багрова et al., 2001: 50). This zone, which reaches an elevation of up to 400 metres, has many vineyards and castles surrounded by parks. Some of the places of great natural beauty are now nature preserves. This is the zone which has retained many historic monuments from ancient

[1] The article uses official, i.e. Ukrainian and not Russian place names.

and medieval contacts with the Mediterranean countries. When the Crimea was annexed by Russia many impressive castles were built here. A student of the universities of Turku, St. Petersburg and Jena, Christian Steven (1781–1863), founded the famous botanic garden near the former Greek village of Nikita. Steven, who came to the Crimea in 1806, lived in Sudak from 1807 onwards (Русанов, 2003: 299). Another famous person connected with Sudak is the explorer Peter Simon Pallas (1741–1811), who established the local wine industry and managed a wine school there from 1804–1809 (Русанов, 2003: 298). The south coast is now highly populated. The numerous settlements and tourist attractions and the roads joining them heavily pollute nature. During the Soviet period the Theodosia region was crammed with military companies, some of which are now open to the public (Русанов, 2003: 314). The major cities and the present-day tourism centres are Yalta in the West and Theodosia in the East, and Alushta and Sudak in between.

ABOUT PLACE NAMES, ADMINISTRATIVE DIVISIONS AND PRESENT STATUS

In order to understand the modern Crimea better, one must look at its recent history, as the events that took place during the Soviet period are still having a major cultural and economic impact. During the Soviet period the Crimea lost a great deal of its historic heritage, as the eradication of the obsolete remnants of the past was an important part of the Soviet ideology, and this included the breaking up of the old administrative system and the changing of place names.

The last major renaming process took place after the deportation of the Crimean Tatars, Germans, Greeks, Armenians, Bulgarians and Roma people in the spring and summer of 1944 (Габриелян et al., 1998). While before only a few place names had been changed, now a wholesale renaming of place names took place – especially the renaming of settlements, as the Russification of the many natural sights was beyond the reach of the all-powerful Soviet system. Thus the majority of natural sights still have their traditional names (see for example: Абкадыров, 2002).

On 14 December 1944 Aqmeçet[2] became Черноморское, Aqşeih Раздольное, Büyük-Onlar Октябрское, İçki Советский, Qarasuvbazar /black water market/ was given the opposite meaning Белогорск, Kolay became Азовское, Curçi Первомайское, Mayaq-Salın Приморское, Seitler Нижнегорский, Qurman-Kemelç Красногвардейское, Freidorf Новоселовское (Административно-территориальные…, 1999: 396).

The Crimean Oblast which was formed on 30 June 1945 included six cities under *oblasts* jurisdiction (*oblast* – an administrative unit in Russia) – Simferopol, Sevastopol, Eupatoria, Kerch, Theodosia and Yalta), seven cities under district jurisdiction (Azovo, Alushta, Balaklava, Bakhchisaray, Bilohirsk, Dshankoy, Old-Crimea) and 26 rural districts Azovo, Alushta, Balaklava, Bakhchisaray, Bilohirsk, Dzhankoy, Eupa-

[2] The Crimean Tatar names have been written in the new Latinised alphabet (Kurs 2002b, 2002c).

toria, Zuya (Crimean Tatar Züye), Kirovske, Krasnohvardiyske, Krasnoperekopsk, Kuybysheve, Lenine, Nizhnohirskyi, Novoselovske, Oktyabrske, Pervomayske, Primorske, Razdolne, Saki, Simferopol, Sovetske, Old-Crimean, Chornomorske and Yalta. On 18 May and 21 August 1945, 333 village councils and all of the subordinate settlements were renamed (Административно-территориальные..., 1999: 13). As after deportation the rural areas of the Crimea were quite deserted despite the introduction of new settlers, the administrative units soon began to be closed down. In 1948–1953 the districts of Yalta and Novosyolovske and many village councils disappeared.

On 19 February 1954 the Crimean oblast was incorporated into the Ukrainian SSR. The transfer was confirmed on 26 April 1954. Although Sevastopol – the Soviet Union's most important military centre by the Black Sea – also officially became a part of the Ukrainian SSR, it retained its overtly Soviet status. In contrast to the other parts of the Crimean, the schools in Sevastopol did not teach Ukrainian, as the motto of the families of military personnel and families involved in military industry was – "I live in the Soviet Union" (Русанов, 2003: 185). As opposed to life in Sevastopol, the rest of the Crimea lived in an atmosphere of administrative change. From 1954–1962 the districts of Azovo, Balaklava, Zuya, Kirovske, Kuybysheve, Oktyabrske, Pervomayske, Prymorsky, Razdolne, Saki, Simferopol, Sovetske, Sudak and Old-Crimea were liquidated, several other village councils were joined together and renamed, and the city of Dzhankoy, which was subordinate to an oblast, was established. From now on the districts were restored and other rearrangements were made – hence in 1980 the Crimea had 9 cities under oblast jurisdiction and 5 cities under district jurisdiction, and 15 rural districts (Административно-территориальные..., 1999: 13–14).

After the referendum that was conducted on 20 January 1991, the Crimean ASSR was formed on 12 February; one year later (on 26 February 1992) it was renamed the Republic of Crimea and on 21 September 1994 the Autonomous Republic of Crimea. It was in this period that the Crimea developed its current administrative division. The district of Sudak was transformed into a region of a city under the republic's jurisdiction and Armyansk a town under district jurisdiction. The composition of the Autonomous Republic of Crimea does not include the region of Sevastopol, which is directly subordinate to the government of the Ukraine. The joint Russian and Ukrainian marine base – Sevastopol – is the largest town in the peninsula in terms of both area and population, whereas the official population is smaller than the actual population, as it does not include the members of the armed forces. The administrative divisions (Fig. 1) and the population of present-day Crimea (as of 1 January 2001) are shown in Table 1.

ABOUT THE POPULATION AND ITS ETHNIC COMPOSITION

The deportation of the Crimean Tatars, Germans, Greeks, Bulgarians, Armenians and other national minorities paralysed the economic life of the peninsula and destroyed its cultural diversity. The population of 430 000 people after the deportation was increased by way of compulsory immigration. This is how a totally new population has developed in the Crimea. In 1953 the number of inhabitants was 994 000, 1 201 000 in 1959 and 2 430 000 in 1989 (Гармаш, 2001: 38–39; Григорьев, 1961: 394). After the mass return of the Crimean Tatars and other deported national minorities at the beginning of the 1990s, when 250 000 people returned (Габриелян et al., 1998: 147), the increase in the total population continued despite the negative population growth which began in 1992 (Габриелян et al., 1998: 259), because the increased mortality was initially balanced by the number of repatriates. With the decrease in immigration the total population began to decrease from 1994 (Багрова et al., 2001: 170). As the majority of the repatriates – more than 75% of the Crimean Tatars (Габриелян et al., 1998: 153) – went to live in the countryside, the rural population increased.

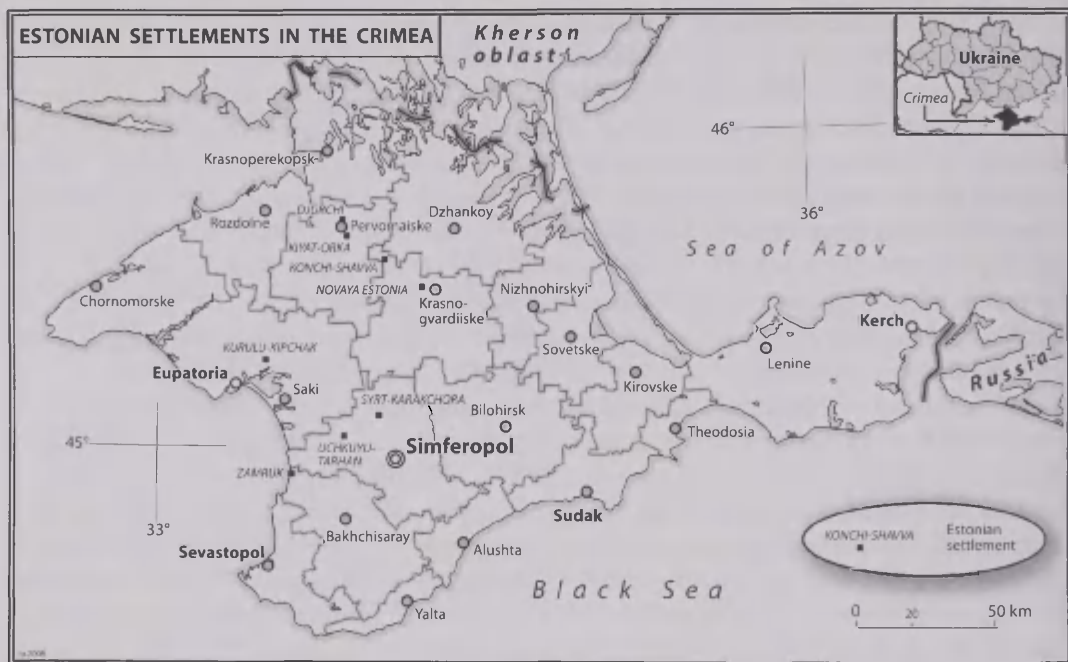

Fig. 1. Estonian settlements in the Crimea

Based on the data of the most recent census of 2001, the number of people living in the Autonomous Republic of Crimea was 2 024 056 (Всеукраинская…, 2003: 3) and in the region of Sevastopol 377 153, thus the total number was 2 401 209, of which more than 60% are Russians. The proportion of Russians was even higher in cities, being more than 70% in Sevastopol and almost 80% in Kerch (Table 2).

Table 1. The Crimean administrative division (Багрова et al., 2001: 11)

Administrative unit	Area (km^2)	Population (as of 1/1/2001)	Total population in cities (%)	Density (people per km^2)	Number of rural settlements	Number of small towns
Districts:						
1. Bakhchisaray	1 600	95 600	36.4	59.8	81	3
Bakhchisaray		27 500				
2. Bilohirsk	1 900	67 100	34.3	35.3	79	1
Bilohirsk		16 900				
3. Dzhankoy	2 700	85 500	9.2	31.7	111	2
4. Kirovske	1 200	60 700	31.3	50.6	39	1
Old-Crimea		10 600				
5. Krasnohvardiyske	1 760	94 400	23.3	53.6	83	2
6. Krasnoperekopsk	1 200	32 100	0.0	26.8	38	0
7. Lenine	2 900	75 800	37.9	26.1	68	2
Shcholkine		12 900				
8. Nizhnohirskyi	1 200	58 300	18.0	48.6	58	1
9. Pervomaiske	1 470	40 800	20.8	27.8	41	1
10. Rozdolne	1 230	38 000	31.3	30.9	39	2
11. Saki	2 260	82 600	8.0	36.6	82	1
12. Simferopol	1 750	149 400	14.4	85.4	104	3
13. Sovetske	1 100	38 300	29.2	34.8	39	1
14. Chornomorske	1 500	36 100	33.5	24.1	33	1
City areas and cities:						
1. Alushta	600	59 000	72.0	98.3	24	1
city of Alushta		34 000				
2. Armyansk	162	26 600	91.0	164.2	3	0
city of Armjansk		24 200				
3. Eupatoria	66	128 500	100.0	1 947.0	0	3
city of Eupatoria		111 700				
4. Simferopol	109	360 600	99.8	3 308.3	1	4
city of Simferopol		336 900				
5. Sudak	539	34 800	57.2	64.6	14	1
city of Sudak		18 500				
6. Theodosia	350	112 400	90.7	321.2	11	5
city of Theodosia		77 300				
7. Yalta	283	157 200	98.1	555.5	9	21
city of Yalta		83 500				
Alupka		10 200				
8. Kerch	108	160 100	100.0			
9. Dzhankoy	26	45 800	100.0			
10. Krasnoperekopsk	22	31 200	100.0			
11. Saki	29	29 800	100.0			
Sevastopol	864	388 400	94.2	449.5	29	1
city of Sevastopol		352 700				
Inkerman		12 900				

Table 2. Major nationalities in the Crimea as of 5 December 2001 (Всеукраинская..., 2003: 73–77)

Town, district	Total population	Proportion of nationalities in the population (%)					
		Russians	Ukrainians	Native Crimeans (Crimean Tatars)	Bela-rusians	Tatars	Armenians
Cities and city areas:							
Simferopol	358 108	66.7	21.3	7.0	1.1	0.4	0.6
Alushta	52 215	67.1	23.0	5.9	1.4	0.2	0.4
Armyansk	26 867	55.7	36.2	3.5	1.1	0.3	0.3
Dzhankoy	42 861	59.8	25.9	8.1	2.4	0.3	0.4
Eupatoria	117 565	64.9	23.3	6.9	1.5	0.2	0.5
Kerch	158 165	78.7	15.4	1.0	1.1	0.2	0.3
Krasnoperekopsk	30 902	51.0	40.9	3.0	1.2	4.7	0.3
Saki	28 522	65.1	24.3	5.8	1.8	0.4	0.5
Sudak	29 448	59.2	17.6	17.4	1.3	1.0	0.5
Theodosia	108 788	72.2	18.8	4.6	1.8	0.2	0.5
Yalta	139 584	65.5	27.7	1.3	1.6	0.3	0.6
Cities (total)	**1 093 025**	**67.4**	**22.4**	**5.2**	**1.3**	**0.3**	**0.5**
Rural districts:							
Bakhchisaray	92 542	54.3	19.6	21.3	1.2	1.4	0.2
Bilohirsk	66 458	49.2	16.2	29.2	0.9	0.7	0.3
Dzhankoy	82 328	38.9	33.8	21.6	1.7	0.2	0.2
Kirovske	58 016	50.5	17.6	25.5	1.6	1.3	0.3
Krasnohvardiyske	93 782	48.7	27.3	16.7	2.2	1.1	0.4
Krasnoperekopsk	31 843	33.2	43.4	17.2	1.2	0.8	0.2
Lenine	69 629	54.8	22.9	15.5	1.3	0.5	0.4
Nizhnohirskyi	56 976	50.4	28.8	16.0	1.8	0.3	0.1
Pervomaiske	40 367	35.5	37.9	21.5	1.7	0.7	0.3
Rozdolne	37 185	41.1	40.1	13.3	1.4	0.9	0.7
Saki	80 964	45.2	31.5	17.5	2.2	0.8	0.5
Simferopol	149 253	49.4	23.5	22.2	1.4	0.4	0.6
Sovetske	37 576	48.5	22.1	22.2	1.3	2.0	0.2
Chornomorske	34 112	52.8	29.3	12.7	1.5	1.5	0.4
Districts (total)	**931 031**	**47.6**	**26.6**	**20.0**	**1.6**	**0.8**	**0.4**
Autonomous Republic of Crimea	2 024 056	58.5	24.3	12.0	1.4	0.5	0.4
Sevastopol	377 153	71.6	22.4	1.1	1.6	0.7	0.4
Crimea (total)	**2 401 209**	**60.4**	**24.0**	**10.3**	**1.5**	**0.6**	**0.4**

ABOUT ESTONIANS IN THE LIGHT OF THE 2001 CENSUS

The Estonians form an insignificant minority in the population of present-day Crimea – there are 674 Estonians. There are 612 Estonians in the Autonomous Republic of Crimea and 62 in Sevastopol. An overview of locations and language use is given in Table 3.[3]

[3] The author unfortunately was unable to gather more specific data about Estonians with special status in Sevastopol.

Table 3. Estonians in the Crimea as of 5 December 2001 (Всеукраинская…, 2003: 4–69)

Town, district	Number	Language use							
		Estonian		Russian		Ukrainian		Other or unknown	
		Number	%	Number	%	Number	%	Number	%
Cities and city areas:									
Simferopol	145	15	10.3	128	88.3	2	1.4	0	0.0
Alushta	10	2	20.0	8	80.0	0	0.0	0	0.0
Armyansk	5	0	0.0	4	80.0	0	0.0	1	20.0
Dzhankoy	8	1	12.5	7	87.5	0	0.0	0	0.0
Eupatoria	31	4	12.9	27	87.1	0	0.0	0	0.0
Kerch	21	3	14.3	17	80.9	0	0.0	1	4.8
Krasnoperekopsk	5	1	20.0	4	80.0	0	0.0	0	0.0
Saki	14	0	0.0	14	100.0	0	0.0	0	0.0
Sudak	2	0	0.0	2	100.0	0	0.0	0	0.0
Theodosia	24	3	12.5	21	87.5	0	0.0	0	0.0
Yalta	45	12	26.7	33	73.3	0	0.0	0	0.0
Cities (total)	310	41	13.2	265	85.5	2	0.6	2	0.6
Rural districts:									
Bakhchisaray	36	4	11.1	32	88.9	0	0.0	0	0.0
Bilohirsk	14	3	21.4	11	78.6	0	0.0	0	0.0
Dzhankoy	13	3	23.1	10	76.9	0	0.0	0	0.0
Kirovske	7	0	0.0	7	100.0	0	0.0	0	0.0
Krasnohvardiyske	112	32	28.6	80	71.4	0	0.0	0	0.0
Krasnoperekopsk	1	0	0.0	1	100.0	0	0.0	0	0.0
Lenine	4	0	0.0	4	100.0	0	0.0	0	0.0
Nizhnohirskyi	10	0	0.0	10	100.0	0	0.0	0	0.0
Pervomaiske	40	0	0.0	40	100.0	0	0.0	0	0.0
Rozdolne	3	0	0.0	3	100.0	0	0.0	0	0.0
Saki	32	2	6.3	30	93.7	0	0.0	0	0.0
Simferopol	22	1	4.5	21	95.5	0	0.0	0	0.0
Sovetske	4	2	50.0	2	50.0	0	0.0	0	0.0
Chornomorske	4	0	0.0	4	100.0	0	0.0	0	0.0
Districts (total)	302	47	15.6	255	84.4	0	0.0	0	0.0
Autonomous Republic of Crimea	612	88	14.4	520	85.0	2	0.3	2	0.3
Sevastopol	62								
Crimea (total)	674								

Initially the Estonians lived in the places (Fig. 1) from which the indigenous nomadic population (native Crimeans, or Crimean Tatars) had been driven away or had decided to move away – thus in plain steppe areas, where the exterior and both the soil and plant conditions differed greatly from that of their homeland. The Estonians were initially not admitted to the southern areas with a more varied relief and more forests. These parts were inhabited by the native Crimeans or, in the places with the most favourable positions, occupied by the former colonists, especially the Russians. The closest place to the areas with a more varied relief was – in addition to the Zamruq (now Berhove in Bakhchisaray district) – Üçquyu-Tarhan (established in 1879, now Kolodyazne, in the Simferopol district). At the beginning of the 20th century, however, Estonians also lived in the cities of the southern Crimea (Viikberg, 2002). In tracing the total number of Estonians in the Crimea, the number of Estonians was 2 367 (0.3% of the population) in 1921, 2 084 in 1926, 1 900 in 1939 (0.2% of the population), 1 048 in 1979 and 898 in 1989 (Kurs, 2002a). The subsequent dispersion was influenced both by the repressions by the Soviet system and the Second World War, which forced the Crimean Estonians to come to Estonia.[4] There were Crimean Estonians working in the governmental bodies of the post-war Estonian SSR, some of whom later returned to the Crimea.[5] Some of the people who had gone to Estonia to leave the ravaged post-war Crimea also included those who had decided to return. They decided to return to their home in the Crimea after the formation of collective farms began.[6] Some of the Crimean Estonians, however, stayed in Estonia.[7]

As regards the citizenship of the Crimean Estonians, they are most likely Ukrainian citizens, although there are no direct data to prove this.[8] Among those who have listed themselves as Estonians, 55% live in cities and 45% in districts. Thus the former country folk have mainly become townspeople, as the districts also include smaller towns and villages. 245 Estonians lived in rural settlements (*Національний*..., 2003: 12), i.e. 40% of the national minority. 39% of the Estonians living in major cities live in the capital Simferopol. A couple of hundred people have chosen the six largest coastal cities – Sevastopol, Yalta, Eupatoria, Theodosia, Kerch and Alushta – as their home. Of the Estonians who have remained in the districts, about 80% have stayed in their initial homes or in the close neighbourhood, of those in turn almost half live in the district of Krasnohvardiyske, which is home to 112 Estonians, of whom 103, i.e. the majority (92%), live in the countryside (*Національний*..., 2003: 216). The neighbouring district, the Pervomaiske district, the centre of which is located in the old Estonian settlement, already has fewer Estonians.

The majority of the Crimean Estonians (85%) have by now become Russified. The language of their forefathers has been retained better in the countryside, in the former Estonian settlements, especially in the Krasnohvardiyske district, where the proportion of Estonian speakers (those who speak Estonian as a home language) is highest (about 29%). Only two Estonians have begun to use Ukrainian. There are also two Estonian whose language use is unknown. Language use tendencies in the case of the other small national minorities are approximately the same. The proportion of Latvians (the

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[4] The most famous people to return to Estonia at the beginning of the 20th century are Eduard Laaman (1888–1941) and Ottomar Laamann (1900–1988), who was born in Zamruk.

[5] These include Roland Valkman (1922–2007), who later spent his retirement in his birthplace, Pervomayske.

[6] Such examples are the sisters Erna Tashevskaya (born 1933) and Meeri Nikolska (born 1937) from Novoestoniya village, who have now lived in Simferopol for a long time.

[7] The descendants of the Crimean Estonians include the general director of the Police Board of the Republic of Estonia Robert Antropov (born 1965) and another man with a colourful life, Alexander Lepajõe (born 1961).

[8] In the Table of citizenship included in the census materials (Всеукраинская..., 2003: 81), there is a data row about the Estonian citizens living in the Crimea. Among the them there is one child of up to 15 years of age and one adolescent of between 15 and 17 years of age; three adults between 40 and 49 years of age, two people between 50 and 59 years of age and one person between 30 and 39 years of age.

total number being 413) speaking Latvian is slightly higher (17.9%), the proportion of those speaking Russian is smaller (80.4%), the proportion of Lithuanians (total number being 513) speaking Lithuanian is even higher (24.8%) and the proportion of Russian speakers lower (73.9%). Of the Baltic Finnic people, the following are represented in the Republic of Crimea: Karelians (87, native speakers 10.3%), Finnish (68, native speakers only 1.5%), Livonians (7, native speakers 57.1%), Vepsians (7, no native speakers) and Izhorians (788, no native speakers).[9]

The Crimean Estonians are losing their ability to speak Estonian, because from the second half of the 1930s the Estonian language has no longer been taught in schools. The language is only spoken by the older generation, especially those who managed to attend school in Estonia for a few years. After Estonia regained its independence the interest of the Crimean Estonians in the Estonian language and culture has increased. The interest and contacts with Estonia are maintained by the Estonian Society in Crimea, which was established in Simferopol in 1997 with 110 members. The society initially had subdivisions in Yalta, Kerch, Alupka and in Bakhchisaraskyi, Krasnohvardiyskyi and Pervomaiskyi district (*Национально-культурные…*, 1999: 41). At present, branches of the centre, which has headquarters in Simferopol and is headed by Meeri Nikolska, operate in Krasnodarka (Leo Bergman), Alupka (Alfred Türmes), Sevastopol (Erich Kalling), Berehove (Inna Torbek) and Pervomaysk (Lilia Gribanova). A major event organised by the Estonian Society in Crimea took place on 7–9 September 2001 in Berehove, and there were also many guests from Estonia. This event, organised in the framework of the second summer days of the Crimean Estonians with the motto "140 years of Estonian culture in the Crimea", was in a way a turning point in relations between the Crimean Estonians and Estonians living in Estonia.

In September 2001 a delegation from the Estonian Ministry of Education headed by Jüri Valge visited the Aleksandrovka Secondary School in Krasnohvardiyske district and negotiated with the school management the possibility of providing funding for a teacher of Estonian and English to come from Estonia. The delegation then visited Krasnodarka [former Qonçi-Şavva] in the north-easternmost corner of the Krasnohvardiyske [Qurman-Kemelçi] district, and was warmly welcomed into the home of Rita Kadilkina. Since autumn 2002 a teacher of Estonian and English sent from Estonia has worked at Aleksandrovka Secondary School and lives in the home of Rita Kadilkina: in 2002–2003 Merge Simmul, 2003–2004 Raina Reiljan, 2004–2006 Helle Aunap and 2006–2007 Enda Trubok. Hence, after a hiatus of 65 years it was once again possible to receive school instruction in Estonian in this part of world. Last year the number of students studying Estonian in grades 1–11 in Aleksandrovka was 27. In addition, the same teacher gives lessons to members of the Estonian Society in Crimea in Simferopol. Young people from the Crimea have also come to Estonia to study at Estonian institutions of higher education. Among those is Tatjana Pohil, the granddaughter of

[9] Of the Izhorians, as many as 93.3% have indicated Crimean Tatar as their native language (Всеукраинская…, 2003: 4). This is apparently a group of people who lived in the same deportation stations with the Crimeans, who returned to the Crimea with the native Crimeans and not to their native land.

the chairwoman of the Estonian Society in the Crimea, Meeri Nikolska. In winter 2003/04 the publishing of a quarterly information and literary bulletin of the Estonian Society in the Crimea – *Crimean Estonians* – began. The newspaper publishes articles in Russian about the history and culture of the Crimean Estonians and their connections with Estonia.

CONCLUSION

Due to the events that took place in the Crimea in the 20th century, the population today differs greatly from that documented during the first census in 1897. Then the population was much more varied, but at the same time more evenly distributed – the cities were smaller and the number of people living in rural areas was higher. The Estonians had remarkable high numbers in many rural settlements in northern and western Crimea. Their farms prospered, falling only behind the German farms, which truly set an example for the first emigrants. One could hear people speaking Estonian in homes and schools. Now, a hundred years later, there is nothing left of the former prosperity, and life in the countryside is in stagnation. Life is better in the cities, where the majority of the Crimean Estonians live. Isolated in the cities and away from their former homes, the language and ethnic distinctness of this small minority are disappearing. Hence the Estonians of modern Crimea form only one-third of the number documented during the first census. The situation is even worse with those who speak Estonian as a native language – that level has decreased from 100% to 13–14%. The situation is not, however, completely hopeless. While the language skills of younger middle-aged people disappeared in the Soviet period, interest in the Estonian language and culture will help improve the situation. For that purpose, measures have been taken on both sides – in the Crimea and in Estonia. As the experience of Europe and the world in general shows, it is also possible to restore ethnicity in cities that were formerly considered to be absolute melting pots. At present people are learning the basics of the Estonian language and culture, both in Aleksandrovka school in the North Crimean countryside and in the capital city Simferopol. Hopefully this trend will continue.

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SEGREGATED SUBURBAN LANDSCAPES: TRANSFORMATIONS ON THE FRINGE OF TARTU

Antti Roose, Ain Kull

INTRODUCTION

Residential segregation has often been seen as a significant urban problem. Below we focus on the segregation of landscapes as a result of suburbanization. There are numerous negative aspects associated with suburbanization and urban sprawl, but the socio-economic and environmental costs of these effects and how to address them in the short term and also long term remain unclear. The lack of knowledge and agreement is largely due to a lack of consensus on what constitutes sprawl and the forces driving sprawl (Hoggart, 2005; EEA, 2006). Whereas it is generally recognized that sprawl is initiated by individual choices regarding land use and location, the collective understanding of factors influencing personal decisions and how these decisions accumulate over time and space to create sprawl is inadequate. In Europe, sprawl is defined as the physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas (EEA, 2006). Development, in spatial terms usually patchy and scattered, is characterized by discontinuity, leaving a lot of empty spaces, which indicate inefficiencies in development and highlight the consequences of uncontrolled growth. According to Estonian law, planning in urban areas, i.e. in a high-density built environment is clearly distinguished from rural planning. The areas subject to sprawl, treated by the legislation as rural, are located on the furthermost edge of urban growth.

Four broad types of urban population development can be distinguished: urbanization, overall urban decline, suburbanization and re-urbanization or counter-urbanization (Champion, 2001). Suburbanization refers to population growth in the periphery of the urban area at the expense of the core city. When Western Europe had already reached the re-urbanization phase, in Estonia, similarly to other Central and Eastern European (CEE) countries, since the late 1990s the cycle of urbanization had switched from urbanization to suburbanization (Tammaru et al., 2004). Suburbanization is masked by expected rapid economic development, internal economic dynamism, greater access to EU markets and other macro-level impact, globalization and ICT (Audriac, 2005). The spectacular growth of suburban communities in the cities of CEE countries has not been widely noted (Kok, 1999; Timár & Váradi, 2001; Tammaru, 2005). Some authors argue that suburbanization itself is an important dimension in the post-socialist stratification order (Kostinskiy, 2001; Timar & Varadi, 2001; Ott, 2001). Most models of urban spatial structure simplify space to a one-dimensional measure of distance (Herold et al., 2003; Kasanko et al., 2006). The traditional urban bid-rent model defines space in terms of distance to a city centre and ignores the remaining heterogeneity by imposing the assumption of a featureless plain (Strazheim, 1987). A theory of sprawl must treat space as multidimensional to account for the relative distance among agents as well as the spatial distribution of key sources of landscape heterogeneity and supporting environmental resources.

Suburbanization, particularly in the form of urban sprawl, is traditionally perceived as a negative process (Champion, 2001). Suburbanization or suburban development produces functionally homogenous zones (Hoggart, 2005). There is a clear link between suburbanization and landscape segregation, while the proportions of new settlements and other land use types are not homogenous and tend to be strictly separated throughout a defined space. Suburban buildings occupy former agricultural land, natural habitats or sparsely developed rural areas; in the 1990s suburbanites introduced alien features to architecture and the social environment, and deepened socio-spatial polarization. This raises needs for traffic and technical infrastructure. Stopping sprawl is critically important because of the major socio-economic and environmental impacts, increased energy, land, habitat and soil consumption. Regarding the legislative context, neither European Union nor Estonian laws act directly and comprehensively against urban sprawl, as physical planning is ultimately in the authority of municipalities (EEA, 2006). Thus the spectrum of environmental, social and economic impacts of urban sprawl should lead to new initiatives to counter its effects.

The paper set up the framework of indicators and modelling methods for developing an analytical tool for spatial planning decision support in the urban fringe. The indicator approach aims to measure urbanization processes and landscape segregation through the use of a simple set of spatial indicators, a common database and statistical methodology. In particular, the objective of this article is to illustrate the potential usefulness of pattern metrics analysis complementing other spatial analysis methods for the assessment of the impacts of physical planning on landscape change. Detailed data of the Tartu urban region as a prototype of a mid-size university city and regional service centre with 100 000 inhabitants are employed to demonstrate fast suburbanization. The paper assesses the processes that are changing the suburban zones in Tartu, focusing on residential suburbanization and discussing physical and landscape changes in suburban areas. An analysis of the main determinants of the patterns of suburban communities – economic prosperity, residential development and housing in the context of infrastructure and the decentralization of planning intensified by diverse planning practices – is applied, followed by a comparison between five suburban municipalities. Lastly, the policies of physical planning are assessed. The focus of the debate on suburbanization appears to shift more and more from functional zoning or total protection of green networks in segregated areas to combining different land uses in different landscapes, the integrated concept of modern land use management and physical planning practice.

MATERIAL AND METHODS

In order to tackle issues of suburbanization, it is essential to fully understand the socio-economic motors of suburbanization. Micro-economic factors, such as rising living standards, the price of land, the availability of cheap agricultural land, and competition between municipalities have played the most important role (EEA, 2006). The primary precondition for suburbanization and urban sprawl is the availability of free land for development. The restitution and privatization of land in Estonia took place in patches, and did not follow any geography from the perspective of land use planning. The second precondition is the willingness of city dwellers to upgrade their housing and to move from Soviet-era flats to single-family dwellings, while at the same time maintaining an urban lifestyle and a strong connection with the core city (Kostinskiy, 2001; Sykora & Cermak, 1998; Tammaru, 2005). The main motivator for moving to a suburb is to provide a better and safer living environment for one's children. People with mid to low socio-economic status leave the core city. The third precondition is the easing of mortgage conditions and economic prosperity. Real estate developers took advantage of low land prices and the shortage of supply. Private housing developers and banks became the new key actors in housing construction (Tammaru, 2005).

Cohesion of sustainability aims at cohesion of content and scales for national plan, county plan, physical plan and master plan. Environmental assessment tools such as LCA (life cycle assessment), SEA (strategic environmental assessment), EIA (environmental impact assessment) are deployed. The aims are to establish a spatial model for the surveying and tracking of suburbanization processes, to provide information and enhance standards for spatial planning, combining various non-spatial and spatial modelling techniques, landscape metrics and network analysis, overlay and buffering. The modelling method for integrated assessment links standalone components, which allows the assessment of land use and landscape change, the examination of suburban areas at master plan scale and provides capabilities for the analysis of the environmental, socioeconomic and planning aspects of urban systems and the built-up environment. Sub-models include a spatial urban data base, indicator systems and a range of models such as a model for calculating landscape metrics, a land use model for quantifying land use changes and its environmental and socio-economic aspects, an LCA model providing primary energy use and ecological footprint, mapping sub-models that simulate landscape change and its visualization and topical mapping (Fig. 1). The synthesis is achieved through the life cycle assessment of suburban living.

There is a growing demand for improved planning and policy-making that takes into account demographic, social, economic, civic and environmental concerns. The full range of impacts of urbanization should be considered, including impacts on environmental resources, natural areas, rural environments, the quality of urban life and health, as well as socio-economic impacts. The purpose of choosing the described approach is the fine-tuning and upgrading of the EU Urban Audit (Eurostat, 2004), to enable an assessment of the state of dynamic, transitional cities, in particular tracking suburbanization processes, and to provide information for physical planning. A comparison of the indicator scores will allow cities and suburban municipalities to judge their progress and identify any specific difficulties. The indicators provide a basis for the comparison of urban qualities as a result of rapid suburbanization. A clear-cut time-series of selected indicators demonstrates the disparities of development. The comparison of the indicator scores will allow cities and suburban municipalities to judge their progress in urban qualities as a result of rapid suburbanization.

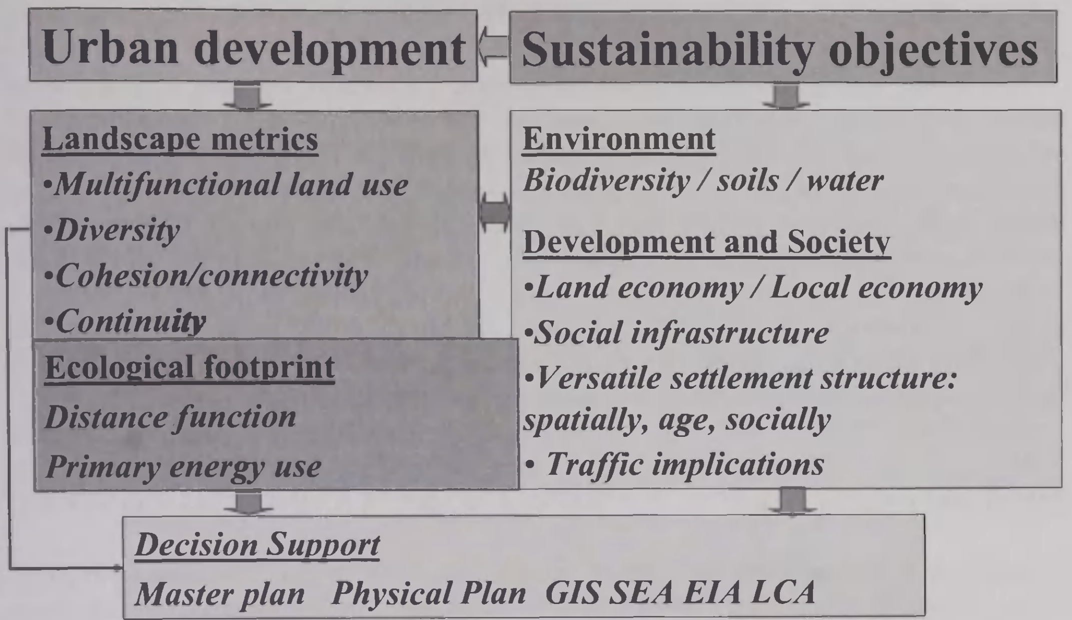

Fig. 1. Conceptual framework for urban modelling

The effort to verify and filter indicators of the EU Urban Audit was initiated by the urgent need for an analysis tracking suburbanization in the period 2000–2007, instead of awaiting information from centralized sources. The relevant aspects of urbanization are assessed at the level of one administrative unit. The sub-city analysis is left out of this survey, as the apparent level of disparities is indicated by conditions between core cities and fringe municipalities. The analysis comprised suburbs where the reference area had its own administrative identity or where the adjoining local authority areas participated significantly in the life of the city. In defining wider functional units, neither CORINE data showing the five land use characteristics of urban areas nor the method of population density is sufficiently effective in examining the semi-natural fringe of Estonian cities (Kasanko et al., 2006). That is why only adjoining administrative units with core city were chosen for the analysis. The suburban municipalities are an approximation of the functional urban zone centred around the city.

Indicators are chosen to represent the urban realm in CEE and those interests to be taken into account in the assessment of processes. The indicators are chosen based on information available (the national and Eurostat databases), the directions and sensitivities of indicators and the relative importance of those indicators. In complex assessments, all indicators are considered to have the same importance, and no weighting coefficient is used. The main data sources are the Statistical Office of Estonia (Population and Housing Census 2000; Estonian Labour Force Survey, Household Budget Survey) and registry offices of counties and local governments; the Central Database of the Police Board; the Ministry of the Environment; and the

National Motor Vehicle Registration Centre. The method was based on combined use of register data and sample survey data.

Landscape ecology provides a comprehensive theoretical framework and concomitant methodology in pattern metric analysis that is well suited for the extraction of processes through the examination of spatial patterns. In landscape ecology, pattern metrics analysis yields quantitative measures of spatial configuration that are critical in understanding not only pattern but also, more importantly, process (Turner et al., 2001). Environmental indicators related to land use and landscape metrics were derived on the basis of the Estonian basic map (1:10 000) and soil map (1:10 000). Landscape metrics were computed using Patch Analyst, an ArcView GIS extension (Rempel & Carr, 2003; Elkie et al., 1999). A suburban green network has been composed on the basis of CORINE land cover and the Estonian basic map (1:10 000).

THE TARTU CITY REGION: BACKGROUND DATA AND LOCAL CONTEXT

The university city of Tartu in Southern Estonia has been chosen as a case study area. Tartu is the second largest city in Estonia with a population of 98 000, and it thus belongs to the group of medium-size cities in European terms. As the regional pole of Southern Estonia, it fulfils a central role as Estonia's leading research, educational, health-care, and administrative centre. In addition to the education sector, the timber and furniture industries, garment manufacturing, food processing, chemicals, the production of building materials and printing are all important economic activities. Tartu is modest in terms of economic performance and population size. The comparison with other EU urban audit cities gives high scores for the percentage of one-person households, the percentage of households living in owned dwellings, the percentage of resident population with tertiary education, and public green space. Total resident population, the average price per square meter of a house, the number of recorded crimes per 1000 population, unemployment rate, median disposable annual household income and the percentage of journeys to work by car are low in comparison to other EU cities.

In the 1990s, Tartu County was the only county in Estonia to have positive net migration on all levels, countywide, both in the urban fringe and in the peripheries. The data clearly shows the primary trends of declining population in Southern Estonia and the primarily increasing and balanced development in the Tartu area. Only suburban municipalities that are located around major cities gain from migration (Table 1), where population growth follows the growth of built-up areas. Suburban population declined in Tähtvere, where natural accrual and conservative planning practice supports depopulation. Population dynamics are affected by an aging population in the majority of suburban municipalities, which is an essential characteristic of demographic change in Estonia. Accordingly, the proportion of young people and children among residents is quite low in rural municipalities. In turn, the share of the student population is significant in the historic city.

Young workers make up the bulk of those who leave economically disadvantaged Southern Estonia for metropolitan Tallinn. Age distribution and natural population trends are both affected by this. Migration from city centres to the suburban area is a significant aspect in migration dynamics (Tammaru et al., 2004). The core city tended to lose a smaller share of its population to suburban municipalities.

Table 1. Changes in resident population of Tartu city region 2000–2007

Municipality	2000	2001	2002	2003	2004	2005	2006	2007	Growth 2000–2007	%
Luunja	2 626	2 649	2 661	2 644	2 606	2 677	2 706	2 877	251	9.6%
Tartu rural	5 140	5 127	5 102	5 108	5 102	5 200	5 154	5 318	178	3.5%
Tähtvere	2 785	2 780	2 785	2 699	2 609	2 640	2 618	2 654	–131	–4.7%
Ülenurme	4 403	4 438	4 480	4 479	4 557	4 788	4 995	5 312	909	20.6%
Tartu city	96 359	99 207	100 912	100 453	100 872	99 882	97 938	98 690	2 331	2.4%

Economic growth is indicated by gross salaries, which rose more rapidly in suburban areas such as Ülenurme and Tartu rural municipality than in the city or urban areas in the 2000s. Very low unemployment rates are observed in the Tartu urban area, and this is associated with the economic boom of the period 2000–2006. We cannot observe large differences in unemployment rate between suburban neighbourhoods. As the percentage of the population with tertiary education is high, the well educated are best placed to exploit the economic opportunities available in seeking higher living quality in the suburbs.

RESULTS

Land use implications and landscape change due to suburbanizationin the Tartu urban region

The development of suburban settlements in the Tartu urban region follows the typical configuration of suburban growth in Estonia since 2000. The suburban zone has witnessed large changes in land use. Before that, in the 1990s, many settlements around Tartu were underdeveloped, and were still related to rural restructuring and diversification; hence these agro-villages had substantial potential for residential growth. The migration from core to suburban zone intensified around the millennium and reached its peak in 2007 (Table 2). The forms of suburban development differ significantly from place to place and vary from greater and relatively autonomous new settlements to individual projects of separate single-family dwellings. Suburban development is mainly based on individual homes.

Poor planning control of land subdivision has been more the rule than the exception during the exponential growth of the suburbs since 2003. Planning at the edge of cities has largely been concerned with containment, with the promotion of a more compact urban form, and with the planned separation of rural and urban land use and activities (Naess & Jensen, 2004).

Table 2. Timeline of suburbanization for a mid-size city (100 000 residents), the Tartu case

Period	Urbanization process	Key areas of development	Planning practice
1992–1997	Gradual urbanization	Vacant lots in the core city; single lots on the fringe; individual construction	No master plans; shortage of know-how; few districts in the city
1998–2002	Gradual suburbanization	Small settlements on the fringe	No or few master plans; comprehensive city planning
2003–2006	Peak of suburbanization / patchy urban sprawl	Mid-size settlements on the fringe; peak of detached houses; apartment houses in the core city	Massive issuing of master plans; establishment of green networks; drafting of general plans
2007–present	Suburbanization slowing down	Infill in the city as well in suburbs; growing share of semi-detached and terraced houses	County-level QC; issuing of general plans

There has inevitably been some dilution of sharply distinguished uses to create a unique landscape and interface of town and country, which is why this is labelled the rural-urban fringe. These areas have been created more by accident than design: less-favoured urban uses such as sewage works, processing units and wholesale centres have been forced out of residential areas. Rural uses, mainly farming and forestry, have become mixed with periurban activities and uses. In Tartu, the development of suburban communities corresponds to the typical configuration of suburban growth (Fig. 2). Due to the suburbanization process, some of traditional village-based settlements are merged into city agglomerations. The settlement of many areas on the urban fringe that were previously considered too rural and disconnected has been a defining feature of the current suburbanization. As a rule, new suburban settlements are located in areas close to the city perimeter, in cultivated fields, near suburban agro-villages and along major roads; and also in garden allotments and summer-house districts. This process is characterized by the increase in the mean area of suburban settlements from 1.3 ha to 1.8 ha, while the median area of settlements in 5 municipalities has increased only slightly (from 0.53 ha to 0.55 ha). This indicates that remote villages are still unaffected by real estate development.

New construction is located either on empty parcels, in-fills within existing settlements or as new satellite villages further from the former settlement. The median distance of new settlements is 6 km, and average distance 7 km. Only 13% of new settlements are further than 10 km from the city centre (Fig. 3). The most remote new settlements are situated around 12 km from the edge of Tartu. The first wave of suburbanization runs along major roads and agglomerates larger rural settlements.

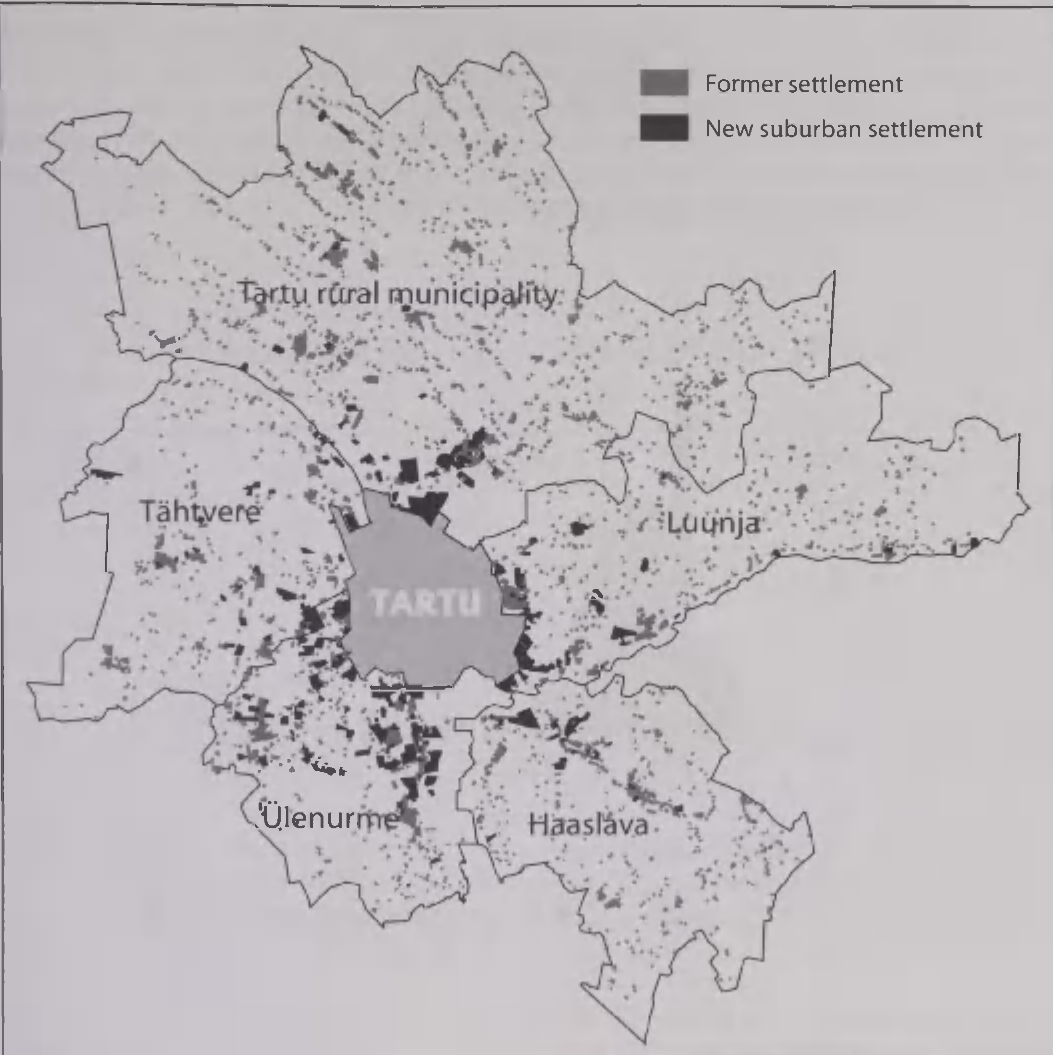

Fig. 2. Map of new and former suburban settlements in the Tartu urban region.

Accessibility is the primary criterion – most settlements are located in the vicinity of main roads, and the most distant settlements are present only along major highways. Another area of major residential development has transformed summer cottage settlements into permanent housing (Külitse, Aardlapalu, Männisalu, Kurepalu). Spatial organization remained fragmented into urban low density and rural uses. A special feature of suburban development in the Tartu urban region is the development of small real estate projects consisting of 10–20 family homes. 60% of settlements have less than 20 households. In the late 1990s and early 2000s, single-family homes tended to become more spacious and luxurious. The widespread access to mortgages has opened up the opportunity of acquiring single-family house to a growing number of upper middle class, double-income younger families since 2003. This caused the suburban spread of communities, with net migration growth in the periurban zone. The new residential districts can be categorised into elite districts and those for ordinary residents. There are settlements of higher standard in attractive localities and more remote or unfavourable locations with cheaper housing. As in the case of landscape segregation, newcomers with entrepreneurial or white-collar backgrounds and former agro-village citizens are quite segregated from each other.

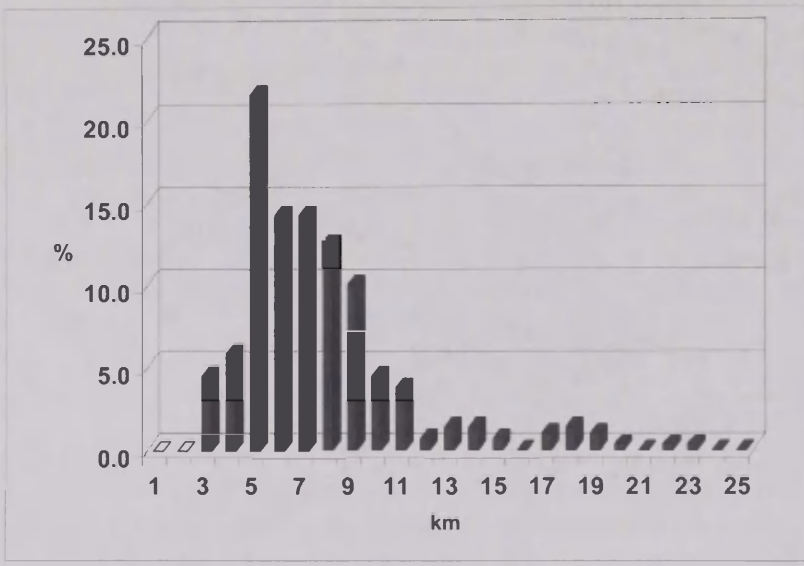

Fig. 3. Distribution of average distance of new settlements from city centre (city hall).

In conventional cases, the degree of landscape diversity and fragmentation gradually decreased when urban land-use types became dominant (Jenerette & Wu, 2001; Herold et al., 2003). A highly urbanized landscape is actually more homogeneous and better-connected than a rapidly urbanizing landscape. Infill development, which can help reduce patch density, has been rare, though the degree of fragmentation may have been lowered due to the planning of 65 new apartment dwellings (up to 1 400 apartments in total). In total, 350 massive lots are for sale on the fringe (Uus Maa, 2007). Regarding the property market, demand is predictably higher on the perimeter of the city; supply is expansive at distances from the core city.

The majority of master plans have been adopted after 2000. Nevertheless, there was a legal window to begin 6 new residential areas without any planning. In total, 274 master plans and 2 865 dwellings were analyzed in five municipalities on the Tartu fringe (Table 3). The core city itself was excluded from landscape assessment. On average, 12.2 dwellings were designed and planned in the master plan (293 dwellings per km^2). There is a strong relationship between distance from the city centre and the size of master plan area: average size near the city is 5.2 ha, decreasing to 2.5 ha in more distant areas. In total, the master plan for single-family homes covers 919 ha, and for dwellings 186 ha. The area varies between municipalities, and to a great extent depends on the availability of attractive land for residential development and connection with the city. The leading municipality was Ülenurme, with 104 adopted master plans covering an area of 453 ha, followed by Tartu with 65 (281 ha), Luunja with 49 (224 ha), Tähtvere with 35 (110 ha) and finally Haaslava with 21 (53 ha) master plans.

Table 3. Number of issued master plans and new single-family dwellings planned within the master plan areas

Municipality	Master plans			No. of new single-family dwellings within the issued master plan areas
	2003	2006	In total	
Ülenurme	n/a	22	104	1 432
Tartu rural	1	23	65	677
Luunja	9	19	49	474
Tähtvere	5	9	35	156
Haaslava	n/a	n/a	21	126
Total			274	2 865

Estimates based on the adopted master plan allow one to forecast the growth in the number of residents (Fig. 4). The population of Luunja, Tartu and Ülenurme municipalities could double if all issued master plans were to be applied. On the other hand, this is a long-term prospect that directly depends on economic conditions, as the Estonian economy entered a recession in 2007.

Landscape metrics analysis

Suburbanization has a clearly visible influence on landscape pattern. Rapid urbanization initially caused dramatic alteration of landscape patterns. Landscape pattern itself strongly influences ecological processes and characteristics. Changes in landscape structure cause a change in function and vice-versa (Forman & Godron, 1986). The establishment of relationships between landscape components and dynamic interactions between structure and function enables the ecological consequences of proposed spatial solutions to be predicted. Landscape metrics is usually used to describe landscape pattern, and more generally the ecological condition of landscapes. Based on landscape metrics analysis in the surroundings of Tartu, the patchy and scattered landscapes are characterized by vast discontinuity. The distribution of patch types on master plans is highly uniform (*Shannon's Evenness Index = 0.96*), their shape is simple (*Area Weighted Mean Shape Index = 1.44*), median master plan area size is very small (2.1 ha), and average size is only 4.1 hectares (Table 4). The mean area covered by a master plan is relatively similar in Luunja, Ülenurme and Tartu rural municipalities (4.6, 4.4 and 4.3 ha, respectively), but is smaller in Tähtvere (3.1 ha) and Haaslava (2.5 ha) municipality. The median size of the master plan is even smaller (1.9–2.2 ha), and the median value of parcels in Haaslava municipality is just 1.5 ha. At the beginning of physical planning, the shape of the fringe neighbourhoods was strictly tetragonous, followed by a so-called semi-curvy, American-style pattern of suburbs. The majority of land was allocated for dwellings, leaving marginally low proportions for public use. A slightly more complex shape of master plans was evident in Tähtvere, while the most regular parcels are found in Ülenurme. The general tendency is for new settlements to increase the edge of villages (from 405 m to 480 m), though edge density in contrast decreases from 0.032 m/ha to 0.026 m/ha.

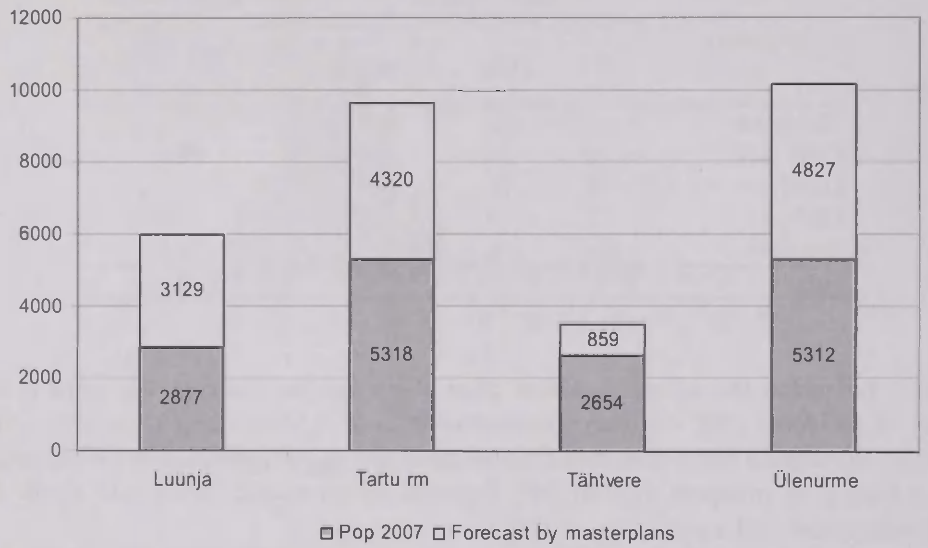

Fig. 4. Population growth forecast on the Tartu suburban fringe.

New suburban settlements mainly occupy former arable land with fertile soils on the urban fringe. Another approach is "natural beauty driven" where gleysols, histosols (6%) and alluvial (1%) soils are occupied in river valley and on lakeshores. 51% of the area of master plans is covered by Stagnic Luvisols, 21% by Calcic Luvisols and 14% by Gleysols. While in terms of land use type nearly 28% of master plans cover sparse rural settlement areas (Fig. 5), only 1% of the area of master plans consists of technogenic soils, which is more indicative of extensive sprawl than intensive expansion on account of rebuilding. The same trend appears when new suburban settlements are established on former agricultural land (45%), natural grasslands (17%) or forests (9%). Master plans that aim to establish new residential settlements in forests, wetlands and natural grasslands are more frequent at distance of 5–10 km from the city centre, while arable land naturally dominates in near-fringe development.

Table 4. Landscape indices by master plans and settlements

Index	New master plans*	Former and new settlements	Former settlements
Class Area (ha)	1112.1	3 951.8	2 839.7
No. of settlements	274	2157	2 109
Mean Patch Size (ha)	4.1	1.8	1.3
Median Patch Size (ha)	2.1	0.55	0.53
Patch Size Coefficient of Variance	143.6	348	321
Patch Size Standard Deviation (ha)	5.96	6.4	4.1
Total Edge (km)	22.8	103.5	85.4
Edge Density (m/ha)	0.021	0.026	0.032
Mean Patch Edge (m)	851.8	479.6	404.9
Mean Shape Index	1.35	1.21	1.19
Area Weighted Mean Shape Index	1.44	1.71	1.50
Mean Perimeter-Area Ratio (m/ha)	0.039	0.055	0.057
Shannon's Evenness Index	0.96	–	–

* adjoining master plans may form a new settlement or will be part of existing settlement if adjoining with its border

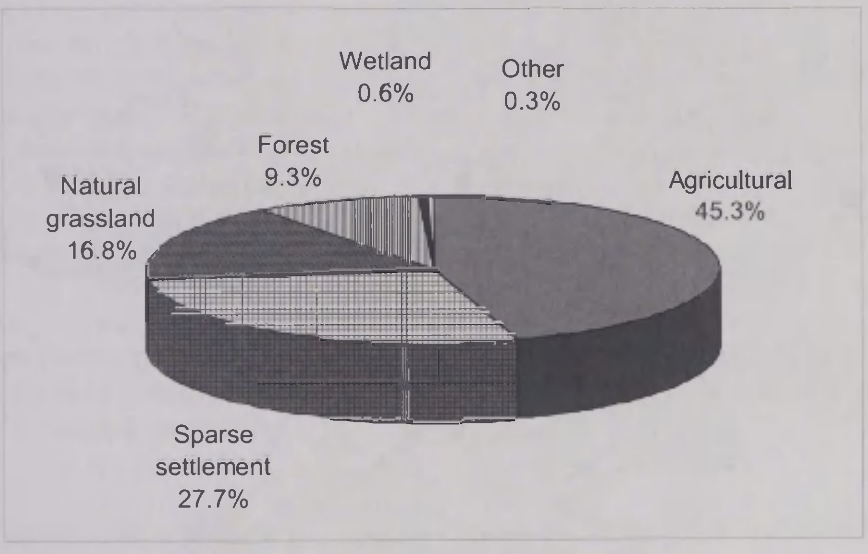

Fig. 5. Main land use types allocated for suburban development, according to issued master plans.

Sustaining green network

The green network is the "gold standard" of urban planning. The methodology for delineating the green network states that the main objective of planning is first and foremost to guarantee the natural and environmental spatial structure (Remm et al., 2004). The main goals in the context of urbanization are: to shape the spatial structure of natural areas; to assess the ecological, environmental, economic and social aspects; to facilitate a complete functional network; to moderate, compensate and forestall the anthropogenic impact on nature; to guide settlement and land use; and to compensate the spatial contradiction of developments. Assessing the status of the main components of the network, core areas at the national and local level are not overrun by sub-urbanization in Tartu; hence a major green corridor such as the Emajõgi River and its floodplain is confronted by new settlements (Fig. 6). Green networks were the most

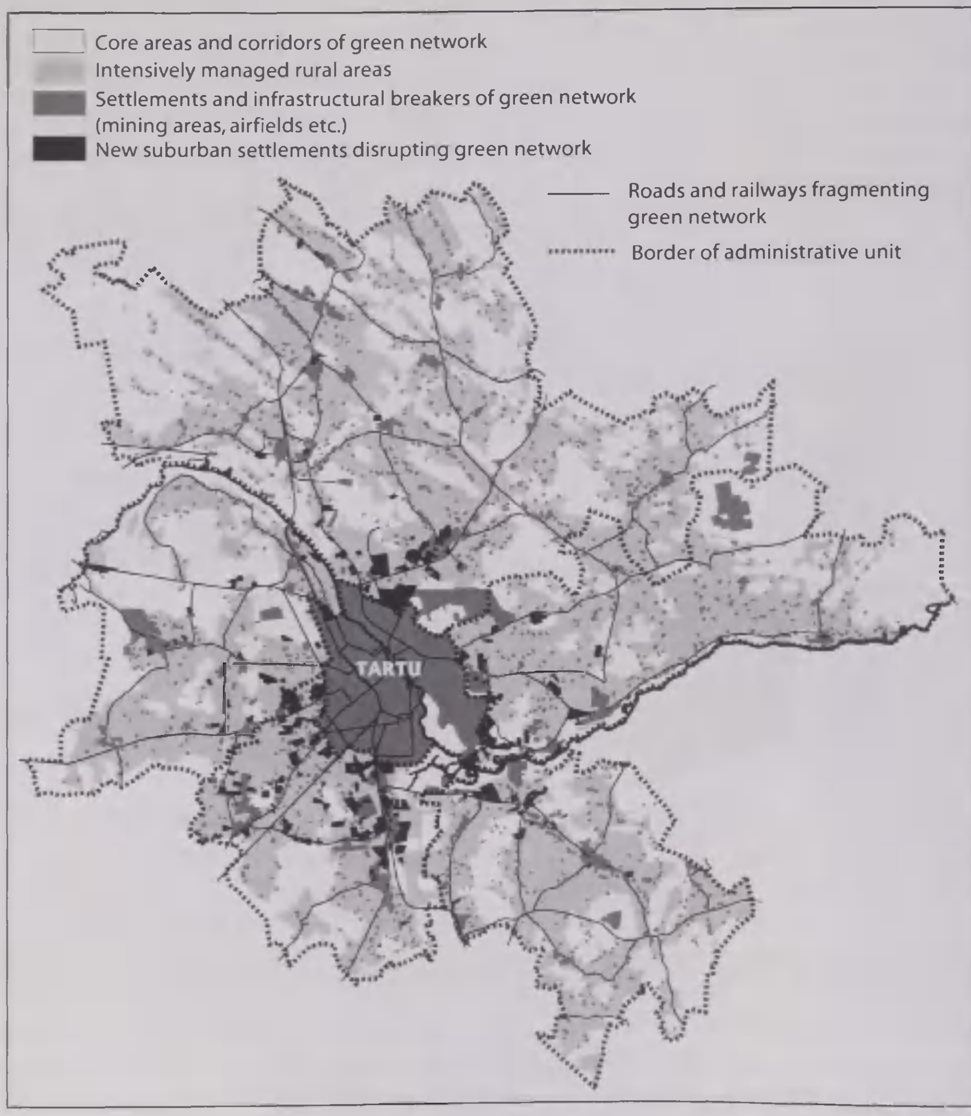

Fig. 6. Map of areas of conflict in green network

affected in the following cases: access to the river and cutting through corridors of natural habitats along the river and floodplains; disruption of continuous wooded corridors along roads from the city to the nearest forest/woodland; pine stands and dry habitats on light sandy soils. The components are rather scattered which causes the need to fill the structure in the suburban areas to safeguard functioning of the network, despite urbanization. The restricted directions of suburbanization are set northwards along the eastern and western bank of the River Emajõgi as well as the forested area in Tähtvere. Development is also restricted by the floodplain wetland in the core Aardla area on the southeastern fringe of the city. Urban development is encouraged in the south-western direction. The green network is also affected by the expansion of road network, as several bypasses have been extended and the intensity of transit has increased substantially. Another important feature of the green network is integration of urban green space, semi-natural areas and green corridors in the urban environment into a general green network in suburban areas. Cities with more than 15 000 inhabitants need a green belt for mainly recreation purposes. The desirable width of the belt could be around 5–12 km. In particular, greeneries and parks support integration in the near vicinity of the city perimeter.

Ecological footprint of suburbanization

The cities as nodes of energy and material consumption are causally linked to accelerating both local and global ecological decline. The ways in which new settlements act and function are not sustainable, in the same way that the lifestyles introduced by suburbanites themselves fail to pass many sustainability criteria. Cities' footprints typically greatly exceed, or overshoot, their biocapacities by 15–150 times (Doughty & Hammond, 2004). In contrary, the Tartu case indicates much lower footprints in food and consumer services, as the footprint categories were not included in the survey. That is why we have not emphasised that in the total footprint figure. Instead, the most important insight from this discussion of the connections between land use and other indicators is whether the Tartu urban region can achieve sustainability on its own. As suburbanization dramatically increases consumption and pollution and traffic problems, the complex indicator to show pressure is the ecological footprint (Table 5). The greatest share consists of household energy (76%) followed by transport (15%), and construction (9%).

Table 5. Estimated ecological footprint of the inhabitants of the new residential areas of Tartu

Component	Average consumption	Ecol. footprint ha/inhab./y	Share	Trend
Transport	20 km	0.18	15%	Up
Dwelling/construction	200 m^2	0.11	9%	Down
Household energy	5000 kWh	0.90	76%	Up

The suburbanization of the 2000s brought about important changes in the internal functioning of the urban area. The growing component of the footprint is transport. Daily average traffic frequency on Tartu transit roads and bypasses shows a sharp increase from 2003, in most busy crossings of bypasses and major city roads reaching 20 000 cars per day (Fig. 7). Tartu and its suburbs have relatively low urban densities, and a large share of the urban growth is concentrated on the urban fringe and in rural-type areas. Low density disturbs create opportunities for shorter distances between main trip-generating factors such as home–work, home–school and the development of a quality public transport system. The reduction in the number of work places in rural areas, the focus on the service sector, offices, shopping and leisure facilities in cities and the increase in car ownership has increased mobility. The major dividing line in terms of transport mode in European cities falls between the Old and New European Union Member States, with public transport playing an increasingly small role, which is being replaced by cars. Car ownership has grown sharply, by one third since 2002, from 255 to 328 cars per 1000 inhabitants in 2006.

New suburbanites are completely dependent on commuting to the core city. Daily commuting is most troublesome for numerous young families, since the infrastructure for children is also generally located in the city. Travelling to work has become a major challenge in everyday life. In 2001, 34% of journeys to work were made by car, rising to 55% in 2006 (Tartu transport survey, 2007). One out of every five jobs in the core city goes to someone commuting from outside the city. According to another assessment, more than 61% of working-age people in Ülenurme work in the city of Tartu, followed by Tähtvere (53%), Luunja (41%), and Tartu rural municipality (34%). During the period 1996–2005, the employment age population has grown 15.3% in the core city, compared with 25% in Luunja, 21% in Ülenurme and 19% in Tartu rural municipality. Local service centres receiving a distinguished role should become more dominant to avoid massive commuting between the suburbs and the core city. Assessing demography, car ownership and land use, the city is not well structured by transport and transit mode. Assessing the distance figures of the relatively compact city of Tartu, the walking zone covers the city centre and its surroundings. Controversially, the public transport zone equals the car dependent zone in flat house neighbourhoods as well suburban settlements. There are still very few bicycle routes in the city.

Another critical component of the ecological footprint is construction and household energy. There are several indicators that assist in the analysis of household consumption rates. The average household size is 2.21 persons in Tartu, which has decreased in recent decades. One-person households tend to gravitate towards the centre of the city and university campuses. The housing market responds to such demands, meaning housing for one-or-two-person households, but student accommodation can often be difficult to find outside the city center, in suburbs. The private home ownership rate is high in the core city area as well as in the suburbs. Also, differences in living space per resident are not significant across the Tartu urban area. The average living space per inhabitant is 22 square meters. The push factor is the small size of apartments in the Soviet panel-blocks, forcing families with children needing more space to move out of the city. High house prices in the historic city are another significant push factor driving the population towards the rural fringes of the city. Suburbanites have more living space per inhabitant than city dwellers.

Fig. 7. Daily average traffic frequency on Tartu transit roads and bypasses (Roads Technocenter, 2007).

DISCUSSION AND CONCLUSION

Broader implications on physical planning models and reflections at the local authority level

What is the role of local planning institutions in the development of new communities, in particular, how does the interaction between the public and the private sectors and conflicting interests shape the geography of these developments, which are often framed by neo-liberal conditions (Dimitrovska Andrews et al., 2005)? The regulatory framework of physical planning, weak land use planning, the poor enforcement of existing plans and the lack of horizontal and vertical coordination often cause dramatic sprawl around the cities (EEA, 2006). Cities and suburban municipalities, like local councils or governments, bear most of the responsibility for managing urban change in Estonia. The fundamental question is how much power cities have, and who the stakeholders are. Due to the enhancement of the system of public administration, the regional government and county administration has undergone considerable reform in the last decade, resulting in increased devolution of authority to local authorities in many matters involving physical planning (Kulu & Billari, 2006). Nevertheless, regional and municipal government share responsibility for many public sector services and tasks to be dealt with at the county level. Since 2000, associations of local authorities have begun to play greater role in decision-making at the county level. The ability of city and suburban municipality leaders to seize the opportunities available to them will often be determinant for the future development of cities. The process has been supported by the neo-liberal legal, planning and business environment. Meanwhile, as historically centralized states have taken steps towards greater devolution, countries with a tradition of strong local government, including the Nordic Countries, Germany and Austria, continue their structured multi-level approach (Hoggart 2005; EEA 2006). Estonia has stuck to its model and, in some cases, has sought to further enhance the powers of local authorities. The planning practice is characterized by the following:

- The legal framework is liberal in issuing planning and construction permits.
- Moderate or non-existent intervention by the central government.
- Long-term strategies and general plans become outdated, and are replaced by tactical decisions by municipal politicians.
- Poor management, auditing and inspection of developments.

Since the mid-1990s, when national governments began the decentralization of planning regulations, each municipality has become the primary administrator of planning on its territory. Planning capacities were weak and decentralized, having few controls at the county level, poor regional coordination and sporadic local participation. The detailed plans for small parcels of land initiated by private housing developers rather than the comprehensive strategic land use plans of the municipalities guide residential development. This occurs in a mechanistic way. Although the suburban municipalities of Tartu seem quite similar in terms of area, infrastructure, resources, existing population, development history and overall institutional structure, they present two very different approaches to the development of suburban communities: a conservative legalistic planning system, and an *ad hoc* legalistic planning system, in which codes are modified according to development. Development has proceeded without strategic documents, and neither a general plan nor development agenda were issued in the early 2000s. The major conflicts, issues and participatory debates in the planning process are as follows:

- restrictions established by environmental protection and EIA memorandums,
- the development of infrastructure, road, energy, water and sewage networks,
- mixed functions of land use (residential, commercial, processing, agriculture),
- the usage of private roads and the development of access roads,
- transit flows and the implementation of traffic regulations in settlements.

While conservative municipal councils used their administrative power to enforce tighter controls on land use in order to continue mainly agricultural uses, in the case of Tähtvere the less strict municipalities used their new ability to modify planning codes to attract real estate developers. Decentralized development predominates in suburban municipalities due to weak county-level planning, and competitiveness between municipalities. The crisis in planning should encourage a search for more flexible and effective modes of urban intervention. The transition to democracy enhanced the means for political and social representation in securing greater popular participation in urban planning (Rodríguez et al., 2001). After a period of highly speculative and disorganized urban growth in the mid-2000s, the economic recession that began in 2007 opened up a phase of increasing concern with environmental and social justice and equity considerations in suburban planning. Recently the co-operation between neighbouring municipalities in harmonizing physical planning has improved. In the near future, challenges to statutory planning should tackle and respond effectively to economic and urban restructuring and lead urban regeneration.

The current residential suburbanization is very expansive and has led to criticism similar to that observed in the past development of Western cities. In the Tartu case study, the massive increase in the number of master plans issued indicates the rapid suburbanization and the establishment of suburban settlements, but also the preservation of planning rights for the future. The locations of new residential settlements have been chosen on the basis of the availability of land. The critical task is to manage the growing demand for development land, both by ensuring more efficient use of urban land and taking into account regional plans for the settlement system, transport network and green network. Municipalities are unable to strictly direct the planning process, which causes biased results. The planning of new settlements should proceed from general plans or local agendas, which are available in the majority of municipalities. It is obvious that new policies and tools are necessary to direct urban expansion so that landscape diversity is preserved and urban areas can develop in a more sustainable manner. Further studies should improve the understanding of how urbanization affects the landscape differently across space and time.

ACKNOWLEDGEMENTS

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ATMOSPHERIC RESEARCH IN THE ARCTIC WITHIN THE DAMOCLES PROJECT

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INTRODUCTION

Climate warming has been significant in the Arctic region (IPCC, 2007), where great changes have been observed in recent decades. Air temperature has increased significantly, and sea level pressure as well as the extent and thickness of sea ice have decreased. Climate change projections for the future indicate that the highest warming will take place in the Arctic.

The warming will significantly decrease the extent of permanent sea ice. The minimum extent of sea ice for the end of the melting period in summer has decreased by 7.3% per decade during the period 1979–2004 (IPCC, 2007). In the years 2005 and 2007 new minimum sea ice extents have been recorded, while the extent in 2007 was approximately one million square kilometres less than in 2005 (Maslanik et al., 2007; Comiso et al., 2008). It is predicted that the summer sea ice in the Arctic Ocean will mostly have disappeared by the middle of the 21st century. This will cause dramatic changes for living beings and human activity in the Polar Regions.

Climate warming in the Arctic is directly related to a significant decreasing tendency in sea level pressure (SLP) over the Arctic Ocean (Serreze et al., 2000). This means that cyclonic weather conditions have become more frequent in that region. This change could be explained by a change in the large-scale atmospheric circulation system.

Although the using of satellite data substantially improved knowledge of geophysical processes over the Arctic Ocean, much more detailed empirical data are needed for scientific purposes. The International Polar Year (IPY) was organised for March 2007 – March 2009. This is an extensive scientific programme focused on the Arctic and the Antarctic, an intense, internationally-coordinated campaign of research that will initiate a new era in polar science. IPY includes research in both polar regions and recognises the strong links between these regions and the rest of the globe. It involves a wide range of research disciplines, including the social sciences, but the emphasis will be interdisciplinary in approach, and truly international in participation. It aims to educate and involve the public, and to help train the next generation of engineers, scientists, and leaders.

The European integrated project DAMOCLES (Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies) of the EU Sixth Framework Programme is the main European contribution to the IPY. DAMOCLES is an integrated ice-atmosphere-ocean monitoring and forecasting system designed for the observing, understanding and quantification of climatic changes in the Arctic. It will last for four years – from December 2005 until November 2009. An advanced observation system will be developed and deployed, for the first time providing synoptic, continuous and long-term monitoring of the lower atmosphere, sea-ice and the upper ocean. It is designed to evaluate and improve global and regional climate forecasting models based on the validation, assimilation and integration of observed data. The ultimate goal is to lengthen the lead-time of extreme climate changes predicted to occur in the Arctic within this century.

The main objectives of DAMOCLES are related to synoptic observations of the Arctic Ocean sea ice pack, key atmospheric processes occurring in the Arctic Ocean and Arctic Ocean circulation and key processes. The observation data will be integrated and assimilated with large-scale models. The potential impacts of climate changes on the environment and human activity in the Arctic will be assessed.

DAMOCLES brings together a total of 48 partners from 11 EU countries, Russia and Belarus. The Department of Geography of the University of Tartu, has been one partner involved in the studies of the atmospheric research group. We have been involved in the implementation of three tasks – analysis of changes in Arctic cyclones, analysis of moisture transport in the Arctic and field measurements at the Tara ice station.

CHANGES IN CYCLONIC ACTIVITY AND TRAJECTORIES IN THE ARCTIC BASIN

Significant climate changes in the Arctic are related to changes in large-scale atmospheric circulation. A decrease in sea-level pressure means that cyclonic weather conditions have become more frequent. Many studies have demonstrated that cyclonic activity in Polar Regions has increased significantly (IPCC, 2007).

The analysis of long-term changes in cyclonic activity over the Arctic during the period 1948–2002 has demonstrated that the number and intensity of cyclones entering the Arctic from mid-latitudes has increased significantly (Zhang et al., 2004). This means a shift of the storm track into the Arctic, especially in summer. The frequency of winter cyclones has significantly decreased in mid-latitudes and increased at higher latitudes during the period 1959–1993 (McCabe et al., 2001). The intensity (or depth) of these lows has increased in both cases.

The analysis of deep cyclones, i.e. with a minimum sea level pressure below 1000 hPa, during 1958–1999 revealed an increase in the intensity of cyclones and a decrease in minimum SLP over the western part of the Pacific and the Atlantic Ocean (Gulev et al., 2001). An opposite trend has been detected in the eastern part of the Pacific and North America. The number of cyclones has increased over the Arctic Ocean and the western part of the Pacific, while it has decreased over the Gulf Stream and sub-polar Pacific.

The objective of this frame of the present study is to analyse in details the changes in the frequency of cyclones formed in the Arctic and outside the Arctic but moving into it. The Arctic basin is defined here as an area north of 68°N. The general aim of the analysis is to evaluate these main trends using a different database of cyclones. As the local climate is clearly dependent on the trajectories of cyclones, changes in frequency and other parameters of cyclones entering into the Arctic basin are analysed for different sectors. Changes in the parameters of the life cycle of entering and Arctic cyclones are analysed.

The database of cyclones described by Gulev et al. (2001) was used in this study. The database consists of cyclone tracking output of the 6-hourly NCEP/NCAR Reanalysis (Kalnay et al., 1996) SLP fields, using the software developed by Grigoriev et al. (2000). Cyclones are presented by the geographical coordinates of their centres and SLP at these points. This database is also used and described by Sepp et al. (2005).

The borderline 68°N is chosen empirically to separate cyclones of different behaviour. Arctic cyclones are defined as cyclones that have formed north of 68°N, while entering cyclones have formed south of that borderline, but have crossed it and moved into the Arctic. Arctic cyclones and entering cyclones are analysed separately. We defined deep cyclones having a minimum SLP below 1000 hPa and shallow cyclones, having a minimum SLP equal to or above 1000 hPa. The following variables are determined and studied: the total number of cyclones; the duration of cyclones expressed in the number of tracking points, whose interval is 6 hours; the mean sea-level pressure of cyclones; sea-level pressure at the first, last, deepest and northernmost points of cyclones. In addition, the longitude of the point on the parallel 68°N where the cyclone has entered the Arctic region is calculated. According to these points, the cyclones are grouped by sectors (Fig. 1).

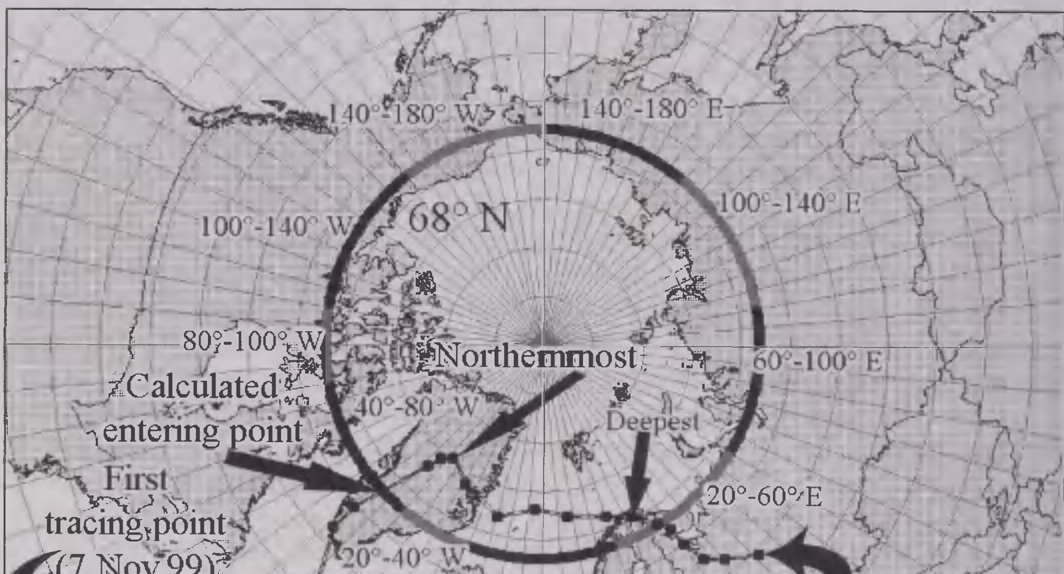

Fig. 1. The map of the study area with the 68°N borderline of the Arctic basin and its sectors used in this study, and characteristic tracing points of the life cycle of an entering cyclone.

Linear regression analysis is applied for the detection of long-term changes. A linear trend is calculated for every time series, and their significance level is found using Student's t-test. Trends are considered to be statistically significant at the level $p<0.05$. Time series of annual and seasonal mean values are composed. Seasons were defined by grouping three months, as usual – winter (DJF), spring (MAM), summer (JJA) and autumn (SON).

The total number of cyclones in the Arctic basin north of 68°N during the period 1948–2002 was 29 387, which amounts to 22.1% of the total number of cyclones throughout the Northern Hemisphere available in the database of cyclones (Gulev et al., 2001). Of these, 18 233 cyclones formed in the Arctic region, while 11 154 formed at lower latitudes but crossed 68°N and moved into the Arctic. This means that the mean annual number of cyclones in the Arctic basin was 534.3; 331.5 of these cyclones were of Arctic origin and 202.8 were entering cyclones.

The total number of cyclones in the Arctic basin has increased due to the increase in the number of entering cyclones. Their number has increased significantly, by 43.9 cyclones, during the years 1948–2002 (Fig. 2). In general, this change is concurrent with the trend in the total number of cyclones over the Northern Hemisphere. At the same time, the trend in the time series of the number of Arctic-born cyclones is insignificant.

It is characteristic that the number of deep cyclones has significantly increased during the 55 years examined, both in the case of entering and Arctic cyclones, by 27.3 and by 43.4 cyclones respectively. It is important to note that the number of shallow cyclones has significantly decreased in the case of Arctic cyclones and the percentage of deep cyclones has increased by 11.7%. However, the number of shallow entering cyclones has increased in parallel with deep cyclones and the ratio between them has not changed.

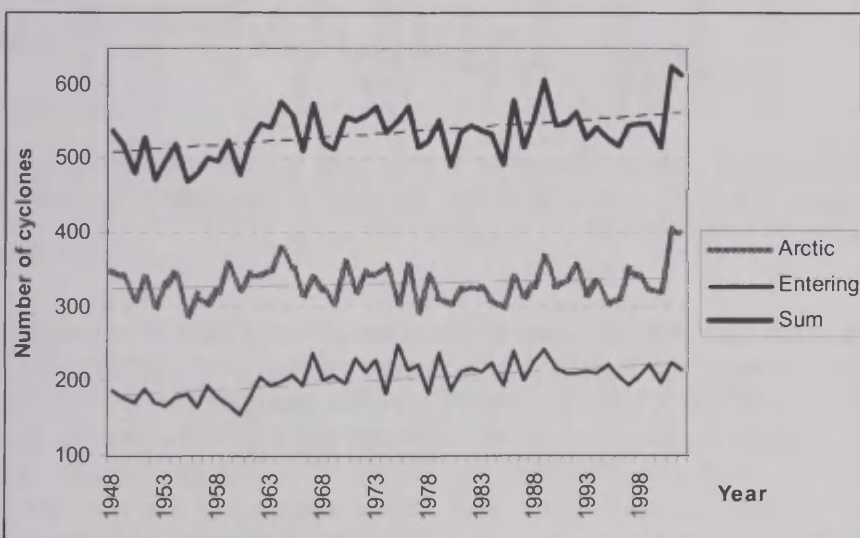

Fig. 2. Time series and trend lines of entering and Arctic cyclones and their sum.

Seasonal changes in the time series of the cyclones in the Arctic basin generally follow the trends that exist for the annual values. Statistically significant trends, however, appear much more frequently during the winter season. Despite the fact that the number of cyclones is greater during the other seasons, these are mostly shallow cyclones, and only a few statistically significant trends were detected. An important exception occurred in the case of entering cyclones, where the rate of increase of shallow and deep cyclones in summer exceeds that of winter ones.

The entering cyclones were grouped and analysed by sector. The total increase by linear trend of 43.9 cyclones is not equally distributed over the sectors. The number of entering cyclones has increased in the majority of sectors, but in many cases the increase is not statistically significant (Fig. 3).

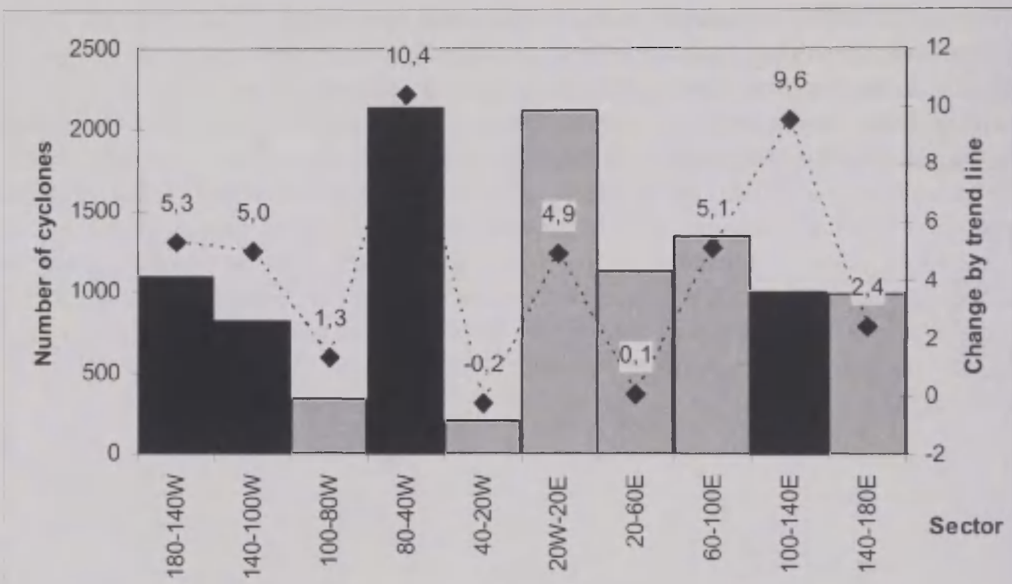

Fig. 3. The Number of cyclones crossing 68°N from south to north and their changes by trend during the years 1948–2002, divided by sectors. The black columns indicate statistically significant changes at the level of $p<0.05$.

According to stronger and significant trends, more cyclones have been moving into the Arctic basin through the Bering Strait, Alaska (sector 140°–180°W) and western Canada (100°–140°W). A large number of cyclones penetrate the Arctic in the sector 40°–80°W, through the western coast of Greenland and the Baffin Sea. The increase in the number of cyclones is greatest in this sector. A remarkable increase in the frequency of cyclones has taken place over central and eastern Siberia (100°–140°E), where cyclones are usually rare. A weak and insignificant decrease in the number of cyclones during the last 55 year is recorded in the central and south-eastern part of Greenland (20°–40°W).

In spring the number of entering cyclones has increased by 3.3 in the sector 80–40°W (Baffin Sea), while the mean number has been 9.2 cyclones. The number of entering cyclones has also increased in the European sector (20°–60°E).

The biggest changes in the characteristics of the entering cyclones are observed for some sectors in summer. In sectors 180°–140°W and 20°–40°W, a decrease in sea-level pressure and an increase in the percentage of deep cyclones has been observed. In the eastern sectors (20°W–20°E, 140°–180°E), however, an opposite trend is revealed – an increase in mean pressure and the percentage of shallow cyclones.

In autumn, as in spring, there are few significant trends in the parameters of cyclones entering the Arctic basin. The number of cyclones has only increased in sector 100–140°E, by 3.6 cyclones. According to the trend line, at the end of the 1940s there were 1–2 cyclones in autumn, but now their number is 5–6.

The mean duration of the entering cyclones was 19.4 tracking points, i.e. 116 hours or up to five days. There are practically no trends in the duration of any of the analysed types of entering cyclones. The only significant and important change occurred over Siberia in sectors 60°–100°E (eastern Siberia) and 100°–140°E (central Siberia), where the duration of cyclones has increased accordingly by 22 hours and 2.5 days. In general, the duration of the Arctic cyclones has also not changed. The duration of Arctic cyclones is up to two times shorter than of entering cyclones. Their mean duration was 10.6 tracking points, i.e. 63.6 hours.

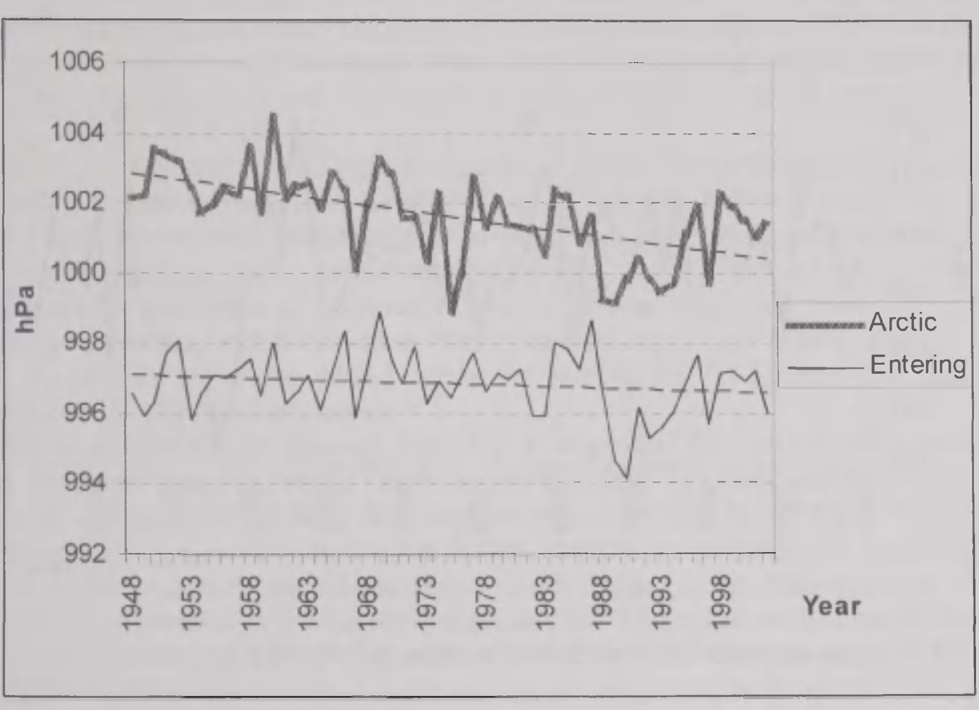

Fig. 4. Time series of the mean SLP of Arctic and entering cyclones and their linear trend lines during the years 1948–2002.

The mean SLP of the Arctic cyclones was 1001.6 hPa, and that of entering cyclones was much lower – 996.8 hPa. SLP in the Arctic cyclones has shown a significant decreasing trend by 2.5 hPa during the years 1948–2002, while the entering cyclones have no trends in SLP (Fig. 4). Taking into account only the deep cyclones, their mean SLP has decreased significantly in the case of both Arctic and entering cyclones.

The annual cycle of the SLP of the Arctic cyclones has an opposite curve than the number of cyclones – pressure is higher in summer and lower in winter. It corresponds very closely to the annual distribution of the number of deep cyclones. Mean SLP has decreased significantly in winter. Similar changes are evident in spring and summer. There are no statistically significant changes in mean SLP in autumn.

The amount of statistically significant trends in the SLP of the entering cyclones divided by the sectors is rather small. These trends are more often in sectors where the number of entering cyclones has also significantly increased. Remarkable trends are evident for sector 100–140°E (eastern Siberia). The deepening tendency of cyclones is also observed in the western sectors – 20–60°E (northern Europe) and 60–100°E (western Siberia). In the latter case, a significant increasing trend exists in the number of deepest tracking points with SLP below 1000 hPa, and a decreasing trend in minimum SLP (by 3 hPa). These trends indicate substantial changes in cyclones crossing the northern part of western and eastern Siberia. There are much deeper cyclones than ever before, and mean air pressure has declined.

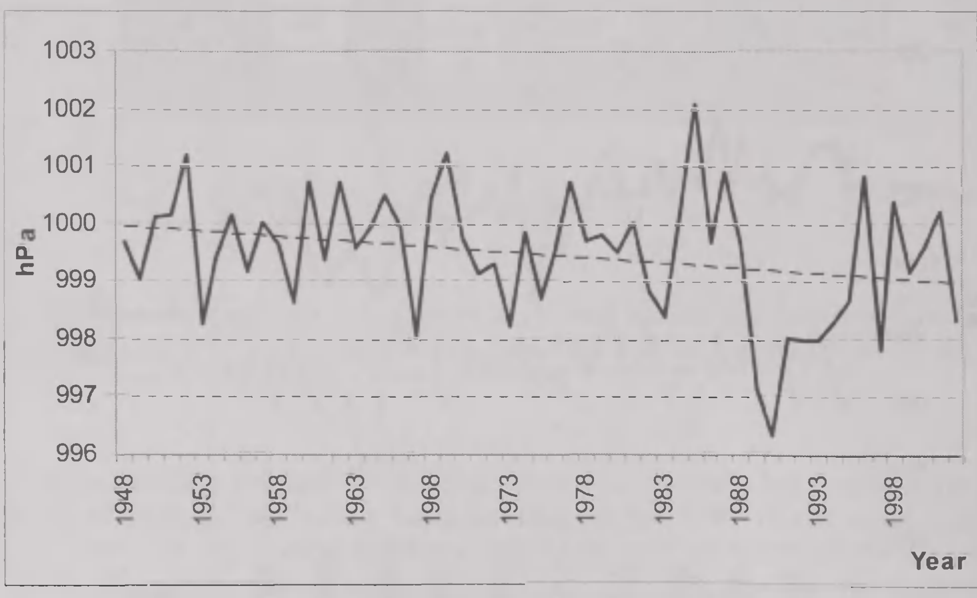

Fig. 5. Time series and trend line of northernmost mean SLP tracing points.

The mean sea-level pressures of the entering cyclones in the first, last, northernmost and deepest tracking points were 1000.4, 1002.5, 999.4 and 988.3 hPa respectively.

These values have not generally changed significantly, but the frequency of tracking points with deep pressure (i.e. below 1000 hPa) has increased, and mean air pressure at these points has decreased. The most significant change was revealed in the case of the northernmost tracking points. Mean SLP at these points has decreased by 1.2 hPa (Fig. 5) and even by as much as 1.6 hPa for entering cyclones of southern origin (formed south of 60°N). Similar tendences also occurred in the case of tracking points of Arctic cyclones.

MOISTURE TRANSPORT IN THE ARCTIC

Cyclones are closely related to moisture transport. The moisture budget and moisture transport in the Arctic were analysed using data from the ERA-40 re-analysis. ERA-40 reanalysis covers 44 years (1958–2001) with a resolution of 1×1 degree grid for every six hours and 60 vertical levels. In this study we use the data from 55°N to 90°N with 27 lower levels (about 300 hPa). Specific humidity q, northward wind v, surface barometric pressure p_0, 2 m temperature t_{2m}, precipitation P, evaporation E and flux divergence DIV were collected directly from the ECMWF data archive. The temporal resolution was 6 h, and only flux divergence was collected with temporal resolution of one month.

Integrations through an atmospheric column were made from surface pressure to the 27^{th} level pressure. Taking a vertical integral of specific humidity (g/kg) through an atmospheric column, we obtain integrated precipitable water vapour, IPWV (kg/m^2 or mm). Moisture transport is analysed using vertically integrated meridional moisture flux, MMF (kg/m/s). The F-test was used to estimate if the linear trends are statistically significant at $p<0.05$ level.

The time series were divided into two periods: before the satellite era (1958–1978) and during the satellite era (1979–2001) (Fig. 6). Before the satellite era the IPWV and precipitation trends were statistically significantly positive, evaporation trend was significantly negative and in temperature there was no significant trend. During the satellite era the time series of temperature had a significantly positive trend, whereas in IPWV, precipitation and evaporation there were no significant trends. During this study we concentrate on the period during the satellite era (1979–2001), in order to eliminate artificial effects and trends.

Spatial distribution on specific humidity is expressed by vertical cross-sections along the longitudes 0°E, 90°E, 180°E and 270°E (Fig. 7). There appears a general regularity that specific humidity decreases towards the North Pole. This is due to the northward decrease in air temperature, which controls the atmospheric capability to contain water vapour. Specific humidity is clearly higher in the Atlantic sector (0°E) due to the Gulf Stream. In the Bering Sea sector (180°E) one can note a small decrease in specific humidity at 67°N, at the Chukchi Peninsula, during all seasons. This is visible through the entire vertical scale and can be explained by the smaller evaporation rate at the land area.

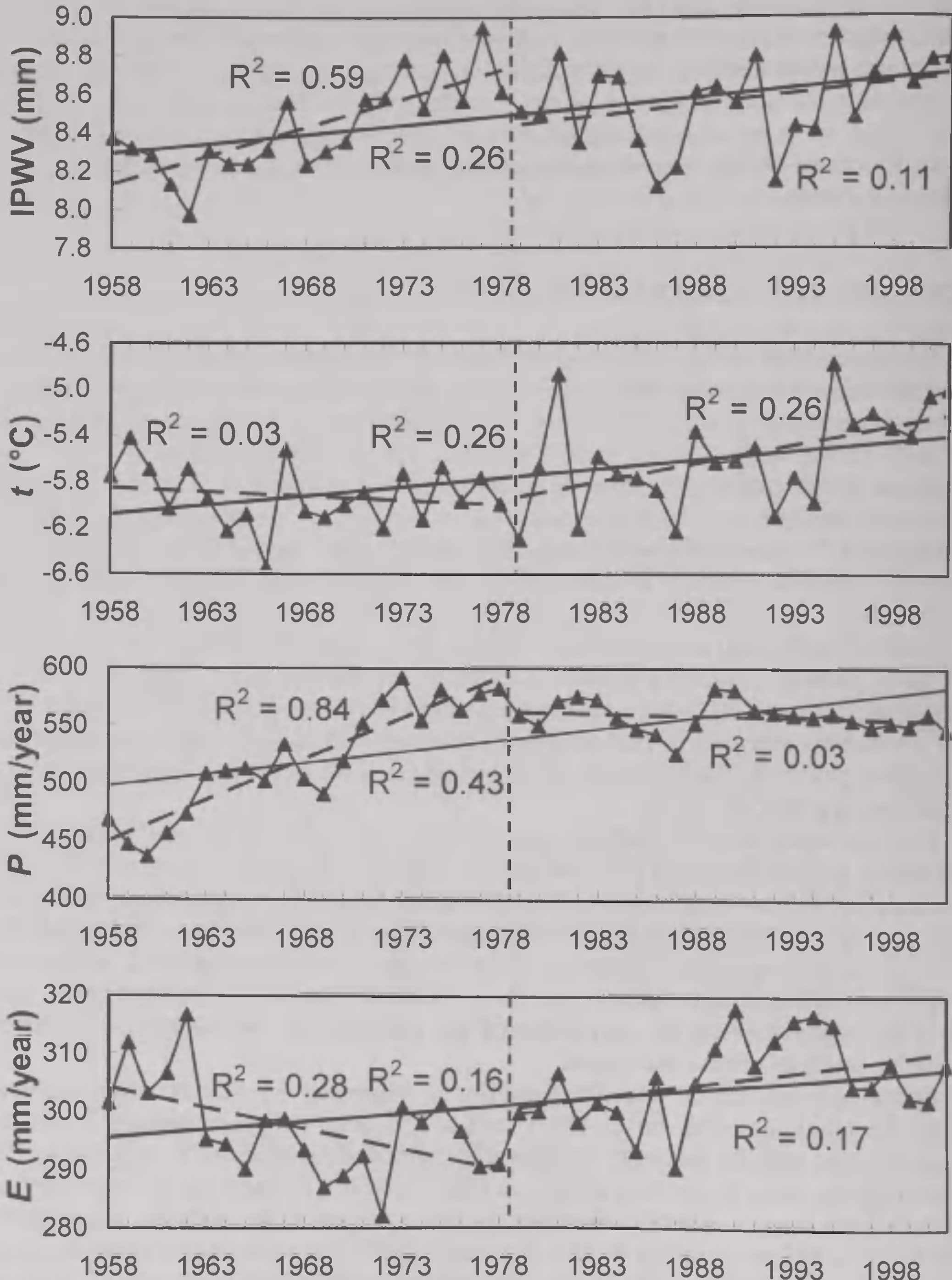

Fig. 6. Time series of IPWV (mm), temperature (°C), precipitation (mm/year) and evaporation (mm/year) yearly averages for entire region (from 55°N to 90°N).

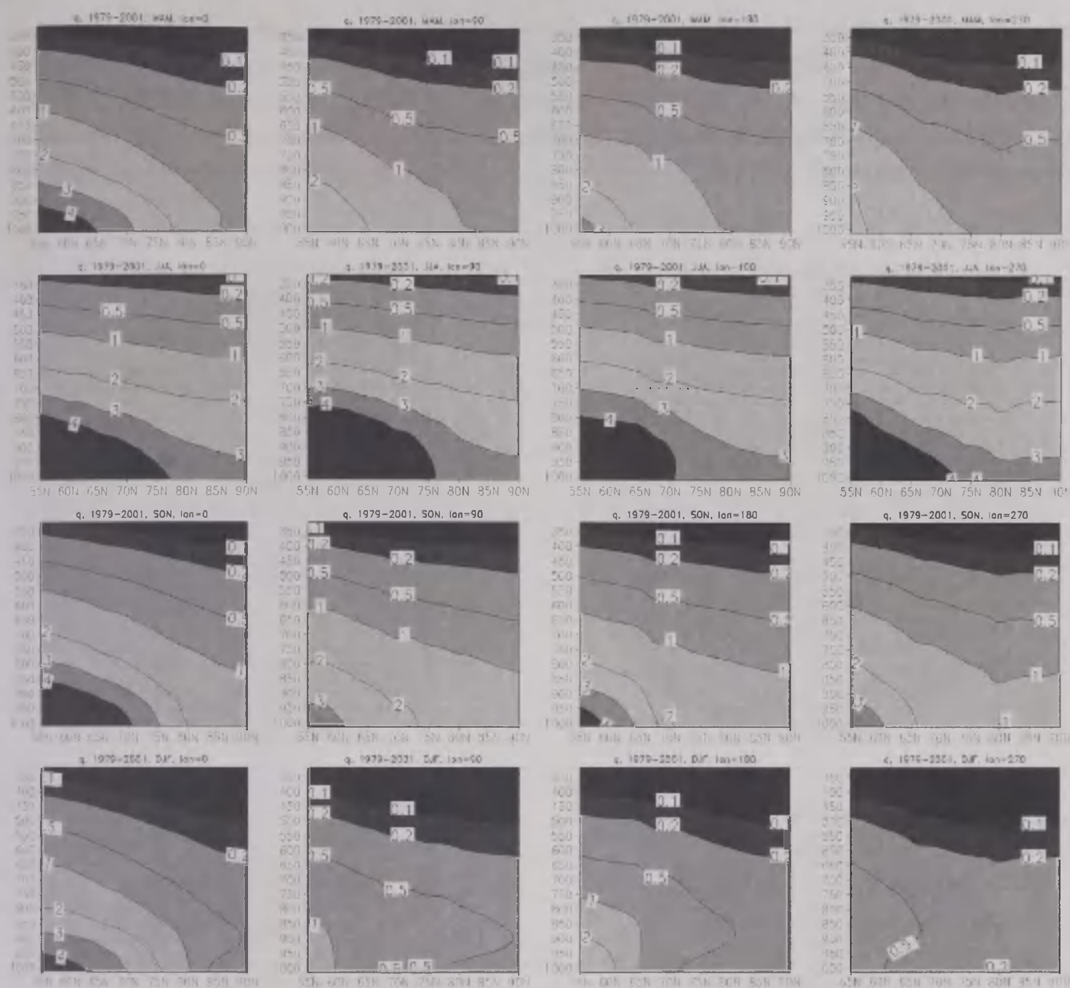

Fig. 7. Specific humidity (g/kg) seasonal average vertical profiles at the longitudes 0, 90, 180 and 270° for the years 1979–2001.

At the Canada sector (270°E) the minimal values of specific humidity occur at 80°N at the Queen Elizabeth Islands. At higher latitudes the specific humidity slightly increases in the entire vertical scale. This is related to the general circulation patterns. There is not much air coming to the Queen Elizabeth Islands from the south, but the regions closer to the North Pole are more affected by the transport of moisture from the Fram and Bering Straits.

During the winter there is a notable inversion in specific humidity in the atmosphere boundary layer (up to about 850 hPa). These inversions are explained by the temperature inversions that are very common during the polar nights.

The seasonal distribution of integrated precipitable water vapour (IPWV) for the years 1979–2001 is presented in Fig. 8. Mean values of IPWV for the studied region are 6.3 mm in spring, 16.2 mm in summer, 8.2 mm in autumn and 4.0 mm in winter. Higher values are observed in the Atlantic section due to the Gulf Stream. In the summer the highest values are found in continental Europe and western Asia. Minimum IPWV values are observed in Greenland. This can be explained by both low temperatures and high altitude.

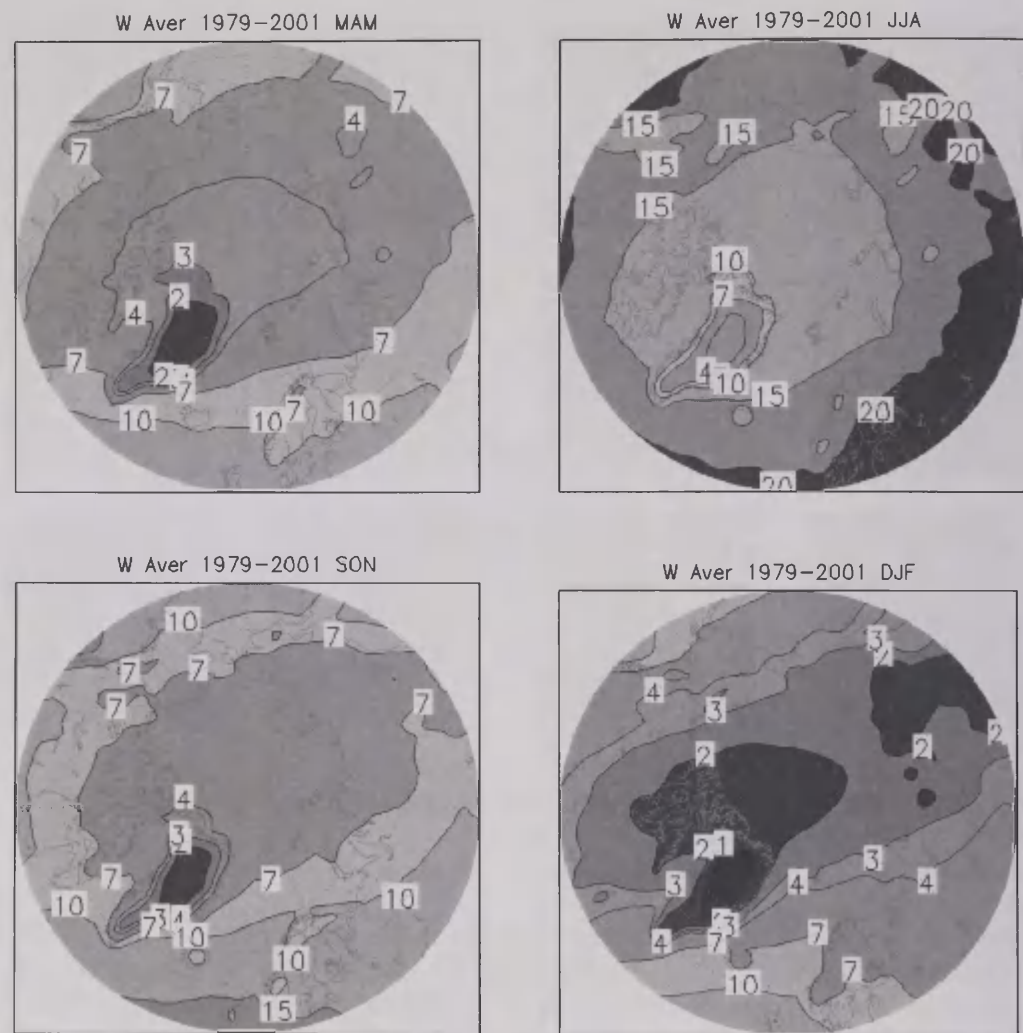

Fig. 8. IPWV (mm) seasonal averages for the years 1979–2001.

Great variations in IPWV occur in Siberia, for example at Yakutsk, where in the summer the average value exceeds 20 mm, while in the winter the average value is

1–2 mm. Small variations in IPWV occur, for example, in northern Scotland, where all seasonal averages are in the range of 10–20 mm.
The Gulf Stream from the Atlantic Ocean and the Nordic Stream from the Pacific Ocean both heat the Arctic. For this reason, the isolines of IPWV are prolonged in the Canada–Asia direction during all seasons.

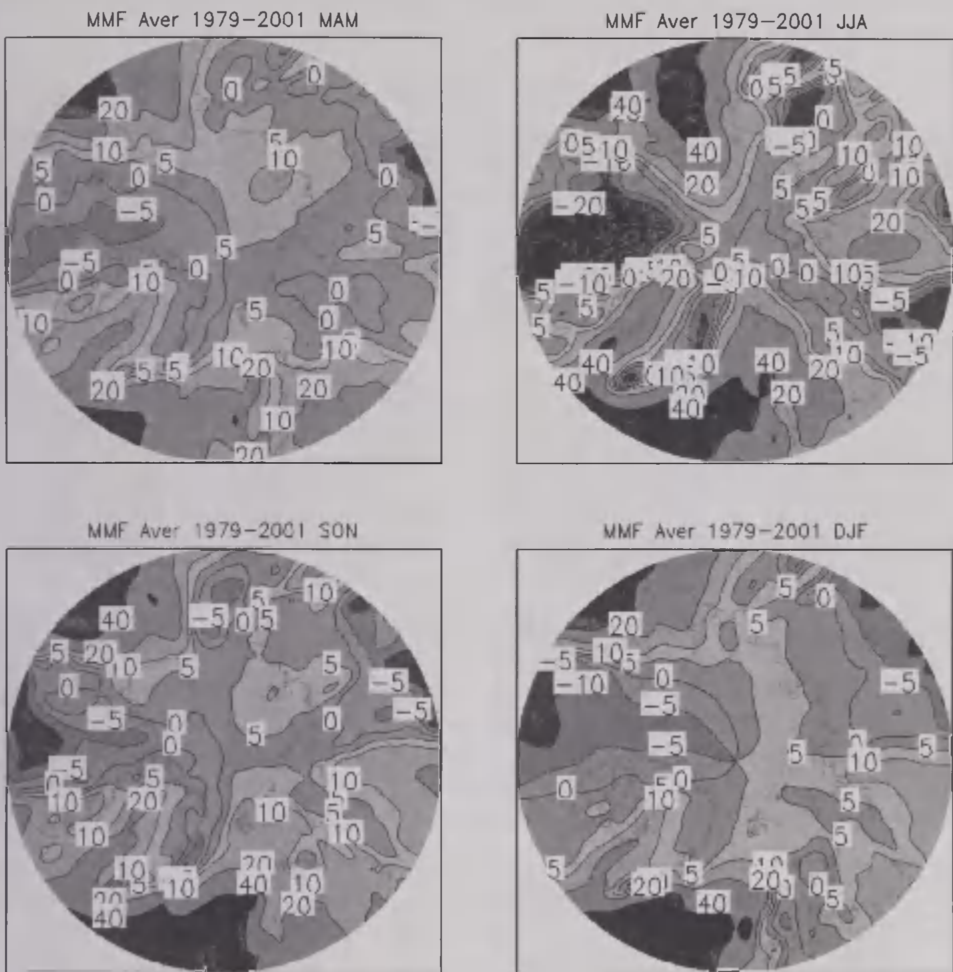

Fig. 9. Meridional moisture flux MMF (kg/m/s), seasonal averages for years 1979–2001.

Trend analysis of the time series of IPWV revealed mostly increasing trends. In summer the area with a statistically significant positive trend of IPWV covers approximately 10% of the studied territory, mostly the Canadian Arctic Archipelago. 13% of the study area has a significantly positive trend in IPWV in autumn, mostly in the

Atlantic Ocean. In winter there is 8% of area with a significantly negative trend in IPWV, mostly in eastern Siberia and in the East Siberian Sea.

The ERA-40 results for the vertically integrated meridional water flux MMF (Fig. 9) demonstrate that average meridional water transport is northward. Mean values of MMF for the studied region are from 8.1 kg/m/s in spring to 11.3 kg/m/s in autumn. Major MMF northward transport takes place in the Atlantic section and in the Alaska section. Major MMF southward transport takes place in the Canada section, but it is altogether weaker than the northward transport. In all seasons there is a high clockwise transport of moisture around Greenland.

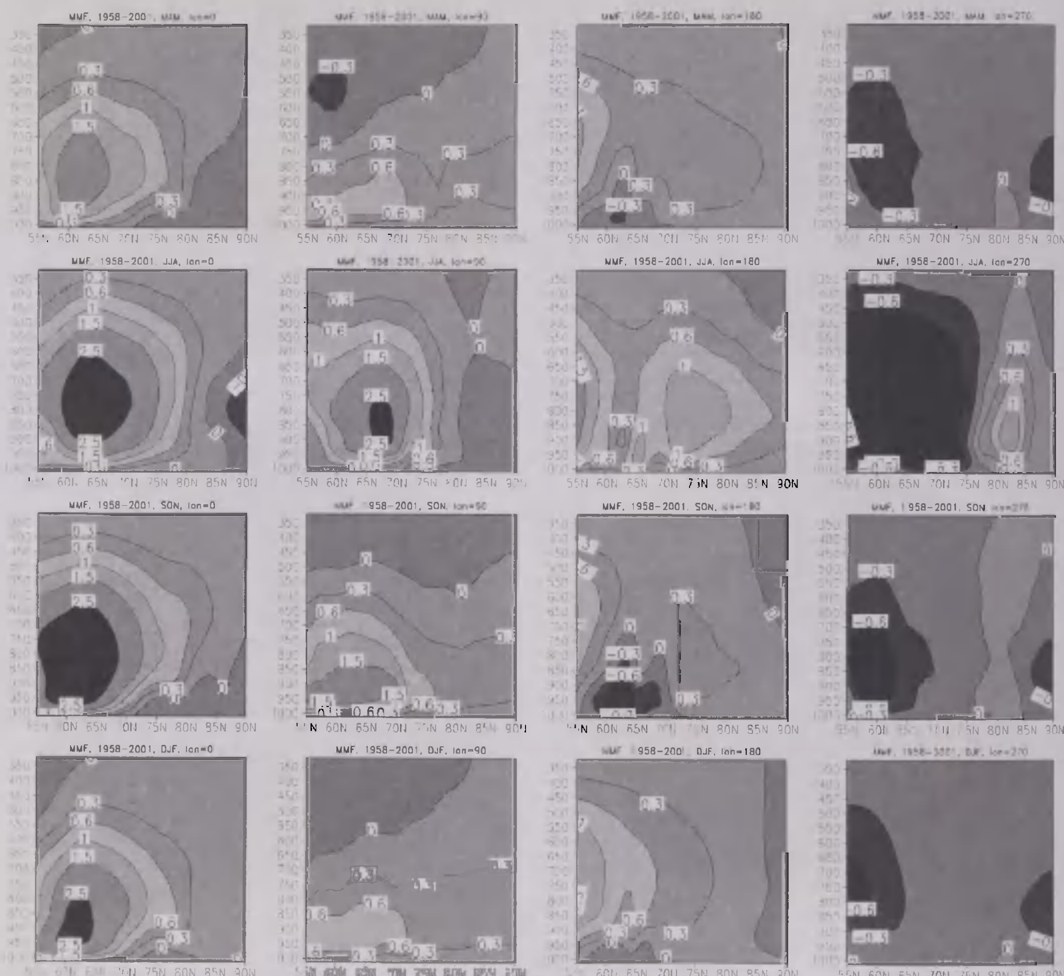

Fig. 10. Meridional moisture flux MMF (kg/(m s hPa), seasonal average vertical profiles at longitudes 0, 90, 180 and 270°E for the years 1979–2001.

In the Atlantic sector (0°E) there is a strong northward humidity transport in a the entire vertical scale. At the boundary layers there is a southward humidity transport at Greenland latitudes, which is caused by the clockwise winds around Greenland.

In the Bering Sea sector (180°E) there is a southward humidity transport during spring and autumn at lower vertical levels at East Siberia latitudes (Fig. 10). Around and above this volume, there is northward humidity transport. At the Canada sector (270°E) there is mostly southward humidity transport, and only in summer is it northward from the Queen Elizabeth Islands.

FIELD MEASUREMENTS AT THE TARA ICE CAMP IN 2007

In situ meteorological observations in the Arctic Ocean have always been very sparse. There has been a long history of Soviet polar expeditions, where routine meteorological measurements were made. In 1937–1938, from 1950 to 1991, and again from 2003 onward, meteorological measurements have been made on 35 Russian North Pole (NP) drifting stations on multi-year ice floes. The meteorological measurements included observations on the near-surface air temperature, humidity and wind, snow surface temperature and solar radiation. In addition, rawinsonde soundings on the vertical profiles of wind, temperature and humidity were performed.

In summer 2007 extensive meteorological, oceanographic and sea ice measurements were performed at the drifting ice station Tara (Gascard et al., 2008). The Tara expedition was part of the DAMOCLES project. The Tara drift began on 3 September 2006. Some meteorological measurements were made from September 2006 to April 2007. Due to storms and the breaking up of the ice floes surrounding the ship, however, the crew had to evacuate the equipment several times during this period. The continuous measurement period began on 21–27 April, with the exact date depending on the measurement quantity, and ended on 19 September 2007. We will only address data from this period. The observations from April to September 2007 were mostly made by Timo Palo. During the first two weeks, Erko Jakobson assisted with the installation of the equipment and in performing measurements. The Tara drift, the mean Arctic ice edge and the minimum in 2007 are presented on Fig. 11.

A weather station (Aanderaa model AWS 2700) with a 10 m mast was installed on the ice. Temperature and wind speed sensors were installed at nominal heights of 1 m, 2 m, 5 m and 10 m, pressure and relative humidity sensors at 2 m and a wind direction sensor at 10 m. The heights of the mast-mounted sensors above the snow/ice surface varied during the drift because of snow accumulation and surface melt, and some systematic differences also arise from the changing of the mast in April 2007. Data was collected at Tara with an interval of two minutes.

The radiation mast consists of two pyranometers (Eppley PSP) for the measurement of incident and reflected shortwave global radiation and two pyrgeometers (Eppley PIR) for the measurements of downward and upward longwave radiation. One of each of the sensors was uplooking and one was downlooking. The height of the radiation mast was about 2 m. The data measurement interval was 1 minute. There was no internal heating of the sensors, so the main task was to clean the sensors regularly from

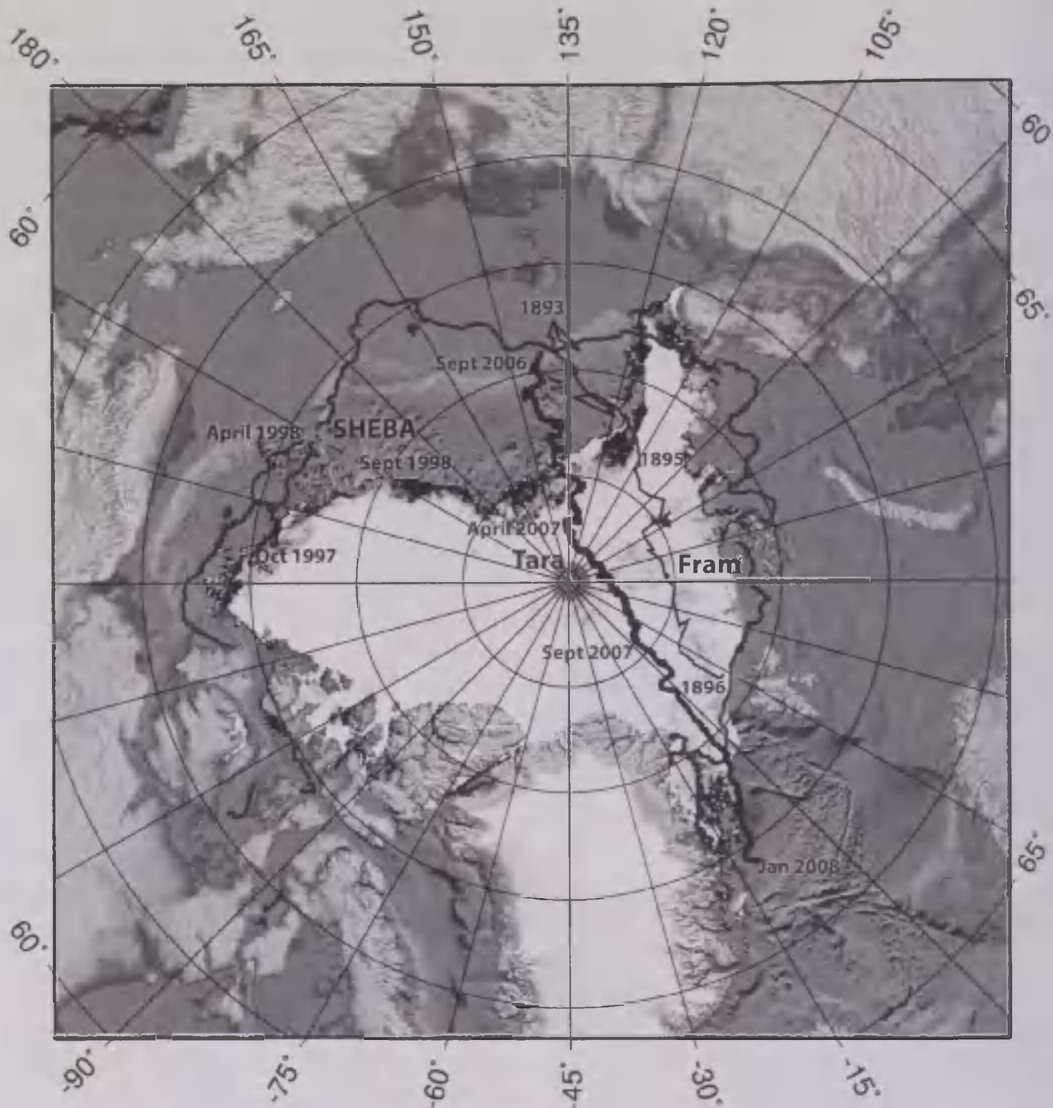

Fig. 11. Drifting trajectories of Tara (2006–2008) and Fram (1893–1896).

condensate and ice. In addition, the levelling of sensors was done many times, as the frame tilted due to uneven ice melting during the melt period in summer 2007.

The Vaisala DigiCORA Tethersonde System was used to profile air temperature, relative humidity, wind speed and wind direction from the surface up to 2 km of altitude. Sensor altitude was calculated by barometer. Because of frequent icing of the tetherline, sensors and balloon that made the entire system much heavier, the average top altitude was 1242 m. There were usually three sensors connected to the line with an interval of about 20 m, and a reference sensor at 1 m level. The sampling interval was about 8 s.

There were two sounding days per week, with one deep sounding and 1–2 fast soundings per sounding day. There were 39 sounding days with 95 soundings over 129 days. The profiling days were not distributed uniformly, because of the dependence on the weather – the system works at wind speeds lower than 15 m/s, so the profiles do not include stormy weather.

At beginning of the deep soundings, the balloon went up as high as it could go. According to the ascending profiles, all mutable layers with rapid changes in linear profiles of temperature, relative humidity, wind speed and direction, were selected for closer investigation. During the descent, at every selected altitude the balloon was stopped for five to ten minutes. During the fast soundings the balloon ascended and descended with no stops to understand temporal variations. For better understanding of the diurnal variations of vertical profiles, three 24-hours profiling campaigns were performed: from 29 to 30 May ten profiles, from 29 to 30 June seven profiles and from 17 to 18 July twelve profiles.

The near-surface meteorological variables are presented for the season for which Tara data is available: from 23 March to 19 September (from 2 April to 19 September for wind speed, air temperature, and air humidity). The data are presented as daily means for the Tara and NP stations, while the daily means are calculated as averages of the 31 NP stations (15 for the radiative fluxes). As most NP stations operated for more than a year, each daily mean is based on 64–79 daily data sets (39–44 for the radiative fluxes). Hence most synoptic-scale variability is filtered out of the averaged NP station data. In the following, spring is defined as the period from 23 March (or 2 April) to 31 May, summer as 1 June to 31 August, and autumn as 1 to 19 September.

During the Tara observation period, the latitude of Tara ranged from 85.9 to 88.5°N, while in the same season the range was, on average, from 80.4 to 83.0°N for the NP stations. Due to these differences, until mid-April and from the end of August onwards, the intensity of the daily mean incident solar radiation at the top of the atmosphere (TOA) was lower at Tara.

The Tara observations on downward solar radiation at the height of 2 m are similar with respect to the seasonal cycle and the amplitude and temporal scale of fluctuations (Fig. 12a). The peak values occur close to the summer solstice. After that the values decrease more rapidly than they increase before the summer solstice. This is due to the increase in cloudiness in July and August. Filtering out the synoptic-scale fluctuations, the Tara data qualitatively follow the seasonal cycle of NP data but decrease even faster towards the end of our study period. The atmospheric transmissivity for shortwave radiation (the ratio of the surface to TOA solar radiation) shows clearly higher values at the NP stations – the mean ratio is 0.54, while it is 0.50 for Tara (Fig. 12b). This suggests a lower cloud fraction or optically thinner clouds at the Russian stations than in Tara.

In spring and autumn the mean albedo was higher at Tara than at the NP stations (Fig. 12c), while the mean value for summer was highest at the NP stations (0.69). The reflected shortwave radiation at Tara in 2007 was generally lower than the mean values measured at the NP stations. Due to the combined effects of the increase in TOA radiation towards the summer solstice, the increase in cloud cover towards summer and

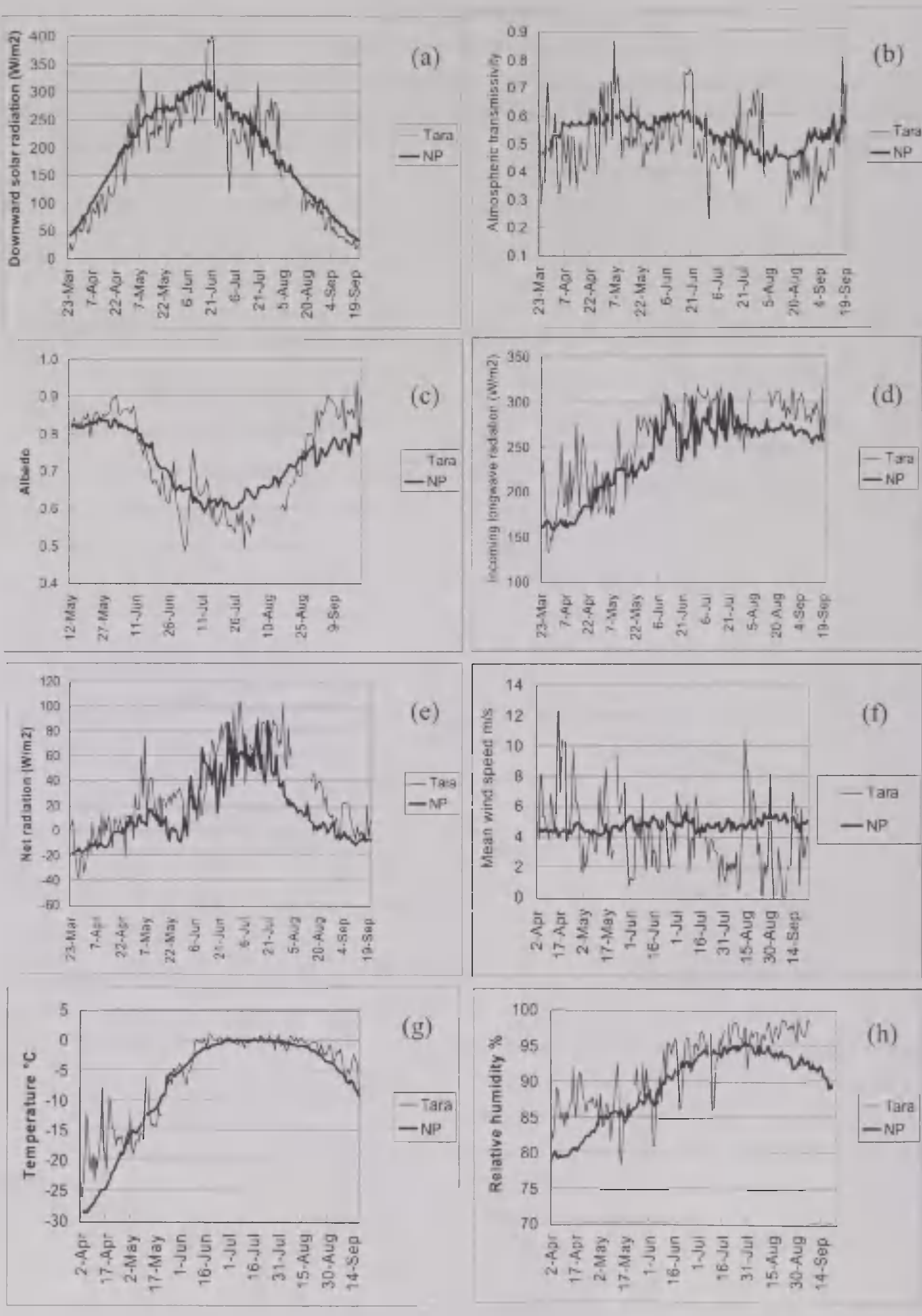

Fig. 12. Time series of daily means of meteorological observations at Tara in 2007, and at the 31 NP drifting stations: (a) downward solar radiation, (b) atmospheric transmissivity for shortwave radiation, (c) albedo, (d) downward longwave radiation, (e) net radiation, (f) 10-m wind speed (the 5-order polynomial for Tara is also shown), (g) 2-m air temperature, and (h) 2-m relative humidity (with respect to water).

the rapid decrease in surface albedo in June, the reflected radiation reached its maximum values 10–15 days before the summer solstice.

Downward longwave radiation was not measured at NP stations, but we calculated it as a residual of net radiation, downward solar radiation, reflected solar radiation, and upward longwave radiation. The results (Fig. 12d) indicate much higher downward longwave radiation at Tara than at the NP stations. It seems probable that the downward longwave radiation has increased in the Arctic by 2007 since the period 1968–1991. This is in line with the results for the atmospheric transmissivity for shortwave radiation, suggesting that Arctic cloudiness has increased in coverage or thickness or both. The seasonal evolution of net radiation (Fig. 12e) was qualitatively similar at the Tara and the NP stations, except that at Tara a strong peak occurred in early May. Net radiation was remarkably greater at Tara than at the NP stations.

The 10-m wind speed averaged over the study period was 4.3 m/s at Tara and 4.8 m/s at the NP stations. The seasonal evolution was, however, different (Fig. 12f): at the NP stations the winds increased towards the end of the study period, while the trend was opposite at Tara.

On average, April was much warmer at Tara than at the NP stations (Fig. 12g). In the Tara data, the snow/ice surface temperature was typically within 1°C of the 2-m air temperature. The melting season, defined as the period when air temperature stabilised to values near 0°C, started on average on 29 June at the NP stations and much earlier at Tara – on 10 June in 2007. The melting season ended on approximately 4 August at the NP stations and much later, around 24 August, at Tara. The long melting season at Tara is noteworthy, as it is located further north than the NP stations.

Relative humidity values at Tara were mostly higher than those at the NP stations (Fig. 12h). The date when relative humidity first exceeds 93–95% coincides with the air temperature reaching 0°C. The results support the idea of Andreas et al. (2002) that the near-surface relative humidity over the ice-covered Arctic Ocean is usually near saturation with respect to the ice phase. At Tara the mean relative humidity with respect to ice was 98%.

The average vertical profiles of air temperature and relative humidity from 25 April to 31 August are presented in Fig. 13. To calculate a representative mean profile for the period, it is essential that the data be uniformly distributed over time. Hence, from the irregular Tara data, weekly averages were first calculated, and the mean profile for the whole period was based on the averaging of these.

The Tara mean profiles were calculated only up to an altitude of 1080 m; too few soundings reached higher. Due to problems in operating the tethersonde with wind speeds exceeding 15 m/s, the Tara data set is not a representative sample of the wind profile. We found, however, that with winds ranging from 1 to 14 m/s, the air temperature and specific humidity had no correlation with wind speed. We further compared the tethersonde-based 2 m air temperature and relative humidity to the weather mast observations for the entire period of 25 April – 31 August. The mean 2 m air temperature based on the soundings was 0.35°C lower than that based on the weather mast, while the mean values of relative humidity were equal within 0.1%. Hence we conclude that the Tara data set is a fairly representative sample of the temperature and humidity profiles, but it may also have a small cold bias at higher altitudes.

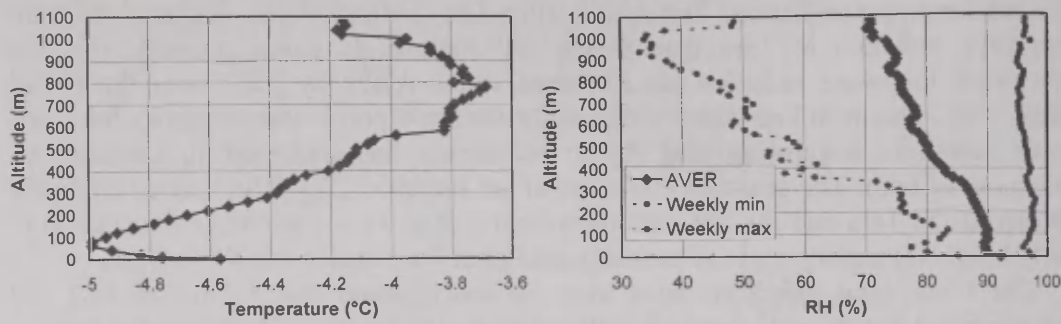

Fig. 13. Mean vertical profiles of air temperature (°C) and relative humidity (%) from the period 25 April to 31 August 2007.

The mean temperature profiles showed an inversion with base height at 70 m with temperature –5.0°C and the inversion peak at 780 m with –3.7°C. The greatest inversion was measured on 18 July, when at inversion base height 220 m the temperature was –2.0°C and rose to +11.2°C at inversion peak 1020 m.

Mean relative humidity was very high, about 90% at the lowest 100 m, but after that the profile almost uniformly decreased with a slope of 1.8% / 100 m. Weekly minimal values of RH were between 920 m and 1020 m less than 35%, and weekly maximum values were stable at more than 95%.

CONCLUSIONS

The analysis of Arctic cyclones revealed several statistically significant trends expressing intensification of cyclonic activity over the Arctic Ocean. The number of cyclones in the Arctic north of 68°N has significantly increased during the period 1948–2002. This is caused by the increase of the entering into Arctic cyclones. Number of cyclones formed in the Arctic Circle has not changed. The number of deep cyclones has increased and of shallow cyclones decreased. The biggest changes have occurred in winter. Statistically significant increase in the number of the entering cyclones has taken place in the regions of the Bering Strait, Alaska, western Canada, Baffin Bay and the western coast of Greenland. Duration of the Arctic cyclones has not changed while their mean sea-level pressure has decreased significantly. The amount of deep cyclones has increased significantly, first of all during the winter season.

The results of the analysis of moisture budget and moisture transport in the Arctic indicate remarkable changes during the period 1958–2001. Integrated precipitable water vapour, air temperature, precipitation and evaporation have general displayed increasing tendencies, although these were not continuous throughout the entire period. Specific humidity decreases with increasing latitude, while it is much higher over the Atlantic sector due to the Gulf Stream, and lower over land areas in the Arctic region. IPWV demonstrates an increasing trend in the Canadian Arctic Archipelago in summer, in the Atlantic sector in autumn and over the East Siberian Sea in winter. A northward meridional moisture transport prevails in the Northern Hemisphere. It is highest in the Atlantic and Alaska sectors. A lower degree of southward moisture transport exists in the Canadian sector.

Field measurements at the Tara ice camp from April to September 2007 provided valuable empirical data on the atmospheric boundary layer. The dynamics of the main meteorological variables in the Central Arctic region during this extremely warm year was peculiar. Due to greater cloudiness in July and August, incoming shortwave solar radiation decreased rapidly after its maximum near the summer solstice. Albedo and reflected shortwave radiation in summer were much lower at Tara than the mean values measured at the NP stations. Downward longwave radiation and net radiation were remarkably high at Tara in 2007. As a consequence, the melting season when air temperature stabilised at the mean temperature of around 0°C began at Tara about 20 days earlier and ended 20 days later than the average of the NP observations. Relative humidity at Tara was higher than the average in 2007.

The mean vertical air temperature profile indicates the presence of a strong inversion starting from a height of 70 m and reaching the highest temperatures at heights of 600–900 metres. Relative humidity gradually decreases in the lower 1000 m layer of the atmosphere.

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THE IMPACT OF FOREST COVER ON POLLEN SPECTRA IN LAKE SEDIMENTS

Mihkel Kangur, Tiiu Koff

INTRODUCTION

Pollen analysis is mainly used to reconstruct patterns of vegetation composition and landscape. As it is determined by changes in climate, vegetation reconstructions give fairly detailed information about climatic conditions and past trends. Over the last few thousand years, the human impact has risen, becoming an increasingly strong determinant of the nature of plant cover. Agriculture, one of the most intensive human activities, has triggered the opening up of the landscape and the reduction of forest areas in the boreal zone. Human-driven changes in the landscape plant cover may bring about changes in the geochemical matter cycle, hydrological regime and albedo. These factors may in turn influence climatic conditions. In recent years, a need for quantitative reconstructions of vegetation development has arisen in parallel with debates over the impact of climate change. Understanding of the long-term history and dynamics of landscapes is an essential component in fully valuing and effectively managing them. In addition, the new hypothesis that humans are responsible for the CO_2 rise that took place over the last 8000 years (Ruddiman, 2003) needs to be supported by qualitative information on forest clearance.

The percentage of NAP (non arboreal pollen) in the total pollen assemblage has been considered to be an indicator of landscape openness, but assessment data from Europe (Frenzel, 1992) and Sweden (Gaillard et al., 1998) demonstrate that the relationship between landscape openness and NAP percentages from lake surface sediments is not straightforward, and is not directly connected with landscape openness (Sugita et al., 1999). Detection of landscape openness requires calibration of the correlations between the pollen spectra and vegetation. The model-based approaches in the calibration of pollen-vegetation relationships that have increasingly been applied in recent years require extensive parametrization for a particular landscape. This may be one of the targets of criticisms of such approaches. The modern analogue technique is a well-functioning pollen and plant-cover calibration method (Nielsen & Odgaard, 2005). The use of the "modern analogue-comparative approach" – in other words, a comparison of pollen assemblages from traditional cultural landscapes still existing today with past pollen assemblages from soil, peat and lake sediment has helped in the interpretation of fossil pollen data in terms of past land uses such as mowing and grazing (Gaillard et al., 1994; Hjelle, 1999). Recent methodological developments (by the Nordforsk-pollandcal network, 2001–2005) in the interpretation of pollen provide means to reconstruct past land cover in much more precise quantitative terms (landscape/vegetation units in hectares or percentage cover) than was earlier possible (Brostrom et al., 2005).

Estonia, which has a large number of continuous lake and bog sediment sequences and dramatic changes in land-use, offers a good opportunity for the studying of the correspondence between pollen-based reconstructions and historical data. Integrated palaeoecological research into laminated lake sediments and historical data was applied to study the land-use changes over the past 1000 years (Veski et al., 2005) and the last hundred years (Koff & Punning, 2002). Though the role of human activity in effecting changes over the last hundred years is well documented in historical maps and/or archives, the correlation between this and changes in the composition of pollen spectra in sediments has not been thoroughly studied. The aim of the present study is to find relationships between vegetation structure and pollen spectra using the example of some Estonian lakes. In this study, topographical maps, aerial photographs and data on forestry management have been used for the quantification of forest cover.

STUDY SITES

Lakes of similar size (3–6 ha) from different parts of Estonia were selected as study sites (Fig. 1, Table 1). Lake Viitna Linajärv (hereafter Lake Viitna) is situated in the area of the Viitna kame field in northern Estonia. Forests surround the lake. No information exists concerning significant changes in vegetation in the surroundings of the lake over the past hundred years. A recently established motel on the lakeshore has not caused a significant decrease in forest cover in the area (Punning et al., 2003). Lake Matsimäe is situated in central Estonia. 75% of the area surrounding the lake is covered by an ombotrophic bog (Fig. 1, Table 1).

1-L. Viitna Linajärv; 2-L. Matsimäe, 3-L. Õdre; 4-L. Alevijärv; 5-L. Väike-Juusa

Fig. 1. Location of studied lakes

Table 1. Characterisation of studied lakes.

Lake	Position	Area, ha	Dominant vegetation types on catchment	Sources of vegetation data
Matsimäe	59°04' N 25°31' E	4.8	Ombrotrophic bog forest	1963, topographic map
Õdre	57°45' N 26°27' E	3.0	Fresh boreal forest	1963, topographic map 1995, topographic map
Viitna Linajärv	59°40' N 25°45' E	3.8	Dry boreal forest	1995, topographic map
Alevijärv	58°30' N 26°29' E	2.4	Cultivated pastures / dry boreonemoral forest	1920, topographic map 1963, aerial photograph 2005, forest management map
Väike-Juusa	58°30' N 26°30' E	3.0		

Gravel pits were established on the esker lying west of the lake in the 1950s and 1960s. After the utilisation of these resources the area was partially reforested, and a swimming site was established on the lakeshore. A historic farm with small fields and meadows has remained on the esker (Koff & Punning, 2002). Lake Õdre is situated in southern Estonia in the Karula uplands (Fig. 1, Table 1). The lake is surrounded by forests, which in certain areas have been logged over the past century. None of the logging has reached the shores of the lake. The most extensive logging, conducted closest to the lake, took place at the end of the 1950s. This has naturally been afforested by now (Koff & Punning, 2002). Lake Väike-Juusa (hereafter Lake Juusa) and Lake Alevijärv lie in the Otepää uplands in southern Estonia (Fig. 1, Table 1). These lakes are located a few dozen metres apart. It can be assumed that the relevant source areas of the pollen found in both lakes overlap to a large extent. These lakes are surrounded by an open landscape that has become increasingly afforested over the past century (Kangur, 2005b).

METHODS

Sediment samples were obtained through the ice using a modified Livingstone-Vallentyne piston corer equipped with an extension rod. The lithology of the sediments was recorded in the field. The sampling was continuous, at 1-cm intervals up to 40 cm and 2-cm intervals at greater depths. Samples were placed in plastic bags and kept in a refrigerator until the analyses were performed. A measured volume of samples was dried at 105 ^{0}C, and the water content and density was estimated. For pollen analysis, 50 mg of dried sample was boiled in 10% KOH and treated using standard acetolysis (Moore & Webb, 1978). Three tablets with a known content of *Lycopodium* spores (Stockmarr, 1971) were added to each sample at the beginning of the laboratory treatment to calculate pollen concentration. In general, at least 500 AP grains were identified and counted under the microscope. The pollen diagrams were prepared using the TILIA program (Grimm, 1990). Percentage pollen diagrams are based on total terrestrial pollen, which is to say the sum of AP and NAP. For age estimation we applied the ^{210}Pb method with the layers, with a maximum of ^{137}Cs (ref. yr. 1986) (Punning et al., 2000) as a reference level. Through consideration of the history of the high temperature combustion of fossil fuels in Europe and in Estonia, the sediment layers that had a significant increase in the concentration of spherical fly-ash particles concentrations were regarded as having accumulated towards the end of the 1940s. The age of individual layers and the deposit rate were calculated on the basis of the mean annual sedimentation rate between the reference layer and the sediment surface, using the measured dry matter content in individual layers (Punning et al., 2000). Considering the dating and the age of each sediment layer, periods were determined in pollen diagrams that correspond to the changes in vegetation distinguished on maps.

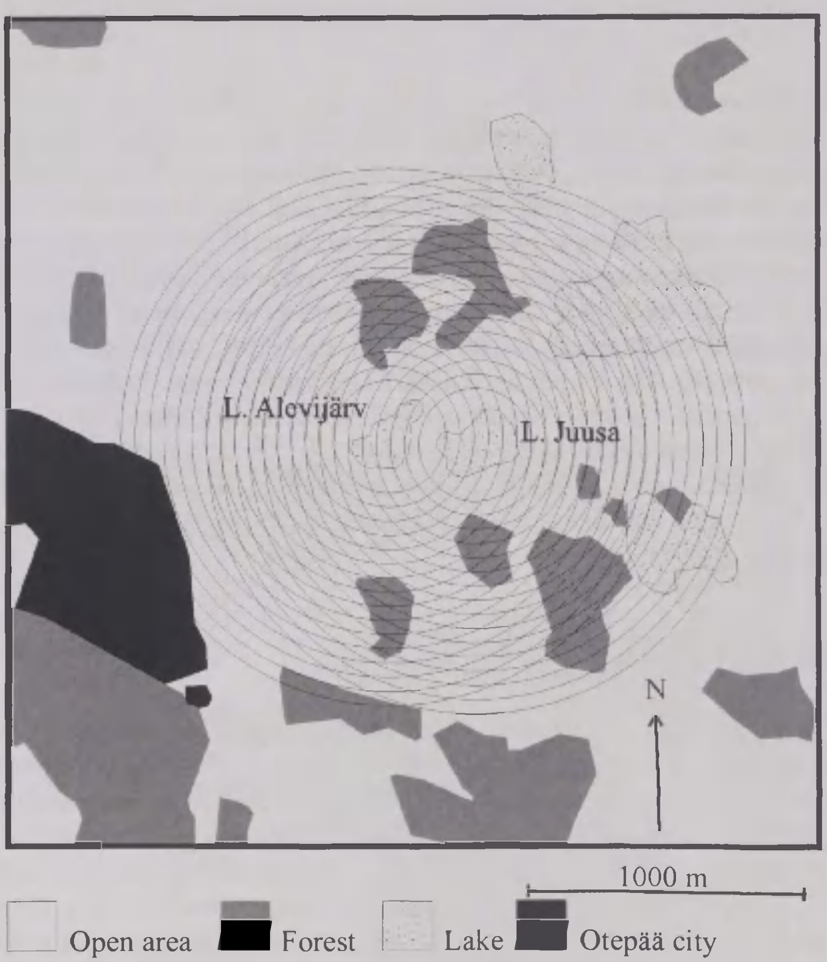

Fig. 2. Example of the digitalised map of the surroundings of Lakes Väike-Juusa and Alevijärv from the 1920s, divided into 50-m-wide zones.

All of the lakes under investigation have an area of a few hectares. The relative source area of pollen, the area from which the chief part of the pollen forming the pollen spectra originates, is a zone approximately 450 m wide around the lake (Kangur, 2005a). In the case of all of the lakes, a 900 m-wide area around the lake (twice the size of the relevant source area of pollen) was digitalised. In the process of digitization, the following landcover types were identified: forest, open landscape, lakes, and non-pollen-producing area. The latter was identified only in the cases of Lakes Juusa and Alevijärv, where the town of Otepää does not have proper plant cover. Even though pollen may be extracted from a town's green areas, it is difficult to determine the plant cover structure and plant composition there. In order to assess the spread of forest cover, the digitized areas were divided into concentric 50-m-wide zones within which the amounts of forest-covered and open landscape areas were calculated. As an example, in Figure 2 the digitized map of the surroundings of Lakes Juusa and Alevijärv divided into 50-m-wide zones is reproduced. Leaving lakes and non-pollen-producing areas out of consideration, the forest coverage of every 50-m-wide zone was calculated on the basis of this data. Taking into account the forest coverage of theses zones, the average forest coverage around the lake under investigation was calculated. In Figure 3, the distribution of forest on a zone 900 m wide around Lakes Juusa and Alevijärv is presented as it was in the years 1920, 1963 and 2005.

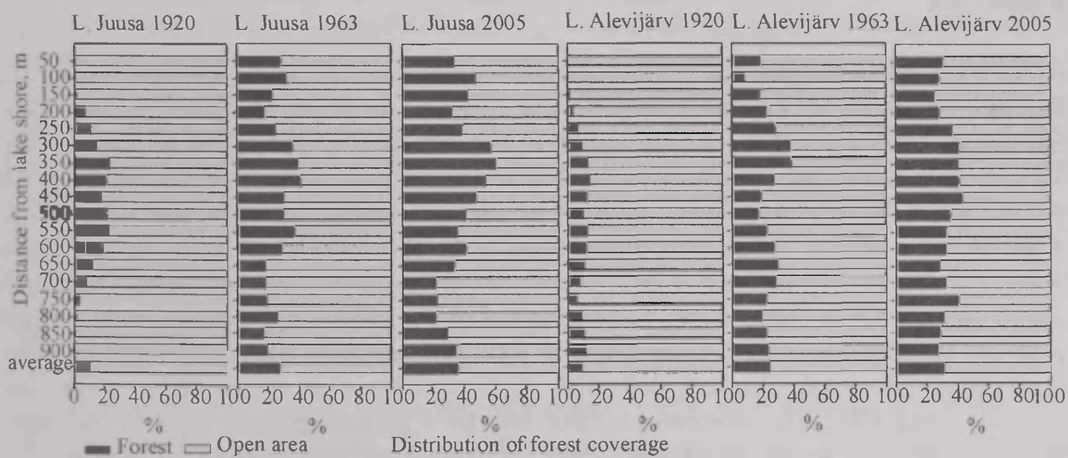

Fig. 3. Distribution of forested and open areas around Lake Väike-Juusa and Lake Alevijärv.

The percentage of forested areas identified in this zone is compared with the average percentage of AP in the pollen spectra of the three subsequent sediment layers formed at a particular period of time (Fig. 4).

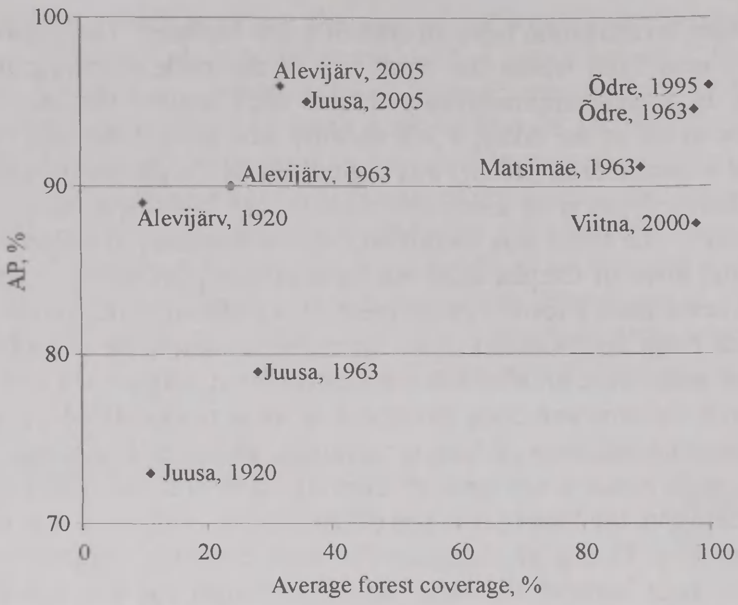

Fig. 4. Percentages of forest coverage around studied lakes and corresponding percentages of arboreal pollen in pollen spectra.

RESULTS

Despite the great variation in the landscapes surrounding the lakes, the AP content in the lake sediments is also quite high. In the case of any lakes, however, the AP does not reach 100% even if the surroundings of the lake are fully covered by forest. The highest forestation rate has been registered in the vicinity of Lake Õdre in the mid-1990s, when the area was 100% covered by forest. Even in this case, the AP content remains 96% in the zones that correspond with that period of time. In the mid-twentieth century, when vast logging took place in the vicinity of Lake Õdre, the lowest percentage of forest cover was registered in the 1963 topographical map. At that time the logging zones were closest to the lake, yet remained outside the 450-m-wide zone from the shore. The proportion of forest in the zone up to 900 m from the lakeshore was 97%. The proportion of AP was 94% in the sediment layer in the same time period. The area surrounding Lake Viitna is mostly covered by forest: the proportion of forest is about 98%. However, the AP content in the sediment layer is 88%. The minimum proportion of forestation on the shores of Lake Matsimäe – 98% – was recorded on the topographic map dating from 1963. In the sediment layers from the same time period, the AP content is 91%.

The lowest proportion of forest at Lakes Juusa and Alevijärv was recorded at the beginning the last century. Forest coverage then reached only 10% in the areas surrounding these two lakes (Fig. 3). It is remarkable that at that time the zone around the lakes was not forested for several hundred metres. The forested area generally stopped 350 to 550 metres from the lakeshore. In the case of Lake Juusa, the proportion of forest coverage is higher in these zones, reaching 20%. In the zone 750–900 m from the lakeshore, the forest coverage decreases once again. In the case of Lake Alevijärv, the forest coverage is more homogenous, remaining at 10% throughout the territory. Nevertheless, the content of tree pollen makes up 73% of all of the terrestrial pollen found in Lake Juusa sediments dating from that period. At Lake Alevijärv the proportion is even higher, reaching 89%. As forestation increases in the area, the amount of AP shows an increasing trend in both lakes. In the 1960s the average proportion of territory covered by forest around both lakes had increased to 24–28%. By that time, the shores of the lakes had begun to reforest. In the case of Lake Juusa the shores are more forested: approximately 30% of the lakeshores are forested. The greatest forest density is at a distance of 300–450 m from the lakeshore. In the case of Lake Alevijärv, forest coverage appears in 25% of the areas closest to the lakeshore. The areas with greatest forest coverage lie 300–350 m from the lakeshore. Even though the forest coverage and vegetation structure are similar in the case of both lakes, the AP percentages in corresponding sediment layers differ. In sediments from Lake Juusa, tree pollen makes up 79% of the pollen total. In Lake Alevijärv this reaches 90%. Currently the forest covers approximately one-third of the area around the lakes. The proportion is slightly higher in the case of Lake Juusa: 36%. In the case of Lake Alevijärv, the forest covers 32% of the surrounding territory. The shores of both lakes are still forested. In the case of Lake Juusa, the proportion has remained the same: 30%. A noticeable increase in forest coverage has occurred at a distance of 100–150 m from lakeshores, where the forest coverage reaches over 40%. The highest forest coverage is still found at a distance of 300–350 from lakeshores, where 60% of territory is covered by forests. Further away, the forest coverage decreases and remains below 40%. In the surroundings of Lake Alevijärv the forest coverage has increased in all separated zones. Compared to Lake Juusa, the forest coverage is more uniform around Lake Alevijärv – approximately 30–40% of the territory is covered by forest in every separated zone. The AP proportion in the uppermost sediment layers of Lake Juusa and Lake Alevijärv is 95% and 96% respectively.

DISCUSSION

In palaeoecological studies involving pollen analysis, it has long been understood that there is no 1:1 relationship between the pollen incorporated in sediment and the vegetation produced. This is because of differences in pollen production, pollen dispersal and pollen deposit levels between species (Hicks, 2006). Therefore the proportional cover of forest and grassland vegetation, known as landscape openness, has been particularly difficult to reconstruct. The results of the present study confirm this statement.

Taking into account the share of forestation in the surroundings of the studied lakes, they can be divided into two groups. The first group of lakes includes those situated in highly forested landscapes (Õdre, Matsimäe and Viitna lakes). 90–100% of surroundings of these lakes are covered by forests. The AP proportion in sediments taken from these lakes varies between 87% and 96%. Only in the case of Lake Matsimäe is the AP percentage in pollen spectra higher than the proportion of forested land around the lake. In the case of the other lakes the situation is reversed. We can generally say that in the sediments of lakes situated in forested areas, the share of AP in pollen spectra is high, but it is lower than the percentage of forest coverage in the surroundings of the lake. This is caused by the herbaceous vegetation growing under the trees, which also contributes to the formation of pollen spectra (Kreuz, 2008). Even if the amount of undergrowth is equal to the amount of forest, the pollen from herbs has a smaller chance of reaching the lake. As wind speed is lower in trunk space, the distribution ability of NAP is therefore smaller if compared to the wind speed above the forest canopy and the distribution ability of AP (Tauber, 1965; Kuparinen et al., 2007). In addition, the deciduous trees growing on the lakeshores act as filters for pollen originating from undergrowth and travelling in trunk space, preventing them from reaching the lake (Thomson, 1937).

Compared to the lakes that have been considered so far, the share of forest coverage in the landscapes surrounding Lakes Juusa and Alevijärv is much lower. During the last hundred years, the forest coverage of the surroundings of these neighbouring lakes has increased from 10% to 36%. An increase in AP percentages is also visible in the pollen profile, but the AP curves differ in both lakes. In the case of Lake Alevijärv, the AP proportion has increased from 89% to 96% over the last century. This is the same rate as the AP percentage found in the lakes in highly forested landscapes, as given previously. In the case of Lake Juusa the AP percentage increased from 73 to 95 during the same period. In the middle of the last century the AP proportion was lower than in the other lakes we studied. In the uppermost sediment layers, formed in recent years, the AP percentage is similar to those of the other lakes studied.

Overrepresentation of the AP and underrepresentation of the NAP in pollen profiles may have several causes. First of all, trees can produce six to eight times more pollen than *Poaceae*, the most abundant non-arboreal pollen type, thereby overwhelming a signal from non-arboreal vegetation (Brostrom et al., 2004). Moreover, trees growing in sparse forest or on the edge of a forest tend to produce more pollen than trees growing in dense forest (Kreuz, 2008).

Using the example of the landscapes surrounding Lakes Juusa and Alevijärv, it is possible to say that abandoned open areas become forested relatively quickly. A continuous input of human activity is required to keep the landscapes open. Grasses that have been mown do not normally flower like others, and they reproduce vegetatively (Kreuz, 2008). This could be one reason why in the case of Lakes Juusa and Alevijärv the share of AP in pollen spectra is high and comparable with pollen spectra formed in lakes within totally forested landscapes.

As herbaceous plants are shorter than trees, their pollen grains also have less potential energy released from the stamen. Therefore the pollen of herbaceous plants is distributed over a smaller area (Dupont et al., 2006; Kuparinen et al., 2007), and it is possible to assume that the NAP pollen in lake sediments originates from a much narrower area around the lake than AP. If meadows begin to be overgrown by forests in the immediate vicinity of the lakes, this causes a decrease in NAP in pollen spectra. This effect may appear even when the trees are not yet generating pollen (Hicks, 2006).

One can observe increased AP percentages in pollen spectra formed in the second half of the century in both lakes Juusa and Alevijärv. At the beginning of the last century the shores of both lakes were open to an extent of at least 100–150 m. In the 1960s one third of both lakeshores were forested, and we can assume that in the second half of the century they were already generating pollen. Therefore the AP percentage increases more rapidly in the last decades of the century. A high proportion of the pollen produced by plants growing on the lakeshores falls directly into the lake (Bonny & Allen, 1984; Walker, 2000). Even if one third of the lakeshores are forested, the pollen spectra in these lakes are similar to those of lakes located in forested landscapes. The distribution of forest patches around the lake influences the speed and direction of the wind in the layers of the atmosphere near the ground, and could therefore affect the transportation of pollen to the lake (Gash, 1986; García-Mozo et al., 2004). The pollen grains of herbaceous plants have a smaller chance of being carried into higher atmosphere layers, as the wind speed near the ground is lower (Tammelin, 1991; Kuparinen, 2006). As trees produce pollen much higher from the ground, their pollen is more common in atmospheric layers above canopies (Kuparinen et al., 2007). Forest, if it grows directly on the shores of a lake, reduces the wind speed above the lake and causes pollen grains to fall from the atmosphere (Gash, 1986; Miller et al., 1991). This effect is a complementary factor leading to the increase in AP accumulation in the lake (Koff et al., 2000) and therefore also AP percentages if the lake is partly or wholly surrounded by forests.

SUMMARY

It is a well known fact that there is no linear relationship between AP/NAP and landscape openness. Despite this, studies of pollen/vegetation calibration provide valuable information about the processes involved in the formation of pollen spectra in sediments and required for quantified vegetation reconstructions. Detection of landscape openness, defined as the abundance and distribution of trees and herbs, is essential for the accurate interpretation of past vegetation, the understanding of the resilience of systems to human impact and refining paleoclimate reconstructions. Despite their long history, such studies are still topical in palynology today (Von Post, 1967; Gaillard et al., 1998; Sugita et al., 1999; McLauchlan et al., 2007).

In the present study, a comparison between the landscape forestation surrounding six small (2.4–4.8 ha) closed lakes and the pollen spectra of the sediments of these lakes was performed. The results of the study are:

- In highly forested landscapes the AP proportion in the lake sediment pollen profile is generally lower than the proportion of forest around the lake. Pollen originating from herbaceous plants of the forest undergrowth participate in the formation of a pollen profile.
- In open landscapes the AP content in pollen spectra was considerably higher than the forest coverage in the surroundings of lakes. The AP content rises sharply if the lakeshores are partly forested. This is caused by several factors. One is the large

amount of pollen produced by trees growing on the lakeshores falling directly into the lake. Pollen from trees has a greater chance of rising above the canopies and is transported in higher atmosphere layers. The forest edge on the lakeshore causes a decrease in wind speed above the lake and therefore an increased accumulation of pollen in the lake. Because of the relatively smaller height of herbaceous plants, the potential energy of their pollen is smaller and therefore this is distributed closer to the source. The number of sources of the pollen of herbaceous plants decreases if the lakeshores are forested, causing a lower level of NAP content in pollen spectra.

One can conclude that the proportion of forested areas in the surroundings of a lake does not solely determine the content of AP in sediments. Vegetation structure, for example landscape patchiness and the position in relation to the lake, is also of great significance.

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ON THE FORMATION OF THE BOTTOM DEPOSITS OF LAKE PEIPSI, IN NORTH-EASTERN EUROPE

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INTRODUCTION

Lake Peipsi, on the border between Estonia and Russia, is one of the largest lakes in Europe (3555 km^2). Its average depth is 7.1 m and maximum depth 15.3 m. The northernmost and largest part of the lake is Peipsi proper or Lake Peipsi *sensus stricto*. It is connected to the southernmost part, Lake Pihkva, via the narrow strait-like Lämmijärv. The area in the immediate vicinity of the lake is wetlands of international importance, especially for migrating birds, some of which are included in the Ramsar list of wetlands.

In this paper we describe the biggest part of the lake – Peipsi proper (hereafter Lake Peipsi), which has the most important role in fishery and transport, both of which depend greatly on bottom deposits and shore types. Main attention will be focused on the formation of bottom deposits, which has been controlled by several geological and physico-geographical factors such as tectonic movements, deglaciation history, winds, waves and water level fluctuations, ice push, river inflow, human impact, etc.

Systematic lake investigations were begun after the catastrophic inundations in 1840 and 1844 which caused great damage to adjacent areas. As the fish-breeding in the lake needed some regulation, the first scientific studies mainly involved the lake's hydrology and biology. The first data on the lake's bottom deposits date from the end of the 19th century. Since then, the problems relating to the structure and geological development of the lake basin have been discussed in many publications. Bottom deposits are most thorougly described in the collection of papers in Russian in 1981 (Раукас, 1981a), as well as in several recently published monographs in Estonian (Pihu & Raukas, 1999; Haberman et al., 2008) and in English (Miidel & Raukas, 1999). Some new maps of the bottom deposits have recently been compiled (Hang et al., 2001; Punning et al., 2008b), but the formation mechanism and secondary processes like re-sedimentation and post-sedimentation diagenesis of deposits has not been studied very thoroughly. In this paper we seek to examine natural and human-induced changes in matter cycles and the role of different geological and physico-geographical factors in the formation of bottom deposits.

FORMATION OF THE LAKE

The present-day lake is located in the ice-scored depression. The amount of glacial erosion of the middle part of Lake Peipsi has been estimated to be at least 50–60 m (Miidel & Vaher, 1999).

A digital reconstruction of the evolution of the lake in late-glacial time was recently performed (Rosentau et al., 2004). The reconstruction was based on a geographic information system (GIS) method that removed isostatically deformed palaeowater planes from the current digital terrain model. A reconstruction of the proglacial water levels was performed with respect to the geomorphological correlation of river terraces, raised shorelines and the eroded surfaces of various aqueoglacial landforms (Hang & Miidel, 2008a). It is well known that the simulations depend on the amount and quality of the input data, which for the Lake Peipsi is quite inconclusive. Even the locations of the glacier margins in the depression are unclear. The local directions of the late-glacial ice movement are clearly recorded by the drumlinization pattern (from a SW direction in the south and north to a SE direction in the central part of the depression). The complicated Iisaku end moraine–esker–kame system to the north of Lake Peipsi formed as an interbolate complex between the Peipsi (moving towards the SW) and East-Pandivere (moving towards the SE) glacier lobes (Раукас et al., 1971; Karukäpp & Raukas, 1999).

Some 12 600 ^{14}C years ago, meltwater flowed to the southwest from Pihkva Ice Lake I, which had a water level of up to 95 m a.s.l., into the proglacial lakes of northern Latvia. Later the water level sank, and Pihkva Ice Lake II came into being; older outflows were closed and new ones opened (Раукас & Ряхни, 1969). The further withdrawal of the glacier to the northwest about 12 250 ^{14}C years ago led to the formation of Peipsi Ice Lake I. Two hundred years later, Peipsi Ice Lake III was formed. After the retreat of the glacier into the Gulf of Finland, the water level dropped and the Peipsi Depression was isolated from the glacial lake, located in the Gulf. It is assumed that the southern part of the depression dried up in the Younger Dryas or at the very beginning of the Holocene, and the northern part of the depression was occupied by L. Small Peipsi, into which the Velikaya River and its tributaries (Emajõgi, Võhandu a.o.) discharged (Orviku, 1960; Раукас & Ряхни, 1969; Hang et al., 2008). As the configurations and water level of the lake changed significantly over a brief period, it highly influenced sedimentation processes.

As we do not possess radiocarbon datings of sediments in the lake and in its surroundings for late-glacial time, the only possibility for the chronology is varvometry with simultaneous investigation of the secular variations of the geomagnetic field. In reality, however, annual layers are far from always identifiable, and in any cases seasonal lamination is frequently accompanied by the arrangement of material in layers within one annual cycle. And, as proglacial Lake Peipsi was isolated from the ice lakes in Finland and Sweden (Raukas, 1992; 1994), the accuracy of the estimated rate of ice recession in areas where glaciolacustrine sediments are absent is extremly disputable.

In order to achieve reliable correlations, additional criteria must be found. The first of these are reference layers, which differ from ordinary varves and may be formed in the course of unusually warm or cold years (being markedly thick or thin respectively) or as a result of rapid changes in water level in the basin. The thickness of the "drainage" varves, created when waters of one of the ice-dammed lakes broke through into another, can be as much as 50–80 cm in the Lake Peipsi depression (Ряхни, 1963). The correlation of the NE Estonian varve series with those of the Luga basin in the Leningrad (St. Petersburg) district was based mainly on a drainage varve series showing that the Luga-Peipsi and Neva basins were first joined 12 080–12 083 years ago and for the second time 12 049 years ago, when a thick (up to 80 cm) drainage or overflow varve was formed. This event, which occurred twice, in the 79^{th} and 111^{st} years of the existence of the Luga basin, was used as a fixed point for dating the ice retreat from the Pandivere line north of the present-day lake about 12 050 varve years ago (Raukas et al., 1969; Raukas, 1986). In practice, however, the correlation of ice marginal zones on the basis of varve chronolgy is much more complicated, because the retreat of the ice changed many times with short intervening new advances. It would be very difficult or even impossible to estimate how many years it took for the ice margin to retreat from a chronologically dated line to the north and to re-advance back to a new line. Moreover, we do not know how far the ice margin retreated before it was subjected to a new advance.

According to Hang (2003), deglaciation of the northern part of the Lake Peipsi depression began around 13 500 varve years ago and ended about 370 years later. Karukäpp and Ukrainian scientists (Бахмутов et al., 1987) combined varve chronology with magnetostratigraphy and concluded that glaciolacustrine sedimentation in North-East Estonia began much later, about 12 000 years ago. This means that up to now all age conclusions for the Late-glacial part of the Lake Peipsi sediments are disputable.

At the beginning of the Pre-Boreal, a shallow body of water existed in the lake depression, and the water level was considerably lower than it is now. The low lake level episode is represented in the basal deposits by a ca 80 cm thick bed of coarse detritus gyttja dated to 9600–9100 radiocarbon years BP. The gyttja lies at an elevation of 20–31 m a.s.l., i.e. about 9 m below the present lake level (Hang et al., 2008). As suggested by the increase in planctonic diatoms, the water level began to rise after 9 200 radiocarbon years BP, when the accumulation of calcareous gyttja was replaced by the accumulation of detritic gyttja (Punnig et al., 2008a). Due to uneven tectonic movements and changing climatic conditions, the water level rose quite fast, and in the Atlantic Chronozone it also inundated extensive areas on the northern coast of the lake. It was probably at that time that the outflow from the lake via the Narva River was formed (Miidel & Raukas, 1997), and the water level there was 5–6 m higher than it is now. The curve of water-level changes compiled for the southern part of L. Peipsi (Hang et al., 1995) demonstrates a dramatic water-level lowering at the end of the Late Weichselian, and a continuous rise since the beginning of the Boreal and an increase in pace in the Sub-Boreal Chronozone. The lake is continuing to retreat southwards. At the northern coast the water level is now more or less stable.

Recently a comprehensive study (chronological, lithological and geochemical) of an 8.5 m postglacial sediment sequence taken in 2004 from the central part of Lake Peipsi (Fig. 1) was conducted to elucidate the effects of lake-level changes on the sedimentary environment and biogeochemical studies (Punning et al., 2008a), and this is described later.

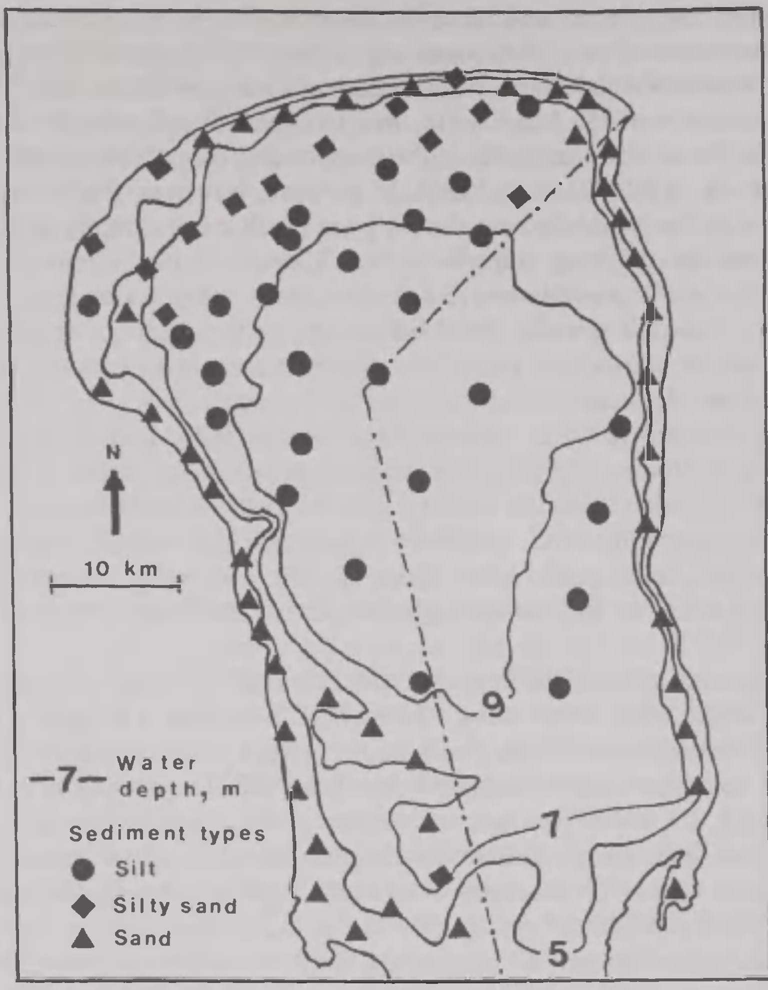

Fig. 1. Grain size of bottom deposits of Lake Peipsi against the background of water depth intervals.

THICKNESS AND STRUCTURE OF BOTTOM DEPOSITS

The structure of the Quaternary cover in the lake depression is quite simple: the till of the last glaciation is covered with glaciofluvial sand and gravel or glaciolacustrine varved clay, silt or nonlaminated sandy clay. These are covered with Holocene deposits (lake marl, gyttja and peat). In some places the bedrock (mainly in coastal areas) or till (in the northern part of the lake) crops out. The lake deposits are not thick, but have only been reliably investigated in several places due to drillings of sand resources offshore of Remniku, between Kodavere and Lahepera, at the mouth of the Emajõgi River and in the surroundings of Piirissaar Island. On the basis of seismic reflection profiling data (Noormets et al., 1998), the distribution and thickness of the Holocene and Upper Weichselian lake and glaciolacustrine deposits were established. The maximum thickness (34 m) of those deposits was recorded in the middle part of the lake. In the topmost part of that complex, an unstable and weak reflector appears. This up-to-5m-thick layer upon the reflector was interpreted as a loose and gas-rich lacustrine deposit from the Holocene age.

From 1996–2000, coring was performed from lake ice at ten sites (Hang et al., 2002) located 2–15 km offshore, with a water depth of 8–10 m. Upper Weichselian deposits above brownish loamy till were represented by glaciolacustrine homogenous or varved clay. At several sites the varved clay was covered by a thin (0.2–0.5 m) layer of sand containing remains of subfossil molluscs. The lacustrine lime was covered with greenish gyttja. The total thickness of the Holocene deposits was 0.2–6.5 m (Hang & Miidel, 1999).

An 8.5 m long sediment sequence taken in the central part of the lake (co-ordinates 58°41'53''N and 27°23'53''E) in 2004 was divided into 4 lithostratigraphic units (Punning et al., 2008a). Unit 1 (8.5–7.0 m) consists of fine-grained clayey silt, which corresponds to the unit described by Hang et al. (2001) as glaciolacustrine silt covering proglacial varved clay. This demonstrates that the coring had penetrated the entire Holocene sequence. The organic matter content of the clayey silt is ca 5% and the water content is up to 50%. The upper contact of glaciolacustrine sediments is sharp at a depth of 7.0 m. Unit 2 (7.0–5.2 m) is dark-grey slightly laminated gyttja characterized mainly by a continuous increase in carbonate from 4% up to 25%. The organic matter and water contents of this unit increase continuously up to 15% and 60% respectively. Unit 3 (5.2–0.4 m) consists of homogeneous greenish-grey gyttja characterized by a slight increase in water content (from 60% to 85%). The organic matter content reaches its maximum value (28%) at a depth of 3.9 m, fluctuating up to around 25%. The topmost 0.4 m of the sediment (unit 4) consists of unconsolidated homogeneous dark gyttja with water content greater than 90%.

SURFICIAL SEDIMENTS

The basic material of surficial lake deposits was collected in the 1970s and 1980s during expeditions onboard research vessels. Sampling density depended on the heterogeneity of the deposits, but in most cases the distances of tours were 6–8 km, and 4–6 km between sampling points. As the bottom of L. Peipsi proper is monotonous and the sediments are more or less similar (Fig. 1), it was enough to receive a reliable map of bottom deposits (see Раукас & Ряхни, 1981 with later modifications as Raukas, 1999a; 2008). Only in the central part of the lake, where the thickness of the water layer ranges from 8–10 metres, there were several oval hollows of up to 12.4 m, where additional sampling was performed. The lake's coastal zone is extremely shallow. In the vicinity of the mouth of the Emajõgi River, for instance, a 2-metre isobath extends about a kilometre towards the lake. The shallow coastal areas were investigated with rubber boats equipped with GPS systems (Fig. 2). At a distance of about 2 kilometres from the shoreline, the water depth begins to increase rapidly almost everywhere, until it reaches 6–8 metres. The most pronounced changes occur on the northern and eastern coasts, where underwater scarps have been found.

Fig. 2. Well-equipped rubber boat of the Institute of Ecology of Tallinn University, which is very convenient for studying shallow nearshore areas. Photo by A. Raukas

The Quaternary deposits in the coastal zone of the north-western part of the lake are mostly represented by till and sand (Fig. 1). Sands are thicker on the backshore. Till, covered with from tens of centimetres to several metres of sand, is distributed on the foreshore. Well-sorted different-grained sands (Md 0.15–0.47 mm) are spread over the stretch of beach between Avijõgi and the outflow of the Narva River. Fine and medium-grained well-sorted sand (Md 0.15–0.20 mm) according to Udden-Wenthworth grain size scale (Last, 2001) occurs in the coastal zone between Avijõgi and Kauksi Brook and between Jaama and the outflow of the Narva River. Due to the river input and erosion of the backshore sands, medium and coarse-grained (Md 0.38–0.44 mm) and less sorted sand was mapped in an area between Kauksi Brook and Jaama (Tavast, 1984). The mineral composition is dominated by quartz (84–94%) and feldspars (6–16%). Other minerals are represented in amounts less than 1%.

In the shallow coastal regions, lake sediments are everywhere relatively coarse-grained (prevailingly sands), whereas in sheltered areas (behind islets and in bays) and in the deep central part of the lake, fine-grained sediments (clayey silts and silty clays) predominate (Раукас & Ряхни, 1981). In the central part of the lake, unconsolidated sediments are rich in organic matter (up to 40%), known as lake muds. The colour of lake mud varies from light-beige to black, but is mainly greenish-grey and has a consistence between jelly-like and plastic. The average water content is 80–90%; after drying colour changes. The chemical composition is variable, depending on grain-size composition and formation peculiarities. The content of organic matter displays a clear regularity: it increases towards fine-grained sediments, being highest in clays, silty clays and clayey silts (more than 10%).

If one compares the bottom deposits map compiled at the beginning of the eighties (Раукас & Ряхни, 1981) with the recently compiled map by T. Hang (Hang et al., 2001; Hang & Miidel, 2008b) for the western part of the lake, we can see great differences in the distribution of till and varved clay, which is difficult to explain. In the map of T. Hang, lake mud is not granulometrically analysed, and therefore the contours of fine sediments in two different age maps are not comparable.

During the summer seasons of 2006 and 2007, 58 grab samples from a research vessel and three short sediment cores from the ice were taken by researchers from the Institute of Ecology of Tallinn University (Punning et al., 2008a). The samples were treated with hydrochloric acid and hydrogen peroxide, and the grain-size spectra for particles were measured using a Fritsch Laser Particle Size Analysette 22. Coarse grain compounds larger than 250 μm were extracted before laser spectrometry. In order to avoid flocculation, an ultrasonic disperser and the addition of sodium hexametaphophate (Calgon) were applied. For sandy samples, grain-size wet sieving was used. The results were given as the medium diameter of particles following the Udden-Wentworth grain-size scale (Last, 2001). Dry matter in sediments was determined by drying the samples to constant weight at 105°C. Organic matter was measured as loss-on-ignition (LOI) upon heating at 550°C for 210 min. The carbonate content was calculated as the loss of weight after burning the LOI residue at 950°C for 150 min (Heiri et al., 2001).

According to the most recent surface sediment map (Fig. 1), all sediments are roughly divided into three groups (Punning et al., 2008b): coarse-grained sediments (mostly sands in the nearshore area of the southern part of the lake), fine-grained sediments (mainly silts) and silty sands, both in the central, deeper part of the lake. At sampling sites, the median diameter variability of particles ranged from approximately 58.3 to 192.8 μm for sand, from 13.1 to 18.2 for silt and from 5.0 to 102.2 for silty sands. The granulometrically characterized groups of sediments have a distinct spatial distribution. The silt sediments are restricted mainly to the lake centre within the 8–11 m contour. Silts have the highest organic matter content. In principle, the newest sediment map only slightly differs from data published in the 1980s (Раукас, 1981b). In comparing the data, it should be taken into account that different grain-size scales were used and the measurements of the location of the sampling sites in the 1970s were performed with an accuracy of hundreds of metres, and in 2006–2007 tens of metres.

SEDIMENTATION PROCESSES

Under contemporary physico-geographical conditions, the process of sedimentation is characterised by a host of specific features, the combined effect of which causes accumulation and erosion areas to change. Wind-generated waves serve as the most important energy-transfer agents that change the coast and transport sediments. Waves on Lake Peipsi are steep and short, and with a wind force of 8 m/s, their height is 60–70 cm (Соколов, 1983). Waves of this height are most common (57%). The highest waves (240 cm) were recorded in 1961 and 1962, with a wind force of 20 m/s. Wave energy is influenced by the fetch (the distance over which the wind blows), wind velocity and the time over which the wind blows (Bird, 2000). The activity of coastal processes and storm impact also depend on coastal geomorphology: near-shore topography, shoreline configuration and exposure to waves.

The south-westerly and southerly (45–50%) winds predominate in the depression of the lake, causing high rises in the water-level in the northern part of the depression and intensive erosion of the coast (Raukas & Tavast, 2005). Due to the erosion of the northern sandy coast, which has high dunes, this causes enrichment of the foreshore, and all material is moving to the east in the direction of outflow of the Narva River, causing clogging of the outflow. As a result of longshore erosion, modern lake sediments are absent in extensive areas here, or till and varved clays are covered with a thin layer of residual sediments ranging from several to a few dozen centimetres in thickness. From 1932–39, approximately 10 km of the upper course of the Narva River was deepened, and 3 jetties across the river current and a 1.4 km long current diversional dam were built at the head of the river (Jaani, 2001). All of the structures that regulated the current are now filled with sediments, and new deepening of the river is needed.

The extensive sand area is located in the southern shallow part of the lake, where wave action is very low. There is a zone with stable accumulation of sedimentary material derived from the Piirissaar glaciofluvial delta. The delta sediments are covered with poorly-sorted silts, sandy silts and fine sands. The Tartu–Praaga–Piirissaar–Pskov shipping route is very shallow and needs continuous removing of great quantities of sand (Fig. 3). The estimated resources of low-quality construction sand in the Piirissaar area are over two million cubic metres. Other sandy areas include Kodavere Bank near Kallaste town (estimated resources 2 275 000 cubic metres), Meerapalu Bank and the area between Raskopel`e and Podolesh`e (Raukas, 1999b).

The largest areas of the Lake Peipsi floor are covered with fine-grained and organic-rich lake muds that have been formed in low-energy depositional environments under the influence of a specific current system (Kallejärv, 1973). The surface water moves in the direction of the wind in the northern part of Lake Peipsi proper, and anticyclonic and cyclonic circulation is characteristic on the southern part. Near the bottom of the northern part of Lake Peipsi proper, compensation streams form; in the shallow southern part, surface currents reach the bottom. The sources of these fine organic rich sediments are unclear. Organic matter is mainly autochtonous; silty-clayey material is probably derived from the erosion of the lake floor and its shores, and river input seems to be limited. This conclusion is also supported by our recent study of the spatial distribution of resistance high-molecular weight polycyclic aromatic hydrocarbons (PAH) (Punning et al., 2008c).

Fig. 3. Excavation of sand near Piirissaar Island. Photo by A. Raukas.

To pinpoint the main pathways of PAHs into the reference core in the central area of Lake Peipsi, we studied bottom surface sediments from 4 sites in the western and northern near-shore areas of the lake. The composition of PAHs in the studied sediments as well as their low concentrations are very similar to those of the background values estimated in the lower sediment layers. This shows the absence or limited extent of the transport PAHs from the coastal area in the water environment in soluble form or sorbed as suspended matter. Though the wave action on the resedimentation of surface sediments in the central, deeper part of the lake is lower, the distribution of ^{210}Pb in high porosity layers on the surface and elevated sedimentation rate (up to 0.07 g/cm^2/y) during recent decades indicate a certain mixing of sediments. The disturbance of the paleolimnological records is also evident from fly-ash particle distribution in sediments (Nõges et al., 2006).

An important role in the sedimentation and resedimentation of bottom and coastal deposits in shallow lake was played by lake ice, which lasts 114 days on average. Almost every spring, ridges of pressure ice up to 10 m high are pushed forward against the shore, shaping the coast, redepositing older sediments and transporting huge boulders. Lake ice and small icebergs can carry coarse material to the area of fine-grained sediments.

CONCLUSIONS

Of all of the lakes of Europe, Lake Peipsi ranks among one of the best fishing grounds, producing about 95% of the total fish catch caught in Estonian inland waters. Investigation of bottom deposits is necessary for the investigation and defending of spawning grounds of commercially important fishes. Coastal and subwater erosion are the principal sources of material for the bottom deposits. Suspended loads carried by rivers and brooks appear to be limited. Some of the material is also provided by wind and drift ice, and distributed by waves and streams in accordance with the bottom topography and the stand of water in the basin. Water level fluctuations in Lake Peipsi are considerable. During the last hundred years, an amplitude of 3.04 m has been registered. The impact of water level fluctuations and near-bottom currents on sedimentation dynamics will be the most important topics for further studies.

In the shallow coastal regions, sediments are relatively coarse-grained and mostly consist of sand. In the bays, in the lee of islets and in the deep central part of the lake, the sediments are mainly fine-grained organic-rich lake muds. It is currently unclear when the lake mud began to accumulate, and how long the process lasted. The central part of the lake was probably under water throughout the Holocene, and there was enough time and a sufficient amount of organic matter to form such a thick layer of gyttja.

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THE USE OF LANDSCAPE METRICS IN LANDSCAPE STUDIES IN ESTONIA

Evelyn Uuemaa, Jüri Roosaare, Ülo Mander

INTRODUCTION

Landscape ecology is largely based on the notion that environmental patterns strongly influence ecological processes (Turner, 1989). A disruption in landscape patterns may compromise its functional integrity by interfering with critical ecological processes necessary for population persistence and the maintenance of biodiversity and ecosystem health (With, 1997). For these and other reasons, much emphasis has been placed on developing methods to quantify landscape patterns, which is considered a prerequisite for the study of pattern-process relationships (Turner, 1990; McGarigal & Marks, 1995). Hundreds of landscape metrics have been proposed by various researchers to analyse landscape structure. The term "landscape metrics" is generally used for all measures that quantify the spatial pattern of landscapes, from topographic measures (Vivoni et al., 2005) to the proportions of land use/cover, and shape and area metrics (Li et al., 2001; Palmer, 2004). Spatial pattern is represented and quantified in a number of different ways. Most landscape pattern analysis is performed on categorical maps, which tend to ignore the spatial variation within spatial units and trends in system properties across landscapes (Gustafson, 1998). A large number of metrics have been developed to quantify spatial heterogeneity on categorical maps. These metrics fall into two general categories: those that evaluate the composition of the map without reference to spatial attributes, and those that evaluate the spatial configuration of system properties, requiring spatial information for their calculation (McGarigal & Marks, 1995; Gustafson, 1998). Most of these are covered by the computer program FRAGSTATS (McGarigal & Marks, 1995). Since the emergence of FRAGTATS in 1993, the measures and methods incorporated in this software have been very widely used in characterizing patterns (Li et al., 2001; Corry, 2004), detecting land use changes (Egbert et al., 2002; Li et al., 2004; Southworth et al., 2004) and predicting ecological processes (Bender et al., 2003; Coulson et al., 2005; Fearer et al., 2007).

Despite the many advantages of landscape metrics and their extensive use, there are also inherent limitations to landscape metrics (Li & Wu, 2004): many landscape metrics are mutually correlated (O'Neill et al., 1999; Hargis et al., 1998; Botequilha & Ahern, 2002); there are difficulties in interpreting landscape metrics (Gustafson, 1998; Hargis et al., 1998; Turner et al., 2001), and these are scale-dependent (Wickham & Riitters, 1995; Griffith et al., 2000; Wu et al., 2002; Uuemaa et al., 2005). Two primary scaling factors affect measures of landscape pattern: grain is the resolution of the data (pixel size), and extent refers to the size of the mapped or studied area (Gustafson, 1998).

This paper gives an overview of studies related to the use of landscape metrics in Estonia.

EARLY DEVELOPMENTS

Although there are long traditions of both landscape research and the use of quantitative measures in Estonia, they existed separately. In 1922 J.G. Granö introduced a cartographic landscape delimitation method that we now call “map overlay” (see Granö, 1997), and regard this as a principal method of analysis in GIS. E. Kant’s work is based on mathematical methods, and his original map (1935) on the system of Estonian centres (central places) is acknowledged by Forman and Godron (1986:409).

Possible integrations of Granö’s ‘pure geography’ and Kant’s human ecology were interrupted by World War II and its consequences. Landscape research performed in Estonia in the 1950–1960s was dictated by the situation in Soviet geography (Roosaare, 1994), consisting in a blackout in cartography (Jagomägi & Mardiste 1994) on the one hand, and in compiling good synthetic soil maps on the other hand. The basic contours of these maps corresponded to the basic typology of landscape units in use at that time. Based on the ideas of the Muscovite ‘landscape science’ school, young geographers interested in modern methods began to implement the cartometric approach in landscape research (Роосааре, 1975; Мандер, 1978). J. Roosaare applied a system of indices to analyze the landscape structure of the small island Vormsi (Роосааре, 1982). His neighborhood indices were also included in landscape metrics calculation software МОЗАИКА developed at Odessa State University (Андерсон, 1987), and the landscape diversity index was modified by Ü. Mander and used to study amelioration areas (Ягомяги и Мандер, 1982). Later, Mander and Murka (2003) proposed determining landscape coherence as the correspondence between potential (biophysical) landscape diversity (measured on the basis of soil maps) and the diversity of the cultural landscape (calculated on the basis of the density of the ecotone network).

However, due to the use of paper maps and the lack of analytical software, interest in landscape metrics was rather limited during the pre-GIS era.

LANDSCAPE STRUCTURE AND LAND USE CHANGE

Land use changes over time are a topic of growing popularity among geographers. Several Estonian researchers have used landscape metrics for this purpose. Palang et al. (1998) studied landscape diversity dynamics in Estonia during the 20^{th} century. The analysis of maps from four different time periods in terms of 12 diversity indicators showed that landscape diversity changes in Estonia are minor. Nevertheless, there were some regional differences. Principal Component Analysis (PCA) indicated four types of diversity, namely the shape of the patch, ‘classical’ diversity, land use, and the number of units, which explain 80% of the total variability in landscape change. However, despite all kinds of land use changes, overall landscape diversity remained stable (Palang et al., 1998).

K. Sepp (1999) investigated land use changes for monitoring areas using interpreted aerial photos for different time periods. He calculated several diversity indices, carried out a PCA of the results and concluded that differences in land use pattern and landscape diversity for the selected time periods (1950, 1970, 1990) are clearly separable.

Aunap et al. (2006) studied the spatial autocorrelation (Moran's I) of raster format land use maps from three different time periods (1900, 1940, and 2000) in 13 study areas representing most of the landscape regions in Estonia. Human influence was taken into consideration in compiling a scale of the contrast between 10 land use groups. A simple characteristic based on spatial correlograms was introduced: a half-value distance lag, $h_{I=0.5}$ – a distance where Moran's I drops below 0.5. No significant change was detected in values of $h_{I=0.5}$ over time. In addition, no difference between lowlands and heights was detected. In the analysis of landscape metrics, Edge Density (ED), Patch Density (PD), Contrast Weighted Edge Density (CWED), Mean Patch Area Distribution (AREA_MN), and Percentage of Like Adjacencies (PLADJ) showed significant changes comparing the year 2000 with 1900 and 1940. However, the results showed no significant change in landscape metrics between 1900 and 1940. ED, PD and CWED had higher values in 2000 than in 1900 and 1940. Therefore landscape heterogeneity has increased in recent decades. ED, PD, CWED, AREA_MN and PLADJ metrics also indicated a significant difference between lowlands and heights. It appeared that heights have a more heterogeneous landscape structure than lowlands. The heterogeneity of Estonia's landscapes overall has generally changed over recent decades.

Soil cover, which is one of the most informative and integrative landscape factors, can be used for the analysis of landscape patterns. Uuemaa et al. (2008) studied the spatial autocorrelation (Moran's I) of raster format soil maps (1:10 000; 10 m pixel size) in 35 study areas representing all landscape regions in Estonia (Arold, 2005). The carbonate concentration of soils, volumetric soil moisture (%) and the depth of the groundwater table were taken into consideration in compiling a scale of contrast of 17 soil groups. A half-value distance lag, $h_{I=0.5}$ was used. Spatial autocorrelation decreased very rapidly in the case of heights (Fig. 1) with a very heterogeneous landscape composition, showing low values of $h_{I=0.5}$ (<100 m in all 6 study areas). In uplands and depressions, the spatial autocorrelation also decreased quite rapidly ($h_{I=0.5} < 200$ m). In most of the plains, coastal lowlands, sea islands and inland paludified lowlands, the values of Moran's I decreased slowly with increasing lag, being $h_{I=0.5} > 200$ m in all forest and bog areas with complex topographical conditions, due to the variety of glacial landforms and peatlands (Fig. 1).

Landscape metrics analysis showed a significant difference between heights and lowlands. Heights have significantly higher values of Patch Density and Edge Density than lowlands, i.e. the landscape structure is more heterogeneous and fragmented than in lowlands. In calculating landscape metrics for study sites, an interesting phenomenon was detected. In PD values there is a relatively large interval where none of the study areas are presented (Fig. 2). We did not find any study areas (chosen by landscape regions) whose value would have been between 25 and 45. The heights had very high values of PD (between 47 and 73), whereas plains and uplands had significantly lower values of PD (less than 25).

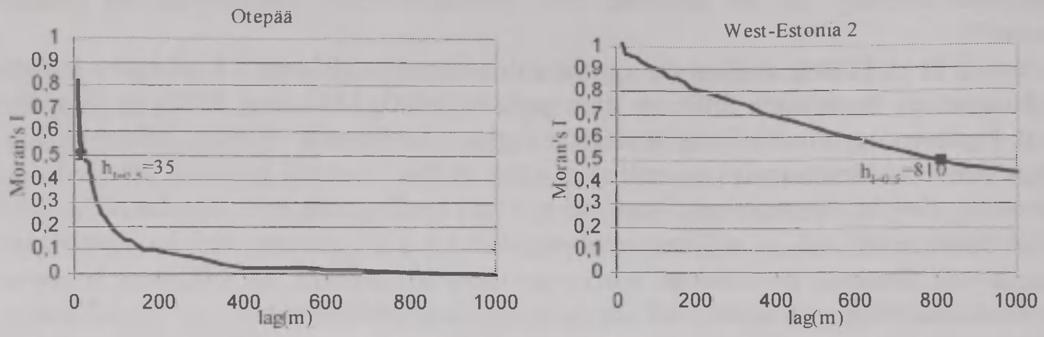

Fig. 1. Correlograms of study areas from different landscape regions. Otepää is used as an example of heights and West-Estonia 2 as an example of lowlands.

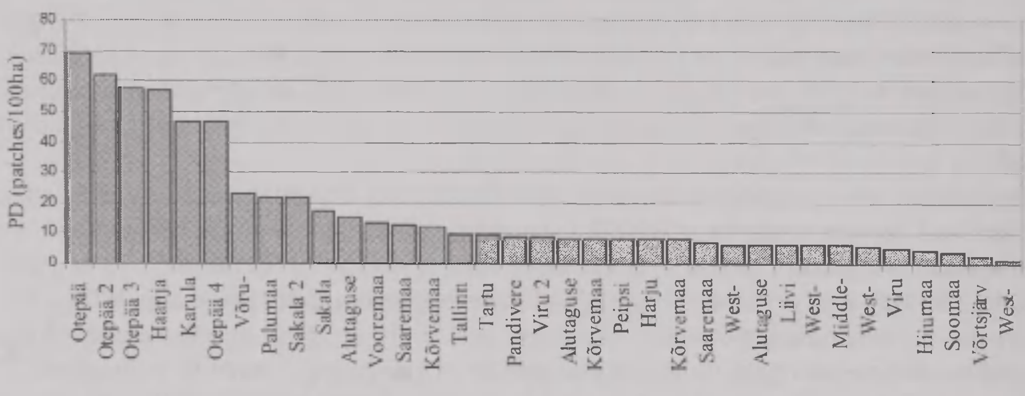

Fig. 2. Values of PD of 35 study areas from different landscape regions.

Since January 1994, a National Monitoring Programme has been implemented in Estonia under the supervision and coordination of the Ministry of the Environment. The main purpose of the programme is to monitor long-term and large-scale changes in the environment and thus identify problems that call for operational measures or complementary studies in the future (Roots & Saare, 1996). Several landscape metrics (proportions of land use, configuration of linear and areal landscape objects) are used in the Estonian monitoring programme for agricultural landscapes (Roose et al., 2007). Recently, A. Roose and A. Kull applied landscape metrics to analyze the influence of suburbanization on landscape fragmentation (see pp. 68–87 in this issue).

LANDSCAPE STRUCTURE AND WATER QUALITY

Several studies have shown that landscape pattern is an important factor influencing nutrient and organic matter runoff from catchments (Stålnacke et al., 1999; Arheimer

& Brandt, 2000). The composition of the landscape (land use/cover proportions) partly reflects human influence and, as many studies have shown, it can be used as a predictor for nutrient runoff from catchments (Davies & Neal, 2007; Poor & McDonnell, 2007). For example, if there is a high proportion of agricultural areas in the catchment, the nutrient runoff is higher due to more intensive fertilization. In Estonia, however, there has been a substantial decrease in the use of fertilizers and livestock production in recent decades since the collapse of the Soviet Union, which has caused a reduction of nitrogen in river water. Iital et al. (2003) examined the impact of these reductions on concentrations of nutrients (N and P) at 22 sampling sites on Estonian rivers. They found that decreases in total-N were related to substantial reductions in the use of organic and inorganic fertilizers and the reduction of cultivated and ploughed areas and increased proportions of grassland and abandoned land and improvements in farm management practices. They found a close correlation between total-N and agricultural areas. For total-P, significant downward trends were detected at only two sites, and there were also two upward trends. The Total-P trends can mainly be explained by changes in phosphorus discharges from municipal sewage treatment plants.

High levels of nutrient and organic matter loading can have adverse effects on both humans and aquatic ecosystems. In addition to land use proportions, however, the configuration of landscape pattern is also important, i.e. the spatial arrangement of patches, especially riparian zones (Gergel, 2005). The relationship between water quality and landscape pattern has been studied in 24 catchments in Estonia. BOD_7 and COD_{KMnO4} values, total-N and total-P concentrations in water samples from the closing weirs of studied rivers were used to determine the relationships between landscape metrics (Edge Density, Patch Density, Mean Shape Index, Mean Euclidean Nearest Neighbour Index, Contagion, Patch Richness Density and Shannon's Diversity Index) and nutrient and organic matter runoff in catchments (Uuemaa et al., 2005; Uuemaa et al., 2007). Multiple regression analysis showed that the most important predictor for BOD_7, total-N and total-P was the proportion of urban areas, but landscape metrics also had a significant relationship with water quality. Mean Shape Index and Contagion were the most important predictors for COD_{KMnO4}. The knowledge that land use and landscape configuration impact water quality can be used in establishing and implementing water management plans in Europe.

LANDSCAPE STRUCTURE AND BIODIVERSITY

There are many aspects of patches in landscape structure (size, shape, isolation, core area etc.) that may influence species richness. For example, many species have minimum area requirements: the minimum area needed to meet all life history requirements. Some of these species require that their minimum area requirements be fulfilled in contiguous habitat patches; in other words, the individual habitat patch must be larger than the species' minimum area requirement for it to occupy the patch. Such species are sometimes referred to as "area-sensitive" species (McGarigal & Marks, 1995).

In recent decades landscape metrics are widely used to find relationships between biodiversity and landscape structure (McGarigal & Marks, 1995). In Estonia most of the studies focus on birds diversity. Oja et al. (2005) used landscape parameters for the modelling of forest bird habitat suitability at different scales. Parameters characterizing landscape pattern were determined for the UTM 10 km × 10 km cells covering the whole of Estonia and were correlated to the distribution of over 30 forest bird species. The landscape parameters included the areas of lakes, mires and built-up areas, the length of borders between different land cover units and the length of selected line elements, as well as proportions of different kinds of forests and peatlands. The bird species were grouped by correlation into three major groups: (a) independent, (b) wetland preferring (with subgroups of those avoiding built-up areas and roads and those that do not) and (c) groups dependent on built-up areas (with subgroups depending on the importance of line elements). For selected predator species, nesting success was related to landscape parameters on a finer scale, using cells of 10 km^2. Land pattern was characterized by the total length of line elements (streams, roads, borders, ecotones) and certain areal coverage (forest, mires, fields, built-up areas) within the cell. The impact of variations in food availability was linked to the relation. The results confirmed the previous hypothesis that the importance of foraging areas in better habitats is in most cases significant. In addition, the preferred biotopes as described in most descriptive studies are present in species breeding territories, and are more prevalent in high quality habitats. The most ''informative'' species tend to be those with clear habitat preferences that inhabit a large enough number of grid cells.

Farmland in Estonia occupies approximately 20% of the country's territory. Due to political and economical changes, Estonian farmland has changed dramatically since the early 1990s. Since the beginning of the 1990s farming intensity declined considerably due to the collapse of the Soviet Union. Nowadays, due to European Union support, agriculture in Estonia has recovered considerably. On the assumption that this has taken place during land-uses changes in recent decades, many bird species associated with farmland have been decreasing in number in Estonia (Elts et al. 2003). The relation between farmland birds and landscape structure has been studied by Marja (2007), who used FRAGSTATS metrics to determine farmland birds' landscape preferences in 30 test areas (1 km^2) in three different Estonian counties. Six landscape metrics were calculated on the Estonian Basic Map (1:10 000): Patch Density (PD), Edge Density (ED), Mean Patch Area Distribution (AREA_MN), Contagion (CONTAG), Shannon's Diversity Index (SHDI) and Shannon's Evenness Index (SHEI). For the characterization of bird fauna, the following indexes were calculated: species density, Shannon`s Diversity Index and Simpson`s Dominance Index. The results of this study showed that if the value of PD is high, then there is higher bird species richness and abundance. In landscapes with different habitat composition (bushes, stone fences, forest patches etc.), there is probably greater bird species diversity than in a homogenous landscape. Landscapes with high values of CONTAG (homogenous landscape structure) have low species diversity (negative correlations with species density and Shannon`s diversity index and positive correlations with Simpson`s Dominance index). Therefore landscapes with heterogeneous structure also have high bird species diversity.

LANDSCAPE STRUCTURE AND AESTHETICS

Landscape aesthetics was already important to J.G. Granö. This is, however, subjective, and therefore it is difficult to find standardized methods for the evaluation of the visual quality of landscapes. Several studies have used photo-questionnaires and landscape metrics for the evaluation of the visual quality of landscapes (Dramstad et al., 2006). In Estonian landscape studies, landscape metrics are not very widely used, but some research has been done. Estonians' landscape preferences relationships with landscape metrics have been studied by Palang et al. (2000). For Estonia, one of the main driving forces in landscape change is the changing agricultural and rural policy. To foresee the outcome of these political changes, four scenarios were created for one of the least developed parts of the country, the Obinitsa area. Local inhabitants were questioned about their preferences concerning these scenarios. To characterize landscape diversity, they used simple diversity characteristics: the number of landscape elements and the number of land use types. The latter is known as patch richness. The results show that of different development options, people prefer those that resemble the identity of the landscape or those which, although introducing larger changes, create a feeling of certainty, predictability, welfare and well-being.

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HYBRID CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT IN ESTONIA AN OVERVIEW OF A PILOT PROJECT

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INTRODUCTION

Constructed wetlands (CW) of various types are becoming popular worldwide (Kadlec & Knight, 1996). In addition to their satisfactory performance, CWs, which are multifunctional in terms of biodiversity and landscape services (Vymazal, 2001), have one significant disadvantage: in cold climates, constructed wetlands (CWs) for wastewater treatment are often over-designed to compensate for uncertainty due to low temperatures, which raises construction and operating costs (Werker et al., 2002).

One possible operational method to achieve proper results without over-dimensioning CWs is to re-circulate the wastewater. The recirculation of wastewater as a procedure to enhance aeration and purification processes has been used in various pilot- and full-scale CW systems for the treatment of different types of wastewater (Sun et al., 2003; Green et al., 2002; Brix et al. 2002; Tchobanoglous & Schroeder, 1987). In some countries the recirculation of wastewater in subsurface flow filters has been included in the official guidelines on CWs (Bahlo, 2000; Brix & Arias, 2005).

As the effluent is being re-circulated, additional oxygen for aerobic microbial activities can be added to the wastewater. Re-circulation also enhances contact between the pollutants and microorganisms. Of water quality indicators, the values of BOD and COD (Zhao et al., 2004; He et al., 2006), and concentrations of total suspended solids (TSS) (Zhao et al., 2004; He et al., 2006), N_{tot} (Sun et al., 2005), and P_{tot} (Zhao et al., 2004) have been reduced. In addition, as the suspended solids are predominantly removed by filtration, re-circulating the effluent increases the chances for suspended solids to be trapped in the system (Sun et al., 2003). These factors should account for the improvement of overall purification processes, and without over-dimensioning would make CWs a much more attractive wastewater treatment technology. On the other hand, the recirculation of effluent also requires additional input of electric power, although increased pumping costs are not considered to be relevant in comparison to the changes in the dimensions and treatment performance of the filter system with recirculation (Noorvee, 2007).

In a batch-operated CW, the filter is rapidly filled to capacity, remains filled for a long enough period of time and in a repeating process, is drained and refilled. The advantage of batch-operation over continuous-flow operation in wetland systems is supported by the fact that even at very low drain-fill frequencies, the batch operation of subsurface flow (SSF) CWs ensures that the microbial population at any given point will be exposed to decreasing organic carbon concentrations, allowing the wetland environment to be subjected to temporal redox variation (between aerobic and anoxic conditions), therefore enhancing BOD and N removal (Stein et al., 2003). Several studies have shown that the quantity of additional oxygen introduced to the filter matrix during the drain process increases as the drain-fill frequency increases (Tanner et al., 1999). However, little information is available on the performance of batch-operated CWs, as most of the studies that have been carried out so far have been conducted in lab conditions using artificial wastewater.

To develop compact hybrid constructed wetlands (CW) for use in cold climates, a project on "Hybrid constructed wetlands for wastewater treatment" was launched in December 2004. During the summer of 2005, three pilot-scale experimental filter systems (FS) for the treatment of different types of wastewater were established, and one full-scale FS for the treatment of municipal wastewater was reconstructed in Southern Estonia.

The study was supported by Enterprise Estonia project No. EU19215, and managed by the Department of Geography of the Institute of Ecology and Earth Sciences of the University of Tartu and the Institute of Technology of the University of Tartu.

The main objective of the study was to compare continuous flow hybrid filters and batch-operated filters, and to test different flow regimes in order to determine optimal loading, design parameters, management schemes and operational regimes of FSs filled with crushed limestone (CL) and light weight aggregates (LWA) for the treatment of municipal wastewater.

According to Estonian legislation, the most stringent limit values for the effluent from small wastewater treatment plants are: BOD_7=15 mg/l, COD=125 mg/l, TSS=25 mg/l and P_{tot}=1.5 mg/l. According to the legislation, there is no requirement for the removal of N_{tot} from effluent, but as the charges are set for the nitrogen as pollutant, the limit effluent value for N_{tot} of 15 mg l^{-1} was set as an internal goal of the study.

One of the outcomes of the project was The handbook for the establishment of hybrid soil filter and constructed wetlands systems [*Kombineeritud pinnasfilter-süsteemide ja tehismärgalapuhastite rajamise juhend*] by Noorvee et al. (2007a).

MATERIALS AND METHODS

Site description

Three pilot-scale experimental filter systems (FS) for the treatment of different types of wastewater were established, and one full-scale FS for the treatment of municipal wastewater were reconstructed in Southern Estonia during the summer of 2005.

The continuous-flow pilot scale FSs in Nõo and Rämsi consists of two parallel systems with different operating regimes designed on the same principle: a vertical sub-surface flow filter (VSSF) 0.7 m in depth, filled with crushed limestone (CL) and LWA, followed by a horizontal subsurface flow filter (HSSF) 1 m in depth, filled with LWA.

Table 1. Average values of the hydraulic loading rates (HLR, mm/d; without re-circulation), discharge (Q, m^3/d), temperature (^0C), pH and water quality concentration (mg/l) parameters in the inflow of the studied filter systems during sequential operational regimes.

Period	Filter system	HLR (mm/d)	Q (m^3/d)	Temp ^{0}C		pH		Average water quality parameters in the inflow of FSs (mg/l)											
				A*	S*	A*	S*	BOD_7 (A*)	(S*)	TSS (A*)	(S*)	COD_{Cr} (A*)	(S*)	N_{tot} (A*)	(S*)	NH_4-N (A*)	(S*)	P_{tot} (A*)	(S*)
1	Nõo	52	0.73	6.5	2.2	7.4	0.2	405	102	132	33	745	141	72	26	52	12	20	3
Nov-	Rämsi	16	0.4	5.1	2.5	6.6	0.8	5519	1993	541	282	7039	2073	507	132	412	123	191	80
Dec	Kodijärve	22	3.8	6.9	1.8	7.5	0.1	109	32	39	10	217	44	96	7	90	4	17	1
	Ilmatsalu	59	0.47	5.4	1.8	7.5	0.2	135	58	33	13	224	67	54	9	48	11	6.6	2
2	Nõo	26	0.37	3.9	0.7	7.6	0.2	425	69	126	54	750	112	71	20	52	15	21	4
Jan-	Rämsi	4	0.10	2.7	0.9	6.3	0.1	5700	265	523	35	8068	247	527	143	431	76	158	38
Mar	Kodijärve	30	5.3	3.4	1.5	7.5	0.2	133	72	42	37	274	111	83	27	70	23	16	3
	Ilmatsalu	58	0.46	3.1	1.2	7.3	0.2	191	44	48	28	311	55	44	7	38	6	6.6	1
3	Nõo	21	0.29	7.4	3.2	7.4	0.4	446	216	219	192	808	519	55	18	47	14	21	8
Mar-	Rämsi	4	0.10	8.2	4.6	6.2	0.3	3838	2089	220	89	5512	2783	305	142	265	120	120	50
May	Kodijärve	34	6.0	8.4	2.3	7.6	0.4	108	34	48	16	206	44	71	20	61	12	20	8
	Ilmatsalu	66	0.53	7.3	1.9	7.3	0.1	168	71	37	10	248	84	33	9	31	9	5.8	2
4	Nõo	16	0.22	16.4	3.5	7.0	0.1	644	138	287	154	1077	369	92	33	78	39	31	9
May-	Rämsi	4	0.10	18.1	5.8	5.8	0.1	7483	1596	504	165	11180	789	594	70	474	42	297	66
Jul	Kodijärve	34	5.6	16.2	2.5	7.4	0.1	105	36	122	91	276	186	71	9	59	16	12	6
	Ilmatsalu	59	0.47	13.4	2.5	7.2	0.4	237	31	66	26	385	67	68	18	60	17	8.1	2
5	Nõo	21	0.30	16.9	2.8	7.2	0.3	646	150	387	155	1136	533	112	33	81	33	45	15
Aug-	Rämsi	5	0.13	17.3	2.3	5.7	0.2	4656	1105	291	99	7267	1471	426	89	368	97	194	34
Oct	Kodijärve	34	5.6	16.0	0.8	7.5	0.1	70	12	77	26	180	44	67	18	59	17	14	8
	Ilmatsalu	59	0.47	14.6	1.0	7.2	0.2	206	31	97	29	383	129	82	13	71	1	10.3	4
6	Nõo	14	0.20	8.3	2.1	7.2	0.2	376	75	118	19	590	59	78	10	62	11	26	5
Oct-	Rämsi	4	0.10	8.7	2.9	6.4	0.2	4655	1078	1032	468	7246	601	517	58	396	60	208	43
Dec	Kodijärve	40	7.0	10.0	1.9	7.5	0.1	74	19	58	19	148	30	67	14	56	12	11	2
	Ilmatsalu	59	0.47	8.4	2.3	7.3	0.1	100	29	55	12	163	51	40	9	32	8	6.6	1

* A – average; S – standard deviation.

The continuous-flow full-scale FS in Kodijärve consists of two parallel systems designed on the same principle: a vertical subsurface flow filter (VSSF; beds are used alternately) 1.3 m in depth, filled with crushed limestone (CL), followed by a horizontal subsurface flow filter (HSSF; with different operating regimes) 1 m in depth, filled with LWA. Due to some water leakage problems (the PVC liner was broken), it was only possible to use one bed of the HSSF filters in most periods.

The batch-operated pilot-scale LWA filter in Ilmatsalu consists of eight identical LWA filter cells with a depth of 1.15 m and an area of 1 m^2 each, operated in batch mode.

The LWA used in all FSs is produced in Estonia from local clay mineral (trademark name Filtralite S, M, L), and does not have characteristics of Filtralite-P. The Estonian LWA does not have a high phosphorus sorption capacity (see Jenssen & Krogstad, 2003), and is not crushed. The systems were not planted, because of the short test period, which was insufficient for the proper growth of vegetation. Therefore the FSs do not meet the strict definition of a wetland, and we used the term “LWA or CL filter system”.

During winter, the pilot-scale FSs were covered with 5-cm-thick foamed plastic slabs for insulation. In Southern Estonia, long-term mean ambient temperatures are –7.1°C in January and 16.5°C in July. During the experiments (November 2005... December 2006), ambient temperature fell to –35°C during the winter.

Table 1 reports the average water quality parameters in the inflow of the FSs during 6 operational regimes.

The Nõo experimental FS is located near the existing activated sludge wastewater treatment plant (AWP) of Nõo village. The wastewater (domestic wastewater combined with dairy and meat industry wastewater) is pumped into the filter system before it reaches the screen of the AWP. The exact volume of water is controlled by a timer-operated pump. A certain amount of wastewater is first pumped into a septic tank (2 m^3), where the hydraulic retention time (HRT) was, by period, 1, 3, 3, 5, 3 and 5 days respectively. After the septic tank, the wastewater is divided equally in the inflow well between both parallel (left-hand and right-hand) experimental systems (area of VSSF: 2 x 4 m^2; area of HSSF: 2 x 10 m^2), Fig. 1. Table 2 reports the cross-section of the VSSF. The HSSF is filled with a 1.0 m deep LWA fraction of 2–4 mm (Filtralite S), which is suitable for use in filters due to its high hydraulic conductivity, porosity and good insulation properties (Jenssen & Krogstad, 2003). Treated wastewater is directed to Nõo stream by gravity flow.

The Rämsi experimental FS is located near the existing pig farm. The wastewater entering the FS is obtained by separating the liquid fraction from the solid fraction of the swine slurry in a separation well. A timer-operated pump pumps the desired amount of wastewater into the experimental system. The wastewater is first pumped into a septic tank (2 m^3), where the hydraulic retention time (HRT) was, by period, 3, 10, 10, 10, 8 and 10 days respectively. After the septic tank, the wastewater is divided equally between both parallel experimental systems (area of VSSF 2 x 10 m^2; area of HSSF 2 x 15 m^2). Fig. 1. Table 2 reports the cross-section of the VSSF. The HSSF is filled with a 1.0 m deep LWA fraction of 2–4 mm (Filtralite S). Treated wastewater is directed to a natural ditch by gravity flow.

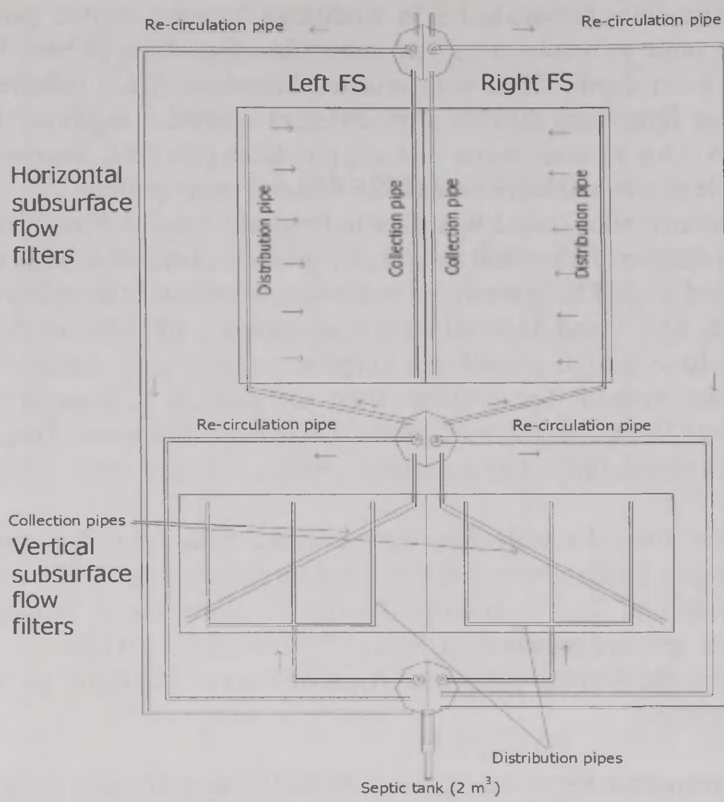

Fig. 1. Plan view of Nõo and Rämsi FSs. The parallel systems (right-left units) are determined on the basis of the direction of wastewater flow.

Table 2. Cross-section of VSSF filter in Nõo and Rämsi experimental filter systems and in Kodijärve FS.

Cross-section	Nõo right FS	Nõo left FS and both FSs in Rämsi	Kodijärve FS
Upper layer (with lowest hydraulic conductivity)	CL Ø 2–8 mm	LWA Ø 2–4 mm (Filtralite S)	CL Ø 4–8 mm
Middle layer	CL Ø 8–16 mm	LWA Ø 4–10 mm (Filtralite M)	CL Ø 5–20 mm
Bottom layer (with highest hydraulic conductivity)	CL Ø 12–32 mm	LWA Ø 10–20 mm (Filtralite L)	CL Ø 16–40 mm

The Kodijärve full-scale FS is located near the hospital (40 population equivalents, pe) of Kodijärve Hooldekodu Ltd. The wastewater, domestic wastewater from a dual-chamber septic tank (circa 10 m^3) outflow, is channelled into an inflow well. The hydraulic retention time (HRT) in the dual-chamber septic tank was, by period, 3, 2, 2, 2, 2 and 1 days respectively. The wastewater is pumped by floater-controlled pump into the VSSF (constructed in 2002), Fig. 2. Table 2 reports the cross-section of the VSSF. The beds of the VSSF are loaded intermittently. One bed (18.7 m^2) is loaded for a period of from one week to a month (depending on the sampling periodicity), while the other bed rests (Noorvee et al., 2005a; Noorvee et al., 2005b). Resting VSSF beds for several days prevents surface hydraulic and organic overloading, in order to avoid clogging (Weedon, 2003). After the VSSF, the wastewater is divided equally in the inflow well of the HSSF. Both parallel (left-hand and right-hand) HSSFs (area: 2 x 156.25 m^2) are filled with a 1.0 m deep LWA fraction of 2–4 mm (Filtralite S). The HSSF filter material was exchanged in the summer of 2005, because the phosphorus retention capacity of the HSSF FS was reaching its limit. Due to some water leakage problems (the PVC liner was broken), it was only possibility to use one bed of the HSSF filters in most test periods. Treated wastewater is directed to the HSSF outflow well, and from there to Väike-Kodijärv Lake by gravity flow.

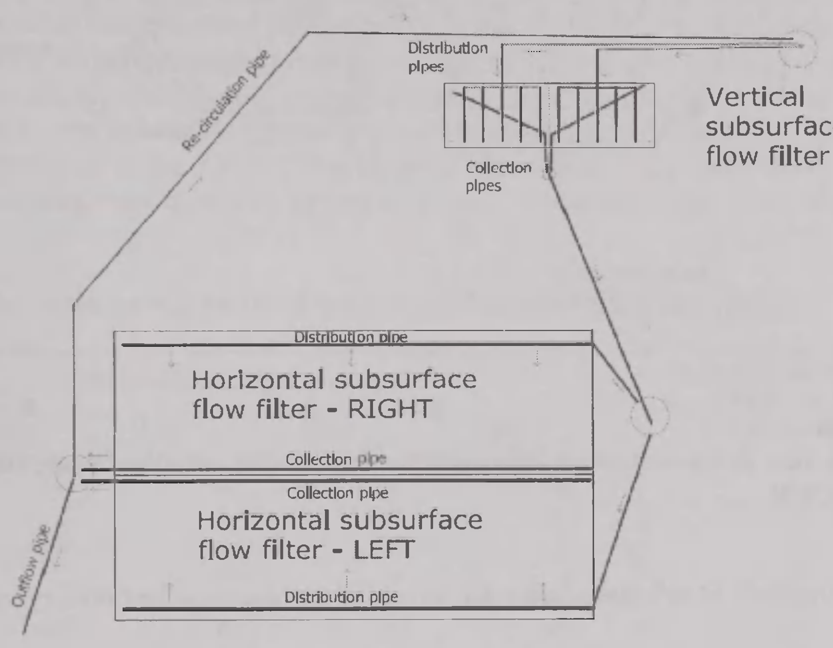

Fig. 2. Schematic layout of the hybrid FS in Kodijärve (after reconstruction in 2005).

The Ilmatsalu pilot-scale LWA filter was set up near the existing AWP in Ilmatsalu for the treatment of municipal wastewater from Ilmatsalu settlement. The system consists of a septic tank (2 m^3), distribution well, eight identical LWA filter cells (with a depth of 1.15 m and an area of 1 m^2 each) and an outflow/ recirculation well (Fig. 3). The cells are filled with a 1.15 m deep LWA (Filtralite S). The fraction of 2–4 mm was used in all of the cells. The porosity of the humid LWA measured at site was 0.43 m^3/m^3.

The hydraulic and pollution load of the Ilmatsalu LWA filter is determined by the test regime, the pore volume of the filter material and the water level in the wetland cells. While operating in batch mode, it is possible to re-circulate the treated water. The batch cycle consists of filling time, incubation time (variable), draining time (~0.5–1 hour) and recuperation time (up to ~24 h). The inflow and outflow fluxes of the cells are controlled by 25 mm solenoid valves installed in the inflow and outflow wells. Data about different operational regimes during the six test periods with incubation and recuperation times and water level are reported in Table 3. As the hydraulic load of the Ilmatsalu LWA filter system was ~0.5 m^3 during the six test periods, the HRT of the septic tank was 4 days.

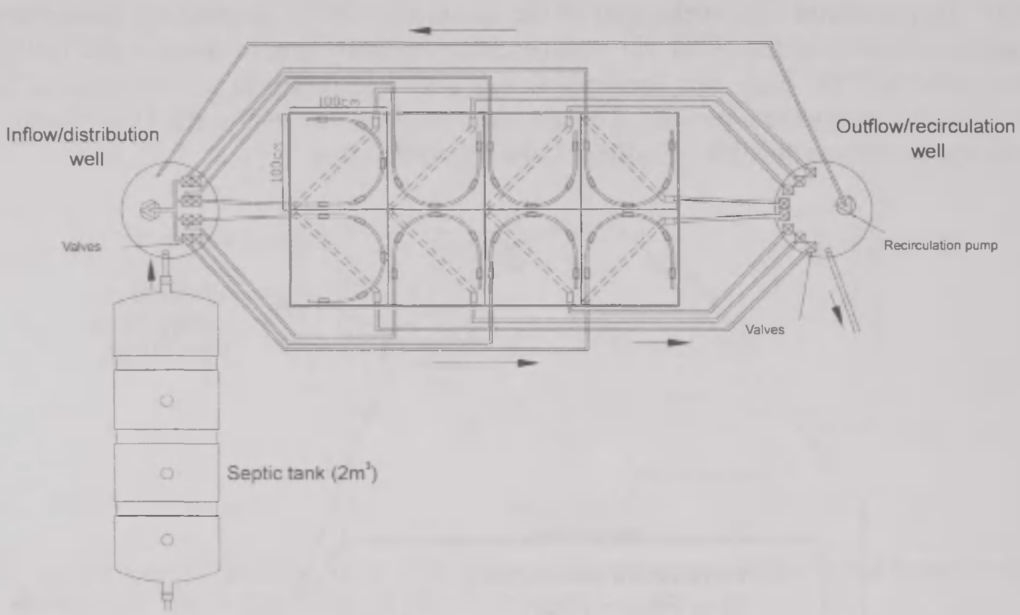

Fig. 3. Plan view of Ilmatsalu batch-operated filter system with associated septic tank, inflow and outflow well.

Table 3. Parameters of different operational periods of the batch-operated filter system (FS) in Ilmatsalu.

Parameter	Operational period					
	1	2	3	4	5	6
Water level in FS cell (m)	1.1	0.8	1.1	1.1	1.1	1.1
Incubation time (d)	7.0	~5.3	~5.3	3.5	2.3	1.8
Recuperation time (h)	~23	~17	~17	~11	~7	~5

Wastewater from the grit channel of the ASTP is first pumped into the septic tank and further flows into the inflow cell, from where it is pumped into the cells through solenoid valves. The cells are filled and drained in rotary mode: when the first cell is filled, the next is drained, etc. Pumps and valves are operated by a controller installed in the service building of the ASTP. The time between the fill and drain operation of the same cell is the incubation time, and the time between the drain and fill operation of the same cell is the recuperation (rest) time. The recuperation (rest) period allows for the degradation of accumulated suspended organic material in order to prevent clogging of the filter (Green et al., 1997). Also, intermittent flushing lets the surface dry out for certain periods of time (von Felde & Kunst, 1997). Recirculation of the treated water is achieved by pumping the water from the outflow well back to the inflow well at the same time as filling takes place.

Re-circulation regimes

The aim of our studies was not to over-dimension the systems, and therefore to explore the effect of effluent re-circulation on the purification efficiency (PE, %) of different types of filters systems. Effluent re-circulation was achieved using timer-controlled pumps. The re-circulation rates applied during the six test periods are presented in Table 4. The layout of the re-circulation schemes are shown in Fig. 1, Fig. 2 and Fig. 3. The usage of timer-controlled pumps narrows the distinctions between natural treatment systems and conventional systems, but for the achieving of smaller FS areas with at least the same or better purification efficiency (PE, %), it is appropriate. Brix and Arias (2005) concluded that recycling also improved and stabilised the overall treatment performance of the VSSF CW system. Re-circulation is also used in the activated sludge processes, for instance to remove nitrogen (Tchobanoglous & Schroeder, 1987).

Table 4. Re-circulation regimes (% of hydraulic loading rate) of filter systems (FS).

Period	Recirculation regimes of Nõo FS				Recirculation regimes of Ilmatsalu FS
	Right	Left	Right	Left	Outflow well, %
	Interim well, %	Interim well, %	Outflow well, %	Outflow well, %	
1	0	0	25	35	0
2	0	0	25	35	0
3	75	50	0	0	20
4	70	0	0	85	100
5	150	0	150	300	200
6	0	150	300	150	300
Period	**Recirculation regimes of Rämsi FS**				**Recirculation regimes of Kodijärve FS**
	Right	**Left**	**Right**	**Left**	**Outflow well, %**
	Interim well, %	**Interim well, %**	**Outflow well, %**	**Outflow well, %**	
1	25	30	40	20	0
2	0	0	35	30	75
3	55	40	40	30	150
4	90	70	50	40	200
5	300	0	300	600	250
6	0	300	600	300	300

Sampling

Water grab samples specified in Estonian and EU legislation were taken from FS systems once a week (November 2005...December 2006), from the outlet of the septic tank and the outlet of both VSSF and HSSF beds in Nõo, Rämsi, Kodijärve and from the outlet of the LWA filter in Ilmatsalu. Water samples were taken 8, 11, 9, 9, 9 and 11 times from Nõo FS, 8, 3, 7, 6, 9 and 11 times from Rämsi SF, 8, 9, 7, 8, 9 and 11 times from Kodijärve FS and 10, 9, 7, 10, 9 and 11 times from Ilmatsalu during the 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th} and 6^{th} periods respectively. Rämsi was partly frozen during the 2^{nd} period (in winter) and partly clogged during the 4^{th} period. As a result, fewer samples were taken from Rämsi SF.

Water samples were analyzed for pH, BOD_7, total suspended solids (TSS), COD_{Cr}, N_{tot}, NH_4-N, NO_2-N, NO_3-N, P_{tot}, temperature and dissolved O_2.

Statistical analysis

All parameters were verified for normality (Kolmogorov-Smirnov, Lilliefors' and Shapiro-Wilk's tests). Since the variables were not normally distributed, nonparametric Kruskal-Wallis ANOVA tests were carried out for the comparison of the purification efficiencies in different periods, and a non-parametric Spearman Rank Order Correlation coefficient was detected between influencing factors and purification efficiencies of BOD_7, TSS, N_{tot}, NH_4-N and P_{tot}. In the case of Nõo and Rämsi FSs, summarized recirculation rates from the outflow and interim well were used in the correlation analysis. The level of significance of $p<0.05$ level was accepted in all cases. We used *Statistica 7.0* for the data analysis.

RESULTS AND DISCUSSION

Results of FSs

With the decrease in wastewater and pollutant load and the greater re-circulation of wastewater (Table 4), purification efficiency (Table 5) increased in **Nõo** and **Rämsi FS** in terms of most water quality indicators. For instance, the purification efficiency of BOD_7, COD_{Cr}, N_{tot} and NH_4-N increased in both the right-hand and left-hand systems of the FSs. As expected, we found a significant positive correlation between the re-circulation rate and purification efficiency of BOD_7, COD_{Cr}, N_{tot} and NH_4-N in both parallel systems of **Nõo** and **Rämsi FS**.

In the left-hand system of the **Nõo FS** we also found a significant negative correlation between inflow (Q) and P_{tot} purification efficiency. In the left-hand system of the **Nõo FS** we also observed a significantly positive correlation with inflow temperature (°C) and BOD_7 purification efficiency. The comparison between two parallel systems is not direct, because of the difference in VSSF filter media (Table 2). The differences in the purification efficiencies between the two parallel systems in Nõo may be caused by the relatively poor properties of CL (larger grain size, dusty and different solubility properties) compared to LWA (smaller grain size and therefore higher surface area) in terms of aeration and insulation, which enhance the effects of other factors such as hydraulic loading rate and temperature regime. The significantly lower purification efficiency of P_{tot} during the 3rd operational regime (Table 4) probably reflects the influence of the lower water temperature and the switching of the recirculation from the outflow well to the interim well (Zaytsev et al., 2007).

In terms of purification efficiency (Table 5), the right-hand parallel of the **Rämsi FS** was more stable than the left-hand system. Better overall purification efficiencies in water quality parameters were noted in the 2nd, 4th and 5th periods. There were also higher re-circulation rates in the right-hand parallel (Table 4). Only the efficiency of P_{tot} purification decreased in the 5th and 6th periods, when HRT also decreased. We observed a significantly negative correlation with re-circulation and TSS, as well P_{tot} purification efficiency in both **Rämsi FSs**.

Since it was not possible to change the hydraulic loading in the **Kodijärve FS**, the differences in system performance could only be controlled through re-circulation. The increase in re-circulation improved purification efficiency in all water quality indicators except for N_{tot} and P_{tot} (Table 5). We observed a significant improvement in BOD_7 purification efficiency, comparing the last operational period with higher re-circulation to the first operational periods. A significant improvement in NH_4-N purification efficiency was also found between the 2nd and 6th operational periods. The Spearman Rank Order Correlation analysis showed a significantly positive correlation between re-circulation rates and the purification efficiencies of BOD_7, COD_{Cr}, NH_4-N and TSS. A significantly positive correlation between water temperature and BOD_7 purification efficiency was also observable. However, no significant correlations were found between hydraulic loading (m^3/d) and the purification performance of any parameters.

The purification efficiencies of **Ilmatsalu LWA FS** during the six periods are reported in Table 5. The pollution parameters of the effluent of the **Ilmatsalu LWA FS** met the normative values for COD_{cr} and TSS during all of the test periods. The BOD_7 normative concentration of 15 mg/l was achieved during the 5th and the 6th period, when the respective re-circulation rates of 200% and 300% were applied. The normative values of N_{tot} and P_{tot} were not achieved – the lowest mean outflow concentration of P_{tot} (2.5 mg/l) was recorded in the 1st period, whereas the lowest mean outflow concentration of N_{tot} (21 mg/l) was recorded in the 6th period. The Spearman Rank Order Correlation analysis shows a significantly positive correlation between the re-circulation rate and purification efficiency of BOD_7, COD_{cr}, N_{tot} and NH_4-N. However, we also found a significantly positive correlation between the water temperature and purification efficiency of BOD_7, COD_{cr}, N_{tot}, and NH_4-N, which probably indicates the concurrence of the increasing re-circulation rates and rising water temperature, as the experimental period lasted only 13 months. The stronger influence of higher re-circulation rates rather than higher water temperature on the purification efficiency of BOD_7 and N_{tot} is displayed by the fact that the mean purification efficiencies of BOD_7 and N_{tot} were not significantly lower in the 6th period than in the 5th period, although the water temperature was significantly lower – 8.5°C and 15.6°C respectively.

Table 5. Hydraulic retention times (HRT) and purification efficiencies (PE, %) of organic matter (by BOD_7), total suspended solids, COD_{cr}, N_{tot} and P_{tot} at outflow of filter systems (FS).

			HRT	PE at outflow (%)							HRT	PE at outflow (%)				
Period	**FS**	**Parallel**	**(day)**	**BOD_7**	**TSS**	**COD_{Cr}**	**N_{tot}**	**P_{tot}**	**FS**	**Parallel**	**(day)**	**BOD_7**	**TSS**	**COD_{Cr}**	**N_{tot}**	**P_{tot}**
1	Nõo	Right	6	51	92	51	11	76	Rämsi	Right	14	64	92	58	54	96
		Left	6	67	94	64	5	47		Left	16	67	98	61	53	97
	Ilmatsalu	-	8	88	82	70	16	62	Kodijärve	-*	26	91	88	74	39	58
2	Nõo	Right	11	76	91	72	25	66	Rämsi	Right	70	78	99	68	60	99
		Left	11	82	93	78	28	31		Left	73	66	98	61	46	96
	Ilmatsalu	-	6	74	91	61	0	36	Kodijärve	-*	18	85	90	74	28	47
3	Nõo	Right	10	87	91	84	38	45	Rämsi	Right	49	82	84	78	58	99
		Left	13	89	95	86	46	40		Left	56	82	80	79	58	96
	Ilmatsalu	-	7	83	81	69	8	41	Kodijärve	-*	16	90	85	78	52	73
4	Nõo	Right	14	84	87	82	51	75	Rämsi	Right	39	93	87	91	79	99
		Left	14	89	72	83	66	67		Left	45	87	82	87	78	92
	Ilmatsalu	-	8	91	83	83	43	53	Kodijärve	-*	17	97	88	82	36	64
5	Nõo	Right	4	95	92	92	74	73	Rämsi	Right	10	96	78	96	81	78
		Left	5	98	90	94	80	76		Left	10	96	79	95	79	71
	Ilmatsalu	-	8	96	84	90	51	53	Kodijärve	-*	17	97	88	81	42	66
6	Nõo	Right	6	99	86	93	82	61	Rämsi	Right	13	98	94	97	87	77
		Left	7	99	87	93	80	69		Left	13	99	94	98	87	71
	Ilmatsalu	-	8	95	89	85	48	44	Kodijärve	-*	14	98	94	83	37	45

* Due to some water leakage problems (the PVC liner was broken), in most periods it was only possible to use one bed of the HSSF filters.

Discussion

The higher re-circulation rate of the wastewater significantly improves the aeration and overall purification efficiency of FSs operated with different flow regimes. In Nõo, Rämsi and Ilmatsalu pilot FSs, we observed a significant positive correlation between the re-circulation rate and purification efficiency of BOD_7, COD_{cr}, N_{tot} and NH_4-N. In the Ilmatsalu FS we also found a significantly positive correlation between the water temperature and purification efficiency of BOD_7, COD_{cr}, N_{tot} and NH_4-N. In the Nõo FSs we observed a significant positive correlation only between the water temperature and purification efficiency of BOD_7. However, the positive effect of water temperature on purification efficiency could be partly explained by the fact that the application of higher re-circulation rates was in part concurrent with the rise in water temperatures during the test period. In Kodijärve FS the Spearman Rank Order Correlation analysis showed a significantly positive correlation between re-circulation rates and the purification efficiencies of BOD_7, COD_{Cr}, NH_4-N and TSS. A significantly positive correlation between water temperature and BOD_7 purification efficiency was also observable.

However, the small amount of re-circulated water (25–50% of inflow) has only a small effect on purification efficiency when the system is heavily overloaded. The re-circulation rate must be at least 100–200% of the inflowing wastewater in order to achieve satisfactory results in terms of effective BOD_7 and COD_{cr} removal and nitrification.

If one applies higher re-circulation rates, the hydraulic constraints of the filter material must also be taken into consideration. Typical hydraulic loading for VSSFs is 40–500 mm/d (Kadlec et al., 2000) or 100–400 mm/d (Paing et al., 2006). Average recommended hydraulic loading for HSSF CWs varies from 20 to 100 mm/d (Kadlec et al., 2000). During the study period, the hydraulic loading rates regarding the re-circulation rates of tested filter systems reached 84 and 236 mm/d in the case of continuous-flow and batch-operated systems respectively. However, no negative side-effects such as clogging were observed when the higher recirculation rates were applied. Also, higher re-circulation rates did not significantly affect the phosphorus removal rate. Inorganic chemical reactions such as phosphorus adsorption and precipitation are normally rapid processes that are not greatly affected by the increasing of wastewater-media contact time (Noorvee, 2007; Noorvee et al., 2007b). Therefore, employing effluent re-circulation may have little impact on P_{tot} removal (Sun et al., 2003). Noorvee (2007), however, has concluded that a very high re-circulation rate (up to 600%), when the filter material acts as a phosphorus precipitating substrate, has a negative effect on TSS and P_{tot} removal (studied in the Rämsi LWA FS). As found in Rämsi, calcium present in the wastewater itself can promote phosphorus precipitation (Maurer, et al., 1999). This is probably the explanation for the very effective phosphorus removal in the FS at Rämsi pig farm. Since the pig fodder also contains Ca-minerals (according to the pig farm data, average Ca content is 11.3 g/kg), it also contains phosphorus (average 8.6 g/kg), and some of the Ca is excreted with the slurry. The Ca inside the wastewater probably allows the phosphorus to precipitate as Ca-phosphate.

In terms of applying pre-denitrification, a better solution would be not to pump the wastewater back into the inflow well, but instead to pump the wastewater into the septic tank, where more organic matter is available for denitrification. Since the change in the re-circulating origin in the case of the Nõo hybrid filter system (interim + outflow well or only the outflow well) showed no significant effects on purification performance, the use of re-circulation from the interim well seems to be irrelevant in terms of additional improvement of purification performance, and back-pumping only from the outflow well is more adequate (Noorvee, 2007).

Unfortunately the LWA (Filtralite S, M, L) used as filter material rapidly lost its phosphorus adsorption and sedimentation properties. In LWAs, especially in Filtralite P, Ca-minerals are a very important additive for the precipitation of phosphorus. In contact with water, this may yield a dramatic increase in pH (pH up to 12), which may favour the precipitation of phosphates (Jenssen & Krogstad, 2003). Although we did not register great changes in pH in our systems, it is very important to find a suitable filter material for phosphorus removal via adsorption or precipitation. Another possibility to assure sufficient phosphorus removal (<1.5 mg/l in the outflow) is to use chemical precipitation inside the septic tank (Brix & Arias, 2005).

For further developments, we recommend that the area of the VSSF filter should measure up to 2.5 m^2/pe (pe – person equivalent) for effective organic matter removal and nitrification. Implementing re-circulation over 100% results in an area need of 1.7 m^2/pe for VSSF filters. We recommend that VSSF filters be designed with a depth of 1.0 to 1.3 m. Taking into account both hydraulic loading and organic matter loading, the recommended area for HSSF filters is 3.0 to 5.0 m^2/pe when they are placed as a second stage of the CW system (Noorvee, 2007).

The construction costs of such CWs filled with LWA (Filtralite S, M, L) would, in Estonia, range from 1279 to 1051 €/pe (for 50 to 100 pe). Compared to AWP with equivalent loading rates (for 50 to 100 pe) and treatment performance, consisting of concrete basins for nitrification, secondary sedimentation and sludge thickening, with construction costs of 1432 to 1112 €/pe, CWs would be less expensive to establish.

If we also consider operating costs, such as electrical power, chemical, labour, sludge treatment costs and depreciable cost, which total 84 to 56 €/y for 50 to 300 pe CWs and 129 to 65 €/y for 50 to 300 pe AWPs, then it is reasonable to select CWs for communities from 50 to 300 pe (Noorvee et al., 2007a). This conclusion is based on the lifetime assessment of different treatment systems. In the evaluation of depreciable cost, the lifetime of facilities is considered to be 40 years, although in the case of CWs a lifetime of 20 years is assumed for filter material.

CONCLUSIONS

In the Nõo FS the mean purification efficiencies (PE, %) of BOD_7, N_{tot}, P_{tot} during the test period were 82%, 47% and 66% respectively for the CL and LWA FS and 87%, 51%, 55% respectively for the LWA FS. The highest purification efficiencies, 99% and 82% for BOD_7 and N_{tot} removal respectively, were achieved in the LWA FS, when the re-circulation rate of 300% was applied. Because of its higher surface area, LWA is a better filter material than crushed $CaCO_3$-rich limestone in VSSFs. Better aeration and insulation enhance the effects of other factors, such as hydraulic loading rate and temperature regime.

In the Rämsi FS the mean purification efficiencies (PE, %) of BOD_7, N_{tot}, P_{tot} during the test period were 85%, 70% and 91% respectively for the right-hand LWA FS and 83%, 67%, 87% respectively for the left-hand LWA FS. The highest purification efficiencies, 98.5% and 87% for BOD_7 and N_{tot} removal respectively, were achieved in both Rämsi FSs, when a re-circulation rate of 300 to 600% was applied.

In the Kodijärve FS the mean purification efficiencies (PE, %) of BOD_7, N_{tot}, P_{tot} during the test period were 93%, 39% and 59% respectively for the CL and LWA FS. The highest purification efficiencies, 98% for BOD_7 removal, were achieved when a re-circulation rate of 300% was applied and 58% for N_{tot} removal were achieved when a re-circulation rate of 150% was applied.

In the batch-operated pilot-scale LWA filter for the treatment of municipal wastewater, the mean purification efficiencies (PE, %) of BOD_7, N_{tot} and P_{tot} during the test period were 88%, 28% and 48% respectively. The highest purification efficiencies of 96% and 51% for BOD_7 and N_{tot} removal, respectively, were achieved when the re-circulation rate of 200% was applied at the same hydraulic loading rate. Nitrification was the rate-limiting step in nitrogen removal, when 0–20% re-circulation was applied, indicating poor oxygen conditions in the LWA filter matrix. When the re-circulation rate was increased to 300%, the rate-limiting step in the nitrogen removal process became denitrification, inhibited by the low organic carbon concentration.

The main factors affecting the performance of the batch-operated and continuous flow hybrid CL and LWA FSs in the areas of BOD_7 and N_{tot} removal are water temperature and recirculation rate, on which the effect of recirculation and thus retention time was more noticeable. In terms of applying pre-denitrification, a better solution would be not to pump the wastewater back into the inflow well, but instead to pump the wastewater into the septic tank, where more organic matter is available for denitrification. Further and more complex research should focus on the investigation of batch-operated LWA filters in terms of applying shorter incubation times and higher organic carbon loading.

We observed a significant positive correlation in all FSs between the re-circulation rate and purification efficiency of BOD_7, COD_{cr} and NH_4-N. There was no clear influence of other influencing factors such as water temperature, hydraulic and mass loading rate on purification efficiency during the test period, as the filter systems were tested in field conditions using real wastewater. Thus the mass loading rate of filter systems was determined on the basis of the characteristics of wastewater and applied hydraulic loading rate.

The re-circulation of wastewater is a good solution for the improvement of the aeration and overall purification efficiency of CWs. The re-circulation of the wastewater significantly improves purification and also makes it possible to avoid the over-dimensioning of CWs, leading to the establishment of more cost-effective CW systems.

We recommend that the re-circulation rate must be from 100 to 300 percent of the inflowing wastewater to achieve satisfactory results in terms of effective BOD and COD removal and nitrification/denitrification, as well as TSS and P_{tot} removal.

The area of the VSSF filter should measure up to 2.5 m^2/pe, whereas with re-circulation over 100% the area needed is 1.7 m^2/pe (with a depth of 1.0 to 1.3 m). The recommended area for HSSF filters is 3.0 to 5.0 m^2/pe when they are set up as a second stage of the CW system and appropriate recirculation is included.

The results of the project "Hybrid constructed wetlands for wastewater treatment" give us forward guidelines to develop systems that meet the requirements of Estonian legislation, when treated wastewater is channelled into a body of water.

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