

Lowland river reference condition: spatial and temporal patterns of the zoobenthos community in the Volga headwaters (2006–2010)

M. Schletterer · L. Füreder · V. V. Kuzovlev ·
Y. N. Zhenikov · I. L. Grigorieva

Received: 30 January 2012 / Accepted: 2 February 2013 / Published online: 16 March 2013
© Springer Science+Business Media Dordrecht 2013

Abstract The Volga, the largest river in Europe, has experienced multiple stressors from human activities. Recently we showed that its upper course (about 500 km, from its source to Tver) still has large sections with low impact and a natural type-specific potamal flora and fauna. Our present research in the East European lowlands aim to define reference conditions for mid-sized to large lowland rivers in order to build a basis for future management and conservation. Three monitoring sites were selected based on the results from intensive sampling in 2005. In subsequent field campaigns between 2006 and 2010 regular surveys were carried out each year in summer and additional ones in spring. A taxon-rich macroinvertebrate fauna, including several rare potamal relict species, was

recorded and the data was used to provide an overview of annual and interannual variation in community indices and metrics. The conditions described for the headwaters of the Volga River system can be used as a reference state for medium-sized and large lowland rivers in regions where reference sites of these types are lacking.

Keywords Large river · Biomonitoring · Reference conditions · Variability

Introduction

Large rivers are exceptional ecosystems (Tockner & Stanford, 2002; Thorp et al., 2006) and concerning a general typology it is evident that large rivers are complex ecosystems with each river being an individual (Tockner et al., 2009). Different definitions of large rivers exist, taking account catchment size,

Electronic supplementary material The online version of this article (doi:10.1007/s10750-013-1466-0) contains supplementary material, which is available to authorized users.

Guest editors: H. Habersack, S. Muhar & H. Waidbacher /
Impact of human activities on biodiversity of large rivers

M. Schletterer (✉)
Division Engineering Services, TIWAG–Tiroler
Wasserkraft AG, Eduard-Wallnöfer-Platz 2,
Weißgattererstr. 27, 6020 Innsbruck, Austria
e-mail: martin@schletterer.co.at

M. Schletterer · L. Füreder
Department of River Ecology and Invertebrate Biology,
Institute of Ecology, University of Innsbruck,
Technikerstraße 25, 6020 Innsbruck, Austria

V. V. Kuzovlev · Y. N. Zhenikov
Tver State Technical University, nab. Afanasiya Nikitina
22, 170026 Tver, Russia

I. L. Grigorieva
Institute of Water Problems, Russian Academy of
Sciences, Gubkin Street 3, 119333 Moscow, Russia

channel width and hydrologic regime (Pardé, 1964; Marcinek, 1978; Mangelsdorf et al., 1990). In the present discussion on European level, rivers with a catchment area $>10,000 \text{ km}^2$ are classified as large rivers; according to the Water Framework Directive—WFD (Directive 2000/60/EC) these would be “very large rivers”. There is alarming evidence that European lowland rivers are threatened ecosystems, due to numerous stressors (organic pollution, and nutrient enrichment acidification and alterations of hydrology and morphology; Stanner & Bordeau, 1995; Tockner et al., 2009; Moss, 2010). In addition there is a lack of effective and generally accepted sampling methodology for large lowland rivers. Further, sampling effort is huge, assessment is cost- and time-consuming (Humpesch & Elliott, 1990; von Tümpling & Friedrich, 1999). These issues cause a very limited data base for large rivers in general, and their natural spatial and temporal variability in particular (Ehlert et al., 2002; Chessman & Royal, 2004).

A high degree of background noise has to be considered in order to ensure the reliability of biological assessments and to define reference conditions for large rivers, as demanded by the WFD. Using baseline data assessed before a stressor affects the ecosystem, comparisons can be made using a “Before-After Control-Impact” design (BACI; Stewart-Oaten et al., 1986). The reference condition approach (Impact Versus Reference Sites; IVRS) is based on these principles. For the definition of reference conditions guidelines were compiled (REFCOND, 2003). It is a great problem, however, that near natural conditions do not exist for most large European rivers. One reason for this is the fact that neobiota restructured the original communities (e.g. 80% aliens in the lower Rhine). Historical data are scarce and often imprecise. Thus the definition of reference conditions for lowland rivers was recognised as a difficult task (Ehlert et al., 2002). On the other hand WFD requires a high level of confidence for defining reference conditions (Ofenböck et al., 2004) in order to ensure precision in the classification process. A possibility to overcome this problem is to use reference conditions from adjacent geographical regions, which have a low population density and little anthropogenic impacts (Nijboer et al., 2004). Within the second phase of the intercalibration exercise of the Common Implementation Strategy (CIS) of the WFD the quality elements benthic diatoms and benthic fauna are included for an

intercalibration of large river data (Birk et al., 2011). Since there is a paucity of reference data and it was impossible to find a common window of pressure for alternative benchmarking, the approach of continuous benchmarking (using LDC-sites; least disturbed conditions) was applied (Birk et al., 2011).

The “Upper Volga Expedition 2005” (Kuzovlev & Schletterer, 2006) has shown that the free-flowing section of the Volga River upstream of Tver is a refugial system for the European potamal fauna (Schletterer & Füreder, 2010). These results stipulated regular data assessment, which is important to estimate and monitor the conditions of the water ecosystem, as well as for the assessment of the ecological status. We selected three sites in the headwaters of the Volga River (Rzhev, Staritsa, Tver) for a monitoring programme (hydrobiology and hydrochemistry). Herein we provide the results obtained within the first 5 years (2006–2010), with a focus on the macroinvertebrate communities, including (1) an overview of the interannual and annual variation in community indices and metrics, as well as (2) a faunistic characterisation.

The main objective of the study is to test metrics based on the macroinvertebrate communities. Having in mind that the study area is only under slight anthropogenic influence (Schletterer & Füreder, 2010), which is rare situation in lowland areas of Europe, the results of the study could be used for setting up the reference community for large lowland rivers, not only in the region (headwaters of the Volga River or Central Russia), but on European scale.

Methods

Study sites

The headwaters of the Volga are located in the ecoregion 16 - Eastern Lowlands (Illies, 1978) and, with respect to the European biogeographical regions, in the boreal zone (Uhel et al., 2003). According to Krever et al. (1994) the area belongs to the Russian bioregion 2 (Kola-Karelian & Eastern European Forest). The World Wildlife Fund (WWF) classification of ecoregions assigns the area as PA0346 “Sarmatic mixed forests”, which belongs to the cluster “Temperate Broadleaf and Mixed Forests” (Olson et al., 2001).

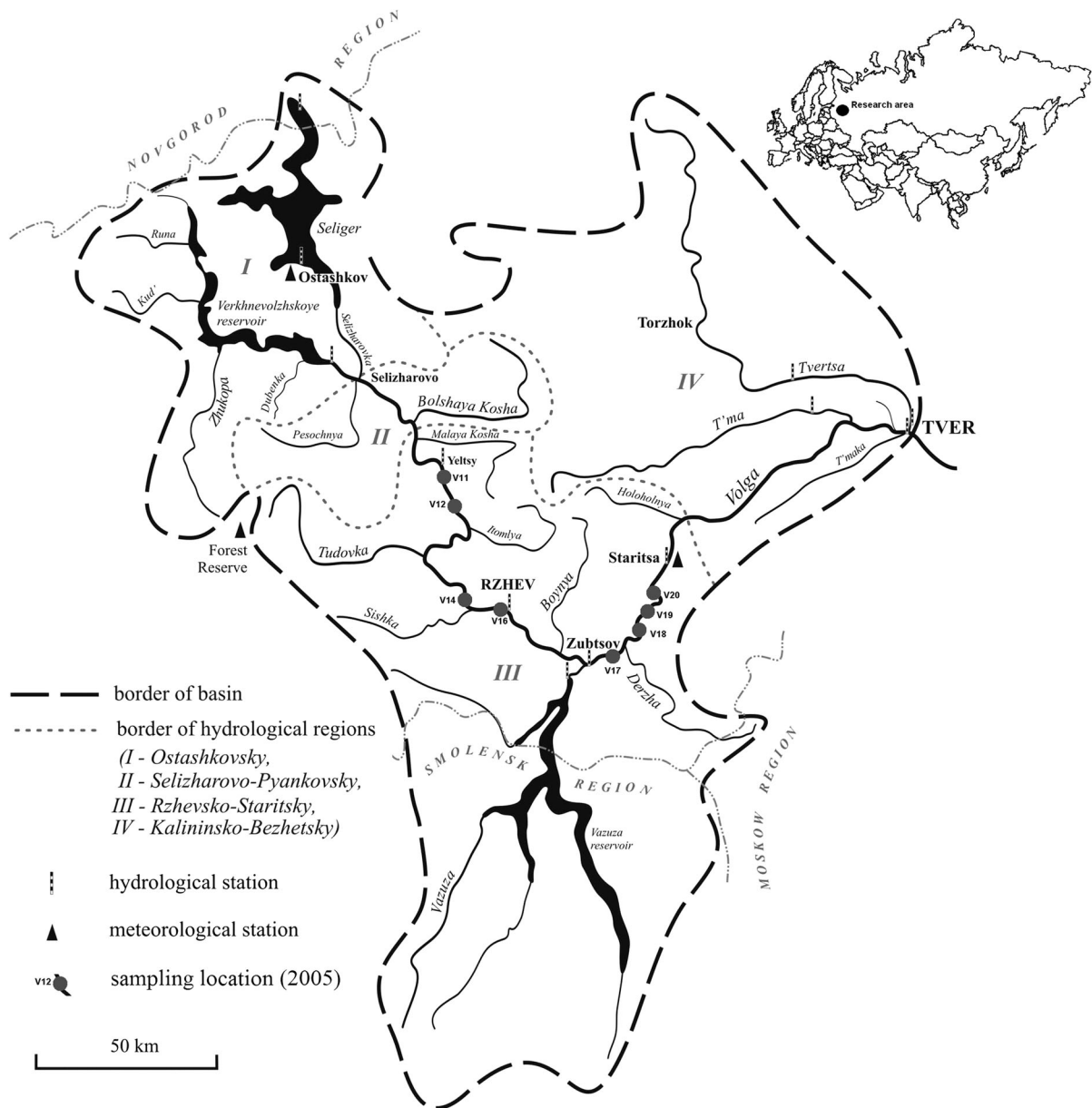


Fig. 1 Research area, indicating the monitoring points Rzhnev, Staritsa and Tver, as well as the sampling locations which were included in the present study

The catchment area of the headwaters (Fig. 1) covers major parts of the administrative region of Tver, and minor parts are located in the regions of Novgorod (northern part of Lk. Seliger) and Smolensk (Vazuza River). Tver region covers 84,586 km² of gently undulating landscape with low altitude (less than 300 m). The region has dense forests (Pinetum and Betuletum type), which belong to the southern taiga (Klimo & Hager, 2001). Climate is moderate

continental, with a mean temperature of -9.5°C in January and 17.5°C in June; the average precipitation is 650 mm per year (Gravenhorst et al., 2000). The hydrological regime is pluvio-nival, with floods in spring (March–May), accounting for up to 60% of the annual discharge, and a summer low-flow period (Vladimirov, 1997). The Volga is fed mainly by snow-melt (60% of the annual discharge), groundwater (30%) and rain (10%). Naturally there is a high flood

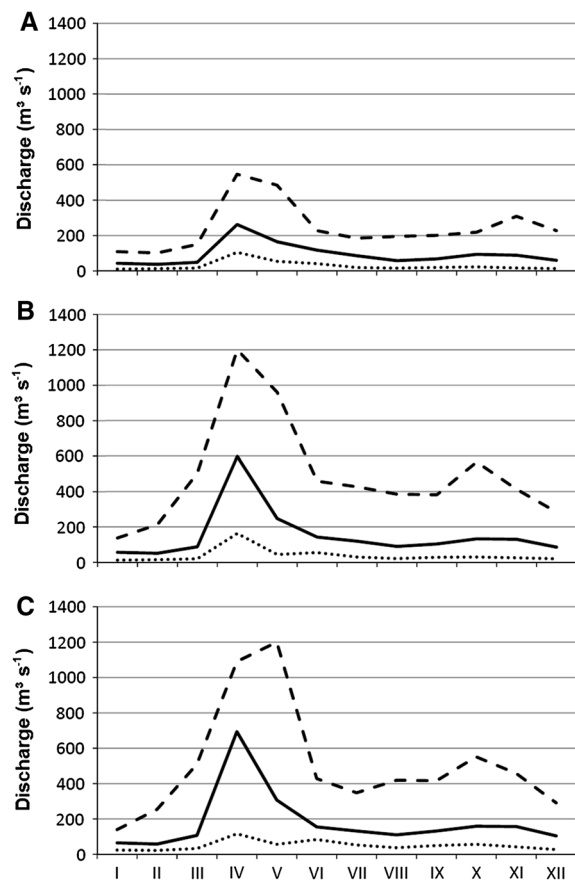


Fig. 2 Hydrological regime ($\text{m}^3 \text{s}^{-1}$; black line MQ; dotted line NM; dashed line HM) at the three monitoring points: **A** Rzhev (1924–1985; from Shiklomanov, 1999); **B** Staritsa (1891–1985; from Shiklomanov, 1999); **C** Tver (1876–1936; from Yablokov & Zorova, 1967)

in spring (April–June), a summer low-flow period, followed by higher discharge in autumn due to rainfalls and again a long winter low-flow period (Yablokov, 1973; see also Fig. 2).

Since the Volga River emerges at only 228 m a.s.l. and runs through a river lake continuum in the uppermost course, downstream the Upper Volga Lakes the Volga is already a typical lowland river in its headwaters (Schletterer & Füreder, 2010). The Upper Volga Lakes (Sterzh, Vselug, Peno and Volgo) were natural lakes, however, nowadays their water level is raised by a dam, the “Bejshlot” (constructed in 1843, rebuilt in 1943), which was built and operated to improve navigation conditions, by maintaining nautic depth between Bejshlot and Tver (catchment at Bejshlot = $3,500 \text{ km}^2$). The effect of this “reservoir” is nowadays minor and the Upper Volga Lakes can be

considered as semi-natural river-lakes (river kilometer 3,520–3,426; i.e. from 11 to 105 km from the source). Effects on the free-flowing section are not evident, only close to the outlet the macroinvertebrate community was characterised by faunistic elements typical for lake outlets. The mean slope between the source and Tver is only 0.24‰ and the river is surrounded by flat terraces along the banks. We consider the section between Eltsy (catchment = $9,130 \text{ km}^2$) and Rzhev (catchment = $12,200 \text{ km}^2$) as true reference, respectively LDC (= least disturbed conditions) for large lowland rivers. Downstream the confluence with Vazuza River at Zubzov anthropogenic activities are increasing (e.g. reservoir on the Vazuza River, settlements, farming), however, the Volga is till the city of Tver in good condition.

The monitoring sites upstream the cities of Rzhev, Staritsa and Tver (Fig. 1) were selected nearby roads, in order to ensure easy access. Characteristics of the sites are provided in Table 1. The hydrological regime at these three stations is presented in Fig. 2, data for the stations Rzhev and Staritsa were available from Shiklomanov (1999) and for Tver from Yablokov & Zorova (1967); the thermal regime is summarized in Table 2.

The station Rzhev (UVS_V-M01) is located about 1.0 km upstream the main bridge of the city (56.258°N , 34.319°E). Substratum is dominated by gravel, and carbon deposits (especially on the right side) are rich in fossils (e.g. the brachiopod *Productus*). The right bank is more than 30 m high, while the left one is lower. The banks are dominated by the reed canary grass (*Phalaris arundinacea*), but only single shrubs or trees occur on the shoreline. Nearby this point the sampling location “upstream Rzhev” of Roshydromet (which is classified as category 3, i.e. samples are taken during the main hydrological phases) is located. Further data about the station Rzhev can be found in Schletterer & Kuzovlev (2007) and Schletterer & Füreder (2009). The site Staritsa (UVS_V-M02) is located about 0.5 km downstream the bridge of Staritsa (56.510°N , 34.930°E); the floodplain is dominated by *Carex* spp. and *Phalaris arundinacea*. Tver/Migalovo (UVS_V-M03) is the lowermost station upstream the city of Tver (56.847°N , 35.774°E), located about 0.7 km upstream the bridge of the M10 highway (Moscow—St. Petersburg), at the beginning of backwater of the Ivankovskoe reservoir. Nearby of this site, a monitoring location of Roshydromet (which is classified as

Table 1 Main morphological characteristics of the sampling sites (width and max. depth are given for summer low flow period)

Site	Rzhev (V-M01)	Staritsa (V-M02)	Tver (V-M03)
Distance from source (km)	277	376	438
Width (m)	134	168	180
Max. depth (m)	2	3	5
MQ ($\text{m}^3 \text{s}^{-1}$)	94.2	154.3	178.6 ^b
Catchment area (km^2)	12,200	21,100	24,300
Catchment ^a (% forests)	55	44	41
Catchment ^a (% wetlands)	4	2	2
Catchment ^a (% mires)	4	3	2
Sea level (asl)	154.2	136.9	124.0
Substrate (dominant)	Gravel	Gravel	Sand

^a Data from: Yablokov & Zorova (1967)

^b Until the construction of the Ivankovskoe reservoir, hydrological measurements were carried out at Tver (1876–1936; MQ = $182 \text{ m}^3 \text{s}^{-1}$), about 9 km downstream of Migalovo. The mean annual discharge of the Volga River at Tver/Migalovo was calculated to be $178.6 \text{ m}^3 \text{s}^{-1}$ (i.e. $3.4 \text{ m}^3 \text{s}^{-1}$ less than in the place where the hydrological station was situated)

Table 2 Average water temperatures in the river Volga between April and November at Rzhev and Staritsa for the period 1945–1962 (from: Yablokov & Zorova, 1967) and at Tver for the period 1946–1970 (from Surina, 1976)

	Average (10 days)			Average monthly						Average (10 days)		
	IV ^a			V	VI	VII	VIII	IX	X	XI ^a		
	1	2	3							1	2	3
Rzhev	–	2.3	6.0	11.8	17.8	19.5	17.7	12.1	5.7	2.0	0.7	–
Staritsa	–	2.6	6.6	12.3	18.3	19.9	18.3	12.5	5.7	2.2	0.8	–
Tver	0.5	2.6	6.8	12.9	18.7	20.4	18.8	13.2	6.1	2.1	0.8	–

^a Mean values for the first 10 days of the month (=1), for the middle 10 days (=2) and the last 10 days (=3) of the month

category 4, i.e. monthly analyses of the water quality are carried out) is located. Detailed information about this site were recently provided by Schletterer & Kuzovlev (2012).

Sampling and analyses

Fieldwork was carried out in the headwater of the Volga River during the summer low flow period (2006–2010); additionally, samples were collected two times in spring (2007, 2008). At Tver/Migalovo macroinvertebrate samples were taken with a bottom grab (sampled area = $23 \times 23 \text{ cm} = 0.053 \text{ m}^2$, at each site three replicates). Before analyses the data from the three replicates were pooled (sampled area = 0.159 m^2). Samples at Staritsa and Rzhev were taken using a multi-habitat sampling method (Hering et al., 2003, modified; sampled area = 0.225 m^2 ;

see Schletterer et al., 2011). The material was sieved (mesh size $500 \mu\text{m}$) and the invertebrates were preserved in ethanol (95%). In the laboratory, determination was carried out to the lowest possible level (Ostracoda, Hydrachnidae, Chironomidae and Oligochaeta were not determined). For one year (2007) also Chironomidae and Oligochaeta were determined to the lowest possible level and these data were included to represent the richness of the whole macroinvertebrate community (“2007-08-CO” in Table 3). To provide a wider spatial range, further sites that were assessed in 2005 were included to the present dataset: V11 (Eltsy-lithal), V12 (Klimovo), V14 (Zavolzhsy), V16 (Rzhev), V17 (Rublevo), V18 (Danilovo), V19 (Borovyja) and V20 (Molokovo); these samples were taken with a bottom grab and classified as reference sites (see Schletterer & Füreder, 2010). Taxa richness (TR) was calculated as an overall number of taxa (Ostracoda, Hydrachnidae,

Table 3 Community metrics and indices for the investigated sites

Site	Year and month	Abundance (ind. m ⁻²)	TR/EPT	Diversity (Shannon–Wiener index/evenness)	Saprobic index	SPEAR _{pesticides}
UVS_V-M01	2006-08	1,106	31/13	2.32/0.71	1.98	34.43
UVS_V-M01	2007-05	789	19/12	2.13/0.81	1.14	50.74
UVS_V-M01	2007-08	1,720	50/25	2.67/0.77	2.02	31.61
UVS_V-M01	2007-08-CO ^a	1,720	76/25	3.50/0.86	2.05	31.61
UVS_V-M01	2008-05	1,151	25/9	1.94/0.67	1.93	39.40
UVS_V-M01	2008-08	3,440	40/16	2.62/0.74	2.36	31.83
UVS_V-M01	2009-06	2,196	38/21	2.63/0.75	2.20	40.46
UVS_V-M01	2010-08	1,440	31/18	2.41/0.72	2.16	44.70
UVS_V-M02	2006-08	3,076	34/13	2.14/0.64	2.19	31.82
UVS_V-M02	2007-05	415	15/6	2.11/0.92	2.13	39.50
UVS_V-M02	2007-08	1,018	42/15	2.71/0.74	2.25	29.07
UVS_V-M02	2007-08-CO ^a	1,018	57/15	2.77/0.73	2.24	29.07
UVS_V-M02	2008-05	3,719	23/9	1.53/0.53	2.04	38.38
UVS_V-M02	2008-08	1,067	31/8	2.44/0.76	2.37	27.27
UVS_V-M02	2009-06	1,716	18/8	2.01/0.79	2.21	35.88
UVS_V-M02	2010-08	1,831	22/8	2.14/0.73	2.08	34.38
UVS_V-M03	2006-08	7,304	16/6	0.34/0.16	1.84	32.6
UVS_V-M03	2007-05	1,516	15/5	1.44/0.63	2.06	21.43
UVS_V-M03	2007-08	4,768	22/12	1.31/0.45	1.92	37.14
UVS_V-M03	2007-08-CO ^a	4,768	34/12	2.47/0.76	1.93	37.14
UVS_V-M03	2008-05	8,444	16/8	0.93/0.39	2.03	21.34
UVS_V-M03	2008-08	2,993	14/8	0.84/0.38	1.90	33.52
UVS_V-M03	2009-06	–	–	–	–	–
UVS_V-M03	2010-08	1,911	12/6	0.49/0.24	2.13	34.35

TR total richness, EPT number of EPT-Taxa, LDC least disturbed conditions

^a Index values for August 2007, calculated with all taxonomic groups (also Chironomide and Oligochaeta determined to the lowest possible level), which were included for external validation in the European IC exercise (Rzhev = reference/LDC site, Staritsa and Tver = free-flowing site with no navigation, but not in LDC)

Chironomidae and Oligochaeta were handled as one taxon each) within a sample. The EPT index (Lenat, 1988) reflects TR within the orders Ephemeroptera, Plecoptera and Trichoptera. The Shannon diversity index (H') and the evenness (E), which provides information on the community structure, were calculated according to Shannon (1948). The calculation of Saprobic Index (SI; Zelinka and Marvan, 1961), biocoenotic region and functional feeding groups were carried out by using authecolological data provided by the Fauna Aquatica Austriaca (Moog, 2002). Calculations of H' , E , SI, biocoenotic region and functional feeding groups were carried out with the programme Ecoprof 3.2 (Schmidt-Kloiber and Vogl, 2010). The index SPEAR_{pesticides} (Beketov, 2009) was calculated

with the program SPEAR Calculator (UFZ, Leipzig, Germany), freely available on the Internet (<http://www.systemecology.eu/SPEAR/Start.html>). For metric comparison we calculated the coefficient of variation (CV; Sokal & Rohlf, 1998), using the formula $CV = \text{standard deviation}/\text{arithmetic mean}$.

Water samples were taken in the summer seasons and analyzed by three laboratories depending on the years, i.e. from 2006 to 2007 (all sites) by the Dubna Ecoanalytical laboratory (Dubna), and from 2008 to 2009 (all sites) and in 2010 the sample from Rzhev by the laboratory of the Institute of Water Problems (Moscow) and Staritsa + Tver by the Laboratory for ecological monitoring of Tver State Technical University (Tver). All laboratories used standard methods

Table 4 Mean physico-chemical parameters and standard-deviation at the three monitoring sites and normative (PDK) in the Russian Federation (from Normativy kachestva vody vodnyh objectov rybohozyaistvennogo znacheniya, 2010)

	Normative	M01 Rzhev	M02 Staritsa	M03 Tver
Sampling dates ($n = 6$)		22.06.2006 17–22.08.2008 23.05.2007 01.08.2008 15.06.2009 01.08.2010	22.06.2006 17–22.08.2008 23.05.2007 01.08.2008 15.06.2009 09.04.2010	22.06.2006 17–22.08.2008 23.05.2007 01.08.2008 15.06.2009 16.08.2010
pH	6.5–8.5	7.72 ± 0.35	7.96 ± 0.45	8.03 ± 0.45
Conductivity, $\mu\text{S cm}^{-1}$	–	215.17 ± 15.85	222.67 ± 44.37	267.50 ± 19.52
Dissolved oxygen, mg l^{-1}	4	8.57 ± 1.07	9.53 ± 1.62	9.48 ± 2.60
Colour, °Pt/CO scale	–	70.67 ± 17.52	67.67 ± 22.71	51.80 ± 18.79
TSS, mg l^{-1}	–	107.00 ± 30.05	132.00 ± 16.81	157.50 ± 31.40
HCO_3^- , mg l^{-1}	–	118.96 ± 16.97	126.08 ± 47.96	149.38 ± 24.99
SO_4^{2-} , mg l^{-1}	100	14.98 ± 7.78	15.97 ± 9.09	16.00 ± 8.50
Cl^- , mg l^{-1}	300	6.50 ± 3.99	7.37 ± 6.18	6.62 ± 3.39
Ca^{2+} , mg l^{-1}	180	31.22 ± 3.91	33.32 ± 7.75	39.98 ± 2.90
Mg^{2+} , mg l^{-1}	40	7.06 ± 1.31	6.88 ± 1.52	9.52 ± 2.12
K^+ , mg l^{-1}	10	30.10 ± 5.66	23.47 ± 18.53	26.73 ± 21.63
NH_4^+ , mg l^{-1}	0.5	0.41 ± 0.27	0.31 ± 0.21	0.26 ± 0.12
NO_2^- , mg l^{-1}	0.08	0.06 ± 0.09	0.05 ± 0.04	0.05 ± 0.03
NO_3^- , mg l^{-1}	40	1.32 ± 0.40	1.30 ± 0.68	1.21 ± 0.48
PO_4^{3-} , mg l^{-1}	0.2	<0.05	<0.05	<0.05
Fe (total Fe), mg l^{-1}	0.1	0.29 ± 0.27	0.29 ± 0.18	0.22 ± 0.22
Si, mg l^{-1}	–	1.50 ± 0.52	1.00 ± 0.29	1.53 ± 0.44
COD ($\text{K}_2\text{Cr}_2\text{O}_7$), mg l^{-1}	–	33.30 ± 10.42	21.25 ± 5.40	23.80 ± 11.67
COD (KMnO_4), mg O l^{-1}	–	11.56 ± 1.63	15.84 ± 5.82	12.76 ± 4.64
BOD5, mg O l^{-1}	–	1.20 ± 0.80	1.50 ± 0.70	1.80 ± 0.30
Mn^{2+} , mg l^{-1}	0.01	0.08 ± 0.05	0.09 ± 0.04	0.08 ± 0.04
Alkalinity, mEq l^{-1}	–	1.95 ± 0.28	2.36 ± 0.49	2.45 ± 0.41
Hardness, mEq l^{-1}	–	2.14 ± 0.28	2.48 ± 0.26	2.78 ± 0.32

TSS total suspended solids, COD chemical oxygen demand, BOD5 biologic oxygen demand (5 days)

for the analyses of surface waters (Dobroumova, 1978). At the sampling sites some parameters (temperature, pH, conductivity and dissolved oxygen) were measured in situ.

Results

The hydrochemical conditions of the headwaters of the Volga River (Table 4) are determined by the characteristics of the catchment area: the water has intermediate mineralisation and according to the classification of Alekin (1953) it belongs to the

hydrocarbonate class and the Ca type II group (see also Zenin and Belousova, 1988). Several parameters increased along the continuum (e.g. pH 7.72 to 8.03, conductivity 215.17 to 267.50 $\mu\text{S cm}^{-1}$), while other parameters decreased (e.g. colour from 70.67° to 51.80°, ammonium from 0.41 to 0.26 mg l^{-1}); mean values and standard deviations for all assessed parameters are provided (Table 4). The high colour and high concentrations of ammonium, iron and magnesium indicate the influence of geomorphological settings (i.e. mires) in the catchment area (Shaporenko et al., 2006). Considering physico-chemical parameters the Volga River between Rzhev and

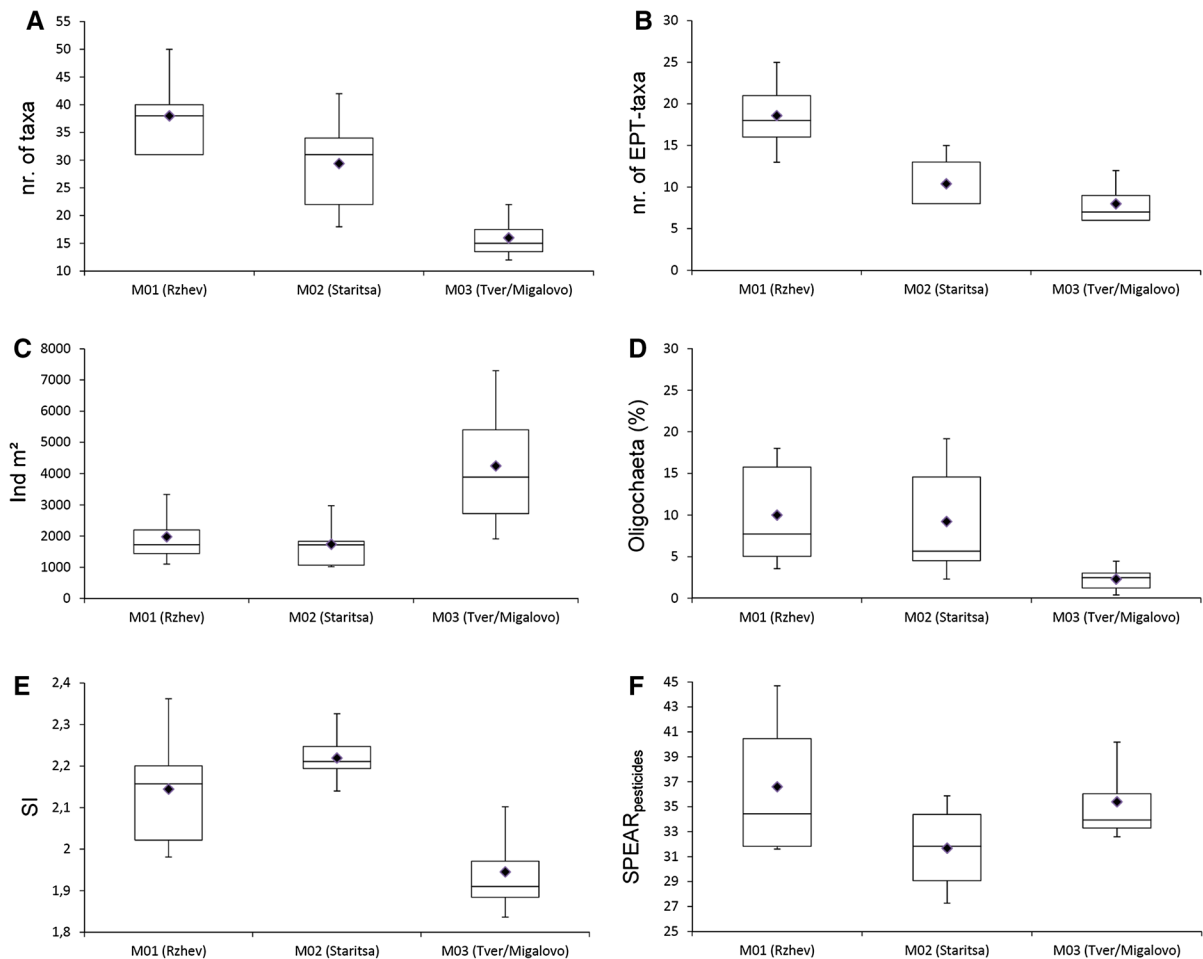


Fig. 3 Box–Whisker Plots of selected community metrics and indices showing their longitudinal pattern and temporal variability (means, 25% percentiles and ranges calculated on the base of the temporal data from the summer low flow period

are given for each of the three sampling sites). **A** number of taxa, **B** number of EPT-taxa, **C** abundance (ind. m⁻²), **D** percentage of Oligochaeta (%), **E** saprobic index, **F** index “SPEAR_{pesticides}”

Tver is in good condition and was classified as “low polluted”.

At the three sampling sites, from 2006 to 2010, a total of 128 macroinvertebrate taxa were identified (Ostracoda, Hydrachnidae, Chironomidae and Oligochaeta were treated as one taxon each), mostly at species level. Additionally Ostracoda (1 taxon), Hydrachnidae (12 taxa), Chironomidae (30 taxa) and Oligochaeta (13 taxa) were determined (see Annex in Supplementary Material). During the summer low flow period the average density of benthic macroinvertebrates was 1,980 ind. m⁻² (range 1,106–3,440) at V-M01 (Rzhev), 1,742 ind. m⁻² (range 1,018–3,076) at V-M02 (Staritsa) and at V-M03 (Tver/Migalovo) 4,244 ind. m⁻² (range, 1,911–7,304). Ephemeroptera

(27 taxa), Coleoptera and Trichoptera (each group had 15 taxa), Gastropoda (13 taxa) and Bivalvia (12 taxa) were the most diverse groups. The average number of taxa at M01 was 33 (±10), at M02 26 (±10) and at M03 16 (±3). The total number of taxa, as well as the number of EPT-taxa decreased along the continuum (Fig. 3). Abundances were quite similar at V-M01 and V-M02 (mean values = 1,980 and 1,742 ind. m⁻², respectively), while they were significantly higher at V-M03 (mean value = 4,244 ind. m⁻²).

Concerning temporal (i.e. inter-annual) variation of the biotic indices (Table 3), it was found that SI was the most stable parameter, as the lowest CV value (coefficient of variation) was 0.07 (site V-M01, Table 5). Similarly, the SPEAR_{pesticides} index was

Table 5 Temporal (year to year) and spatial (site to site) variation of index values (expressed as “coefficient of variation”) during the summer low flow period

	Temporal variation 2006–2010 (summer low flow period)			Spatial variation ^a
	V-M01	V-M02	V-M03	Reference sites 2005
Sites (<i>n</i>)	1	1	1	8
Samples (<i>n</i>)	5	5	4	8
SPEAR _{pesticides}	0.16	0.11	0.11	0.24
SI	0.07	0.05	0.06	0.06
TR	0.21	0.33	0.27	0.35
EPT	0.25	0.32	0.35	0.35
<i>H'</i>	0.06	0.12	0.58	0.25
Evenness	0.03	0.08	0.44	0.27
Abundance	0.46	0.48	0.56	0.74

^a Data from Schletterer & Füreder (2010)

characterized by relatively low CV values (0.16 at V-M01 and 0.11 at V-M02 and V-M03; Table 5), and therefore it appeared to be a stable parameter at the investigated monitoring sites. The highest temporal variation was observed in abundance (CV = 0.56), whereas the SI and SPEAR_{pesticides} were characterized by intermediate variation (Table 5).

The comparison of the temporal variation between the monitoring sites and the spatial variation between eight reference sites investigated in 2005 (Schletterer & Füreder 2010) has shown accordance between these two types of variation (i.e. similar coefficients of variation). The indices characterized by low temporal variability also had low spatial variability (SI, SPEAR_{pesticides}), and vice versa (Abundance, TR, EPT; Table 5). However, the diversity indices *H'* and Evenness had low spatial, but relatively high temporal variability at the site V-M03 (Table 5).

The magnitude of inter-annual differences in abundance (ind. m⁻²) was expressed by the ratio of maximum to minimum densities and were up to 3.11 (V-M01), 3.02 (V-M02) and 3.15 (V-M03), respectively. The magnitude of intra-annual differences (ratio spring:summer) was 2.18 (V-M01), 2.45 (V-M02) and 3.15 (V-M03) in 2007 and 2.99 (V-M01), 0.29 (V-M02) and 0.35 (V-M03) in 2008. In 2008 the densities of benthic invertebrates were higher in spring; however, in general, the higher abundances were observed during the summer low flow period. Temporal dynamics of TR and EPT were similar at the sites investigated (Fig. 4). Richness measures (TR, EPT) were lowest in spring, when the habitats

were instable due to flood peak. The saprobic indices were decreasing at V-M01 and V-M02, mainly due to a higher abundance of Plecoptera that—due to their life cycle—were missing in summer already or present only as immature stages in low densities (e.g. *Amphinemura* spp., *Isoperla* spp., *Diura bicaudata*). However, the extremely low SI at V-M01 in May 2007 is probably an outlier. In contrast at V-M03 saprobity showed a tendency to increase in spring; this might indicate different river types (i.e. gravel dominated vs. sand dominated lowland river). This division is obviously shown by the Shannon diversity index, which is much lower at V-M03 than in the other two sites. This dynamics can be also seen for the index SPEAR_{pesticides}, which increased at V-M01 and V-M02 (= better quality) and decreased at V-M03.

The macroinvertebrate community is dominated by potamophilic species. While Rzhev and Staritsa had similar shares of epipotamal species, at Tver the mean share of epipotamal species was twofold higher, which reflects the longitudinal gradient between the sampling sites (Fig. 5A). Detritivorous feeders were most frequent, however, it seems that they are decreasing slightly along the continuum; also scrapers decreased along the continuum, while active filter feeders (e.g., Trichoptera-like *Hydropsyche* species, *Brachycentrus subnubilus* and *Bivalvia*) as well as predators increased (Fig. 5B). The other functional feedings groups play a minor role in the investigated system.

The faunistic composition of the macroinvertebrate communities at the three monitoring sites is shown in

Fig. 4 Selected community metrics and indices at the three sampling stations (Rzhev, Staritsa, Tver) in the Volga River headwaters from 2006 to 2010

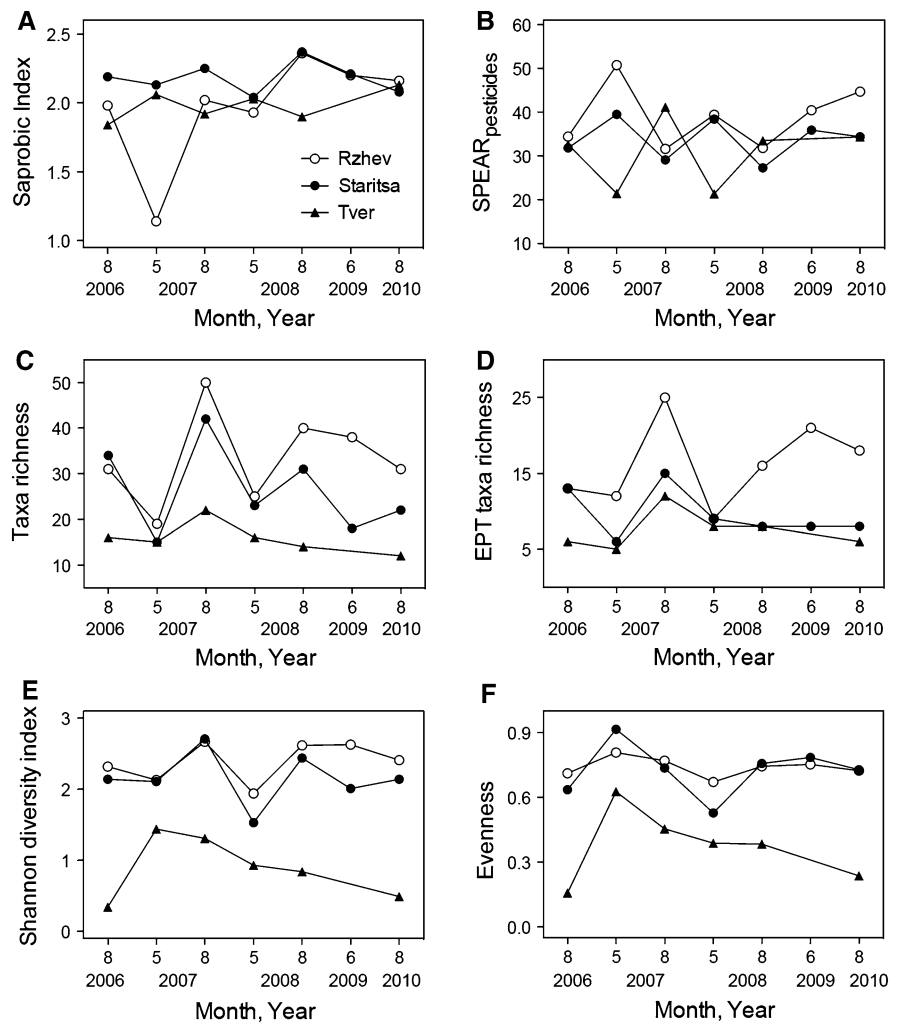


Fig. 6: At V-M01 we found two eudominant taxa (Chironomidae, Oligochaeta), two dominant ones (*Bithynia tentaculata*, Baetidae) and five subdominant ones (*Caenis luctuosa*, *Leuctra fusca*, *Potamanthus luteus*, *Baetis tracheatus*, *Limnius volckmari*). At V-M02 we found two eudominant taxa (Chironomidae, *Bithynia tentaculata*), two dominant ones (Oligochaeta, *Centroptilum luteolum*) and six subdominant ones (*Procladius bifidus*, Corixidae, Baetidae, *Cloeon dip-terum*, *Helobdella stagnalis*, *Caenis luctuosa*). At V-M03 we found one eudominant (Chironomidae) and four subdominant taxa (*Pisidium amnicum*, Oligochaeta, *Gmelinoides fasciatus*, *Baetis digitatus*).

Discussion

The free-flowing section between the Upper Volga Lakes and Tver was previously characterised as a refugium for the potamal fauna (Schletterer & Füreder, 2010). In the present paper we give information on the variation in functional aspects and bioindices. Seasonal changes and differences of macroinvertebrate communities at reference sites were described to be small (Zamora-Muñoz and Alba-Tercedor, 1996) or large (Furse et al., 1984), depending on the investigated systems. For the description of natural conditions it is essential to measure and describe the natural

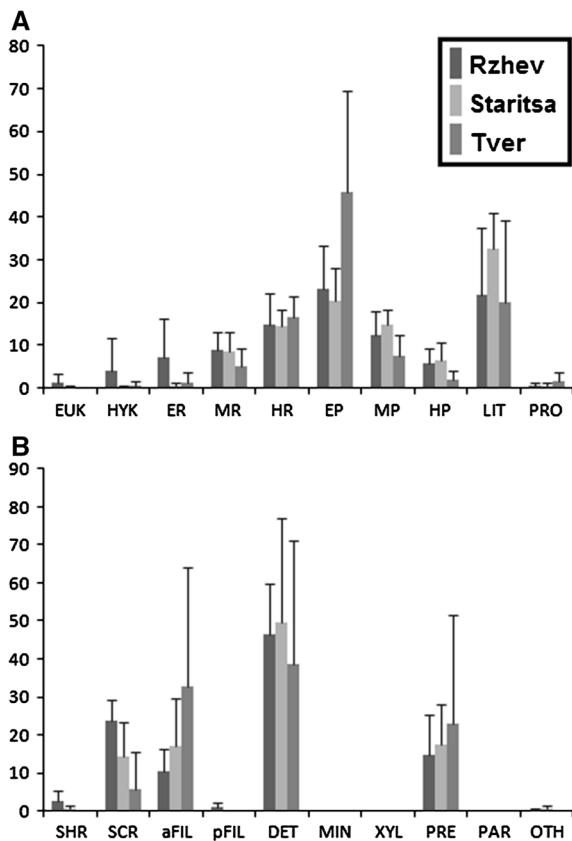


Fig. 5 **A** Longitudinal zonation (EUK/HYK eucrenal/hypocrenal, ER/MR/HR epi-/meta-/hyporhithral, EP/MP/HP epi-/meta-/hypopotamal, LIT littoral, PRO profundal). **B** Functional feeding types (SHR shredders, SCR scrapers, aFIL/pFIL active/passive filter feeders, DET detritivore collectors, MIN miners, XYL xylophagous taxa, PRE predators, PAR parasites, OTH other feeding types); summarized for the three monitoring sites (2006–2010, summer low flow period, mean values + standard deviation)

variation of biota in pristine water bodies (Nijboer et al., 2006). The system investigated has specific hydrochemical features, due to the geomorphological settings in the catchment area. The high share of huminic acids in the natural surface waters is reflected, among others, by high ammonium and COD loads which decrease along the investigated continuum. A COD (bichromate) level in the range of 4–50 mg O l⁻¹ is common in natural running waters in the Tver region (Yablokov, 1973).

The observed inter-annual variations of the macroinvertebrate community, especially its abundance, are related to annual variations in environmental factors. For example, the summer 2010 was extremely hot, with high water temperatures and low water

levels. In general, variations could be also due to processes within the macroinvertebrate population, e.g. introduction of neozoa (Arbačiauskas et al., 2008). Temporal changes in the abundance of benthic invertebrates were strongly influenced by environmental factors (i.e. flood events in spring) as well as the life cycles of the species and their emergence patterns (for example *Diura bicaudata* and *Amphinemura borealis* in May). Taxon richness and abundance of benthic invertebrates generally increased during the summer low flow period due to increasing habitat stability. Similar observations were shown earlier (e.g. Boyero et al., 2005). Invertebrate densities showed high variation, which is generally associated with the fact that abundance measures are seldom used in multi-metric approaches (Barbour et al., 1999). Richness measures (TR and EPT) appeared to be less variable and provided a comparable diversity metric for assessing perturbation (e.g. Resh et al., 1995; Wallace et al., 1996).

Considering functional feeding groups the benthic communities were dominated by detritivores. The percentage of shredders and scrapers decreased in the free-flowing section between V-M01 and V-M03, while predators increased. Active filter feeders (e.g. Porifera, Bivalvia) and passive filterers (e.g. Simuliidae, Hydropsychiidae) were well represented and increased downstream along the investigated stretch. The investigated lowland river system has a pronounced proportion of detritivores. We were able to show that the active filter feeders (i.e. higher FPOM availability) and predators (i.e. higher consumer levels) increased and shredders (i.e. restricted availability of CPOM) decreased in their relative abundance along the continuum. This is in accordance with general river concepts (Petts & Calow, 1996), represented by a reach/section specific composition of feeding guilds (Vannote et al., 1980). Thus the inclusion of TR, diversity and functional community parameters, as it was done for Central European Water courses (Böhmer et al., 2004), is also needed to develop metrics for East European lowland rivers. In the Russian Federation, monitoring of biological parameters is included in the “State Service of Observation and Control of Environmental Pollution” (prior 1992 = OGSNK, since 1992 = GSN), which is run by the Federal Service of Russia for Hydrometeorology and Environmental Monitoring (Roshydromet). Zhulidov et al. (2001) underlined the need of a

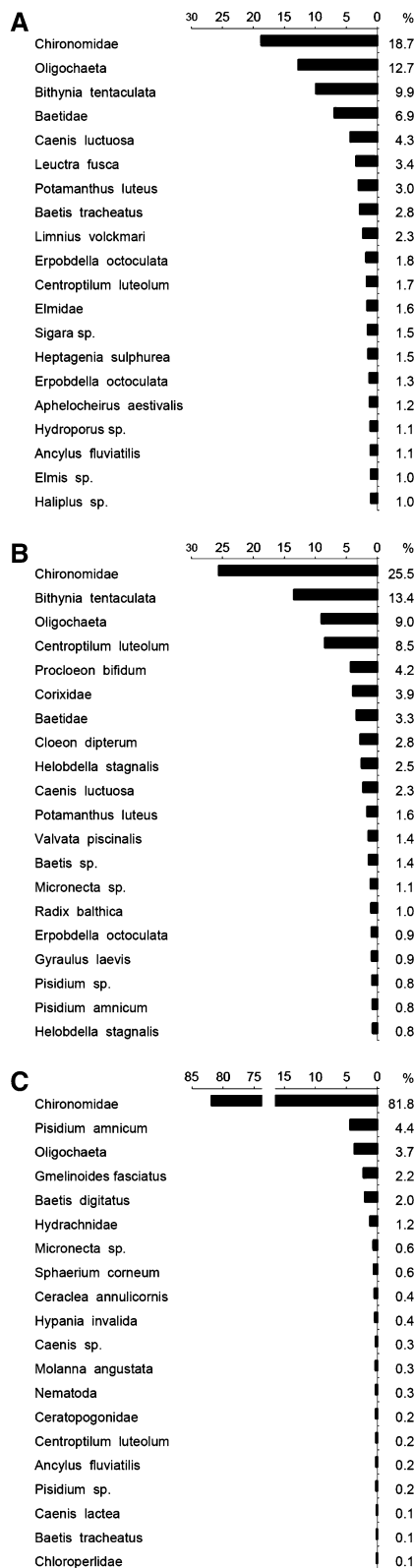


Fig. 6 Faunistic composition at the three monitoring points (relative abundance of the 20 most common taxa, mean values for the summer low flow period, 2006–2010): **A** Rzhev, **B** Staritsa, **C** Tver

flexible monitoring system with a focus on water quality management. Concerning the biological quality element “zoobenthos”, standards (GOST 1977, 1982) should be refined. Thus we recently suggested the use of SI, SPEAR_{pesticides} and the ITC for surface water monitoring in the Tver region (Schletterer et al., 2011), which may stipulate decisions on future monitoring programmes.

We described the headwaters of the Volga River recently as a unique system to define reference conditions for medium-sized and large rivers in Europe, and to investigate the coherence of bioassessment indices with respect to important environmental factors (Schletterer & Füreder 2010). In the present study we provided data from the first 5 years (2006–2010) of the monitoring programme, which was established on the basis of the expedition in 2005. During the monitoring programme a couple of rare species with high conservation value on a European Scale (e.g. *Unio crassus*, *Myxas glutinosa*, *Potamanthus luteus*, *Prosopistoma pennigerum*, *Isoperla obscura*, *Xanthoperla apicalis*, *Aphelocheirus aestivalis* and others) were recorded. The actual national red book (Iliashenko & Iliashenko, 2000), as well as the red book of the Tver region (Sorokin, 2002), is hardly considering benthic invertebrates. The inclusion of the faunistic data into future red book versions and the elaboration of specific conservation strategies for this kind of freshwater habitats in Eastern Europe is essential, before their biodiversity gets lost.

The paper presented data on inter-annual and intra-annual, as well as spatial differences within macroinvertebrate communities in the headwaters of the Volga River. Lowland rivers are dynamic systems concerning their zoobenthos communities and environmental conditions and should be of special concern in research and management. In the headwaters of the Volga River seasonal changes in the hydrological and hydrochemical regime are driven by natural factors based on different water sources, i.e. snow-melt versus groundwater (Schletterer & Kuzovlev, 2012). The spatial heterogeneity in the main channel, as well as its

pristine tributaries, provides diverse habitats for the biota and thereby ensures the overall ecosystem health (sound functionality) and biodiversity.

Acknowledgments We would like to acknowledge Dr. Reinhard Gerecke (University of Tübingen, Germany) for determination of water mites and Dr. Santiago Gaviria-Melo (University of Vienna, Austria) for determination of Ostracoda. Thanks to K.Y. Zhenikov (Tver State Technical University), A.B. Komissarov (Russian Academy of Sciences) and Mag. H. Mildner (Kärntner Institut für Seenforschung, Austria) for support during sampling and analyses, Dr. M.A. Beketov (UFZ–Helmholtz Centre for Environmental Research, Leipzig, Germany) as well as the reviewers for valuable comments on the manuscript. The first author was supported by scholarships of the University of Innsbruck („Kurzfristige wissenschaftliche Arbeiten im Ausland“; 2008, 2009) and a scholarship granted by the Rotary Club Innsbruck („Forschungstipendium des Rotary Club Innsbruck“, 2010).

References

- Alekin, O. A., 1953. *Osnovy gidrochimii* [Основы гидрохимии], Leningrad: 295 pp.
- Arbačiauskas, K., V. Semenchenko, M. Grabowski, R. Leuven, M. Paunović, M. O. Son, B. Csányi, S. Gumuliauskaitė, A. Konopacka, S. Nehring, G. van der Velde, V. Vezhnovetz & V. E. Panov, 2008. Assessment of biocontamination of benthic macroinvertebrate communities in European inland waterways. *Aquatic Invasions* 3: 211–230.
- Barbour, M. T., J. Gerritsen, B. D. Snyder & J. B. Stribling, 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, 2nd ed. EPA/841-B-98-010. U.S. EPA. Office of Water, Washington, DC.
- Beketov, M. A., 2009. SPEAR (pesticide) pinpoints pollution in minutes. *TrAC-Trends in Analytical Chemistry* 28: III–IV.
- Birk, S., J. Böhmer, F. Schöll & B. König, 2011. Typology of European large rivers based on benthic invertebrate fauna—summary of methods and results. Report to CIS ECOSTAT (XGIG Large River Intercalibration Exercise): 13 pp.
- Böhmer, J., C. Rawer-Jost & A. Zenker, 2004. Multimetric assessment of data provided by water managers from Germany: assessment of several different types of stressors with macrozoobenthos communities. *Hydrobiologia* 516(215–228): 2004.
- Boyer, L., M. Valladolid & M. Arauzo, 2005. Dynamics of invertebrate benthic communities and drift in a regulated river of Central Spain. *International Review of Hydrobiology* 90: 392–411.
- Chessman, B. C. & M. J. Royal, 2004. Bioassessment without reference sites: use of environmental filters to predict natural assemblages of river macroinvertebrates. *Journal of the North American Benthological Society* 23: 599–615.
- Directive 2000/60/EC of the European parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of European Union L327: 72 pp.
- Dobroumova, G. G., 1978. *Unifitsyrovannyye metody analiza vod SSSR*. Gidrometeoizdat, Leningrad: 144 pp. (in Russian).
- Ehlert, T., D. Hering, U. Koenzen, T. Pottgiesser, H. Schuhmacher & G. Friedrich, 2002. Typology and type specific reference conditions for medium sized and large rivers in North Rhine-Westphalia: biological aspects. *International Review of Hydrobiology* 87: 151–163.
- Furse, M. T., D. Moss, J. F. Wright & P. D. Armitage, 1984. The influence of seasonal and taxonomic factors on the ordination and classification of running-water sites in Great Britain and on the prediction of their macro-invertebrate communities. *Freshwater Biology* 14: 257–280.
- GOST, 1977. 17.1.2.04-77: Nature protection. Hydrosphere. Procedures for quality control of water in reservoirs and stream flows. State standard of the Russian Federation (in Russian).
- GOST, 1982. 17.1.3.07-82: Nature protection. Hydrosphere. Procedures for quality control of water in reservoirs and stream flows. State standard of the Russian Federation (in Russian).
- Gravenhorst, G., G. Kiely, A. Tishenko, V. P. Zvetkov, J. Cermak & J. Gurtz, 2000. The response of the water flows of the boreal forest region at the Volga's source area to climatic and land-use changes (Volgaforest), Final report: EU-Project INCO—COPERNICUS.
- Hering, D., A. Buffagni, O. Moog, L. Sandin, M. Sommerhauser, I. Stubauer, C. Feld, R. Johnson, P. Pinto, N. Skoulidakis, P. Verdonchot & S. Zahradkova, 2003. The development of a system to assess the ecological quality of streams based on macroinvertebrates—design of the sampling programme within the AQEM project. *International Review of Hydrobiology* 88: 345–361.
- Humpesch, U. H. & J. M. Elliott (eds), 1990. Methods of biological sampling in a large deep river—the Danube in Austria. *Wasser und Abwasser Supplement 2*: 83 pp.
- Iliashenko, V. Yu. & E. I. Iliashenko, 2000. *Krasnaya kniga Rossii: pravovye akty* [Red Book of Russia: legislative acts]. State committee of the Russian Federation for Environmental Protection, Moscow: 143 pp. (in Russian).
- Illies, J. (ed.) 1978. *Limnofauna Europaea*. A Checklist of the Animals Inhabiting European Inland Waters with Account of Their Distribution and Ecology (Except Protozoa). Gustav Fischer Verlag, Stuttgart: 532.
- Klimo, E. & H. Hager (eds), 2001. *The Floodplain Forests in Europe. Current Situation and Perspectives*. Brill Publishers, Leiden.
- Krever, V., E. Dinerstein, D. M. Olson & L. Williams, 1994. *Conserving Russia's Biological Diversity: An Analytical Framework and Initial Investment Portfolio*. WWF, Washington, DC.
- Kuzovlev, V. V. & M. Schletterer, 2006. Upper Volga Expedition 2005—Technical Report. *Proceedings of Freshwater Research* 1: 1–140.
- Lenat, D. R., 1988. Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. *Journal of the North American Benthological Society* 7: 222–233.
- Mangelsdorf, J., K., Scheurmann & F. Weiss, 1990. *River Morphology, A Guide for Geoscientists and Engineers*. Springer, Berlin: 243 pp.

- Marcinek, J., 1978. Das Wasser des Festlandes. Gotha. 3. Auflage: 198 pp.
- Moog, O. (ed.), 2002. Fauna Aquatica Austriaca, Lieferung 2002, 2nd ed. Wasserwirtschaftskataster, Bundesministerium für Land-und Forstwirtschaft, Umwelt und Wasserwirtschaft, Wien [available on internet at <http://www.wassernet.at/filemanager/download/6626/>].
- Moss, B., 2010. Ecology of Freshwaters: A View for the Twenty-First Century, 4th ed. Wiley-Blackwell, Oxford.
- Nijboer, R. C., R. K. Johnson, P. F. M. Verdonschot, M. Sommerhauser & A. Buffagni, 2004. Establishing reference conditions for European streams. *Hydrobiologia* 516: 91–105.
- Nijboer, R., P. Verdonschot, A. Piechocki, G. Tończyk & M. Klukowska, 2006. Characteristics of pristine Polish river systems and their use as reference conditions for Dutch river systems. *Alterra-rapport* 1367: 1–221.
- Normativy kachestva vody vodnykh ob'ektov rybohozyaistvennogo znacheniya, 2010. Prikaz Rosrybolovstva 18.01.2010 N.20.
- Ofenböck, T., O. Moog, J. Gerritsen & M. Barbour, 2004. A stressor specific multimetric approach for monitoring running waters in Austria using benthic macro-invertebrates. *Hydrobiologia* 516: 251–268.
- Olson, D. M., E. Dinerstein, E. D. Wikramanayake, N. D. Burgess, G. V. N. Powell, E. C. Underwood, J. A. D'Amico, I. Itoua, H. E. Strand, J. C. Morrison, C. J. Loucks, T. F. Allnutt, T. H. Ricketts, Y. Kura, J. F. Lamoreux, W. W. Wettengel, P. Hedao & K. R. Kassem, 2001. Terrestrial ecoregions of the world: a new map of life on earth. *BioScience* 51: 933–938.
- Pardé, M., 1964. Fleuves et rivières. Coll. Armand Colin, Nr. 155, 4th edition: 223 pp.
- Petts, G. & P. Calow, 1996. River Biota, Diversity and Dynamics. Blackwell, Oxford: 1–257.
- REFCOND, 2003. Guidance on establishing reference conditions and ecological status class boundaries for inland surface waters. Final Report of the Working Group 2.3 (EU Common Implementation Strategy (CIS) for the Water Framework Directive): 86 pp.
- Resh, V. H., R. H. Norris & M. T. Barbour, 1995. Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. *Australian Journal of Ecology* 20: 108–121.
- Schletterer, M. & L. Füreder, 2009. The family Prosopistomatidae (Ephemeroptera): a review on its ecology and distribution, with particular emphasis on the European species *Prosopistoma pennigerum* Müller, 1785. *Aquatic Insects* 31(Suppl. 1): 603–620.
- Schletterer, M. & L. Füreder, 2010. The River Volga headwaters: inventory, biodiversity and conservation. *River Systems* 19(1): 15–32.
- Schletterer, M. & V. V. Kuzovlev, 2007. First record of *Prosopistoma pennigerum* from the Russian Federation (Ephemeroptera: Prosopistomatidae). *Zoosystematica Rossica* 16: 169–172.
- Schletterer, M. & V. V., Kuzovlev, 2012. Documentation of the presence of *Gmelinoides fasciatus* (Stebbing, 1899) and the native benthic fauna in the Volga River at Tver (Tver Region, Russia). *Aquatic Insects* 34(1): 139–155.
- Schletterer, M., M. Schönhuber & L. Füreder, 2011. Biodiversity of diatoms and macroinvertebrates in an east European lowland river, the Tudovka River (Tver Region, Russia). *Boreal Environment Research* 16: 79–90.
- Schmidt-Kloiber, A. & R. Vogl, 2010. Ecoprof—Handbuch zur version 3.2 9 [available on internet at <http://www.ecoprof.at/>].
- Shannon, C. E., 1948. A mathematical theory of communication. *Bell System Technical Journal* 27: 379–423.
- Shaporenko, S. I., V. V. Kuzovlev & I. I. Terentyev, 2006. Hydrological and hydrochemical investigations on the Upper Volga River. In: Kuzovlev, V. V. & M. Schletterer (eds), *Upper Volga Expedition 2005—Technical Report, Proceedings of Freshwater Research*, Vol. 1, DAV: 15–75.
- Shiklomanov, I. A., 1999. World Water Resources and their use—a joint SHI/UNESCO product [available on internet at <http://webworld.unesco.org/water/ihp/db/shiklomanov/>].
- Sokal, R. R. & F. J. Rohlf, 1998. Biometry. Freeman, New York.
- Sorokin, A. S. (ed.), 2002. Red Book of Tver Region. ANTEK Press, Tver: 254 pp. (in Russian).
- Stanner, D. & P. Bordeau, 1995. Europe's Environment: The Dobbris Assessment. European Environment Agency, Luxembourg: 712 pp.
- Stewart-Oaten, A., W. W. Murdoch & K. R. Parker, 1986. Environmental impact assessment: pseudoreplication in time? *Ecology* 67: 929–940.
- Surina, Z. S. (ed.), 1976. Resursy poverkhnostnykh vod SSSR, T. 10. Verhne-Volzhskiy Rayon [Resources on surface waters of the USSR. Vol. 10. The Upper-Volga area]. Gidrometeoizdat, Moscow: 536 pp (in Russian).
- Thorp, J., M. C. Thoms & M. D. Delong, 2006. The riverine ecosystem synthesis: biocomplexity in river networks across space and time. *River Research and Applications* 22: 123–147.
- Tockner, K. & J. A. Stanford, 2002. Riverine floodplains: present state and future trends. *Environmental Conservation* 29: 308–330.
- Tockner, C., C. T. Robinson & U. Uehlinger (eds), 2009. Rivers of Europe. Academic Press, London.
- Uhel, R., A. Meiner, P. Bosch, P. Saunders, A. Kostin, A. Sochirca, N. Perritaz, A.D. Hansen, C. Colliander Golding & C. Islev (eds), 2003. Europe's environment: the third assessment. Environmental assessment report No. 10, European Environment Agency (EEA).
- Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell & C. E. Cushing, 1980. The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130–137.
- Vladimirov, V. A., 1997. Case Study X—Moscow Region, Russia. In: Helmer, R. & I. Hespanhol (eds), *Water Pollution Control—A Guide to the Use of Water Quality Management Principles*. Thomson Professional, London.
- von Tümpling, W. & G. Friedrich, 1999. Methoden der biologischen Wasseruntersuchung. Vol. 2, Chapter: Makrozoobenthos. Gustav Fischer Verlag, Jena: 133–153.
- Wallace, J. B., J. W. Grubaugh & M. R. Whiles, 1996. Biotic indices and stream ecosystem processes: results from an experimental study. *Ecological Applications* 6(1): 140–151.

- Yablokov, Y. E. & T. I. Zorova (eds), 1967. *Resursy poverkhnostnykh vod SSSR, T. 10. Verhne-Volzhskiy Rayon* [Resources on surface waters of the USSR. Vol. 10. The Upper-Volga area], Gidrometeoizdat, Moscow: 768 pp. (in Russian).
- Yablokov, Y. E. (ed.), 1973. *Resursy poverkhnostnykh vod SSSR, T. 10. Verhne-Volzhskiy Rayon* [Resources on surface waters of the USSR. Vol. 10. The Upper-Volga area], Gidrometeoizdat, Moscow: 474 pp. (in Russian).
- Zamora-Muñoz, C. & J. Alba-Tercedor, 1996. Bioassessment of organically polluted Spanish rivers, using a biotic index and multivariate methods. *Journal of the North American Benthological Society* 15: 332–352.
- Zelinka, M. & P. Marvan, 1961. Zur Prazisierung der biologischen Klassifikation der Reinheit fließender Gewässer. *Archives of Hydrobiology* 57: 389–407.
- Zenin, A. A. & H. B. Belousova, 1988. *Gidrokhimicheskii slovar* [Гидрохимический словарь]. Gidrometeoizdat, Leningrad: 274 pp. (in Russian).
- Zhulidov, A. V., R. D. Roberts & V. V. Khlobystov, 2001. The need and requirements for modernizing surface water quality monitoring in the Russian Federation. *Water International* 26(4): 536–546.