

**REFCOND\_VOLGA: a monitoring programme for water quality in the headwaters of the Volga River (Tver region, Russia)****REFCOND\_VOLGA: um programa de monitoramento da qualidade da água nas cabeceiras do rio Volga (região de Tver, Rússia)****Martin Schletterer**

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**Abstract**

Within the research expedition "Upper Volga 2005" an assessment of hydrological, hydrochemical and biological parameters was carried out in the Volga River upstream of Tver, including the main channel as well as major tributaries. This assessment revealed that the headwaters of the Volga River represent conditions which are either reference or least disturbed and stipulated the establishment of the monitoring programme "REFCOND\_VOLGA", which is in operation since 2006 and includes stretches along the Volga River (Rzhev, Staritsa, Tver) as well as along the tributary Tudovka. This paper summarizes the "first 10 years" of this joint Russia-Austrian research project, focusing on a sound description of the research area and providing a complementary view on the available data as well as a view ahead.

**Keywords:** European lowland river, Ecoregion 16 – Eastern Lowlands, long-term ecosystem research and monitoring (LTERM).

**Resumo**

Como parte da expedição de pesquisa "Upper Volga 2005" uma avaliação dos parâmetros hidrológicos, hidroquímicos e biológicas foi realizada no rio Volga a montante de Tver, incluindo o canal principal, bem como principais afluentes. Esta avaliação revelou que as cabeceiras do rio Volga representam condições que são referência ou minimamente perturbadas e estipulou o estabelecimento do programa de monitorização "REFCOND\_VOLGA", o qual está em operação desde 2006 e inclui trechos ao longo do rio Volga (Rzhev, Staritsa, Tver), bem como ao longo do tributário Tudovka. Este artigo resume os "primeiros 10 anos" deste projeto de investigação Rússia-austriaca conjunta, concentrando-se em uma descrição detalhada da área de pesquisa e fornecendo uma visão complementar sobre os dados disponíveis, bem como uma visão de futuro.

**Palavras-chave:** rio Europeu de planície, Ecorregião 16 – Planícies orientais, pesquisa e monitoramento de longa duração em ecossistemas.

## INTRODUCTION

According to the European Water Framework Directive (WFD) the hydro-morphological quality-components for rivers are (1) hydrology (discharge patterns and connection of the surface water body to aquifers), (2) riverine morphology (depth and width variation, bottom substratum and the structure of littoral / banks) and (3) the patterns according to longitudinal fish migration. Many aspects play an important role for riverine morphology (DAVY-BOWKER; FURSE, 2006), such as sedimentation processes (MIDDELKOOP; ASSELMAN, 1998; MIDDELKOOP *et al.*, 2005), wood in rivers (GURNELL *et al.*, 1995; KAIL, 2003) and riparian vegetation (PERUCCA *et al.*, 2008). Some research projects on European scale concentrated on this topic (e.g. FURSE *et al.*, 2006). Assessing the habitat quality in river systems, became an important tool in aquatic ecology (RAVEN *et al.*, 2002), and the WFD requires the assessment of hydro-morphological parameters to distinguish “undisturbed” from “heavily modified” running waters. On a European scale the RHS (River Habitat Survey) is a common instrument to assess hydromorphology (GIBBS, 2003; ERBA *et al.*, 2006). WFD implementation groups such as ECOSTAT have developed objective criteria for the establishment of reference conditions for various purposes (WALLIN *et al.*, 2003).

For the assessment of the ecological quality of a running water (i.e. surface water body), the WFD puts a focus on biological components: based on phytobenthos, phytoplankton, macrophytes, zoobenthos and fish the ecological integrity of a system is determined, describing the status according to a deviation from a defined reference condition. Recently assessment methods and evaluation procedures were modified and developed to overcome this task, but the issue of large rivers is one that is not resolved yet.

Nowadays, different classifications based on length, catchment size, channel width and hydrologic regime exist (PARDÉ, 1964; MARCINEK, 1978; MANGELSDORF,

*et al.*, 1990) and there is disagreement on this question among scientists. The World Meteorological Organization characterizes rivers with a mean annual discharge (MQ) at the mouth  $> 2,000 \text{ m}^3/\text{s}$  or with a catchment area  $> 500,000 \text{ km}^2$  as large (WMO 2006). A review of different classifications was done by GUPTA (2008). According to his findings, river length and / or catchment size are a common measure for large rivers (e.g. DYNESIUS; NILSSON 1994, HOVIUS, 1998). POTTER (1978) identified the world's 50 largest rivers, using catchment size, length, discharge and volume of sediment transported – but data on the last 2 criteria is often hardly available. The included rivers cover 47 % of the earth's land mass (excluding Greenland and Antarctica) and the smallest catchment size was  $105 \text{ km}^2$  and the length exceeded 1000 km. LEOPOLD *et al.*, (1964) and POTTER (1978) showed only a relation between river length and catchment area, but not for other variables. MEADE (1996) listed the largest 25 rivers on the basis of water and sediment discharges (at the mouth). However, some large rivers in terms of discharge may have low sediment loads (e.g. Lena, Volga) or anthropogenically reduced sediment regime due to impoundments (e.g. Mississippi, Nile). Thus MIALI (2006) pointed out to use historical data in order to classify “large rivers”. In Europe the discussion is stipulated by the implementation of WFD, which classifies rivers with a catchment area larger than  $10,000 \text{ km}^2$  as large rivers, however according to the WFD these would even be “very large rivers” which is in line with DYNESIUS; NILSSON (1994).

The reference condition approach (comparison of a given site with a pristine reference site) is today an important method for bioassessments in Europe. Thus during the last decade for most types of running waters, reference conditions were defined. However, for large river systems it turned out to be problematic, since these types are affected by several anthropogenic stressors throughout Europe (EHLERT *et al.*, 2002, NIJBOER *et al.*, 2004, MORENO *et al.*, 2006).

A possible approach to overcome this problem is the use of reference conditions from other geographical regions having low population density and minor anthropogenic impacts, but a comparable ecology (NIJBOER *et al.*, 2004). In this context “go East” might be the solution, as some areas in Eastern Europe remained least contaminated due to low population density and little land-use pressure, providing pristine or near-natural lowland rivers (BIRKE; LORENZ 2006; SCHLETTERER, 2006).

Already in the middle of the 1990ties scientists from Tver State Technical University, started investigations of physico-chemical conditions along River Tudovka (Tver Region, Nelidovo Rayon). This river was selected, because (1) a major part of its catchment is protected, (2) there are only very little anthropogenic impacts and (3) with its paludified catchment is a typical river in this region. Hydrobiological assessments started in 2005, when during the expedition “Upper Volga 2005”, samples were taken at the mouth of this river into Volga. We decided to intensify the investigations along river Tudovka and selected six stations along the course of this pristine river for hydrobiological investigations. On the one hand the longitudinal zonation of biozooenosis of this river and on the other hand reference coenosis were investigated (ZHENIKOV *et al.*, 2007).

The expedition “Upper Volga 2005” was carried out in August 2005 by scientists from the Russian Academy of Science, Tver State Technical University, Tver State University and the University of Innsbruck. This assessment was a unique possibility for a detailed investigation of hydrology, hydrochemistry and hydrobiology in the headwaters of Europe's largest river (KUZOVLEV; SCHLETTERER, 2006). This assessment showed that the headwaters of the Volga River represent conditions which are either reference or least disturbed and stipulated the establishment of the monitoring project “REFCOND\_VOLGA”, which is in operation since 2006 and includes stretches along the Volga River

(Rzhev, Staritsa, Tver) as well as along the tributary Tudovka (Fig. 01, Fig. 02). The following research questions were considered by SCHLETTERER (2009):

- What are the ecological factors in lowland rivers?
- Biodiversity in East European Rivers?
- Where are reference sites for lowland rivers?
- Water quality assessment in Western Russia: which refinements and adaptations will be needed?

On this basis the following research topics, regarding the ongoing monitoring programme, were defined:

- Long term monitoring to analyse the ecology of rivers in the Eastern lowlands
- Seasonal and temporal variability at reference sites and LDC
- Hydromorphological conditions & habitat availability
- Climate change: linking temperature & biota

Herein summarize the “first 10 years” of this joint Russia-Austrian research project, focusing on a sound description of the research area and providing a complementary view on the available data as well as a view ahead.

## RESEARCH AREA

The following sections about the research area (i.e. biogeography, headwaters of the Volga River and geological setting) were compiled from KUZOVLEV and SCHLETTERER (2006) and SCHLETTERER (2009).

### Biogeography

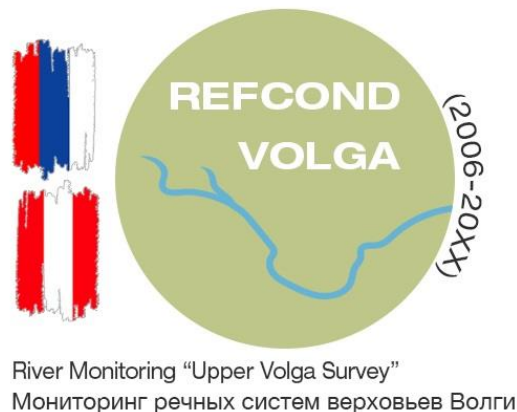
ILLIES (1978) defined 25 (+ 2 additional) European Ecoregions, due to zoogeographical reasons. The headwaters of the Volga River are located in the ecoregion 16. The boundaries of the area are described by ILLIES: “*Ecoregion 16 – Eastern Lowlands: The area includes Vistula (beyond the Carpathian Mountains)*”

and great reaches of Dnjestr, Dnjepr, Don, Volga, the Rokitno swamps as well as the russian and ukrainian uplands. In the North the area is terminated by the Baltic (Area 15) and the Taiga (Area 23), in the East by Ural Mountains and the southern border is above Don and Volga.” Despite of this definition it has to be considered, that an exact demarcation is not possible due to diffuse distribution and migration of organisms (MOOG *et al.*, 2001); thus the ecoregions should be understood as areas with diffuse borders.

On national level, in Russia 14 bioregions were designated (KREVER *et al.*, 1994), and the headwaters of Volga

River are located in the bioregion 2 “Kola-Karelian & Eastern European Forest”. Concerning the terrestrial ecoregions, as defined by the WWF (World Wildlife Fund), the headwaters of Volga are located in ecoregion PA0346 “Sarmatic mixed forests” and partly (i.e. parts of the Tvertsa catchment) in the ecoregion PA0608 “Scandinavian and Russian taiga” (OLSON *et al.*, 2001). Within the European biogeographical regions the research area is located in the boreal region, which is characterised by coniferous forest and the climate is cool and mainly continental and among the largest biogeographical regions of Europe (UHEL *et al.*, 2003).

**Figure 1: Logo of the joint Russia-Austrian monitoring programme “REFCOND VOLGA”**



#### Headwaters of the Volga River

The headwaters of the Volga River (Fig. 02) are located in the political province “Tverskaya Oblast” (capital Tver, former Kalinin), which spreads over 84.586 km<sup>2</sup> of gently undulating landscape (sea level < 300 m), with temperate deciduous and mixed forests. The moderate continental climate indicates a mean temperature in January of -9,5°, in June 17,5° and a precipitation of about 650 mm per year (GRAVENHORST *et al.*, 2000) with a mean annual temperature of about 5.8°C (GURTZ *et al.*, 1999). The research area is located near the southern border of the “Dfc-climate” (PEEL *et al.*, 2007), which covers northern Russian and Western Siberia: D indicates that the coldest month has an

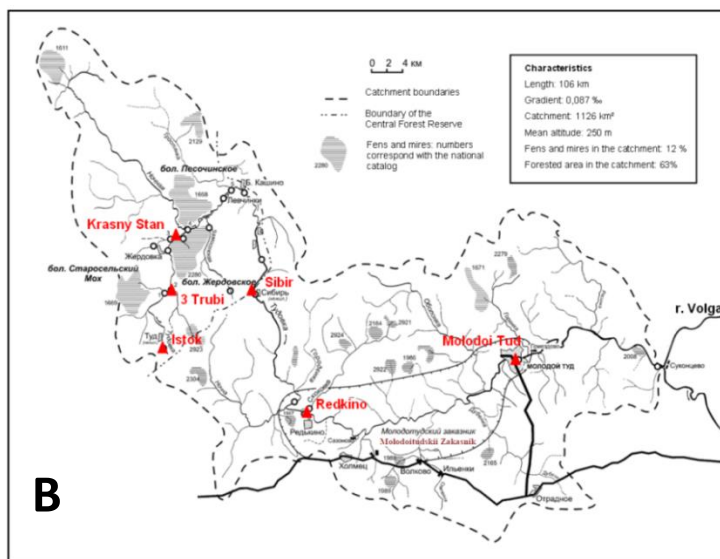
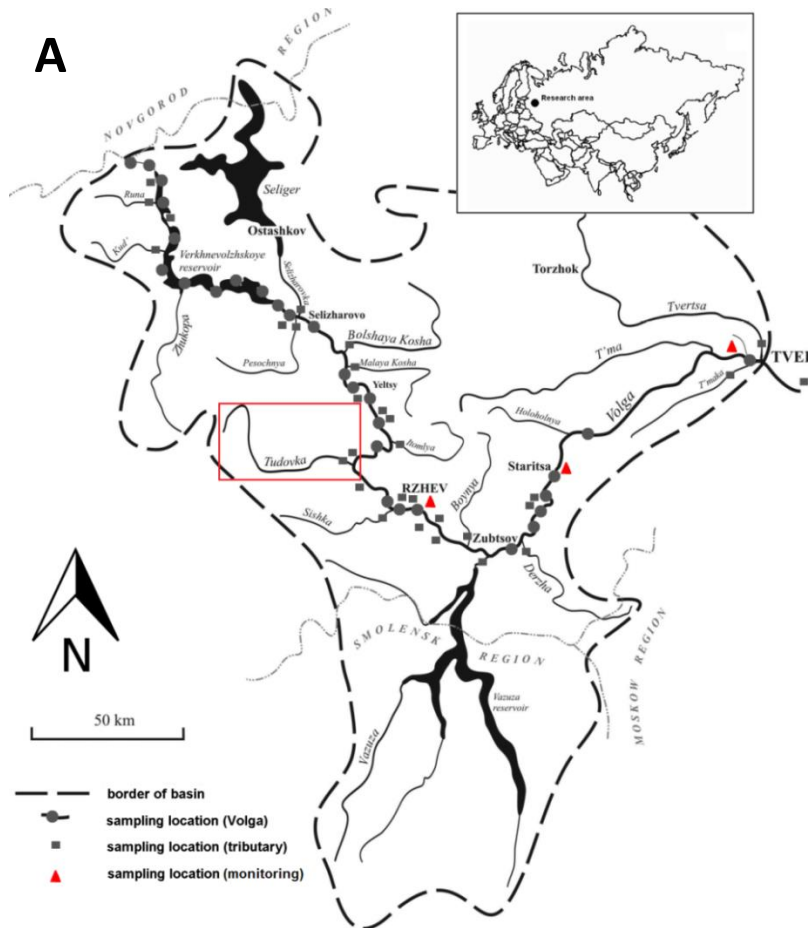
average temperature below -3°C (i.e. “Schneewaldklima”), f indicates that all months are humid and c indicates that the summer is cold/mild with only one to three months with an average temperature above 10 °C. In Tver region there is the northernmost distribution of oaks, though it can be considered as climatic border, since further south the “Dfb-climatezone” (typical oak-climate) follows, with at least four months with an average temperature above 10 °C.

The territory is drained by three big watersheds, the Western Dvina which drains to the Baltic Sea, the Dnepr watershed which drains to the Black Sea and the Volga River which drains to the Caspian Sea. The Volgo-Caspic watershed (basin of Volga and Ural) is one of the 10

main hydrographic rayons within the Russian Federation. The rivers in the headwaters of the Volga are fed by melt water and summerfall precipitation and their

regime is characterised by floods in spring (March-May), accounting for up to 60 % of the annual discharge, and summer low-flow period (VLADIMIROV, 1997).

**Figure 2: A - Headwaters of the Volga River including sampling locations from the expedition in 2005 as well as the monitoring stations; B - tributary Tudovka in detail**



The Volga River and Moskva River, as well as some of their tributaries play an important role for the water supply of Moscow (MOSVODOKANAL, 2005) - for more than 11 million people, industry and environment. Since the construction of the water resource system (WRS) for Moscow City Agglomeration, it is using mainly surface water, which caused a radical change in the natural hydrological regime of surface and ground waters. From the Volga River about 82 m<sup>3</sup>/s are taken from Ivankovskoe reservoir for the water supply of Moscow.

Actually, Moscow's WRS is working with a 97 % reliability and pumps in total approximately 133 m<sup>3</sup>/s. About 1/3 of this water (48 m<sup>3</sup>/s) is used for environmental purposes (adding water to the Moskva, Klyazma and Yauza River) (VASILIEV; VELIKANOV, 2002). The other water is pumped to treatment plants, where a traditional, two stage purification scheme is applied: after clarification in settling tanks and filtering through quartz sand, chlorine in combination with an ammonia chemical is added to the water, to ensure the required sanitary standard. Approximately 73 % are used for domestic, 25 % for commercial and industrial needs and there are losses of about 2 % (MOSVODOKANAL, 2005).

#### Geological setting

Geologically, the catchment area of the Upper Volga belongs to the Moscow Basin in the Russian Platform (DOLGINOV; KROPATSCHJOW 1994, KARPUNIN *et al.*, 1997, KHERASKOVA *et al.*, 2005, SAHAGIAN *et al.*, 1996) and is composed of east-dipping layers from Devonian to Cretaceous: the Source and the Upper Volga Lakes lie in Devonian sediments and at Bejshlot the river enters carboniferous layers, which are the main lithological factor in the research area. Some kilometers downstream Tver, approximately at the mouth of River Orsha, Jurassic layers appear which dominate until Rybinsk reservoir. In this area also some Triassic and very few eroded Permian

layers appear, but they are not directly cut by the Volga River (CGI 1971). The lime layers in the catchment of the Volga River in the reach from Bejshlot to Staritsa can be dated back about 310 million years to carboniferous time, the Serpukhovian. The surface layers, were formed by glacial activities and the deposited quaternary sediments, consist of conglomerates, sandstones, marls and limestones (SPREITZER, 1935) and the main end moraine layers are up to 70 m thick (GURTZ *et al.*, 1999); modern landscape is formed by fluvial activity. Recent soils are mainly loamy-podzolic and in depressions with water accumulation marshy peat-bog-soils occur.

The groundwater in this area is estimated to amount to approximately 10% of the surface waters and in river valleys hydraulic connections between aquifers and surface waters are often established. The main aquifers are located in carboniferous limestones in depths from 10 to 250 m, where they are embedded between clayey strata, and their thickness can last from 15 to 80 m (VELIKANOV; FULIANG 2001). The groundwater is of hydrocarbonate and calcium magnesium type, with a total mineralisation of 150 to 400 mg l<sup>-1</sup> (AKHMETIEVA; LAPINA 1997). At the moment, about 5 m<sup>3</sup>/s are pumped from the Moscow artesian basin to the WRS of Moscow (VLADIMIROV, 1997). Aquifers in the vicinity of Ivankovskoe reservoir would allow a water withdrawal of about 8 m<sup>3</sup>/s, to be used during dry periods – and in times of water overspill, these groundwater resources could be restored (VASILIEV; VELIKANOV, 2002).

#### Water management (legal aspects)

The history of water management in Russia can be divided into three distinct periods (KOTOV, 2009): the pre-Soviet period (before 1917), the Soviet period (1917–1990) and the post-Soviet period (from 1991). At present the Russian Water Code of 2006 is the main state document for water management regulation (in force since 1 January 2007) and thus the starting point for a 4th phase of water management.

In the Russian framework of water management there are three major players, i.e. the Ministry of Nature Recourses (responsible for governmental politic and normative-legal rules regulation in the sphere of nature use and conservation), the Federal Agency of Water Recourses “Rosvodresurs” (with the authority on monitoring and setting standards) and the Basin administration(s) (RBC; River Basin Councils).

With the new Water Code of 2006, which was established on the basis of the Water Code of 1995, a redistribution of ownership of waters between the federation and the regions took place. It strengthened the position of the federal authorities significantly (“*revival of centralized water management in Russia*”, sensu KOTOV 2009) and determined federal competence in water management (art. 24) (SHEVCHUK *et al.*, 2007).

Some responsibilities were transferred from federal level to the regions, including protection of waters, pollution prevention, the concluding of agreements with water users, flood mitigation, and disaster relief. It allowed the private ownership of waters and the possibility of regulating water relations through civil law. State-owned (by federal or regional authorities) water bodies were declared “accessible to public”, i.e. natural persons have free access to water resources (art. 6). Licences were replaced by agreements, which grant the right to use state-owned waters (art. 8) to legal entities (water users) for up to 20 years (art. 13). While licences could be cancelled unilaterally by the issuing authority, water agreements can be terminated only according to civil law procedures (art. 17). Water use fees (arts. 18, 20) are an agreement-based payment, rather than a tax. Federal entities claimed, however, that water use fees are a primary financial tool and the collected money serve purposes that are very distant from water economy (KOTOV, 2009).

According to Article 65 “Water protection zones are territories adjacent to the shoreline of seas, rivers, streams, channels, lakes, water reservoirs, for which

special conditions of economic or other activities are established in order to prevent contamination, littering, silting and water depletion of water bodies and conserve the habitat for aquatic biological resources and other flora and fauna.”. In the near-shore protective belts (within water protection zones) additional restrictions to economic or other activities apply. The width of the water protection zone depends on the length of the river, i.e. rivers < 10 km (50 m), rivers from 10 – 50 km (100 m) and rivers > 50 km (200 m). For lakes and water reservoirs (with water surface area > 0.5 square kilometres) the protection zone is 50 meters and at the seashore the protection zone is 500 m.

### HYDROMORPHOLOGY

Catchment analyses resulted that the headwater downstream to the city of Tver amounts 31,300 km<sup>2</sup>: about 41.5 % (12,980 km<sup>2</sup>) are forested, 2.4 % (760 km<sup>2</sup>) covered by mires and 2.1% (668 km<sup>2</sup>) of the area are lakes (RESURSY POVERHNOSTNYH VOD SSSR 1976). Around the Upper Volga Lakes even 66 % are forested and downstream to Elzi 60 % and the basin downstream to Rzhev still 55 % of the Basin is covered by forests of *Pinetum* and *Betuletum* type, that can be specified in parts as southern taiga (Klimo and Hager 2001). The mixed forest is dominated by pine (*Pinus sylvestris*), spruce (*Picea abies*), birches (*Betula pendula*, *B. verrucosa*) and on the banks and meadows alder (*Alnus glutinosa*) is dominant. Along the banks and around islands wood assemblages with bite traces of *Castor fiber* where observed, thus it can be assumed that the European beaver plays a role for the input of wood into the Volga River, mainly through tributaries, where a couple of beaver dams are established.

During the preparation of the expedition in 2005, sampling locations were pre-selected on vector and raster maps. In addition satellite images (Landsat 7 and Aster) were used to define three morphological reaches (Tab. 01).

**Table 01: Morphological reaches in the headwaters of the Volga River**

Reach / Description	rkm	length [km]	altitude [m asl]	catchment size [km <sup>2</sup> ]	MQ [m <sup>3</sup> /sec] at the end of the reach
1 - Source region	3531 - 3520	11	226-206	30	-
2 - Upper Volga Lakes	3520 - 3426	94	205	3,500	28.4
3 - Upper Volga River	3426 - 3085	341	200-124	31,300	182.0

- Reach 1: Source region (rkm 3531 - 3520)**

The source of the Volga River is located near the village Volgoverkhovje (228 m asl, 57.25146 N 32.46882 E), in the Valdaian Hills. The Revenitskye hills (321 m asl) near the source are the highest point in the catchment area down to Bejshlot, separating the Volga catchment from the north-west Valdai-syncline, that belongs to the Baltic Sea catchment (GURTZ *et al.*, 1999). The source of the Volga, a limnokrene, it is located at the south eastern boarder of a swamp, from where the water seeps towards two lakes: the Small and Big Verkhit (russ. верх реки = "headwaters of the river"). Several meters downstream its source the Volga River forms a small runnel not wider than half a meter, but soon it is becoming a creek. Near the mouth into Lake Sterzh it has a width of about 10 meters and a depth of about 1 meter. R1 with it's two river lakes (Small and Big Verkhit) is a natural, untouched section of the river.

The area between the source at Volgoverkhovje and Selizharowo is often described as "source region" of the Volga (ANUTCHIN, 1898) and also some authors consider the Lake Seliger as "second source of the Volga" (SHAPORENKO *et al.*, 2002).

- Reach 2: Upper Volga Lakes (rkm 3520 - 3426)**

At Kokovkino the Volga flows into the seminatural Upper Volga Lakes, which extend on about 126 km<sup>2</sup>: Sterzh (18 km<sup>2</sup>), Vselug (30 km<sup>2</sup>), Peno (17 km<sup>2</sup>) and Volgo

(61 km<sup>2</sup>). These were natural lakes, but their water level is raised by the Upper Volga Dam (Verkhnevolzhskaja Plotina, Bejshlot). This weir "Bejshlot" (near Selishe), has been built in 1843 according to plans of the director of the Upper Volga Shipping Lt.-Col. Stjernwall, to maintain nautical depth between Rzhev and Tver (VON KÖPPEN, 1841). After damages in the second world war, it was reconstructed in 1943; it is intermitting longitudinal fish migration and retains water over the original lake surface. But also the natural dynamic during the flood in spring caused a change of the water level of Lk. Volgo (nowadays Volgo 2): in 1838 during the flood in spring it's level was highered 1.3 meters and it is even described that Lk. Volgo could be raised up to 2.73 m (VON KÖPPEN, 1841). R2 is impacted by water level regulation since 1843. Despite this change, morphology can be defined as semi-natural, because it is still similar to the former lake river system.

- Reach 3: Upper Volga River (rkm 3426 - 3085)**

At Bejshlot the free flowing section of the Upper Volga River begins and this reach leads until the mouth of Tverza river at Tver. According to the stream order assessment, 192 creeks and rivers are flowing into the Volga River in reach 3. The stream orders show, that the majority of the tributaries are small (stream order 1 or 2). The river bottom is mainly composed of quartz-sand and in the upper reach gravel and stones from glacial boulders are common. In some



parts there is clay on the bottom and in areas with low discharge mud is deposited. BEHNING (1928) mentioned bottom sills formed by glacial boulders between Selizharovo and Rzhev, which disable shipping on this upper reach. During the expedition it was possible to register 42 such rapids. In R3, hydro-morphological conditions are over large stretches intact. Only in some locations riparian vegetation is missing and some anthropogenic pressure is on the hinterland (agriculture, settlements).

Since the construction of the Ivankovskoe reservoir in 1937, Tver (rkm 3085, 124m asl) is in its backwaters. The water surface of this hydroelectric power plant stretches over 327.8 km<sup>2</sup>, its volume is 1.12 km<sup>3</sup>, and its power unit with 2 Kaplan turbines (max. flow rate 130 m<sup>3</sup>/s) allows in connection with 8 openings at the concrete dam a max. discharge of 7,660 m<sup>3</sup>/s. For navigation locks are located there (PAVLOV *et al.*, 1999, MALIK *et al.*, 2000). Near the dam at Dubna the “Moscow Canal” (128 km long, 19 km on reservoirs), which is the connection to River Moskva (via 11 locks), enters the Volga.

An assessment sheet for hydro-morphology was compiled from different protocols (LAWA, 1998; MUHAR *et al.*, 2000; FÜREDER *et al.*, 2001; VACHA *et al.*, 2002; AQEM Consortium 2002). To enable comparability the assessed data was transformed according to the River Habitat Survey (RAVEN *et al.*, 1997) and the HQA (Habitat Quality Assessment), a measure of natural habitat diversity (RAVEN *et al.*, 1998a, 1998b), was calculated. With a topographic map (Roskartografiya 2003 – M 1:100.000) the stream orders were assessed using the system of STRAHLER (1957). In case, that a river begins at the outflow of a lake (e.g. Selizharovka), the highest stream order of the tributaries of the lake was applied for further assessment.

Along the 446 km between the Source in the Valdaian Hills and Tver there is a difference in altitude of 104 m (= 0,232 ‰). The highest gradient is at Bensky Parog

(3 ‰) near the village Elzi (SHAPORENKO *et al.*, 2006). For the tributaries stream orders according to STRAHLER (1957) were assessed and it turned out, that in reach 1 all, in reach 2 about 90 % and in reach 3 over 81 % of the tributaries belong to low stream orders. There are only few larger tributaries (with stream orders of 5 or 6), namely Zhukopa, Selisharovka, B. Kosha, Vazuza, Derzha, Tma and Tvertsa (Fig. 03a).

About 64 % of the sampling sites along the Volga River (see Fig. 2a) had a HQA score between 50 and 60 and 10.5 % between 61 and 84. Two locations scored between 30 and 35, in four locations HQA amounted between 45 and 49; in the city of Tver the HQA index is only 25 (Fig. 03b). The mean HQA index in the headwater is 51.8, which reflects an excellent “habitat quality” in the Upper Volga River. A study on British lowland rivers showed, for example that the average the HQA score amounts between 45 and 65 (RAVEN *et al.*, 1998). According to the HMS index along the free flowing section of the Upper Volga River 20 sites are pristine, 7 are semi-natural and one site in the city of Tver is significantly modified.

## HYDROLOGY

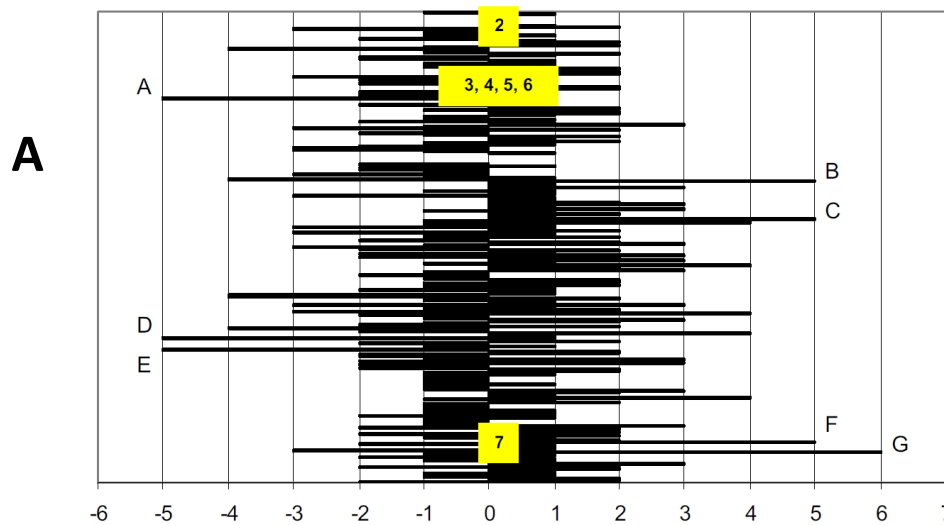
In 1841 the plans for the Upper Volga Reservoir were described by VON KÖPPEN and he provided hydrological tables for six locations (Tver/Tverza, Tver, Mologa, Rybinsk, Kostroma, Nishnij Novgorod); this is probably the first publication of hydrological data of this region. VON KÖPPEN mentioned that this information from the years 1839 and 1840 is based on the logbooks of navy-inspectors. A brief description of the river course was published by ROSKOSCHNY (1887), who also provided data on hydrology and ice cover. The official hydrological monitoring started 1876, when five monitoring stations on the Upper Volga Lakes and seven along the river were established (SHAPORENKO *et al.*, 2006). The serial “Water Resources of the SSSR”, with the Volumes about the “Upper Volga

Region” (e.g. JABLOKOV 1973, SURIN 1976), provides an excellent reference book for hydrological topics.

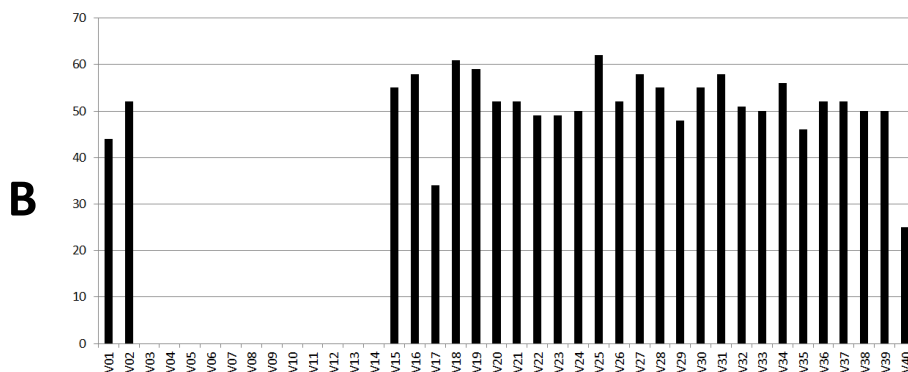
Concerning hydrology, a dataset from the stations at Bejshlot, Eltcy, Rzhev and Staritsa with monthly discharge values from 1891-1985 (SHIKLOMANOV, 1999) was analyzed and the key figures are summarized in Tab. 02. This includes the following hydrologic variables: mean annual

discharge (MQ), lowest monthly discharge in the observation period (NMQ), highest monthly discharge in the observation period (HMQ), as well as specific discharge per unit area (q). To enable comparability between different river systems the SK value was calculated for each month (i) with following formula:  $SK_i = MQ_i / MQ_{annual}$  (PARDE, 1960).

**Figure 03: A - Stream orders of the tributaries to the Volga River. B – Habitat Quality Assessment (HQA) scores at the 40 sampling sites assessed during the “Upper Volga Expedition 2005”.**



Notes: (positive values: left tributaries, negative values: right tributaries) in the research area according to STRAHLER (1957). In reach 1 all, in reach 2 (Upper Volga Lakes) about 90% and in reach 3 over 81% of the tributaries belong to low stream orders, while there are only few large ones. The main tributaries are indicated: A = Zhukopa, B = Selisharovka, C = B. Kosha, D = Vazuza, E = Derzha, F = Tma, G = Tvertsa.



Notes: no assessment was carried out for the Upper Volga Lakes [V03-V14]; V20 + V21 are the same location (Eltsy), the same applies to V22 and V 23 (Klimovo), i.e. left + right bank.

**Table 02: Hydrological characteristics at four locations in reach 3**  
 (Bejshlot, Elzi, Rzhev, Staritsa)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Okt	Nov	Dec
<b>rkm: 3426, altitude: 200.2 m, catchment: 3500 km<sup>2</sup>, MQ: 28.40 m<sup>3</sup>/sec</b>												
<b>Bejshlot</b>												
MQ <sub>Month</sub>	10.7	7.80	7.19	15.7	53.2	52.4	40.4	26.6	36.2	42.0	30.0	18.0
NMQ	0.2	0.2	0.2	0.25	3.84	1.06	0.34	0.19	0.16	0.6	0.27	0.28
HMQ	52.5	56.3	70.1	110.0	140.0	95.5	96.8	124.0	99.8	118.0	94.8	63.1
Sk (MQ/MQ <sub>a</sub> )	0.38	0.28	0.25	0.55	1.88	1.85	1.43	0.94	1.28	1.48	1.06	0.63
q (l/sec/km <sup>2</sup> )	3.1	2.2	2.1	4.5	15.2	15.0	11.5	7.6	10.3	12.0	8.6	5.1
<b>rkm: 3370, altitude: 186.0 m, catchment: 9130 km<sup>2</sup>, MQ: 75.20 m<sup>3</sup>/sec</b>												
<b>Elzi</b>												
MQ <sub>Month</sub>	33.9	28.8	33.8	149.0	136.6	103.5	78.2	56.0	72.7	85.3	74.4	49.4
NMQ	8.7	8.6	9.4	62.8	46.5	32.9	15.5	10.4	15.8	17.5	13.0	10.2
HMQ	34.2	95.5	111.0	337.0	354.0	231.0	151.0	252.0	226.0	215.0	241.0	149.0
Sk (MQ/MQ <sub>a</sub> )	0.45	0.38	0.45	1.98	1.82	1.38	1.04	0.74	0.97	1.13	0.99	0.66
q (l/sec/km <sup>2</sup> )	3.7	3.2	3.7	16.3	15.0	11.3	8.6	6.1	8.0	9.3	8.1	5.4
<b>rkm: 3274, altitude: 154.2 m, catchment: 12200 km<sup>2</sup>, MQ: 94.24 m<sup>3</sup>/sec</b>												
<b>Rzhev</b>												
MQ <sub>Month</sub>	43.6	37.5	49.1	262.3	165.2	117.7	86.0	58.0	68.2	93.8	88.9	60.3
NMQ	10.4	12.7	16.1	105	54.5	41.2	19.4	15.7	19.7	23.1	16.7	13.1
HMQ	109.0	102.0	150.0	547.0	485.0	228.0	185.0	195.0	201.0	219.0	309.0	228.0
Sk (MQ/MQ <sub>a</sub> )	0.46	0.40	0.52	2.78	1.75	1.25	0.91	0.62	0.72	1.00	0.94	0.64
q (l/sec/km <sup>2</sup> )	3.6	3.1	4.0	21.5	13.5	9.6	7.0	4.8	5.6	7.7	7.3	4.9
<b>rkm: 3175, altitude: 136.9 m, catchment: 21100 km<sup>2</sup>, MQ: 154.30 m<sup>3</sup>/sec</b>												
<b>Staritsa</b>												
MQ <sub>Month</sub>	56.9	51.4	87.7	598.1	247.7	142.9	119.7	90.0	103.6	132.8	130.6	85.7
NMQ	12.1	14.7	20.0	163.0	44.6	55.4	30.0	21.3	28.6	29.9	25.7	20.2
HMQ	138.0	213.0	504.0	1200.0	960.0	459.0	427.0	385.0	382.0	567.0	413.0	284.0
Sk (MQ/MQ <sub>a</sub> )	0.37	0.33	0.57	3.88	1.61	0.93	0.78	0.58	0.67	0.86	0.85	0.56
q (l/sec/km <sup>2</sup> )	2.7	2.4	4.2	28.3	11.7	6.8	5.7	4.3	4.9	6.3	6.2	4.1

### Hydrochemistry

During field work at the sampling sites some parameters (temperature, pH, conductivity and dissolved oxygen) are measured in situ. Water samples are

analysed in the laboratory according to standard methods for the analyses of surface waters (DOBROUMOVA, 1978).

During the expedition in 2005 hydrochemical parameters were assessed in detail: Secchi depth (transparency) was

low in the mire influenced reaches and had also a tendency to increase the Volga River downstream. The highest value of colour was measured at the source of the Volga River (640°) because of inflowing humic acids from the mire; the lowest value (92°) was observed near Rzhev. The lowest acidity was observed at the paludified source of the Volga River at Volgoverkhovje (pH = 6.0) and the highest value (pH=8.0) near Stolipino. The specific conductivity regularly increased from Bejshlot to Tver. A specific feature in this mire-determined system are nitrogen compounds. The high concentration of ammonium in the source of the Volga River is due to the natural runoff, because peatland water can contain up to 4.5 mg NH<sub>4</sub><sup>+</sup> per l. The mean value of ammonium in the Upper Volga River is 0.8 mg N/l. In all samples analysed the concentration of NH<sub>4</sub><sup>+</sup> is over the normative limits (0.39 mg/l). The mean value of the total N of 1.7 mg N/l (nutrient load) is linked to natural runoff characteristics (SHAPORENKO *et al.*, 2006).

The Volga River between Rzhev and Tver is in good condition considering physico-chemical parameters and was classified as “low polluted”. The hydro-chemical conditions of the headwaters of the Volga River are influenced 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; BELOUSOVA, 1988). Between Rzhev and Tver parameters linked to mineralisation increase (e.g. pH 7.72 to 8.03, conductivity 215 to 270 µS cm<sup>-1</sup>), while other parameters, characterizing the natural content of organic matter and nutrients (related to mires in the catchment), decreased (e.g. colour from 70° to 52°, ammonium from 0.41 to 0.26 mg l<sup>-1</sup>). High colour and concentrations of ammonium, iron, magnesium and copper indicate the influence of geomorphological settings (i.e. mires) in the catchment area. Downstream Tver the content of biogenic components (nitrogen and phosphorus)

rise due to the influence of anthropogenic pollution (SHAPORENKO *et al.*, 2006).

Two of our monitoring points are also in the official physico-chemical monitoring framework of Roshydromet: Nearby our sampling location Rzhev the sampling location “upstream Rzhev” of Roshydromet (which is classified as category 4, i.e. samples are taken during the main hydrological phases – 7 times per year) is located (Fig. 04). And nearby Tver / Migalovo, a monitoring location of Roshydromet (which is classified as category 3, i.e. monthly – as well as additional ones at the peak of the flood – analyses of the water quality are carried out – 13 times per year) is located. The hydrochemical observations in the federal monitoring network of Roshydromet include the assessment of 40 parameters (physical properties, dissolved gases, ionic composition, indicators of organic substances, petroleum products, heavy metals, detergents and pesticides). Our assessments go in line with the official (regular) sampling activities of Roshydromet.

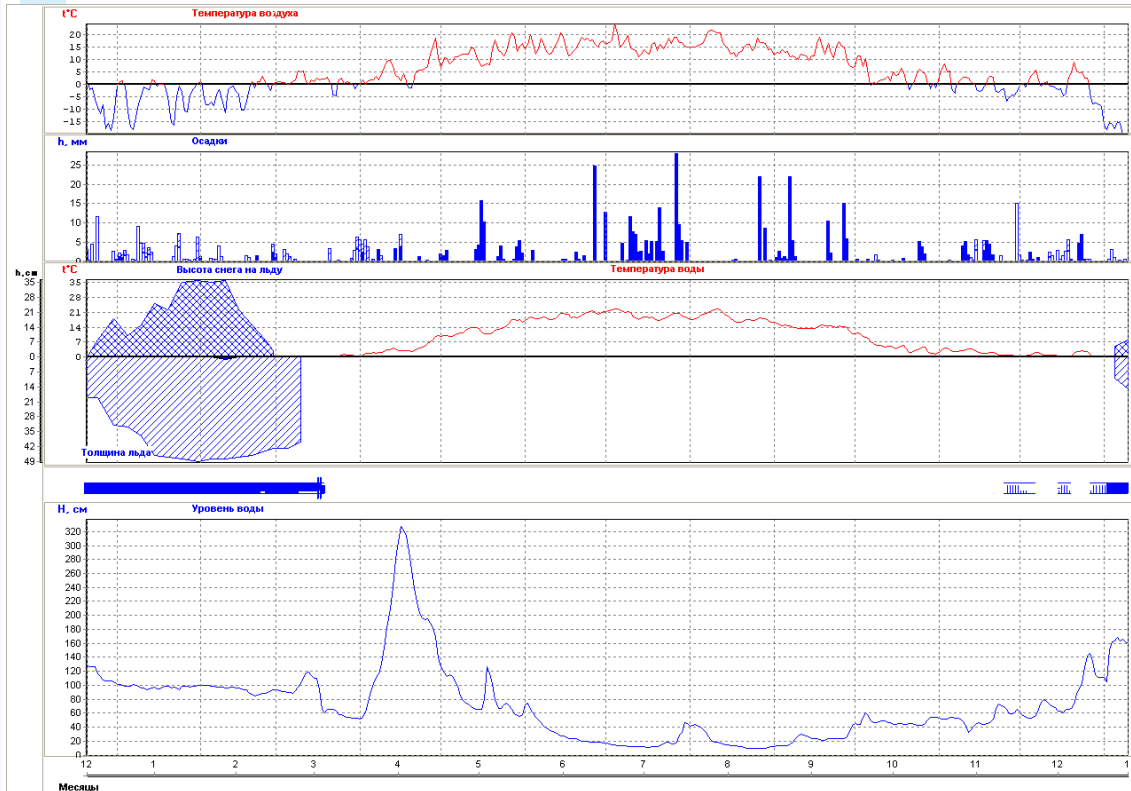
The composition of the water of the Volga River at Rzhev during the summer low-water period of 2015 can be described by the Kurlov formula

$$M_{0.16} \frac{HCO_3 94 SO_4 5 Cl 4}{Ca 68 Mg 29 (K + Na) 3},$$

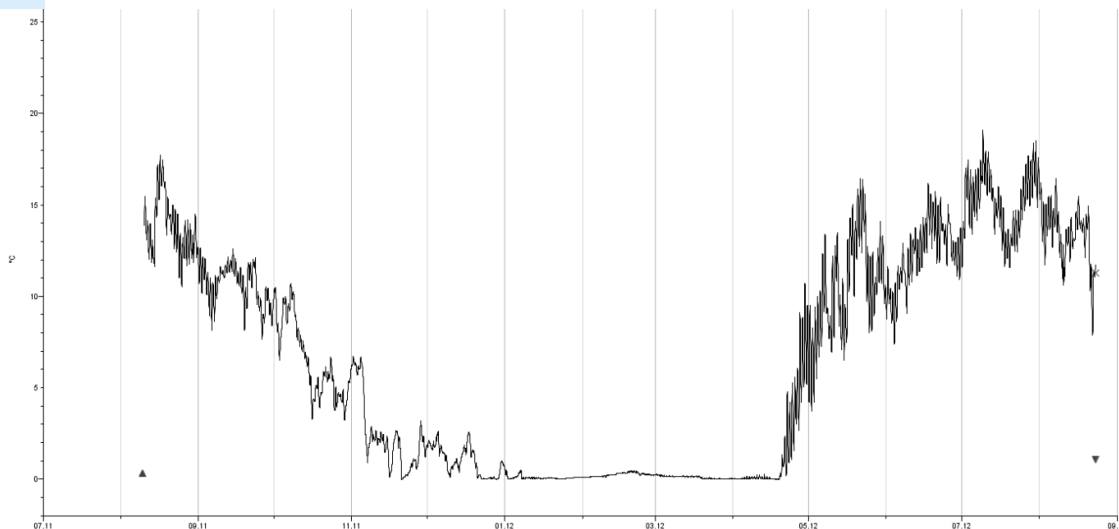
M – mineralization, g/l; percent-equivalent concentration of the main ions (see ZENIN; BELOUSOVA, 1988).

In order to assess data about the temperature regime of River Tudovka, TinyBit loggers (Modell TBI32-05+37; <http://www.onsetcomp.com/>) are exposed since May 2008. These underwater temperature data loggers are recording temperatures between -5°C and 37°C. They are completely sealed and for launch and readout an optic communication shuttle is needed. A measurement interval of 60 minutes was selected. A long term assessment of water temperatures (Fig. 05) enables predictions on possible changes in future.

**Figure 04: Example for a complex graphic from ROSHYDROMET for the station Volga – Rzhev in 2015, including air temperatures, precipitation and the thickness of ice / snow cover on the ice and water temperatures, as well as water levels.**



**Figure 05: Water temperature (°C) regime at the source of R. Tudovka – “Istok” between august 2011 and august 2012**



### Hydrobiology

Extensive sampling of **benthic invertebrates** was done during the “Upper Volga Expedition” in the low flow period in

summer 2005. In the Volga River at 40 sites (approximately each 15 km) zoobenthos samples were taken with a bottom grab (sampled area 0.025 m<sup>2</sup>, three replicates per site) and from 30 tributaries

qualitative kick-samples were collected. Based on the results of this detailed study, we defined three monitoring sites in the headwaters of Volga River (Rzhev, Staritsa

and Tver`) as well as from six sites along the course of a pristine tributary, the Tudovka River (Fig. 02, Fig. 06).

**Figure 06: Monitoring sites along the Volga River (A – Rzhev, B – Staritsa, C – Tver) and it's tributary Tudovka (D - location "Istok" [source], E - river-ponds at "3Trubi", F – Krasny Stan: junction of R. Tudovka and R. Nochnaya, G – Sibir, H – Redkino, I – M. Tud)**



The dataset from the expedition in 2005 revealed that abundances and biomass were increasing longitudinally and that there was a high interconnectivity between the main river and its tributaries (SCHLETTERER; FÜREDER, 2010a). With this dataset also the coherence of several bioassessment indices was investigated: macroinvertebrates showed a beta-mesosaprobic basic status and further the ecological status boundaries of the index SPEARpesticides was shown to be applicable across Europe (SCHLETTERER *et al.*, 2010a).

Concerning the monitoring along the tributary Tudovka the analyses showed that invertebrates responded more to physical factors, while diatoms depended on water

chemistry, which underlines that both components are needed to assess river health (SCHLETTERER *et al.*, 2011a). The subsequent surveys along the Volga, that are carried out each year in summer as well as two additional surveys in spring, provided data from reference or least disturbed conditions and revealed annual and interannual variation in community indices and metrics (SCHLETTERER *et al.*, 2014). In the Volga River at Tver we carried out a detailed sampling campaign, in order to assess and analyze effects on benthic communities caused by the invasive amphipod *Gmelinoides fasciatus*; it turned out that abundances and biomass of *G. fasciatus* was stable over three years and no increase was observed, however

this has to be observed in the future monitoring activities (SCHLETTERER; KUZOVLEV, 2012).

Altogether 381 zoobenthos taxa were identified (Table 3). Microscopical observations of diatom mounts, processed from material of the Upper Volga Expedition 2005, even revealed the presence of four sponge species (SCHLETTERER; EGGERS, 2007). An assessment of zoophytes communities, i.e. invertebrates associated with macrophyte stands, included the development of a special sampling device and revealed a clear dominance of Ephemeroptera (SCHLETTERER *et al.*, 2007). Mayflies are also an important part in the benthic fauna, as due to intact hydromorphology in the research area – which is reflected in a high amount of different mesohabitats – an individual and species rich mayfly fauna, including several rare and threatened species is supported (SCHLETTERER; FÜREDER, 2010b).

The taxa lists demonstrate the high integrity of the headwaters of the Volga River. In particular the finding of Prosopistomatidae is outstanding, because this mayfly family is very rare and thus it was a unique possibility to assess the ecology of the species *Prosopistoma pennigerum*. Within the monitoring activities in the headwaters of River Volga the mayfly *Prosopistoma pennigerum* was recorded for the first time in Russia (SCHLETTERER; KUZOVLEV, 2007). This species was found in the 19<sup>th</sup> century regularly in European watercourses but disappeared in the 20<sup>th</sup> century almost completely (SCHLETTERER; FÜREDER 2009, and references therein), thus the present records were a unique chance to assess habitat as well as taxonomic specifics of the species (SCHLETTERER *et al.*, 2015, BARBER-JAMES *et al.*, 2015).

Also other biological quality elements were considered (Table 3):

- The dataset about **benthic diatoms** (Bacillariophyceae) includes, according

to the “German Red Book” (LANGE-BERTALOT; STEINDORF, 1996), two very rare species (*Navicula constans* var. *symmetrica* and *Nitzschia paleaeformis*) and two very endangered ones (*Eunotia arcus*, *Navicula stankovicii*), as well as three endangered ones (*Fragilaria lapponica*, *Navicula maceria*, *Navicula variostrata*). Nine species are known to be rare in Europe (*Achnanthes bioretii*, *A. oblongella*, *Cymbella mesiana*, *Diploneis oblongella*, *D. ovalis*, *Fragilaria delicatissima*, *Gomphonema sarcophagus*, *Stauroneis acuta* and *Stauroneis phoenicentron*).

Recent analyses revealed >200 diatom taxa with the richest taxa complexes around *Navicula* (26 spp.), followed by *Nitzschia* (22 spp.), *Fragilaria* (15 spp.) and *Achnanthes* (14 spp.) (ISMAIEL *et al.*, 2016).

- Concerning **macrophytes** 37 species were recorded in 2005, of which two species are considered as endangered and nine as valuable (LUDWIG; SCHNITTLER, 1996). Within the Potamogetonaceae two species are considered as valuable (*Potamogeton perfoliatus*, *P. lucens*); both occurred with high constancy (0.37 and 0.22). Also other “valuable species” *Sagittaria sagittifolia* (0.30), *Butomus umbellatus* (0.22) and *Fontinalis antipyretica* (0.11) were found to be common in the investigated stretch, while the rest (*Caltha palustris*, *Potentilla palustris*, *Ranunculus circinatus*, *Zannichellia palustris*) occurred subrezentent. Also the “endangered species” *Cicuta virosa* and *Menyanthes trifoliata* were found. The banks of the Upper Volga River in Reach 3 are overgrown by *Phalaris arundinacea*, which can get dominant in floodplains and form single species stands (APFELBAUM; SAMS, 1987). Often the circumboreal wetland species *Carex elata* was co-dominant with *P. arundinacea*.

**Table 03: Aquatic biodiversity in the headwaters of the Volga River (current knowledge)**

Biological quality element	Taxa (n)	Sources
diatoms (quantitative data)	> 200	SCHLETTERER, 2006, SCHLETTERER <i>et al.</i> , 2010b / 2011a, ISMAIEL <i>et al.</i> , 2016.
macrophytes (quantitative data)	37	SCHLETTERER, 2006, ZHENIKOV <i>et al.</i> , 2007.
zoobenthos (quantitative data)	381	SCHLETTERER 2009; SCHLETTERER and EGGERS 2006; SCHLETTERER and KUZOVLEV 2007 / 2012; SCHLETTERER and FÜREDER, 2009, 2010a, 2010b; SCHLETTERER <i>et al.</i> , 2007 / 2010a / 2010b / 2011a / 2011b / 2014.
fish (qualitative data)	25	SCHLETTERER, 2006.

### DISCUSSION

High-quality and long-term datasets (i.e. long-term ecosystem research and monitoring, LTERM) are essential for an assessment of status and developments of environmental conditions (“environmental change”) as well as natural and anthropogenic drivers (PARR *et al.*, 2003, LOVETT *et al.*, 2007, MAGURRAN *et al.*, 2010). For example sound long-term datasets are used to evaluate trends related to global warming, i.e. for the analyses of the effects of an increase of water temperature on biota, as carried out recently for the Upper Rhône River (DAUFRESNE *et al.*, 2004). JACKSON and FÜREDER (2006) documented the value of long-term ecological studies (i.e.  $\geq 5$  years) of freshwater macroinvertebrates and highlighted their major contributions to the understanding of interannual variation, abiotic and biotic interactions as well as natural and anthropogenic disturbance and recovery. Despite the fact that ecological monitoring programs are needed in a long time perspective, often financial limitations are given, thus CAUGHLAN and OAKLEY (2001) pointed out that setting of objectives and sampling design optimization are important processes for setting up a monitoring program, including also an analyses of costs and benefits. Concerning aquatic diversity it is needed to run detailed biodiversity surveys, as the use of

surrogates (group or cross-taxon congruence) for predicting biodiversity did not appear to be relevant for conservation in the freshwater realm (HEINO, 2010). Thus, monitoring of biodiversity using indicator species as well as functional traits of species and communities is essential to analyse the responses of ecosystems to global change (VANDEWALLE *et al.*, 2010).

Most central European streams are affected by anthropogenic impacts such as morphological degradation (HERING *et al.*, 2004), while the headwaters of some East European streams are in a better condition, because they have experienced less environmental change. Due to natural processes (and anthropogenic impacts), a high variation in habitat characteristics is to be expected (HYNES, 1970; TOWNSEND and HILDREW, 1994), resulting in patches, that differ in age, size and environmental conditions (BEISEL *et al.*, 1998). Given the large amount of natural, respectively semi-natural, habitats in the headwaters of the Volga River, our monitoring contributes to the knowledge about the aquatic ecology in the lowland and provides data about seasonal and temporal variability at reference and/or LDC sites for lowland rivers in the eastern plain, i.e. the European ecoregion number 16.

DYNESIUS and NILSSON (1994) described the Volga River (virgin mean annual discharge [VMAD] = 8050), among



the most European rivers (e.g. Danube, Daugava, Dnjepr, Don, Nemunas, Elbe), as strongly affected water body: their analyses classified the fragmentation of Volga with “4”, i.e. only 0 to 24% of the main-channel (longest segment related to the entire main channel) are without dams and there are also dams in the catchment of the largest tributary. Flow regulation is described by reservoir live storage (34), reservoir gross capacity (75) and irrigation consumption (2) for the entire river system expressed as the percent of its VMAD. It is discussed whether a higher resolution of river conditions would provide another view, i.e. strongly affected large river systems (LRS) might have large unaffected tributaries, but DYNESIUS and NILSSON (1994) concluded, that the large intact tributaries can not be handled as complete rivers, because they have no connection to the sea, thus e.g. estuarine flora and fauna is missing in the system. Contrary, our opinion is that a pristine headwater or intact tributaries, are important for aquatic ecology to understand natural processes and dynamics in a large river system.

Our monitoring activities focus on physico-chemical parameters as well as on benthic invertebrates, but also other biological quality elements are covered, such as diatoms and macrophytes (SCHLETTERER, 2006, ZHENIKOV *et al.*, 2007, SCHLETTERER *et al.*, 2011, ISMAIEL *et al.*, 2016).

Although BEHNING (1924, 1928), as well as BUTORIN and MORDUKHAI-BOLTOVSKOI (1978), gave an overview on the whole Volga River, in the headwaters of the Volga the knowledge about benthic invertebrates was scattered and limited to few studies (PANKRATOVA, 1940, BOGATOV and ZYGANOV, 1973, SKVORTSOV *et al.*, 2003). Downstream the herein covered research area several studies were carried out on Ivankovskoe reservoir (BAKANOV, 2003) and most research concentrated on Rybinsk reservoir, where the hydro-biological station Borok is located (KOPYLOV, 2001 and references therein).

The REFCOND\_VOLGA monitoring programme revealed a comprehensive inventory of the zoobenthos and diatoms, including also other biological quality elements, and therefore it is an important contribution to the knowledge of the benthic fauna and flora in Tver region. Synergies are given with the official monitoring activities of Roshydromet, as regular physico-chemical assessments are carried out at Rzhev and Tver; also gauges are operated at Rzhev, Staritsa and Tver. Our scientific monitoring programme including data about aquatic biota therefore provides a valuable complementary dataset.

The invertebrate fauna of East European lowland rivers turned out to be very similar to West European lowland rivers. Intact East European rivers can therefore be used as a reference system in a European context, as they support the knowledge and understanding of natural processes in lowland rivers and though the definition of reference conditions. The headwaters of Volga River still provide suitable conditions for a pristine fauna and flora, which is characterised as a rich and diverse potamal benthic community. The ongoing monitoring programme is planned as LTERM of rivers in the Eastern lowlands and will focus on (I) seasonal and temporal variability at reference sites and LDC, (II) hydromorphological conditions & habitat availability and (III) effects of climate change. At the edge of the 21<sup>st</sup> century, the headwaters of Volga River might be one of the few last uncontaminated large lowland river systems in Europe and our long term monitoring provides key data about this system. In conclusion, intact East European river systems provide a unique opportunity to study and understand the functioning of lowland rivers.

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