Lithuanian karst region rivers' water ecology: hydrochemical and hydrobiological evaluation

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Abstract The Lithuanian karst region covers about 1000 km^3 in the northern part of the country. This is the most vulnerable area from a pollution point of view.

The structure of the total dissolved solids (TDS) shows that the flow of rivers in the karst region is from hydraulically interconnected aquifers. For the last decade (1991–2000) TDS has varied considerably, from 529 to 732 mg/l. The predominant sources of nitrogen and phosphorus within the headwaters of the monitored rivers were diffuse and agricultural in nature. Downstream from the towns nitrogen and especially phosphorus showed both diffuse and point source signals. Contributions of point sources to the stream pollution by nutrients prevail.

The time series of monthly dissolved oxygen (O_2) in the main karst region river – the Musa – shows the existence of multiplicative seasonality. The trend cycle (1991–1999) shows low levels of dissolved oxygen in 1991–1993, with a similar fluctuation in 1994, 1995 and 1996 (due to point pollution from the town of Siauliai) and a gradually improving situation since 1997. The general multiplicative trend of dissolved oxygen in the lower reaches of the Musa river (near the border with Latvia) is decreasing (within the accuracy limits).

The abundance and species of zoo benthos are suitable criteria (biotic index – BI) for evaluation of a river's biological water quality. Zoo benthos demonstrates tolerances that vary among species, the oxygen regime and the pollution with nitrogen. The best living conditions for invertebrates are in the riverhead of the karst region rivers – BI = 5.62–6.74 (1991–1999), where pollution with nutrients is caused mostly by agricultural activity. Rare and asynchronous data of biological water quality shows up tendencies that invertebrates prefer less contaminated reaches of rivers.

Keywords Dissolved oxygen; nitrogen; phosphorus; phytoplankton; zoo benthos

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Introduction

The karst region in Lithuania is situated in the northern regions – Birzai and Pasvalys (Figure 1). The most intensive karst processes occur in this area, covering about 800–1000 km^2, where conditions are favourable for atmospheric precipitation to enter the subsurface and dissolve shallow-occurring gypsum beds. The Lithuanian karst territory (like all Lithuania) is situated within the area of surplus humidity. Infiltration of precipitation is higher than evapotranspiration and that creates surface runoff. In this area thin layers of Quarternary sands and glacial tills overlie the late Devonian soluble gypsiferous sediments. On the land surface a dense network of sinkholes, land subsidence and karst lakes expresses surface karst. Rivers in the region often cut the Quaternary sediments and reach groundwater aquifers (Paukstys 1996).

The precipitation standard (yearly average) is 605 mm, according to Birzai meteorogical station. The range is 434–921 mm/yr. Yearly wet deposition (1994–1996, received with precipitation) of nitrogen, phosphorus and potassium are 18.5, 0.67 and 14.9 kg/ha, respectively (Chomcenko *et al.* 2000).

Rivers of the karst region are tributaries of the Latvian river Lielupe, which enter the Baltic Sea. The largest tributary of the Lielupe is the river Musa, which is 148 km long with its own tributary, the Levuo river, being 145 km long. Other rivers (the Tatula, the Apascia and the Upyte) are smaller than the Musa (Figure 1).

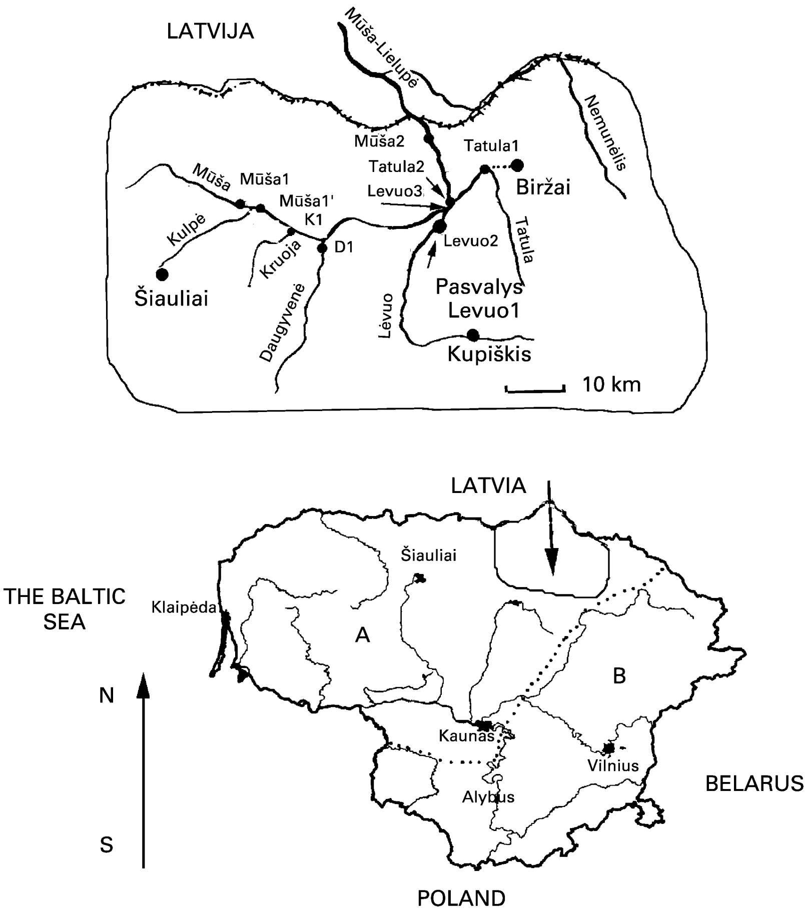

Figure 1 Scheme of two Lithuanian hydrological regions (A and B) and, above, the karst region in the north of the country with rivers and gauge stations

The Musa–Nemunelis lowland covers the main part of the karst region, where the specific annual average runoff is 5.7 l/s/km^2. Concentrations of total nitrogen and total phosphorus in the Musa and the Tatula rivers are 7 mg/l and 0.07–0.09 mg/l, respectively (Chomcenko *et al.* 2000).

Many rivers in the region cut through the upper part of the karst rocks and aquifers. Therefore, karst groundwater, depending on the season, is recharged by surface streams or discharges into the rivers. Groundwater discharge in the form of outlet springs can be directly observed in the valleys of the Apascia, Levuo and Smardone rivers and also in the bottom of the Tatula river during the low water periods (Paukstys 1996).

Four hydraulically interconnected aquifers: one Quaternary and three Upper Devonian, are located in the zone of active groundwater circulation. The Quaternary and karst aquifers have direct relations with a river network of the karst terrain. The Quaternary aquifer has mainly a fresh water bicarbonate–calcium–magnesium composition, with the total amount of dissolved solids 0.3–0.6 g/l. In the valleys of the Musa, Tatula and Apascia rivers, shallow Quaternary groundwater has a calcium–sulfate composition and the amount of dissolved solids comes to 2.2 g/l. This shows the hydraulic relation between the Quaternary and saline karst aquifers (Paukstys 1996).

Many groups of organisms have been used as indicators to estimate environmental quality. Algae and benthic invertebrates are typical species in biological monitoring.

Zooplankton plays a significant role in the functioning of water ecosystems. Zooplankton can reduce the concentration of nutrients by feeding on phytoplankton and microorganisms. It is possible to judge the water quality by zooplankton species predominating in the communities. Therefore, zooplankton is used as an indicator of saprobity. The abundance of zooplankton predetermines mainly the biomass and species composition of phytoplankton. Zooplankton is a trophic base for fish fry and for adult fishes of certain species. Species abundance and the biomass of zooplankton predetermine bioproduction of fish in the water ecosystems.

The species composition of zooplankton in the rivers is related to the river size. The greatest diversity of zooplankton species was established in the largest Lithuanian rivers. Species diversity, abundance and biomass of zooplankton in the medium-sized rivers depend on the river type, flow velocity and water temperature (Pliuraite 1999).

As is stated in the literature (see *Lietuvos upiu ir ezeru vandens kokybes pagal hidrobiologinius ir bakteriologinius tyrimus 1991–1999 m. darbo ataskaitos* 1992–2000), the abundance and species of zoo benthos are more suitable criteria for the evaluation of a river's biological quality. The responses of aquatic organisms or zoo benthos in streams to different quantities of inorganic, and especially organic, pollution are well documented. The biotic index is a systematic survey of invertebrate organisms. Since the diversity of species in a stream is often a good indicator of the presence of pollution, the biotic index can be correlated with chemical variables. The biotic index, used in determination of the types, species and numbers of biological organisms present in a stream, is commonly used in addition to biological oxygen demand (BOD) determination in determining stream pollution (Spellman 1996). The Trent biotic index (BI) is accepted in Lithuania (*Methods of determination of the surface water biological pollution* 1995).

There are several different forms of the biotic index. The Trophic Diatom Index (TDI) and Mean Trophic Rank (MTR) were developed in the UK as monitoring tools to quantify the impact of nutrient concentration on eutrophication (Jarvie *et al.* 2002).

Diatoms (*Bacillariophyta*) are a group of algae with ornamented silica cell walls, or 'frustules'. The frustules resist decay, even by treatment with oxidation agents to remove the organic material of the cell, and can then be used to identify each species. Many species have specific environmental preferences, which can be used to assess the current or historical environmental conditions of a water body.

Plant communities (MTR) might generally be expected to respond more directly to changes in inorganic nutrient concentrations than heterotrophic microorganisms and animals such as invertebrates or fish.

The multi-metric approach, as exemplified by the index of biotic integrity and numerous state or regional derivatives, is currently the most widely used bio-assessment tool (Seegert 2000).

Referring to the characteristic features of fish communities, the Index of Bio-integrity (Karr *et al.* 1986) was modified and adapted to the conditions in Lithuania (Kesminas and Virbickas 2000). For testing biointegrity nine metrics in three categories (species composition, abundance and biomass, trophic composition and fish condition) were chosen. Metrics of a biotest assess attributes that are assumed to correlate with biotic integrity. These metrics by the sum of their ratings together characterise the underlying biotic integrity of the sampling site. According to research data six integrity classes (excellent, good, fair, poor, very poor and no fish) of river fish communities were singled out. Individual tests were adapted to brooks (up to 10 km in length), streams (up to 50 km and the riverheads of bigger rivers), medium-sized rivers (up to 200 km and the middle reaches of large rivers) and large rivers (over 200 km and the lower reaches of the medium-sized rivers).

Fish community production changes, depending on the Lithuanian river size, thermal regime and tropic level. The mean fish production is lowest (7.4 kg/ha/yr) in the canalised cold-water (water temperature in midsummer does not exceed 18–20 °C) streams and highest in the dammed-up rivers (46.1 kg/ha/yr). The mean production of cold-water river fish communities (20.5 kg/ha/yr) is lower than that of warm-water (over 20 °C) communities (32 kg/ha/yr). If compared with other European countries, fish community production in the rivers of Lithuania is low: river trout productivity in Western Europe rivers is 1.4–547 kg/ha/yr, whereas in Lithuanian rivers it is 0.34–14.8 kg/ha/yr (Kesminas and Virbickas 1999).

As is stated in the literature (Kesminas and Virbickas 1999) the structural composition of the fish communities in Lithuanian rivers is determined by the following factors (in descending order of importance): 1) river size, 2) heat budget, 3) stream flow, 4) biotope diversity, 5) level of human generated eutrophication and 6) pollution level.

The goal of this study is to evaluate the biological water quality of karst region rivers and the relation between river biota and pollution by organic and inorganic matter as well as to evaluate the conditions for animals and plants of the flowing water.

Methods

To evaluate the river water quality the generalisation of karst river water quality observations from 5 rivers (12 monitoring points) in Lithuania (Table 1 and Figure 1) for the years 1991–2000 has been carried out. Data on the runoff in the rivers is obtained from the Lithuanian Hydro Meteorological Service. Time series of organic and inorganic matter (sampled once per month) as well as hydrobiological data (annual averages) are obtained from the Environmental Ministry. The species composition, abundance and biomass of phytoplankton, zooplankton (from the index of saprobity) and zoo benthos (from the biotic index) data are taken from yearly reports (*Lietuvos upiu ir ezeru vandens kokybes pagal hidrobiologinius ir bakteriologinius tyrimus 1991–1999 m. darbo ataskaitos* 1992–2000). The fish community composition and biomass data are obtained from the Lithuanian Institute of Ecology (Kesminas *et al.* 1994).

The Levuo stream consists of four reaches to be studied: 1) the riverhead 32.7 km long, gauge station Levuo 1 (above the town of Kupiskis, 5500 inhabitants); 2) below the town of Kupiskis, gauge station Levuo 1′; 3) 104.7 km below the town of Kupiskis, gauge station Levuo 2, above the town of Pasvalys (9200 inhabitants) and 4) 5.3 km below the town of Pasvalys, gauge station Levuo 3, mouth (Figure 1).

For the Musa stream the reaches are: 1) the riverhead 18.5 km long, gauge station Musa 1, the heavily polluted (by the industrialized town of Siauliai, 167,000 inhabitants) tributary Kulpe; 2) 6.4 km below the Kulpe mouth, gauge station Musa 1′ and 3) 91.5 km below the Kulpe mouth, gauge station Musa 2, below the settlement of Salociai (750 inhabitants), close to the border with Latvia (Figure 2).

For the Tatula stream the reaches are: 1) the riverhead 32.7 km long, gauge station Tatula 1 above the town of Birzai; 2) below the town of Birzai, gauge station Tatula 1′ and 3) the lower reach of the Tatula river, 17 km below the village of Trecionys, gauge station Tatula 2, 1.8 km above the mouth. The Tatula stream flows outside the town of Birzai (16,000 inhabitants) but sewage water through a channel contributes to the stream pollution (Tatula 1′).

In the above-mentioned towns sewage treatment plants exist.

At present the standards of the former Soviet Union are still used in Lithuania with some temporary changes and additions for water bodies meant for cultural, domestic needs and

Table 1 The list of analysed rivers and annual average (1991–2000) biological data: saprobity index (SI) of phytoplankton, zooplankton and biotic index (BI) of zoo benthos

	River, monitoring posts from mouth (km)	Name in Figure 1	Basin area (km^2)	Phyto plankton (SI)	Zoo plankton (SI)	Zoo benthos (BI)
1	Levuo above Kupiskis, 110	Levuo 1	307	1.93	1.74	5.62
2	Levuo below Kupiskis, 107	Levuo 1′	317	2.39	1.80	4.25
3	Levuo above Pasvalys, 5.3	Levuo 2	1503	1.91	1.73	5.50
4	Levuo mouth	Levuo 3	1588	2.20	1.80	5.30
5	Tatula above Birzai, 18.8	Tatula 1	198	1.96	1.98	6.74
6	Tatula below Birzai, 17.7	Tatula 1′	211	2.54	2.15	4.20
7	Tatula Trecionys, 1.8	Tatula 2	460	1.96	1.80	5.90
8	Musa above Kulpe mouth. 258.2	Musa 1	300	1.82	1.73	6.15
9	Musa below Kulpe mouth, 243	Musa 1′	512	2.42	2.21	4.00
10	Musa below Salociai, 152.5	Musa 2	4996	2.05	1.82	5.00
11	Kruoja mouth	K 1	355	2.04	1.93	5.95
12	Daugyvene mouth	D 1	495	2.00	1.87	5.20

fishery. According to the indices of combined water pollution classification used in Lithuania (biochemical oxygen consumption, ammonium hydrate and ammonia salts, nitrites, total nitrogen, phosphates, total phosphorus and other chemical substances) water bodies are divided into 6 classes (*Lietuvos upiu ir ezeru vandens kokybes pagal hidrobiologinius ir bakteriologinius tyrimus 1991–1999 m. darbo ataskaitos* 1992–2000).

Based on the abundance of phytoplankton, zooplankton and periphyton the river water can be divided into classes as well. Biologically, 7 classes of water quality by invertebrates are expressed quantitatively by the index of saprobity (SI) and 6 classes by the percentage of zoo benthos species *Oligochaeta* (SOK) and the biotic index (BI) (Table 2).

River water quality in this study was analysed recognising the river basin as a geosystem, while the runoff polystructure represents its main constancy and mobility characteristics (Tumas 2000). The formation of geosystems includes the active development and interaction of components of the natural area. Two hydrological transformation systems – A and B modes – are distinguished in terms of the regularities of their water balance. In system A (Figure 1) the karst region (the western part of Middle Lithuania) stands as the lithological foundation, where the internal structure of water balance factors is governed by soils of heavy mechanical constitution and by specific features of the landscape. Landscape components, such as valleys and gullies are catalysts in the runoff development. The landscape factors are important in morenic and limnoglacial semi-clay soils, where the runoff consists of surface and infiltrated water. The landscape components are less important

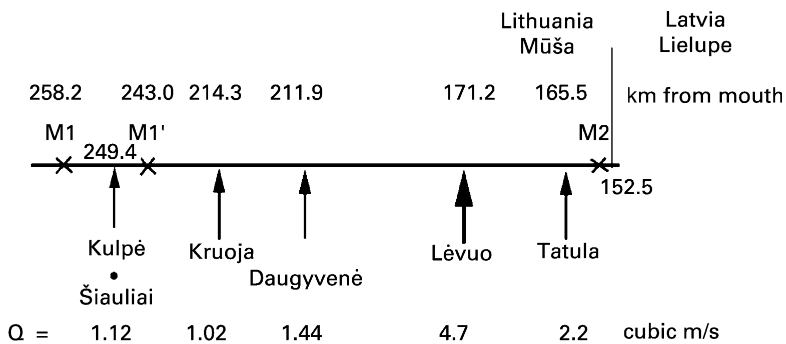

Figure 2 The annual average discharge to the main karst region river, the Musa

Table 2 Classification of Lithuanian river water according to indices of biological quality (Kesminas *et al.* 1999)

Class of quality	Description class of quality	Phyto-, zooplankton, periphyton (SI)	Zoo benthos (SOK)	Zoo benthos (BI)
I	Very clean	<1	1–20	10
II	Clean	1.1–1.5	21–35	7–9
IIIA	Moderate slightly polluted	1.51–2.0	36–50	5–6
IIIB	Slightly polluted	2.01–2.50		
IV	Polluted	2.51–3.50	51–65	4
V	Very polluted	3.51–4.0	66–85	2–3
VI	Heavily polluted	>4.0	86–100	0–1

in natural geosystems on mixed morenic soils and fluvioglacial sands, where infiltrated subsurface runoff prevails. Due to this, the polystructure of the runoff is different. In the eastern Lithuanian area (Figure 1, subregion B), in rivers flowing through agricultural areas, the biodiversity of invertebrates is richer: the zoo benthos biotic index ranges between 6.3–6.8 (the annual average for 1991–1999). In the western area it is less than 6.0 and in middle part of Lithuania there is a mixed situation: in some rivers, invertebrates have favourable oxygen conditions, while in others they have less favourable ones (Tumas 2002).

Results and Discussion

Total dissolved solids (TDS) (the sum of the concentrations of the dissolved major ions in Lithuanian rivers) vary regionally, due to the variability of natural anthropogenic input and flow intensity. In recent years (1991–2000) TDS in the karst region rivers has varied considerably (529–732 mg/l). The situation when the river water TDS contains more than 50% HCO_3^-, reflecting the dominance of sedimentary rock weathering and especially carbonate minerals, is common only in the upper part of the Levuo river (Table 3). In the lower reaches of the Levuo and Tatula rivers in the hydraulically interconnected aquifers, the concentration of SO_4^{2-} increased.

Catchments in the Musa–Nemunelis lowland, covering the main part of the karst region, are intensively farmed and fed by aquifers. Consequently, there are concerns over nutrient inputs from agriculture into the groundwater, diffuse source inputs into stream runoff during high flow conditions, together with changing patterns of agriculture and fertiliser usage.

Table 3 Major dissolved components (annual average from 1991–2000, except for Levuo 1′, Levuo 2′ and Tatula 1′, where the annual average was from 1996–2000) in karst region streams (mg/l)

	TDS	Ca^{2+}	HCO_3^-	SO_4^{2-}	O_2	BOD_7	Nmin	Ntot	PO_4	Ptot
Levuo 1	386	69	207	45	7.4	2.7	1.8	2.7	0.04	0.06
Levuo 1′	–	–	–	–	7.3	3.4	2.6	3.2	0.20	0.21
Levuo 2	529	80	246	104	7.6	2.3	2.6	3.3	0.08	0.12
Levuo 3	593	140	251	139	7.2	3.2	3.4	4.6	0.48	0.60
Tatula 1	586	131	261	119	7.3	2.1	3.3	4.5	0.12	0.16
Tatula 1′	701	159	283	128	4.8	8.4	7.3	7.8	0.70	0.71
Tatula 2	732	125	209	196	7.1	2.6	4.0	5.6	–	0.23
Musa 1	565	117	292	88	8.9	3.3	3.6	4.8	0.04	0.08
Musa 1′	–	–	–	–	8.3	6.7	8.0	9.7	0.41	0.57
Musa 3	590	133	253	135	7.2	3.4	3.5	4.3	0.20	0.25

TDS – total dissolved solids. Nmin – sum of NO_3-N, NO_2-N and NH_4-N

Of primary concerns are those essential elements that potentially limit metabolic processes in streams. These are nutrients (N, P): their uptake, transformation and eventual release.

The predominant sources of nitrogen and phosphorus within the headwaters of the monitored rivers were diffuse and agricultural in nature. Land uses in the upper part of the catchments of the analysed rivers (Levuo, Tatula and Musa) are predominantly rural and agricultural. Data in Table 3 are presented from the sampling sites Levuo 1, Tatula 1 and Musa 1. The concentration of total nitrogen did not exceed the annual average (1991–2000) value – 4.8 mg/l – until the streams reached the point sources of pollution (from urban areas). Below the towns nitrogen, and especially phosphorus, showed both diffuse and point source signals. The contribution of point sources along the gradient of the monitored rivers is evident (Table 3). The Levuo stream is more and more polluted downstream. From its headwaters (Levuo 1), where the Levuo is mostly polluted by diffuse sources (arable area in the catchment is 43%), the contribution of point sources (below the towns of Kupiskis and Pasvalys) along the river increases: at its mouth the Levuo (Levuo 3) becomes heavily polluted with phosphorus (Table 3). Nitrate values are typically elevated by the runoff of agricultural fertilizer while phosphorus values are elevated by the sewage effluent from the towns of Kupiskis and Pasvalys. However, changing geological karst conditions along the river length may also contribute to the longitudinal trend. Total phosphorus concentration is the highest in the Tatula river at Birzai (Table 3), whilst the concentration in the Musa is similar to the Levuo river. Sewage effluents affect all rivers analysed.

Transformations, which are associated with streambed processes, as well as with deposition on stream banks and the floodplain, are the principal mechanisms of retention. Nutrient supply affects biological productivity and biodiversity and will generally influence the supply of nutrients being transported downstream. Figure 3 represents the dynamics of total phosphorus in the karst river Levuo from its headwaters (Levuo 1) to its mouth (Levuo 3). Relatively high ranges of phosphorus concentration indicate that multiple sources (sewage and agriculture runoff) contribute to the pollution of the river.

Time series showing the changes in dissolved oxygen – O_2 and organic pollution – against BOD_7 along the Musa river are presented in Figure 4. Due to the smaller Siauliai sewage inputs discharging into the upper Kulpe, the plot of O_2 against BOD_7 at sampling site

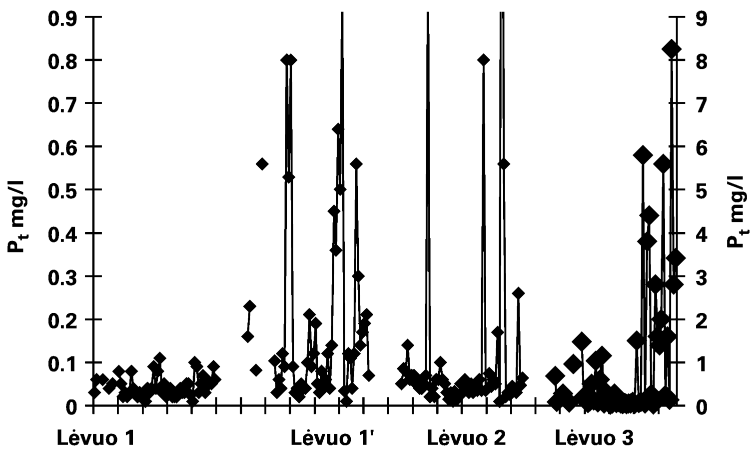

Figure 3 The dynamica of total phosphorus along the Levuo river (average monthly data from 1996–2000): chart scale is different (Levuo 3)

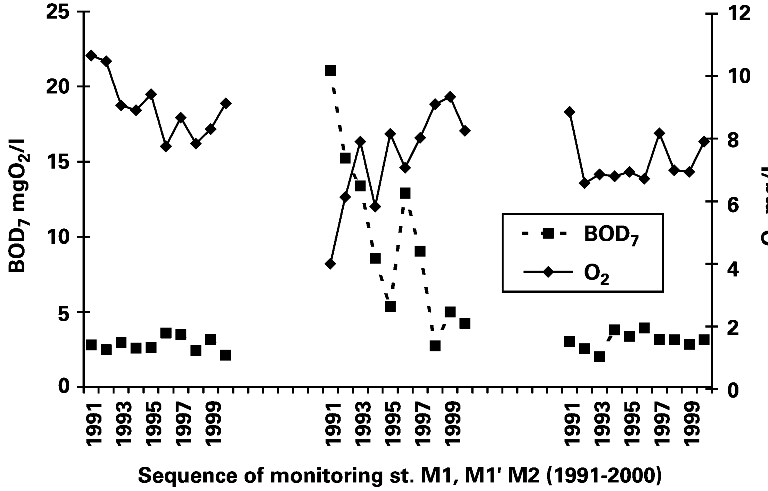

Figure 4 Dynamics of dissolved oxygen (O_2) and level of organic pollution (BOD_7) along the Musa stream. Average annual data from 1991–2000: M1 – above the heavily polluted Kulpe tributary, M1′ – below the mouth of the Kulpe, M2 – below the mouth of the Kulpe (91.5 km)

M1′ (below the confluence of the highly polluted tributary Kulpe with the Musa) showed stream recovery for the period 1996–2000).

After reestablishment of the independence of the Baltic States, Lithuanian agriculture was restructured, due to the sudden decrease in demand for farm products. Agricultural production declined more than 50% in the period of 1990–1994. Thus, the application of both commercial fertilisers and manure has decreased at an unprecedented rate. Due to the efforts of the Lithuanian Government, foreign donors and investors the network of sewage treatment plants has expanded. Despite this, the terrestrial and aquatic ecosystems that control the riverine export have substantial inertia and there is no unequivocal evidence that this change has influenced the riverine nutrient load (Tumas 2000). However, more detailed analysis of point sources shows a decreasing trend of organic pollution (Figure 5): due to the economic situation, operation of the formerly overloaded sewage treatment plant at Siauliai

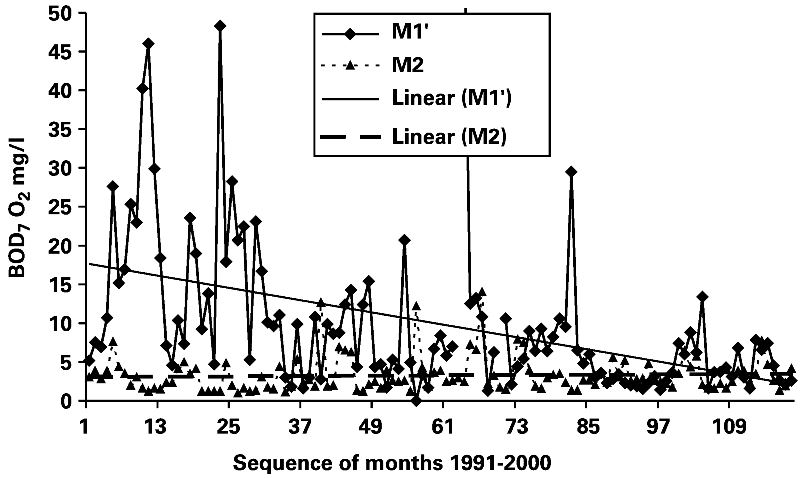

Figure 5 Organic pollution (BOD_7) of the Musa river at the reaches M1′ (6.4 km below the Kulpe tributary) and M2 (91.5 km below the Kulpe tributary)

is improving and the Kulpe tributary of the Musa is gradually becoming less polluted. The trend in organic pollution (BOD_7) is decreasing.

Statistical analysis of dissolved oxygen at both the reaches M1′ and M2 (monthly 1991–2000 data amounts to 120 cases for each) enable us to decompose such time series to make the pattern clearer. In general, a time series can be thought of as consisting of four different components: 1) a seasonal, 2) a trend, 3) a cyclical and 4) an error, or irregular, component. Time series can be additive or multiplicative in nature. The dynamics of dissolved oxygen in the Musa river indicates that the relative amplitude of seasonal changes is constant over time, and thus it is related to the trend. The seasonal pattern repeats every year. In the Census I method (Abraham and Ledolter 1983), the trend and cyclical components are combined into a trend-cycle component (Figure 6).

The trend-cycle of the most polluted Musa reach (M1′) 6.4 km below the confluence with the Kulpe tributary shows low levels of oxygen in 1991–1993, with similar fluctuations in 1994, 1995 and 1996, and a gradually improving situation since 1997. After self-purification of the running water in the lower reach of the Musa river (fixed at gauge station M2) the dissolved oxygen dynamic general multiplicative trend is slightly decreasing (within the limits of accuracy).

Algae growth in lakes is usually limited by the supply of inorganic phosphorus and thus the lake's productivity is primarily a function of phosphorus availability. Nitrogen is considered to be secondary. Phosphorus concentrations in running waters are often above the level that induces a eutrophic state in lakes. This is especially true for larger rivers influenced by human activity and for streams flowing through agricultural land (Allan 1995).

The saprobity index of plankton (both phyto- and zooplankton, Table 1) shows that biological water quality in the upstream of the karst region rivers (where non-point pollution prevails) is favourable for plankton: class IIIA – moderate to slightly polluted (Table 2). In the lower reaches of the rivers (below the towns) living conditions for invertebrates and phytoplankton are worse.

General biological water quality – dynamics of phytoplankton, zooplankton and zoo benthos (Table 1) – follow the pollution by nutrients (Table 3), but no direct relation between pollution with nutrients and biological streamwater quality has been found (Tumas 2001).

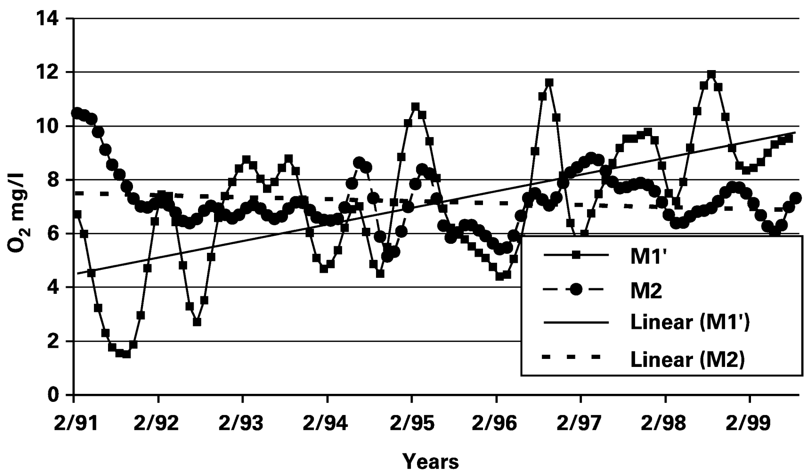

Figure 6 Trend cycles of decomposed dissolved oxygen time series of the Musa river streamwater at the reaches M1′ (6.4 km below the Kulpe tributary) and M2 (after self-purification of running water, fixed at 91.5 km below the Kulpe tributary)

The best living conditions for invertebrates are in the Tatula riverhead (upstream of the town of Birzai) BI = 6.74 (Table 1). Down to its mouth streamwater quality decreases (Tatula 2, BI = 5.9). A similar situation has been established in the Musa river: below the confluence with the polluted Kulpe tributary, in the Musa river running water living conditions for invertebrates are worse (the annual average BI decreased from 6.15 to 4.0). In the middle reach, after self-purification BI = 5.0.

Figure 7 shows the dynamics of the biotic index for last few years: the very polluted reach (below the confluence with the heavily polluted Kulpe tributary) of the Musa river (Musa 2) gradually recovers along the gradient of the stream.

The dependence of the fish community structure and production upon the level of pollution along the stream gradient in the Musa river in the karst region was estimated in 1991–1993 by the Institute of Ecology (Kesminas *et al.* 1994). Over the period mentioned the Musa was the most polluted river in the karst region: the oxygen regime downstream (Musa 2) in 1993 was the lowest (Figures 4 and 6). Seventeen fish species were found and only roach (*Rutilus rutilus*) were present at all sites along the stream gradient. Fish density ranged from 143 to 1970 individuals/ha, with the highest value in the unpolluted upstream sections (Musa 1). Fish biomass ranged from 5.9 to 169 kg/ha and was highest in the eutrophicated middle reaches. Fish production ranged from 2.1 to 55.6 kg/ha/yr and was found to be lowest at the most polluted sites with low oxygen concentration (Figure 6: in 1991–1992 the dissolved oxygen concentration in the Musa 2 river was low) and a favourable level of eutrophication. Roach accounted for 64% of the total fish species production. Production to biomass ratio (P/B) of the roach population decreased from upstream (1.0) to downstream (0.25), depending on the age structure and the extent of river pollution and water eutrophication. The P/B ratio of roach decreased from upstream to downstream and this reflected the impact of pollution and the shift of population age structure towards older fish. In the upstream (Musa 1) less polluted river sections the number of young was higher while in the more polluted reaches older fish dominated.

The mean fish density of 1053 individuals/ha in the Musa river is low. In some Lithuanian rivers of similar size the mean fish density is 2400 individuals/ha, and in some of them, e.g. in the Sventoji river (East Lithuania), it amounts to 7090 individuals/ha.

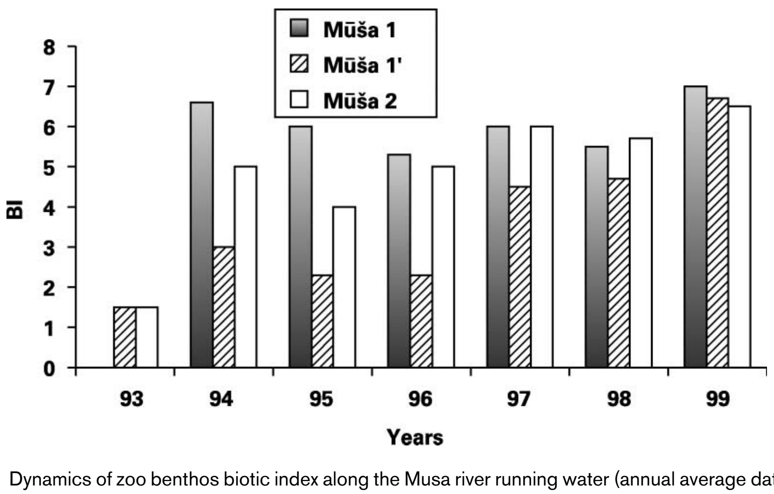

Figure 7 Dynamics of zoo benthos biotic index along the Musa river running water (annual average data): M1 – slight fluctuation in the headwater (where non-point pollution prevails), M1′ – dramatically changes over the years due to point pollution from the city of Siauliai (in the lower reaches of the confluence of the Kulpe tributary) and M2 – fluctuation after self-purification in the lower reach

Conclusions

The composition of total dissolved solids shows that flow in the karst region rivers is through hydraulically interconnected aquifers.

Point sources contribute significantly to the stream pollution with nutrients, in comparison with the non-point pollution from agriculture.

The time series of monthly dissolved oxygen (O_2) in the main karst region river – the Musa (1991–1999) – show existing multiplicative seasonality. The trend cycle shows a low level of dissolved oxygen for 1991–1993, with similar fluctuations in 1994, 1995 and 1996 (due to point pollution from the town of Siauliai) and a gradually improving situation since 1997. The general multiplicative trend of dissolved oxygen in the lower reaches of the Musa river (near the border with Latvia) is decreasing (within the limits of accuracy).

Rare and asynchronous data of zoo benthos show tendencies that invertebrates prefer the less contaminated reaches of rivers (in the upper reaches, where non-point pollution prevails) where living conditions for animals in running water in recent years have been gradually improved.

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