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Impact of agriculture decline on nitrogen and phosphorus loads in Lithuanian rivers

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During the last fifteen years Lithuanian agriculture experienced a drastic decline – the gross agricultural product on the national scale decreased by 40%, the area under crops by 35%, meat production by 69%. In the same period the quantities of mineral fertilizers applied to arable land dropped from 107 and 67 kg ha^{-1} to 15 and 5 kg ha^{-1} per year for nitrogen and phosphorus, respectively.

This paper analyses the impact of the decline of agriculture on nitrogen and phosphorus loads in seven rivers of Lithuania. The catchment areas of these rivers are agriculture-dominated territories located in different regions of Lithuania. The study period covered the years 1991–2000. The seasonal and partial Mann–Kendall tests were applied for detecting trends.

Despite the drastic decrease of agricultural activity, very little evidence was found that the change had influenced riverine concentrations of nutrients. Only one of the seven studied sites showed a statistically significant downward trend (one-sided test at a 5% level) in the total nitrogen and one in the dissolved inorganic nitrogen data. Considering phosphorus (PO_4-P and P_{tot}), temporal changes from only two sites showed statistically significant downward trends. It is suggested that the limited response to agriculture decline is related to a significant inertia of the terrestrial ecosystems that control the loss of nutrients from land to rivers.

Key words: agriculture, rivers, nitrogen, phosphorus, trends, Lithuania

INTRODUCTION

The last fifteen years in Lithuania have been characterized by major political changes. However, the changes were followed by a drastic economical recession. The transition from state-planned to market-oriented economy took place. The most remarkable economical recession was registered in the period 1991–1994 when the gross domestic product (GDP) decreased by 57% in comparison with that in 1989 (Statistical…, 2002).

Gross agricultural production (crop and animal husbandry) decreased substantially. In the period 1990–1994, it decreased by 64%. In 1995–1997, however, an increase was observed. In 1997, the gross agricultural production made 72% and that of crop production 89% of the 1989 level. However, in 1999 the production again deceased correspondingly by 20 and 23% (Žemės ūkio…, 2001). The animal production has been gradually decreasing during the last decade. Due to the lack of markets the volume of milk and meat production decreased by 69% from 1990 to 2001 (Gyvulininkystės…, 2002). The quantities of applied mineral and organic fertilizers decreased significantly as well. In 1990, the average amounts of mineral fertilizers applied to arable land were as follows: 107 kg ha^{-1} of nitrogen, 67 kg ha^{-1} of phosphorus and 115 kg ha^{-1} potassium. In 1992 the application levels were three times lower – accordingly 40, 27 and 49 kg ha^{-1}, and in 1997 they were only 15, 4.9 and 5 kg per ha of arable land (Agriculture…, 2001).

The decline of agricultural production significantly increased the area of non-cultivated land (Povilaitis, 2001). In the last decade the area utilised for crop production decreased from 2.3 to 1.48 million ha (35%). Such a significant economic recession led to decreasing N and P loads in river catchments. One might expect that this should result in a corresponding decrease in riverine loads of N and P, but did it? In this respect, the reported results from various river water monitoring sites differ greatly. Loigu and Vasilyev (1997), Mander and Kull (1997), Pekarova and Pekar (1996) observed a decrease in N concentrations in Estonian and Slovakian rivers, which were explained by a decreased application of fertilizers. Similar tendencies were observed in Hungary in the large agriculture-dominated Tisza river catchment (Olah and Olah, 1996). Unfortunately, most investigations in the rivers Daugava and Lielupe in Latvia and also in the Oder and the Vistula in

Poland showed that a significant decrease of agricultural production did not essentially influence the nitrogen and phosphorus loads of the rivers (Laznik et al., 1999; Tonderski, 1997; Stålnacke et al., 1999). Many researchers indicate that weather conditions and hydrological processes, large groundwater aquifers as well as soils have a stronger limiting influence on nitrogen and phosphorus export from land to the rivers than fertilization (Sileika, 1996; Tumas, 2000; Vagstad et al., 2000; Grimvall et al., 2000; Stålnacke et al., 2003). Due to these factors, river catchments are distinguished by a stronger or weaker inertia in retaining and releasing N and P.

This paper presents the results of a study whose objective was to analyse the impacts of the agriculture decline on trends in nitrogen and phosphorus concentrations in the Lithuanian rivers where agricultural land constitutes the major part of the catchment area.

DATA BASE AND METHODS

Data on nitrogen and phosphorus compounds in seven Lithuanian rivers for the period 1991–2000 were used in this study. Because of low water sampling quality the data before 1991 were not included. The following rivers were chosen for the investigation: the Akmena, the Mūša, the Nevėžis, the Lėvuo, the Šventoji, the Merkys and the Skroblus (Fig. 1). The catchments of these rivers are located in different regions of Lithuania. According to river pollution classification approved in Lithuania, the Skroblus is recognized as a river with minimum (natural background level) pollution (Lietuvos upių…, 2002). The Akmena river upstream the Kretinga town, the Mūša river upstream the mouth of the Kulpė river, as well as the Lėvuo upstream the Kupiškis town, the Nevėžis upstream Panevėžys, the Šventoji upstream Anykščiai and the Merkys upstream Varėna are described as the rivers in which water quality is affected by non-point pollution from agriculture. A brief description of the river catchments and water sampling sites is presented in Table 1.

Water quality data were provided by the Joint Research Centre (JRC) at the Ministry of Environment. Water samples were taken at seven sites once per month according to the sample collection procedures approved by the national environmental monitoring programme. The following parameters were determined in the water samples: concentrations of ammonium nitrogen (NH_4-N), nitrite (NO_2-N), dissolved inorganic (N_{inorg}) and total nitrogen (N_{tot}) as well as orthophosphate (PO_4-P) and total phosphorus (P_{tot}) and biochemical oxygen demand (BOD_7). The analyses of total nitrogen and total phosphorus started in 1993. All chemical analyses were done according to water quality investigation standards (LAND, LST ISO and LST EN) in the laboratory of the JRC. The portion of organic nitrogen in stream water was estimated as the difference between total and inorganic nitrogen.

Transport of nitrogen and phosphorus was calculated by multiplying daily water discharge by daily concentrations. Daily concentrations were estimated by linear interpolation between the values measured at two sampling events. The choice of the linear interpolation method could be justified by its low inter-

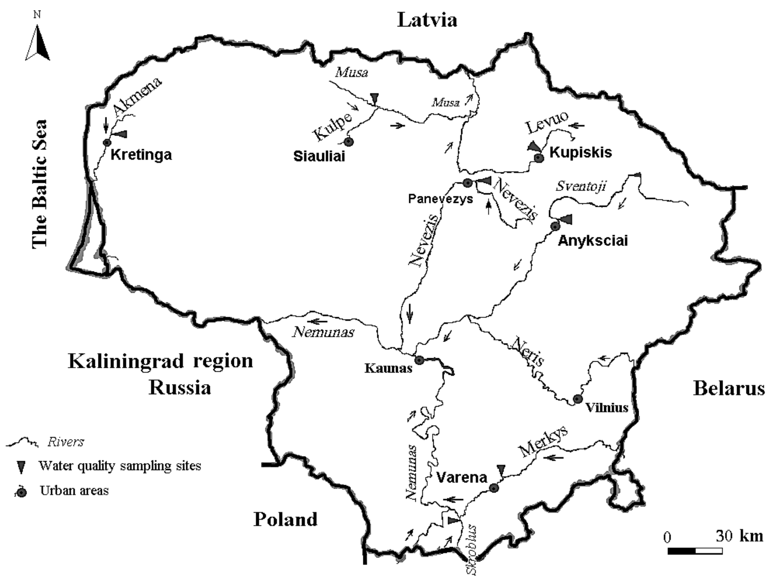

Fig. 1. Location map of study rivers with sampling sites

Table 1. **Description of study sites**

River	Sampling site	Distance from the outlet, km	Catchment area, km^2	Arable land, %	Forest, %	Wetlands, %	Population density, inh./km^2
Akmena	Upstream Kretinga	41.0	193.5	33.8	30.1	0.6	46
Mūša	Upstream Kulpė	137.7	312.0	42.3	27.4	5.6	28
Nevėžis	Upstream Panevėžys	150.3	1052.0	38.1	24.0	6.0	20
Lėvuo	Upstream Kupiškis	109.3	303.3	22.1	12.0	5.0	23
Šventoji	Upstream Anykščiai	89.0	3564.1	35.0	12.4	10.1	19
Merkys	Upstream Varėna	46.0	2872.2	28.1	34.0	9.9	14
Skroblus	At the outlet	0.2	71.0	1.0	94.1	2.0	2

polation error (Tonderski et al., 1995) and robustness compared to, *e.g.*, the ratio estimator, regression or strata methods. Annual transport totals were obtained by accumulating the daily transport values.

The Lithuanian Agrochemical Research Laboratory and State Cadastre office provided site-specific information about the soils in the study areas. Data on land use and agricultural activity in the catchments of the study rivers were obtained from Statistics Department at the Government of the Republic of Lithuania.

Two statistics were used to analyse changes in nutrient concentrations in this study. Therefore, a modified version of the Mann–Kendall test (MK) to account for seasonal variation and the partial Mann–Kendall test (PMK) to detect trends with correction for influencing variable (water discharge) were calculated (Libiseller and Grimvall, 2002).

Data on continuous measurements of daily air temperature, daily precipitation amount and daily water discharge at seven hydro-meteorological stations situated nearby water sampling sites were obtained from the Lithuanian Hydrometeorological Service. Due to a high spatial variability the annual precipitation amount in the Western region was by 25–40% higher than that in other places. The precipitation was most often of acid reaction (pH < 5.5). The average annual nitrogen load from wet deposition varied from 10.6 kg ha^{-1} in the western and 9.12 kg/ha in the eastern parts to 7.4 kg ha^{-1} in the southern part (Oro…, 2001). Monthly concentrations of NO_3-N in precipitation fluctuated from 0.02 to 4.0 mg l^{-1} and those of NH_4-N from 0.005 to 3.47 mg l^{-1}. Statistically significant downward trends at the 5% significance level (one-sided test) in the dynamics of both forms of nitrogen were observed. The seasonal Mann–Kendall statistics varied from –1.85 to –2.10, while the PMK test with correction for monthly precipitation as an explanatory variable was –2.23 and –2.35 for NH_4-N and NO_3-N, respectively.

All the study rivers have mixed water supply. In the catchments of the Akmena, Mūša, Nevėžis and Lėvuo rivers, 30–50% of precipitation is transformed into surface runoff. The groundwater supply makes up to 10% of annual runoff amount. Due to a higher annual precipitation amount, frequent thaws in winter and heavy

Table 2. **Riverine concentrations of nitrogen and phosphorus measured at sampling sites**

Parameter		River						
		Lėvuo	Mūša	Nevėžis	Akmena	Šventoji	Merkys	*Skroblus**
NH_4^+-N mg l^{-1}	Average	0.36	0.27	0.35	0.32	0.26	0.20	*0.13*
	Minimum	0.00$^+$	0.00$^+$	0.00$^+$	0.00$^+$	0.00$^+$	0.02	*0.00$^+$*
	Maximum	2.30	1.70	1.95	1.10	1.21	1.34	*0.40*
	N	116	118	119	118	119	116	*115*
NO_3^--N Mg l^{-1}	Average	1.37	2.67	2.48	1.34	0.86	0.65	*0.29*
	Minimum	0.00$^+$	0.00$^+$	0.00$^+$	0.08	0.07	0.09	*0.02*
	Maximum	5.20	10.5	9.00	3.00	3.20	2.20	*1.60*
	N	116	118	119	118	119	116	*115*
N_{inorg} Mg l^{-1}	Average	1.75	2.98	2.80	1.68	1.13	0.86	*0.43*
	Minimum	0.07	0.03	0.01	0.22	0.14	0.14	*0.04*
	Maximum	6.36	10.6	9.28	3.44	3.56	2.38	*2.01*
	N	116	118	119	118	119	116	*115*
N_{tot} Mg l^{-1}	Average	2.70	5.17	3.67	3.35	1.94	1.38	*0.70*
	Minimum	0.20	0.50	0.50	0.76	0.70	0.60	*0.05*
	Maximum	6.70	24.6	10.5	11.0	7.0	2.80	*2.50*
	N	96	100	95	106	97	97	*90*
PO_4-P Mg l^{-1}	Average	0.044	0.042	0.071	0.033	0.062	0.050	*0.070*
	Minimum	0.001	0.001	0.001	0.001	0.005	0.001	*0.010*
	Maximum	0.245	0.280	1.200	0.18	1.050	0.270	*0.110*
	N	116	118	119	118	116	113	*108*
P_{tot} Mg l^{-1}	Average	0.059	0.085	0.091	0.080	0.119	0.092	*0.110*
	Minimum	0.010	0.020	0.010	0.010	0.030	0.010	*0.030*
	Maximum	0.52	0.60	1.30	0.28	1.43	0.56	*0.20*
	N	96	100	97	106	94	100	*101*
BOD_7 mgO_2 l^{-1}	Average	2.54	2.79	2.01	2.94	1.70	3.42	*2.47*
	Minimum	1.0	0.7	0.7	1.0	0.6	0.9	*0.6*
	Maximum	23.0	15.0	4.7	6.6	4.8	8.7	*5.2*
	N	116	118	119	118	119	116	*115*

* River with minimum (natural background level) pollution; $^+$ Below detection limit; N – number of samples.

Table 3. **Significance of temporal changes in nitrogen and phosphorus concentrations**

River	N_{inorg}		N_{tot}		PO_4-P		P_{tot}	
	MK	PMK	MK	PMK	MK	PMK	MK	PMK
Šventoji	–1.61	–1.63	–1.10	–0.89	**–2.01**	**–2.01**	**–1.86**	**–1.93**
Nevėžis	0.167	0.69	–1.37	–1.09	0.75	–0.26	–0.96	–1.41
Mūša	**2.09**	**2.25**	1.33	1.30	**–1.83**	**–1.75**	–1.60	–1.42
Akmena	0.13	–0.55	**–2.78**	**–2.79**	–0.89	–0.26	–0.34	–0.35
Lėvuo	–0.69	–0.44	–0.63	–0.67	–0.66	–0.70	–1.30	–1.32
Merkys	–0.17	–0.50	0.49	0.04	–0.71	–0.71	–0.53	–0.70
Skroblus	**–2.11**	**–2.28**	0.32	1.33	–0.45	–1.25	0.75	–0.84

Results in bold-face type are statistically significant at the 5% level (one-sided test). MK, Mann–Kendall test; PMK, Partial Mann–Kendall test.

rainstorms in summer, the flow regime in the Akmena is different from those in other rivers. The average annual specific discharge is by 35–50% higher there than in other rivers. The Nevėžis and the Lėvuo rivers are not abounding in water. Flat topography along with soils of high water holding capacity and low (3–8%) groundwater supply dominate in their catchments. The Merkys and the Skroblus rivers have a dominating (up to 30–50%) groundwater supply. Highly water permeable sand and sandy loam soils absorbing melting snow and rainwater are widely spread in their catchments. In the Šventoji river, the groundwater supply reaches 15–25% from annual runoff volume. It is important to note that no statistically significant decrease / increase trends in monthly runoff were detected in the study rivers in 1991–2000. A more evident downward trend (MK = –1.67; $p < 0.050$) was detected in the Nevėžis river only.

RESULTS AND DISCUSSION

Table 2 presents descriptive statistics of nitrogen and phosphorus concentrations and BOD_7 values measured at the sampling sites in the rivers during the study period. The results indicate that compounds of inorganic nitrogen and soluble phosphorus dominate in the water of all rivers.

Table 3 summarizes the results obtained using the MK and PMK methods for trend analysis of the period 1991–2000. Analysis of temporal changes in N_{inorg} revealed only two statistically significant (at a 5% significance level) trends. The downward trend was detected in the Skroblus river and the upward in the Mūša river. The PMK test repeated these findings. The results for N_{tot} revealed significant downward trends ($p = 0.003$) for both statistics in the Akmena river. Temporal changes in N_{tot} concentration showed statistically insignificant trends in the other rivers.

Considering PO_4-P and P_{tot}, downward trends were observed in all the study rivers. However, the MK and PMK tests for PO_4-P detected statistically significant downward trends at two (for the rivers Šventoji and Mūša) of the seven monitoring sites. The greatest significance ($p = 0.020$) was found for the Šventoji river. As for P_{tot}, the results of the MK and PMK were statistically significant ($p = 0.030$) for the Šventoji river only. Different reasons could affect those tendencies.

The impact of natural conditions on nitrogen concentrations is best observed in the Skroblus river. No significant increase / decrease trends in runoff or total nitrogen concentrations were detected in this river. However, a statistically significant decrease (MK = –2.11, $p = 0.020$; PMK = –2.28, $p = 0.010$) is observed in the dynamics of inorganic nitrogen concentrations (Fig. 2). This decrease was most probably caused by a lowered nitrogen load from wet deposition. During the period 1994–1996, in southern Lithuania nitrogen load (NO_3-N + NH_4-N) in precipitation ranged from 8.5 to 10.4 kg ha^{-1} per year, while in 1997–2000 it was only 4.0–7.1 kg ha^{-1}. As podzolic sandy and sandy loam soils dominate in the catchment area of the Skroblus, it has a high precipitation infiltration capacity. Although the river catchment area is relatively small, due to large groundwater aquifers the water residence time is long there. It is supposed that the compounds of inorganic nitrogen are retained in groundwater aquifers and purified (due to the denitrification process) and only then (with some delay) enter the river. Due to the dominating groundwater supply, inorganic nitrogen concentrations in the river are three times lower than in precipitation. These regularities show that nitrogen in precipitation is the main factor determining nitrogen concentrations in the Skroblus river.

Due to a higher precipitation amount than in the other zones the soil in the Akmena river catchment has been periodically soaked. For many years stable organic elements have accumulated in the upper 0–30 cm soil layer (humus content over 4.0%; total nitrogen 0.25–0.30%). In addition to that, until 1990 the arable land of the Akmena catchment received excessive amounts of mineral fertilizers (on average 150 kg N ha^{-1}, 90 kg P ha^{-1} and 200 kg K ha^{-1}) and manure (12–14 t ha^{-1}). However, in the period from 1991 to 2000 a large area (25% from its previous level) of the land was taken out of production. It seems that the decrease of agricultural activity affected the decrease of organic nitrogen in stream water most (Fig. 3c). Intensive processes

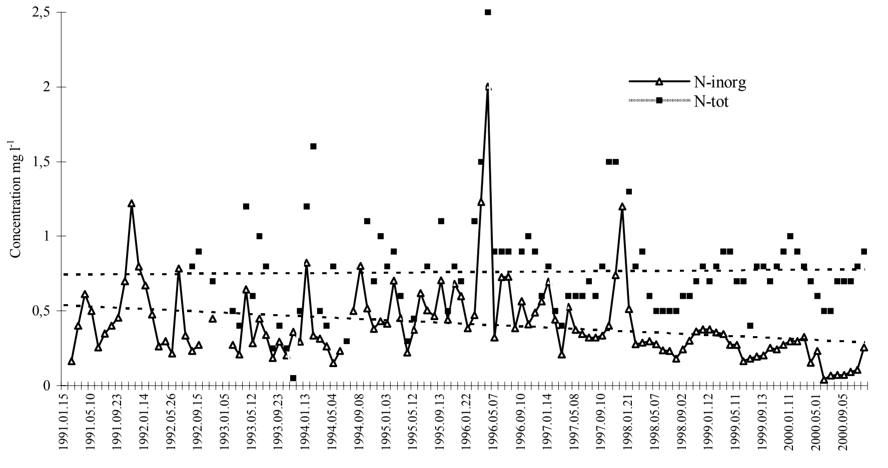

Fig. 2. Inorganic and total nitrogen concentrations in the Skroblus river (dash lines show linear trends for N_{tot} (upper) and N_{inorg} (lower))

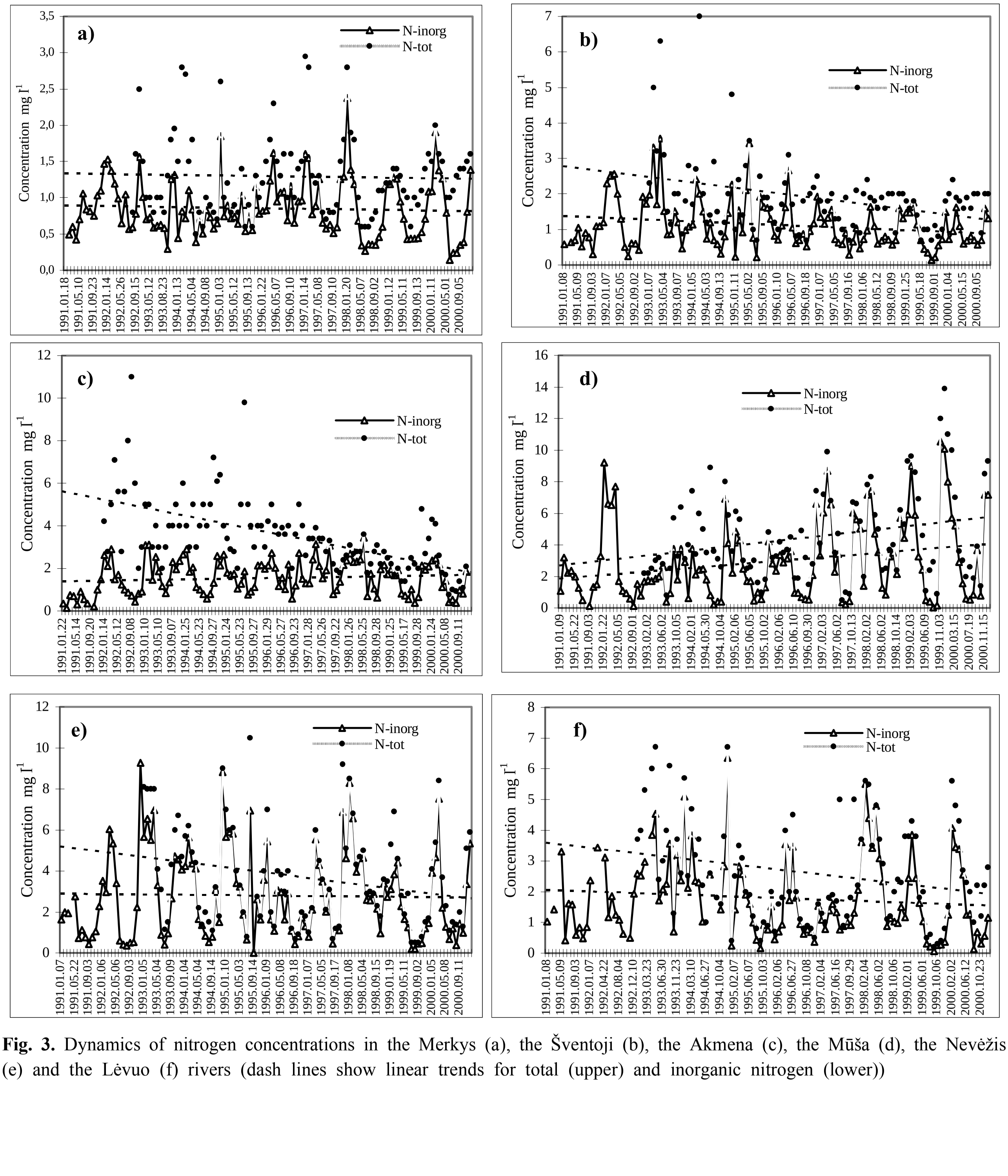

Fig. 3. Dynamics of nitrogen concentrations in the Merkys (a), the Šventoji (b), the Akmena (c), the Mūša (d), the Nevėžis (e) and the Lėvuo (f) rivers (dash lines show linear trends for total (upper) and inorganic nitrogen (lower))

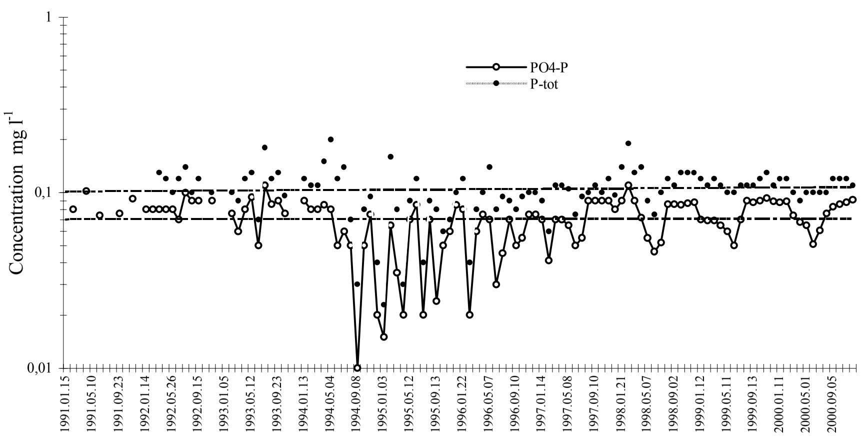

Fig. 4. Concentrations of total phosphorus and PO_4-P in the Skroblus river (y axis is represented on log scale; straight lines show linear trends for P_{tot} (upper) and PO_4 (lower))

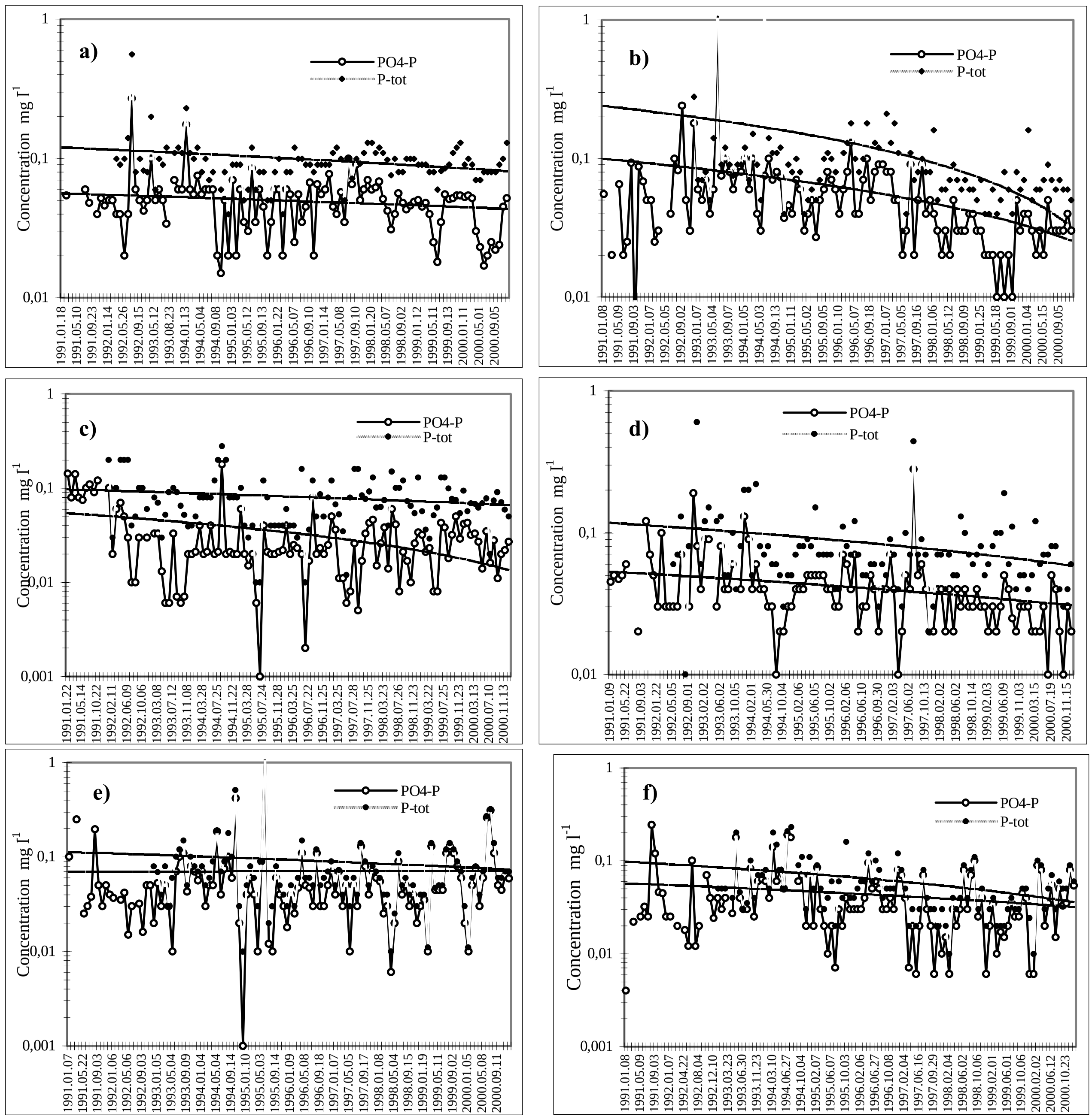

Fig. 5. Dynamics of phosphorus concentrations in the Merkys (a), the Šventoji (b), the Akmena (c), the Mūša (d), the Nevėžis (e) and the Lėvuo (f) rivers (dash lines show linear trends for total phosphorus (upper) and phosphate-phosphorus (lower); y axis is presented on log scale)

of humus decomposition and mineralization in abandoned land may have also started. Therefore, decomposition of organic matter resulted in a slight increase (insignificant upward trend) of inorganic nitrogen.

Although nitrogen load from wet deposition in the Mūša river region decreased, trends in variation of total (insignificant) and inorganic (significant at the 2% level) nitrogen concentrations in the river showed the tendencies to increase (Fig. 3d). Upward trends in nitrogen concentrations are most likely related to intensified agricultural activity. In the investigated part of the Mūša river catchment, fertile sod gleyic medium texture clay loam soils (humus content in 0–30 cm layer over 2.5%, total nitrogen 0.15–0.20%) predominate, therefore, this area has been used for agricultural production for many years. From 1990 to 1995, arable land utilized for crop production decreased by 11% there, however, in 1996 it started increasing again and in 1999 it reached the level of 1991. Therefore, increased agricultural activity (including application of mineral fertilizers) could have remarkably increased the concentrations of inorganic nitrogen – on average from 2.3 (1991–1995) to 3.6 mgN l^{-1} (1996–2000).

Although the area taken by arable land in the Šventoji, the Merkys, the Nevėžis and the Lėvuo river catchments decreased (on average by 30%), no statistically significant trends in nitrogen concentrations were detected (Figs. 3a, 3b, 3e and 3f). This implies that the riverine concentrations of N, rather than by human activity, have been influenced by other factors (soil properties, hydrological conditions and the way nitrogen is released from the soil).

Although there is no farming activity in the Skroblus river catchment, this river contains increased concentrations of orthophosphates and total phosphorus (Table 2). However, neither increasing nor decreasing trends were observed in the variation of PO_4-P and P_{tot} (Fig. 4). The soils predominating in the Skroblus catchment are poor in labile phosphorus (P_2O_5 = 4.2 mg 100 g^{-1}), therefore, the increased and steady phosphorus delivery to the river has most probably been determined by the process of decomposition of organic elements in the forest litter (Tumas, 2000).

In the analyzed period, the riverine loads of phosphorus in the Merkys and the Šventoji were similar (on average 0.12 kg ha^{-1} (PO_4-P) and 0.24 kg ha^{-1} per year (P_{tot})). However, statistically significant downward trends were observed only in the Šventoji (Table 3; Figs. 5a and 5b). In both rivers, groundwater supply makes a significant part of the annual runoff volume, however, the soils predominating in their catchments contain small amounts of phosphorus (P_2O_5 = 3.5–4.4 mg 100 g^{-1}; pH = 4–5). Thus, more equal and steady phosphorus delivery to the Merkys river in the analyzed period was most likely determined by the forest factor. As fertilization was an important source of phosphorus supply to the phosphorus-poor soils in the Šventoji catchment, the reduced amounts of applied fertilizers resulted in a decrease of orthophosphates in the river on average from 0.083 (1991–1995) to 0.042 mgP l^{-1} (1996–2000) and of total phosphorus from 0.161 to 0.083 mg l^{-1}.

Statistically insignificant decreasing trends were observed in PO_4-P and P_{tot} concentrations in the Akmena, the Nevėžis and the Lėvuo rivers (Figs. 5c, 5e and 5f). Soils in the river catchments have a large pool of organic matter, therefore, the amount of total phosphorus (P_2O_5) in the upper 0–30 cm soil layer is high and varies from 0.13 to 0.26% (Mažvila, 1998). Organic phosphates make up to 80% of total phosphorus content in the soil. Most likely these phosphates (along with the P release from riverbed sediments) were among the most important sources of phosphorus delivery to the river. For this reason phosphorus concentrations in the river did not decrease significantly.

In contrast to the observed trends in inorganic nitrogen concentrations, orthophosphate-phosphorus concentrations in the Mūša river significantly decreased (Table 3; Fig. 5d). Soils in the Mūša catchment contain less total phosphorus (0.07–0.13%) in comparison with the Akmena, however, they contain more labile phosphorus (P_2O_5 = 6–9 mg 100 g^{-1} soil) which could easier get into the soil solution and reach the river. Although the agricultural activity in this catchment started to increase from 1996, a surprising decrease in phosphorus (PO_4-P in particular) concentrations in stream water was observed. Most probably it is related to an increased phosphorus uptake by the crops.

CONCLUSIONS

1. Despite the drastic decrease of agricultural activity, no significant trends in riverine concentrations of inorganic and total nitrogen were observed. Only one of the seven sites studied showed a statistically significant downward trend in the total nitrogen and one in the dissolved inorganic nitrogen data.

2. Nutrient retention processes in the agricultural landscape play an important role in controlling changes in the loss of nitrogen from land.

3. Lithuanian soils are humus-rich (2–4% based on dry weight), therefore, the lack of response to agricultural activity decline was most likely related to the continued mineralization of soil nitrogen, which could be a significant source of inorganic nitrogen delivery to stream waters.

4. Changes in agricultural activity have had a significantly stronger impact on the phosphorus than on the nitrogen input to stream waters. However, the absence of significant trends in the time series (only two of seven sites showed to be statistically significant) presumes that factors other than agriculture decline significantly influence phosphorus delivery to stream waters as well.

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Arvydas Povilaitis

ŽEMĖS ŪKIO NUOSMUKIO ĮTAKA AZOTO IR FOSFORO KONCENTRACIJOMS LIETUVOS UPĖSE

S a n t r a u k a
1990–2000 m. Lietuvos žemės ūkis patyrė didelį nuosmukį, todėl azoto ir fosforo apkrovos upių baseinuose mažėjo. Straipsnyje analizuojama, ar sumažėjusi apkrova turėjo esminės įtakos azoto ir fosforo koncentracijų sumažėjimui upių vandenyje.

Darbe panaudoti 1991–2000 m. duomenys apie mineralinio ir bendrojo azoto bei ortofosfatinio ir bendrojo fosforo koncentracijas ir nuotėkio dinamiką septyniose Lietuvos upėse. Analizuojamų upių baseinai yra skirtingo dydžio ir priklauso skirtingoms Lietuvos zonoms pagal gamtines sąlygas ir antropogeninę apkrovą. Jų vandens kokybę lemia pasklidoji žemės ūkio tarša. Biogeninių medžiagų koncentracijų didėjimo / mažėjimo tendencijos įvertintos pagal standartinį ir dalinį Mano–Kendalo (*Mann–Kendall*) kriterijus.

Tyrimai parodė, kad žemės ūkio veiklos sumažėjimas neturėjo esminės įtakos azoto ir fosforo koncentracijų mažėjimui upių vandenyje. Biogeninių medžiagų prietakai į upes būdinga inercija. Ją lemia baseinų miškingumas, dirvožemių cheminės savybės ir humuso kiekis.

Raktažodžiai: žemės ūkis, upės, azotas, fosforas, trendai