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Fluxes of carbon and nutrients through the inflows and outflow of Lake Võrtsjärv, Estonia

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Abstract. We determined the incoming fluxes of total organic carbon (TOC), dissolved inorganic (DIC) and organic carbon (DOC), nitrogen, phosphorus, and silicon via four main inflows into Lake Võrtsjärv and compared these with the outgoing fluxes from the lake during 2008–2009. The discharge and loads of the studied substances from the four main rivers alone were higher than the amounts carried out of the lake in 2008. In 2009, the outflow of water exceeded the inflows and this was the case with the amounts of TOC, DIC, and DOC as well. However, the incoming load of nutrients was continuously higher than the outgoing load. The lake accumulated nutrients (nitrogen, phosphorus, and silicon) irrespective of whether water retention was positive or negative, but the balance between carbon accumulation and carbon emission depended on the lake's water budget.

Key words: carbon, inflows, Lake Võrtsjärv, nutrients, outflow.

Abbreviations: TOC – total organic carbon, DIC – dissolved inorganic carbon, DOC – dissolved organic carbon, TC – total carbon, TIC – total inorganic carbon, DC – dissolved carbon, TN – total nitrogen, TP – total phosphorus.

INTRODUCTION

It has become increasingly important to quantify carbon and nutrient fluxes in the environment owing to their role in the processes of global warming, climate change, and eutrophication of water bodies. Generally, global warming intensifies the hydrological cycle and increases the magnitude and frequency of extreme climatic phenomena, including heavy rainfalls in most parts of Europe (Christensen & Christensen, 2003), which cause abrupt fluctuations in the discharges of rivers (Graham et al., 2006). Concentrations of different substances in river water are related to discharge but this relationship is commonly nonlinear (Volk et al., 2002). High concentrations of dissolved organic matter may occur during floods as well as in low water periods. Although the content of dissolved organic matter is generally high in high water periods, the highest concentrations have been measured at relatively low water (Royer & David, 2005). The same phenomenon was also reported for mineral substances and nutrients (Järvet, 2003; Bärlund et al., 2009).

Lake Võrtsjärv, the second largest lake in the Baltic countries, represents one of the most intensively investigated inland water bodies in Estonia (Haberman et al., 2004 and references therein). The catchment area of the lake is 3104 km^2 and it receives DOC and nutrients via four main inflows (Väike Emajõgi, Õhne, Tänassilma, and Tarvastu).

Earlier calculations of the nitrogen and phosphorus budgets of Lake Võrtsjärv were based on monthly data from 1988–1991 (Nõges & Järvet, 1998), on weekly measurements in 1995 (Nõges et al., 1998), as well as on the annual mean for 23 years (1980–2002) (Järvet, 2004a). A downward trend for the total loadings of nitrogen and phosphorus into Lake Võrtsjärv since the early 1990s was reported by Järvet (2004a), and a downward trend for nutrient concentrations for several inflows was reported by Iital et al. (2010). There are no calculations of silicon loadings into the lake. A single study exists of the temporal dynamics of silicon fluxes into the lake via one inflow (Väike Emajõgi) (Nõges et al., 2008). Tamm et al. (2008) studied the import of DOC into the lake; in their paper the loading of DOC was calculated indirectly from the chemical oxygen demand (COD_{Mn}). Until now there are no data about direct measurements of carbon fluxes into Lake Võrtsjärv.

This study is part of a larger project whose goal was to establish a budget of organic matter and nutrients of Lake Võrtsjärv in order to answer the question whether the lake is a carbon-emitting or a carbon-binding system. The aim of this study was to determine the incoming fluxes of carbon (TOC, DIC, DOC), nitrogen, phosphorus, and silicon into Lake Võrtsjärv via the four main inflows. The main objective was to compare these incoming fluxes with the outgoing fluxes from the lake. We posed the following questions: (i) What is the magnitude of different fluxes? (ii) Which substances does the lake accumulate or release? (iii) Is there any seasonal regularity in the course of fluxes of different substances?

MATERIAL AND METHODS

Lake Võrtsjärv is located in the southern part of Estonia (Fig. 1). Through the outflowing Emajõgi River its catchment area forms a sub-catchment of Lake Peipsi, the fourth largest lake in Europe. Forest and wetlands occupy more than 50% of the catchment area of Lake Võrtsjärv (Table 1). The lake is natural and unregulated. The main four inflows make up about 75% of total discharge from the catchment (Järvet et al., 2004).

Long-term fluctuations and changes of the water level of the lake during the study period are presented in Fig. 2. The years 2008 and 2009 were hydrologically different for Lake Võrtsjärv. From January to December 2008 the water level rose

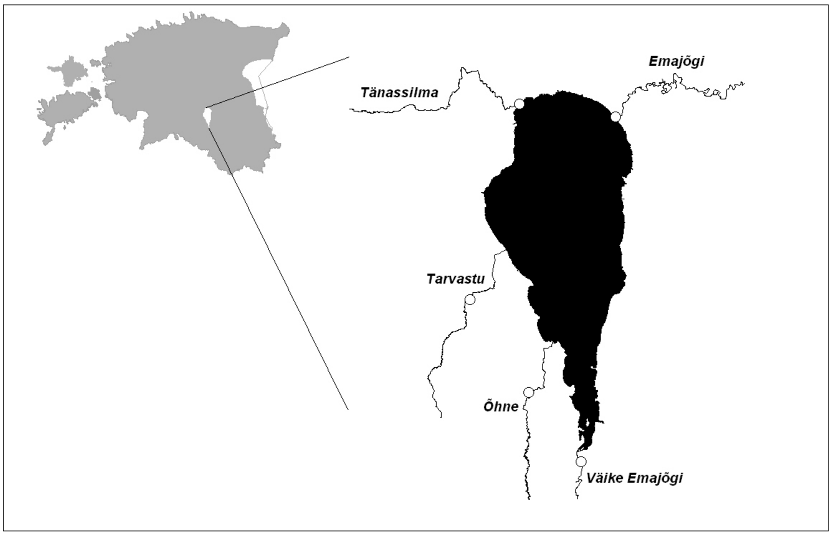

Fig. 1. Sampling stations of the four main inflows and the outflow of Lake Võrtsjärv.

Table 1. River characteristics and land types in the catchment areas according to Järvet (2003)

River	Length, km	Catchment area, km^2	Land type, %			
			Forest	Wetland	Agricultural	Other
Väike Emajõgi	83	1380	61	2	33	4
Õhne	94	573	61	6	32	1
Tänassilma	34	454	57	5	35	3
Tarvastu	22	108	51	0.5	48	0.5

significantly but in December 2009 it was only slightly lower than in December 2008. This means that in 2008 the lake collected water but lost only a small part of it in 2009. In 2008 the annual mean air temperature was 7.2 °C and total precipitation was 875 mm. In 2009 the respective figures were 6.0 °C and 806 mm.

Water samples were collected from the lower course of the inflows and from the outflow of the lake (Fig. 1) at least monthly in 2008 and 2009. Additionally, we used the data of nutrient concentrations drawn from the National Monitoring Programme.

The content of TOC, DIC, and DOC was quantified at the Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, using the TOC analyser and standard methods (ISO 8245, 1987; EN 1484, 1992). All

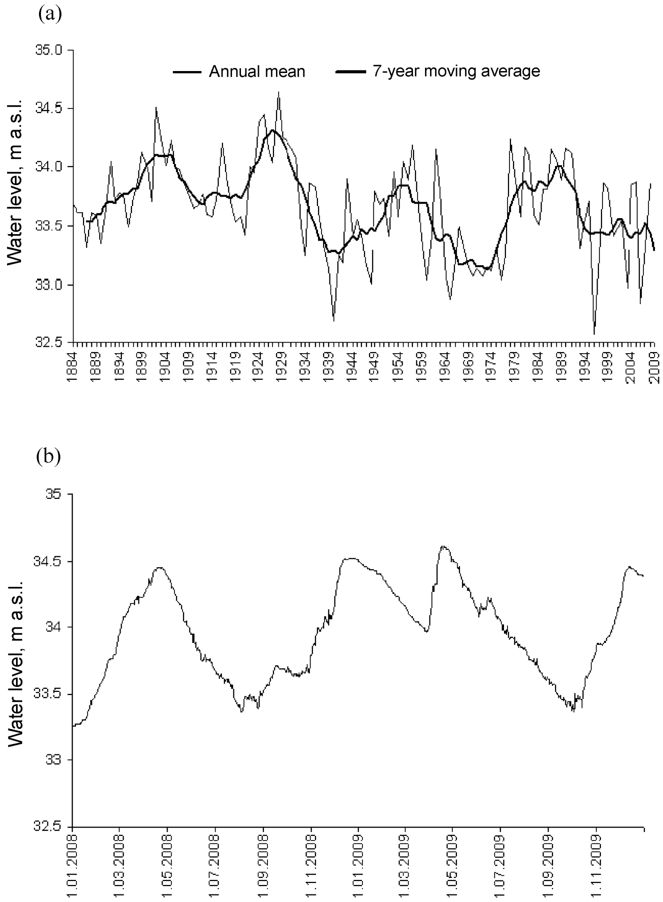

Fig. 2. Long-term fluctuations (1884–2009) (a) and changes during the study period (2008–2009) (b) of the water level of Lake Võrtsjärv (a.s.l. – above sea level).

methods for determining carbon compounds in the water samples were based on the oxidation of organic compounds into carbon dioxide (CO_2), which was then detected quantitatively. The Dr. Lange TOC cuvette tests LCK 380 involve wet chemical oxidative digestion followed by photometric determination of the CO_2. Oxidation of organic compounds took place at 100 °C in the thermostat Hach/Lange LT 200, with a reaction time of 2 h. The CO_2 from the digestion cuvette was passed through a gas-permeable membrane into an indicator cuvette. The resulting colour change in the indicator was evaluated with Dr. Lange photometer DR 2800. We used the difference method: TC – TIC = TOC. Dissolved organic carbon was measured from filtrated water in the same way: DOC = DC – DIC (Kraatz & Wochnik, 1998).

Analysis of the content of nutrients (TN, TP, Si) was carried out in the laboratory of Tartu Environmental Research Ltd. The obtained data are comparable and reliable owing to the implementation of a quality assurance programme and the annual international inter-laboratory testing of chemical laboratories according to the standard ISO/IEC 17025: 2005 for analysing monitoring samples.

Daily flow values and water level data were obtained from the National Monitoring Programme. To calculate the water discharge of the rivers, the daily flow measured in the gauging station of the river was multiplied by a coefficient that considers the distance of the gauging station from the river mouth and the peculiarities of the river basin (Järvet, 2005).

Water chemistry values were linearly interpolated between the sampling dates and the calculated values were multiplied by the values of the daily discharge to obtain daily loads. Further, monthly and annual loads were calculated.

We calculated Spearman's Rank Order Correlations to relate discharges, loadings, and concentrations. Differences at the $p < 0.05$ level were accepted as significant. The software STATISTICA for Windows 8.0 (StatSoft, Inc., 2007) was applied.

RESULTS

The lowest mean and median nutrient and DIC concentrations were recorded in the outflow of the lake (Table 2). The lowest DOC and TOC concentrations were found in the Tarvastu River. The highest DOC and TOC values occurred mostly in the Tänassilma River. The real maximum, however, was registered in the Väike Emajõgi River. The Tänassilma was the richest in phosphorus and the Tarvastu, in nitrogen (Table 2). The concentrations of TN and Si were higher in winter and lower in summer. The spring decrease appeared earlier in the concentration of Si than in TN. The concentration of TP rose from April to January and decreased thereafter. The concentrations of TOC and DOC were higher from June to January and lower from February to June. The seasonal dynamics of DIC was quite indistinct except for a sharp decrease after ice breaks – a phenomenon characteristic of all rivers (Fig. 3).

The daily hydrological load from the four main inflows varied from 0.4×10^6 m^3 (11.06.2008) to 14.7×10^6 m^3 (8.04.2009) and from the outflow, from 0 to 4.2×10^6 m^3 (1.05.2009). The lake had no outflow in the periods 22.01.–23.01.2008, 1.11.–8.11.2008, and 28.10.–29.10.2009 when a backflow (max 0.37×10^6 m^3 d^{-1}) occurred in the Emajõgi. The inflow of water from the four studied rivers predominated over the outflow in winter and spring 2008, in spring 2009, and in some periods in the autumn of both years (see Fig. 4).

In 2008 the annual discharge of the four inflows exceeded the outflow; in 2009, vice versa, the outflow was higher than the inflows. A similar situation was observed for all studied substances (Table 3). In 2008, 21 400 t of TOC, 40 360 t of DIC, and 19 900 t of DOC entered the lake via the four studied rivers. In 2009

Table 2. Ranges of the concentrations (mg L^{-1}) of total organic carbon (TOC), dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), total nitrogen (TN), total phosphorus (TP), and silicon (Si) in the main inflows and in the outflow of Lake Võrtsjärv in 2008–2009

Substance	*n*	Mean	Median	Minimum	Maximum
Väike Emajõgi					
TOC	26	22.53	20.35	12.00	53.40
DIC	26	43.58	45.00	26.50	54.90
DOC	26	18.76	18.55	3.00	47.60
TN	45	1.54	1.50	0.52	3.10
TP	45	0.05	0.05	0.03	0.07
Si	27	2.90	3.00	1.50	4.30
Õhne					
TOC	26	21.88	21.10	11.70	32.30
DIC	26	41.15	44.05	22.00	52.60
DOC	26	19.43	19.55	10.00	30.10
TN	45	1.77	1.70	0.77	3.30
TP	43	0.05	0.05	0.03	0.09
Si	27	2.55	2.50	1.30	4.50
Tänassilma					
TOC	26	23.52	22.50	11.60	37.00
DIC	26	51.85	51.30	34.60	72.20
DOC	26	21.44	21.40	7.10	33.80
TN	45	2.21	2.20	0.57	4.60
TP	45	0.07	0.07	0.01	0.13
Si	27	2.30	2.10	0.30	4.60
Tarvastu					
TOC	26	20.22	16.85	9.40	48.40
DIC	26	51.35	54.00	32.70	64.00
DOC	26	16.95	15.80	2.90	33.40
TN	39	2.62	2.50	0.91	5.10
TP	39	0.05	0.05	0.03	0.08
Si	27	2.60	2.60	1.40	3.90
Emajõgi (outflow)					
TOC	26	21.58	21.95	12.90	36.20
DIC	26	35.72	35.15	28.00	46.70
DOC	26	17.72	18.20	12.00	21.60
TN	51	1.43	1.40	0.28	3.60
TP	50	0.04	0.04	0.02	0.08
Si	36	1.94	2.05	0.17	3.10

the respective amounts were much lower, 18 300 t, 35 300 t, and 15 200 t. Similarly, in 2008 the incoming amounts of nutrients were higher, 2270 t of TN, 49 t of TP, and 2500 t of Si, while in 2009 the respective amounts were 1500 t, 44 t, and 2400 t.

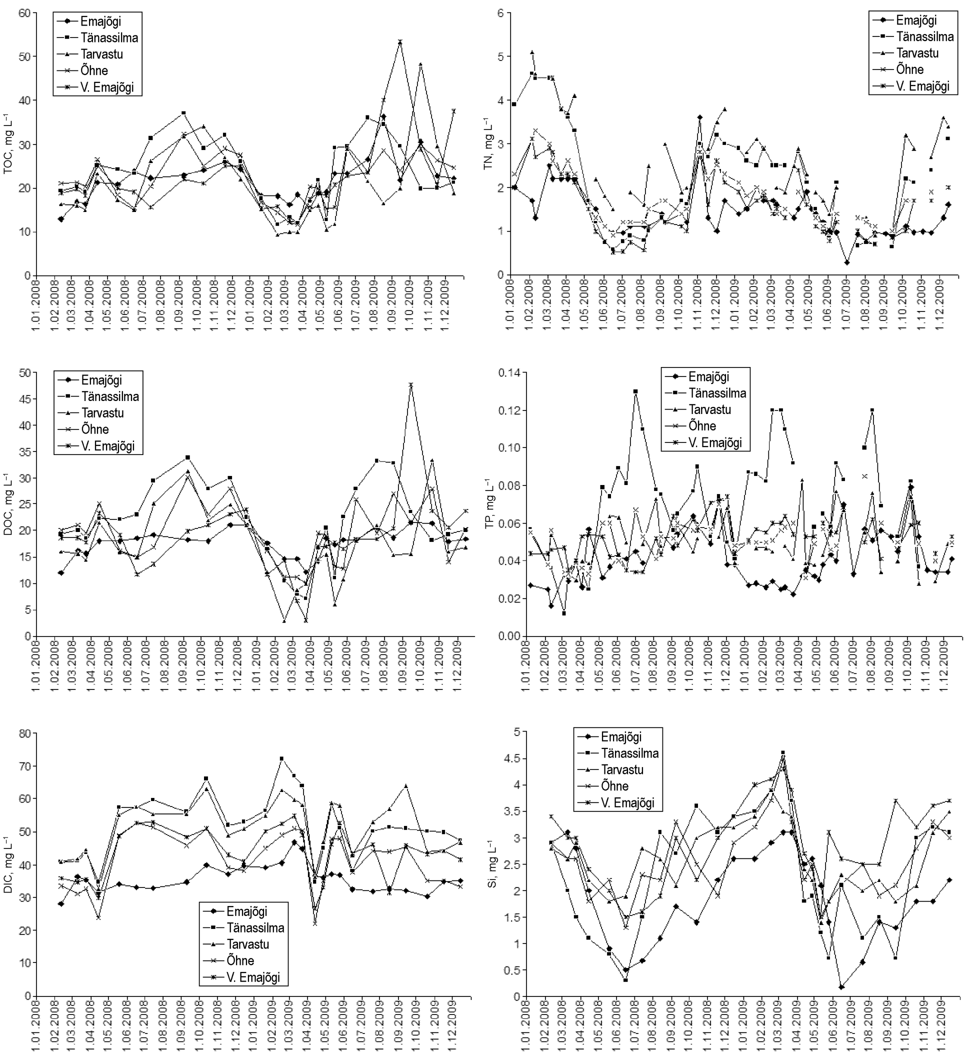

Fig. 3. Dynamics of the concentrations of total organic carbon (TOC), dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), total nitrogen (TN), total phosphorus (TP), and silicon (Si) in the outflow (Emajõgi) and in the main inflows (Väike Emajõgi, Õhne, Tänassilma, Tarvastu) of Lake Võrtsjärv in 2008 and 2009.

Data from 2008 showed that the inflow of water and the studied substances from the four main rivers alone were higher than the respective amounts carried out of the lake. In 2009 the outflow of water exceeded the inflow and this was also the case with TOC, DIC, and DOC. However, the incoming load of nutrients was continuously higher than the load of outgoing nutrients. More detailed data are presented in Fig. 5.

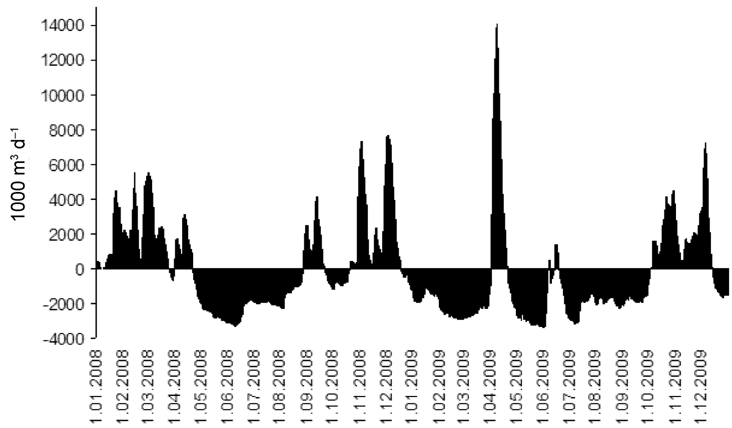

Fig. 4. Daily differences between the sum of discharge from the four main inflows (Väike Emajõgi, Õhne, Tänassilma, Tarvastu) and the outflow (Emajõgi) of Lake Võrtsjärv in 2008 and 2009.

Table 3. Discharge (Q, 10^6 m^3) and loadings (tonnes) of total organic carbon (TOC), dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), total nitrogen (TN), total phosphorus (TP), and silicon (Si) into Lake Võrtsjärve via four main inflows and in the outflow in 2008 and 2009

River	Year	Q	TOC	DIC	DOC	TN	TP	Si
Väike Emajõgi	2008	445	9 490	18 722	8 859	944	24	1 301
	2009	401	9 329	17 378	7 432	668	22	1 302
Õhne	2008	231	5 591	9 139	5 153	534	12	574
	2009	206	4 651	7 836	3 937	343	10	562
Tänassilma	2008	207	5 348	10 369	4 996	632	11	536
	2009	166	3 430	8 119	3 195	383	10	432
Tarvastu	2008	44	981	2 131	896	156	2	122
	2009	39	865	1 924	658	100	2	106
Emajõgi (outflow)	2008	788	17 029	27 484	14 422	1 216	34	1 306
	2009	1 052	23 307	39 197	18 692	1 329	41	1 993

Spearman’s nonparametric correlations were stronger between water discharge and loadings of substances than between concentrations and loadings (Table 4). In some cases, correlations between loadings and concentrations were non-significant or even negative as in the case of DIC in the inflows. There were significant negative correlations (from –0.6 to –0.84) also between DIC concentrations and water discharges in the inflows. We found strong positive correlations

(>0.66) between water discharge and nitrogen concentration. Correlations between water discharge and phosphorus concentration were positive for some inflows, negative for some, and non-significant for some. Correlations between water discharge and TOC and DOC concentrations for the Õhne River were weak but significant.

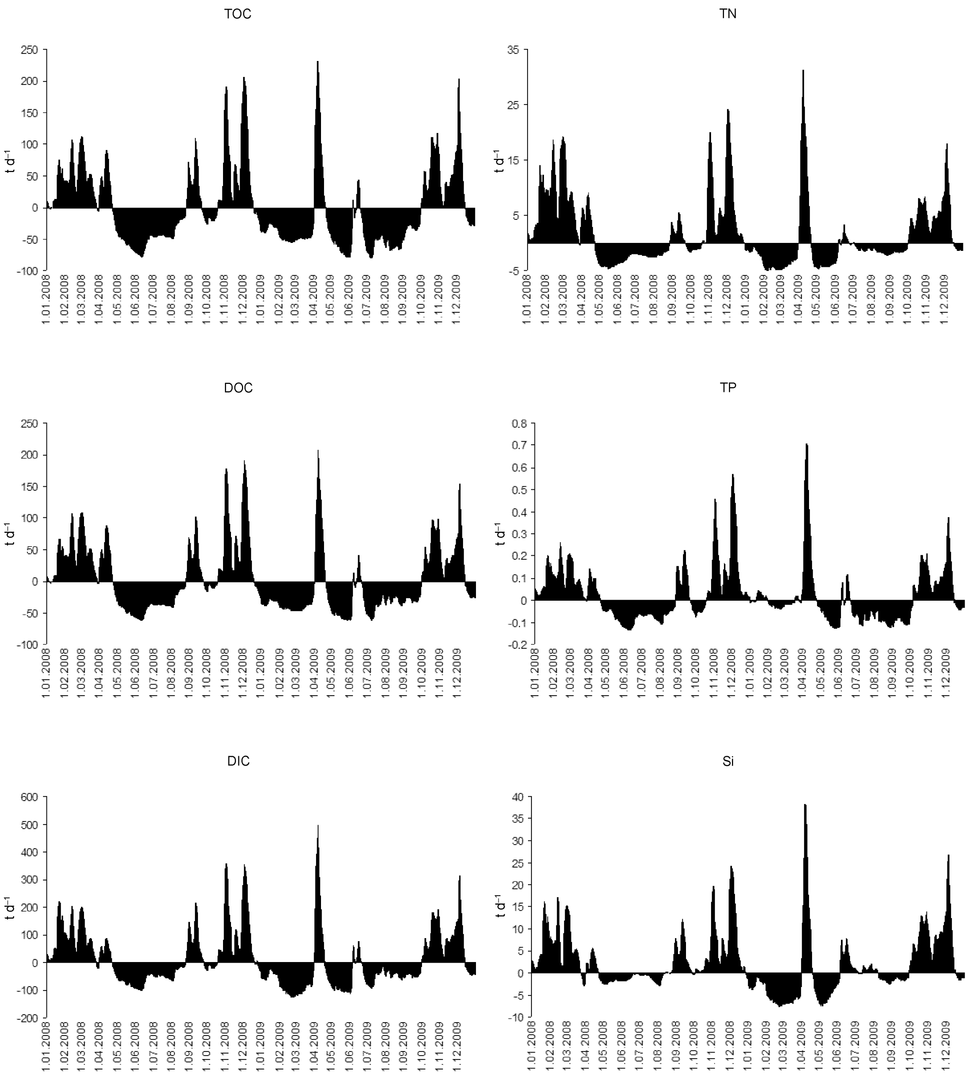

Fig. 5. Daily differences between the sum of loads of total organic carbon (TOC), dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), total nitrogen (TN), total phosphorus (TP), and silicon (Si) in the main inflows (Väike Emajõgi, Õhne, Tänassilma, Tarvastu) and the outflow (Emajõgi) of Lake Võrtsjärv in 2008 and 2009.

Table 4. Spearman's Rank Order Correlations between discharges (Q), loadings (L), and concentrations (C) of total organic carbon (TOC), dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), total nitrogen (TN), total phosphorus (TP), and silicon (Si) in the main inflows and in the outflow of Lake Võrtsjärv; $p < 0.05$, n.s. – not significant

Variable	Correlations between		
	Q and L	Q and C	C and L
Väike Emajõgi			
TOC	0.87	n.s.	0.51
DIC	0.97	−0.72	−0.57
DOC	0.86	n.s.	0.69
TN	0.97	0.82	0.92
TP	0.98	0.34	0.45
Si	0.96	n.s.	0.47
Õhne			
TOC	0.94	0.48	0.70
DIC	0.96	−0.84	−0.69
DOC	0.95	0.47	0.71
TN	0.96	0.71	0.85
TP	0.95	n.s.	n.s.
Si	0.94	n.s.	0.39
Tänassilma			
TOC	0.90	n.s.	n.s.
DIC	0.98	−0.60	−0.49
DOC	0.89	n.s.	n.s
TN	0.93	0.66	0.87
TP	0.79	−0.70	n.s.
Si	0.80	n.s.	0.55
Tarvastu			
TOC	0.87	n.s.	0.66
DIC	0.98	−0.84	−0.74
DOC	0.88	0.27	0.64
TN	0.92	0.69	0.90
TP	0.92	−0.36	n.s.
Si	0.94	n.s.	0.44
Emajõgi (outflow)			
TOC	0.83	n.s.	n.s.
DIC	0.96	n.s.	0.46
DOC	0.91	n.s.	n.s.
TN	0.81	n.s.	0.48
TP	0.58	n.s.	0.56
Si	0.67	n.s.	0.74

DISCUSSION

Already in the first hydrochemical comprehensive study of Estonian water bodies by Simm (1975) it was shown that in our streams the content of inorganic substances is relatively high and the amount of dissolved organic matter never exceeds it. Because of the calcareous bedrock, the continuously higher amount of DIC, compared to DOC, is a characteristic feature of Estonian river waters. In the outflow of Lake Võrtsjärv, the mean concentration of inorganic carbon was twice as high and in the inflows even 2.5 to 3.5 times as high as that of organic carbon (Table 2).

The concentrations of TOC and DOC in the river system studied by us were higher than those reported from a lotic system in Canada (Finlay et al., 2010), from some streams in Germany (Sachse et al, 2005), and from lakes and rivers of Finland (Rantakari et al., 2004; Mattsson et al., 2007) and Poland (Siepak, 1999). Higher DOC concentrations were reported from streams draining peatland systems in Scotland (Dawson et al, 2004); however, a different method was used. The concentration of DIC varied more in our study compared with the study by Finlay et al. (2010).

The loads of DOC into Lake Võrtsjärv via the four main inflows estimated for the period 1990–2002 were 1320–4934 t y^{-1} (Tamm et al., 2008). Differences between our results and those reported by Tamm et al. (2008) are due to different methods used. We calculated the carbon load directly from carbon content, which is a far more exact method than deriving it from the chemical oxygen demand. According to our calculations, the amount of DOC was more than four times higher than reported previously. However, the concentrations of TOC and DOC in our study may be overestimated. In the analysis we used the difference method of Dr. Lange TOC cuvette test and not the purging method (Kraatz & Wochnik, 1998). The used method presumes that the TIC concentration is smaller than the TOC concentration in the water samples. In our samples the TIC concentrations were higher than the respective TOC concentrations. There is an assumption that total carbon analysis may overestimate the organic carbon content in fresh waters in the presence of high DIC (Findlay et al., 2010).

In 1995, 1930 t of N and 57 t of P were introduced into Lake Võrtsjärv (Nõges et al., 1998) and the annual mean values for 23 years (1980–2002) were 2752 t and 78 t, respectively (Järvet, 2004a). In 1995, 986 t of N and 44 t of P were discharged from Lake Võrtsjärv via the outflow (Nõges et al., 1998) and the respective values for the 23-year period were 1729 t and 39 t (Järvet, 2004a). Our results are in good accordance with the findings by Nõges et al. (1998) but show somewhat lower figures than those reported by Järvet (2004a). Here we have to consider the fact that there was a downward trend in the nutrient loadings and concentrations during more than the last 20 years (Järvet, 2004a; Iital et al., 2010). In line with earlier findings (Nõges et al., 1998; Järvet, 2004a), Lake Võrtsjärv accumulated nutrients. We found that also Si has been retained in the lake as in both years the inflow of all N, P, and Si from the four tributaries exceeded their outflow. There were, however, some differences between 2008 and 2009.

In 2008, all incoming fluxes were higher than the outgoing fluxes: only 80% of the introduced TOC was carried out of the lake. For DIC, DOC, TN, TP, and Si, the respective percentages were 68, 72, 54, 70, and 52. As we measured only the fluxes from the four main inflows but not the total flux, the percentages should even be lower. This means that Lake Võrtsjärv accumulated all the above substances in 2008.

In 2009, more carbon was carried out of the lake than was discharged via the four main inflows. Export was 127% for TOC, 111% for DIC, and 123% for DOC. Still, the percentage was lower than 100 for all nutrients: 89, 94, and 83 for TN, TP, and Si, respectively.

Several studies estimated only the concentrations of nutrients and DOC in stream water, without taking account of hydrology (Bernot et al., 2006; Eimers et al., 2008; Goodale et al., 2009; Iital et al., 2010). Discharge, however, is the primary factor determining the fluxes of nutrients and different carbon fractions into lakes. In 2008, when the discharge was 12.5% higher compared to 2009, all studied fluxes were also higher: TOC, 15%; DIC, 13%; DOC, 26%; TN, 34%; TP, 8%, and Si, 5%.

Daily differences between the values of the loads of the studied substances in the four main inflows and the outflow are presented in Fig. 5. In the case of positive values more substances entered than left the lake via the rivers. Negative values in the figure do not indicate that the lake necessarily emitted the substances as we only took into account four inflows. Daily differences in the loads of the substances (Fig. 5) and in the discharge (Fig. 4) vary only slightly and one may conclude that the lowest accumulation takes place in low water periods – in summer and under the ice cover in winter. Nevertheless, it is evident that nutrient uptake, which leads to the accumulation of N, P, and Si in the lake, is more intensive during the vegetation period, i.e. in summer. This was once again confirmed by our study (Fig. 3). As the retention period of water in Lake Võrtsjärv is about one year (Järvet et al., 2004) and the loading of substances is far more discharge-dependent than concentration-dependent (Table 4), comparison of daily differences may lead to confusing conclusions. Therefore, a longer period should be considered.

Our findings are consistent with those of Pastor et al. (2003) and Eimers et al. (2008), who showed that changes in stream flow have an essential impact on concentrations of chemical substances such as DOC. Like in hard-water lakes in Canada (Finlay et al., 2010), hydrologic inputs seem to play a more leading part in carbon fluxes than lake metabolism. It was shown that in Finland weather-driven fluctuation in discharge is the main reason for changes in nitrogen and phosphorus fluxes (Vuorenmaa et al., 2002; Bärlund et al., 2009). Nõges et al. (1998) pointed out that the seasonal dynamics of the load of nutrients (N and P) from the catchment of Lake Võrtsjärv depends on the hydrological load rather than on changes in nutrient concentrations. Also the load of Si is strongly linked to water discharge in the catchment of Lake Võrtjärv (Nõges et al., 2008).

The years 2008 and 2009 were different in respect of the hydrological regime of Lake Võrtsjärv (Figs 2 and 4). In 2008, the outflow accounted for only 91% of the four main inflows and water accumulated in the lake. In 2009, the respective figure was 130%, indicating that more water flowed out of the lake than entered it. The length of the ice-free period in the two years was also different. In 2008, Lake Võrtsjärv froze only for a short period in January, while in 2009 the permanent ice cover lasted until late March. As is evident from Fig. 4, the difference between the inflow and outflow in late winter and early spring was positive in 2008 but negative in 2009. In the warm season differences in the discharges between the study years were not so distinct. The difference was negative from May to August in 2008 and from May to September in 2009. This is in good concordance with the annual mean water balance for Lake Võrtsjärv, which is negative for February, May, June, July, August, and September and positive for the remaining six months (Järvet, 2004b). As the discharge was the more important component of the loading, it is clear why the fluxes of substances differed between the study years.

CONCLUSIONS

Tens of thousands of tonnes of TOC, DIC, and DOC, thousands of tonnes of TN and Si, and tens of tonnes of TP enter Lake Võrtsjärv annually. The lake accumulated nutrients (nitrogen, phosphorus, and silicon) irrespective of whether water retention was positive or negative. However, the balance between the amounts of incoming and outgoing carbon via the rivers was much more dependent on the water budget of the lake. The smallest differences between the incoming and outgoing fluxes occurred in the low water periods in summer and winter. Within the scope of this study we cannot yet answer the question whether the lake is a carbon-emitting or a carbon-binding system. For this purpose, a number of missing components of the carbon budget of Lake Võrtsjärv need to be studied.

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Süsiniku ja toitesoolade koormus Võrtsjärve sissevooludes ning väljavoolus

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On arvutatud nelja peamise sissevoolu (Tänassilma, Tarvastu, Õhne, Väike Emajõgi) kaudu Võrtsjärve tuleva ja sealt Emajõe kaudu väljuva üldise orgaanilise süsiniku (TOC), lahustunud orgaanilise süsiniku (DOC), lahustunud anorgaanilise süsiniku (DIC), lämmastiku, fosfori ning räni koormused kahe aasta jooksul (2008–2009). Aastas tuleb jõgede kaudu järve kümneid tuhandeid tonne TOC-i, DOC-i ja DIC-i; tuhandeid tonne lämmastikku ja räni ning kümneid tonne fosforit. Nii vooluhulk kui ka uuritud nelja jõe kaudu järve kantavate ainete koormused olid 2008. aastal, võrreldes järvest väljakantavate kogustega, suuremad. 2009. aastal aga ületas väljavool neli uuritud sissevoolu nii vooluhulga kui ka süsiniku koormuse poolest. Sissetulev toitesoolade hulk oli aga väljuvast endiselt suurem. Järv akumuleeris lämmastikku, fosforit ja räni, sõltumata järve veebilansist. Süsiniku puhul oli akumuleerumine või järvest väljakandumine rohkem veebilansiga seotud.