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Nutrient budget of Lake Peipsi in 1998

Peeter Nõges[a, b*], Ülle Leisk[c], Enn Loigu[c], Alvina Reihan[d],
Boris Skakalski[e], and Tiina Nõges[a, b]

[a] Institute of Zoology and Botany, Estonian Agricultural University, Võrtsjärv Limnological Station, 61101 Rannu, Tartumaa, Estonia
[b] Institute of Zoology and Hydrobiology, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia; tnoges@zbi.ee
[c] Tallinn Technical University, Department of Environmental Engineering, Ehitajate tee 5, 19086 Tallinn, Estonia; ennloigu@edu.ttu.ee
[d] Estonian Institute of Meteorology and Hydrology, Rävala pst. 8, 10143 Tallinn, Estonia; alvina@hydro.emhi.ee
[e] Russian Hydrometeorological University, Malookhtinski pr. 98, 195196 St. Petersburg, Russia; skak@lake-peipus.net

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Abstract. In the wet year of 1998, Lake Peipsi (3555 km^2) received 23 800 t (67 kg ha^{-1}) of total nitrogen (Ntot) and 1300 t (3.6 kg ha^{-1}) of total phosphorus (Ptot). The area-specific loading of Ntot was higher from the Estonian part of the watershed while that of Ptot was higher from the Russian part. Precipitation contributed 11% of the Ntot load and 4% of the Ptot load. Since 1985–89, Ntot loads had decreased three times but Ptot loads had remained on the previous level. The resulting decrease in the N/P loading ratio has led to heavy blooms of nitrogen-fixing cyanobacteria in recent years. For the lake to reach mesotrophic status, the P load should be decreased 1.7 times.

Key words: water balance, mass balance of nutrients, N/P loading ratio, nutrient retention, Vollenweider's model.

INTRODUCTION

Lakes act as efficient traps for nutrients due to the comparatively long retention time. Over extended periods such as an annual cycle there is a net deposition of P in the sediment even in most eutrophic lakes (Boström et al., 1982). On the other hand, the efficiency of a lake in retaining nutrients reflects its ecological status and processes going on in the ecosystem. In lakes that have received high nutrient loadings for many years, the in-lake concentrations of phosphorus may remain high after even a substantial reduction of external nutrient loading (Marsden, 1989; Jeppesen et al., 1991;). The resistance to restoration is caused by internal

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[*] Corresponding author, tnoges@zbi.ee

loading of nutrients from polluted sediments. Under extreme conditions, P release may last for decades after the effluent was diverted (Jeppesen et al., 1991). Some recovery can be expected in highly enriched shallow lakes with a low hydraulic load during summer.

As a basis for nutrient budget calculations a detailed water budget is needed. First water budgets for L. Peipsi were calculated by Sokolov (1941), monthly water budgets have been regularly computed since 1953 and published in hydrological yearbooks of the former Soviet Union. Since 1994 water budget calculations have been temporarily discontinued due to the absence of source data from the Russian side. The last comprehensive water budget (Gronskaya & Jaani, 2001) is based on data from 1953–93.

Despite several nutrient load estimations from the whole catchment of L. Peipsi (Loigu et al., 1991a, b; Stålnacke et al., 2002) and from the Estonian part (Järvet, 1991; Blinova, 2001), no real nutrient budget has been compiled up to now. The nutrient budget is needed as one of the bases for the ecosystem modelling of the lake.

THE STUDY AREA

As general descriptions of L. Peipsi have been recently published (Nõges et al., 1996; Jaani & Raukas, 1999; Jaani, 2001), we confined ourselves to giving only the most essential data, which the budget is based on. The lake with a total area of 3555 km^2 consists of three parts: L. Peipsi *sensu stricto*, L. Pihkva (L. Pskov), and the narrow river-shaped L. Lämmijärv (L. Teploe) connecting the two larger parts. All three parts of the lake are divided between Estonia and Russia by the border line (Table 1).

For calculation purposes, the drainage basin can be divided between L. Peipsi *s.s.*, L. Pihkva, and L. Lämmijärv as given in Table 1. However, in reality the three parts of the lake are arranged hierarchically so that the drainage basins of lakes Pihkva and Lämmijärv are, at the same time, sub-basins of L. Peipsi *s.s.*, where the two lakes figuratively act as settling ponds. The whole drainage basin is divided between three countries: Estonia, Russia, and Latvia (Table 2).

Table 1. General morphometric parameters of L. Peipsi, its different parts, and catchment. Division of the aquatory of the lake between countries

Parameter	L. Peipsi	L. Pihkva	L. Lämmijärv	Total
Total area, km^2	2611	708	236	3555
Estonian aquatory, km^2	1442	10	118	1570
Russian aquatory, km^2	1169	698	118	1985
Mean depth, m	8.3	2.5	3.8	7.1
Maximum depth, m	12.9	15.3	5.3	15.3
Volume, km^3	21.79	0.60	2.68	25.07
Drainage basin area, km^2	13 158	28 130	2957	44 245

Table 2. Division of the catchment of L. Peipsi between countries

Country	Area including the lake		Area without the lake	
	km^2	%	km^2	%
Estonia	16 323	34.1	14 753	33.3
Russia	27 917	58.4	25 932	58.6
Latvia	3 560	7.4	3 560	8.0
Total	**47 800**		**44 245**	

MATERIAL AND METHODS

The water budget was calculated according to the equation

$$I + P - E - O \pm \Delta V \pm BE = 0, \tag{1}$$

where I – inflow;
P – precipitation on the lake surface;
E – evaporation from the lake surface;
O – outflow from the lake;
ΔV – change in the lake volume;
BE – budget error.

Traditionally, the riverine inflow is calculated as the sum of measured discharges at gauging stations plus the discharge from the non-monitored area, to which the average specific runoff is applied (Eipre, 1983). For the nutrient load calculations, the algorithm was slightly modified. In the rivers for which water quality data were available (Table 3), the discharges measured at gauging stations were

Table 3. Areas of the river basins (according to Jaani, 2001) used in the nutrient budget calculations for L. Peipsi

Basin	Drainage area		Area upstream of the gauging station, km^2	
	km^2	%		
Velikaya R.	25 200	57.0	20 000	(Pyatonovo)
Võhandu R.	1 420	3.2	1 130	(Räpina)
Piusa R.	796	1.8		
Zhelcha R.	1 220	2.8	791	(Yamm)
Avijõgi R.	392	0.9	366	(Mulgi)
Omedu/Kääpa R.	627	1.4	282	(Kose dam)
Alajõgi R.	150	0.3	140	(Alajõe)
Emajõgi R.	9 745	22.0	7 850	(Tartu)
Rannapungerja R.	601	1.4	313	(upstream of Tagajõgi)
Non-monitored rivers	4 094	9.3		
Total	**44 245**	**100**	**30 872**	
L. Peipsi	3 555			
Narva R.	47 800			

extrapolated to the river mouths by applying the measured specific runoff. For the Piusa River, on which runoff measurements were stopped in 1996, the discharge was calculated on the basis of the neighbouring Võhandu River using the method of analogy. The discharge from the remainder 9.3% of the catchment was calculated by applying to it the average specific runoff from the measured part.

The amount of precipitation to the lake surface was calculated as the average of four measuring points at Vasknarva, Mustvee, Praaga, and Mehikoorma (Fig. 1). Seasonal changes in the lake surface area depending on the water level were taken into account.

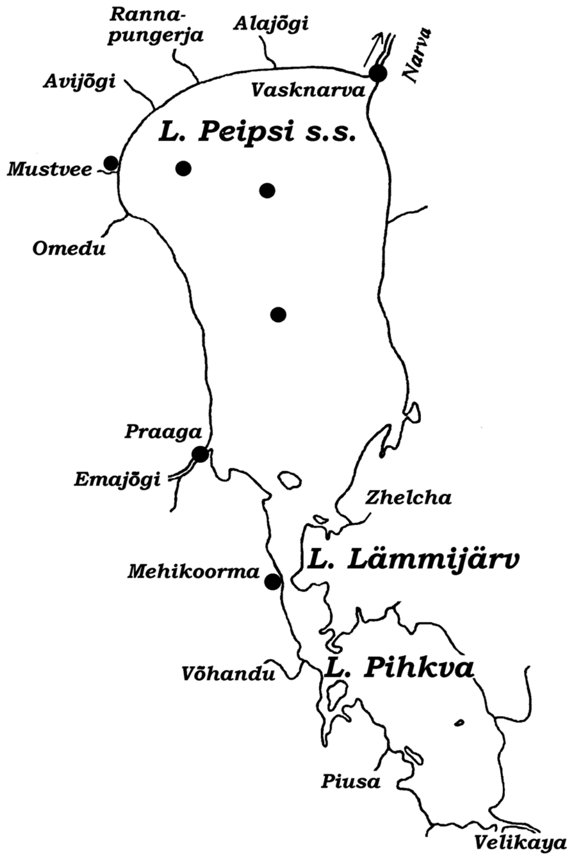

Fig. 1. L. Peipsi and the rivers whose runoff and water quality data were used to build the budget. Dots on the shoreline show the places of precipitation and water level measurements, dots in the lake show the stations from which nutrient concentrations were used to calculate the mean values for L. Peipsi *s.s.*

The evaporation for winter months was calculated according to the equation of Kuzmin (1953):

$$E = 24n\,(0.0075 + 0.0041W_{1000})\,(e_0 - e_{200}), \tag{2}$$

where E – evaporation, mm month^{-1};
n – number of days in a month;
W_{1000} – wind speed at 1000 cm above the surface, m s^{-1};
e_0 – pressure of water vapour at the snow surface calculated from the snow surface temperature, mbar;
e_{200} – pressure of water vapour (absolute humidity) at 200 cm above the surface, mbar.

For summer, evaporation was calculated according to the equation given by Eipre (1983):

$$E = 0.14n\,(e_0 - e_{200})\,(1 + 0.72W_{200}), \tag{3}$$

where W_{200} is wind speed at 200 cm above the surface (m s^{-1}).

The outflow from the lake was measured at the Vasknarva gauging station on the Narva River. Change in the lake volume was calculated as the difference between the end and the beginning of a month (or year), and the lake volume was found from the regression relating it to the absolute water level (above sea level):

$$V = 3.715WL - 86.391 \qquad (R^2 = 0.999), \tag{4}$$

where V – lake volume, 10^6 m^3;
WL – absolute water level, m.

The regression formula was developed on the basis of data presented in appendices 2.1 and 2.2 in the monograph edited by Sokolov (1983). In order to avoid errors caused by seiches (incline in water surface), the weighted average water level of four stations located at Mustvee, Praaga, Mehikoorma, and Vasknarva (Fig. 1) was taken as the basis for calculations. The budget error (*BE*) showing the difference between budget-based and water-level-based accumulation was calculated as the difference between the ‘plus’ and ‘minus’ parts of the budget (Table 4) and the error percentage was calculated from the part that happened to be larger. For example, the error percentage for September and November (Table 5) was calculated from the negative part, in all other months from the positive part of the budget.

All elements of the water budget were calculated in 10^6 m^3. The relative error (*BE%*) was calculated as the percentage of *BE* from the total water input.

Monthly mean nutrient concentrations (NH_4-N, NO_x-N, Ntot, PO_4-P, Ptot, Si) were available for all rivers included in Table 3 except the Zhelcha, to which concentrations of the Võhandu River were applied. The non-monitored area was divided proportionally between the sub-catchments of lakes Peipsi, Lämmijärv,

Table 4. 'Plus' and 'minus' part of the water budget. In the phase of the increasing water level (**A**), the water income covers both the loss and the increase in the lake volume while in the phase of the decreasing water level (**B**) losses exceed the water income by the change in the water volume

<table>
<tr><td>A</td><td>(+)</td><td colspan="2">Income</td></tr>
<tr><td></td><td>(–)</td><td>Loss</td><td>ΔV</td></tr>
<tr><td>B</td><td>(+)</td><td>Income</td><td>ΔV</td></tr>
<tr><td></td><td>(–)</td><td colspan="2">Loss</td></tr>
</table>

Table 5. Monthly water budget (in 10^6 m^3) of L. Peipsi in 1998. Annual positive and negative parts of the budget are calculated from the annual hydraulic load, annual loss, and annual change in volume and are not equal to the sums of monthly values

Month	River discharge	Precipitation	Total hydraulic load	Outflow (uncorrected)	Outflow (corrected)	Evaporation	Total loss	Change in volume	Positive part of the budget	Negative part of the budget	Budget error in volume (outflow uncorrected)	Budget error in percent (outflow uncorrected)	Budget error in percent (outlow corrected)
1	1 384	155	1 539	739	828	0	739	565	1 539	1 304	235	15.3	9.5
2	1 015	147	1 163	755	845	0	755	108	1 163	863	300	25.8	18.0
3	1 581	72	1 653	975	1 092	29	1 004	432	1 653	1 436	217	13.1	6.0
4	1 818	128	1 946	1 070	1 199	91	1 161	666	1 946	1 827	119	6.1	–0.5
5	1 098	275	1 372	1 235	1 383	178	1 412	–185	1 557	1 412	145	9.3	–0.2
6	1 337	508	1 845	1 159	1 298	157	1 316	297	1 845	1 613	232	12.6	5.1
7	2 180	510	2 690	1 320	1 479	179	1 499	1 083	2 690	2 582	108	4.0	–1.9
8	1 432	512	1 944	1 414	1 584	219	1 633	79	1 944	1 712	232	11.9	3.2
9	1 168	114	1 282	1 361	1 524	274	1 634	–235	1 517	1 634	–118	–7.2	–21.9
10	993	253	1 246	1 502	1 683	140	1 642	–661	1 907	1 642	264	13.9	6.8
11	870	50	920	1 382	1 547	45	1 427	–228	1 148	1 427	–278	–19.5	–48.3
12	667	213	880	1 277	1 431	0	1 277	–668	1 548	1 277	271	17.5	13.3
Year	**15 542**	**2 937**	**18 479**	**14 189**	**15 891**	**1 311**	**15 500**	**1 253**	**18 479**	**16 753**	**1 727**	**9.3**	**0.1**

and Pihkva, and the average nutrient concentrations measured in the inflows to these lakes were applied to the non-monitored parts.

The atmospheric loading of nutrients by precipitation was calculated on the basis of monthly measured concentrations of NH_4-N, NO_x-N, and PO_4-P in rain and snow at Tiirikoja. As bulk values were used at Tiirikoja, the estimates include both wet and dry deposition of nutrients. We assumed that the atmospheric loading consists only of inorganic forms of nutrients. No data on soluble silicon in precipitation water were available; thus, its budget is based only on riverine data.

We used the model of Vollenweider (1969) to predict the average nutrient concentrations in the lake:

$$C_{\mathrm{N,P}} = L_{\mathrm{N,P}} t_{\mathrm{w}} \big/ z\,(1 + t_{\mathrm{w}}^{0,5}), \tag{5}$$

where $C_{\mathrm{N,P}}$ – annual mean concentrations of Ntot and Ptot in the lake, g m^{-3};
$L_{\mathrm{N,P}}$ – annual load of Ntot and Ptot to the lake, g m^{-2} y^{-1};
t_{w} – water renewal time (volume/hydraulic load), y;
z – mean depth of the lake, m.

RESULTS AND DISCUSSION

Water budget

The initial water budget calculated on the basis of original input data was unbalanced and showed systematically larger accumulation, which exceeded the real values in almost all months (Table 5). The annual discrepancy of 1727×10^6 m^3 made up nearly 10% of the balanced parts and exceeded, for example, the amount of annual evaporation. As the amounts of evaporation and precipitation were realistic (at least not twice under- or overestimated), some of the runoff data should have been erroneous. In order not to include the error of the water budget to the nutrient budget, we made a correction to the outflow. The annual water budget appeared to be well balanced after multiplying the outflow by a factor of 1.12, although the errors for September and November increased (Table 5).

Considering the mean volume of the lake in 1998 equal to $26\,419 \times 10^6$ m^3 and the total outflow of $14\,189 \times 10^6$ m^3 y^{-1} ($15\,891 \times 10^6$ m^3 y^{-1} in the corrected version), the water exchange coefficient was 0.54 y^{-1} (0.60 y^{-1}) and the hydraulic retention time 1.86 y (1.66 y).

The year 1998 was cool and wet. The amount of precipitation in spring and summer exceeded the norm nearly twice. Compared to earlier water budgets (Table 6), the amount of precipitation was similar to that of the wet year 1990 but the evaporation was smaller by 41%. Probably the precipitation was unevenly distributed in the catchment and it rained more in the close vicinity of the lake. The discharge of large rivers draining the peripheral parts of the catchment was much smaller (by 19%) in 1998 compared to 1990 while the runoff from the rest of the catchment was almost equal in these years.

Table 6. Comparison of the annual values of the present water budget in 10^6 m^3 (with non-corrected and corrected by factor of 1.12 outflow values) with budgets by Gronskaya & Jaani (2001)

Component	Present non-corrected	Present corrected	Average 1953–93	Wet year 1990	Dry year 1973
Large rivers at gauging stations	9607	9607	6143	11 876	3495
Remainder part of the catchment	5930	5930	4077	6104	2643
Precipitation	2937	2937	2319	2925	1800
Total input	18 474	18 474	12 539	20 905	7938
Outflow	14 189	15 891	10 385	16 401	5087
Evaporation	1311	1311	1784	2220	1835
Total output	15 500	17 203	12 169	18 621	6922
Accumulation (calculated)	2974	1271	370	2284	1016
Accumulation (real)	1253	1253	24.7	2989	560
Budget error	1721	18	345.3	–705	456
Budget error, %	9.3	0.1	2.8	–3.4	5.7
Large rivers/remainder inflow	1.6	1.6	1.5	1.9	1.3

Nutrient budget

Our calculations showed that in 1998 the lake received nearly 24 000 tonnes of nitrogen, more than 1200 tonnes of phosphorus, and nearly 44 000 tonnes of silicon (Table 7). The contribution of atmospheric loading made up more than a half (52%) of the total loading of ammonium (Fig. 2) and 16% of that of NO_x. The role of calculated atmospheric loading in the total loading of nitrogen and phosphorus (Ntot and Ptot) was, correspondingly, 11 and 4%. As data on precipitation chemistry were available only for the Tiirikoja station (Table 8), located not far from the industrial area of NE Estonia, the nutrient loadings by precipitation may be overestimated. However, a comparison with independent estimates from neighbouring areas shows a rather good agreement. According to EMEP Report to HELCOM (http://www.emep.int/helcom2001/), in 1998 the catchments of the Gulf of Finland and the Gulf of Riga received from the atmosphere 404 and 734 mg N m^{-2} y^{-1}, respectively. By applying these loadings to the 3555 km^2 area of L. Peipsi, the lake would have received 1436 or 2609 tonnes of N during 1998. The estimate of 2563 tonnes of N made on the basis of data from the Tiirikoja station (Table 9) fits well into this range. The riverine loadings (21 256 t N and 1230 t P) calculated by us are in good accordance with the loading estimates by Stålnacke et al. (2002) for the years 1995–98 (20 500 t N and 910 t P).

The role of the Emajõgi River in the NO_x-N load was twice as high as its proportion in the total water discharge (Table 9). Sixty percent of Ptot load entered the lake by the Velikaya River, whose contribution to the total hydraulic load was 50%. The combined contribution of other rivers remained between 12 and 24% of the loading of different nitrogen and phosphorus compounds.

Table 7. Total (riverine + atmospheric) loading (t/month) of nutrients into L. Peipsi in 1998

	NH_4-N	NO_x-N	Norg	Ntot	PO_4-P	Porg	Ptot	Si 1999
January	165	775	743	1 683	25	103	127	4 739
February	109	660	891	1 661	18	67	85	3 647
March	108	1 205	1 393	2 706	53	95	148	5 940
April	215	1 101	1 203	2 520	80	62	142	4 423
May	108	894	790	1 793	57	39	97	1 869
June	82	1 302	1 160	2 544	58	49	107	2 475
July	170	689	2 223	3 083	43	103	146	5 650
August	134	625	1371	2 131	64	54	118	4 324
Sepember	63	628	831	1 522	82	53	135	3 372
October	130	626	390	1 146	26	31	58	2 375
November	326	1 005	478	1 809	31	27	59	2 690
December	121	640	401	1 162	34	27	61	2 471
Total t/year	**1 733**	**10 152**	**11 873**	**23 759**	**571**	**711**	**1 281**	**43 975**

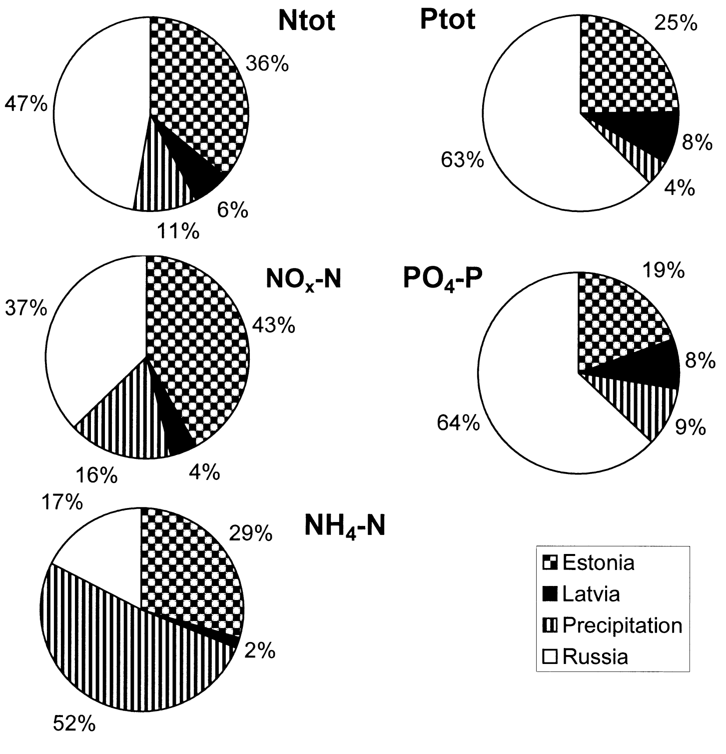

Fig. 2. Distribution of estimated nutrient loads to L. Peipsi between the atmosperic source and countries forming the catchment.

Table 8. Mean concentrations of inorganic nutrients measured in precipitation water collected with wet + dry deposition samplers at Tiirikoja in 1998

Month	NH_4-N, mg L^{-1}	NO_3-N, mg L^{-1}	PO_4-P, mg L^{-1}
January	0.45	0.67	0.007
February	0.2	0.46	0.004
March	0.58	1.24	0.001
April	0.77	0.63	0.007
May	0.16	0.3	0.001
June	0.04	0.63	0.005
July	0.13	0.14	0.005
August	0.15	0.19	0.055
Sepember	0.06	0.22	0.002
October	0.38	0.41	0.005
November	0.55	0.94	0.012
December	0.3	0.76	0.042

Table 9. The breakdown of the hydraulic and nutrient loads to L. Peipsi between the main sources

Source	W, 10^6 m^3 y^{-1}/%	NH_4-N, t y^{-1}/%	NO_x-N, t y^{-1}/%	Ntot, t y^{-1}/%	PO_4-P, t y^{-1}/%	Ptot, t y^{-1}/%	Si, t y^{-1}/%
Velikaya R.	9 229/50	223/13	3 163/31	10 308/43	339/59	775/60	23 989/55
Emajõgi R.	2 833/15	413/24	3 031/30	5 632/24	48/8	206/16	7 065/16
Other rivers	3 480/19	209/12	2 298/23	5 283/22	135/24	252/20	12 921/29
Precipitation	2 937/16	889/52	1 674/16	2 563/11	53/9	53/4	0/0
Total	**18 479/100**	**1 734/100**	**10 167/100**	**23 786/100**	**575/100**	**1 286/100**	**43 975/100**

Area-specific losses of inorganic and total nitrogen were higher from the Estonian part of the catchment area while phosphorus losses were higher from the Russian side (Table 10). A comparison of the losses from 1 ha of the catchment with loadings to 1 ha of the lake area shows that the nutrients are approximately 10-fold concentrated in the lake.

Table 10. Annual area-specific losses of nutrients (kg ha^{-1}) from the Estonian and Russian parts of the catchment and annual area-specific loading to the lake (kg ha^{-1})

	NH_4-N	NO_x-N	Norg	Ntot	PO_4-P	Porg	Ptot	Si
Estonia	0.35	2.88	2.58	5.81	0.07	0.14	0.22	10.26
Russia	0.12	1.46	2.74	4.31	0.14	0.17	0.31	9.82
Load	4.9	28.6	33.4	66.8	1.6	2.0	3.6	123.7

The ratio in which the main nutrients, nitrogen and phosphorus, are loaded to the lake is a crucial point for the ecosystem. At low N/P ratios N_2-fixing cyanobacteria get a competitive advantage and may cause heavy water blooms (Smith, 1983). According to an earlier estimate for the period 1985–89 (Loigu & Leisk, 1996), the load of total N to L. Peipsi was 55 350 t y^{-1} and that of total P 1163 t y^{-1}, resulting in a N/P ratio of 48. The N load in 1998 was less than a half of the earlier estimate, but the P load showed even a small increase. The total N/P mass ratio varied from 11 to 31 in different months and was on average 19. The ratio of inorganic forms of nitrogen and phosphorus reflects generally better the availability of these nutrients to phytoplankton. The inorganic N/P ratio in the inflowing water reached its highest values (>40) during January and February at the time when it was low at the outflow (Fig. 3). The opposite situation was observed temporarily in April and May followed by a 6-month period during which the ratio in the inflowing water exceeded again that at the outflow. From July to November, the inorganic N/P ratio was permanently <10, which was shown to enhance the bloom potential of diazotrophic species (Oliver & Ganf, 2000). The decrease of the N/P ratio in the lake in summer is caused, on the one hand, by intensive denitrification responsible for 70–80% of the nitrogen retention (Jensen et al., 1990; Nõges et al., 1998) and, on the other hand, by phosphorus release from sediments enhanced by high temperature (Boström et al., 1982). As a result of the decreased N/P ratio, heavy blooms caused by the N_2-fixing species *Gloeotrichia echinulata* and *Aphanizomenon flos-aquae* have been observed in the lake during recent years (Nõges et al., 2002).

In a nutrient budget, loading estimates from different sources are counterbalanced with measurements made at the outflow. Therefore, every single concentration measurement made there is of great importance, and every biased value inevitably affects strongly the final result. In order to establish control over potentially erroneous results, the budget was calculated in two versions (Table 11):

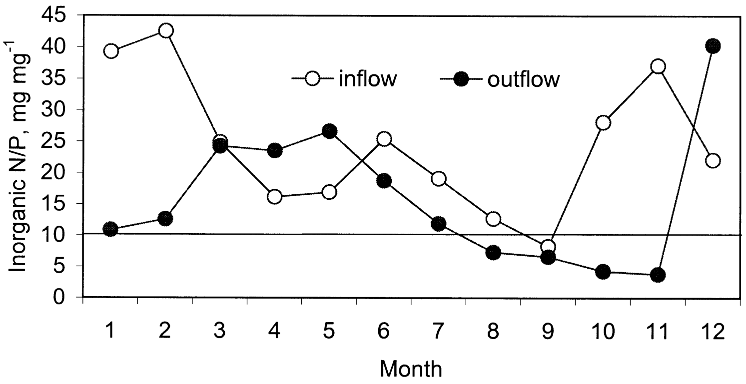

Fig. 3. Seasonal changes in the inorganic N/P ratio in the loading (weighted average inflow) and at the outflow of L. Peipsi in 1998.

in the first version we used real outflow data measured at the Vasknarva station but in the second version we replaced them with average concentrations for three stations in L. Peipsi (Fig. 1). We supposed that the quality of outflowing water should not differ much from the average lake water quality. Comparison of these two budget versions showed a twice smaller inorganic nitrogen loss, three times smaller organic phosphorus loss, and a four times larger silicon loss from the lake when calculations were based on data measured in the outflow. The calculated outflow of Si exceeded the total load to the lake 1.5 times, which was unrealistic. There is no explanation for such large silicon emission from the lake. The second budget version gave more realistic figures for silicon. The retention estimates of other nutrients were more or less comparable. In 1998 L. Peipsi retained 30–40% of the Ntot load and 50–70% of the Ptot load. As the year was wet and it rained much during summer, the balance between the inflow and outflow of nutrients remained positive until September–October (not shown). Looking at the retention of different forms of nutrients in Table 11, the second version of the budget, based on averaged lake data, seems more realistic again as on an annual scale the lake should retain more PO_4-P than organic P. In two nutrient budgets calculated for L. Võrtsjärv (Nõges & Järvet, 1998; Nõges et al., 1998) the retention of organic P was even negative showing an almost constant emission of bound phosphorus from the lake. The in- and outflow of organic nitrogen was almost equal in both versions whereas the inorganic nitrogen compounds were most strongly retained.

The Ptot concentration predicted by the model of Vollenweider (1969) was in good accordance with the observed values in Lake Peipsi *s.s.* (Table 12) showing that the internal phosphorus loading probably does not play an important role in

Table 11. Two versions of the nutrient budget for L. Peipsi using (1) concentrations measured at Vasknarva and (2) mean concentrations measured at three sampling stations in L. Peipsi *s.s.* for calculating the outflow of nutrients

	NH_4-N	NO_x-N	Norg	Ntot	PO_4-P	Porg	Ptot	Si
Total load, t y^{-1}	1 734	10 167	11 885	23 786	575	711	1 286	43 975
Version 1								
Outflow (Vasknarva), t y^{-1}	562	2 945	12 177	15 684	272	160	433	68 123
Retention, t y^{-1}	1 172	7 222	−291	8 102	302	551	853	−24 148
Retention, kg ha^{-1}	3.3	20.3	−0.8	22.8	0.8	1.6	2.4	−67.9
Retention, %	68	71	−2	34	53	77	66	−55
Version 2								
Outflow (lake water)	228	1 660	12 061	13 949	213	470	683	17 452
Retention, t y^{-1}	1 506	8 507	−176	9 837	362	241	603	26 523
Retention, kg ha^{-1}	4.2	23.9	−0.5	27.7	1.0	0.7	1.7	74.6
Retention, %	87	84	−1	41	63	34	47	60

Table 12. Annual mean concentrations of total phosphorus and total nitrogen predicted by the model of Vollenweider (1969) and observed in L. Peipsi and in the Narva River in 1998

Nutrient	Predicted (Vollenweider, 1969)	L. Peipsi (3 stations)	Narva R. (Vasknarva)
Ptot, mg L^{-1}	0.034	0.042	0.025
Ntot, mg L^{-1}	0.627	0.903	0.972

the lake. However, the real average Ptot concentration for all three parts of the lake was probably higher. The observed Ntot concentration exceeded that predicted by the model by nearly one third. This might be a sign of the activity of nitrogen-fixing cyanobacteria in the lake.

By substituting a desirable concentration goal for C_P into Vollenweider's model (Eq. 5), one can obtain a loading target L_P for the watershed that can be used to guide management efforts (Havens et al., 2001). To achieve the C_P goal of 0.020 mg L^{-1}, which according to Vollenweider (1975) delineates eutrophic and mesotrophic waters, the annual Ptot load should not exceed a limit of 0.213 g m^{-2} y^{-1} (758 t y^{-1} per lake). To reach this goal, phosphorus loading to the lake should be decreased 1.7 times.

CONCLUSIONS

In spite of several uncertainties interfering the nutrient budget calculations for L. Peipsi, the obtained estimate is consistent with the decreased nitrogen loading. Although the present loads of both nitrogen and phosphorus can be considered low, they cause problems because of their disbalance. The presently low N/P ratio supports algal blooms and forms the basis for other ecological problems such as fish kills observed in the lake during recent years.

The correctness of runoff and nutrient concentration measurements at the outflow from the lake at Vasknarva is crucial because the negative side of the budget is based solely on these data.

In order for the whole lake to reach mesotrophic status, a 1.7-fold decrease in phosphorus loading is required.

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Peipsi järve toiteelementide bilanss 1998. aastal

Peeter Nõges, Ülle Leisk, Enn Loigu, Alvina Reihan,
Boris Skakalski ja Tiina Nõges

Euroopa Komisjoni projekti MANTRA-East raames koguti andmestik Peipsi piirkonna sademete, järve suubuvate jõgede vooluhulkade ja jõgedes sisalduvate toiteelementide kohta 1998. aastal. Sellega jätkati 1994. aastast katkenud Peipsi järve tervikliku veebilansi arvutusi, mida oli järjekindlalt tehtud aastatel 1953–1993. Ehkki nii valglast kui ka atmosfäärist tulevat toiteelementide koormust Peipsi järvele on korduvalt arvutatud (Järvet, 1991; Loigu jt, 1991a, b; Blinova, 2001; Stålnacke jt, 2002), on käesolev töö esimene katse hinnata tasakaalustatud veebilansile toetudes lämmastiku, fosfori ja räni aastast massibilanssi ja peetumist järves. Koormuse arvutustes vaadeldi eraldi atmosfäärse koormuse osatähtsust ning valglast lähtuva koormuse jaotumist Eesti, Venemaa ja Läti vahel. Massibilansi arvutused tehti kahes variandis. Esimeses variandis arvutati ainete väljakanne Vasknarva lävendis mõõdetud kontsentratsioonide alusel, kuid kuna see andis mitmes osas ebaloogilisi tulemusi (sissekannet ületav räniemissioon, orgaanilise fosfori suurem peetus võrreldes fosfaatse fosforiga), tehti teine massibilanss, milles ainete väljakanne saadi Peipsi *s.s.* kolmes proovipunktis mõõdetud kontsentratsioonide keskväärtuste alusel.

Sademeterohkel 1998. aastal lisandus järve 23 800 t lämmastikku (67 kg ha^{-1}) ja 1300 t fosforit (3,6 kg ha^{-1}) ning umbes 44 000 t räni. Aastate 1985–1989 kohta tehtud koormuse arvutustega võrreldes oli lämmastiku koormus üle kahe korra langenud, fosfori koormus aga jäänud peaaegu samaks. Selle tulemusel oli N/P suhe Peipsisse voolavas vees langenud varasemalt 48-lt 19-ni. N/P suhte langus järve koormuses on peapõhjus, mis on esile kutsunud õhulämmastikku seondavate sinivetikate massilised õitsengud viimastel aastatel. Lämmastiku erikoormus (pindalaühikult lähtuv koormus) oli suurem Eesti osavalglas, fosfori erikoormus aga Vene osavalglas. Vollenweideri (1969) mudeli alusel tehtud arvutused näitasid, et mesotroofse seisundi saavutamiseks kogu Peipsis tuleks fosfori koormust vähendada 1,7 korda. Bilansist selgus, et 1998. aastal peetus järves 30–40% sissekantud lämmastikust ja 50–70% fosforist. Fosfori keskmine kontsentratsioon järves oli heas kooskõlas koormuse põhjal ennustatuga. See kinnitab, et fosfori sisekoormus ei ole järve toitelisuse mõjutajana kuigi oluline. Lämmastiku keskmine kontsentratsioon oli aga koormuse põhjal ennustatust umbes kolmandiku võrra kõrgem. See viitab õhulämmastiku seondamisele järve elustiku poolt.