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Eutrophication level of *Phragmites australis* habitats at a shallow coastal lake, Paljassaare Peninsula, Tallinn, Estonia

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Abstract. The eutrophication level of a lake situated in the centre of the Paljassaare Peninsula, Estonia, was estimated using chemical characteristics of common reed (*Phragmites australis*). Comparison with other Estonian waterbodies revealed considerable differences. The N and P concentrations in the leaves and the N concentration in the stems of *P. australis* during the phenophase of early flowering were in Paljassaare (data from 11 sampling sites) 1.5–2-fold higher than in the eutrophic Lake Võrtsjärv, in the high-productivity delta of the Kasari River, and in the Väike Väin Strait. For P in stems the differences were even greater. The N/P ratio in *P. australis* shoots indicated N limitation in the lake and seashore on the Paljassaare Peninsula (N/P ratio 6–11), the Kasari River delta (ratio 8), and the Väike Väin Strait (ratio 12), but P limitation in the oligotrophic Lake Tänavjärv (ratio 21). In the eutrophic Lake Võrtsjärv the accessibility of N and P is probably balanced (N/P ratio 15). As large amounts of nutrients have accumulated in the lake on Paljassaare, the process of its growing over has accelerated during the last decade.

Key words: shallow coastal lake, *Phragmites australis* clones, nutrients, N/P ratio, Paljassaare Special Conservation Area.

INTRODUCTION

Reedbeds are one of the communities with the greatest productivity (3000–8500 g dry matter per 1 m^2 a year) on our planet (Masing, 1992). Particles carried by water settle here and part of the plant material accumulates as peat or silt. Large amounts of chemical elements are bound in the course of absorption from water in the upper, detritus-rich layer of underwater soils, from where a significant part of nitrogen volatilizes as a result of denitrification. Reedbeds together with flooded *Carex* communities and *Salix* stands play an extremely important role of being the place where denitrification takes place, that is the place where the nitrogen cycle is completed or the superfluous nitrogen accumulated in the biosphere is returned to the atmosphere as inert molecular nitrogen. Thus, reedbeeds are expected to counteract the effects of eutrophication.

The northern part of the Paljassaare Peninsula was a closed military area since World War II until the Soviet military forces were withdrawn from Estonia in 1994. Today the area with several coastal lakes has no human settlements. The peninsula is a favourable habitat for bird species of all-European importance and other protected animal and plant species. In 2005, with the Estonian Government Regulation No. 144 (RTI 07.07.2005, 38, 300), the Paljassaare Special Protection Area with an area of 277 hectares was placed under legal protection as Paljassaare Special Conservation Area (Paljassaare hoiuala kaitsekorralduskava, 2006–2008).

The centre of the Paljassaare Special Conservation Area hosts a coastal lake that provides essential habitat for reeds. The biota of the lake, its trophic level, and pollution have been previously studied by employees of the Estonian Marine Institute (Mets, 1992). According to their study, the amount of minerals in the water was small but the lake was very rich in organic matter. The Secchi depth of the water was estimated at 0.4–0.5 m. The dichromatic oxidation was 46.5 mgO/L. No inflows or outflows were observed in the lake. The concentrations of heavy metals (Pb, Cu, Cd) and organic contaminants (PCB, DDT, hydrocarbons from oil products) in the above- and belowground parts of the higher plants *Typha latifolia* and *Myriophyllum verticillatum* and in lake deposits did not differ markedly from the respective values obtained from the coastal sea elsewhere in Estonia and were also similar to values obtained in other coastal areas of the Gulf of Finland. The species composition and dominance structure of phytobenthic and benthic invertebrate communities suggested that the lake suffers from heavy eutrophication.

The purpose of this study was (1) to estimate the eutrophication level of the lake on Paljassaare on the basis of the chemical characteristics of common reed (*Phragmites australis*) in the phenophase of early flowering of clones and (2) to compare these estimates to the relevant findings for other Estonian waterbodies. The results of the study will be helpful in planning protection activities on the Special Conservation Area on the Paljassaare Peninsula.

MATERIAL AND METHODS

Site description

Paljassaare is a peninsula with two capes. It protrudes into Tallinn Bay north of the north-eastern coast of the Kopli Peninsula (Fig. 1). The Paljassaare Peninsula consists of Väike-Paljassaare in the east, Suur-Paljassaare in the west, and Saartevahe Haak in between (Mens & Miidel, 1998). The length of the Paljassaare Peninsula is 2.8 km, width 1.5 km, and area 3.5 km^2; the highest point on the peninsula is 7.9 m above sea level (Mets, 1992).

According to Linkrus (1998), the Paljassaare Peninsula is located on the lowland before the Estonian klint escarpment; the blue clay of the Lower Cambrian Lontova and Lükati stages is mostly below the Quaternary sediments at a depth of 10–15 m. In the southern part of the peninsula the Cambrian blue clay basement reaches almost the ground surface (to a depth of 1–5 m) as a relatively gently sloping buried escarpment.

Saarse & Vassiljev (2008) argue that Suur-Paljassaare began to emerge from the sea as a result of neotectonic uplift 800–700 BC and by AD 150 also a small islet had emerged from the sea in the place where Väike-Paljassaare is located

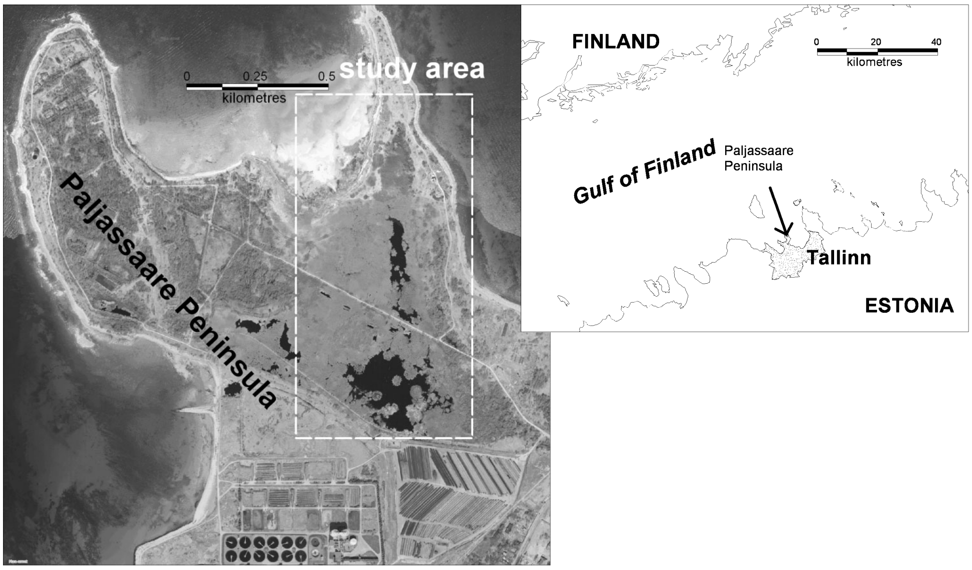

Fig. 1. Location of the Paljassaare Peninsula and the study site. Ortophoto from the Estonian Land Board.

today. As late as in AD 1700 Paljassaare was not yet connected with the mainland and Suur- and Väike-Paljassaare were separated by a strait. The original relief of the peninsula has been significantly changed by human activity: ground has been used to gain land from the sea, a railway embankment, ports, and military structures have been built. Numerous natural relief forms have therefore disappeared (Saarse & Vassiljev, 2008). Suur-Paljassaare and Väike-Paljassaare were connected to the mainland in 1912–1917, when part of the sea area was filled with ground in the course of the construction of a port (Miinisadam) (Gustavson, 1993).

Till occurs almost all over the peninsula. Its greatest thickness is at least 14.5 m in the terraced valley carved out by a glacier. Till is covered by marine gravel and shingle. In the northern and eastern parts of the peninsula a compact layer of well-washed marine sand has formed as a result of the accumulating activity of waves. Filling material consisting of building debris and debris with turned-up natural earth occurs almost everywhere in the area (Mets & Nelke, 1992a).

The lake studied is situated in the centre of the Paljassaare Peninsula (coordinates 59°28′ N, 24°42′ E). The area of the open water of the lake's part situated between a railway embankment and a causeway is 3.5 ha (Fig. 1). On the eastern coast of the lake a shingle beach ridge parallel to the coast has formed. The accumulating activity of waves has occurred and is occurring also in the bights of the peninsula and in its central part, where deposits transported from erosion areas are accumulated. Here the profile of the coast is gentle and fine material dominates in the sediment. Also organic material occurs in sediments. Neglecting the modern, human-formed relief, we can say that the major part of the peninsula has been shallow water with calm sedimentation conditions, in which a coastal lake that has lost its connection with the sea located in a slightly marshy basin has formed (Mets & Nelke, 1992b). The influx of water into the lake is slow and its source is mainly precipitation water.

The lake on Paljassaare is a relic. A bight that became separated from the sea developed into a lake with good natural conditions for the growth of aquatic plants and accumulation of organic matter in the form of peat and mud. The thickness of sediments in the lake is not over 0.5–1.0 m; under these lies organic-rich fine sand not thicker than 1.0 m (Nelke, 2008).

The lake has fresh water and is shallow: the depth of the water column is from 0.3 to 1.0 m. The level of the water depends on the amount of precipitation and the inflow of ground water from the klint escarpment; during northerly storms sea water presses into the lake (Nelke, 2008).

From the early 1990s until today the lake has suffered rapid eutrophication (there are no data available from the period before the 1990s because the studied area was a closed military territory), caused obviously by infiltration of waters rich in nutrients from Tallinn Wastewater Treatment Plant located in its vicinity and the adjacent landfill, which now is closed. The landfill was located on the southern coast of the lake. It served the city of Tallinn and was used from the end of World War II to 1974. In the 1970s Tallinn Wastewater Treatment Plant was launched on the same territory (oral information by the plant manager E. Mihklep and a long-term employee P. Päro). The open-water area of the lake decreased 2.3 times from 1992 to 2006 (Elvisto et al., 2010). Today most of the lake area in the centre of the peninsula is covered by reeds in which the clones of common reed (*Phragmites australis* (Cav.) Trin ex Steud.) predominate.

The locations of the sampling sites are shown in Fig. 2. Sampling sites K1–K6 are located south of a causeway while sites P1–P3 are north of it. The sampling sites had visually different clones and were situated at different distances from Tallinn Wastewater Treatment Plant along the open water of the lake. Two sites were selected on the seashore and are not connected with the lake (P4 and P5). Random sampling was used to select the concrete plot inside the clone.

Sampling site K1 is south of the railway embankment, 25 m west of a drainage well, and 15 m from the edge of the reedbed. The general appearance of the reedbed was uniform, its colour was fresh green, and the number of yellowed leaves on shoots was small. Three quarters of the shoots in the sample were vegetative. The flowers on the shoots collected had not yet opened. Around the sampling site some viscid deeper places occurred where *Typha latifolia* grew between the reeds. The water depth in the sampling site was 0 to 6 cm. Of other species *Lysimachia vulgaris*, *Cicuta virosa*, *Lycopus europaeus*, *Lemna trisulca*, and *Lemna minor* were present.

Sampling sites K2 and K3 are located north of the railway embankment and the ditch proceeding parallel to (north of) the embankment. In **sampling site K2** most of the reed shoots (in the sample 100%) were generative and in the phenophase of early flowering (some in full flowering stage, some not yet flowering). The water depth in the sampling site was 0 to 6 cm. Of other species *Typha latifolia*, *Lemna*

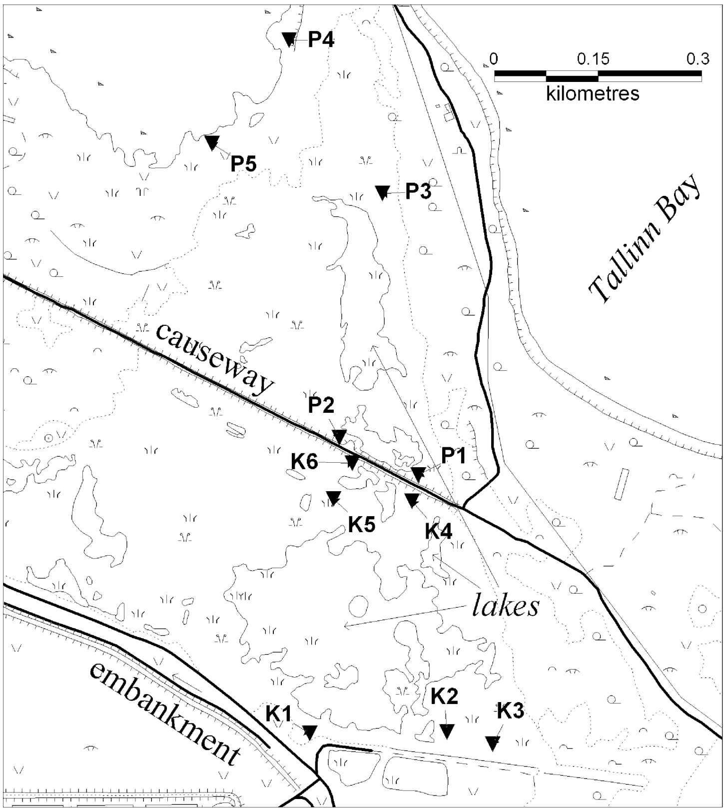

Fig. 2. Sampling sites K1 to K6 and P1 to P5 for chemical analysis of common reed (*Phragmites australis*). The geographical coordinates of the sampling sites are as follows: K1 59°28.36′ N, 24°42.44′ E; K2 59°28.36′ N, 24°42.65′ E; K3 59°28.35′ N, 24°42.72′ E; K4 59°28.54′ N, 24°42.60′ E; K5 is 60 m to the direction of 200° from K6; K6 59°28.57′ N, 24°42.51′ E; P1 59°28.56′ N, 24°42.61′ E; P2 59°28.59′ N, 24°42.49′ E; P3 59°28.78′ N, 24°42.56′ E; P4 59°28.90′ N, 24°42.42′ E; P5 59°28.82′ N, 24°42.30′ E.

trisulca, and *Lemna minor* and the moss *Amblystegium riparium* were present. In the immediate vicinity of the sampling site *Lythrum salicaria* was flowering and 15 m east of the sampling site *Salix* species were growing.

Sampling site K3 is in the easternmost part of the reedbed, which borders in the west on a few willows (at a distance of 15 m). Reeds were in the early stage of flowering, some shoots were in full flower. The number of yellowed leaves was relatively large. Over 4/5 of the shoots in the sample were generative. Over a half (!) of the reed shoots were branched; four-, three-, two-, and one-branch shoots were observed of which one branch could be generative but also shoots with two or three generative branches occurred. Mass damage of caterpillars of twin-spotted wainscot (*Archanara* (= *Nonagria*) *geminipuncta*) was observed. The caterpillars of this species feed on reed shoots (within the stem) moving from one shoot to another, causing drying of shoot tips and after that the branching of the stem. The species could be determined on the basis of characteristic damage of reed and the exit holes of the moth. The author has not seen so abundant occurrence of the twin-spotted wainscot during her several decades of study of reedbeds. There was no surface water in this sampling site. *Epilobium* sp., *Carex* sp., *Lythrum salicaria*, and a few *Typha latifolia* shoots were growing on the site.

Sampling sites K4, K5, and K6 are located south of the causeway, sites K4 and K6 are close to the causeway, and K5 is 60–70 m from it within a reedbed.

Sampling site K4 is 85 m north-west of a bird watching tower, within a reedbed about 10 m from its edge. The reedbed was uneven with a few higher shoots in it. From a distance the reed seemed to be flowering; however, in the sample the majority of shoots had the panicle a few centimetres between the upper sheaths, flowers had not opened. In the sample 4/5 of the shoots were generative. About a third of the shoots were damaged by caterpillars of twin-spotted wainscot. A three-branch shoot with all three branches having a well-developed panicle (lengths 22, 18, and 17 cm) was found. The leaf blades and sheaths of reed had black spots of fungi. Of other plant species *Cicuta virosa*, *Lycopus europaeus*, *Lemna trisulca*, and *Cardamine pratensis* occurred.

In sampling site K5 the reed was tall, most of the shoots were in the final phase of flowering and formation of seeds. All shoots in the sample were generative. Numerous leaves were yellow. The lower sides of leaves had relatively wide spots of fungi. There was no water in the sampling site. Of other plant species *Cicuta virosa*, *Lycopus europaeus*, and *Lemna trisulca* occurred (the last species indicates that the area is for the most time covered with surface water).

Sampling site K6 is located about 10 m from the edge of the reedbed. In the sample 3/4 of the shoots were generative, in the early stage of flowering. Of other plant species *Typha latifolia* and *Lemna trisulca* were observed.

Sampling sites P1 and P2 are located north of the causeway in its vicinity. **Sampling site P1** is 75 m north-west of the bird watching tower, inside the reedbed 7–8 m from its edge. In the sample 4/5 of the shoots were generative. Flowers had not opened. Leaf sheaths had large spots of rust fungus. There was 0 to 2 cm of water. In the immediate vicinity of the sampling site *Schoenoplectus tabernaemontanii*, *Typha angustifolia*, *Galium palustre*, *Hippuris vulgaris*, *Epilobium* sp., and the mosses *Drepanocladus aduncus* and *Amblystegium riparium* were growing.

Sampling site P2 is located 20 m north-west of the bird board, 12 m from the open water, about 10 m from the edge of the reedbed. There was moving water between the reeds. The reedbed was bright green. Generative shoots made up 4/5 of the sample. Most shoots were starting to flower, some were in bud. Leaf sheaths had large numbers of blackish-greyish-reddish spots of rust fungus. Branched shoots were observed (probably caused by twin-spotted wainscot damage). Of other species *Typha angustifolia* occurred.

Sampling site P3 is located on the line of an overgrown ditch (on its left bank) about 20 m from the edge of the reedbed. The reeds were in the early stage of flowering. Generative shoots made up 3/4 in the sample. Of other plant species

Typha angustifolia, *Galium palustre*, *Lythrum salicaria*, *Lysimachia vulgaris*, *Lemna trisulca*, and the moss *Warnstorfia exannulatus* occurred.

Sampling site P4 is located below the shingle ridge on sand onto which the sea carries large amounts of algae during storms. The reed looked fine, it was bright green with very few yellow leaves (the light falls on the reedbed also from the sides both from the land and the sea). The sample was collected from the centre of the reedbed. Of the shoots 4/5 were generative, half were in full flower and in the other half a few centimetres of the panicle was still within the last sheath. There was 2 cm of water. Under the panicle of one shoot we discovered galls formed by larvae of *Giraudiella inclusa* (Diptera, Cecidomyidae) as determined by external characteristics. No other plant species besides common reed were found in the site.

Sampling site P5 is located between the shingle ridge and the sea. The reedbed was uneven with quite thin and sparse shoots. Pebble, sand, and clay occurred in the ground. All the shoots in the sample were generative, in the phenophase of early flowering. *Agrostis stolonifera* was growing between reeds.

In 2007 the reeds both south and north of the causeway was somewhat shorter than the reed growing during the vegetation period of 2006 and the yellowed stems still standing in 2007.

Methods and analyses

The samples for chemical analysis of common reed were collected from sites P1–P5, K4, and K6 on 9 August and from sites K1–K3 and K5, on 13 August 2007 at the time the clones were in the phenophase of early flowering. The concentration of chemical elements in plants varies during the vegetation period depending on their phenophase (Dykyjová, 1973). To get comparable results it is suggested that samples of *Phragmites australis* should be collected in the phenophase of early flowering (Dykyjová et al., 1973). In each sampling site seven shoots closest to the centre were cut at the surface of mud for chemical analysis and eight to ten 'maximum' shoots (Dykyjová et al., 1973) were taken for morphological measurements. The samples of yellowed reed were collected after night frosts on 30 October 2007.

Aboveground parts of reed were analysed. The length of the 'maximum' shoots was measured from the bottom up to the top of the panicle, the length of the panicle from its lowest hair ring up to the tip. In the samples collected in August the percentage of nitrogen, phosphorus, and calcium in the dry matter was determined in the following three fractions: leaf blades (entirely green to 1/5 yellowed), stems with leaf sheaths, and panicles. The panicle sample included the panicle from its lowest hair ring. From the samples collected in October two fractions were separated: leaf blades and stems with leaf sheaths (the panicles were ragged by the wind in October). After separating the fractions, the plant parts were cut into 1–1.5-cm pieces with pruners and scissors, and carefully mixed. An average sample was extracted and air-dried. Chemical analyses were performed on air-dry samples in the Control Centre of Plant Production, Saku, Estonia. The following methods were applied: dry matter – 71/393 EEC; N – AOAC 2001.11; and P and Ca – AOAC 984.27.

The mass ratios of *P. australis* stems (with leaf sheaths) and leaf blades for the calculation of the N/P ratios were taken from earlier studies. The author studied the mass ratios of the aboveground parts of *P. australis* in Matsalu Bay, Lake Võrtsjärv, and Lake Tänavjärv in the early 1980s. Considering the appearance of shoots, the ratio of stems (together with sheaths) to leaf blades in the lake on the Paljassare Peninsula and the Väike Väin Strait was taken equal to that in Lake Võrtsjärv, that is 83/17, for the Kasari River delta 81/19, and for Lake Tänavjärv 87/13.

RESULTS

Table 1 presents the morphological characteristics of the 'maximum' shoots. The tallest shoots grew on sites K5 and P4, and the shortest shoots on site P1. The studied clones had quite similar panicle lengths and number of leaf blades on shoot, only in clone P2 the panicles were taller than on the other sites. Correlation analysis of the morphological features of separate shoots (102 in all) collected from all clones showed a correlation only between the total number of leaves and the length of panicles ($r = 0.209$, $p = 0.195$).

In August, during the early flowering stage of reed, and in October, after the aboveground parts had dried, the largest concentration of nitrogen was determined in leaf blades, panicles had less nitrogen and stems the least. The concentration of phosphorus was the highest in panicles, followed by leaves and stems (Figs 3 and 4 and Appendices 1 and 2).

The highest nitrogen levels in August were determined in samples from sites K1, K4, and P2. In all these places the reed was bright green at the time the

Table 1. Morphological features of the 'maximum' *Phragmites australis* shoots. The arithmetical mean is given with the standard deviation

Site	*N*	Total stem length, cm	Panicle length, cm	Number of leaf blades
K1	10	248.8 ± 16.9	23.3 ± 3.9	10.4 ± 1.0
K2	10	216.6 ± 10.5	24.9 ± 1.2	9.8 ± 0.8
K3	9	243.8 ± 12.7	25.8 ± 3.9	10.4 ± 1.2
K4	9	191.6 ± 16.0	22.4 ± 1.7	9.4 ± 0.7
K5	10	279.9 ± 17.2	24.8 ± 2.2	10.0 ± 0.4
K6	9	199.6 ± 15.4	25.6 ± 2.2	10.0 ± 0.7
P1	8	175.7 ± 6.4	23.4 ± 2.0	11.2 ± 0.6
P2	9	203.8 ± 12.2	28.6 ± 2.4	11.4 ± 0.5
P3	10	247.4 ± 20.0	23.8 ± 2.4	11.0 ± 0.4
P4	8	264.6 ± 19.8	22.0 ± 1.5	9.9 ± 1.3
P5	10	225.3 ± 20.3	23.1 ± 1.7	9.7 ± 0.9

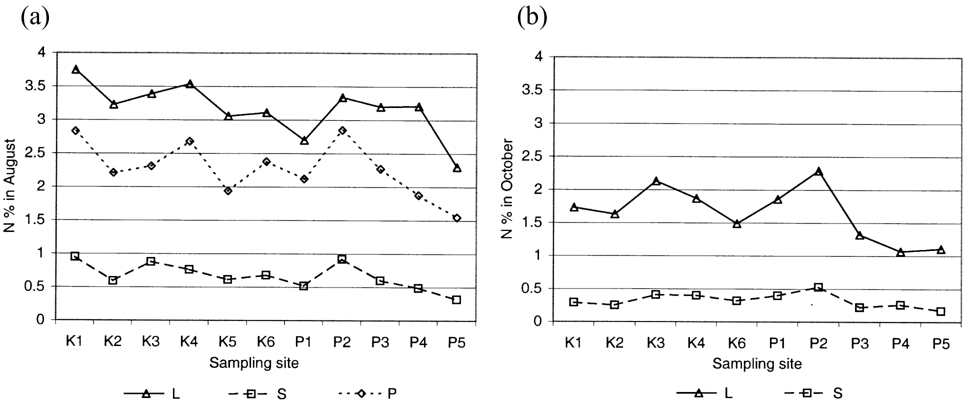

Fig. 3. Concentration of nitrogen in common reed. L – leaf fraction, S – stem fraction, P – panicle (inflorescence) fraction.

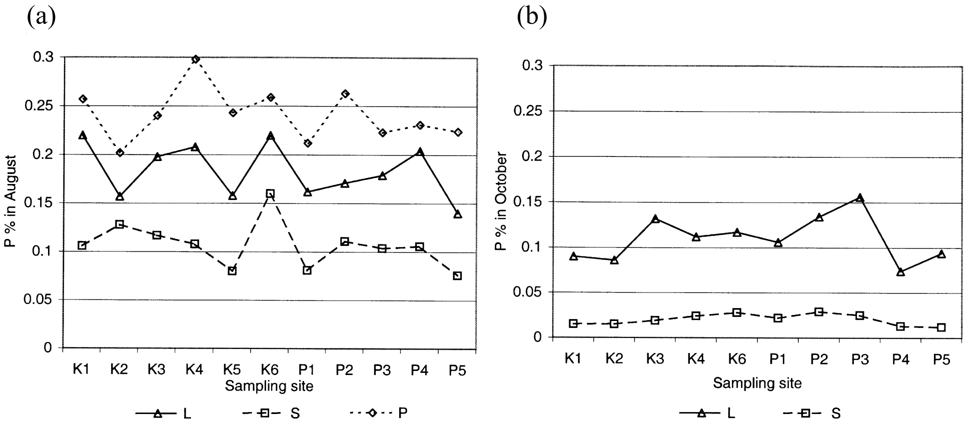

Fig. 4. Phosphorus concentrations in common reed (see Fig. 3 for abbreviations).

samples were collected. At the same time phosphorus showed the highest concentrations in sampling sites K1, K4, K6, and P2 (in the case of leaves also P4). The reed was the richest in nutrients in sampling sites that are located (1) near the former landfill and the present composting fields of Tallinn Wastewater Treatment Plant, that is K1 and K3, and (2) north-west of the bird watching tower on both sides of the causeway, that is K4, K6, and P2.

In August the concentrations of nitrogen and phosphorus were also high in the leaves of reed growing on a seaweed wall at the sea (sampling site P4). The lowest nitrogen and phosphorus levels were in August in the reed from site P5 at the seaside. The levels were also low from P1.

The concentrations of nutrients in the *P. australis* in the lake on Paljassaare were markedly high. Data for comparison from other Estonian waterbodies are presented in Table 2.

Table 2. Average concentrations of nutrients (% in dry matter) and N/P ratio in the aboveground parts of *Phragmites australis* in the early stage of flowering in August. Data on waterbodies other than Paljassaare are from Ksenofontova, 1988 (L – leaf blades; S – stems; P – panicles (inflorescences))

Site	N/P ratio in shoots	Plant part	N	P
Lake on Paljassaare, sampling site K6	7	L	3.11	0.220
		S	0.68	0.160
		P	2.38	0.259
Lake on Paljassaare, sampling site P2	11	L	3.34	0.171
		S	0.92	0.111
		P	2.85	0.263
Seacoast on Paljassaare, sampling site P5	8	L	2.30	0.140
		S	0.32	0.076
		P	1.55	0.224
Lake Võrtsjärv (eutrophic), mean of 1981 & 1982	15	L	2.85	0.17
		S	0.43	0.03
		P	2.60	0.40
Kasari River delta, mean of 1981 & 1982	8	L	2.15	0.17
		S	0.52	0.08
		P	2.32	0.32
Väike Väin Strait, mean of 1981 & 1982	12	L	2.03	0.14
		S	0.56	0.05
		P	1.92	0.28
Lake Tänavjärv (oligotrophic), mean of 1981 & 1982	21	L	1.62	0.06
		S	0.36	0.02
		P	2.00	0.09

DISCUSSION

Analysis of aerial photos reveals an accelerating expansion of reedbed communities and overgrowing of the lake in the central part of the Paljassaare Peninsula. The open water area of the lake south of the causeway decreased 1.1 times from the year 2000 to 2003 and 1.6 times from 2003 to 2006. As compared to 1992, the open water area of the lake had decreased 2.3-fold (Elvisto et al., 2010). Most likely the expansion of reedbeds is due to the large amounts of nutrients carried to the lake. This is confirmed by data of Mets (1992) for 1992 when in the north-eastern and western coastal areas of the lake species from the family Cryptomonas and the phylum Euglenophyta were found. These taxa are characteristic of waters rich in humus and nutrients. Also the diatoms *Diatoma tenuis* and *Stephanodiscus hantzschii* were abundant. According to Streble & Krauter (1975), *S. hantzschii* is an indicator species of heavily polluted waters. The high trophic level of the lake in 1992 was also confirmed by the great abundance (2867 ind./m^2) and biomass (28.9 g/m^2) of benthic animals, which were notably higher in the lake on Paljassaare than in other coastal lakes in Estonia (Mets, 1992).

The rapid expansion of the reedbed communities on the Paljassaare Peninsula during the last 15 years was obviously caused by Tallinn Wastewater Treatment plant on the southern border of the studied lake and the former landfill south of the lake. Underground pipes from the Wastewater Treatment Plant reach coastal wells on the border of the Special Conservation Area. Nelke (2008) in his report mentions nutrient-rich filtration water that flows from the composting fields of Tallinn Wastewater Treatment Plant to the lake as one of the reasons for its eutrophication and overgrowing.

Phragmites australis grows in areas where the depth of surface water is up to 2 (2.5) m (Rodewald-Rudescu, 1974). In the lake on Paljassaare the thickness of the water layer and soft mud was below 1 m in April 2008 (Nelke, 2008), being 60–85 cm in the open water areas studied. In corners of waterbodies sheltered from winds and waves clones of cattail (*Typha* sp.) and reed (*P. australis*) may grow as a floating peninsula also along a water surface. In Lake Võrtsjärv *P. australis* was observed growing in a 80-cm deep place on sands (Ksenofontova, 1988). According to Freiberg (2007), in Lake Peipsi *sensu stricto* the average depth at which *P. australis* grows on the border side of the open water is 0.3 m, in Lake Lämmijärv 0.7 m, and in Lake Pskov (Pihkva) 0.8 m. The distribution of *P. australis* in the different parts of Lake Peipsi is obviously affected by the strength of wind and waves.

As the lake on Paljassaare is small, heavy waves that would mechanically hinder the distribution of *P. australis* do not develop there. The depth of the lake is not an obstacle to further spread of reed.

Vymazal & Kröpfelová (2008) reported for *P. australis* and *Phalaris arundinacea* on natural stands and in constructed wetlands the ranges of N of 0.31–5.10% dry matter (DM) for leaves, 0.05–3.33% DM for stems, and 0.5–4.5% DM for shoots, and the ranges of P of 0.03–0.40% DM for leaves, 0.02–0.43% DM for stems, and 0.04–0.41% DM for shoots. However, in the case of these results the phenophase of the plants during the collection of the samples was not shown. According to Dykyjová (1973), in one Czech *P. australis* stand the nutrient concentrations in dry matter were 2.77% N and 0.48% P in May, 1.91% N and 0.22% P in the middle of July, 1.63% N and 0.23% P at the end of August, and 1.00% N and 0.17% P at the end of October. Thus the concentration of both N and P varied about 2.8 times over the vegetation period. Investigations show that the concentration of nutrients in plants depends on the availability of the elements in the growth site (its trophic level), plant species, and the concrete clone (plant genotype), part of the plant, and the phenophase of the plant (Dykyjová, 1979).

In reed species, including *P. australis*, relocation of N and P from aboveground organs into belowground organs has been observed to occur after flowering and from belowground organs to aboveground organs in spring at the beginning of the vegetation period (Davis & van der Valk, 1983; Choi et al., 2005). In sampling site K1 on Paljassaare, N accounted for 3.75% DM in the leaf blades of *P. australis* in August and for 1.73% in October, so a 2.2-fold decrease was observed. The proportion of P in leaf blades was 0.22% in August and 0.09% in October, meaning a 2.4-fold decrease. In the *P. australis* stems of the same sampling site the reduction of N by October was 3.3 times and that of P, 7.1 times. It is not possible to carry out significant amounts of nutrients from the lake system with mowing the reed in winter.

According to Koerselman & Meuleman (1996), the N/P ratio of the vegetation (at the peak of biomass, in August) indicates the nature of nutrient limitation on a community level (N or P limitation) and an N/P ratio below 14 indicates N limitation on a community level, while an N/P ratio over 16 is indicative of P limitation. At N/P ratios between 14 and 16, either N or P can be limiting or plant growth is colimited by N and P together. The N/P ratio in *P. australis* shoots was from 7 to 11 in Paljassaare sampling sites (Appendix 1). So we can assume that the production of the clones of *P. australis* in the lake and seacoast on the Paljassaare Peninsula, in the Kasari River delta, and in the Väike Väin Strait was limited by nitrogen, in Lake Tänavjärv by phosphorus, but in Lake Võrtsjärv both nitrogen and phosphorus were rather well accessible to plants. According to the data available, the trophic level of *P. australis* in the lake on Paljassaare is higher than the values measured in other natural waterbodies in Estonia. The nitrogen and phosphorus concentrations in the vegetative parts (leaves and stems) of *P. australis* on Paljassaare were higher than in the reed from the eutrophic Lake Võrtsjärv, in the high-productivity delta of the Kasari River, and in the Väike Väin Strait. Differences were 1.5- to 2-fold; phosphorus concentrations in stems differed even more than five times. Nutrient concentrations in generative organs (inflorescences) did not vary so widely as in the vegetative parts of common reed. These data suggest that denitrification processes are active in Paljassaare reeds, and P is accumulating in the bottom sediments. The reedbeds on Paljassaare and in the Kasari River delta are actively functioning as purification wetlands (see Table 2).

So, considering that (1) during the years 1992–2006 the open water area in the central lake on Paljassaare decreased 2.3 times, (2) during the years 2003–2006 the lake was growing over especially intensively, (3) the depth of the open water of the lake is rather small (0.3–1.0 m), (4) further expansion of reedbed communities is not hindered by the waves developing on the lake, and (5) there is a sufficient supply of nutrients for plant growth, we can draw the conclusion that the growing over of the lake on Paljassaare will continue in the near future. One of the possibilities to avoid the reduction of the lake is to clean it of mud and deepen it. This way was suggested in the reports by Mets (1992) as well by Nelke (2008): as the lake is shallow and the soil is easy to dig, it would be relatively simple to accomplish.

CONCLUSIONS

Chemical analyses showed that the trophic level of *Phragmites australis* stands in the lake on the Paljassaare Peninsula was higher than in other Estonian natural waterbodies. Nitrogen and phosphorus concentrations in the leaves and stems of *P. australis* in the lake on Paljassaare were higher than the respective levels measured at the beginning of the 1980s in the eutrophic Lake Võrtsjärv, in the high-productivity delta of the Kasari River, and in the Väike Väin Strait. The differences were mostly 1.5- to 2-fold, but in reed stems the differences were even greater. The N/P ratio of *P. australis* shoot tissues indicates N limitation in the lake and on the seashore on Paljassaare (N/P ratio 7–11), in the Kasari River delta (N/P ratio 8), and in the Väike Väin Strait (N/P ratio 12), but P limitation in the oligotrophic Lake Tänavjärv (N/P ratio 21). In Lake Võrtsjärv the accessibility of N and P was balanced at the beginning of the 1980s.

The lake on Paljassaare is of great significance from the aspects of bird protection and nature education. It undoubtedly needs preservation and effective protection. From the aspect of nature education the location of the lake on the territory of the city of Tallinn is extremely important. The lake has been significantly affected by waters rich in plant nutrients, which flow and leach to it from Tallinn Wastewater Treatment Plant and especially from its composting fields. As large amounts of nutrients have accumulated in the lake the process of its growing over has accelerated during the last decade. Further expansion of reed communities in the lake on Paljassaare is not hindered by the deepness of the lake and waves developing on it. Probably the lake will be losing its importance in bird protection in the near future. One of the possibilities of avoiding that the lake will be totally overgrown is to clean it of mud and deepen it.

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APPENDIX 1

Nitrogen/phosphorus ratio and nitrogen, phosphorus, and calcium concentrations (% in dry matter) in the aboveground parts of *Phragmites australis* in the phenophase of early flowering in the lake on the Paljassaare Peninsula in August (L – leaf fraction, S – stem fraction, P – panicle (inflorescence) fraction)

Sampling site	N/P ratio in shoots	Fraction	N	P	Ca
K1	11	L	3.75	0.220	0.518
		S	0.95	0.106	0.121
		P	2.83	0.257	0.206
K2	8	L	3.23	0.157	0.470
		S	0.59	0.128	0.075
		P	2.21	0.202	0.165

APPENDIX 1. *Continued*

Sampling site	N/P ratio in shoots	Fraction	N	P	Ca
K3	10	L	3.39	0.198	0.818
		S	0.88	0.117	0.139
		P	2.31	0.240	0.270
K4	10	L	3.54	0.208	0.644
		S	0.76	0.108	0.080
		P	2.68	0.298	0.236
K5	11	L	3.06	0.158	0.795
		S	0.61	0.080	0.099
		P	1.94	0.243	0.248
K6	7	L	3.11	0.220	0.240
		S	0.68	0.160	0.038
		P	2.38	0.259	0.132
P1	10	L	2.70	0.162	0.514
		S	0.52	0.081	0.083
		P	2.12	0.212	0.195
P2	11	L	3.34	0.171	0.517
		S	0.92	0.111	0.107
		P	2.85	0.263	0.220
P3	9	L	3.20	0.179	0.762
		S	0.60	0.104	0.097
		P	2.27	0.223	0.615
P4	8	L	3.21	0.204	0.090
		S	0.49	0.106	0.159
		P	1.88	0.231	0.484
P5	8	L	2.30	0.140	0.087
		S	0.32	0.076	0.234
		P	1.55	0.224	n.d.

n.d. – not determined because of insufficient material.

APPENDIX 2

Nitrogen, phosphorus, and calcium concentrations (% in dry matter) in the aboveground parts of *Phragmites australis* after the end of the vegetation period in October (L – leaf fraction, S – stem fraction)

Sampling site	Fraction	N	P	Ca
K1	L	1.73	0.090	0.099
	S	0.29	0.015	–
K2	L	1.63	0.086	–
	S	0.25	0.015	–
K3	L	2.13	0.132	–
	S	0.41	0.019	–

APPENDIX 2. *Continued*

Sampling site	Fraction	N	P	Ca
K4	L	1.87	0.112	–
	S	0.40	0.024	–
K6	L	1.49	0.117	–
	S	0.32	0.028	–
P1	L	1.86	0.106	–
	S	0.40	0.022	–
P2	L	2.29	0.134	–
	S	0.53	0.029	–
P3	L	1.32	0.156	0.084
	S	0.22	0.025	–
P4	L	1.07	0.074	0.091
	S	0.26	0.013	–
P5	L	1.11	0.094	–
	S	0.17	0.012	–

– not analysed.

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Paljassaare rannikujärve roostiku toitelisus

Tiina Elvisto

Käesoleva töö eesmärgiks oli hariliku pilliroo (*Phragmites australis*) keemiliste näitajate alusel anda hinnang Paljassaare poolsaare keskosa järve troofsustasemele ja võrrelda Eesti eri veekogude pilliroo keemilisi näitajaid kloonide õitsemise alguse fenofaasis. Paljassaare järve pillirookogumike toitelisus osutus kõrgemaks kui mujal Eestis looduslikes veekogudes mõõdetu. Paljassaare järve pilliroo lehtede ja varte lämmastiku- ning fosforisisaldused ületavad eutroofse Võrtsjärve, kõrge produktiivsusega Kasari delta ja Väikese väina pilliroo vastavaid näitajaid. Erinevused on enamasti pooleteise- või kahekordsed, fosforisisalduse näitajad pilliroo varres kuni viiekordsed. Järve on olulistes kogustes akumuleerunud taimede toiteelemente ja roostikuala kiire laienemine viimasel kümmekonnal aastal on ilmselt põhjustatud Paljassaare lõunapiiril asuva Tallinna Reoveepuhastusjaama tegevusest ning järvest lõunasse jääva endise prügimäe mõjust.