Water chemistry in Lake Paanajärvi and inflowing rivers, NW Russian Karelia

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The purpose of this research project was to study the annual cycle of basic water properties in a lake covered by ice for about half the year close to the Arctic Circle. Samples were collected from the water column of the lake and the outlets of inflowing rivers with a Ruttner sampler from twelve locations during six visits in 1996–1997, a total of 31 samples each time. The analyses were made in accordance with the Finnish standards and included determinations of organic solids, alkalinity, colour, conductivity, total phosphorus (totP), total nitrogen (totN), ammonia (NH_4^+) and nitrate (NO_3^-). Lake Paanajärvi is an east–west oriented tectonic lake (width 0.6–1.3 km, length 24.5 km, max. depth 128 m) surrounded by carbonate rich rocks and taiga forests. With over nine-tenths of the lake inflow into the western end and the outlet at the opposite eastern end of the lake, the topmost water layers of the lake behave much like a through-flow river. Most of these waters come from Finland and have been affected by human activity while all other inflowing waters drain from natural conditions.

Seasonally, the winter time is characterized by the lowest of all colour values, the highest of all alkalinity contents, and by settling of phosphorus. All these features are mainly due to minimal discharges, high proportion of groundwater flow in relation to surface flow and calm conditions thanks to the ice-cover. Spring-time starts with violent nival floods in May associated with the maximal colour values, minimal alkalinity contents, and the rise of the spring turnover, temperature stratification and biotic activity which proceed in a wave-like fashion through the lake controlled by the through-flow and warming of river waters entering into the western inlet end of the lake. The uptake of nutrients is best seen in a rapid decrease of nitrate in the epilimnion in association with the increase of ammonia as a result of metabolism of organisms. The autumn turnover in late September and early October is associated with close to equal values of all parameters in the whole water column of the lake. The exhaustion of nitrate in the epilimnion suggests that nitrate may be a limiting factor for the biotic life. Other typical features of the lake are the lower temperatures and nutrient levels in the outlet deep compared to the inlet deep of the lake, and this may have led to adaptation and specialization among the biota within this "mini-Baikal" by Fennoscandian standards.

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Introduction

Lake Paanajärvi is a tectonic headwater lake of a large Koutajoki basin draining into the White Sea. The lake is a 24.5 km long, 0.6–1.3 km wide and 128 m deep collector of waters flowing east from the Kuusamo Uplands (Fig. 1). Over nine tenths (93.8%) of the inflowing waters end in the western end of the lake, and the majority of this water (92%) comes from Finland via the Oulankajoki river (in brief Oulanka in the following) (Table 1).

The hydrology of Lake Paanajärvi has many specific features. Firstly, the theoretical retardation

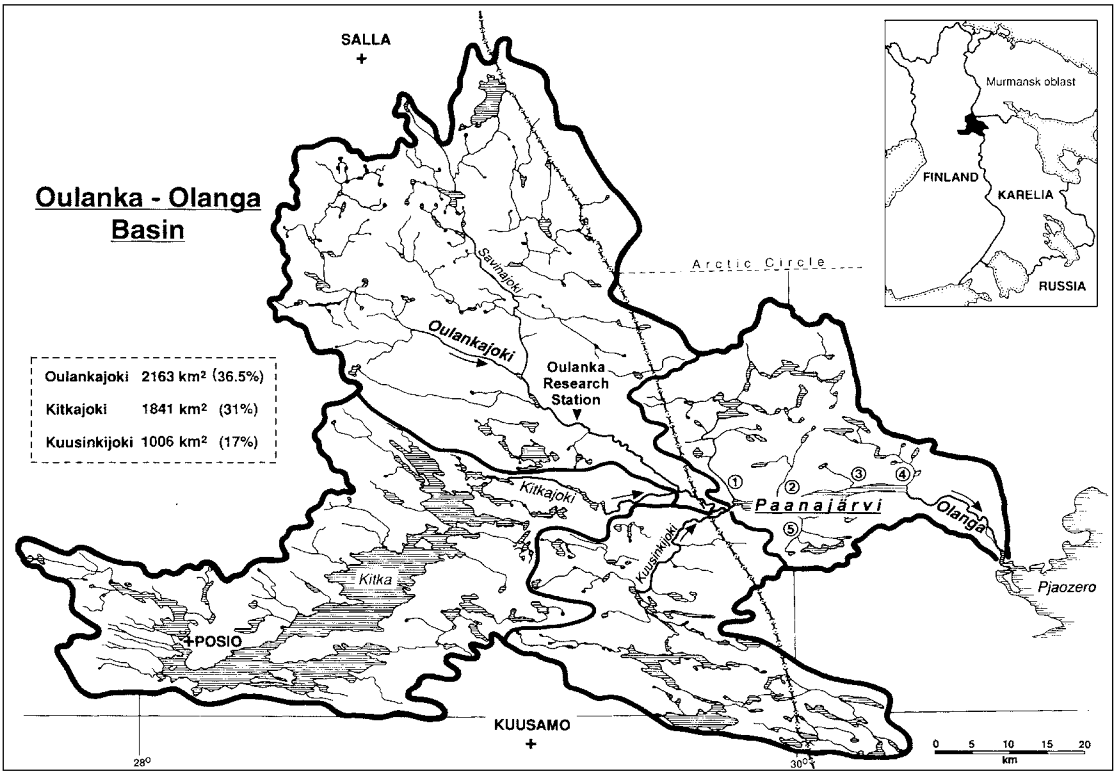

Fig. 1. Lake Paanajärvi in relation to the Oulanka-Olanga basin. Sub-basins around the lake: (1) Tervajoki (also known as Sovajoki), (2) Mäntyjoki, (3) Malinajoki, (4) Mutkajoki (also known as Astervajoki), (5) Selkäjoki (Koutaniemi et al. 1999: Fig. 1 with some additions).

Table 1. Drainage measures for the main sub-regions in the Lake Paanajärvi basin (Koutaniemi & Kuusela 1993: 77). Note: the areal percentages presented herein differ a little from those marked in Fig. 1 where they refer to the whole Oulanka-Olanga basin.

Basin	Area (km²)	Share (%)	Discharge (m³/s)
Oulanka	2163	37.3	24
Kitkajoki	1841	31.8	21
Kuusinkijoki	1006	17.3	9.3
Tervajoki	432	7.4	5.2
Mutkajoki	95.6	1.6	1.15
Selkäjoki	86.7	1.5	1.04
Mäntyjoki	48.5	0.8	0.59
Malinajoki	22.5	0.4	0.27

time of the water is five months, but the hypolimnion waters are changed only during the spring and autumn turnovers since the topmost water layer behaves much like in a through-flow river. Secondly, snowmelt floods are high (up to 3–3.5 m) and violent due to the small number of lakes along the main headwater river (Oulanka) and the steep relief by Finnish standards. Thirdly, the summertime epilimnion is totally formed at first in the inlet end of the lake from where it spreads eastwards and reaches the whole lake in July at the latest. Fourthly, the thermal stratification is much clearer than in typical Finnish lakes due, as a rule, to the through-flow. Fifthly, in the winter the water mass of the eastern (outlet) deep stays colder than that of the western (inflow) deeps (see Fig. 2). Sixthly, as the topography creates a tunnel-like formation around Lake Paanajärvi, winds which blow along the valley often develop into storms resulting in rapid changes in the water layering (Koutaniemi 1984; Koutaniemi & Kuusela 1993; Koutaniemi et al. 1999). Arvola et al. (1993: 96) report of a storm lasting a day and the following night, which dropped the upper level of the metalimnion from 14 m to 20 m in August 1992.

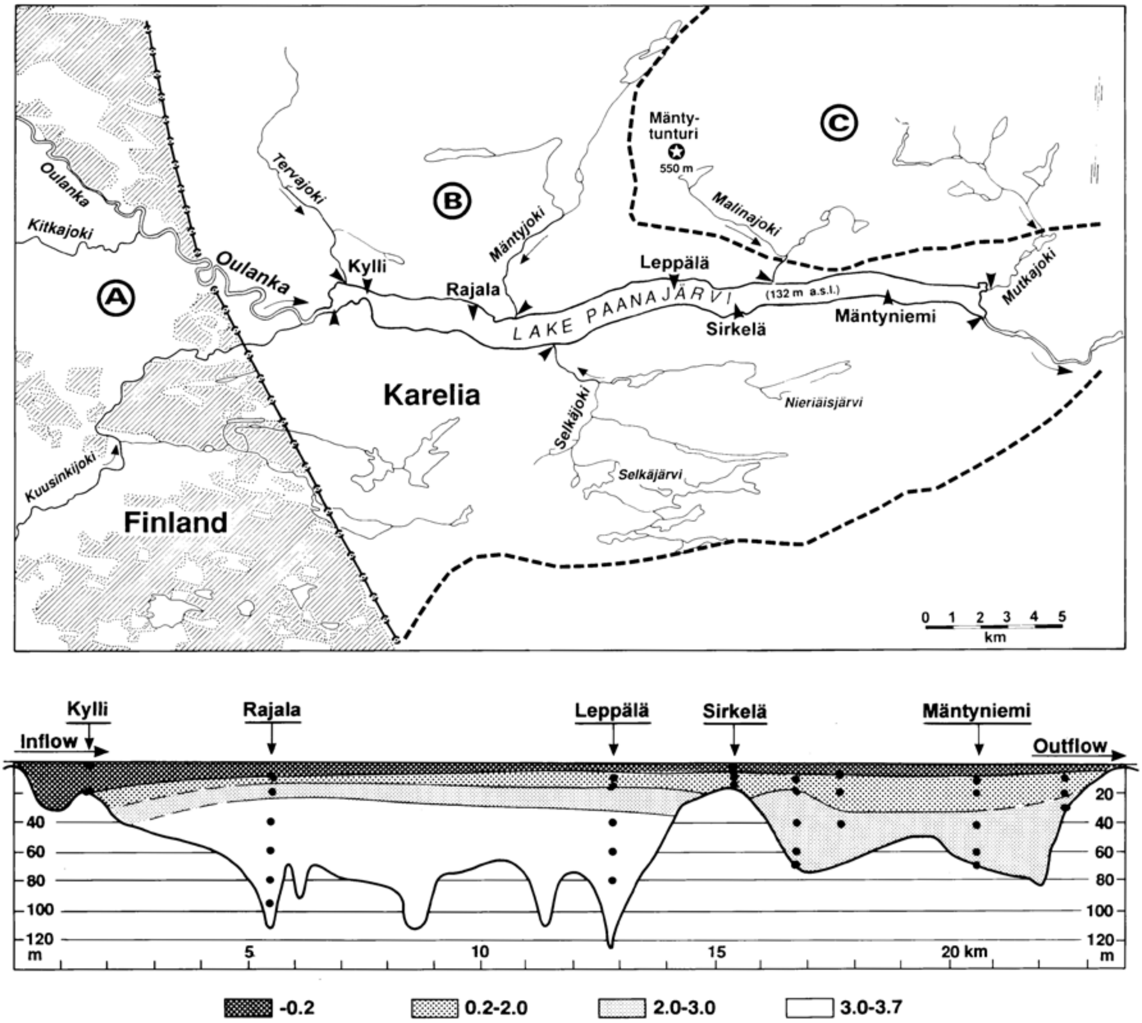

Fig. 2. Above: Sampling sites (black arrowheads, names of lake points according to old Finnish farms) and the main geological elements (A–C). Sub-regions (A) and (B) belong to the nutrient rich Karelian schist belt, the Finnish side of which is strongly human induced e.g. by clear-cuttings (marked by shading as they were by 1984). Sub-region (C) is in natural conditions as (B) but is composed of acid Archean granite-gneisses. Below: Sampling sites of the lake (Kylli etc.) projected along the longitudinal profile of the lake with a temperature distribution in March 1993 (Koutaniemi & Kuusela 1993: Figs. 1 and 15 with some additions).

The bedrock in the area is mostly composed of Karelian schists rich in easily erodible basic carbonate rocks which provide a favorable setting for the buffer capacity. In addition, the valley bottoms of Oulanka and its main tributaries are thickly covered by silts and sands (Koutaniemi 1979: 31–35) whereby infiltration and groundwater production is a slow process which further adds to the buffer capacity (e.g. Kämäri 1984: 21). Archean acid granite-gneisses are to be found on a larger scale only in the headwater areas of the river Kuusinkijoki in Finland and in two small basins of the rivers Malinajoki and Mutkajoki close to the lake outlet (Figs. 1 and 2). The Finnish side of the basin has long been under strong human influence (cultivation, forest cutting, ditching of forests and peat bogs, fish farming, tourism etc.), while the Russian side has stayed uninhabited and in a natural state since the end of the Second World War when Finland had to cede the Paanajärvi area to the Soviet Union (Koutaniemi & Kuusela 1993).

Based on tradition and personal local knowledge, Hänninen (1912: 30) notes that Lake Paanajärvi is frozen abnormally late (November/December; cf. Leppäjärvi 1995: 136) thanks to its great depth, but is ice-free at the same time (late May) as local lakes due to the through-flow. The first limnological observations were made by Lauri Maristo in 1937. He measured a pH of 7.5 and, on the basis of water plants, determined the lake to be oligotrophic (Maristo 1941: 74). The Soviet period did not produce any published material. Since "glasnost", opening of the border and collapse of the Soviet Union, several scientists from Finland and the Russian Academy have conducted multidisciplinary studies on the Paanajärvi basin (e.g. special issue in *Fennia* 177: 1; Kuusela & Systra 2003).

The preliminary water quality mapping in August 1990 revealed high pH and alkalinity values in the inflowing rivers and high nitrogen concentrations in the lake outlet (Kuusela 1991). A summary of the studies made in 1990–1993 (Koutaniemi & Kuusela 1993) showed that both in the lake and the rivers, alkalinity, total nitrogen and nitrate contents were at a higher level in the winter than in the summer. Total phosphorus, however, behaved the opposite, especially in the epilimnion. These values were mostly so low that according to the scale by Forsberg and Ryding (1980: 197), the lake and the inflowing rivers were oligotrophic except for the river Kuusinkijoki, where mesotrophy was obvious. Primary production and plankton have features which indicate that the inorganic phosphorus could be a limiting factor (Arvola et al. 1993: 93).

The present work is the first systematic attempt to study the basic features of the water chemistry in the Lake Paanajärvi area, which was recognized for its particular character among Finnish naturalists as early as one hundred years ago (e.g. Koutaniemi 1992). The same source material has been a basis for a paper on temperature stratification (Koutaniemi et al. 1999), one symposium presentation on the nutrients in the lake (Kuusela & Koutaniemi 2003) and an unpublished Master's thesis (Linnilä 2004).

The opening of the Russian border in the late 1980s allowed daily visits from Finland to Lake Paanajärvi directly across the border until the mid-1990s. During the latter half of the 1990s, these special border crossing arrangements came into a halt, meaning in practice that after this it has taken a day to travel to the lake area. Performing the present study was thus much more complicated than the preliminary water quality studies in the early 1990s, when the water samples could be taken to laboratory for analyses on the very same day. This is why, for example, sampling of the spring turnover of 1996 was missed: the abnormally late ice-break only took place two days after the permission to cross the border back home had expired. From time to time, repeated and unexpected restrictions to move in the lake area have led to gaps in the data which are best seen in the figure illustrations.

Methodology

Water samples were taken with a Ruttner sampler during six visits (July, August and September 1996 and April, June and July 1997) from the outlets of the inflowing rivers and five sites (named according to the old Finnish farms) along the lake (see Fig. 2): Kylli (a strait between the inlet basin and the lake), Rajala (deep), Leppälä (deep), Sirkelä (a shallow transverse shoal) and Mäntyniemi (deep). Lake water samples were taken normally from the depths of 1, 5, 10, 30, 60 and 80 meters. The samples were processed in the laboratory within 48 hours of sampling; in summer they were transported in cooled boxes.

The laboratory of the Oulanka Research Station analyzed the samples for organic solids, alkalinity, colour, conductivity, total phosphorus (totP), total nitrogen (totN), ammonia (NH_4^+) and nitrate (NO_3^-) according to the Finnish standards. The nitrate content also includes nitrite (NO_2^-) since it had been noticed earlier in this laboratory that nitrite concentrations are insignificant in the headwaters of Lake Paanajärvi. The pH results are not presented herein due to a lengthy delay before their measurement. However, in the early 1990s, it was possible to measure the pH within 6–8 hours of sampling. The rivers studied herein had at that time slightly alkaline water: in the late winter (12 samples) pH was 7.3–7.9, in August (15 samples) 7.3–8.2 (Koutaniemi & Kuusela 1993: 78).

The product-moment correlation coefficient (r) and its significance (p) were calculated for colour vs. organic solids and for alkalinity vs. conductivity and totP. The lake consists of an eastern and a western basin which are separated by the Sirkelä shoal (Fig. 2). The eastern basin represents about

30% of the surface area and contains 20% of the water volume (Koutaniemi et al. 1999: 30). The terminology used here is adopted from Wetzel (1983).

Results

Inflowing waters

The water colour had a similar seasonal pattern in all rivers (Fig. 3): it was at its lightest in September and April (14–36 mgPt l^{-1}) and darkest in June (47–76 mgPt l^{-1}). The lowest values (from 14 to 47 mgPt l^{-1}) were found in the river Mäntyjoki, the highest ones (30–69 mgPt l^{-1}) in the inlet (Oulanka). The latter were a little lower than in the outflow of the lake (32–76 mgPt l^{-1}). The colour of the water did not correlate with organic solids ($r = 0.000$, $n = 31$).

The load of organic solids was much the same in all rivers except in summer 1996. In August, for instance, the contents (3.90–6.35 mg l^{-1}) were about twice as high as for other dates (0.75–3.95 mg l^{-1}) (Figs. 3 and 4). The load from the lake was mostly lower than in the inlet, but nearly equal to that of the inflowing rivers.

Alkalinity was high year round in the rivers of Tervajoki, Selkäjoki and Mäntyjoki (Figs. 3 and 4) with its maximum of 1.16 mmol l^{-1} in the last-mentioned case. The lowest values (0.16–0.17 mmol l^{-1}) were measured in the rivers of Malinajoki and Mutkajoki. Alkalinity remained reasonably stable (0.26–0.50 mmol l^{-1}) in the inlet and outlet, the former giving regularly slightly higher values. Alkalinity correlated very significantly with conductivity in river waters ($r = 0.993$, $p < 0.001$, $n = 34$).

The load of phosphorus had a large range (Figs. 3 and 4). The highest concentrations (up to 12.67 µg l^{-1}) were measured in Oulanka during the late winter. The values were almost twice that of the lake surface water. The quantities in the inlet were higher than in the outlet and both exceeded those for the lake in most cases. TotP did not correlate with alkalinity ($r = -0.03$, $p > 0.05$, $n = 31$).

Total nitrogen contents had in almost every river a clear declining trend during the summer 1996, the opposite being true with ammonia (Figs. 3 and 4). In the inlet, the values were in all cases higher (range 99–771 µg l^{-1}) than in the outlet (88–266 µg l^{-1}). The nitrate compounds were at their maximum in April as well as ammonia and total nitrogen in Oulanka. The annual differences were great. In July 1996, for example, the range of totN was 253–403 µg l^{-1}, while a year later only 51–128 µg l^{-1}. In places, nitrate increased by over fifty times from August 1996 to April 1997. In the outlet of the lake totN varied between 88 and 266 µg l^{-1}.

Lake water

The water colour varied within a range of 31–77 mgPt l^{-1} (Fig. 3). During the summer time (June–August) it was about 55–60 mgPt l^{-1}, in the winter (April) around 35 mgPt l^{-1}. The water was darkest (65–70 mgPt l^{-1}) in June. The annual course of the water colour was much the same as in the rivers, but with a smaller variation. The water colour did not correlate with organic solids ($r = 0.11$, $p > 0.05$, $n = 116$).

The amount of organic solids ranged from 0.8 to 6.0 mg l^{-1} without any clear seasonal pattern (Figs. 3 and 5). The western basin featured equal values (around 3 mg l^{-1}, except for Rajala) in the whole column of August 1996, the same being true for the eastern basin a month later. The contents at Rajala were also equal at all depths but double in relation to the other sites. This phenomenon coincided with the highest values in the inflowing rivers.

Alkalinity was at its highest in April and lowest in June (Figs. 3 and 5). The vertical variation was widest in the epilimnion (0.27–0.50 mmol l^{-1}). In the hypolimnion the range was 0.27–0.39 mmol l^{-1}. Conductivity correlated very significantly ($r = 0.959$, $p < 0.001$, $n = 121$) with alkalinity and followed its vertical and seasonal pattern.

The total phosphorus contents varied both temporally, spatially and vertically in a wide range (2.05–12 µg l^{-1}) (Figs. 3 and 6). August and June differed from other dates by their high values in the epilimnion, and, as a whole, the surface waters of the western basin were richer in phosphorus than those of the eastern basin. The vertical distribution of totP followed the temperature stratification in an approximate manner. In September 1996, for example, the concentrations of phosphorus were almost evenly distributed during the first phases of the autumn turnover. TotP did not have any correlation with alkalinity ($r = 0.02$, $p > 0.05$, $n = 114$).

The total nitrogen concentrations varied between 74 and 391 µg l^{-1} (Figs. 3 and 7). The highest contents were recorded in July 1996 and in April 1997. The vertical distribution of all deep sites followed the temperature stratification espe-

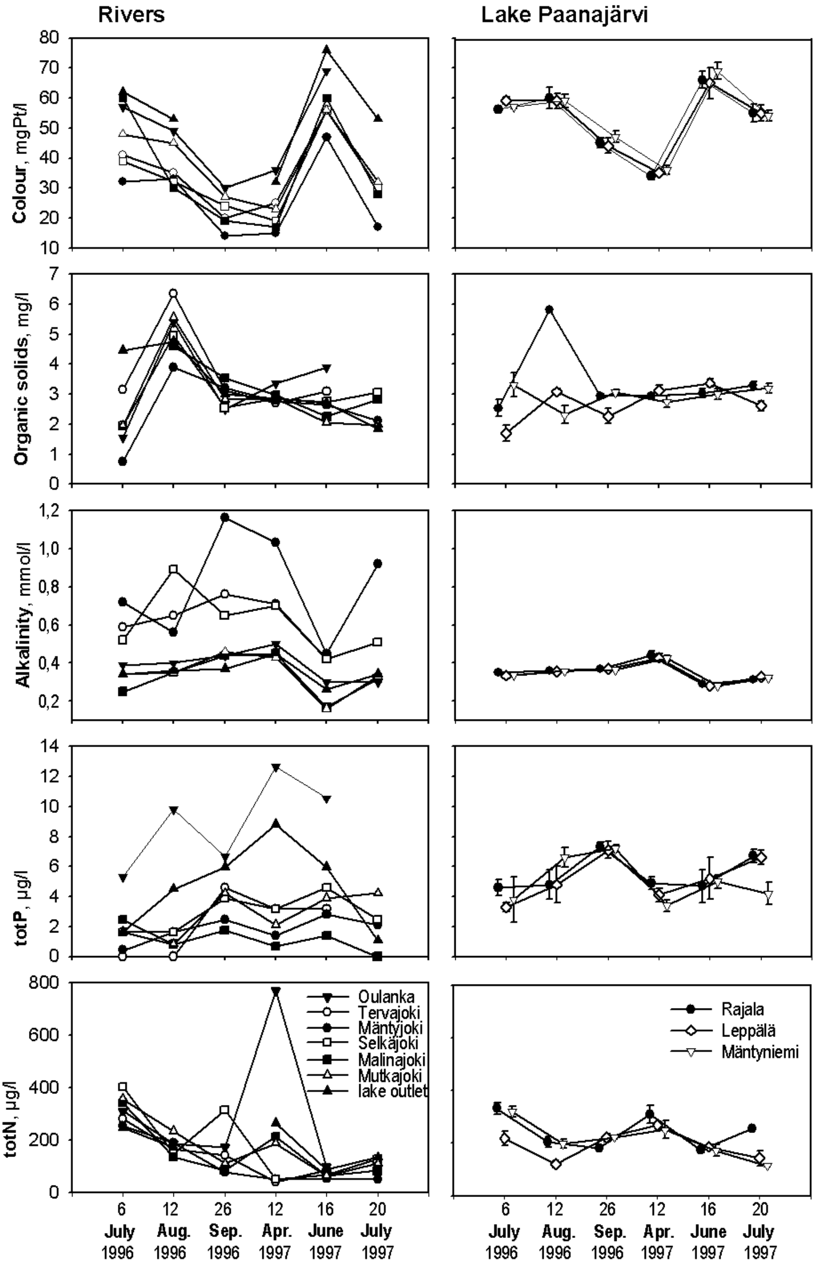

Fig. 3. Contents of colour, organic solids, alkalinity, total phosphorus and total nitrogen in the inflowing rivers and deep sites of the lake. In order to clarify general annual trends the values of the deep sites are presented as means of all depths together with standard errors.

cially in April. Before the autumn turnover, nitrogen had been distributed similarly to phosphorus, i.e. rather evenly both vertically and horizontally throughout the lake.

The nitrate concentrations in April were both horizontally and vertically at a much higher level (50 µg l^{-1} or more) than at any other time (Fig. 7). During the open water season the values were low in the epilimnion and declined to zero, especially in the eastern basin. At the same time the values of the hypolimnion increased much more in the inlet than in the outlet.

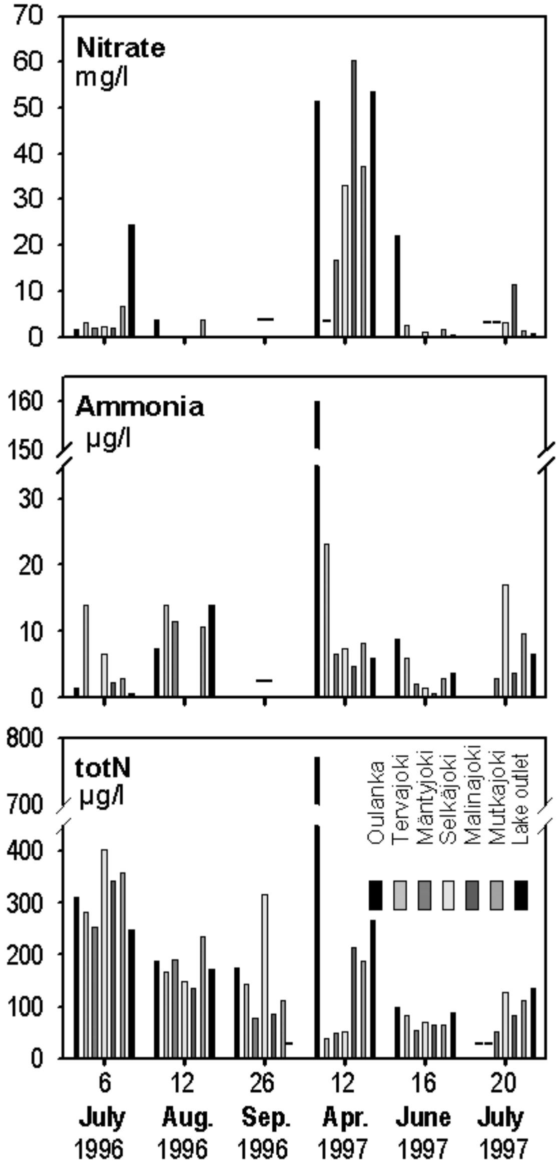

Fig. 4. Nitrate, ammonia and total nitrogen in the inflowing rivers and the lake outlet.

The contents of ammonia varied greatly both temporally, vertically and by sites (Fig. 7). Analysis proved, however, that as a rule, the decrease in nitrate values was closely connected with the increase in ammonium values. This was most clearly seen in the eastern basin as indicated by the following values:

	Depth (m)	Nitrate (µg l^{-1})	Ammonia (µg l^{-1})
From July to August 1996	(1)	21.0 → 0.0	3.7 → 23.1
	(5)	26.2 → 2.5	3.0 → 23.9
	(10)	23.0 → 1.9	4.4 → 20.6
From June to July 1997	(1)	2.2 → 0.4	1.5 → 8.9
	(5)	10.0 → 0.0	3.0 → 8.9
	(10)	12.3 → 0.0	2.2 → 14.2

Discussion and conclusions

Seasonal trends in water quality

The water chemistry in Lake Paanajärvi and the inflowing rivers is characterized by several seasonal regularities and causalities. The winter is a season when the water colour is at its minimum, alkalinity at its maximum, the values of totP and totN have opposite trends in the lake, and the nutrients of rivers have a declining trend, except for Oulanka (see Fig. 3). Low colour values are due to minimal discharges and calm conditions attributed to the ice-cover. The peak in the alkalinity values originates in the increase of groundwater flow, the decreasing surface flow and the decomposition of biota which produce alkalinity enriching bicarbonates (see Puro 1999: 33).

The decrease in the totP values is connected with the low winter-time discharges and settling into the bottom sediments supported by the reactivity of phosphorus bound in the soil particles (see Wetzel 1983: 295). The same is true with both the totP and totN in all rivers except for Oulanka, where the winter-time peaks in nutrient contents are mainly due to high inputs of human effluent in relation to low winter-time discharges. The winter-time excess of total nitrogen and nitrate contents is in accordance with earlier observations (Koutaniemi & Kuusela 1993: Fig. 18), and is a normal phenomenon in lakes when the biota does not use it and decomposition releases it into water (e.g. Wetzel 1983: 241–242).

The spring floods are typified by the highest of all colours and lowest of all alkalinity values. Both parameters are closely connected with snowmelt-induced extreme floods caused by the steep relief. The minimum in alkalinity concentrations is due to large volumes of acidic snowmelt waters together with humic acids from the peat bog areas, the maximum in colour caused by physical and chemical erosion throughout the drainage basin.

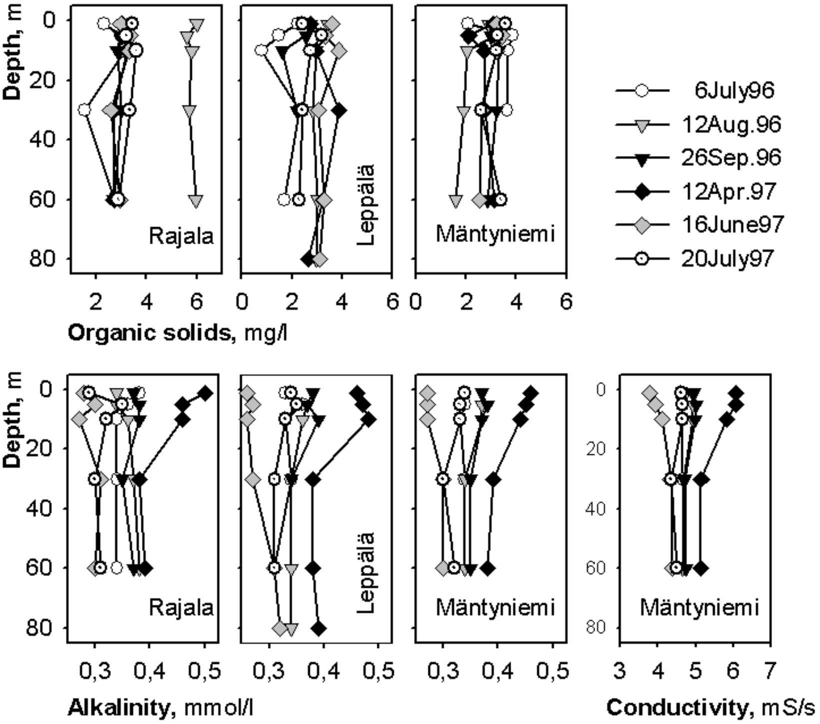

Fig. 5. Organic solids, alkalinity and conductivity by dates and depths in the deep sites of the lake. Conductivity is presented only for Mäntyniemi as an example of the high correlation with alkalinity.

The warming of river and lake waters initiates the spring turnover, temperature stratification and biological activity. The development of temperature stratification and its spreading from the inlet end via the through-flow towards the outlet end of the lake is a key event for all biological activity. It is reflected in the uptake of nutrients at different times depending on place, depth and year (Figs. 5–7). The increase in the biological activity is best seen through the rapid uptake of nitrate in the epilimnion at the same time as the metabolism of organisms liberates nitrate as ammonium (see Wetzel 1983: 253). Nutrients are also used efficiently in the rivers (Fig. 3). Contrary to the totN values, the phosphorus in the lake increases due to the rapid uptake and turnover by phytoplanktonic bacteria and algae (see Wetzel 1983: 270–271), as well as the high loads brought by Oulanka.

The autumn turnover is characterized by close to equal contents of most parameters through the water column in the lake (Figs. 3 and 6). From here onwards follows a period of sedimentation. The clear thermocline typical of Lake Paanajärvi does not prevent the re-distribution of chemicals in any way. The values for phosphorus, for instance, diminish in the whole water column all through the winter. Thus a new phosphorus load is needed for the next production season either from the headwaters, melting snow or bottom sediments.

Non-seasonal phenomena

Also worthy of emphasis are four non-seasonal phenomena. Firstly, the inflowing rivers which feed Lake Paanajärvi are geographically distinct and supply three types of water. Two small sub-basins (Malinajoki and Mutkajoki) with acid rocks provide waters with the lowest of all alkalinity and conductivity values. Typical for three other sub-basins (Mäntyjoki, Selkäjoki and Tervajoki) with basic rocks, are the highest of all alkalinity and conductivity values. The effects of all these waters are nevertheless of minor importance since the inlet flow via Oulanka is superior both in volume, richness in nutrients and as regards its trough-flow in controlling water chemistry of Lake Paanajärvi.

Secondly, the uptake of nitrate to the point of elimination in the summer-time epilimnion indicates that nitrate may be a limiting factor for the aquatic life. Arvola et al. (1993: 93) are of an opinion that inorganic phosphorus would be a limiting factor for the primary production. This particular

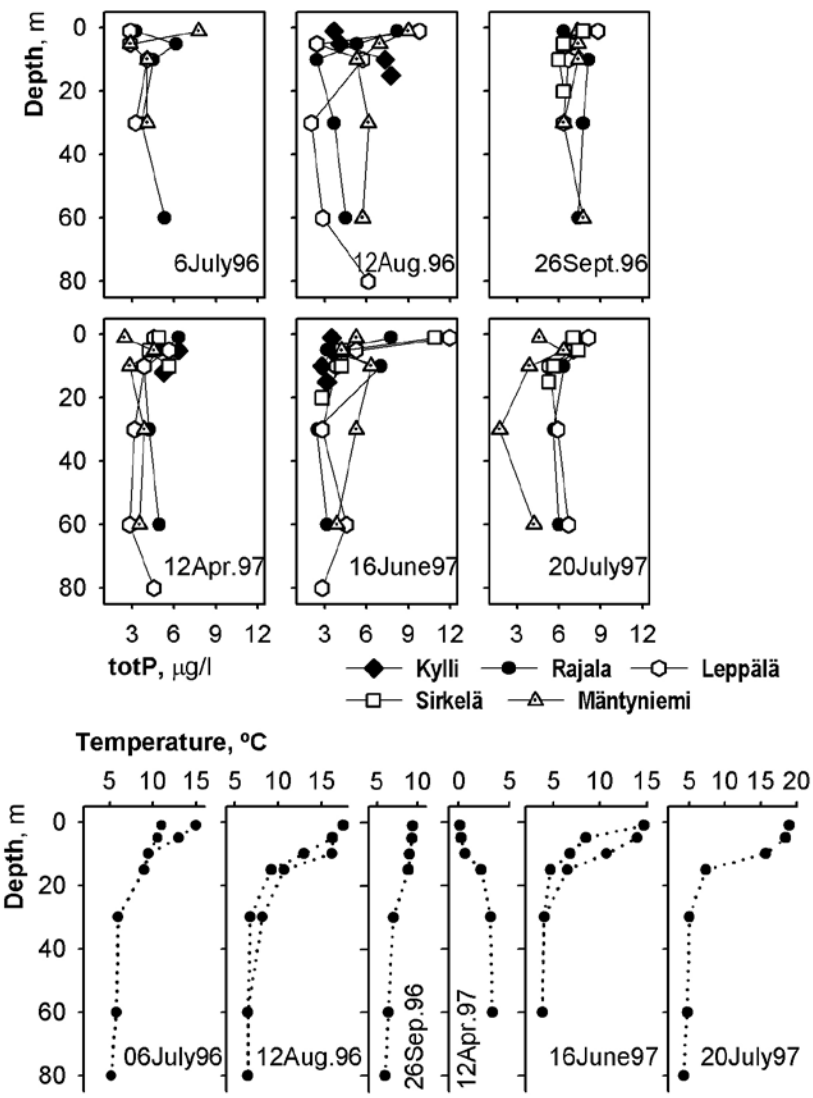

Fig. 6. Total phosphorus contents of the lake water by dates, depths and sampling sites, and the temperature stratification of corresponding dates (redrawn from Koutaniemi et al. 1999: Fig. 3). Note: dividing dotted lines in some temperature curves refer to extreme values when marked differences occurred along the lake.

dependence was not investigated and therefore no estimations can be made here.

Thirdly, the comparison of the alkalinity values with those of the neighbouring basins revealed the following rule: the higher the alkalinity the smaller the difference between the summer- and winter-time values of the lake waters. The comparison was based on the following mean values from a depth of one metre in all cases: Lake Paanajärvi (summer 0.36 mmol l^{-1}, winter 0.47 mmol l^{-1}), the data for 57 lakes collected by Näpänkangas et al. (1999: 52) and Näpänkangas and Ylitolonen (1999: 38) both from the river Kem basin (rich in acid rocks) draining into the White Sea (0.26 and 0.38 mmol l^{-1}) and the river Iijoki basin (rich in acid rocks and peat bogs) flowing into the Gulf of Bothnia (0.18 and 0.27 mmol l^{-1}). Accordingly, the winter-time values in our samples were 1.30, and in two other cases 1.46 and 1.50 times higher than in the summer-time, respectively. The explanation remains open, but to all appearance the phenomenon is connected with the high proportion of winter-time groundwater flow in our study area owing to the relatively steep relief.

Fourthly, the alkalinity values offer a textbook example of how differences in the bedrock may

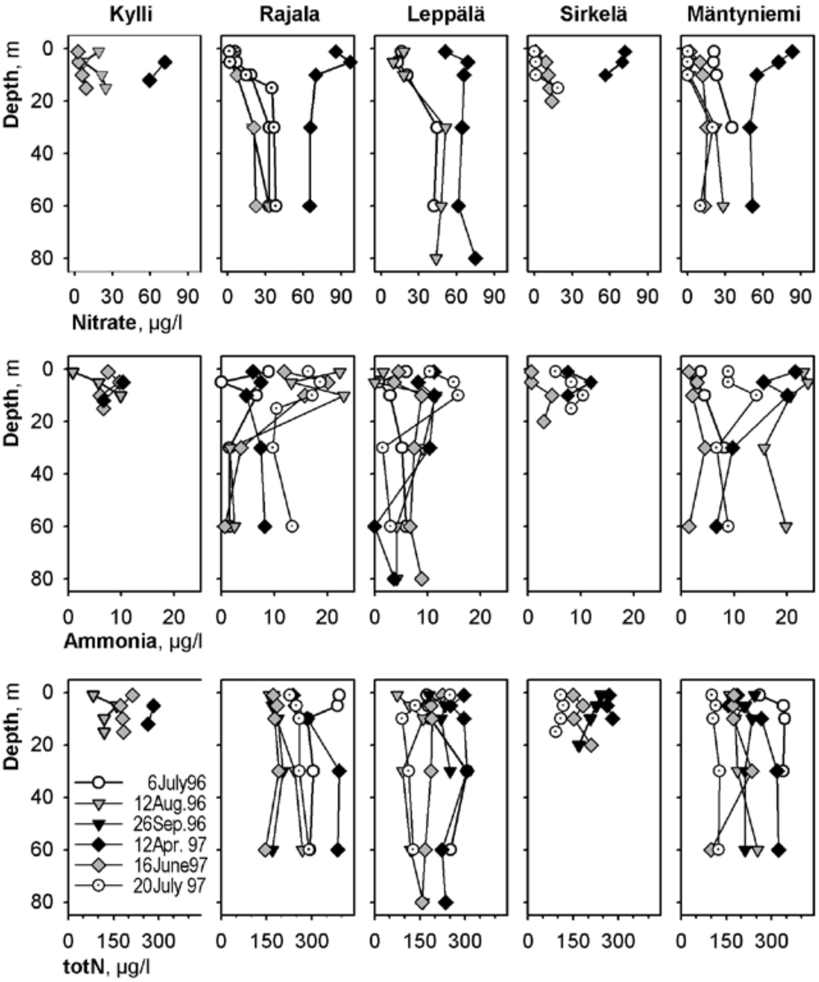

Fig. 7. Contents of total nitrogen, nitrate and ammonia of the lake water by dates, depths and sampling sites.

appear clearly in natural conditions (cf. Kämäri 1984: 13). Values of three sub-basins (Mäntyjoki, Selkäjoki and Sovajoki) with basic rocks are on a high level of their own (Fig. 3). Detailed checking of the original data revealed another interesting finding. The question is whether the input of two small areas (Malinajoki and Mutkajoki) with acid rocks can be seen in the alkalinity values of the outflow. Focused upon the outlet part of the lake (see Fig. 2) these inputs are sufficient to decrease the outflow values to a lower level than in the inlet, although on the way through the lake alkalinity is enriched by the highest of all alkalinity values, i.e. by the three first mentioned rivers.

Perhaps the most exceptional feature of results presented here is the high amount of organic solids in August 1996 in all rivers and in the western basin (Rajala). To all appearances, they originate in river erosion caused by heavy rains. Precipitation of 77 mm between 6th and 15th July at the Oulanka meteorological station (25 km upstream from the lake) resulted in almost tripled discharge (from 20 up to 55 m^3/s^{-1}), and, from this flow alone, 36 million cubic metres of additional water entered Lake Paanajärvi. On the sampling day (12th August), about three weeks after the flood peak, the signs of the flood were to be seen in the inlet (organic solids in the range 2.7–6.4 mg l^{-1}), were uniform in all depths at Rajala (5.6–6.0 mg l^{-1}), had possibly a faint effect in Leppälä (2.8–3.4 mg l^{-1}) but were absent in the eastern basin. There the extra input appeared a month later as higher values than elsewhere in the lake at that time.

Signs of the flood were not recognizable in other parameters, but this need not be in conflict with the flood hypothesis. Tikkanen (1990: 26–27) has shown that the increase of nutrient contents caused by summer floods is relatively low thanks to the growing season, and that the peak is over soon after the flood.

According to the assessment of the trophic state of the water body (Forsberg & Ryding 1980: 197), Lake Paanajärvi and its inflowing rivers (except for Oulanka) are oligotrophic by their relatively low totP and totN contents. The rapid usage of nitrate in the epilimnion suggests oligotrophy, too. Contrary to both these two, the ratio of nitrate to ammonia speaks for higher nutrient levels in two ways. Firstly, the contents of these two had often opposite trends, although the values of ammonia ought not to be related to nitrate in oligotrophic lakes. Secondly, the ratio of nitrate to ammonia was mostly of the order 1–10 (median 5), but this ratio should be one-to-one in lakes where the natural nitrate resources are low (see Wetzel 1983: 234–237, 253–254). Thus, the water chemistry of Lake Paanajärvi has also mesotrophic features.

Conductivity and alkalinity had a very high correlation ($r = 0.96$). This is in accord with Kämäri's (1984: 38) results, which revealed that this correlation is stronger in Kuusamo ($r = 0.99$) than in southern Finland ($r = 0.70$) due to differences in the bedrock and soils (see also Forsius 1987: 49). Kämäri (1984) also detected that alkalinity had a correlation with totP and totN. No dependence between alkalinity and totP was found in our data.

The colour values are a surprise since higher values were observed in the outlet than in the inlet (Fig. 3), yet lakes are normally known for their clarifying effect. One possibility is that the three side-rivers of the lake (Mäntyjoki, Selkäjoki and Sovajoki) with their abnormally high alkalinity and pH-levels contribute to the decomposition of humus acids, the results of which raise the colour values (Seppänen 1986: 186). Fig. 3 also shows decreasing late-summer trends in 1996 for colour and organic solids in river waters. This has its natural explanation in the abnormally dry late summer for this particular year. Precipitation sums for August and September were half and one-third of long-term mean values.

The question of nutrient rich waters from Finland being a threat to the water quality of Lake Paanajärvi warrants examination. The nutrients originate mainly in human activity (e.g. cultivation, ditching and ploughing of forests and peat bogs, aqua-culture, tourism etc.) which has been substantial during the last fifty years. In spite of improved methods for purifying waste-waters, care in ditching operations, overgrowth of most of the earlier ditches and limitations in cultivation, the winter-time inputs are still alarmingly high (Fig. 4). Nevertheless, the general trend is not critical. The totN and totP values in the present material were lower than in those from the early 1990s (Arvola et al. 1993: 98; Koutaniemi & Kuusela 1993: 82). Furthermore, Arvola and Ylitolonen (in prep.) have observed that in Oulanka and in its main tributary Kitkajoki, the declining trend has continued over the last three decades with its greatest decline from 1991–93 to 1996–97.

The discussion ends with an example of an inconceivable discrepancy. The question is of totP contents best seen in April 1996 in Fig. 3. The values for total phosphorus are at their highest in the inlet and outlet ends of the lake, the former (12.8 $\mu g\ l^{-1}$) being clearly higher that the latter (8.8 $\mu g\ l^{-1}$). All other lake values are clearly lower (range 2.5–6.3 $\mu g\ l^{-1}$, mean 3.8 $\mu g\ l^{-1}$). The decrease in totP values between the inlet and the lake is logical due to the winter-time settling and storing into the lake bottom sediments. The discrepancy, however, lies in the high outflow value of 8.8 $\mu g\ l^{-1}$, since such high concentrations have not been detected elsewhere in the lake. Since totN values were already in 1990 clearly higher in the outlet than in the inlet (Kuusela 1991: 18), it seems that nutrient contents of the outlet have stayed on a high level for a longer period. Human activity perhaps lies behind this phenomenon. The outlet end has always been the only entrance to Lake Paanajärvi (except for military personnel who have their own road at the inlet end). The outlet end has witnessed much activity since the 1970s when there were many workers making preparations for a water power plant (abandoned since the late 1980s). Nowadays the number of visitors is 3000–4000 per year, and as before, the present visitors use the sauna and wash their dishes in a small, muddy-bottomed and weedy bay, from where the waste and dish effluents drain to the outlet rapids wherefrom the water samples were collected.

Ultimately, it would appear that the lower levels of nutrients together with the earlier findings of lower temperatures in the eastern basin (see Fig. 2) indicate that the opportunities for of aquatic life are more restricted in the eastern basin than in the western one. Either the summer season is too short for the warmth to spread evenly in this lake which, in its time, was the deepest one in Finland, or the temperature difference is caused by different mixing mechanisms of surface and deep waters (see Koutaniemi et al. 1999: 34). Since this situation must have continued for thousands of years it would be interesting to know, together with the question of high nutrient levels in the outlet, if cooler and more demanding conditions have led to any adaptation or specialization among the lake biota, which can be seen, for example, in the phenology or growth parameters of certain subpopulations.

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