**Hydrology and
Earth System
Sciences
Discussions**

Eutrophication and Phosphorous accumulation in sediments of Karlskärsviken, bay in Lake Mälaren

G. Olli

Department of Physical Geography and Quaternary Geology, Stockholm University, 10691, Stockholm, Sweden

Correspondence to: G. Olli (gull.olli@natgeo.su.se)

HESSD

4, 1823–1843, 2007

Eutrophication and
phosphorous
accumulation

G. Olli

Title Page

Abstract	Introduction
Conclusions	References
Tables	Figures

| ◄◄ | ►► |
| ◄ | ► |

| Back | Close |

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

EGU

Eutrophication and phosphorous accumulation

G. Olli

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Abstract

Biogenic silica (BSi) and phosphorous (P) accumulation were investigated in sediment cores from Karlskärsviken, a bay of Lake Mälaren. The aim was to understand and quantify environmental changes since the Middle Ages, with focus on industrial times, and to evaluate anthropogenic influences on the bay's water quality. The BSi accumulation in the sediments is a better indicator of former nutrient trophy than P accumulation and for this reason a BSi inferred P content, BSi-P, is calculated. There is an increasing trend of BSi-P content in the bay since the Middle Ages, with a small decrease in the inner bay section during the last decades. In Karlskärsviken, the shallow inner section of the bay, where the water quality is dominated by loading from the bay catchment area, is less nutritious than the water in the outer section, which is influenced by the main streams in the Lake Mälaren. The P content in the water column is presently higher than in the mid nineteenth century, and the P loading to Karlskärsviken is not found to have changed since the 1960s and 1970s.

1   Introduction

In the global problem of eutrophication, phosphorus (P) plays a crucial part, as a limiting nutrient in freshwater lakes, especially in Temperate Zone waters (Lund, 1972; Reynolds, 1984; Harper, 1992; Farmer et al., 1993; Persson, 2001). In Sweden, for instance, regular monitoring has been performed in the basins of the big lakes since 1965 (Willén, 1972). Historical nutrient enrichments are found in the sediments, but to estimate P concentrations in the past water column, these enrichments have to be interpreted.

P in sediments is sorbed and desorbed by vegetation and chemical processes in the water (Round, 1981; Boström et al., 1982), so the P accumulation in sediments seldom reflects the P content in the contemporary water column. However, P in the water column is important to know, because it commonly determines the biomass maxima

of phytoplankton, so when P levels are enhanced, algal growth, including silicon algae, diatoms, increase quickly (Andersson, 1994). In contrast to P, diatom frustules are indestructible in sediment, and consequently diatom accumulation provides a better signal of contemporary P in water than the P sediment accumulation does and is therefore accepted as a nutrient criterion (Round, 1981; Stoermer, 1984; Schelske et al., 1983, 1986; Anderson et al., 1993; Bennion et al., 1996; Renberg, 1999).

Different model studies have been performed (ter Braak and van Dam, 1989; Anderson et al., 1993; Bennion et al., 1996; Bradshaw and Anderson, 2001) to determine quantitatively the relationship of diatom species to total phosphorous (DI-TP). Schelske et al. (1983) have shown that the amount of diatom cells and biogenic silica (BSi) is almost identical in the sediments and used the percentages of BSi in sediments as criterion of nutrient enrichment.

Diatoms have also other requirements than nutrients, like light and silica (Schelske, et al., 1983, 1986; Rühland and Smol, 2005; Mackay et al., 2005; Paus et al., 2005; Katsuki and Takahashi, 2005), and their presence in sediments can also be influenced by episodic events, such as storm events. When lakes are covered by ice during long periods, the diatom production is less than in years with hardly any ice and long and warm summers trigger the production. Silica is needed for diatom prosperity (Schelske et al., 1983, 1983), and consequently diatom decrease can be due to silica deficit in the water column. Schelske et al. showed that high BSi content and likewise high BSi TP^{-1} (the ratio biogenic silica and total phosphorous contents) and BSi BAP^{-1} (the ratio biogenic silica and bio available phosphorous contents) ratios in sediment stratigraphies indicate Si depletion in the water column.

The aim of this study is to make use of previously found BSi and P relations in sediment stratigraphies in order to investigate the historical nutrient trophy in a near shore lake environment. This environment is here represented by Karlskärsviken, a bay in Lake Mälaren. The investigation period extends over the last thousand years, but with particular focus on the last century and on establishing the background nutrient trophy in such a near shore environment, which is expected to be dominated by the

loading from its catchment area.

2 Materials and methods

2.1 Site description

Lake Mälaren (Fig. 1), located to the west of Stockholm, is characterized as eutrophic
like all shallow lakes in the European lowland areas (Miljödepartementet, 1991; Foy
and Withers, 1995). Lake Mälaren has a large catchment area and a very long shore-
line including numerous islands, bays, capes and points, with the consequence that the
precipitation directly on the lake only accounts for about 10% of the total water inflow
to the lake (Willén, 2001). Such a lake is very sensitive to the water quality in and
nutrient and pollutant loading from the tributaries (Persson, 2001). In the lowlands, the
tributaries often are drainage ditches from arable land and densely populated areas.
The main tributary to the studied bay, Karlskärsviken, is a ditch from the south, which
was investigated 1997–2000 by the author with respect to P content (Olli, 2007[1]).

This ditch was dug in 1951 and increased the drainage area of Karlskärsviken to
the double, which is about 560 ha today (Fig. 1). The bay of Karlskärsviken, situated
to the north of the island of Färingsö, covers about 20 ha and has an average depth
of about 3 m (2.90–3.45 m in the studied sites). The slope gradient is <1%, which is
common in the western part of Lake Mälaren. The eastern shore is rocky and steep but
the western shore has a broad transition zone with reeds between the open water and
the low lying shore meadows. At present close to the outlet, the ditch is overgrown by
macrophytes and both organic and inorganic phosphorous rich particles are deposited
there as explained by Benoy and Kalff (1999).

---

[1]Olli, G.: Sediment accumulation rates over the last 1000 years in Karlskärsviken, a bay of
Lake Mälaren, Sweden, J. Nordic Hydrol., submitted, 2007.

2.2 Methods overview

To establish the historical nutrient trophies, the BSi contents were measured (Fig. 2a) in sediment cores taken in the bay and transferred into P content, denoted BSi-P (see supporting information 1: http://www.hydrol-earth-syst-sci-discuss.net/4/1823/2007/
hessd-4-1823-2007-supplement.pdf). Schelske et al. (1986) has shown that there is a relationship between nutrient content and BSi. The transfer here is based on the present trophy state, which is known both by the measured P content in the water column and the stored BSi in the uppermost sediments. Several earlier studies have shown how to reconstruct water column P content during past time (Round, 1981; Stoermer, 1984; Schelske et al., 1983, 1986; ter Braak and van Dam, 1989; Anderson et al., 1993; Bennion et al., 1996; Renberg, 1999; Bradshaw and Anderson, 2001). P contents in the water column were also measured in order to calculate the BSi TP^{-1} and BSi BAP^{-1} ratios, as a decrease of BSi may depend on silica deficit. Peaks in these ratios at the same depth as a peak in BSi accumulation may be associated with epilimnic Si depletion (Schelske et al., 1986), resulting in BSi decrease and a coinciding P peak. At such occasions, Si is the limiting element and the stored BSi does not indicate the contemporary P content. The sediments were earlier dated by the author (Olli, 2007[1]; see dating results, year versus sediment depth, for the different cores in Table 1) by counting diatoms and SCP (spheroidal carbonaceous particles, which are fly-ash particles from fossil combustion) and by isotope Cs-137 analysis (see supporting information 2: http://www.hydrol-earth-syst-sci-discuss.net/4/1823/2007/hessd-4-1823-2007-supplement.pdf). Sediment accumulation rates from the earlier study (Olli, 2007[1]) are used to establish the BSi accumulation rates from BSi content and accumulation rates (see supporting information 3). The sediment accumulation rates have signalled that the outer section of the bay is, and has been since the Middle Ages, strongly influenced by the main water streams in Lake Mälaren, while the water quality in the inner section is dominated by the loading from the catchment area.

2.3 Field work

In Karlskärsviken the P content in the water column was regularly measured during 1998 and controlled in 1999 and 2000. Sediment cores were taken in the bay in a section from the above mentioned ditch outlet to the outer end of the bay (Fig. 1). All the core locations are outside the macrophyte zone. In the macrophyte zone the sediments have been dredged, and no historical information is archived. A 1 m long Russian peat corer was used for the cores 1, 2, 4 and 5, all taken in winter when the bay was covered by ice. A turbidity-meter was used to measure the water depth. The cores 1, 4 and 5 were two meters long and core 2 one meter. The cores 3 and 6 were taken with a freeze corer. The length of core 3 was 48 cm and core 6 was 65 cm in length. The upper 40 cm of core 2 was strongly perturbed and without possibility of dating. All cores were sectioned into 1 cm slices until the depth of 70 cm and below that into 2 cm slices. The slices were freeze-dried and prepared for further analyses.

2.3.1 Analyses

BSi content in the sediments was determined colorimetrically in a spectrophotometer. The samples were prepared according to the method elaborated by De Master (1981), but 2% Na_2CO_3 was used instead of 1% and accordingly the HCl content had to be doubled. The samples with anomalous results were repeatedly analyzed two or three times. Selected samples were checked in a light-microscope to make sure that the diatoms were dissolved.

P was analysed in respect to bio available phosphorous (BAP), and total phosphorous (TP) according to Psenner et al. (1984).

2.4 Lithology

The cores consist of clay and gyttja clay in the uppermost sediments. The uppermost 5 cm in core 1 was empty.

EGU

3 Results

3.1 BSi and P content

The BSi content in the sediments shows an increasing trend since the Middle Ages
(Fig. 2a) from about 25 mg BSi g DM^{-1} to 37 BSi g DM^{-1} at present. The P content
oscillates between 600 and 900 μg TP g DM^{-1} (Fig. 2b) and there is no consistently
increasing or decreasing trend, as that for BSi. The accumulated P in the sediments
was not expected to show the historical P concentrations in water, but was used to get
the ratios BSi TP^{-1} and BSi BAP^{-1} for controlling if the Si deficit has diminished the B
Si content in the sediments.

3.2 Reconstructed P values

In the Middle Ages the general uplift of the ground created the freshwater Lake
Mälaren. At the beginning of that stage, the BSi-TP content in Karlskärsviken is esti-
mated 16–18 μg TP L^{-1} (Fig. 3a and Table 1). About 1850, the P content had increased
to 20–22 μg TP L^{-1}. Between 1850 and 1950 Karlskärsviken became more nutritious
and the BSi-TP content rose to 25–27 μg TP L^{-1} (Fig. 3a). The 1920s and 1930s were
periods of drainage undertakings at the island of Färingsö, which increased the nutri-
tious outlets to the lake. Additionally, the temperature rose in the 1930s (Moberg et
al., 2005; Briffa, 2000), resulting in short winters, which is a safe trigger of algal pro-
duction. The hard climate with long periods of ice-cover lakes during the World War II
is reflected in the sediments with lower diatom production in all the sediment cores
(Fig. 3a and Table 1) and the diatoms responded immediately to the more convenient
conditions that followed.

After 1950 the BSi-P content has oscillated between 20 and 30 μg TP L^{-1} with lower
values in the inner section and higher further out. The nutritious outflow from a ditch is
mostly concentrated to March–April and water renewal in a shallow bay occurs mainly
during these months (Persson et al., 1990) and is slowing down at the end of April–

EGU

May, which may explain the lower BSi-P content in the inner section. On average the uppermost sediments may signal a minor recent decrease to the present average BSi-P content of about $25\,\mu$g TP L^{-1} representing the water column conditions in 1998–2000 (Table 1).

5 ## 3.3 Background P content

When estimating the relevant background trophy, the P content at about 1850 may be a more realistic reference value than the medieval P concentrations in the deeper water column that existed at that time. This is also suggested by Willén (2001). From 1850 until today the nutrient level is in this study considered to have increased from about 10 20–22 μg BSi-TP L^{-1} to 25–26 μg BSi-TP L^{-1} (Fig. 3a), which is a 25% increase. The background TP concentration in Lake Mälaren has earlier been estimated to 6–15 μg P L^{-1} by Persson et al. (1990), and to 15–30 μg P L^{-1} by Renberg (1999) and Renberg et al. (2001). Shallow bays were not studied in these previous investigations, but the latter investigation results conform to the presently estimated BSi-TP. Considering the 15 warmer climate during the last decades compared to the cold middle of the nineteenth century the background BSi-P content, 20–22 μg TP L^{-1}, may possibly be put higher but on the other hand these concentrations were also anthropogenic influenced.

3.4 Anomalies

Core 1, which represents the inner section of the bay, has in previous studies shown 20 anomalies between 14 and 10 cm concerning fly-ash particles, carbon content, lead content (Olli, 2007[1]) and here also for BSi content (Fig. 2a). This increment with anomalies is interpreted to have been deposited during the years when the new ditch was dug and a public beach and a marina were constructed, which resulted in a very high sediment accumulation rate. The BSi content during this sediment disruption pe-25 riod is not transferred to nutrient conditions in the water column.

EGU

3.5 The ratios BSi TP^{-1} and BSi BAP^{-1} and Si deficit

Simultaneous peaks in BSi, BSi TP^{-1} and BSi BAP^{-1} may result in Si depletion in the water column and followed by a decrease of BSi, as diatoms need both silica and phosphorous to multiply (Schelske et al., 1986). In Karlskärsviken, the peaks in BSi and in the ratios BSi TP^{-1} and BSi BAP^{-1} (Figs. 4a, b) coincide in modern sediments, which indicate that Si deficit reduces the diatom production in the bay. In the 1990s this seems to have happened every two years in the inner section and three times in the outer section (Fig. 3b). Consequently, the BSi-P decrease after a peak may underestimate the real epilimnic P content. An attempt to calculate the levelled out P content in the cores 3 and 5 considering the epilimnic Si deficit during the last 10–15 years is shown in Fig. 3 (lower panels). In the past, when the water was deeper, more Si was stored in the water column and Si depletion was not as frequent as today.

3.6 BSi accumulation rates

The above performed estimations of P enrichments are based on BSi concentrations in the sediments. Whether it concerns nutrients or other elements it is common to express the water quality conditions in terms of concentrations. The sediment accumulation rates are then mostly considered to be even over time. In Karlskärsviken, however, the sediment accumulation rate is found to have increased considerably, especially in the twentieth century. Average BSi accumulation rates (Fig. 5) do not show any decreasing trend similar to the BSi contents. From about 1200 until 1850 the BSi accumulation rate increased with 25%. During the next century this rate also increased with 25% and was about 1.9 mg BSi cm^{-2} yr^{-1} at the end of World War II. After that, the rate increased dramatically with 300% in 20 years and reached 4.4 mg BSi cm^{-2} yr^{-1} in the 1960s and 1970s, which still remains the present rate, without signs of any decrease.

EGU

4 Discussion

From the first fresh water stage in Lake Mälaren about 1200 AD until 1850, the sediment up silting was about 0.5–1 m and the land upheaval of about 3.5 m lowered the water surface from about 8 m to 3.5–4.2 m. These changes normally result in an increasing nutrient trophy (Ahl, 1979). Lake water is also more nutritious in its shallow sections than in its deeper parts (Lännergren, 1998), assuming that the feeder streams are the same. Ahl (1979) writes about eutrophication that the effect of the lowering of the lake surface has been more serious than the effect of increasing nutrient loading. The increase from 17 μg BSi-P L^{-1} to 21 μg BSi-P L^{-1} (Table 1b) and from 1.2 mg BSi cm^{-2} yr^{-1} to 1.5 mg BSi cm^{-2} yr^{-1} (Fig. 5) during the period 1200–1850 may be a normal effect of the above mentioned morphological changes. From that period until 1950, however, both the BSi accumulation rate and the BSi-P content increased much faster, with about the same percentage, 25%, as in the previous 650 yr period but in only a hundred years.

After that, many former rills, small ditches, in the catchment area were turned into gullies by excavators and the outflows of particles increased both the sediment and the BSi accumulation rates. When considering only the BSi content in the sediments, the nutrient trophy may be viewed as having decreased during the last decades, but that interpretation is questionable if the sediment and associated nutrient accumulation rate is taken into account, which still remains at the high 4.4 mg BSi cm^{-2} yr^{-1} on average for the bay since about 40 years (Fig. 5). However, in the inner section of the bay, here represented by core 3, the nutrient load has diminished, even when regarding the sediment accumulation rate increase. This particular nutrient load decrease may be the result of a greedy macrophyte zone in the discharging ditch, which has not been maintained during the last decades. The reeds take advantage of the nutrient rich water and the diatoms downstream in the bay have no chance to profit on it. Si deficit may also cause the BSi decrease. A shallow bay has a very short hydraulic residence time, which makes the Si reservoir insufficient in late spring and summer, when the

EGU

diatom growth explodes. Si contents in water have at the lowest been measured to be 5–10 μg L^{-1} in May in basins of Lake Mälaren (Lännergren, 1998) and may even have been lower in the bay, limiting diatom production.

It is mentioned above in this paper (section: Reconstructed P values) that climate change may have influenced the diatom production during the 1930s and World War II. In analogy, also the BSi oscillation after the 1950s may be due to temperature fluctuations. From the warmer years in the 1930s to the colder conditions during World War II, the temperature difference was about 1.5°C, which probably is responsible for the BSi-P decrease from 25 to 23 μg TP L^{-1} (Table 1b). Thereafter, there is a temperature difference from the late 1960s to the late 1990s of about +0.7°C, which may mask a TP content decrease of about 1 μg TP L^{-1}. On the other hand, the years 1971 to 1975 were as warm as the late 1990s. Besides that, a difference of 1 μg TP L^{-1} is within the margin of error in this study, which focuses on main trends and approximate values.

When the diatoms do not consume all the P in water due to the Si deficit, there is P left for another spring or summer blooming with flagellating alga and green alga (Schelske et al., 1983). This second blooming, which frequently occurs in Lake Mälaren, is often taken as a proof of eutrophication, even when it depends on silica deficit in spring and the P level is the same as in previous years without this secondary blooming. Strong eutrophication effects is not considered to appear until the P content is above 25–30 μg TP L^{-1} (SEPA, 1993), and as the present nutrient trophy is about 25 μg TP L^{-1} it should not cause these secondary algal blooms, if Si were sufficient and the diatoms could consume the P in water. It is rather the timing of P and Si loading that seems to be bad, and therefore the P level, about 25 μg TP L^{-1}, causes eutrophication effects.

5 Conclusions

In Karlskärsviken, the shallow inner section of the bay, where water quality is dominated by the outflows from the catchment area, is less nutritious than the outer section, which

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◀ | ▶

◀ | ▶

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

is influenced by the main streams into Lake Mälaren. The P content in the inner section was measured 1998–2000 and found to be about 25 μg TP L^{-1}, which possibly is 4–5 TP L^{-1} higher than it was during the middle of the nineteenth century. The BSi content in the sediments is used as an indicator of P enrichment, but other circumstances have also to be considered, such as climate, Si supplies to the water column, and above all the sediment accumulation rates. These factors together indicate that the P outflow to Karlskärsviken has not changed durable since the 1960s and 1970s.

In the inner section of the bay, represented by core 1, former analysis of fly-ash, carbon and lead carried out by the author, showed anomalies at the levels dated 1951–1953. Corresponding anomalies are also recorded in the BSi and P stratigraphies. During that period, both the discharging ditch and its catchment area were enlarged and also water enterprises were in progress.

The background P content must be hypothetic as Lake Mälaren never had a freshwater stage without anthropogenic impact. This hypothetical background BSi-P content is here estimated to be 20–22 μg TP L^{-1}. This conforms to previous results by Renberg (1999) and Renberg et al. (2001), who estimated a background P content about to 15–30 μg TP L^{-1} in the basins of Lake Mälaren.

Coinciding peaks in BSi and in the ratios BSi-P TP^{-1} and BSi-P BAP^{-1} indicate that Si depletion sometimes occurs in the bay water column in spring and the diatom production brakes. The secondary bloom of green alga, which is recurrent in Lake Mälaren, is possibly an effect of silica deficit in the water column, which prevents the diatoms to consume the available P and at such occasions eutrophication effects appear.

References

Ahl, T.: Natural and human effects on trophic evolution, Archiv für Hydrobiologie, Ergebnisse Limnologie, Heft 13, pp 259–277, 1979.

Anderson, N. J., Rippey, B., and Gibson, C. E.: A comparison of sedimentary and diatom-

inferred phosphorous profiles: implications for defining pre-disturbance nutrient conditions, Hydrobiologia, 253, 357–366, 1993.

Anderson, N. J.: Reconstructing Historical Phosphorus Concentrations in Rural Lakes Using Diatom Models, 95–118, in: Phosphorus Loss from Soil to Water, edited by: Tunney, H., Carton, O. T., Brookes, P. C., and Johnston, A. E., pp 467, 1994.

Bennion, H., Juggins, S., and Andersson, N. J.: Predicting epilimnic phosphorous concentrations using an improved diatom-based transfer function and its application to lake eutrophication management, Environ. Sci. Technol., 30, 2004–2007, 1996.

Benoy, G. A. and Kalff, J.: Sediment accumulation and Pb burdens in submerged macrophyte beds, Limnol. Oceanogr., 44(4), 1081–1090, 1999.

Boström, B., Jansson, M., and Forsberg, C.: Phosphorus release from lake sediments, Arch. Hydrobiol. Beih. Ergebnisse, Limnologie, 18, 5–59, 1982.

Bradshaw, E. G. and Anderson, N. J.: Validation of a diatom-phosphorous calibration set for Sweden, Freshwater Biology, 46, 1035–1048, 2001.

Briffa, K. R.: Annual climate variability in the Holocene: interpreting the message of ancient trees, Quat. Sci. Rev., 19, 87–105, 2000.

DeMaster, D. J.: The supply and accumulation of silica in the marine environment, Geochimica et Cosmochimica Acta, 45, 1715–1732, 1981.

Farmer, J. G., Bailey-Watts, A. E., Kirika, A., and Scott, C.: Phospjorous fractionation and mobility in Loch Leven sediments, Aquatic conservation: Marin and Freshwater ecosystem, 4. 45–56, 1994.

Foy, R. H. and Withers, P. J. A.: The contribution of agricultural phosphorus to eutrophication, Proceedings of the Fertilizer Society, 365, 1–32, 1995.

Harper, D. M.: Eutrophication of Freshwaters: Principles, Problems and Restoration, Chapman and Hall, London, 1992.

Katsuki, K. and Takahashi, K.: Diatoms as paleoenvironmental proxiea for seasonal productivity, sea-ice and surface circulation in the Bering Sea during the late Quaternary, Deep-Sea Res. II, 52, 2110–2130, 2005.

Lund, J. W. G.: Eutrophication, Proc. Roy. Soc. London, B 180, 257–382, 1972.

Lännergren, Ch.: Undersökningar i Östra Mälaren 1994–97, Rapport, Stockholm Vatten, 35 p., 1998.

Mackay, A. W., Ryves, D. B., Batterbee, R. W., Flower, R. J., Jewson, D., Rioual, P., and Sturm, M.: Global Planet. Change, 46, 281–297, 2005.

Eutrophication and phosphorous accumulation

G. Olli

EGU

Miljödepartementet: Hur mår Sverige?, Bilaga A till regeringens prop 1990/1991, Miljödepartementet, Stockholm, 279 p., 1991.

Moberg, A., Sonechkin, D. M., Holmgren, K., Datsenko, N. M., and Karlén, W.: Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data, Nature, 433, 613–617, 2005.

Paus, A., Velle, G., Larsen, J., Nesje, A., and Lie, Ö.: Lateglacial nunataks in central Scandinavia: Biostratigraphical evidence for ice thickness from Lake Flåfattjönn, Tynset, Norway, Quat. Sci. Rev., 25, 1228–1246, 2005.

Persson, G., Olsson, H., and Willén, E.: Mälarens vattenkvalitet under 20 år. 1. Växtnäring tillförsel. Sjökoncentrationer och växtplanktonmängder, Naturvårdsverket Rapport 3759, Naturvårdsverkets förlag, Solna, 47 pp, 1990.

Persson, G.: Phosphorous in Tributaries to Lake Mälaren, Sweden: Analytical Fractions, Anthropogenic Contribution and Bioavailability, Ambio, 30(8), 486–495, 2001.

Psenner, R., Pucsko, R., and Sager, M.: Die Fraktionierung organischer und anorganischer Phosphor verbindungen von Sedimenten, Archiv für Hydrobiologie Ergebnisse Limnologi., pp 111–155, 1984.

Renberg, I.: Näringstillståndet I Södra Björkfjärden, Mälaren, under tusen år. En paleolimnologisk undersökning, Institutionen för ekologi och geovetenskap, Umeå Universitet, Umeå, 15 p, 1999.

Renberg, I., Bindler, R., Bradshaw, E., Emteryd, O., and McGowan, S.: Sediment Evidence of Early Eutrophication and Heavy Metal Pollution of Lake Mälaren, Central Sweden, Ambio, 30(8), 496–502, 2001.

Reynolds, C. S.: The Ecology of Freshwater Phytoplankton, Cambridge University Press, Cambridge, 1984.

Round, F. E.: The Ecology of the Algae, Cambridge University Press, Cambridge, 1981.

Rüland, K. and Smol, J. P.: Diatom shifts as evidence for recent Subarctic warming in a remote tundra lake, NWT, Canada, Paleogeography, Paleochlimatology, Paleoecology, 226, 1–16, 2005.

Schelske, C. L., Conley, D. J., Stroemer, E. F., Robbins, J. A., and Glover, R. M.: Early Eutrophication in the Lower Great Lakes: New Evidence from Biogenic Silica in Sediments, Science, 222, 320–322, 1983.

Schelske, C. L., Conley, D. J., Stroemer, E. F., Newberry, T. L., and Campbell, C. D.: Biogenic silica and phosphorous accumulation in sediments as indices of eutrophication in the

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◄ | ►►

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

EGU

Laurentian Great Lakes, Hydrobiologia, 143, 79–86, 1986.

SEPA: An environmentally adapted society, Swedish Environmental Protection Agency, Report 4324 (in Swedish), 1993.

Stoermer, E. F.: Qulitative characteristics of phytoplankton assemblages, in: Algae as Ecological Indicators, edited by: Shubert, L. E., Academic Press, London, pp. 49–67, 1984.

ter Braak, C. J. F. and van Dam, H.: Inferring pH from diatoms: a comparison of old and new calibration methods, Hydrobiologia, 178, 209–223, 1989.

Willén, E.: Four Decades of Research on the Swedish Large Lakes Mälaren, Hjälmaren, Vättern and Vänern: The Significance of Monitoring and Remedial Measures for a Sustainable Society, Ambio, 30(8), 458–466, 2001.

Willén, T.: The gradual destruction of Sweden's lakes, Ambio, 1, 6–14, 1972.

EGU

Table 1. BSi-P content, μg TP L^{-1} and the corresponding depth in brackets, at some years dated by diatom and fly-ash analyses.

(a) Year/Core	1	3	4	5	6	(b) Mean value
2000	25	25	25	26	26	25.2
1973	25 (4 cm)	27 (15 cm)	24 (16 cm)	27 (17 cm)	27 (18 cm)	26
1945	23 (16 cm)	22 (23 cm)	23 (27 cm)	23 (31 cm)	23 (32 cm)	23
1935	25 (17 cm)	25 (24 cm)	25 (29 cm)	26 (33 cm)	25 (34 cm)	25
1850	20 (25 cm)	21 (33 cm)	20 (38 cm)	22 (49 cm)	22 (51 cm)	21
1200	18 (68 cm)	–	16 (108 cm)	16 (148 cm)	–	17

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

I◄ | ►I

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

EGU
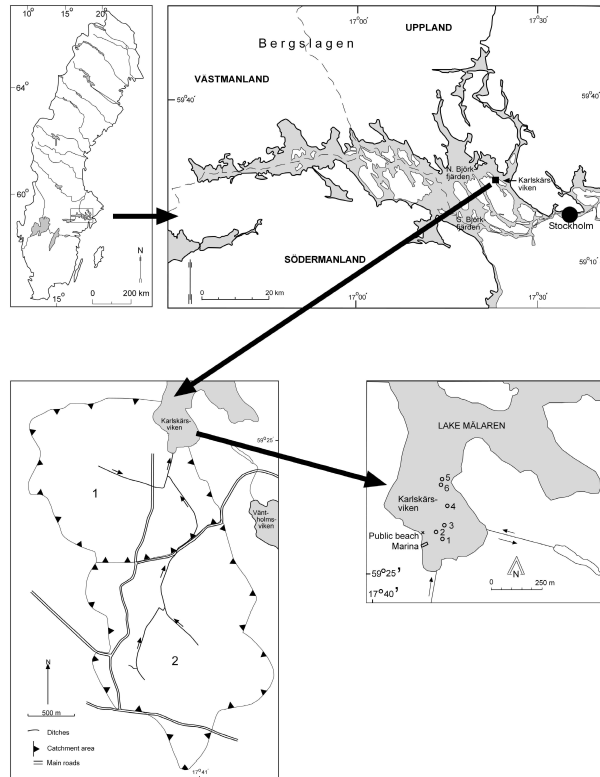
Fig. 1. **(a)** Sweden. **(b)** Lake Mälaren with Karlskärsviken to the north of Färingsö. **(d)** Karlskärsviken with the location of the sampling points and **(c)** its catchment area. (d) The investigated ditch is marked with one arrow and the rest of the former strait between Karlskärsviken and Väntholmsviken with two arrows. (c) 1. The original catchment area. 2. The enlarged catchment area since 1951. Maps by S. Karlsson.

EGU

EGU
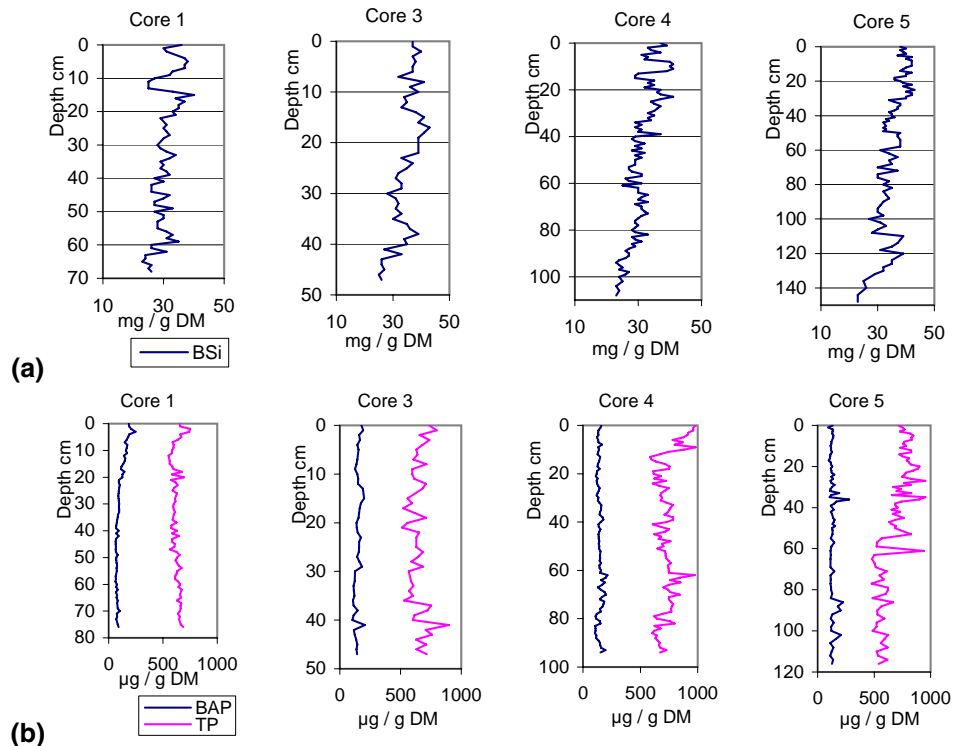
Fig. 2. Concentrations of **(a)** BSi and **(b)** BAP and TP in sediments vs. depth in the cores 1, 3, 4 and 5, Karlskärsviken. The BSi content starts with about 25 mg g DM^{-1} and has increased to 37 mg g DM^{-1} in 2000. The BAP contents are 100–200 μg g DM^{-1} without increasing trend. In core 5 the TP content increases in the middle of the eighteenth century and in core 4 in the very recent sediments.
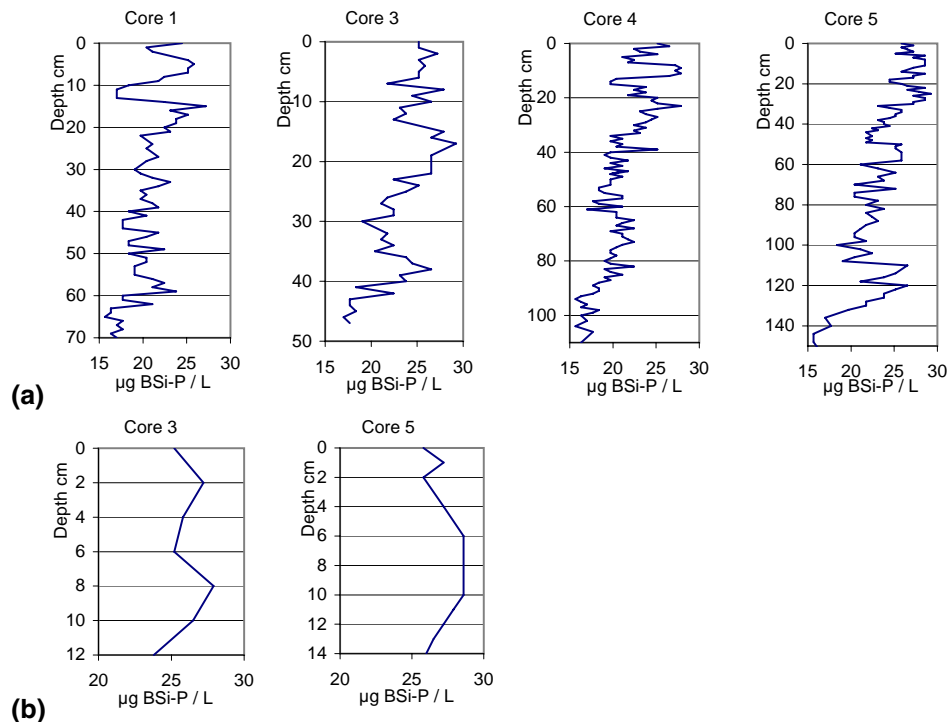
Fig. 3. **(a)** The reconstructed BSi-TP content in the water column and **(b)** an attempt to reconstruct the last decade in the cores 3 and 5 considering epilimnic Si deficit. There is an increasing nutrient trend in the cores but more pronounced further out in the bay than in the inner section represented by core 1 and 3. The cores 1, 4 and 5 start at the level, when Lake Mälaren got fresh water in the Middle Ages estimated by diatom analyses.
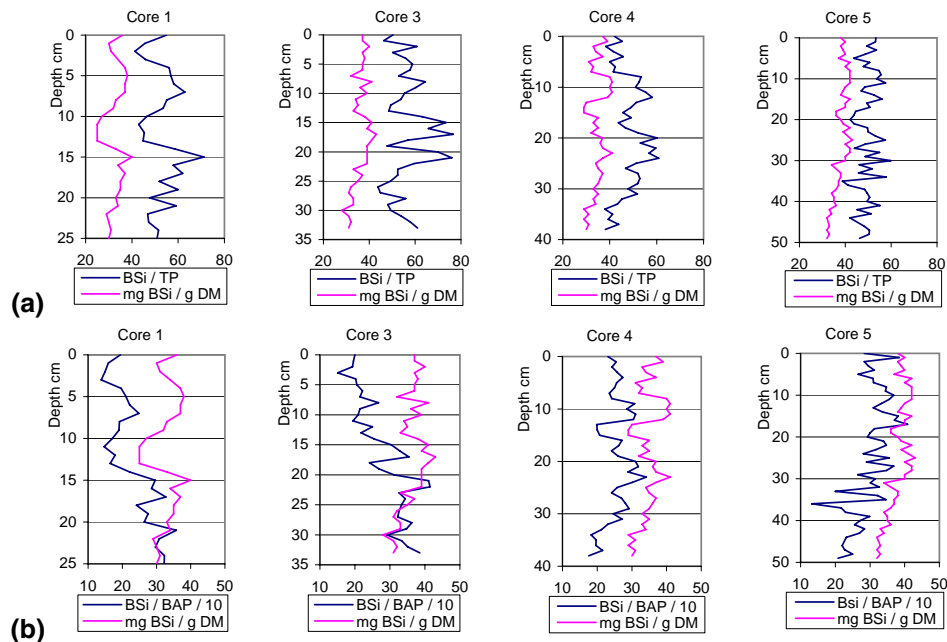
Fig. 4. (a) BSi and the ratio BSi/TP and **(b)** BSi and the ratio BSi/BAP vs. depth in the cores 1, 3, 4 and 5. A peak in the ratios BSi TP^{-1} and in BSi BAP^{-1} and a peak in BSi at the same level may indicate epilimnic Si depletion. If the following BSi decrease depends on Si deficit, the P content is not the limiting factor for diatom production and other vegetation may take advantage of the nutritious water. The decrease between 14 and 10 cm in core 1 represents the years of construction 1951–1953 with a very high sediment accumulation rate and does not show the epilimnic nutrient conditions. The graphs start about 1850.
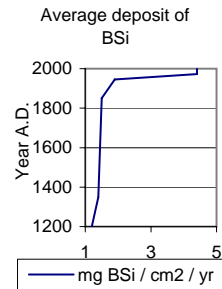
Average deposit of BSi

Fig. 5. Average BSi accumulation rate in Karlskärsviken since the Middle Ages. The accumulation rate has been the same since 1960s, despite the efforts to diminish the nutrient loads.