

Indicators of the Long-term Eutrophication of a Danish lake (Karlsø), and Water Pollution Management

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Abstract: *Karlsø (Karl's lake) in Denmark has been subjected to domestic and agricultural wastewater discharges for many years. The composition of water plants has changed, and the lake has been less clear. Two types of methods are used to describe this transformation. The first is a historical survey of activities in the watershed and the environmental regulation of the lake. The other type of method includes chemical and biological indicators among which are phosphorous and pollen measured in a sediment core to infer past environmental changes. Since the 1960's the lake has developed from an oligotrophic to a eutrophic lake, and environmental management has not succeeded in sustaining the water visibility in the summertime.*

Key Words: Lake eutrophication, indicators, phosphorous, pollen, historical data, water pollution management.

1. Introduction

For many Danish lakes, there is insufficient monitoring data to define natural variability, or to document the trajectories of environmental degradation and recovery, and so many lake management issues remain unresolved.

Karlsø is a shallow lake in the upper part of a catchment area in Jutland, Denmark. It covers an area of 7.6 hectares and has a maximum depth of 3.5 metres. Surrounded by moraine hills, the lake is protected from wind and wave action. Geologically the soils consist of melt watered sand and clay mixture sand. Karlsø's run-off area is 10.5 square kilometres and the catchment area consists of coniferous forests, oak thicket, watercourses, heather, permanent grass areas, farmland (in rotation), roads and houses. Karlsø has two tributaries and one outward flow to Bryrup Langsø (see Figure 1).

In 1918, 40 hectares (Slagballe Bakker) East of the lake were parcelled out as a summer holiday cottages area. Previously, the area had been used for extensive grazing and, consequently, in sandy areas, heather covered much of the land. Karlsø was used for bathing and fishing. In the sixties, the water quality changed and in the summertime the water was unclear. The summer holiday residents complained and alleged that the pollution originated from the town of Vinding and from the farmers' households.

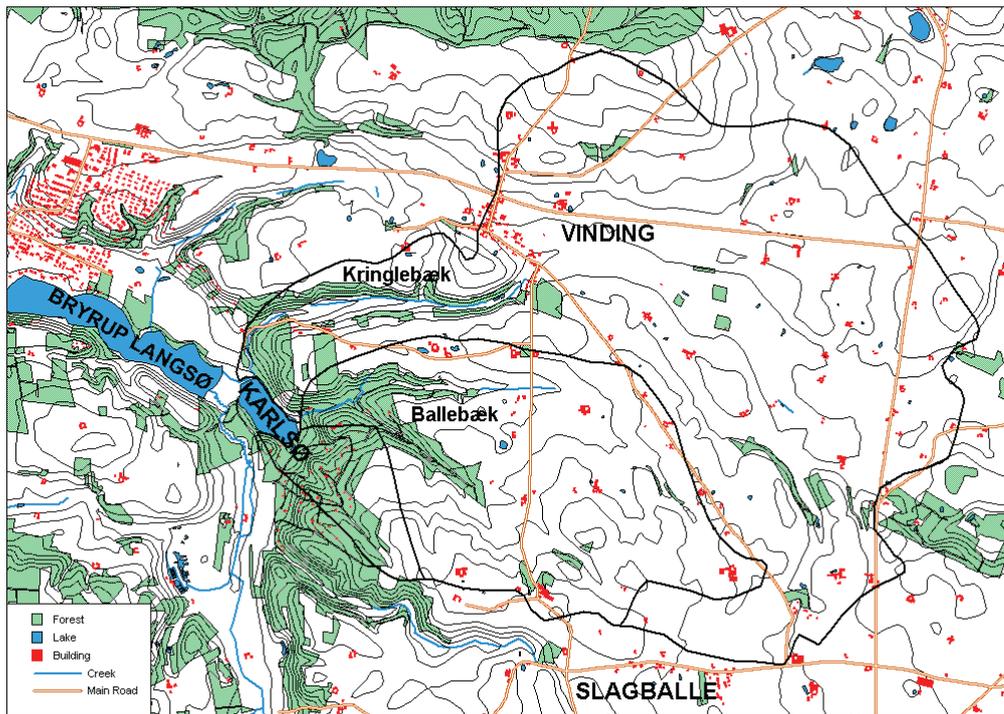


Figure 1: Karlso runoff area with Kringlebæk and Ballebæk and the outward flow to Bryrup Langsø.

It was difficult to document this cause and effect hypothesis because there were many sources of eutrophication, and the effect might be delayed. Some have argued that eutrophication is a natural process, and others believe that the summer residents themselves have caused the pollution. In the beginning of the seventies, a water plant (*Isoetes lacustris*) was found which indicated that the lake water was previously poor on nutrients (Moeslund 1990).

Lobelia dortmanna is another plant indicator of a clear water lake and its presence has never been reported in the lake. *Lobelia* grows in poor nutrient lakes between zero and 2.5 metres in depth. It is a water plant that has aerial flowers which self-pollinate. The production of pollen is probably low (Odgaard 1998). The question arises as to whether paleolimnologic information obtained from a sediment core could infer past environmental changes as sediments accumulating in a lake basin are composed of numerous materials that are derived from the catchment area and the lake itself. In the present case, the catchment area does not include other *Lobelia* lakes. The nearest lake that has a population of *Lobelia dortmanna* is seven kilometres away.

The purpose of the study is to examine whether pollen diagrams and, in particular the presence of clean water plants like *Lobelia dortmanna* or other plants found in the sediment can correspond to historical records concerning eutrophication of Karlso.

2. Materials and methods

Important actors related to the environmental problems of the lake have been farmers, summer residents and the environmental authorities. The actors have been interviewed, and historical records of decisions and monitoring by the responsible authorities have been provided. Karlso is part of an administrative border between two regional councils and two local councils.

Maps from 1913, 1931, 1951 and 1972 and aerial photos that cover the area were provided by Geodetic Institute.

A sediment core was retrieved from the middle of Karlsø on 3 July 1996 with a specially modified sampler. The sampler was a four metre metal rod that could be separated in the middle. The rod was hollow and could be sealed by a cork at one end. There was a thread in the other end where a Plexiglas tube could be placed. From a boat, the sealed sampler was conveyed vertically to the bottom (three metres) and approximately 30 cm down into the sediment. The cork was carefully opened to let air into the rod, which was pressed half a metre further down into the sediment. Water was held in the hole of the rod and when it was full the cork was replaced. The sample was taken to the surface and another cork placed in the opening of the Plexiglas tube.

The core obtained in the Plexiglas tube was transported with a minimum of disturbance to the laboratory and frozen. The core was approximately 50 cm long and 5.2 cm diameter. Sediment was extruded vertically upwards and sectioned into 2 cm intervals, using a saw with a width of 0.2 cm. The result was 20 samples. Sample one was 0-2.2 cm, sample two 2.2 – 4.4 cm etc.. Two sub-samples of 1.9 cm³ for pollen analysis were drilled in the middle of each sample cylinder.

The sub-samples were prepared for pollen analysis according to standard (Boldsen 1992). A known number of *Lycopodium* pollen was added in order to discover the concentration of pollen in the sediment (Stockmarr 1972). For each sample more than 1000 pollen or spores were identified and counted (Fægri 1989 and the NNU (National Museum of Denmark, Environmental Archaeology and Archaeometry)).

The remaining 40.6 cm³ sediment of each sample was freeze dried for an average of 48-50 hours, until the steam pressure showed 0.02 mbar.

In June 1999, the samples were sent to Risø National Laboratory for gamma-analysis. Sediments were analysed for supported and unsupported ²¹⁰Pb (Lead) and for ¹³⁷Cs (Cesium) content in 20 samples taken over the length of the core (Kunzendorf 1999).

Total phosphorous content in the sediment samples was measured (Dansk Standardiserings Råd 1985) and organic content determined as loss on ignition at 550 °C (Dansk Standardiserings Råd 1980).

3. Results

Activities and environmental management:

The catchment area of Karlsø can be divided in two, namely the Kringelbæk (Kringel creek) catchment area of 6.6 square kilometers where 97% is farmland, and Karlsø catchment area of 3.9 square kilometers where 81 % is farmland (Aarhus amtskommune 1990). Comparison between maps and aerial photos dating back to 1913 did not indicate significant changes in cultivated areas, but within this period the farmers have increased the use of nutrients and fodder for animals.

In 1956 a sewer system was constructed in Vinding Town to cater for 200 people. The wastewater was treated mechanically in a sedimentation tank and the effluents ended in Kringelbæk (Statens Vandløbsudvalg 1956).

A down-stream farmer complained about the discharges from Vinding mechanical wastewater treatment because of the flooding of his meadows in spring every year and the bad smell. In order to avoid this pollution problem, an Agricultural Commission decided to build two oxidation basins each with a surface of 440 m² a few hundred metres South of Vinding. (Landvæsenskommisionen 1970).

The Slagballe Bakker summer resident organisation complained in 1974 in accordance with the new Law of Environmental Protection to the Local Council of Them (Them is a town). The argument was that nutrients from Vinding town were affecting Karlsø especially in the winter. When the soil is frozen the wastewater runs on the surface directly into Karlsø. The Local Council of Them rejected the complaint and appeals to three higher levels of authorities; the Regional Council of Aarhus, the Environmental Agency and the Permanent Appeals Committee did not affect the decision. (Resident Organisation 1999)

The monitoring authorities considered Karlsø as a less polluted lake even though the water was occasionally unclear because of maximum plankton algae. According to the Danish recipient planning system, the lake water should show transparency of up to a Secchi depth of three metres and the water quality should comply with standards for bathing purposes. These conditions were not met because of wastewater and illegal discharges and further eutrophication processes were expected (Aarhus Amt 1979). Less than 50 households in Vinding discharged 160 PE in 1977 (Aarhus Amt 1979), and new houses have not been built in the town.

In 1986, Kringelbæk (Kringel creek) was led round Karlsø and directly into the outlet to Bryrup Langsø in order to replace the impacts of nutrients from Vinding town (Jensen 1987). See the map of Figure 1.

Karlsø contains about 175 million litres of water and in 1978 the average turnover time was calculated to be 150 days (Gudenåkomitèen 1982). Kringelbæk is the biggest tributary to

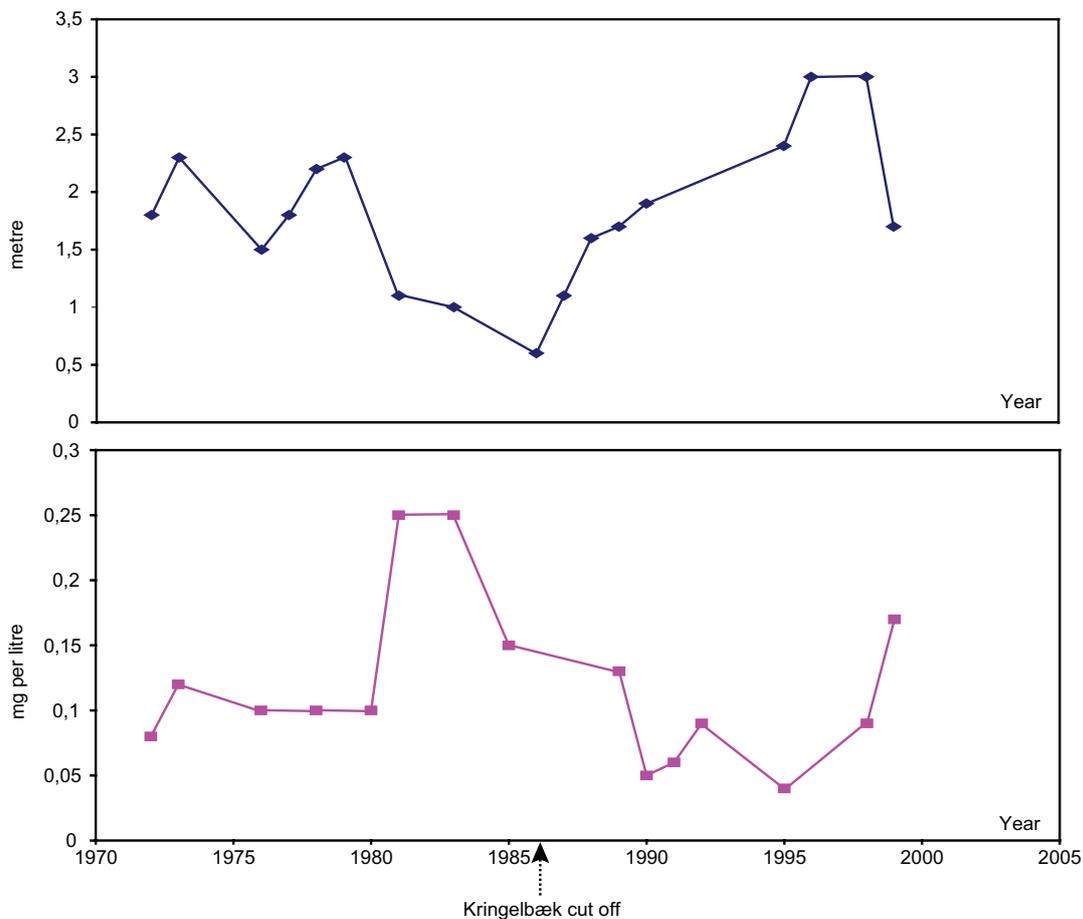


Figure 2. Secchi depth in metre visibility, and total phosphorus in the water of Karlsø. Average of samples taken yearly from May to October.

Karlsø and provided about 60% of the water inflow in 1987. The Kringelbæk cut off will then reduce the phosphorous load to Karlsø from approximately 76 kg Phosphorous/year to 5 kg Phosphorous/year (Aarhus Amt 1979).

The first measurements of water visibility obtained by the Secchi depth method were registered in 1972, and Figure 2. shows the available measurements of Secchi depth and total phosphorous concentration in Karlsø during the years 1970 to 2000. When the concentration of total phosphorous is low, the visibility of the water is correspondingly high indicating that total phosphorous concentration is essential to the algae concentration in the water.

The yearly numbers of Secchi depth measurements differ, and in order to make figures comparable there were at least two weeks between included measurements. The measurements were taken as an average for the period May 1. to September 30th.. Total phosphorous were taken as an average for the period May 1. to September 30th.. Figures from 1989 to 1992 were from the outlet of Karlsø. References are Østergaard 1976, Aarhus Amt 1979, Gudenåkomitèen 1982, Vejle Amt 1992, Miljø- og Levnedsmiddel-kontrolenhed 1983, and own measurements.

The Secchi depth depends on the total phosphorous in the water so that a high concentration of this nutrient causes a high concentration of plankton algae and a low Secchi depth reading. In the beginning of the eighties, the Secchi depths were about one metre or below and the total phosphorous concentration in the water has been rising correspondingly. At the end of the eighties, there was a tendency for the Secchi depths to increase and the total phosphorous concentrations to fall.

Major findings of freshwater sponge *Spongilla lacustris* in 1991 and a growing number of (higher) water plants indicated an improvement of the lake water quality. In the years 1996 to 1998 water plants - especially water thyme (*Heleodera cannadiensis*), - covered the total water volume. (Water thyme was collected from one m³ of the middle of the lake and the dry weight was found to be 120 g). In this period, swimming in the lake was impossible. Kringelbæk was cut off in 1986, and the Secchi depth improved partly because phosphorous was taken up by the water thyme. The water thyme has now disappeared and the plankton algae are back.

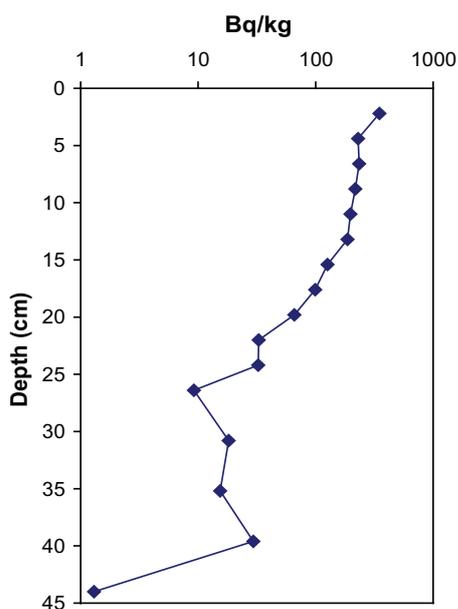


Figure 3: Total ²¹⁰Pb (Lead) activity

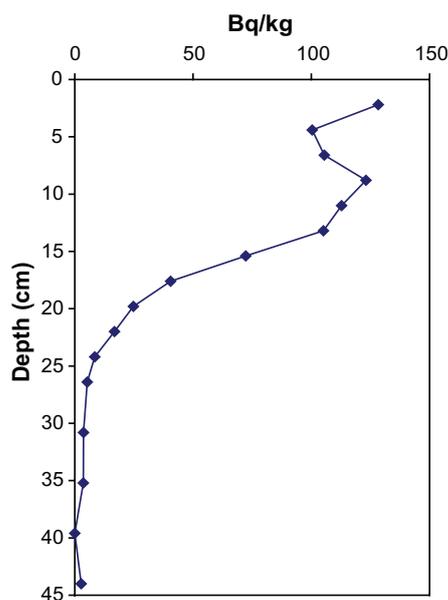


Figure 4: ¹³⁷Cs (Cesium) activity

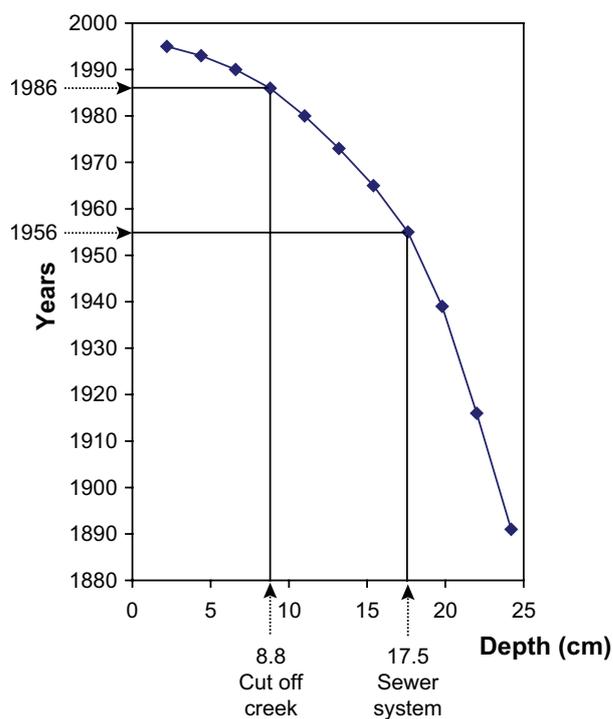


Figure 5. Sediment age calculated from the presence of isotopes. Important historic events of Karlsø are indicated.

4. Core chronology and sediment characteristics

The sediment core showed significant profiles both for unsupported ^{210}Pb (Lead) and ^{137}Cs (Cesium), and the radioactivity declined with sediment depth (Figure 3 and Figure 4). Modelling was accomplished with a cut off of 30 cm and sediment ages appear in Figure 5. The sedimentation rate was calculated on the basis of ^{210}Pb and ^{137}Cs measurements. In the nineties, sedimentation was approximately 10 mm/year while the rate in the thirties was one mm/year (Figure 6). The sediment accumulation rate rose from 150 g/m²/year in the forties till more than 250 g/m²/year in the nineties (Figure 7). In comparison, in Ramsey Lake (Canada) the sediment accumulation rate was 420 g/m²/year (Dixit 1996).

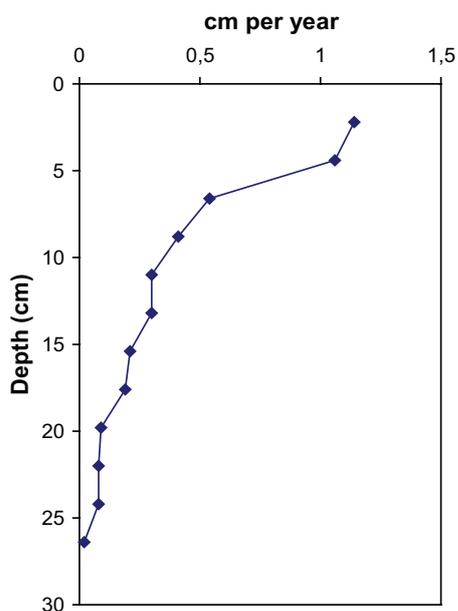


Figure 6: Sedimentation rate

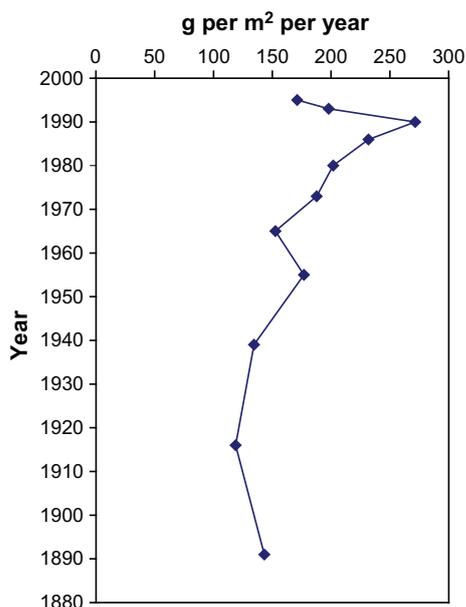


Figure 7: Sediment accumulation rate

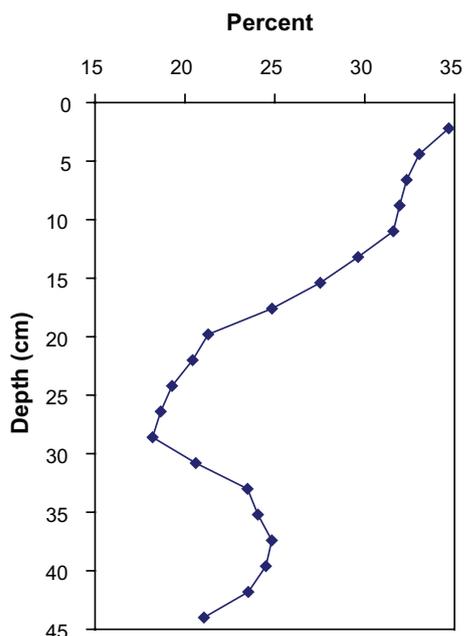


Figure 8: Loss of ignition in different sections of the sediment of Karlso.

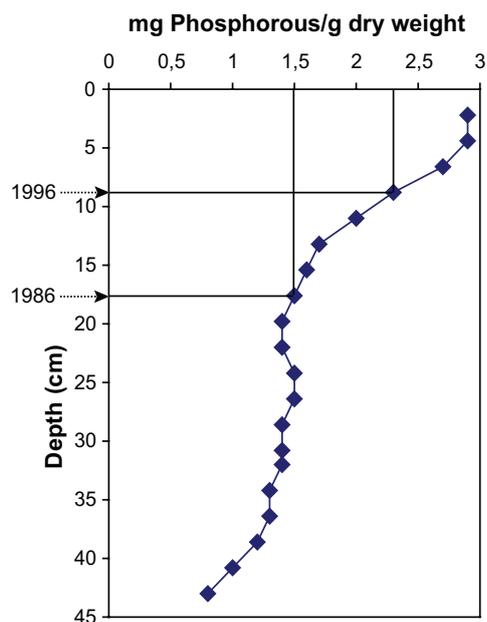


Figure 9: Total Phosphorous in sediment of Karlso.

Loss of ignition and total Phosphorous in the sediment is shown in Figures 8 and 9. The total Phosphorous concentration falls in the sediment and reaches a level of between 1.0 and 1.5 mg Phosphorous/gram organic substance. From 1956, the total Phosphorous in the sediment increases and that corresponds with the building of the established sewerage system and phosphorous discharges from households in Vinding.

Household wastewater has impacted the lake for over 30 years, and the layer of sediment has, in this period, increased from 17.5 cm to 8.8 cm in depth. Thus, it can be calculated that in this part of the sediment there is 1,250 kg phosphorous. According to the information from Aarhus Regional Council, 71 kg Phosphorous year has been discharged annually, so that during the same period 2,130 kg Phosphorous should be expected in the sediment. The figure is lower than expected, but this can be explained as loss due to out flow from the lake. From 1986 to 1996 the phosphorous concentration continued to grow, this additional phosphorous could be caused by households and changes in agricultural crops. In 1987 winter crops were allowed, and many farmers used winter cereals and winter rape in the rotation system (Ministry of Environment 1987). Winter crops are grown with larger fertiliser input and that increases the risk of phosphorous run-off from the fields, and that might explain the growth of total Phosphorous in the sediment after 1986.

The pollen analysis includes 162 different plant pollens, groups of plants, spores or algae that were identified and counted. A selected number is shown in Figure 10. In comparison with 1900, heather pollen have declined, and common spruce and pine pollen have increased in number. Maps and aerial photographs showing that coniferous trees replaced heather in large areas can confirm this.

Pediastrum is a well-preserved group of green algae, and its appearance might be linked to heavy pollution (Berglund 1986). The *Pediastrum* peak between 10 and 15 cm in the sediment corresponds with the increasing load of nutrients from the sewer system of Vinding but obviously in the 1800's there were other peaks. *Botryococcus* was common during oligotrophic period (Berglund 1986), but a decrease is not seen in the present study. Quillwort (*Isoetes lacustris*) spores are found in the upper sediment part, an indication that recently the plant has been present in the lake.

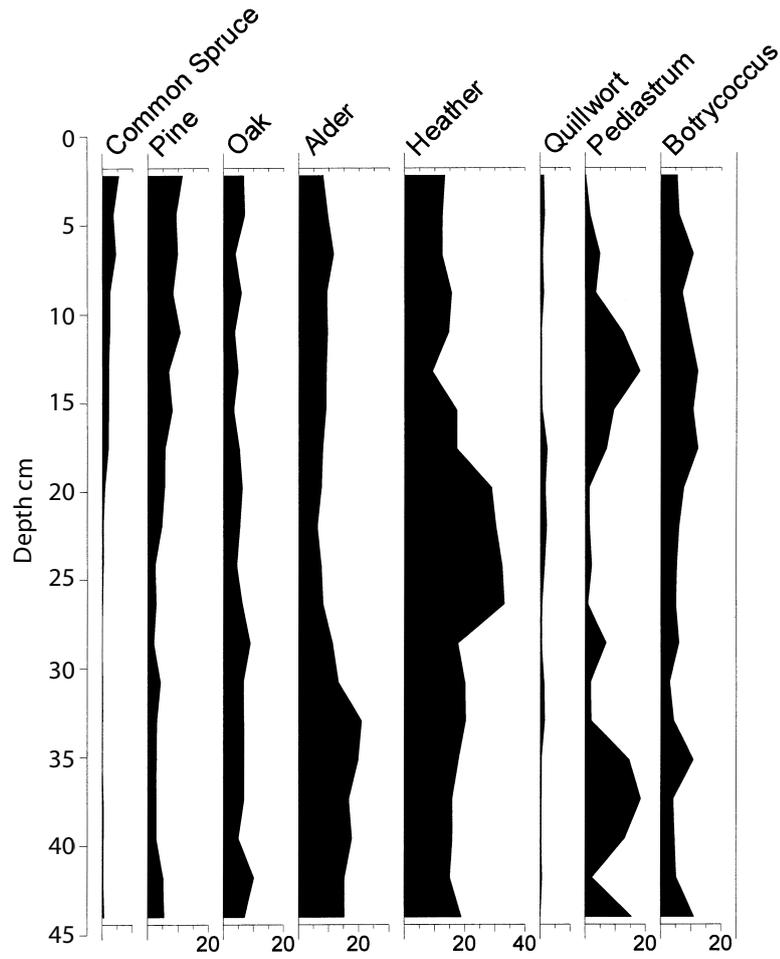


Figure 10: A selected number of pollen from the sediment of Karlso.

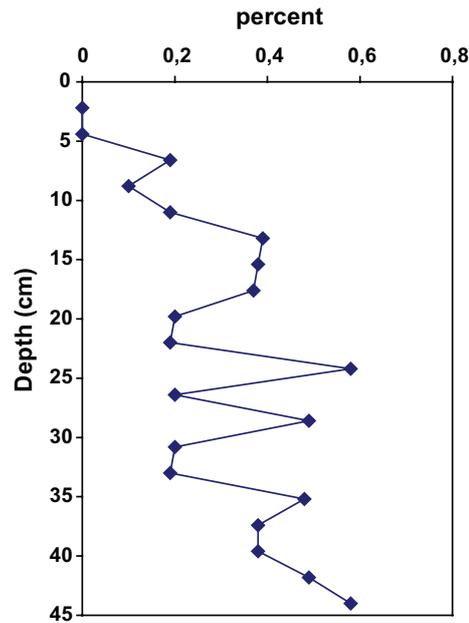


Figure 11: Percent Lobelila pollen in sediment of Karlso

Lobelia dortmanna pollen is not found in the upper part of the sediment, and seems to have been decreasing since 1970, see Figure 11. Only a low amount of pollen is found. Since Karlsø is not very deep the anaerobic periods at the bottom are short and bioperturbation can occur and bring older *Lobelia* pollen to higher levels.

5. Conclusion

The town of Vinding has impacted Karlsø especially since the sewerage system was built in 1956. Over a period of 30 years there was a rise in total Phosphorous in the sediment, and that continued after the cut off of Kringelbæk in 1986. The impact of winter crops and surface run off of phosphorous might explain the continued rise of total Phosphorous in the sediment of Karlsø.

Lobelia pollen has been found, in Karlsø sediment, and that indicates that the lake was clear watered in the summertime some decades ago. The Secchi depths have been low during some periods dating back to 1970 when the first measurements were made. Macrophytes such as *Lobelia* usually have difficulties in surviving when water is unclear. An improvement of Secchi depths in the lake took place after 1986 and from year to year the macrophyte water thymes increased in ratio to the water volume such that in the years 1996, 1997 and 1998 it was impossible to swim in the lake. In 1999, the water thymes disappeared and the Secchi depth fell again because plant plankton succeeded the water thymes.

Phosphorous and pollen measurements in a sediment core indicate the history of a lake and the corresponding water quality even before environmental monitoring (Secchi depths) started in the seventies. Such information is valuable when the background condition of a lake is to be established.

The 1974 environmental Act and the complaints from neighbours led the regional council to remove the Vinding point source at the cut off of Kringelbæk. After more then 20 years environmental management, the objective of visibility has not been acheived in Karlsø, the probable reason is the diffuse impact of nutrients from agriculture and houses in the catchment area of the lake.

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