Kipabiskau Lake - Water Quality Report (2002 to 2010)

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Summary

Kipabiskau Lake has been experiencing a deteriorating water quality since 2007. Based on long-term data and a spatial survey it is most likely that a large amount of P-rich sewage or manure entered the lake in 2006 (an ongoing, chronic addition of nutrients is not supported by the data). The subsequent increase in algal biomass and shift in taxonomic composition resulted in prolonged large surface algal blooms dominated by cyanobacteria. Subsequently, due to the large amount of organic material, respiration rates were high, causing oxygen depletion in winter under ice, which likely resulted in fish kills. The strong reduction in fish biomass was further documented by much higher abundances of preferred fish prey items, both in open water and near-shore areas. A drop in P concentrations in 2010 gives hope that Kipabiskau Lake is slowly recovering, but only future monitoring will be able to tell if this is an ongoing trend or rather a one-time effect of the excessive precipitation and flushing in 2010. To foster a further recovery of the lake any nutrient additions will have to be prevented because Kipabiskau Lake (as most other prairie lakes), especially because the lake usually has a very low flushing rate and a long residence time.

Introduction

Kipabiskau Lake is located in the central Canadian prairies, approximately 26 km east of Pleasantdale. The polymictic (vertically mixed throughout the summer) lake is about 10 km long and less than 500 m wide with a surface area and average depth of 5.2 km^2 and 7 m, respectively. Even though Kipabiskau Lake is part of the Barrier Valley system, the residence time of the water is high because discharge into the lake is largely restricted to periods after snow melt or excessive summer precipitation (e.g., 2010). The shoreline of the lake is mainly covered by natural vegetation but cottages are located along the central part along the northern shore. Other populated places are limited to the Kinistin First Nation, which is approximately two km upstream of Kipabiskau Lake.

Kipabiskau Lake has been part of 1) a prairie lake survey since 2002 conducted through the University of Regina monitoring water quality and food-web structure ,and 2) the fish surveying and stocking program conducted by the Saskatchewan Ministry of the Environment. Every second year, the lake receives between 0.5 and 1.5 million walleye fry (stocked waters report). Population status for walleye, northern pike and yellow perch were moderate, fair and moderate in 2005, but diminished to fair, poor and moderate in 2010, respectively.

Since 2006, water quality has been reported to deteriorate, which was demonstrated by high algal biomass that were often associated with foul odours and surface blooms. The purposes of this study were 1) to evaluate temporal changes in water quality and food web structure over the period from 2002 to 2010, 2) to identify potential causes for the reported decrease in water quality since 2006 and 3) to evaluate the success of management strategies aimed at alleviating the reported poor water quality.

Methods

Water quality parameters that have been monitored since 2002 include nutrients (dissolved phosphorous and nitrogen), salinity, calcium, algal biomass (as chlorophyll *a*) and water transparency (as Secchi depth). Taxonomic compositions of fishes, littoral macroinvertebrates and zooplankton have been recorded since 2004, 2007 and 2007, respectively. Zooplankton and littoral macroinvertebrates represent important energetic links between algal production and fishes, with zooplankton occupying the open water, and littoral macroinvertebrates inhabiting the near shore areas. Furthermore, zooplankton composition is considered a critical indicator of water quality and intensity of fish predation. Sampling for all chemical and biological parameters occurred between May and September and sampling frequency ranged from two to five times per year (with the exception of 2006, no sampling). For the purpose of this report annual averages were calculated for all parameters. All sampling and analytical methods followed widely accepted standard protocols.

To estimate potential causes for the reported decrease in water quality, a spatial survey was conducted in June of 2010, sampling surface water chemistry and sediment composition at 13 locations (Fig. 1). Surface water chemistry data were designed to identify potential locations of point sources for nutrients at the time of sampling, while sediment samples were collected to identify potential locations of past nutrient inputs. Beyond indentifying localized increased nutrient concentrations, the chemical compositions of carbon and nitrogen (stable isotopes) were analyzed to recognize any nutrient inputs that were related to sewage or manure. Such nutrient inputs are commonly associated with low N:P ratios and have a higher proportion of the heavy N isotope (^{15}N).

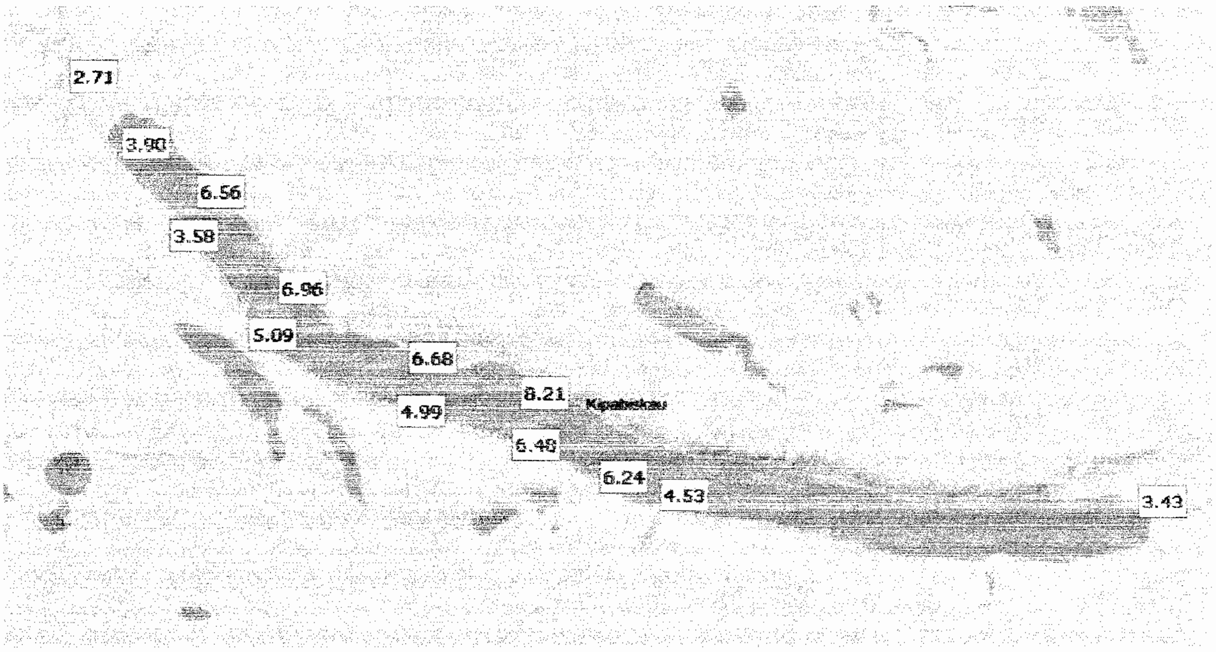

Figure 1: Location of sampling sites of spatial survey conducted in June 2010. At all stations, surface water samples and sediment samples were collected. Values in boxes represent nitrogen stable isotope values of surface sediment in $\delta^{15}N$ (‰), with higher values indicating an increased likelihood of contamination from sewage or manure.

Results

Water Quality - In respect to nitrogen, temporal changes between 2002 and 2010 were small for both dissolved (NH_4, NO_3) and total nitrogen (TKN). NH_4 and NO_3 were slightly lower after 2006, while TKN values were somewhat elevated by about 200 to 300 µg L^{-1} during this period (Fig. 2). In contrast, phosphorous concentrations increased dramatically after 2006 (Fig. 3). Readily available soluble reactive phosphorous (SRP) and total phosphorous (TP) rose from less 5 and 15 µg L^{-1} before 2006 to more than 120 and 160 µg L^{-1} after 2006 (in total, the amount of phosphorous that was added to Kipabiskau Lake was substantial, ranging from two to three tons). As a result, the TKN:TP ratio dropped from about 200 before 2006 to 16 after 2006, indicating a shift from P limitation to N limitation during this time interval (Fig. 3). Surprisingly, despite the higher nutrient concentrations since 2006, the average algal biomass (Chl *a*) was not significantly different between the two time periods (Fig. 4), and water transparency (Secchi depth) increased from less than two to more than three meters in 2009 and 2010 (Fig. 4).

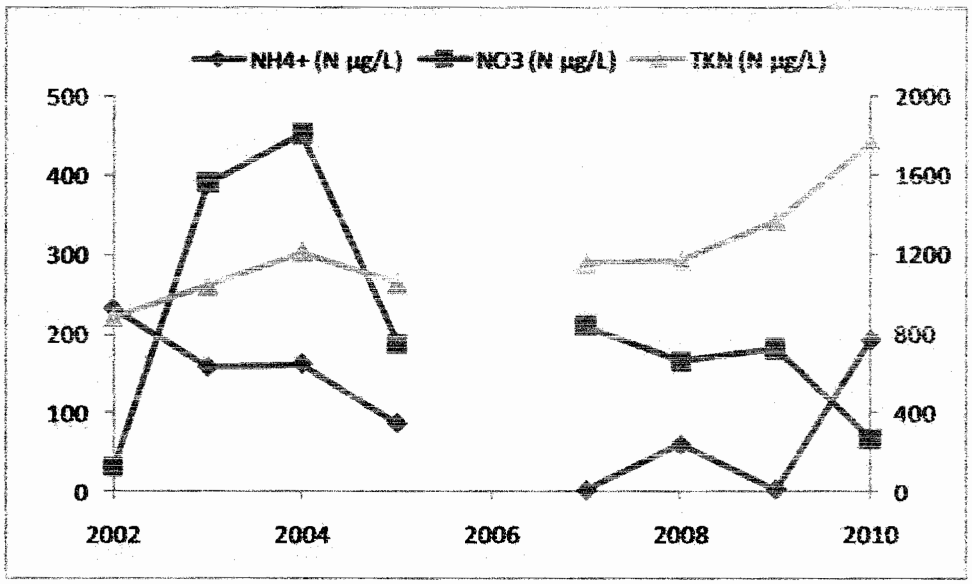

Figure 2: Annual averages (May to September) of water column concentrations of ammonium (NH_4), nitrogen (NO_3) and Total Kjeldahl Nitrogen (TKN, right Y-axis) in µg N L^{-1} for the 2002 to 2006.

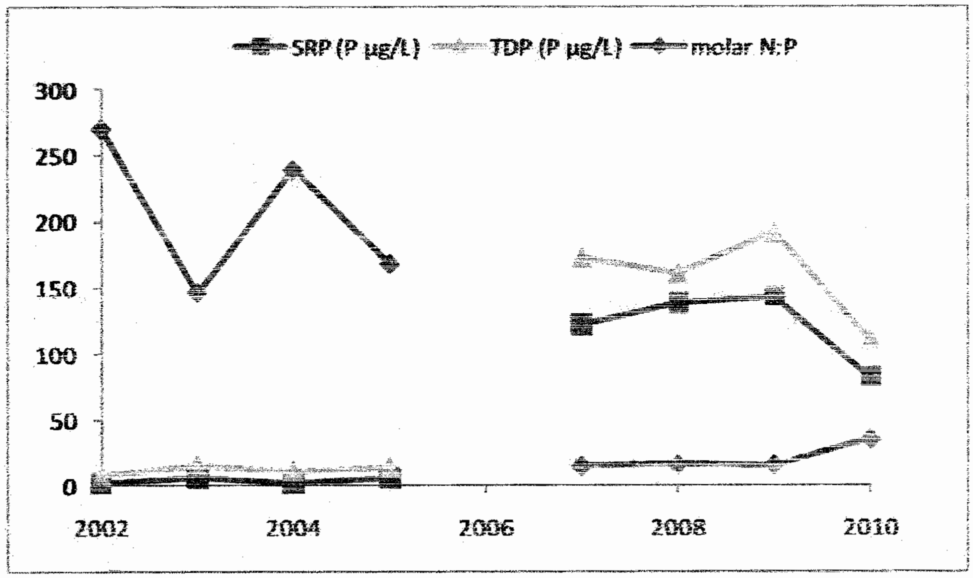

Figure 3: Annual averages (May to September) of water column concentrations of Soluble Reactive Phosphorous (SRP), Total Phosphorous (TP) in µg P L^{-1}, and molar TKN:TP ratio for the 2002 to 2006.

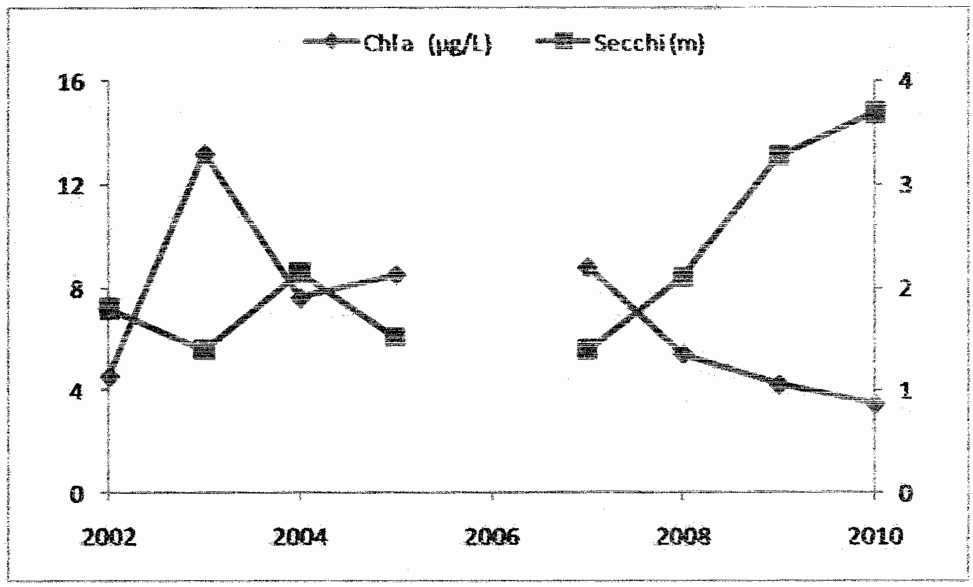

Figure 4: Annual averages (May to September) of water transparency (Secchi depth) and water column concentrations of chlorophyll a (Chl a) in µg L^{-1} for the 2002 to 2006.

Biota - Historically, Kipabiskau Lake supported a diverse fish community and preferred species for recreation angling were walleye, northern pike and yellow perch. In contrast, our fish sampling efforts since 2007 indicated a strongly reduced diversity and low abundances of not only walleye, pike and perch but also shiners and minnows. Nevertheless, a moderate recovery of the fish community seems to be ongoing since 2009. In respect to littoral macroinvertebrates, no major changes were observed with the exception of high abundances of crayfish since 2008. In contrast, zooplankton composition underwent strong temporal changes since 2004 (Fig. 5). Before 2006, the community was typical for prairie lakes with moderate abundances of cyclopoid and calanoid copepods as well as small and large cladocerans. In 2007 and 2008 copepods and large cladocerans increased by a factor of 5 to 10, indicating the absence of fish predation, while since 2009 abundances have been similar to 2004/2005 values.

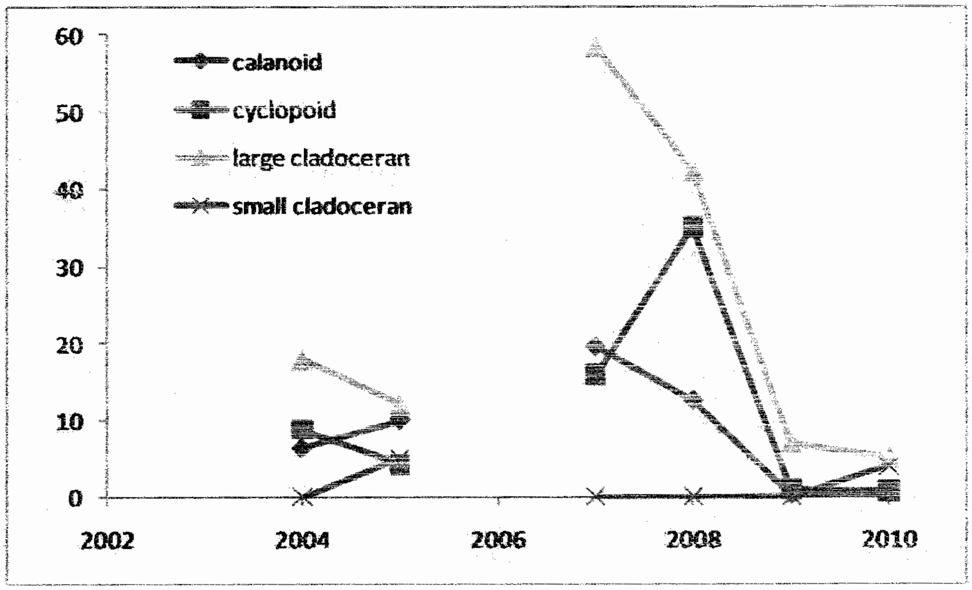

Figure 5: Annual averages (May to September) of major zooplankton taxa in individuals L^{-1} between 2004 and 2010.

Spatial Survey - No significant differences were detected among sampling sites for any of the surface water quality parameters (N, P, salinity, Ca, Chl *a*), indicating no point source contributions into the lake at the time of sampling (June 2010). Likewise, amounts of organic material were similar in the 13 sediment samples. In contrast, nitrogen stable isotope values varied spatially (Fig. 1). $\delta^{15}N$ values (‰) were close to background levels (< 5‰) in the vicinities of the inflow and outflow as well as large areas along the southern shoreline. Highest values were identified along the central part of the lake in the vicinity of cottages.

Discussion

Based on the presented data, it is apparent that Kipabiskau Lake received a large amount of nutrients sometime around 2006. Unfortunately, the exact point in time cannot be specified as no sampling occurred in 2006. The dramatic change in N:P ratio points to a phosphorous-rich nutrient source, such as sewage or manure. Furthermore, the unproportionally high inputs of phosphorous decreased the N:P ratio below 20, which is widely considered as the point where plant growth switches from P to N-limitation. In P-limited lakes, algal growth is generally restricted by the amount of phosphorous in the system, while in N-limited systems nitrogen can be supplemented from atmospheric sources to increase growth beyond ambient concentrations of dissolved nitrogen. To take up nitrogen from the atmosphere algae require specialized cells (heterocysts), which are commonly found in cyanobacteria (a.k.a. blue-green algae). Such algae (e.g., *Lyngbya* sp., *Anabaena* sp.) can also regulate their buoyancy in the water column and often form surface blooms to maximize light energy to support the energy-expensive uptake of atmospheric nitrogen. Furthermore, blue-green algae often produce substances that can be toxic to aquatic organism as well as humans. Accordingly, Kipabiskau Lake changed from a mesotrophic (fairly nutrient-poor), P-limited lake to a eutrophic (nutrient-rich) and N-limited lake. While it would be expected that algal biomass strongly increased since 2006, this was not supported by the Chl *a* data (Fig. 4). One likely explanation for this discrepancy could be related to the sampling design. After 2006 the algal biomass was concentrated in the surface layer, while Chl *a* samples were taken in a way to characterize algal biomass throughout the whole water column. Additionally, increased grazing pressure of zooplankton, such as copepods and large cladocerans on algae may also have kept algal biomass relatively low. In either case, algal productivity (as production per unit time) was probably much higher since 2007.

During the duration of such algal blooms, the main concerns are related to recreational use, toxicity and aesthetics, while after the die-off of algal mass developments, the organic material sinks to the bottom and accumulates at the sediment surface fuelling decomposition by bacterial respiration. During summer conditions, the increased oxygen uptake by bacterial respiration does not affect the lake community as the water column is generally well mixed. Yet, once the lake is ice-covered, the supply of new oxygen from the atmosphere is cut-off and especially during prolonged duration of ice cover oxygen can be completely exhausted and result in fish kills. Such fish kills generally impact large game fish species first because small fishes, such as sticklebacks, shiners and minnows have lower oxygen requirements and may find refuge in smaller tributary streams.

Subsequently, due to the absence / or strongly reduced abundances of fishes in Kipabiskau Lake common prey items were relieved from fish predation pressure, which is clearly documented in the 5 to 10-fold increase in zooplankton biomass (Fig. 5) and the higher abundances of crayfish.

In respect to the timing of the nutrient addition, it seems that the nutrient input was an isolated event as nutrient concentrations increased only between 2005 and 2007 with no further increases thereafter (Fig 3). Furthermore, the fact that no differences in water quality were detected among sites during the 2010 spatial survey strongly reduces the possibility of a chronic, ongoing source of nutrient addition to the lake. Based on the results of the nitrogen stable isotope analyses, it appears that there may have been be some contributions of sewage or manure into the lake. Highest $\delta^{15}N$ values were located in the central part of the lake, which may be related to occasional input of sewage from cottages (Fig. 1). Nevertheless, the relative importance of these inputs was probably small as maximum observed nitrogen stable isotope values did not exceed 10‰, while maximum possible values for sewage / manure may exceed

30‰. Alternatively, a large point-source contribution may have resulted in a similar $\delta^{15}N$ pattern if it originated in the central basin of the lake that was subsequently more broadly distributed. On the other hand, it does not occur that the observed contamination could have been associated with any up or downstream sources of the lake because nitrogen stable isotope values were minimal in these areas (< 5‰).

Management Considerations

Based on a several lines of evidence (presented data, fish facts, personal accounts) the significant water quality problems that arose in Kipabiskau Lake after 2006 are still ongoing. Yet, some improvements became obvious since 2010. Phosphorous concentrations have been decreasing (Fig. 3), which might have been related to increased flushing and shorter residence time of the lake water due to the unusually high amounts of precipitation during the summer months of 2010. The decrease in TP also resulted in a shift to higher N:P ratio (> 20), which should have improved conditions for more desirable algae (e.g., diatoms, green algae) that lack the ability of uptake of atmospheric nitrogen, have negative buoyancy and generally do not produce toxins. During this time, algal biomass receded and water clarity improved (Fig. 4). Furthermore, the decrease in zooplankton densities and changes in composition indicated an a rising predation pressure by fishes. Together with the reports of higher fish abundances since 2010, it is likely that natural fish populations are recovering, augmented by successful fish stocking. Nevertheless, the nutrient concentrations are still significantly higher (10-fold) than during 2002 to 2005, keeping the lake in a more productive (eutrophic) state with an increased likelihood of algal blooms and future winter kills. Due to the long residence time (low flushing) of Kipabiskau Lake it is likely to take years to return the lake to its previous condition, if this is possible at all. Either way, to successfully protect the lake it will be absolutely imperative to prevent any future nutrient additions into the system.