# Effects of pH on algal abundance: A model of Bay Harbor, Michigan

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## Abstract

Cement production, while an important process, creates toxic cement kiln dust as a byproduct. When mixed with water, this cement kiln dust creates a toxic leachate that has a high pH and has detrimental effects on wildlife and human health. Bay Harbor, Michigan has been highly contaminated with this leachate, and this study models Bay Harbor by manipulating pH in a controlled environment and examining the effect on algal abundance. We hypothesized that raising pH will reduce algal abundance, measured as chlorophyll levels. We took water samples from Little Traverse Bay and had one control treatment and two alkalinity treatments in which we raised the pH to 8.9 and 9.9 from the initial level of 7.9. We found a statistically significant difference in the algal abundance of the controls versus each of the two experimental groups. We therefore suggest that the abundance of algae in Bay Harbor is being negatively affected by cement kiln dust leachate.

## Introduction

The Great Lakes Region is the site of many cement production facilities. For the past several decades, the navigable waterways surrounding Michigan have allowed for cheap assembly of materials and later transport and distribution of cement (Morrison 1944). While the cement industry is important to the Great Lakes Region, it also has adverse effects on the ecosystem and environment of the area. Cement kiln dust, a byproduct of the manufacturing process, is very alkaline and because of its fineness, mixes well with the soil (Rodd et al. 2004). It then often leaches into surface water and groundwater, raising the pH of surrounding water bodies and affecting nearby ecosystems (Tip of the Mitt Watershed Council 2007).

Algal abundance is affected by pH. In one study when the pH was lowered from 6.6 to 5.0, algal abundance increased (Leavitt 1999). Because an increase in algal abundance was observed when lowering the pH, it can be expected that algal abundance should *decrease* when the pH is raised. Reduced growth was observed in a group of pHtolerant algae when the pH exceeded 9.5 (Pendersen 2003). In that experiment, however, the pH was manipulated in a marine environment. The most pH-sensitive species in the experiment decreased in abundance when the pH was raised to 8.8, and did not grow at all when the pH exceeded 9.0 (Pendersen 2005). As studies have shown, water contaminated with a high pH has negative effects on algal abundance.

Most organisms have an optimal range of conditions in which they thrive. In an experiment comparing algal growth in two different habitats, one limestone pool (pH 7.6 to 9.2) and one granite pool (pH 6.2 to 6.8) were examined for biotic character, including algal content. The pools were only a few hundred yards from each other, yet none of the algal species found in the limestone pool were found in the granite pool (Reed 1924). This shows how different species of algae have tolerances for different pH ranges.

Algae are a fundamental part of the aquatic environment because of their role in carbon cycling. When humans disturb algal habitats, there are major implications for the rest of the ecosystem. Specifically, human disruptions can cause adverse effects to algae's function in carbon dioxide uptake (Talling 1976). Diminishing algal abundance will contribute to the rising levels of carbon dioxide in the atmosphere.

Because algae are primary producers and make up the base of the food chain, they are essential for the functioning of higher trophic levels. A decrease in algal abundance will impact the rest of the food chain. For example, algae are a major energy source for insects like trichoptera (Mayer 1987). A loss of algae and its direct effect on insect populations, will initiate a wave of effects throughout the rest of the food chain. Examples of such effects, including a loss of aquatic life, have been seen in the case of Bay Harbor (TMWC2 2007).

Bay Harbor, a large resort development including homes, hotels, golf course and marina, is the site of basic leachate contamination. Bay Harbor is located on five miles of Lake Michigan's shoreline between Charlevoix and Petoskey in Northern Lower Michigan (VIC 2007). For several decades, the area was home to the Penn-Dixie Cement Company. Since its inception, 2.5 million cubic yards of cement kiln dust had accumulated (VIC 2007). The cement kiln dust remaining from the manufacturing process mixes with water through runoff, creating a toxic leachate that has a high pH (TMWC1 2007). The leachate enters Little Traverse Bay through rainwater and groundwater runoff (TMWC1 2007).

After areas of high alkalinity were reported in 2004, studies were initiated to monitor pH levels in the bay and the effects to the local ecosystem. Over the past three years, chlorophyll levels have dropped in the Bay Harbor area, indicating a decrease in algal abundance in areas of leachate contamination (Cronk 2007).

The contamination at Bay Harbor affects both the biotic and abiotic environment. Our study modeled the contamination that has occurred in Bay Harbor, and explores the effects of high pH on algal abundance. We hypothesized that high pH would create an inhospitable environment for algae and would have a negative effect on algal abundance. We predicted that the chlorophyll levels would be lower in our alkalinity treatments than in the control treatment with a normal pH.

## Methods

### *Field Sampling*

All experiments were conducted using water samples collected on a single day from Little Traverse Bay on Lake Michigan so that all algal species would be representative of those in Bay Harbor. Care was taken to ensure pollen on the surface of the water was not collected. Water pH (Corning pH meter 430) and temperature (handheld thermometer) were measured at the time of collection. Three 300mL samples were pressure filtered through Millipore membrane filters (pore size= 0.45 μm) for chlorophyll analysis. Within 2 hours of collection, filters were frozen until analyzed.

*pH Manipulation Experiment*

Experimental manipulations were conducted on three 5-gallon water samples from Little Traverse Bay. Five 1-liter bottles were filled with water from one of the 5-gallon containers; these were set as controls, with a pH of 7.9. The pH of the second 5-gallon container was raised to 8.9, with a titration of Sodium Hydroxide. Five 1-liter bottles were then filled with this water, representing our lower alkalinity treatment. The pH of the third 5-gallon container was raised to 9.9. Five 1-liter bottles were filled with this water, representing our higher alkalinity treatment. All fifteen bottles were put into an incubator (Percival Controlled Environment Incubator). Incubator temperature was set at 20ºC, a few degrees above the lake temperature, to promote algal growth. All fifteen bottles received 16 hours of daylight and 8 hours of dark per day. The bottles were rotated once a day to ensure equal lighting. After four days, the pH of all bottles was measured again and 300mL of each sample was filtered for chlorophyll analysis.

*Chlorophyll Analysis*

Samples for chlorophyll analysis were pressure filtered through Millipore membrane filters. We then placed each filter into a glass vial of 10mL acetone and magnesium solution in the dark. Each vial was placed on top of the Thermolyne Maxi Mix Plus (Model #M63215) to ensure that the filter paper was completely saturated with the acetone. Each vial was then placed in the Fisher Scientific Wet Lab 5S15 for ten minutes to break down the filter in the solution, then into the freezer for 24 hours. The chlorophyll fluorescence levels of all samples were then read in the TD-700 Fluorometer by Turner Designs. We also used the Fluorometer to measure levels of phaeophyton, which is the degraded pigment form of chlorophyll. We used the total fluorescence and phaeophyton readings to calculate the phaeophyton-corrected cholorphyll measurements. The chlorophyll concentration from the three initial samples taken from Little Traverse Bay was also measured by this method.

*Data Analysis*

We compared the mean chlorophyll levels between the controls and two experimental groups, as well as the initial and final levels of all three samples using the Analysis of Variance (ANOVA) with SPSS software version 14.0. We used an $\alpha$-value equal to 0.05 for all tests performed.

**Results**

The mean chlorophyll levels of the initial, control treatment, lower alkalinity treatment (pH 8.9), and higher alkalinity treatment (pH9.9) were 0.352, 1.882, 0.390, and 0.040 µg/L, respectively. There was a significant difference between the control treatment and the lower alkalinity treatment and the control treatment and the higher alkalinity treatment, but not the lower alkalinity treatment and higher alkalinity treatment (F-statistic = 8.460, df = 3, p-value = 0.015, 0.004, and 0.683, respectively). (Figure 1)

There was a significant difference between the initial sample and the control treatment, and no significant difference between the initial sample and the lower alkalinity treatment or the initial sample and the higher alkalinity treatment (F-statistic = 10.582, df = 2, p-value = 0.033, 1.000, 0.907, respectively). (Figure 2)

**Discussion**

As we predicted, the mean chlorophyll levels in the control treatment and both alkalinity treatments show there was a significant difference in algal abundance between the sets after four days. There also was only a significant amount of growth occurring in the control treatment. Our results were similar to a study done by M.F. Pendersen and P.J. Hansen, showing a decrease in algal growth under a high pH (Pendersen 2005). In addition, the low chlorophyll levels in the higher alkalinity treatment are similar to the levels recorded in Bay Harbor after leachate contamination (Cronk 2007). Our study accurately modeled the decreased algal abundance that has occurred in Bay Harbor.

The decrease in algal abundance in the presence of high pH is most likely caused by the drastic change to the algal environment. Algae thrive in a specific pH range (Reed 1924). This can be explained by their decreased ability to photosynthesize in basic water. Carbon dioxide available for photosynthesis decreases as alkalinity increases (Singh 1974). Only carbonate and bicarbonate ions are available to submerged photosynthetic plants in water with high pH (Carr 1973). If the ability of algae to photosynthesize is impaired as the pH is increased, then algal abundance will decrease in water with high alkalinity.

In our results we did have a small number of extreme values, as well as one sample that could not be processed. This may have slightly affected our mean values. These extreme values could have been caused by errors during processing or handling. In the future, increasing the number of samples could minimize the effect of such errors.

In conclusion, our experiment showed that increased alkalinity in lake water significantly decreases algal abundance. We would expect to see decreased algal abundance in the water in Bay Harbor and even more extreme effects near the sites of leaching. Because algae are primary producers, our research suggests that the food chain and ecosystem in Bay Harbor has been affected by cement kiln dust contamination. This has important implications for such contamination and ecosystems throughout the world.

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**Appendix:**

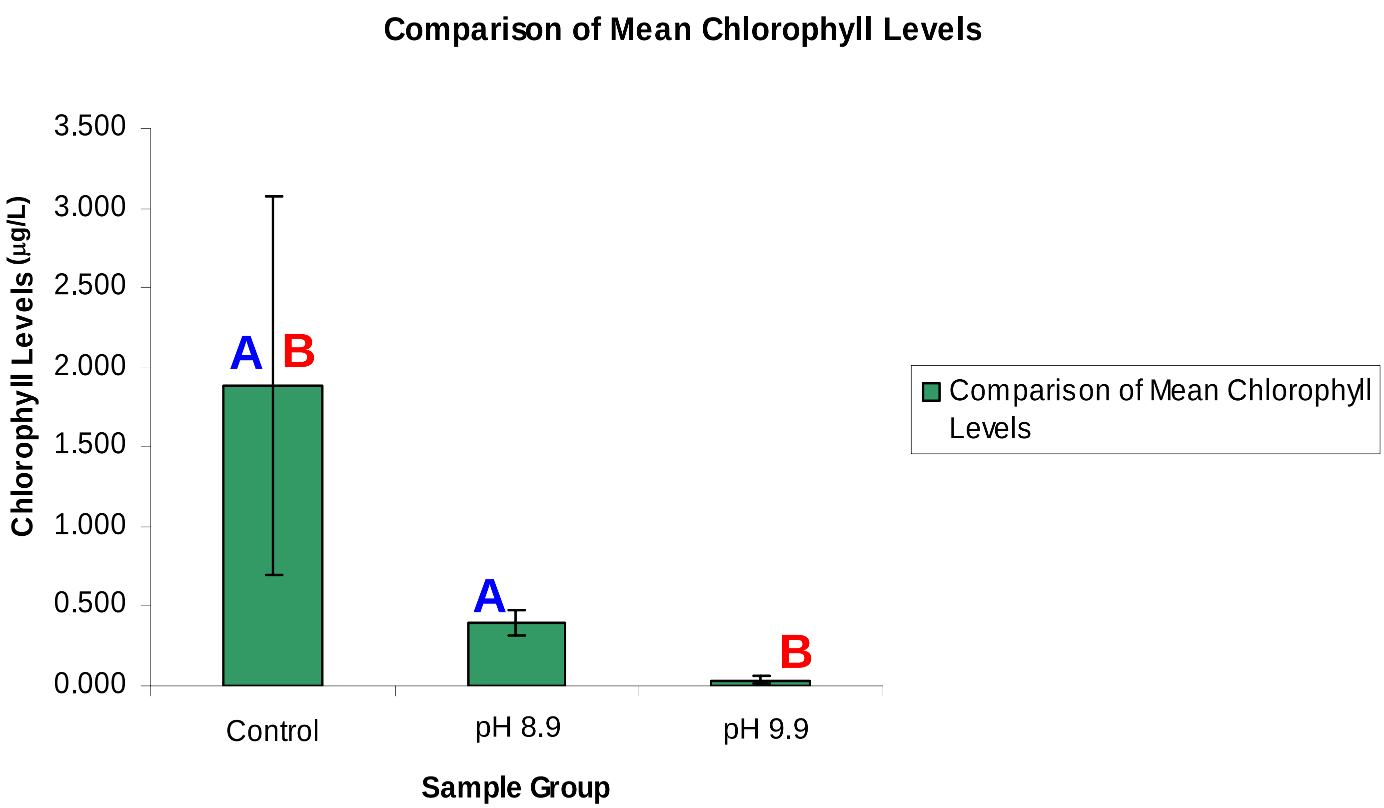


Figure 1. Bar graph of mean chlorophyll levels after four days of growth. Statistical difference is shown between mean levels of the control vs. the low alkalinity treatment pH 8.9 (**A**; p-value=0.015), and control vs. high alkalinity treatment pH 9.9 (**B**; p-value=0.004).

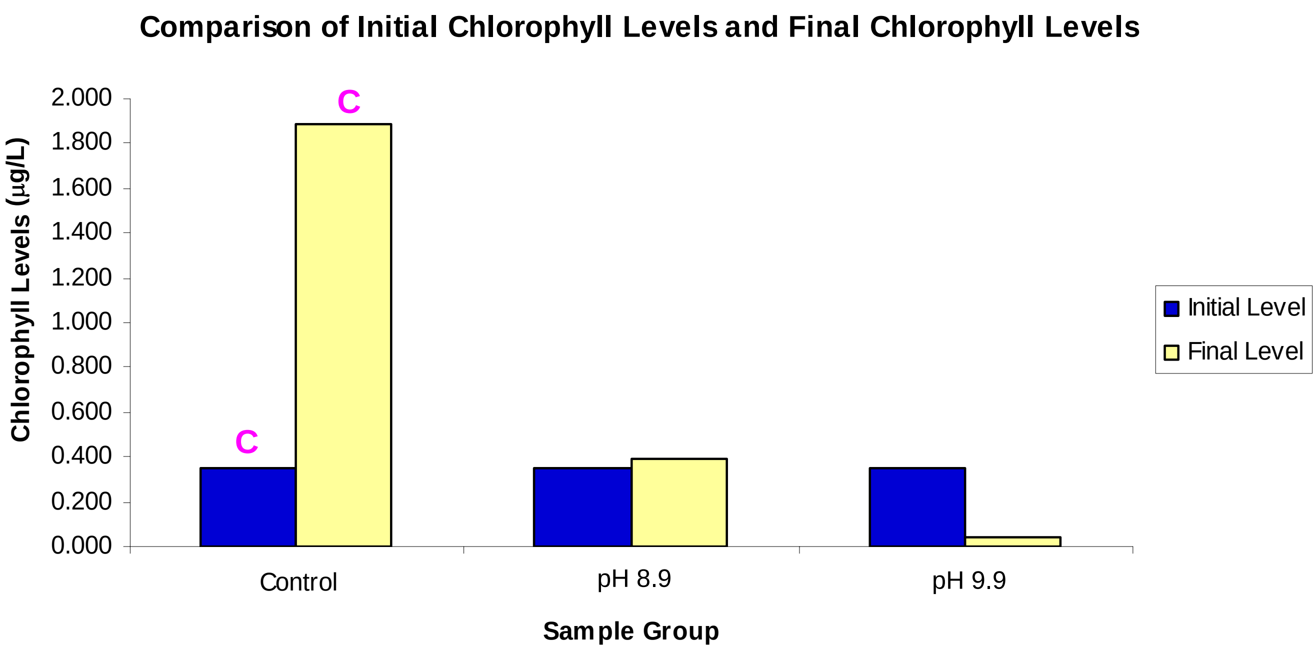


Figure 2. Bar graph comparing the mean chlorophyll levels of the initial sample vs. control group, initial sample vs. low alkalinity treatment of pH 8.9, and initial sample vs. high alkalinity treatment of pH 9.9. Statistically significant difference is shown between the initial level and the level in the control group after the four days (**C**; p-value= 0.033).