Diatom community structure as an indicator of water quality and pH at a chemically disturbed site in Northern Michigan

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Course 381 – General Ecology
8/14/09
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Abstract

Algal communities like diatoms can tell us many things about water quality and past disturbances because of their increased sensitivity to factors such as pH and temperature. This study focused on comparing a recently disturbed site with unaffected sites in the same local area using diatom diversity in order to assess the efficacy of cleanup efforts. Water samples were taken from a total of nine sites and compared for diatom abundance and species composition, and experimental base-emitting devices were constructed in an attempt to induce a shift in the community profile. Principle components analysis was used to compare sites by grouping them by similarity and by algal abundance. This analysis showed that the previously disturbed sites at East Park show no current evidence of leaching or increased pH, leading us to conclude that the cleanup effort in this area was successful.

Introduction

Understanding the structure of algal communities is a useful tool for assessing habitat viability, as well as indicating various measures of water quality. Diatoms are shown to be especially sensitive to factors such as pH (Bergstrom *et al.* 2007), temperature (Soininen and Weckstrom 2009; Weckstrom *et el.* 1997), and varying light conditions. These phytoplanktonic organisms can be used as indicators of current aquatic conditions in addition to acting as quantitative indicators of past water quality.

Because algal abundance and diversity are greatly affected by changes in pH, comparative studies are useful in determining optimal environmental conditions for various species. An evaluation of several freshwater systems concluded that undisturbed rivers and streams generally see higher diversity in the diatom community with less relative abundance between species; however, systems with harsh environmental conditions, such as high acidity or brackish water generally show a much more restricted flora community with higher overall species abundance (Patrick 1963). The diatom species that proliferate in these kinds of systems are those few organisms more able to specialize under harsh environmental conditions.

A 12-month study of freshwater productivity in response to changing seasonal conditions effectively showed that diatoms are most affected by changes in phosphorous levels, as well as chlorophyll and pH (Reid 2005). This study was able to determine spatial responses of diatom communities to varying environmental gradients over a long period of time, showing that even slight changes in water quality affect the relative abundance of diatom species within the same lake. A similar conclusion was reached by Weckstrom *et al.* who used diatoms as predictors of pH and water temperature and managed to determine optimal conditions for many species (Weckstrom *et al.* 1997).

This study will focus on the composition and abundance of the diatom community in and around Little Traverse Bay in Petoskey, Michigan. The Bay region is the site of a past chemical disturbance of cement kiln dust leaching into Lake Michigan following the closure of a local cement plant. The specific region of interest is East Park, where twenty percent of the leachate in the Bay area is thought to have accumulated (Timm 2008). This leachate has been shown to raise the pH of the ground and surface water, in addition to the surrounding soil, to highly basic levels, which has greatly affected the immediate algal community. Since diatoms have been used in past assessments of habitat disturbance and community response, this investigation uses a comparative approach to determine the effectiveness of a clean-up effort in the immediate area of the disturbance compared to unaffected beaches in the same local vicinity.

Cement kiln dust, composed primarily of calcium hydroxide and various heavy metals such as lead, arsenic, and mercury, is the compound considered to be responsible for the dramatic increase in pH levels of the surrounding water and soil. To date, there have been no ecological studies conducted to determine the effects of the leachate on local flora and fauna populations (Timm 2008). The examination of diatom abundance and diversity is an especially important resource because of diatoms' sensitivity to water conditions and their greater ecological importance in overall community structure. Based on previous studies using diatoms as indicator species of environmental conditions, we expect to find a direct relationship between water quality and diatom community composition in those areas affected by pH changes.

Materials and Methods

Site Details

A total of 9 sites were surveyed in Little Traverse Bay, Petoskey, Michigan. Latitude and longitude measurements were taken at each site (Table 1), using a Garmin GPS 60. Sites one through three were located at the East Park site of disturbance, sites four and five were located in Harbor Springs, and sites six through nine were located along an undeveloped bay near Petoskey State Park.

Sampling

To survey the diatom communities, organic samples were taken from Little Traverse Bay, Michigan in order to assess composition and abundance of organisms. Each of nine samples consisted of a rock covered in benthic algae and water from the immediate area. Three of these samples were taken from East Park in areas directly affected by the kiln dust plume and the remaining six samples were collected from unaffected areas of Little Traverse Bay. The pH of the water at each site was measured and diatom slides were prepared as described in Van der Werff 1955.

Diatoms were counted from randomly selected fields until 150 individuals were counted from each site. Slides from sites five and nine had few diatoms and were not counted. These slides were then used to compare the community structure of diatoms from East Park to those from areas that have not recently experienced chemical disturbances.

Experimental Design

An experimental portion was also included in this study that attempted to simulate the previous basic conditions in East Park. Base emitting devices were created by filling three 250mL bottles with sand to the neck of the bottle, and then filling the bottle with solid calcium hydroxide. Three control bottles were filled completely with sand and a piece of porous cloth was then secured over the bottles to create a surface on which the algae were able to colonize. One experimental and one control bottle were secured on opposite sides of three equally-sized cement blocks and sunk in roughly five feet of water in Little Traverse Bay, 150 feet from the shore and 25 feet apart. A third experimental bottle was made and submerged in water taken from site 6 to monitor changes in the pH level over time as a result of the calcium hydroxide. After two weeks two of the three cement blocks were successfully recovered and burn slides were made of the diatom communities collected on the cloth as described by the UCL Department of Geology (2009). As before, random fields were counted until 150 diatoms were recorded.

Data Analysis

A principle components analysis was done to compare the diatom communities from each site. This analysis compared relative abundance of each species at each site, as well as looking at the importance of each species in determining community structure.

The pH values were plotted for each site to determine a relationship between site location and water quality.

Results

Community Diversity

Species abundance and community relatedness were plotted using principle components analysis (PCA) software (Figure 1). Relative importance of species absence or presence is represented by vector size and relatedness of site composition is represented by incident angle. 82% of variation seen between variables was explained by the first two axes and an additional 8% was explained by the third axis.

PCA analysis showed high similarity between sites 1 and 2, between sites 7 and 8, and between site 3 and the two experimental communities. In terms of determining community structure, most explanatory value was seen in *Denticula*, *Achnanthes*, *Gomphonema*, *Diatoma*, *Cocconeis*, and *Cymbella microcephala*. These species were plotted by relative abundance for each site and the experimental sites (Figures 2 and 3).

pH Readings

The pH readings taken at each site are represented by site in Figure 4. Readings were also taken on the water surrounding the control bottle at two stages. A reading of 8.4 was recorded on July 29 and a reading of 8.19 was recorded on August 5.

Discussion

Erin Damery

Guilia Feroo

Ben Oyserman

Our studies suggest that benthic diatom communities are no longer affected by the extreme alkaline environments that characterized East Bay and surrounding areas earlier this century. This is supported by pH readings within the range of 7.83-8.24 accompanied with wide variation in diatom compositions from site to site. This evidence compounded suggests that other factors not tested for in our experiment may play an integral role in determining diatom composition in the East Bay and Bay Harbor area and opposed our hypothesis that diatom diversity would be low and dominated by extreme alkaliphiles. Norina Munteanu & Edward J. Maly (1981) determined that currents have a strong influence on diatom populations. Furthermore salinity has been shown to have a strong influence on diatom community structures (Tuchman, 1984). Other influences such nutrient loading and light levels may have been factors in diatom compositions.

All sites experimented were very close to the shore line and thus to roads. This may have contributed high amounts of salt run off. Of the six major constituents within the diatom communities analyzed *Diatoma tenue* appeared fairly abundantly in all. This species is halophilous (Lowe 1974) and appeared most frequently at East Bay, a site with close proximity to a major highway and a slope that would favor roadside runoff entering the lake.

Our experimental set up was placed in Lake Michigan at the mouth of a stream which may have influenced water flow and nutrient composition. Dominant diatoms found at this site were *Achnanthes minutisima* which is a pH indifferent, periphytic and eurythermal generalist

(Lowe 1974). The entering stream may induce varying temperatures and water flow conditions depending on the season. These varying conditions would give Achnanthes an advantage compared to more restricted diatoms. Furthermore, the fact that Achnanthes is periphytic could explain its abundance because of its ability to fix itself to a substrate despite currents. *Denticula elegans* dominated site 1, 2, 6, 7, and 8 which suggests nothing more than that these site are fairly alkaline around a pH of 8 (Lowe 1974).

Further research would need to be done to determine what factors contribute to diatom compositions in East Bay and Bay Harbor. Evidence from our study suggests that different sites contain different diatom communities and even sites of very close proximity (hundred meters) had radically different diatom ratios (note sites 1, 2, and 3). Lake Michigan is a dynamic large body of water with a shoreline heavily influenced by anthropogenic activities, which may contribute to habitat heterogeneity and different diatom ratios. From this experiment we can conclude that the leachate is no longer affecting the sites pH although further data would need to be collected concerning the legacy of heavy metals contained in the kiln dust.

Carly Ziska

Numerous studies have highlighted diatoms as indicators of environmental change and disturbance (e.g. Bergstrom *et al.* 2007; Patrick 1963). For this reason, an assessment of the algal community in a recovering habitat such as the one at East Park can provide valuable insight into water quality and the progress of clean up efforts. A comparison of the diatom diversity between the East Park sites and the surrounding bay area showed communities mainly composed of slightly alkaliphilous species across all the sites, which is consistent with lake water in the

Great Lakes Region. Therefore, it is reasonable to conclude that water detoxification efforts in this area have been successful.

A comparison of sites one and two at East Park showed highly similar species compositions dominated by species of *Gomphonema*, *Diatoma*, and *Synedra* (Figure 1). It was expected that these sites would show the same species abundance and distribution due to similar levels of disturbance and length of recovery. *Gomphonema* and *Diatoma* are similar in their optimal pH ranges, being slightly alkaliphilous and proliferating best in water with a pH between 7.4 and 7.8 (Lowe 1974). The pH testing at these sites showed a reading of 8.24 for site one and 8.15 for site two, which is slightly higher than these species optimas but still within their tolerable pH ranges. Similar species and pH readings were found at sites seven and eight. Because these sites were located in a different and unaffected part of Little Traverse Bay, similarities between these four sites show little to no residual effects from kiln dust at the algal level.

While sites one and two were similar in composition, it is interesting to note that the third site at East Park shows a surprisingly different community profile. Site three was dominated primarily by species of *Achnanthes*, which tends to be indifferent to pH and is a good generalist able to colonize a multitude of habitats. The proliferation of this species at site three could be the result of a recent disturbance in the local community, such as wave action clearing algae off of substrate, as *Achnanthes* is often considered to be a early succession algal species and is often one of the first diatoms present in new habitats (Bürgi *et al.* 2003). This is consistent with findings at the experimental sites one and two, where the cloth over the bottles acted as a newly colonizable surface where predominantly *Achnanthes* species were found. It is also interesting to note that cloth from the experimental bottles that was subjected to high levels of calcium hydroxide showed the same species compositions as one of the East Park sites were we expected to see a higher pH due to leachate. However, a pH reading at site three showed a pH of 8.15 and therefore any similarities are most likely the result of a recent disturbance in site three.

A third but distinct group of similar sites emerged as those that showed higher concentrations of *Cymbella microcephala*, *Cyclotella*, and *Cocconeis* species. Site four, along with the cloth from the first control site showed significantly higher abundances of these three diatoms, which were noticeably low in all the other sites. These three species are all slightly alkaliphilous and have optimal pH levels between 7.2 and 8 (Lowe 1974). Because these environmental parameters are similar to diatoms found in other sites, it is surprising that so few of these diatoms were found outside of site four and the first control bottle. One possible explanation for this dissimilarity could lie in the location of site four relative to the other sites. Because site four was located in Harbor Springs near a developed area, it is possible that human disturbance and pollution have an effect on the diatom community in the surrounding area. Species of *Cocconeis* especially are resistant to organic pollution and because *Cocconeis* is epiphytic and attaches to substrates, it is more able to withstand water disturbances due to human interaction without becoming dislodged.

All naturally occurring diatom communities sampled showed a wide range of species distribution, even between closely positioned sites. Experimental data was less widely variable but still was not consistent with expected results. Though the experimental bottles showed similar species compositions that were consistent with predicted outcomes at a constant leaching rate, the two control samples were more variable in their communities. This could be due to a variety of factors. If pH played a role in determining diatom diversity on the cloths, it is possible that the lower pH's of the experimental bottles similarly limited diatom growth to more alkaliphilous species, meaning that the control bottles were able to play host to a wider range of diatoms not affected by increased pH. However, it is possible that this discrepancy is due to design error in the experiment and similar conditions were not controlled for at a significant enough level.

Other sources of error in this experiment may have been in sampling and identification errors of diatoms, which could have skewed abundance data. The experimental design of the bottles could have been affected by a discontinuous rate of leaching, as was shown in the control bottle kept in the lab. A longer time frame may have more effectively shown a true representation of species composition.

Further studies could include continued monitoring of algal composition and pH levels at East Park and other disturbed areas to determine the stability of newly recovered communities. It would be useful to assess a wider variety of habitats to confirm that the findings in this study were truly representative.

Conclusion

Similarities in species diversity and community structure were found across multiple sites in the Petoskey region. Those sites sampled followed a chemical disturbance clean up effort were shown not to differ greatly from surrounding sites, both by pH readings and diatom samples. This indicates that there is no current evidence of leachate in these areas and that the ecosystem has almost completely recovering on an algal level.

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Tables

Site	Latitude	Longitude
1	W085^{o}00.050’	N45^{o}22.218’
2	W085^{o}00.200’	N45^{o}22.209’
3	W085^{o}00.394’	N45^{o}22.188’
4	W084^{o}58.359’	N45^{o}25.651’
5	W084^{o}59.685’	N45^{o}25.448’
6	W084^{o}55.072’	N45^{o}23.556’
7	W084^{o}.55.14’	N45^{o}23.526’
8	W084^{o}54.944’	N45^{o}23.595’
9	W084^{o}54.848’	N45o23.779’

Table 1

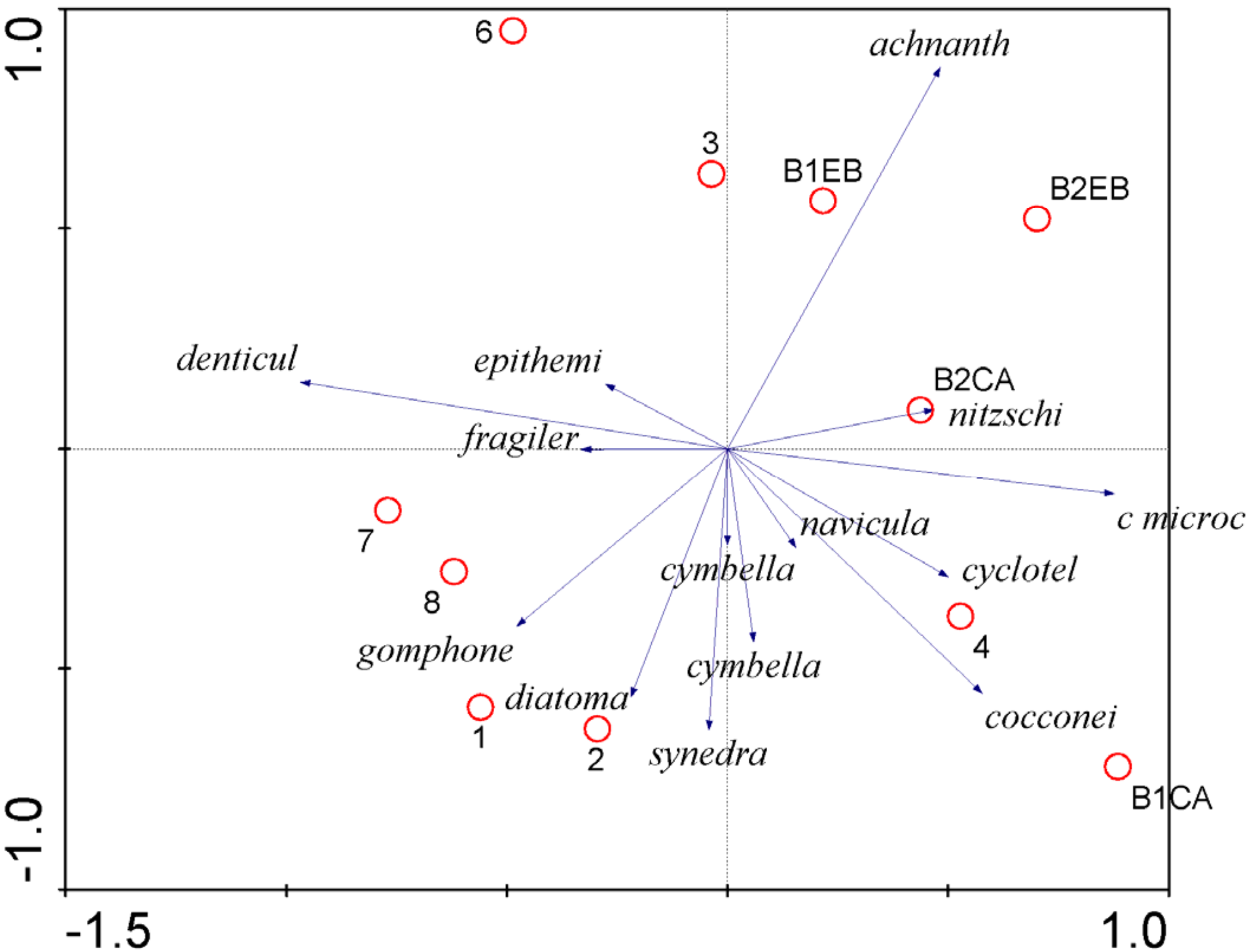
Figure Legend

Fig. 1. PCA plot of species abundance and site similarity plotted in multi-trait space.

Fig. 2. Graph of relative species abundance in each of seven sites analyzed for species abundance for each most representative species, assessed by PCA data. Sites 5 and 9 are omitted due to a lack of algal presence.

Fig. 3. Graph of relative species abundance in each of the experimental and control sites for the most representative species, assessed by PCA data.

Fig. 4. Histogram of relative pH reading by site.



1.0
-1.0
-1.5
1.0
6
3
B1EB
B2EB
achnanth
denticul
epithemi
B2CA
nitzschi
fragiler
c microc
navicula
7
cymbella
cyclotel
8
4
gomphone
cymbella
diatoma
cocconei
1
2
synedra
B1CA

Fig 1

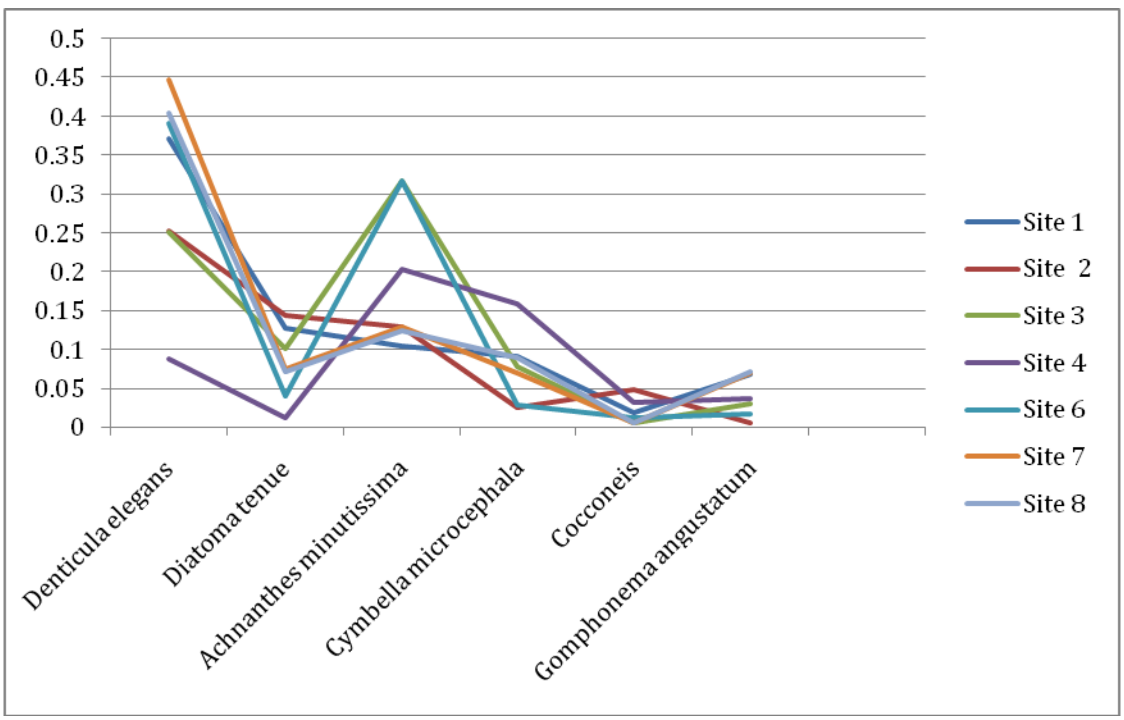

0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Denticula elegans
Diatoma tenue
Achnanthes minutissima
Cymbella microcephala
Cocconeis
Gomphonema angustatum
Site 1
Site 2
Site 3
Site 4
Site 6
Site 7
Site 8

Fig. 2.

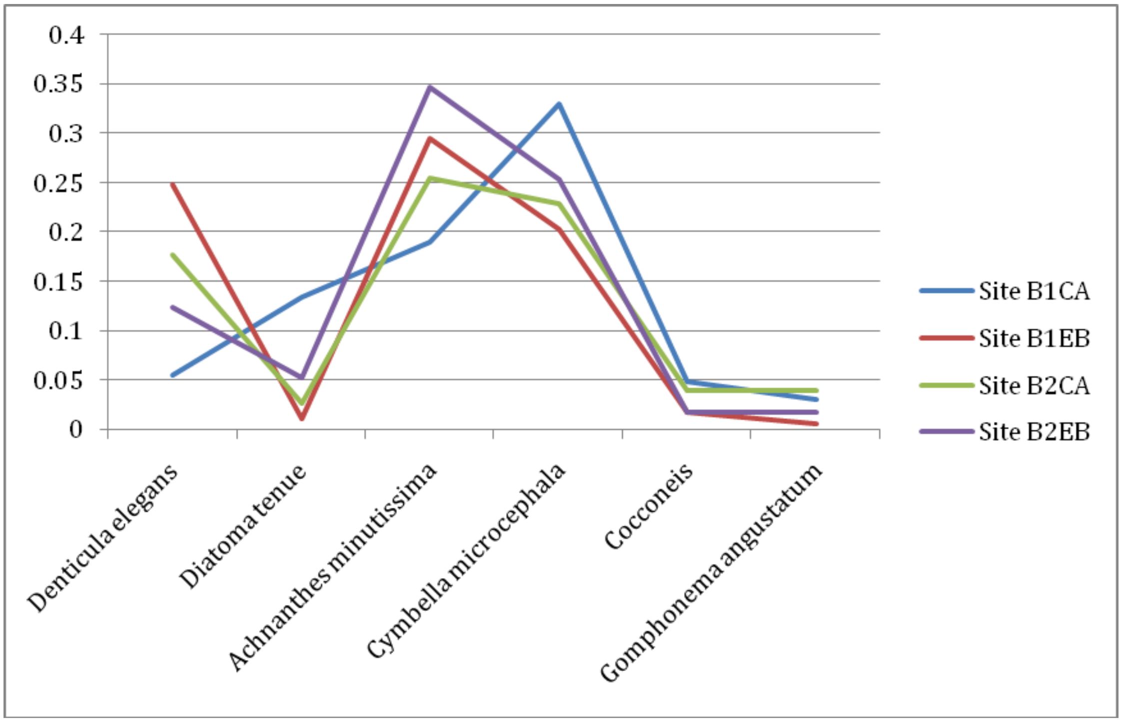

0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Denticula elegans
Diatoma tenue
Achnanthes minutissima
Cymbella microcephala
Cocconeis
Gomphonema angustatum
Site B1CA
Site B1EB
Site B2CA
Site B2EB

Fig. 3.

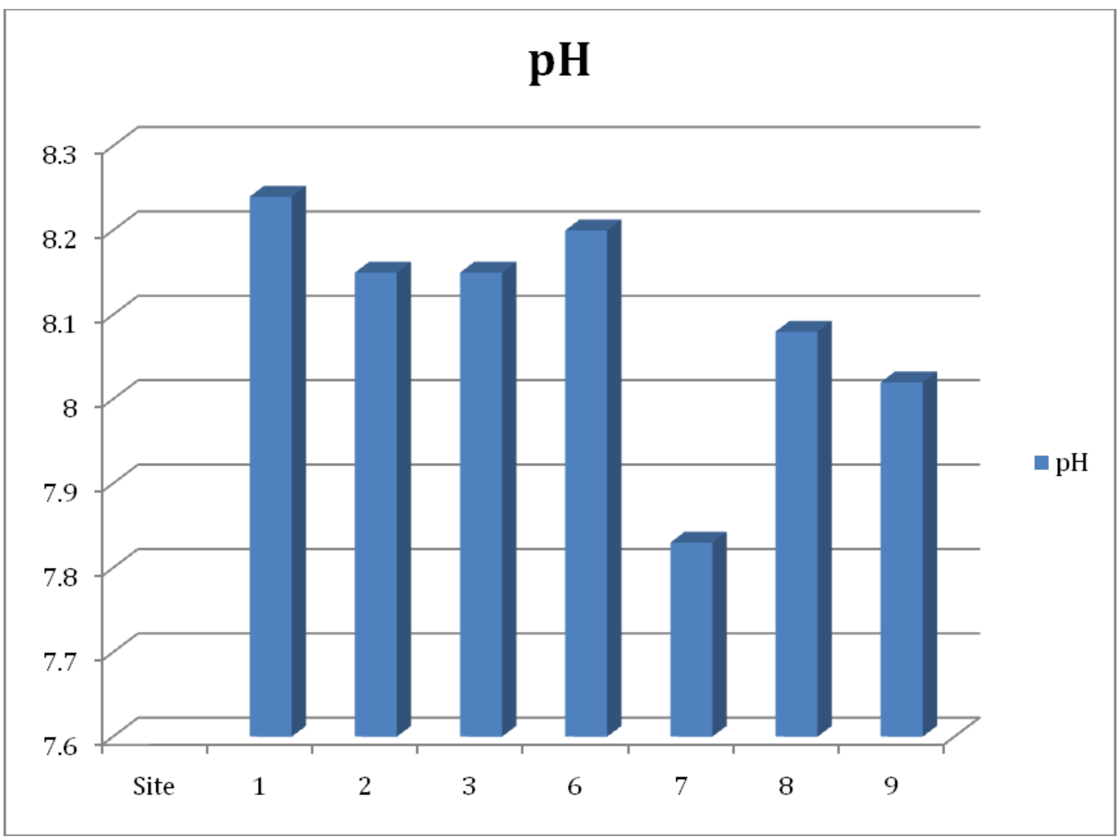

pH
8.3
8.2
8.1
8
7.9
7.8
7.7
7.6
Site
1
2
3
6
7
8
9
pH

Fig. 4.