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# Changes in Diatom Biodiversity in Lake Sinclair, Baldwin County, Georgia, USA

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## ABSTRACT

The effects of increased water temperature on algal community composition were investigated in Lake Sinclair, Baldwin County, Georgia, USA. The lake received waste cooling water from a coal burning power plant. Discharges of recycled lake water were, on average, 15˚C ± 1.5˚C (and up to 23˚C) warmer than typical ambient temperatures. Seasonal changes in algal composition were observed, and the warmer sample site had a greater diversity of diatom species year round independent of changes in temperature. Thermal pollution created a high percent dissimilarity between diatoms at the warmer site and the remainder of the lake. Species turnover observed in natural samples was not detected for the warmer site. Anthropogenic thermal pollution was implicated as the factor inducing changes in the natural algal community composition, which may impact other trophic levels and ultimately the overall ecology of Lake Sinclair.

**Keywords:** Diatoms; Heated Water; Southern Lakes; Thermal Pollution

## 1. Introduction

Thermal pollution is the degradation of water quality by any process that changes the ambient water temperature. Persistent differences in ambient water temperature may result in eutrophication, loss of ecosystem processes such as biological productivity and lake metabolism, contaminant toxicity, and loss of aquatic biodiversity [1]. It has been reported that cooling systems from coal burning power plants have no harmful effects on a system as a whole [2]. However, effects of thermal pollution in aquatic systems are greatly influenced by industry, agriculture, and urban habitats [1,3-9]. Effect of thermal pollution on algae has not been addressed in Georgia, but in a southwestern lake thermal loading depressed primary production of phytoplankton [10]. Lake Sinclair, in Central Georgia, is a manmade lake owned by Georgia Power. Water from the lake is used to cool the turbines of a coal burning Power plant. About a billion gallons of water per day is extracted from the lake, and when pumped back into the lake it is intended to be within a few degrees of the ambient temperature [11]. The effects of thermal pollution have been documented previously [12], and it was reported that approximately 3% of the lake was directly impacted by water that was too warm when it was released.

Cooling towers are supposed to decrease water temperature to ambient temperatures before being released, reducing the impact of thermal pollution on the surrounding system [13]. In 2002, Georgia Power finished installing a cooling tower to comply with Georgia Environmental Protection Division's (GA EPD) [14] regulation to control effluent water temperature. The other condition required for compliance is that at no time is the temperature of the receiving waters to be increased by more than 15˚C above intake temperature or the lake's natural temperature gradient. The installation was done in response to a number of fish kills in the 1990's in Beaverdam Creek [15]. Past research on Lake Sinclair is limited, with little to no research on potential thermal pollution and its effects on primary producers. The State of Georgia has continuously monitored temperature data from DNR/EPD/Watershed Protection Branch since 2009. Three sites that the State monitored on Lake Sinclair provided additional temperature information in this study for the baseline conditions within the lake.

Diatoms (Bacillariophyta) are often reported as the dominant group in lake communities [16] and are known to show definitive responses to different stressors and environmental conditions [17-21]. Their rapid cell cycles have been used to infer changes in composition due to

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anthropogenic influences from days to weeks [22,23]. Diatoms are able to recolonize bare surfaces as primary colonizers in approximately 14 days [24]. They have also been used extensively to directly infer climate variables, such as temperature [25,26], but never as a model to understand thermal pollution within the same aquatic habitat. Diatoms are particularly useful for assessing environmental change because of their fast response rate and potential presence in sedimentary records, which means they can be used to compare past with present communities. Diatoms were used to detect shifts due to global warming when there were changes of only a few degrees centigrade [1], and the community composition shifted to species that preferred longer growing seasons with less ice cover [27-29]. A shift from primarily benthic diatoms to planktonic species has also been suggested as a sign that warming is occurring [30-37]. Visible changes in community dominance of diatoms followed by satellite imagery showed the effects of thermal pollution on shallow estuaries [38], and as little as 1˚C temperature increase changed the dominant species composition in the local area.

Species richness, diversity, and evenness are routinely used to assess community change and. In the case of climate, warmer temperatures have been found to favor higher biological production [39]. High species richness is a measure of high biotic integrity, because of the variety of habitats present and the ability of taxa to adapt to the available niches [40]. Much research on algae has addressed the relationship between species richness and nutrient concentrations [41,42]. High nutrient concentrations can lead to toxic blooms [43]. However, many habitats may be naturally stressed by low nutrients, low light, low temperature or other factors [18]. A slight increase in nutrient enrichment has been shown to trigger an increase in algal species richness in headwater and naturally unproductive, nutrient poor streams [44]. Temperature changes may have a similar effect [45].

However, information from stressor specific monitoring is generally lacking. Little is known about the ecological impacts of thermal pollution on primary producers within the same lake. In an attempt to determine the nature and magnitude of environmental changes in a lake impacted by anthropogenic temperature increase, two sites on Lake Sinclair were systematically monitored and diatom species composition was analyzed to assess response to temperature differences. It can be expected that some algal species differ at the two sites because they have different tolerances to temperature. The goals of this study were to: 1) understand the biological impacts of thermal pollution in Lake Sinclair; 2) evaluate the changes in primary producer community structure and function due to changes in temperature; and 3) assess the potential of change in diatom community structure as an indicator of thermal pollution.

## 2. Materials and Methods

### 2.1. Study Area: Lake Sinclair, from the Oconee River Watershed

Lake Sinclair is located in central Georgia on the Oconee River watershed (33˚10′49.06″N, 83˚17′28.70″W). It stretches through three counties including Baldwin, Hancock, and Putnam. The Oconee River is the main source of water for this reservoir and supplies 70% of the lake's water. The lake is also fed by waters from the Apalachee River and several small creeks in the area [46]. The region is characterized by a warm and humid, temperate climate. The average annual temperature is about 15.6˚C. Runoff is not generally significant.

The Oconee River basin contains parts of the Piedmont and Coastal Plain physiographic provinces, which extend throughout the southeastern United States. Lake Sinclair sits on the Piedmont region. Predominant soil types are sandy loam clay to fine sandy loam [13].

Lake Sinclair is a manmade lake created in 1953. It is the second largest reservoir in Georgia (surface area 62 km²) and has a maximum depth of 27 m. Lake Sinclair and Lake Oconee are considered oligotrophic lakes, with deep nutrient poor lake basins with sandy or rocky bottoms, and scarce bottom vegetation. Georgia Power, a Southern Company, owns the lake and uses it as a reservoir to cool the turbines in their coal burning plant. In addition, the lake area is used for residential housing and recreation. In the counties surrounding the lake, there is a population of about 150,000. The counties that surround Lake Sinclair remain heavily forested by oak/pine forests with little agriculture and industry [13]. The agriculture and housing developments on water bodies above Lake Sinclair have little to no influence on the streams and lakes themselves [47].

### 2.2. Sampling Site Locations

Prior to this study, non-significant differences in diatom community composition from Lake Sinclair were reported in 22 sites [47,48]. For the current study, two sites on Lake Sinclair were chosen for comparison of the temperature effects. One in the immediate "warmer" area of the power plant (where discharge from the cooling tower occurs), and the other was approximately 1.7 km to the south representing ambient temperatures, "the cooler or cold site". The cold and warm locations were sampled for seven months. There were a total of 15 samples taken from each sample site. Sampling methods followed Standard protocols [49,50]. Once collected, the samples were transported to the laboratory in a cooler with ice and immediately preserved. Algal samples were preserved with 3% formaldehyde for later processing and identification [50].

Algal samples were collected approximately every 14 days from August 2008 to February 2009, along with triplicate measures of water temperature, pH, and conductivity with YSI 556 MPS instrument. Turbidity was measured using a LaMotte® Portable Turbidity meter. Turbidity was measured as having sediment or foreign particles stirred up or suspended, muddy. Based on the GA EPD requirement for small differences in natural habitats due to human activities, temperature differences between the two sites were categorized as 1 = small differences from 1˚C to 10˚C, 2 = medium differences from 11˚C to 20˚C, and 3 = high differences more than 20˚C. After classification, 4 sampling events fell into the first category, 5 fell into the second category, and 6 fell into the third category for a total of 15 sampling events. A Secchi disc (Carolina biological Inc.) was used to evaluate the depth of the photic zone. Water for nutrients analyses was collected in 125 ml acid washed bottles and sent to the University of Georgia Marine Extension Service and University of Georgia commercial chemical analyses lab in Athens, Georgia. Water samples were analyzed for nutrients including Ammonium, Nitrate/Nitrite, Total Nitrogen, and total Phosphorus. Three further samples were taken for nutrient analysis and compared to Georgia's DNR data, but there were no significant differences in nutrient concentrations.

Lab analysis of algal diatom assemblage composition was performed using cleaned (digested) samples preserved on permanent slides [50]. The samples were cleaned of organic matter in 50% nitric acid for 2 hours. Then less than one gram of potassium dichromate was added to them as a catalyzer, heated for approximately 5 minutes and left to cool for 30 minutes. Permanent diatom slides were prepared by acid cleaning, to increase the clarity of observing diatoms [51], and then mounted in Naphrax resin (RI 1.74, Northern Biological Supplies L., Ipswich, UK). Taxa that appeared as auxospores or single broken valves without the central area were not included in the analyses.

At least 300 valves were counted from each sample using the 1000x objective lens on an Aus JenaLumar scope (AUSJena Germany). Diatoms were identified to the lowest taxonomic unit using standard identification keys and following standard procedures for diatom identifications [51-56].

### 2.3. Diatom Indices

Presence or absence and species numbers were recorded at the cold site and the warm site. Species richness describes the number of species in a habitat. Species evenness [57] represents the relative abundance of species in a community (if one taxon dominates the community and there are many rare taxa, evenness will be close to 0). Species diversity is a measure of diversity that increases with either species richness or species evenness. The Shannon diversity index considers species richness and proportion of species in a site [58]. Lastly, 2 other measures were utilized to compare the sites. Similarity richness Index (S = 2C/A + B) and % Dissimilarity index (%D = 100 minus Σ min relative abundance of "C"), where C is the number of common species between the two sites, A is the number of species in one site, B is the number of species in the other site and "C" is relative abundance of common taxon that appeared in both sites; the smaller of the 2 relative abundances is summed for the index [59]. Similarity varies from 0 to 1, high Similarity is expected at 0.7 and above. Dissimilarity values vary from 0 to 100% with values close to 0 indicating identical communities and more than 50% indicating very different diatom communities [60].

### 2.4. Statistical Analyses

To test if the number of rare taxa were significantly different between natural and high temperature impacted sites, sites were compared with t tests as $\alpha = 0.05$ and significance was considered. If the assumptions for t test were not met (e.g., normality, equal variance) and if transformation did not help, the Mann Whitney non parametric test was used. Descriptive statistics, Pearson correlations, and regression analyses were conducted to analyze environmental variability and relationships between variables. Linear regression predicted patterns of community indices in the warm and cold environments. Statistical analyses were performed with SYSTAT® 13 [61].

## 3. Results

### 3.1. Physical Parameters

Temperatures at the cold site ranged from 10˚C to 31.5˚C (mean 20.6˚C) and at the warm site from 29˚C to 35˚C (mean 32.5˚C). The seasonal temperatures at the cold site were normal for the lake but the warm site, which received the cooling water discharge, showed little variation throughout the study. Temperature differences between the two sites diverged the most during the winter season, while summer months temperature values overlapped.

Dissolved oxygen concentrations at both sites were similar, with 4.2 mg/L at the warm site and 4.7 mg/L at the cold site, with the highest levels in winter, and declining in the summer months. There was no statistical difference between the dissolved oxygen at each site over each sampling event. Average pH within the study area was 7.04 ± 0.22 with values ranging from 6.82 to 7.26. Secchi depth averaged 0.85 ± 0.50 m for the study area. Conductivity averaged 66 ± 6.24 μS/cm for the study area. Turbidity in the study area averaged 14.32 NTU.

### 3.2. Nutrient Analyses

Water samples for nutrient analysis were taken three times during this research, at the beginning the middle and the end. The average concentrations of ammonia was 0.23 ± 0.04 mg/L, of nitrate was 0.17 ± 0.01 mg/L, and total nitrogen 0.20 ± 0.18 mg/L. There was no statistical difference between the nitrogen, ammonium, and total phosphorus at each site over each sampling event.

### 3.3. Diatom Enumeration

There were a total of 131 diatom species observed from the two sites at Lake Sinclair. Only 10 were considered common species with relative abundance of >25% (**Tables 1** and **2**). Rare species made up approximately 90% of the species documented during the study. Different rare species were observed at both sites. Planktonic and benthic diatoms were observed throughout the study. Variation among total species richness remained low for the duration of the study. The highest species richness in the cold site occurred during the summer months with a total of 37 species observed, which corresponded to the highest Shannon diversity value. The warm sites highest species richness occurred during the summer as well with 39 different species observed. This number correlated with the highest Shannon diversity value for the warm

**Table 1. Species that appeared in 25% or more relative abundance in cold habitat in Lake Sinclair, GA.**

| Date | Diatom Species | % RA |
|---|---|---|
| 2008/10/27 | Achnanthidium minutissimum (Kützing) Czarnecki | 0.310 |
| 2008/11/1 | Achnanthidium minutissimum (Kützing) Czarnecki | 0.307 |
| 2008/12/5 | Aulacoseira ambigua (Grunow in Van Heurck) Simonsen | 0.310 |
| 2008/12/5 | Discostella stelligera (Cleve et Grunow in Cleve) Houk et Klee | 0.273 |
| 2009/1/16 | Achnanthidium minutissimum (Kützing) Czarnecki | 0.578 |
| 2009/1/16 | Aulacoseira granulata (Ehrenberg) Simonsen | 0.278 |
| 2009/1/25 | Achnanthidium minutissimum (Kützing) Czarnecki | 0.430 |
| 2009/2/11 | Melosira varians Agardh | 0.331 |

**Table 2. Species that appeared in 25% or more relative abundance in warm habitat in Lake Sinclair, GA.**

| Date | Diatom Species | % RA |
|---|---|---|
| 2008/9/3 | Fragilaria capucina Desmazières var. mesolepta (Rabenhorst) Rabenhorst | 0.276 |
| 2008/10/3 | Achnanthidium catenatum (Bily et Marvan) Lange-Bertalot | 0.313 |
| 2008/10/3 | Achnanthidium minutissimum (Kützing) Czarnecki | 0.280 |
| 2008/10/10 | Achnanthidium catenatum (Bily et Marvan) Lange-Bertalot | 0.247 |
| 2008/10/10 | Achnanthidium minutissimum (Kützing) Czarnecki | 0.440 |
| 2008/10/17 | Achnanthidium minutissimum (Kützing) Czarnecki | 0.273 |
| 2008/11/1 | Encyonema silesiacum (Bleisch in Rabenhorst) Mann in Round | 0.253 |
| 2008/11/7 | Nitzschia filiformis var. conferta (Richter) Lange-Bertalot in Lange-Bertalot and Krammer | 0.248 |
| 2008/11/17 | Aulacoseira ambigua (Grunow in Van Heurck) Simonsen | 0.277 |
| 2008/12/5 | Aulacoseira granulata (Ehrenberg) Simonsen | 0.333 |
| 2009/1/16 | Aulacoseira granulata (Ehrenberg) Simonsen | 0.291 |
| 2009/1/16 | Thalassiosira pseudonana Hasle et Heimdal | 0.258 |
| 2009/1/25 | Achnanthidium minutissimum (Kützing) Czarnecki | 0.333 |
| 2009/2/11 | Achnanthidium catenatum (Bily et Marvan) Lange-Bertalot | 0.424 |
| 2009/2/11 | Achnanthidium minutissimum (Kützing) Czarnecki | 0.435 |

 

water site as well.

There were 100 species recorded at the cold site. The average number of species was 23 ± 1.90, ranging from 13 to 37 species. The highest species richness and evenness observed in the cold samples occurred during warmer calendar months, when not a single taxon appeared with more than 25% relative abundance (**Table 1**).

There were a total of 103 diatom species documented at the warm site. The average number of species was 23 ± 1.87, ranging from13 to 39 species.

The cold water community was dominated by *Achnanthidium minutissimum* (Kützing) Czarnecki (**Table 1**), with secondary abundances of other pennate genera including *Nitzschia*, *Aulocoseria*, *Melosira*, *Synedra*, and *Cymbella*. For the warm site, the subdominant genera like *Aulacoseira* and *Cymbella* were at much greater abundances than in cold water. *Cocconeis pediculus* Ehrenberg, *Martyana martyi* (Héribaud) Round, and *Caloneis schumanniana* (Grunow in Van Heurck) Cleve, were found only at the warm site (**Table 2**). *Adlafia minuscula* (Grunow) Lange Bertalot, *Amphipleura pellucida* (Kützing) Kützing, *Diadesmis contenta* (Grunow ex Van Heurck) Mann in Round, Crawford and Mann, *Fallacia tenera* (Hustedt in Schmidt) Mann in Round, Crawford and Mann, *Stephanodiscus minutulus* (Kützing) Cleve et Möller, and *Tabularia fasciculata* (Agardh) Williams et Round were only present in the cold site. Warm water community composition remained consistent with the cold site throughout the year. However, as the study progressed over time, the dominant species shifted as the temperature changed in the cold sites more than in the warm sites.

The Shannon diversity values for the cold site ranged from 1.26 to 3.02. The warm sites values were comparable, ranging from 1.73 to 3.10. When temperature differences were small between the two sites, there were no significant differences in values of the average Shannon diversity. With a change in the seasons, the Shannon diversity values at both warm and cold site' varied significantly, showing an increase, on average, in the cold site and a decrease in the average warm sites value. During the winter months at the cold sites, the Shannon diversity value decreased further while the warmer site stayed at about the same. Evenness for the warm site ranged from 0.68 in October to 0.85 in August. The cold site had a low evenness of 0.45 in February and a high evenness of 0.87 in November.

Similarity calculated with presence of common taxa at both sites was very low and reached close to 50% only in September (**Table 3**). Similarity based on species richness related common species between the two sites with the total number of species in both areas. Dissimilarity measured with minimum relative abundance of a common taxon for the two locations was very high for all pairs (**Table 3**), dissimilarity decreased below 50% only during one warmer calendar month. Average richness similarity during winter months similarly was 0.08 to 0.43, dissimilarity based on species identity and relative abundance was high throughout the sampling season.

Temperature explained one third to 50 % of the variation only for the cold or natural habitats (**Table 4**). The Shannon diversity within the cold sites increased significantly with temperature changes (Linear regression, $y = 0.007x + 2.143$, $R^2 = 0.54$, $p = 0.002$). The Species richness for the cold site increased with increase in temperature (Linear regression, $y = 0.77x + 6.838$, $R^2 = 0.37$, $p = 0016$). The Evenness for the cold site significantly increased with temperature too (Linear regression, $y = 0.013x + 0.511$, $R^2 = 0.52$, $p = 0.002$). No significant changes between the communities attributed and temperature were documented for the warm site.

### 3.4. Representative Diatom Species Evaluations (from the Taxonomic Literature)

*Cocconeis pediculus* Ehrenberg, is described as having a valve that is strongly arched, broadly ellipitical. Intercalary band occasionally seen. Raphe valve with narrow, linear axial area terminating in a small semicircular clear space near the valve extremities. Centrals are small, cir-

**Table 3. Species richness similarity and % abundance dissimilarity of diatom community composition in warm and cold sites within Lake Sinclair system for each sampling date.**

| Date | Species Similarity | Abundance % Dissimilarity |
|---|---|---|
| 2008/8/27 | 0.1967 | 67 |
| 2008/9/3 | 0.2040 | 65 |
| 2008/9/12 | 0.4535 | 49 |
| 2008/9/26 | 0.5160 | 63 |
| 2008/10/3 | 0.4895 | 59 |
| 2008/10/10 | 0.3179 | 76 |
| 2008/10/17 | 0.3806 | 55 |
| 2008/10/27 | 0.4829 | 68 |
| 2008/11/1 | 0.1733 | 74 |
| 2008/11/7 | 0.1113 | 73 |
| 2008/11/17 | 0.1942 | 63 |
| 2008/12/5 | 0.2767 | 58 |
| 2009/1/16 | 0.3244 | 72 |
| 2009/1/25 | 0.4394 | 74 |
| 2009/2/11 | 0.0870 | 62 |

 

**Table 4. Mean, Standard Deviation, Regression equations, $R^2$, and p-values for cold and warm sites within Lake Sinclair.**

| Group | Variable | N | Mean | Std. Dev. | Regression equation | $R^2$ | p-value |
|---|---|---|---|---|---|---|---|
| Cold | Shannon | 15 | 2.43 | 0.506 | y = 2.143 + 0.007x | 0.54 | 0.002 |
| | Species Richness | 15 | 23.133 | 7.347 | y = 6.838 + 0.776x | 0.37 | 0.016 |
| | Eveness | 15 | 0.777 | 0.101 | y = 0.511 + 0.013x | 0.52 | 0.002 |
| Warm | Shannon | 15 | 2.346 | 0.433 | y = 1.076 + 0.064x | 0.01 | ns |
| | Species Richness | 15 | 22.667 | 7.355 | y = 21.1 + 0.0056x | 0.002 | ns |
| | Eveness | 15 | 0.76 | 0.09 | y = 0.699 + 0.002x | 0.02 | ns |

cular to somewhat irregular. Raphe filiform, proximal ends close, extending into the central area; distal ends straight, terminating at the small semicircular space near the valve extremities. Striae curved-radiate, finely but distinctly punctuate. Striae not extending completely to the valve margin, but interrupted by a narrow, clear marginal area which is continuous around the valve much as rim. Pseudoraphe valve with very narrow, linear pseudoraphe. Central area lacking. Striae also curved radiate, faintly etched as a shallow trough, with distantly placed conspicuous puncta. Puncta arranged in longitudinally undulating rows. Straie, about 20 in 10 µ along the axial area, 16 - 17 in 10 µ near the margins (RV); 18 in 10 µ along the axial area, 15 - 16 in 10 µ near the margins (PRV). Length, 11 µ - 30 µ. Breadth, 6 µ - 20 µ. The range of this diatom has been reported in the South Eastern United States. This species is a widespread species; epiphytic on many aquatic plants and other objects, but not often found in large numbers. Considered by some as resistant to moderate amounts of organic pollution; alkaliphil, and salt "indifferent". The measured specimens from our samples fell within the range of the given description.

*Achnanthidium minutissimum* (Kützing) Czarnecki (**Figure 1(7)**) is described as having a valve linearellipitical with obtusely rounded subrostrate to capitate ends. Raphe valve with narrow, linear axial area and narrow, somewhat irregularly shaped, central area occupying up to about one-half the total width of the valve in the middle portion. Raphe filiform; proximal raphe ends close, distal ends curving subtlety in the same direction. Striae slightly to moderately radiate, becoming more numerous towards the ends. One or two shorter striae on either side of the central area sometimes spaced slightly farther apart than the reaming straie. Pseudoraphe valve with narrow, linear axial area, slightly broadened in the middle portion of the valve or with an occasional shortened stria at the center, but with no distinct central area as such. Striae character and direction as on the raphe valve. Striae, 30 - 32 in 10 µ at the center, becoming 36 - 38 in 10 µ near the ends (both valves). Length, 5 µ - 40 µ. Breadth, 2 µ - 4 µ. This species has been reported in the South Eastern United States. This species is described as a very widespread taxon to be found throughout the country, Eurytropic, Euryők. Found at very wide range of pH about 6.5 - 9.0. Oligohalobe, probably "indifferent". The measurements in our study were in the range of the given description.

*Fragilaria capucina* Desmazières var. *mesolepta* (Rabenhorst) Rabenhorst (**Figure 2(2)**) is described as having a valve linear to linear-lanceolate, constricted at the rectangularly shaped central area. Apices somewhat attenuated, rostrate. Pseudoraphe very narrow. Central area somewhat variable, may be longer than broad or broader than long. Striae parallel, 15 - 18 in 10 µ. Length, 30 µ - 35 µ. Breadth in narrowest portion of the middle of the valve, 2 µ - 4 µ. This taxon is distinguished from other verities of this species by the constriction in the middle portion of the valve. This species has been reported in the South Eastern United States, and occurs in fresh water, slightly alkaline; sometimes found in slightly brakish

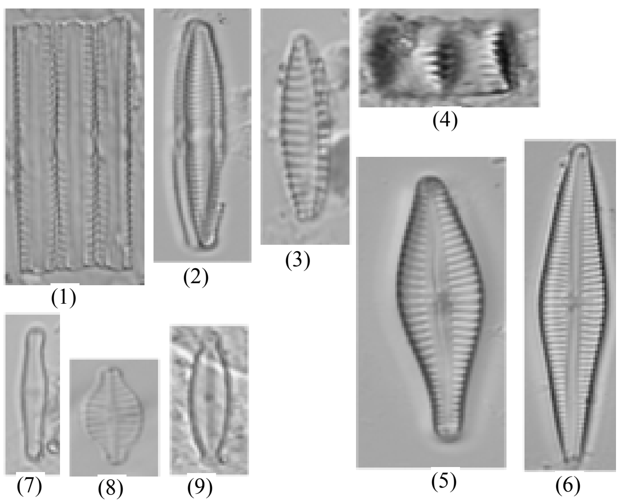


**Figure 1. Warm water pennate araphid, monoraphid and biraphid diatom taxa, (1 - 2) *Fragilaria bidens* Heiberg, (3) *Fragilaria* sp., (4) *Staurosirella sp.* (5) *Gomphonema* sp., 6. *Gomphonema gracile* Ehrenberg, (7) *Achnanthidium minutissimum* (Kützing) Czarnecki, (8) *Planothidium* sp. (9) *Encyonopsis microcephala* (Grunow) Krammer. Scale bar is 10 µm.**

 

water. The specimens in our samples were not the same size as the description given.

*Encyonema silesiacum* (Bleisch in Rabenhorst) Mann in Round, Crawford and Mann (**Figure 3(7)**) is described as having valves that are strongly dorsi-ventral with rounded, undifferentiated apices. The dorsal margin is strongly convex; the ventral margin is more or less straight. The straie are parallel to slightly radiate. Axial area is narrow linear, with slightly expanded central area. Raphe is filiform and more or less straight. Proximal raphe fissures are small pores; distal raphe fissures are strongly deflected towards the ventral surface and extended along the valve margin. The isolated pore (stigma) at the end of the central straie may or may not be discerned with LM. Areolae open externally as slits. *Encyonema silesiacum* has fewer areolae/10 µm. Length 7 µm - 23 µm (*Encyonema silesiacum* usually larger). Width is 4 µm - 7 µm with a straie density of 15 - 18/10 µm. This species was restricted to more eutrophic locali- ties with higher pH and was never dominant in Lake Sin- clair samples. The sizes of our specimens of this species were not the same as the description given.

*Aulacoseira ambigua* (Grunow in Van Heurck) Simonsen (**Figure 4(2)**) is described as having cells that are cylindrical with a mantle height to valve diameter often between 1.5 and 3. The valve face is usually unornamented. Straie on the mantle composed of relatively large, circular areolae that spiral to the right. Since each mantle costae terminates with a spine on the valve face, the density of spines equals the density of straie. Linking spines are short, and triangular, fork or heart-shaped.

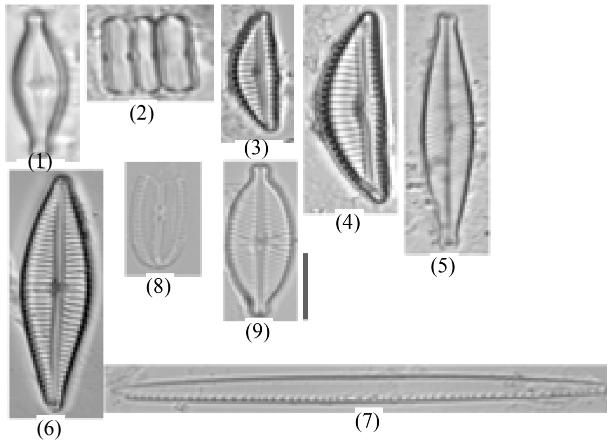


**Figure 3. Cold water Pennate biraphid diatom taxa, (1) *Brachysira vitrea* (Grunow) Ross in Hartley, (2) *Diadesmis contenta* (Grunow ex Van Heurck) Mann in Round, Crawford and Mann, (3) *Encyonema minutum* (Hilse in Rabenhorst) Mann in Round, Crawford and Mann, (4) *Encyonema silesiacum* (Bleisch in Rabenhorst) Mann in Round, (5) *Navicula notha* Wallace, (6) *Gomphonema gracile* Ehrenberg, (7) *Nitzschia filiformis* var. *conferta* (Richter) Lange-Bertalot in Lange-Bertalot and Krammer, (8) *Fallacia tenera* (Hustedt in Schmidt et al.) Mann in Round, Crawford and Mann, (9) *Geissleria decussis* (Østrup) Lange-Bertalot et Metzeltin. Scale bar is 10 µm.**

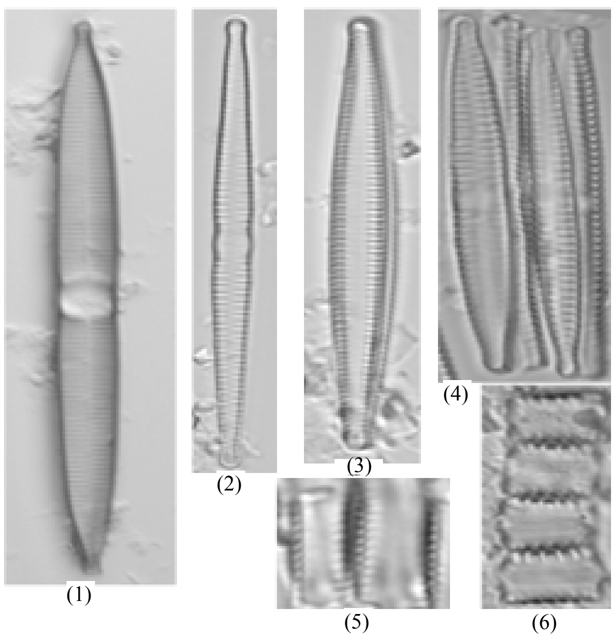


**Figure 2. Cold water Pennate araphid diatom taxa, (1) *Synedra ulna cf. Var ramesi,* (2) *Fragilaria capucina* Desmazières var. mesolepta (Rabenhorst) Rabenhorst, (3) *Tabularia fasciculata* (Agardh) Williams et Round, (4) *Fragilaria bidens* Heiberg, (5) *Pseudostaurosira brevistriata* (Grunow in Van Heurck) Williams et Round, (6) *Martyana martyi* (Héribaud) Round. Scale bar is 10 µm.**

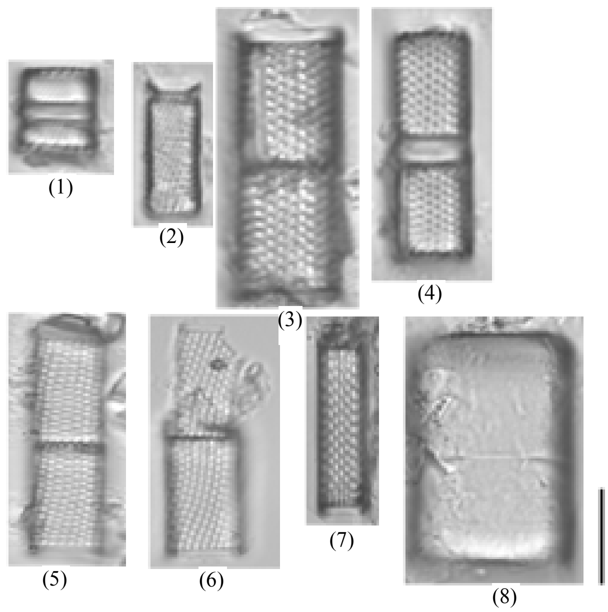


**Figure 4. Warm water Centric diatom taxa, (1) *Aulacoseira alpigena* (Grunow in Van Heurck) Krammer, (2) *Aulacoseira ambigua* (Grunow in Van Heurck, (3 - 7) *Aulacoseira granulata* (Ehrenberg) Simonsen, (8) *Melosira varians* Agardh; scale bar 10 µm.**

Although rare, separating spines are longer, pointed, and also terminate the ends of each mantle costae. Cells have a well-defined collum, the height of which is quite stable, and a thick hollow Ringleiste that forms a characteristic indentation when cells are viewed at mid-focus. The height is 5 μm - 13 μm with a diameter of 4 μm - 17 μm. This taxon is reported to be observed in slightly acidic to slightly alkaline, and mesotrophic conditions. This is a planktonic species that dominated in 6% of our communities. The specimens observed fell within the range of the given description.

## 4. Discussion

There was limited evidence for a shift from benthic to planktonic diatoms as Lake Sinclair is very turbid with a shallow photic zone as compared to arctic lakes where most of the temperature relationships have been reported [27-29]. During the warmer months of the study when there was less than 10˚C temperature difference, diversity values and richness were close in value. When the seasons changed, there was a statistically significant difference between the sites that triggered on average 65% dissimilarity. Within the median increase in temperature differences (still less than 20˚C), cold sites were more diverse. Diatom species composition, richness, and abundance of naturally occurring species in Lake Sinclair were significantly changed in parts of the lake with constant high temperature. The expected decrease in native taxa richness, because these taxa are less competitive in higher temperature, was strongly suggested and observed. Competitive exclusion for other limiting resources, increased predation, or alteration of other abiotic factors through indirect effects of temperature (e.g., dissolved oxygen concentration, microbial interaction, or habitat structure) may all be influencing diatom community characteristics.

The abundance of diatom species was expected to be more sensitive to environmental changes than presence/ absence of taxa, because taxa were expected to change their reproductive rate before being totally lost from a habitat. Taxonomic evaluation of diatoms from natural conditions in either low nutrients [62] or as evaluated in this study, low temperature, present a valuable resource for evaluation of changes due to human activities. Ideally, reference conditions are developed according to the central tendency and variability of natural or minimally disturbed systems.

The ultimate goal of assessing and managing aquatic ecosystems is to restore these ecosystems to natural conditions, which will not be possible for Lake Sinclair. The suite of community assessment presented here (such as native conditions, diatom richness, relative abundance, and species characteristics) should be monitored along the temperature gradients in the future.

Diatoms have long been regarded as excellent indicators of environmental change in aquatic systems, responding with quantifiable trends over relatively short time periods. The warmer sample site was anticipated to promote a greater diversity of species. As our results demonstrated, constant high temperature supported higher biodiversity and prevented natural competitive processes to take place as in the rest of the lake. Winter differences in temperature were above regulation (GA EPD), and significantly changed the community structure of the primary producers. Anthropogenic thermal pollution is implicated here as a factor inducing changes in the natural diatom community composition, which may impact other trophic levels and ultimately the overall ecology of Lake Sinclair.

This is the first taxonomic evaluation of diatoms from Lake Sinclair, and the observed (diatom dominated primary producers community) was due to changes in temperature. The highest similarity values occurred when temperature corresponded to high summer air temperature. Warmer water supported more algal species and higher algal density. Inversely it was observed that as the temperature dropped, similarity decreased and varied with season. The temperature in the lake is affected by recycled water that is released by the power plant daily. Diatoms are an effective source for determining temperature changes over a relatively short period of time and good indicators of impairment.

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