RESULTS OF SEDIMENT CORE TAKEN FROM WHITE ASH AND NORTH WHITE ASH LAKES, POLK COUNTY, WISCONSIN

Paul Garrison and Gina LaLiberte, Wisconsin Department of Natural Resources
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Aquatic organisms are good indicators of a lake's water quality because they are in direct contact with the water and are strongly affected by the chemical composition of their surroundings. Most indicator groups grow rapidly and are short lived so the community composition responds rapidly to changing environmental conditions. One of the most useful organisms for paleolimnological analysis are diatoms. These are a type of algae which possess siliceous cell walls, which enables them to be highly resistant to degradation and are usually abundant, diverse, and well-preserved in sediments. They are especially useful, as they are ecologically diverse. Diatom species have unique features as shown in Figure 1, which enable them to be readily identified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. Some species float in the open water areas while others grow attached to objects such as aquatic plants or the lake bottom.

By determining changes in the diatom community it is possible to determine water quality changes that have occurred in the lake. The diatom community provides information about

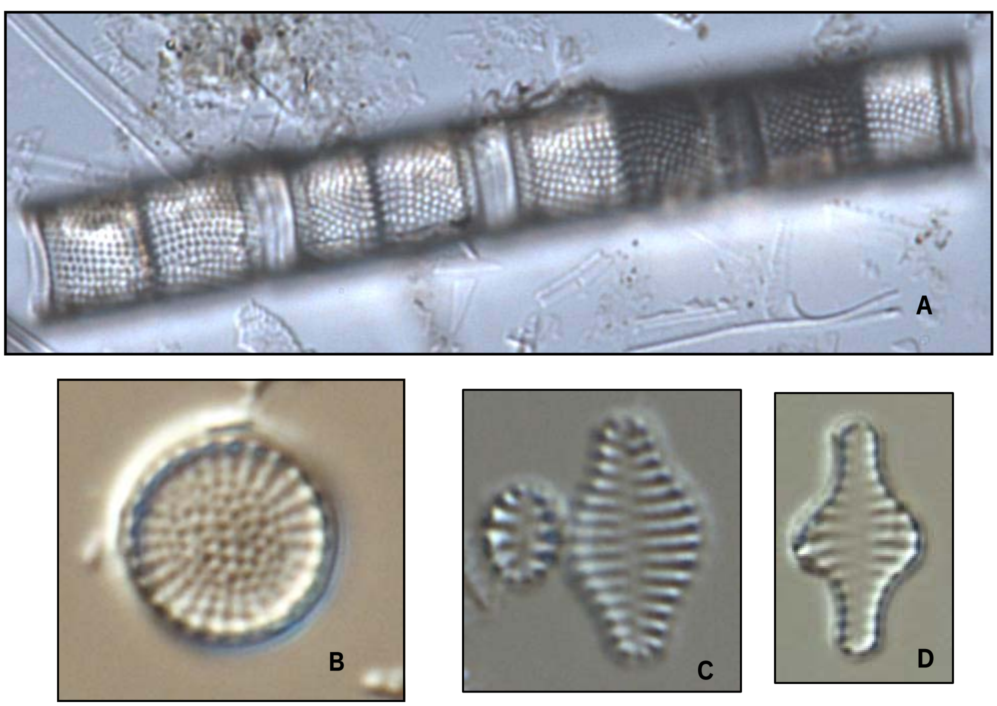

Figure 1. Photomicrographs of the common diatoms in the sediment cores. *Aulacoseira ambigua* (A) and *Stephanodiscus hantzschii* (B) are found floating in the open water. *Staurosira construens* var. *venter* (C) and *Staurosira construens* (D) grow attached to substrates, especially submerged aquatic plants.

changes in nutrient concentrations, water clarity, and pH conditions as well as alterations in the aquatic plant (macrophyte) community.

On 12 May 2010 sediment cores were taken from near the deep areas of White Ash (N45° 26.900' W92° 18.685') and North White Ash (N45° 27.770' W92° 18.680') using a gravity corer. The water depth in White Ash Lake was 9 feet and 6 feet in North White Ash Lake. The length of the White Ash Lake core was 35 cm while the length of the North White Ash core was 50 cm. It is assumed that the upper sample represents present conditions while the deeper sample is indicative of water quality conditions at least 100 years ago. In both cores the upper portion of the core had a dark brown color while the lower portions were light brown in color.

Results

In the White Ash Lake the historical diatom community was dominated by planktonic diatoms which are those that float in the open water (Figure 2). The dominance of planktonic diatoms in a shallow lake like White Ash Lake indicates that historically the lake had elevated phosphorus levels which resulted in reduced water clarity that restricted growth of submerged aquatic vegetation (SAV). In North White Ash Lake, another shallow lake, the historical diatom community was dominated by species that grow attached to substrates, e.g. SAV (Figure 3). In this lake planktonic diatoms only comprised about 10 per cent of the historical diatom community. The dominant diatoms were benthic *Fragilaria* such as *Staurosira construens* and *Staurosira construens* var. *venter* which are pictured in Figure 1. These diatoms are typically found in lakes with moderate to higher levels of phosphorus.

In both lakes the proportion of planktonic diatoms is higher in the top sample even though these are shallow lakes. This implies that phosphorus concentrations at the present time are higher than they were historically. In many lakes in northern and north central WI there has been an increase in SAV and only a small increase in phosphorus in recent years. In both White Ash and North White Ash lakes the increase in phosphorus concentration appears to be much greater. The increase in the phosphorus concentration is also indicated by the diatom taxa. In both lakes *Stephanodiscus* increases, especially *S. parvus* (Figures 2 and 3). Many studies have shown that these diatoms are indicative of elevated phosphorus concentrations.

A comparison was made of the diatom communities at the top and bottom of cores from shallow, lakes somewhat similar to the White Ash lakes. This comparison was made using detrended correspondence analysis (DCA). This is a multivariate statistical analysis that determines relative differences in the diatom community between different samples. The farther apart the top/bottom samples plot on the graph, the greater the differences in the diatom communities. This analysis is shown in Figure 4. Some lakes, e.g. Potato, show little difference in the diatom communities between the top and bottom of the cores while others exhibit larger differences. The differences in the study lakes was large indicating a significant change in the water quality of both lakes in recent decades.

Diatom assemblages historically have been used as indicators of nutrient changes in a qualitative way. In recent years, ecologically relevant statistical methods have been developed to infer environmental conditions from diatom assemblages. These methods are based on multivariate ordination and weighted averaging regression and calibration. Ecological preferences of diatom species are determined by relating modern limnological variables to sur-

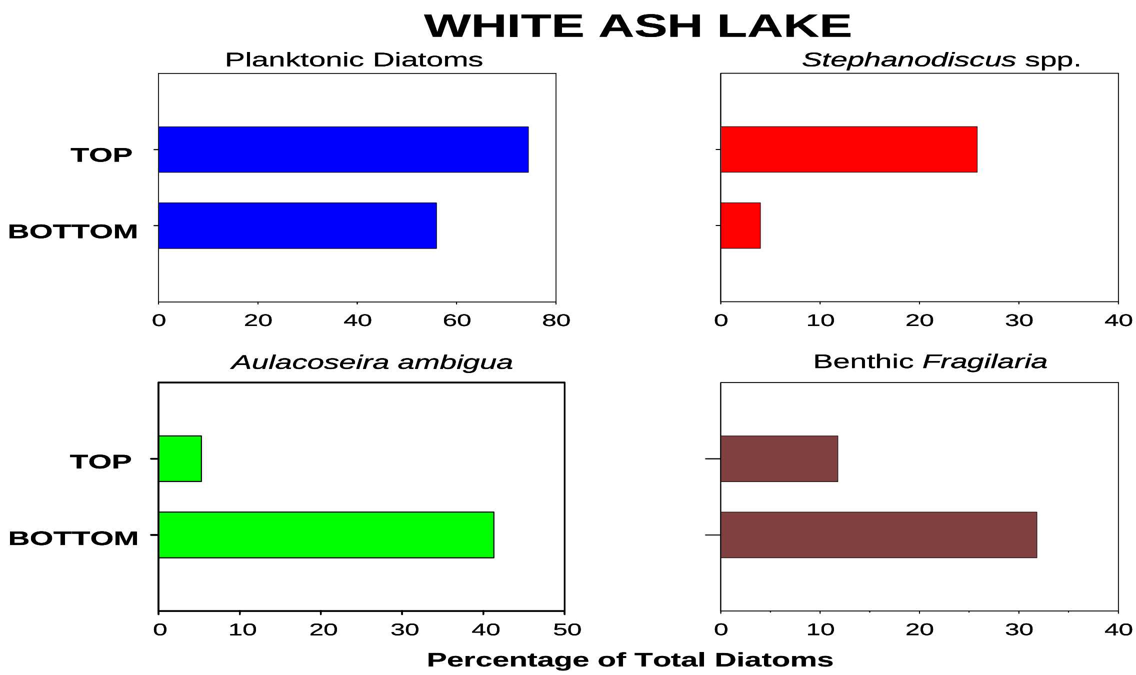

Figure 2. Changes in the abundance of some important diatoms found in the White Ash Lake sediment core. The dominant diatoms were those that float in the open water. The increase in planktonic diatoms in the top sample of this shallow lake, especially *Stephanodiscus*, indicates higher phosphorus levels in the top sample.

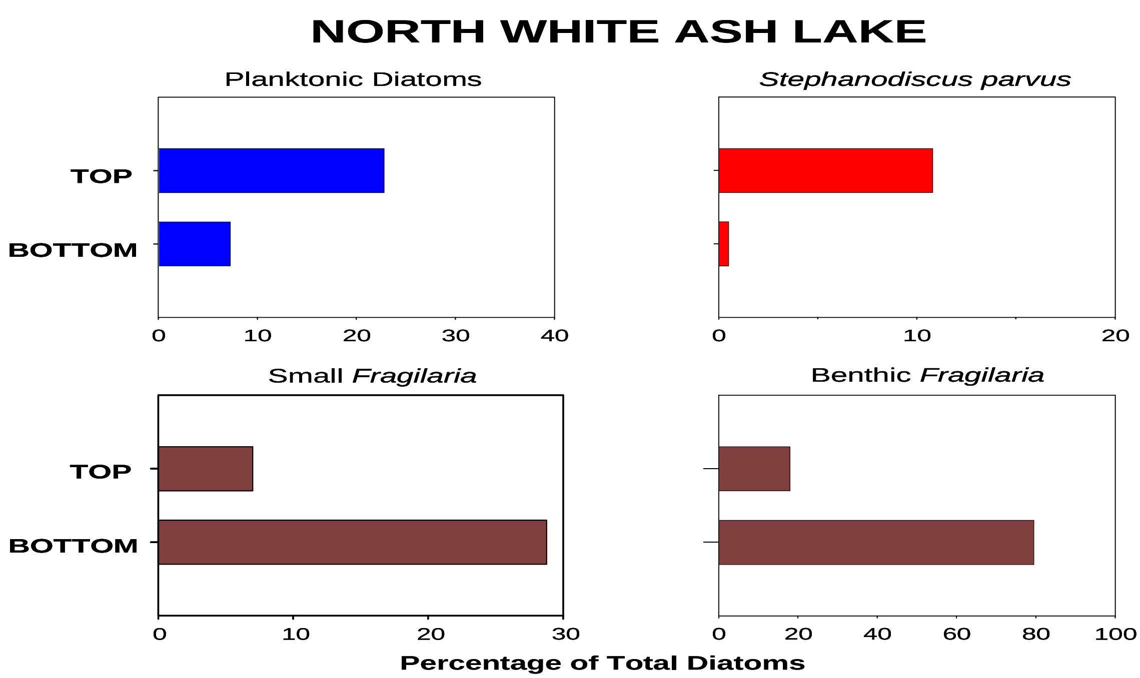

Figure 3. Changes in the abundance of some important diatoms found in the North White Ash Lake sediment core. Historically the dominant diatoms were those attached to substrates, e.g. SAV. The increase in planktonic diatoms in the top sample, especially *S. parvus*, indicates higher phosphorus levels in the top sample.

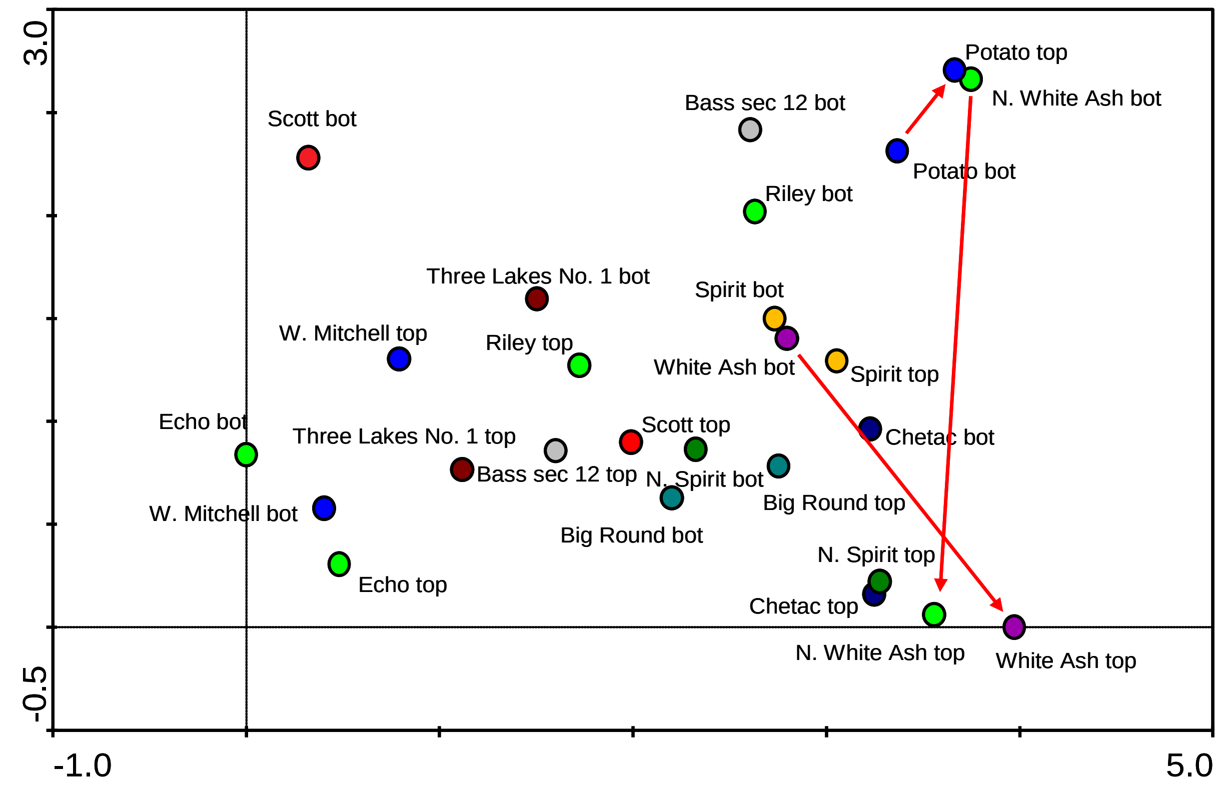

Figure 4. A DCA analysis of top/bottom cores in shallow lakes in northern Wisconsin. This analysis is based upon the diatom community. The closer the samples are, the less change that has occurred in the diatom community. The arrows follow the temporal change in the community. The White Ash lakes have experienced considerable change in their diatom communities from the historical to the present time.

face sediment diatom assemblages. The species-environment relationships are then used to infer environmental conditions from fossil diatom assemblages found in the sediment core.

Such a model was applied to the diatom communities of the White Ash lakes. In both of the lakes the present day phosphorus concentration if significantly higher than it was historically (Table 1). The model indicates that present day concentrations are higher than historical levels. In White Ash Lake the diatom community underestimates the phosphorus at the present time. This lake experiences considerable internal loading during the summer with concentrations in August being much higher than they are earlier in the summer. Because there

Table. 1. Mean summer phosphorus concentrations in the White Ash lakes (µg L^{-1}). The observed value represents the last 5 years in White Ash Lake and 2010 in North White Ash Lake. The concentration for the top and bottom samples were estimated from the diatom community.

	Observed P	Top	Bottom
White Ash	132	80	41
North White Ash	50	56	39

are few diatoms later in the summer because of the high blue-green algal populations, the diatom inferred concentration reflects concentrations in the early part of the summer. In the period 2007— 09 the measured phosphorus levels were close to the diatom estimated value. It is likely that the diatom inferred concentration for the bottom sample is closer to reality as the blue-green algal levels would be lower.

In North White Ash Lake the diatom estimated phosphorus concentration was close to the values measured in 2010. Phosphorus levels in the bottom sample were similar to that estimated for White Ash Lake. It appears that phosphorus concentrations have not increased as much in North White Ash as they have in White Ash Lake. This is likely because most of the flow from the Apple River enters White Ash Lake.

In summary, the diatom community indicates that phosphorus concentrations have increased significantly in both lakes in recent decades. They have increased much more in White Ash Lake. The background phosphorus levels were similar in both lakes at 40 µg L^{-1} but landuse changes in the Apple River watershed have substantially increased the phosphorus export from the watershed. Both of these lakes were naturally eutrophic lakes but the present day trophic level is much higher in White Ash Lake than it is in North White Ash Lake. The increase in phosphorus concentration is much higher than we have measured in most other lakes in northern and north central Wisconsin and is similar with changes observed the southern part of the state where agriculture is a large part of the landuse in the watershed.

WHITE ASH LAKE		
Polk County		
Top (0-1 cm)		
	COUNT TOTAL	
	Number	Prop.
TAXA		
Asterionella formosa Hassal	14	0.035
Aulacoseira ambigua (Grunow) Simonsen	21	0.053
Aulacoseira granulata (Ehrenberg) Simonsen	15	0.038
Aulacoseira italica (Ehrenberg) Simonsen	2	0.005
Cocconeis placentula Ehrenberg	10	0.025
Cocconeis placentula var. euglypta (Ehrenberg) Grunow	3	0.008
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck	1	0.003
Cyclostephanos invisitatus (Hohn et Hellerman) Theriot, Stoermer et Håkansson	11	0.028
Cyclostephanos tholiformis Stoermer, Håkansson et Theriot	102	0.255
Cyclotella meneghiniana Kützing	2	0.005
Discostella woltereckii (Hustedt) Houk et Klee	2	0.005
Eunotia bilunaris (Ehrenberg) Mills	1	0.003
Eunotia minor (Kützing) Grunow	1	0.003
Fragilaria capucina Desmazières	2	0.005
Fragilaria capucina var. gracilis (Østrup) Hustedt	1	0.003
Fragilaria crotonensis Kitton	16	0.040
Fragilaria crotonensis var. oregona Sovereign	11	0.028
Gomphonema minutum (Agardh) Agardh	1	0.003
Gomphonema spp.	1	0.003
Gomphonema truncatum Ehrenberg	1	0.003
Melosira varians Agardh	1	0.003
Navicula cryptocephala Kützing	2	0.005
Navicula minima Grunow	4	0.010
Navicula veneta Kützing	1	0.003
Nitzschia amphibia Grunow	6	0.015
Nitzschia dissipata (Kützing) Grunow	2	0.005
Nitzschia draveillensis Coste et Ricard	3	0.008
Nitzschia frustulum (Kützing) Grunow	1	0.003
Nitzschia recta Hantzsch ex Rabenhorst	1	0.003
Opephora martyi Héribaud	1	0.003
Opephora spp.	1	0.003
Planothidium rostratum (Østrup) Lange-Bertalot	1	0.003
Platessa conspicua (Mayer) Lange-Bertalot	2	0.005
Pseudostaurosira brevistriata (Grunow) Williams et Round	3	0.008
Pseudostaurosira trainorii Morales	1	0.003
Sellaphora americana (Ehrenberg) Mann	2	0.005
Sellaphora pupula (Kützing) Meresckowsky	1	0.003
Staurosira construens Ehrenberg	2	0.005
Staurosira construens var. binodis (Ehrenberg) Hamilton	1	0.003
Staurosira construens var. venter (Ehrenberg) Hamilton	33	0.083
Staurosirella pinnata (Ehrenberg) Williams et Round	2	0.005
Staurosirella pinnata var. lancettula (Schumann) Siver et Hamilton	4	0.010
Staurosirella pinnata var. subrotunda (Mayer) Flower	1	0.003
Stephanodiscus hantzschii fo. tenuis (Hustedt) Håkansson et Stoermer	24	0.060
Stephanodiscus hantzschii Grunow	32	0.080
Stephanodiscus medius Håkansson	2	0.005
Stephanodiscus minutulus (Kützing) Cleve et Möller	1	0.003
Stephanodiscus niagarae Ehrenberg	4	0.010
Stephanodiscus parvus Stoermer et Håkansson	23	0.058
Stephanodiscus vestibulis Håkansson,Theriot et Stoermer	17	0.043
Synedra acus Kützing	1	0.003
Synedra parasitica (Smith) Hustedt	1	0.003
Synedra spp.	1	0.003
unknown pennate	0	0.000
TOTAL	400	1.000

WHITE ASH LAKE		
Polk County		
Bottom (32-35 cm)		
	COUNT TOTAL	
	Number	Prop.
TAXA		
Achnanthidium exiguum (Grunow) Czarnecki	1	0.003
Amphora copulata (Kützing) Schoeman et Archibald	1	0.003
Amphora pediculus (Kützing) Grunow	2	0.005
Asterionella formosa Hassal	13	0.033
Aulacoseira ambigua (Grunow) Simonsen	165	0.413
Aulacoseira granulata (Ehrenberg) Simonsen	7	0.018
Aulacoseira subarctica (Müller) Haworth	1	0.003
Aulacoseira tenella (Nygaard) Simonsen	2	0.005
Cocconeis placentula Ehrenberg	4	0.010
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck	1	0.003
Cyclostephanos invisitatus (Hohn et Hellerman) Theriot, Stoermer et Håkansson	3	0.008
Cyclostephanos tholiformis Stoermer, Håkansson et Theriot	2	0.005
Discostella stelligera (Hustedt) Houk et Klee	3	0.008
Encyonema silesiacum (Bleisch) Mann	1	0.003
Fragilaria capucina Desmazières	7	0.018
Fragilaria capucina var. mesolepta Rabenhorst	1	0.003
Fragilaria crotonensis Kitton	8	0.020
Fragilaria crotonensis var. oregona Sovereign	3	0.008
Fragilaria pinnata var. acuminata Mayer	5	0.013
Fragilaria sepes Ehrenberg	3	0.008
Fragilaria vaucheriae (Kützing) Petersen	3	0.008
Gomphonema minutum (Agardh) Agardh	2	0.005
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin et Witkowski	1	0.003
Navicula cryptocephala Kützing	3	0.008
Navicula minima Grunow	4	0.010
Nitzschia archibaldii Lange-Bertalot	1	0.003
Nitzschia dissipata (Kützing) Grunow	1	0.003
Nitzschia fonticola var. pelagica Hustedt	2	0.005
Opephora martyi Héribaud	3	0.008
Planothidium joursacense (Héribaud) Lange-Bertalot	1	0.003
Pseudostaurosira brevistriata (Grunow) Williams et Round	1	0.003
Pseudostaurosira trainorii Morales	12	0.030
Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	1	0.003
Rhopalodia gibba (Ehrenberg) Müller	1	0.003
Sellaphora disjuncta (Hustedt) Mann	1	0.003
Sellaphora pupula (Kützing) Meresckowsky	1	0.003
Sellaphora seminulum (Grunow) Mann	3	0.008
Staurosira construens Ehrenberg	23	0.058
Staurosira construens var. binodis (Ehrenberg) Hamilton	1	0.003
Staurosira construens var. venter (Ehrenberg) Hamilton	77	0.193
Staurosirella pinnata (Ehrenberg) Williams et Round	5	0.013
Staurosirella pinnata var. subrotunda (Mayer) Flower	3	0.008
Stephanodiscus medius Håkansson	2	0.005
Stephanodiscus niagarae Ehrenberg	1	0.003
Stephanodiscus vestibulis Håkansson,Theriot et Stoermer	13	0.033
Synedra parasitica (Smith) Hustedt	1	0.003
unknown pennate	0	0.000
TOTAL	400	1.000

NORTH WHITE ASH LAKE		
Polk County		
Top (0-1 cm)		
	COUNT TOTAL	
	Number	Prop.
TAXA		
Achnanthidium minutissimum (Kützing) Czarnecki	11	0.028
Amphora copulata (Kützing) Schoeman et Archibald	1	0.003
Amphora pediculus (Kützing) Grunow	10	0.025
Cocconeis placentula Ehrenberg	19	0.048
Cocconeis placentula var. euglypta (Ehrenberg) Grunow	4	0.010
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck	11	0.028
Cocconeis spp.	1	0.003
Cyclostephanos invisitatus (Hohn et Hellerman) Theriot, Stoermer et Håkansson	1	0.003
Cymbella affinis Kützing	2	0.005
Cymbella cistula (Ehrenberg) Kirchner	5	0.013
Encyonema silesiacum (Bleisch) Mann	2	0.005
Epithemia adnata (Kützing) Brébisson	5	0.013
Fragilaria capucina Desmazières	6	0.015
Fragilaria capucina var. mesolepta Rabenhorst	62	0.155
Fragilaria crotonensis Kitton	24	0.060
Fragilaria crotonensis var. oregona Sovereign	6	0.015
Fragilaria sepes Ehrenberg	13	0.033
Fragilaria vaucheriae (Kützing) Petersen	1	0.003
Gomphonema gracile Ehrenberg emend Van Heurck	2	0.005
Gomphonema minutum (Agardh) Agardh	8	0.020
Gomphonema parvulum (Kützing) Kützing	7	0.018
Gomphonema parvulum var. saprophilum Hustedt	1	0.003
Gomphonema sphaerophorum Ehrenberg	3	0.008
Gomphonema subclavatum (Grunow) Grunow	10	0.025
Navicula cryptocephala Kützing	9	0.023
Navicula cryptotenella Lange-Bertalot ex Krammer et Lange-Bertalot	2	0.005
Navicula minima Grunow	6	0.015
Navicula radiosa Kützing	3	0.008
Navicula trivialis Lange-Bertalot	6	0.015
Navicula vitabunda Hustedt	2	0.005
Nitzschia amphibia Grunow	23	0.058
Nitzschia archibaldii Lange-Bertalot	1	0.003
Nitzschia dissipata (Kützing) Grunow	4	0.010
Nitzschia draveillensis Coste et Ricard	4	0.010
Nitzschia incognita Legler et Krasske	2	0.005
Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	1	0.003
Rhopalodia gibba (Ehrenberg) Müller	1	0.003
Staurosira construens Ehrenberg	38	0.095
Staurosira construens var. binodis (Ehrenberg) Hamilton	5	0.013
Staurosira construens var. venter (Ehrenberg) Hamilton	26	0.065
Staurosirella pinnata (Ehrenberg) Williams et Round	2	0.005
Stephanodiscus hantzschii fo. tenuis (Hustedt) Håkansson et Stoermer	1	0.003
Stephanodiscus medius Håkansson	2	0.005
Stephanodiscus minutulus (Kützing) Cleve et Möller	1	0.003
Stephanodiscus parvus Stoermer et Håkansson	43	0.108
Synedra acus Kützing	1	0.003
Synedra spp.	2	0.005
unknown pennate	0	0.000
TOTAL	400	1.000

NORTH WHITE ASH LAKE		
Polk County		
Bottom (48-50 cm)		
	COUNT TOTAL	
	Number	Prop.
TAXA		
Achnanthidium exiguum (Grunow) Czarnecki	2	0.005
Amphora copulata (Kützing) Schoeman et Archibald	1	0.003
Amphora pediculus (Kützing) Grunow	1	0.003
Aulacoseira ambigua (Grunow) Simonsen	19	0.048
Aulacoseira granulata (Ehrenberg) Simonsen	1	0.003
Aulacoseira granulata var. angustissima (Müller) Simonsen	1	0.003
Aulacoseira tenella (Nygaard) Simonsen	3	0.008
Cavinula scutelloides (Smith) Lange-Bertalot et Metzeltin	1	0.003
Cocconeis placentula Ehrenberg	1	0.003
Cocconeis placentula var. euglypta (Ehrenberg) Grunow	1	0.003
Discostella stelligera (Hustedt) Houk et Klee	1	0.003
Fragilaria capucina Desmazières	1	0.003
Fragilaria capucina var. mesolepta Rabenhorst	5	0.013
Fragilaria capucina var. rumpens (Kützing) Lange-Bertalot	1	0.003
Fragilaria crotonensis Kitton	2	0.005
Fragilaria pinnata var. acuminata Mayer	1	0.003
Geissleria acceptata (Hustedt) Lange-Bertalot et Metzeltin	2	0.005
Gomphonema minutum (Agardh) Agardh	1	0.003
Navicula minima Grunow	1	0.003
Navicula pseudoventralis Hustedt	2	0.005
Navicula radiosa Kützing	1	0.003
Navicula vitabunda Hustedt	14	0.035
Nitzschia amphibia Grunow	2	0.005
Opephora martyi Héribaud	3	0.008
Planothidium joursacense (Héribaud) Lange-Bertalot	4	0.010
Planothidium rostratum (Østrup) Lange-Bertalot	3	0.008
Platessa conspicua (Mayer) Lange-Bertalot	2	0.005
Pseudostaurosira brevistriata (Grunow) Williams et Round	8	0.020
Pseudostaurosira trainorii Morales	3	0.008
Staurosira construens Ehrenberg	194	0.485
Staurosira construens var. venter (Ehrenberg) Hamilton	76	0.190
Staurosirella pinnata (Ehrenberg) Williams et Round	36	0.090
Stephanodiscus niagarae Ehrenberg	1	0.003
Stephanodiscus parvus Stoermer et Håkansson	2	0.005
Stephanodiscus vestibulis Håkansson,Theriot et Stoermer	2	0.005
Synedra spp.	1	0.003
unknown pennate	0	0.000
TOTAL	400	1.000