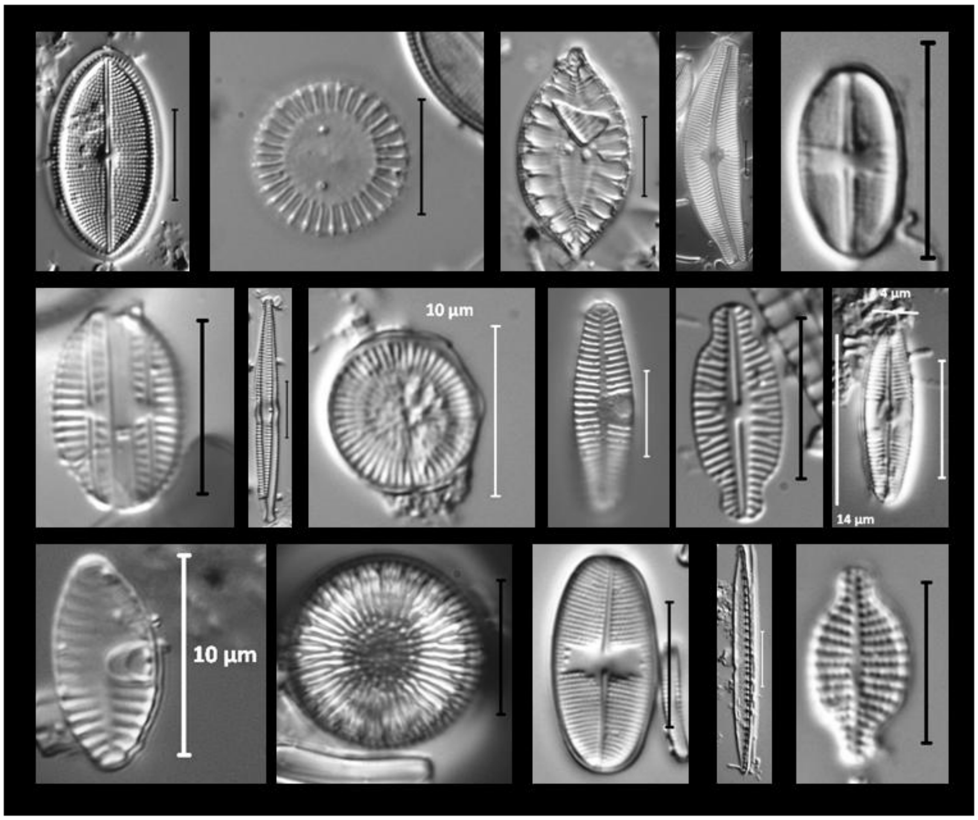
Exploring the Factors Contributing to Changes in Diatom Taxa Assemblages under Varying Enrichment Conditions in CT Freshwater Streams (2010 – 2012)



All diatom images are taxa collected as part of this project and taken by the Phycology Section, Patrick Center for Environmental Research, The Academy of Natural Sciences of Drexel University

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Connecticut Conservation Districts

Connecticut Department of ENERGY & ENVIRONMENTAL PROTECTION

INTRODUCTION

In recent years, the U.S. Environmental Protection Agency (EPA) has identified 'cultural eutrophication' as one of the primary factors resulting in impairment of U.S. surface waters. Eutrophication is the process which leads to an increase in the level of primary production or biomass occurring within a water body. Eutrophication is a slow natural process that occurs within a water body, but human activity can greatly speed up the process primarily through the addition of excess nutrients. Cultural eutrophication is described as human-caused acceleration of eutrophication through excess nutrients in water bodies. Cultural eutrophication causes harmful effects on water bodies such as fish kills, reduction of dissolved oxygen and pH values, and loss of diversity or changes in community structure in aquatic plant, invertebrate and fish communities. Cultural eutrophication is a serious threat to water quality in Connecticut and is also one of the most pressing water quality issues facing the nation. EPA is encouraging all states to develop strategies to reduce nutrient pollution and adopt numeric nutrient criteria into their water quality standards (WQS) to address impairments caused by cultural eutrophication. This purpose of this project is to support the Connecticut Department of Energy and Environmental Protection's (CT DEEP) implementation of ongoing nutrient management efforts to protect aquatic life in freshwater wadeable rivers and streams.

The difficulty in measuring eutrophication directly is that the effects can vary over time and space. Primary producers in streams include photosynthesizing organisms such as algae and macrophytes. The biomass of primary producers may vary greatly throughout a season, from year to year and from one stream reach to another. This variation may result from changes in light availability, temperature and grazer activity. Several studies (Potapova et al. 2004; Potapova & Charles 2007; Smucker et al. 2013; Stevenson 2006) have shown that algal species composition provide a reliable indicator of trophic status in rivers and streams. Specifically diatoms, a collection of microalgae in the Bacillariophyta group, are widely recognized and used as indicators of river and stream water quality (Stevenson & Pan 1999). Several state agencies have evaluated the use of diatom trophic indices to aid in the development of nutrient criteria (Ponader et al. 2007; Danielson 2009). Diatom composition has also been used extensively in Europe as a measure of trophic conditions (Kelly et al. 1998). Stevenson (2006) and Lavoie et al. (2008) found that species composition of diatoms is more likely to reflect actual stream conditions than assessment of water chemistry or algal biomass because they integrate the effects of stressors over time and space.

CT DEEP collected benthic algae community data from 2002 – 2004 and found significant changes in community composition corresponded to the input of excess nutrients (Becker & Stacey, In Prep). CT DEEP used this information to implement a strategy to support phosphorus discharge permitting under the National Pollutant Discharge Elimination System (NPDES) program that is consistent with Clean Water Act requirements and CT WQS narrative standards for nutrients. These methods focus on phosphorus because it is often found to be the primary limiting nutrient in freshwater systems. These methods were approved by the EPA Region 1 in their letter dated October 26, 2010 as an interim strategy to establish water quality based phosphorus limits in non-tidal freshwater for industrial and municipal waste water treatment plant (WWTP) NPDES permits.

This project augmented the current CT Ambient Biological Monitoring (ABM) program by incorporating the collection of a third biological community, benthic algae, in combination with the collection of chemical and habitat samples to better support the Department's nutrient management efforts. Benthic algae communities have only been collected intermittently as part of past grant projects. Since the development of the ABM program in the late 1970s, CT DEEP traditionally collects and evaluates macro-invertebrate and fish communities to assess aquatic life uses in wadeable rivers and streams. However, algal communities respond more directly to nutrients than macro-invertebrate or fish communities and therefore are likely to provide a better indicator of nutrient stress in streams.

Data collected under this project will be used as part of ongoing research to establish a better understanding of aquatic life response to varying trophic conditions in CT. This understanding will help refine development of water quality criteria, reinforce achievement of aquatic life use goals in all freshwater rivers and streams in CT and assist in guiding any necessary refinements to the Department's current methodology to ensure that aquatic life uses are fully attained. This project was partially supported by EPA 104(B) and 604(B) grant funding.

STUDY AREA AND SAMPLING

Algae were collected from natural substrates for the collection of eplithic diatoms. Eplithic diatoms grow on hard relatively inert substrate that are typically bigger than most algae, such as gravel, pebble, cobble and boulder (Stevenson et al. 1996). Eplithic diatoms were collected by scraping periphyton off of cobble-sized rocks or small boulders in wadeable riffle or run sections of the stream. Periphyton is a complex mixture of microscopic algae (including diatoms), bacteria and fungi that grows on the bottom substrate of a river or stream. CT DEEP conducted 100 periphyton surveys at 87 sites across the State generally in June and July in 2010, 2011 and 2012 (Figure 1). One site was sampled in August due to extreme flow conditions during the summer of 2011. 8 sites were sampled in multiple years. 28 samples were collected in 2010, 36 in 2011 and 36 in 2012 (Table 1).

Table 1: Description of Sites Sampled in 2010, 2011 and 2012.

Station ID	Stream name	Landmark	Town	Year Sampled
22	Broad Brook	upstream USGS gage at Route 191	EAST WINDSOR	2010
28	Coginchaug River	downstream Route 66	MIDDLETOWN	2010
49	East Branch Eightmile River	100 meters upstream Mouth downstream Route 156	LYME	2011
54	East Branch Naugatuck River	downstream Franklin Drive	TORRINGTON	2010
77	Five Mile River	under Old Norwalk Road	NEW CANAAN	2011
81	French River	adjacent Route 12	THOMPSON	2011
101	Harbor Brook	upstream Coe Road	MERIDEN	2011
116	Hockanum River	upstream Dart Hill Road	VERNON	2012
122	Hollenbeck River	at Cobble Road	CANAAN	2011
153	Little River	upstream Bushell Hollow Road Route 138	SPRAGUE	2010
163	Mattabesset River	downstream Berlin Street	CROMWELL	2010
192	Naugatuck River	behind Fire Station	BEACON FALLS	2010/2011/2012
236	Norwalk River	upstream Perry Avenue	NORWALK	2010
237	Ridgefield Brook	upstream Route 35 near old pierce road	RIDGEFIELD	2011
252	Pattaconk Brook	first crossing Route 148 downstream Route 9	CHESTER	2012
267	Pequabuck River	adjacent USGS Gage upstream of Central Avenue	BRISTOL	2010/2011/2012
272	Piper Brook	upstream Main Street	NEWINGTON	2012
285	Quinebaug River	upstream Route 197	THOMPSON	2010/2012
288	Quinnipiac River	downstream small dam behind water company building on Syndall Street	CHESHIRE	2012
289	Quinnipiac River	adjacent Route 15 USGS gauge	WALLINGFORD	2010/2012
311	Salmon Brook	upstream House Road	GLASTONBURY	2012
316	Salmon River	downstream 0.7 miles RR bridge	COLCHESTER	2010/2011/2012
317	Sandy Brook	opposite Grange Hall off Riverton Road	COLEBROOK	2010/2011/2012
319	Saugatuck River	downstream Route 107 & Route 53 Junction	REDDING	2010/2011
325	Shepaug River	downstream 100 meters Wellers Bridge Road (Route 67)	ROXBURY	2010/2011/2012

Station ID	Stream name	Landmark	Town	Year Sampled
326	Shetucket River	downstream Plains Road adjacent to USGS gauge	WINDHAM	2011
333	Still River	under Route 7 overpass adjacent to Gray's Bridge Road	BROOKFIELD	2010
345	Tankerhoosen River	upstream Tunnel Road	VERNON	2012
357	West Branch Naugatuck River	downstream Route 4	TORRINGTON	2010
359	West Branch Salmon Brook	upstream 50 meters Barndoor Road	GRANBY	2010
395	Factory Brook	upstream Salmonkill Road	SALISBURY	2011
458	Willimantic River	downstream Stafford POTW	WILLINGTON	2010
462	Roaring Brook	at Route 32	WILLINGTON	2011
469	Mount Hope River	upstream 50 m Elizabeth Road	MANSFIELD	2011
472	Moosup River	adjacent Route 14 one way (east)	PLAINFIELD	2010
480	Merrick Brook	at Station Road	SCOTLAND	2011
554	Sasco Brook	Downstream Hulls Farm Road	WESTPORT	2010
556	French River	at Main Street (Red Bridge Road)	THOMPSON	2012
606	Green Fall River	upstream confluence with Wyassup Bk US Clarks Fall Rd.	NORTH STONINGTON	2011
622	Yantic River	upstream West Town Street adjacent to Connecticut Avenue	NORWICH	2010
741	FARMINGTON RIVER	100 meters upstream Steele bridge on Town Bridge Road	CANTON	2010
923	Mill River	at first pull-off DS Tuttle Road	HAMDEN	2010
997	Muddy River	at end of Old Maple Street (DS of RR bridge)	NORTH HAVEN	2011
1062	Little River	behind #145 Pomfret Street (Medical offices) US of Route 44 crossing	PUTNAM	2011
1081	Roaring Brook	upstream footbridge Lions pool 300 meters US Cottage St.	FARMINGTON	2012
1239	Burnhams Brook	at Mouth	EAST HADDAM	2012
1331	Little Brook	at mouth near wethersfield road	BERLIN	2012
1338	Belcher Brook	at meadow lane	BERLIN	2012
1412	Quinnipiac River	downstream West Center Street	SOUTHINGTON	2012
1469	Leadmine Brook	downstream enter near #781 south road, 400 m from south road bridge	THOMASTON	2011
1513	Cherry Brook	upstream Route 44	CANTON	2011
1648	West Branch Salmon Brook	adjacent Route 20 and Simsbury Road intersection	GRANBY	2012
1744	West Branch Farmington River	at Route 20 (USGS gage) Riverton	BARKHAMSTED	2011
1748	PENDLETON HILL BROOK	Upstream Grindstone Hill Road PENDLETON HILL BROOK NEAR CLARKS FALLS	NORTH STONINGTON	2010
1789	Farmington River	at Satan's Kingdom Tubing Shuttle bus pick up	CANTON	2012
1853	Pond Meadow Brook	upstream confluence with Chatfield Hollow Brook at hiking trail crossing	KILLINGWORTH	2011
1916	Thompson Brook	at Bike Path Crossing (Old RR grade)	AVON	2012
2243	Farmington River	between Route 189 and old bridge tressells (in town park)	SIMSBURY	2011
2288	Guinea Brook	downstream West Woods Road #2 at USGS gage	SHARON	2011
2295	Mott Hill Brook	off Hunt Ridge Drive at Private Drive for houses # 107-109	GLASTONBURY	2011
2297	Hemlock Valley Brook	at Bone Mill Road	EAST HADDAM	2010
2299	Rugg Brook	US first road crossing from reservoir at #224 Old Waterbury Turnpike	WINCHESTER	2011
2306	Flat Brook	at Route 16	EAST HAMPTON	2011
2307	Early Brook	at Haywardville Road	EAST HADDAM	2012

Station ID	Stream name	Landmark	Town	Year Sampled
2312	Jakes Brook	at Route 272	TORRINGTON	2011
2334	Chatfield Hollow Brook	at Mouth on River Road	MADISON	2010
2342	Brown Brook	at Route 63	CANAAN	2010
2346	Little River	at Newtown Turnpyke	REDDING	2011
2457	West Branch Farmington River	at Blacks Bridge Road	NEW HARTFORD	2012
2478	West Branch Farmington River	adjacent # 500 Hogsback Road	HARTLAND	2012
2652	Reservoir Brook	between Route 17 and Wilcox Hill Road	PORTLAND	2012
2676	Nonewaug River	at USGS gage adjacent to route 6	WOODBURY	2011
2711	Bunnell Brook	upstream diversion for swimming area at recreation area at vineyard rd and clear brook rd	BURLINGTON	2010
2726	Beaver Brook	adjacent to park road downstream of crossing	BARKHAMSTED	2012
2728	Hurricane Brook	adjacent to Hurricane Brook road	HARTLAND	2011
2741	North Branch Park River	at Sunny Reach Drive	BLOOMFIELD	2011
2781	Fawn Brook	Downstream Route 66	HEBRON	2012
5064	BIBLE ROCK BROOK	Off Brainard Hill Rd E of Jct with Oxbow Rd	HADDAM	2012
5318	HOWELL'S BROOK	DS of JCT of Mill St and Pond Hill Rd.	HARTLAND	2012
5406	MILL CREEK	Parallel to Park Road	HADDAM	2012
5849	Cherry Brook	at West Road Bridge	CANTON	2012
6009	Negro Hill Brook	at Route 69 Sessions Woods WMA	BURLINGTON	2012
6114	West Branch Farmington River	upstream Henry Buck trail head	BARKHAMSTED	2012
6135	Lydall Brook	at Ambassador Drive	MANCHESTER	2012
6148	Day Meadow Brook	Crossing at River Rd. near cemetary	COLCHESTER	2012
6185	Haleys Brook	DS Packer Road in gorge area	GROTON	2011
6226	Jacks Brook	at South Street	ROXBURY	2011

At each site, 5 rocks were randomly selected throughout a 150 m stream reach in riffle and run areas. Periphyton was removed from the entire top surface area of each rock and composited into one sample. The sample was preserved and sent to EcoAnalysts, Inc. laboratory for diatom taxonomic identification in 2010 and 2011 and The Academy of Natural Sciences of Drexel University phycology laboratory in 2012. Diatom samples were processed using acid to remove organic material before mounting on slides using NAPHRAX™. Diatoms were identified to the lowest practical taxonomic level, typically species, and at least 600 valves were enumerated per sample unless the sample contained less than 600 valves.

At each site, a surface water chemistry sample was also collected and sent to the University Of Connecticut Center for Environmental Sciences and Engineering laboratory for analysis. Nitrogen was determined as NO2 + NO3 (subsequently referred to as NOx) using a cadmium reduction technique and an autoanalyzer for colorimetric measurements (EPA method 353.2). Total phosphorus was determined using the colorimetric EPA methods 365.1 and 365.4, which used persulfate and acid digestion. Turbidity was determined by nephelometry using EPA method 180.1. 11 samples were not analyzed for chemistry in 2011 due to accidental contamination while being stored for transport to the laboratory. Field replicates were collected for both diatom and chemistry samples to adhere to quality control procedures.

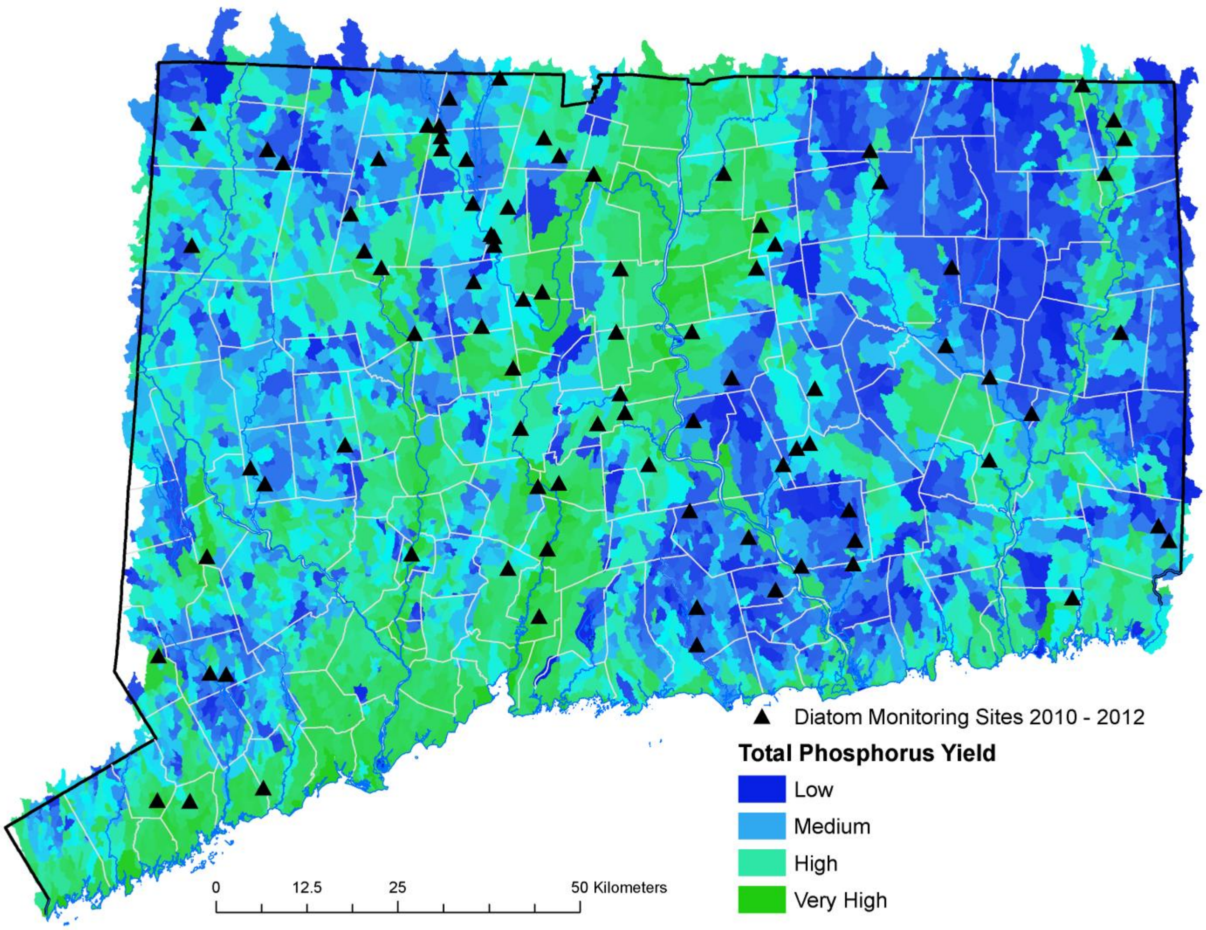

Figure 1: Locations of Diatom Monitoring Sites 2010 - 2012 and estimate phosphorus yields using USGS SPARROW model (Moore 2011).

All sampling was conducted according to EPA approved quality assurance project plans (QAPPs). For further information on sampling and site selection see referenced QAPPs (Becker 2010; 2011; 2012).

EXPLORATORY DATA ANALYSIS AND DISCUSSION

Eighty-eight chemistry samples were collected over the three year period (Table 2). The pH ranged from 3.8 in Hurricane Brook (SID 2728) to 8.1 in Mill River (SID 923). Total Nitrogen ranged from 0.112 mg/L in Hurricane Brook (SID 2728) to 4.02 in Broad Brook (SID 22). Total Phosphorus ranged from 0.001 mg/L in Reservoir Brook (SID 2652) to 0.996 mg/L in the Naugatuck River (SID 192, Yr 2010). Turbidity ranged from 0.3 NTU in Reservoir Brook (SID 2652) to 9.1 in the Mattabesset River (SID 163).

Table 2: Water chemistry samples collected and analyzed at the same time as diatom sampling (2010 - 2012).

Station ID	Stream Name	Year Sampled	pH	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Turbidity (NTU)
22	Broad Brook	2010	7.8	4.02	0.118	3.6
28	Coginchaug River	2010	7.8	0.68	0.084	3.6
49	East Branch Eightmile River	2011	7.1	0.297	0.014	1.1
54	East Branch Naugatuck River	2010	7.2	0.467	0.026	1.9
77	Five Mile River	2011	7.6	1.306	0.076	1.9
101	Harbor Brook	2011	7.8	1.318	0.064	8.3
116	Hockanum River	2012	6.9	1.71	0.253	1
122	Hollenbeck River	2011	7.6	0.269	0.017	2.9
153	Little River	2010	7.3	0.389	0.012	2.2
163	Mattabesset River	2010	7.6	0.971	0.073	9.1
192	Naugatuck River	2010	7.2	1.431	0.996	1.5
192	Naugatuck River	2011	7.3	1.23	0.788	1.3
192	Naugatuck River	2012	6.9	0.765	0.336	1.4
236	Norwalk River	2010	8	0.861	0.032	1.7
237	Ridgefield Brook	2011	7.8	0.792	0.105	5.3
252	Pattaconk Brook	2012	6.5	0.284	0.029	3.3
267	Pequabuck River	2010	7.4	3.244	0.665	1.2
267	Pequabuck River	2012	7.5	1.89	0.497	0.9
272	Piper Brook	2012	7.5	0.969	0.016	0.9
285	Quinebaug River	2010	7.1	0.589	0.026	2.2
285	Quinebaug River	2012	6.7	0.476	0.031	3.7
288	Quinnipiac River	2012	7.6	1.28	0.192	1.2
289	Quinnipiac River	2010	7.5	2.699	0.391	3.9
289	Quinnipiac River	2012	7.5	1.19	0.115	1.1
311	Salmon Brook	2012	7.35	1.635	0.0075	1.15
316	Salmon River	2010	6.8	0.336	0.011	2.1
316	Salmon River	2011	7.1	0.367	0.015	1.6
316	Salmon River	2012	6.9	0.384	0.027	2.1
317	Sandy Brook	2010	7.3	0.273	0.008	0.5
317	Sandy Brook	2011	7.4	0.219	0.015	1.7
317	Sandy Brook	2012	7.2	0.352	0.014	1.1
319	Saugatuck River	2010	8	0.351	0.027	1.4
319	Saugatuck River	2011	7.5	0.425	0.026	2.8
325	Shepaug River	2010	7.3	0.357	0.0305	1.8
325	Shepaug River	2011	7.5	0.274	0.019	2.6
325	Shepaug River	2012	6.8	0.348	0.033	1.2

Station ID	Stream Name	Year Sampled	pH	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Turbidity (NTU)
326	Shetucket River	2011	7.1	0.568	0.045	1.6
333	Still River	2010	7.8	1.835	0.134	1.7
345	Tankerhoosen River	2012	6.9	0.622	0.001	2.1
357	West Branch Naugatuck River	2010	6.9	0.236	0.014	1
359	West Branch Salmon Brook	2010	6.9	0.466	0.01	0.3
395	Factory Brook	2011	7.7	0.833	0.099	3.2
458	Willimantic River	2010	7.1	0.963	0.025	1.8
472	Moosup River	2010	6.8	0.487	0.019	1.3
554	Sasco Brook	2010	7	0.98	0.036	0.8
556	French River	2012	6.9	1.1	0.034	2.4
622	Yantic River	2010	7.1	0.804	0.032	2.4
741	FARMINGTON RIVER	2010	6.6	0.252	0.012	0.6
923	Mill River	2010	8.1	1.25	0.036	2.3
997	Muddy River	2011	7.9	1.643	0.044	2.9
1081	Roaring Brook	2012	7	0.585	0.035	2
1239	Burnhams Brook	2012	6.3	0.286	0.014	1.6
1331	Little Brook	2012	7.3	1.05	0.029	1
1338	Belcher Brook	2012	7.6	0.868	0.011	0.9
1412	Quinnipiac River	2012	7.5	1.06	0.036	1.3
1513	Cherry Brook	2011	6.9	0.4575	0.0105	0.6
1648	West Branch Salmon Brook	2012	6.65	0.39	0.0145	0.65
1744	West Branch Farmington River	2011	4.7	0.207	0.008	0.6
1748	PENDLETON HILL BROOK	2010	6.5	0.5175	0.0255	1.45
1789	Farmington River	2012	7	0.335	0.014	0.8
1853	Pond Meadow Brook	2011	7.1	0.484	0.022	1.7
1916	Thompson Brook	2012	7.1	1.73	0.029	2.9
2243	Farmington River	2011	7.1	0.753	0.067	1.7
2288	Guinea Brook	2011	7.7	0.327	0.012	1.1
2295	Mott Hill Brook	2011	6.75	0.5875	0.0125	0.65
2297	Hemlock Valley Brook	2010	6.8	0.36	0.013	2.8
2306	Flat Brook	2011	6.8	0.338	0.041	3.8
2307	Early Brook	2012	6.25	0.3005	0.015	1.5
2312	Jakes Brook	2011	7.5	0.162	0.008	0.9
2334	Chatfield Hollow Brook	2010	6.7	0.262	0.014	1.4
2342	Brown Brook	2010	7	0.281	0.0155	1
2346	Little River	2011	7.1	0.383	0.016	1
2457	West Branch Farmington River	2012	6.7	0.327	0.01	0.7
2478	West Branch Farmington River	2012	6.8	0.306	0.016	0.4
2652	Reservoir Brook	2012	6.8	0.411	0.001	0.3
2676	Nonewaug River	2011	7.2	0.85	0.038	1.1
2711	Bunnell Brook	2010	7.2	0.522	0.009	0.6
2726	Beaver Brook	2012	6.6	0.434	0.015	1
2728	Hurricane Brook	2011	3.8	0.112	0.007	0.3
2781	Fawn Brook	2012	7	0.351	0.056	2.9
5064	BIBLE ROCK BROOK	2012	6.5	0.248	0.027	3.8
5318	HOWELL'S BROOK	2012	6.4	0.399	0.018	0.9
5406	MILL CREEK	2012	6.3	0.256	0.029	3.7
5849	Cherry Brook	2012	6.8	0.312	0.024	2.2
6009	Negro Hill Brook	2012	6.2	0.153	0.017	2.7
6114	West Branch Farmington River	2012	6.8	0.329	0.014	0.75
6135	Lydall Brook	2012	6.8	0.721	0.001	1.5
6226	Jacks Brook	2011	7.2	0.371	0.011	0.8

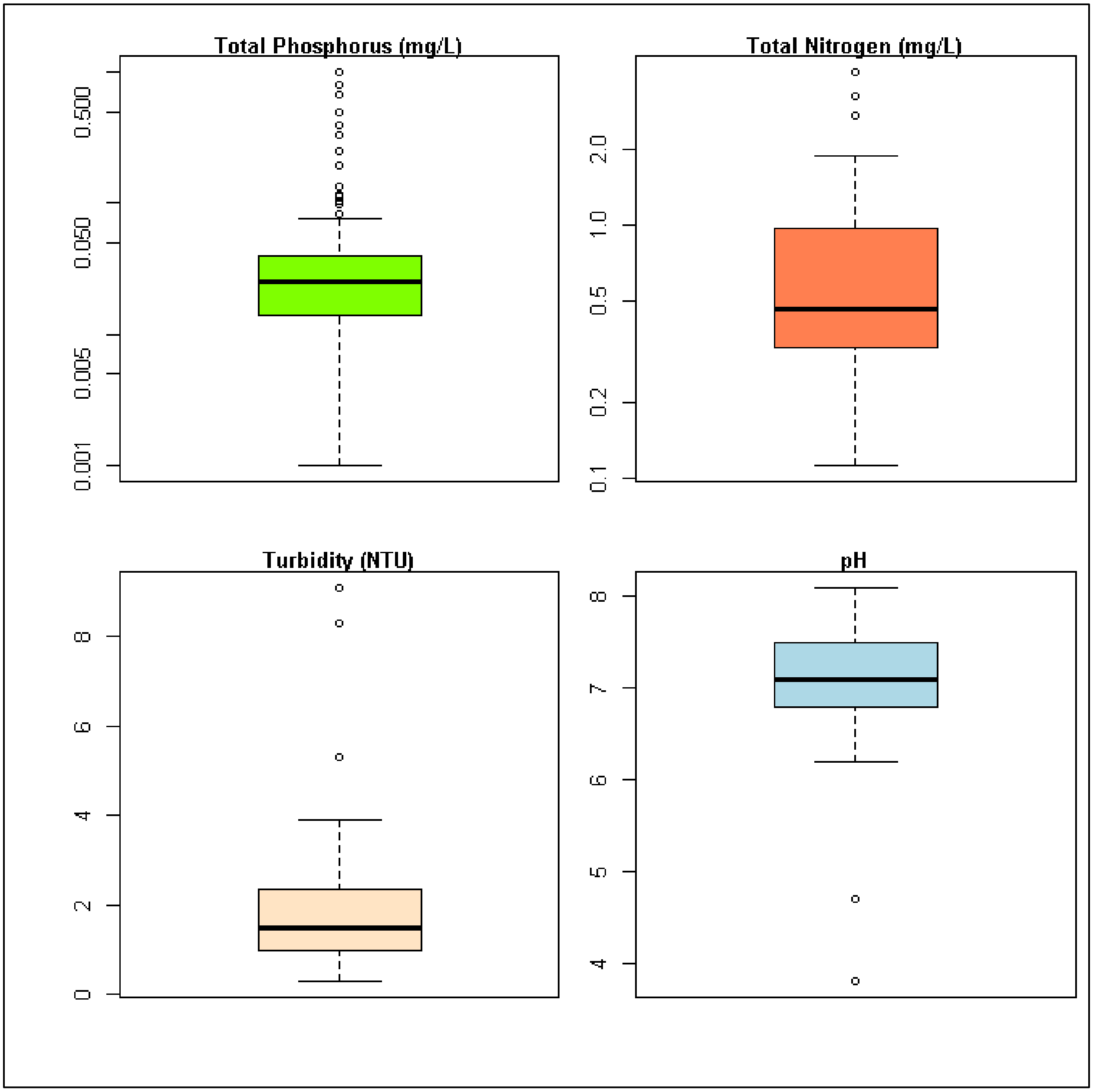

Figure 2: Boxplots of water chemistry ranges observed in samples collected at the same time as diatom sample collection 2010 - 2012

The values in this study (Figure 2) were generally in the same range as those observed in 5-year statewide monitoring study conducted from 2006 – 2010 that included 963 samples collected under ambient conditions (CT DEEP 2011) and approximated similar percentile statistics (Table 3).

Table 3: Comparison of select descriptive statistics for total phosphorus samples collected in this study (n=88) and a state-wide study conducted from 2006 - 2010 (n=963) (CT DEEP 2011).

Statistic	Statewide (n=963)	This Study (n=88)
Count (n)	963	88
25th Percentile	0.012	0.014
50th Percentile (Median)	0.021	0.025
75th Percentile	0.043	0.039
Mean	0.06	0.074

322 diatom taxa were identified in the 2010 – 2012 samples. Only 142 occurred in 5 or more samples (5% of all samples). *Achnanthidium minutissimum* (Kützing) Czarnecki had the highest occurrence appearing in 98% of the samples collected followed by *Gomphonema parvulum* (Kützing) Kützing and *Encyonema minutum* (Hilse) Mann which occurred in 68 and 64 percent of the samples, respectively.

For exploratory purposes, the samples with both diatom data and phosphorus data were divided into three groups of high, medium and low phosphorus levels. A subset of 88 samples included both diatom taxa data and total phosphorus data. The groupings were chosen based on a recent study conducted in CT evaluating biological responses of diatoms to phosphorus (Smucker et al. 2013). Smucker et al. (2013) found that sensitive diatom taxa steeply declined above 0.02 mg/L total phosphorus and were often lost above 0.065 mg/L. Tolerant taxa also steeply increased above 0.065 mg/L. Therefore, 'low' phosphorus levels were characterized as less than or equal to 0.02 mg/l, 'medium' levels were characterized as greater than 0.02 mg/l to 0.065 mg/L, and 'high' levels were characterized as greater than 0.065 mg/L. There were 41 samples in the 'low' group, 30 samples in the 'medium' group and 17 samples in the 'high' group. Sixteen out of the 17 sample sites in the high phosphorus group are waste-receiving streams that contain sewage treatment plant discharges. The subset of 88 samples included 309 diatom taxa in the dataset. One hundred and ninety-eight taxa occurred in less than 5 samples were eliminated for further analysis purposes. This resulted in a dataset that contained 120 diatom taxa.

Indicator species analysis (Dufrene & Legendre 1997) was used to describe the diatom taxa found in each phosphorus level grouping (McCune & Grace 2002). Indicator species analysis detects and describes taxa differences among groups of sites. Indicator species analysis combines a measure of species exclusiveness in a particular group and a measure of faithfulness to a particular group. Indicator values range from 0 (no indication) to 1 (perfect indication). Perfect indication means that a species is always present (faithful) in a particular group and never occurs in any of the other groups (exclusive). The statistical significance of the indicator values (IV) are determined through a Monte Carlo method that randomly reassigns sites to different groups and calculates the probability of a type 1 error that the IV from the randomized data set equals or exceeds the IV from the actual data set. For this analysis 1000 randomizations were used in the Monte Carlo test and p-values < 0.1 were considered significant. Computations were performed using R version 2.15.0 (R Development Core Team, 2012) using the stats version 2.15 package, vegan version 2.0-3 package and labdsv version 1.5-0.

Indicator species analysis assigns each taxa with a group of maximum association, meaning it is most indicative of that particular grouping. Four taxa were significantly associated with the low phosphorus grouping, 1 taxon was significantly associated with the medium phosphorus grouping and 30 taxa were significantly associated with the high phosphorus grouping (Table 4). *Achnanthidium minutissimum* (Kützing) Czarnecki had the highest indicator value in the low phosphorus grouping, *Rossithidium pusillum* (Grunow) Round et Bukhtiyarova had the highest indicator value in the medium group, and *Nitzschia inconspicua* Grunow had the highest indicator value in the high group.

Table 4: Results from the indicator species analysis including the maximum associated group, indicator values, *p*-value and relative abundance in each phosphorus group. Larger indicator values indicate a greater association with a particular diatom group.

Taxa	Max Phosphorus Group	Indicator Value	*p*-value	Relative Abundance in Each Phosphorus Group		
				Low	Medium	High
Achnanthidium minutissimum (Kützing) Czarnecki	Low	0.5	0.003	0.5	0.38	0.13
Fragilaria capucina Desmazières	Low	0.35	0.143	0.53	0.33	0.14
Tabellaria flocculosa (Roth) Kützing	Low	0.3	0.054	0.87	0.12	0.01
Gomphonema sp.	Low	0.29	0.08	0.65	0.15	0.19
Ulnaria ulna (Nitzsch) Compére	Low	0.29	0.267	0.53	0.33	0.14
Encyonema minutum (Hilse in Rabenhorst) Mann in Round, Crawford and Mann	Low	0.28	0.529	0.4	0.22	0.38
Fragilaria sp.	Low	0.25	0.178	0.65	0.17	0.18
Achnanthes sp.	Low	0.24	0.686	0.42	0.4	0.18
Encyonema silesiacum (Bleisch in Rabenhorst) Mann in Round, Crawford and Mann	Low	0.24	0.411	0.44	0.42	0.15
Diatoma moniliformis Kützing	Low	0.19	0.274	0.76	0.21	0.03

Taxa	Max Phosphorus Group	Indicator Value	*p*-value	Relative Abundance in Each Phosphorus Group		
				Low	Medium	High
Rossithidium pusillum (Grunow) Round et Bukhtiyarova	Low	0.18	0.05	0.72	0.28	0
Cymbella tumida (Brébisson ex Kützing) Van Heurck	Low	0.17	0.193	0.59	0.41	0
Eunotia exigua (Brébisson in Kützing) Rabenhorst	Low	0.16	0.26	0.97	0.03	0.01
Eunotia incisa Smith ex Gregory	Low	0.16	0.201	0.73	0.27	0
Achnanthidium minutissimum var. gracillima (Meister) Bukhtiyarova	Low	0.14	0.266	0.82	0.13	0.05
Cymbella sp. 1 ?	Low	0.14	0.453	0.54	0.36	0.1
Fragilaria rhabdosoma Ehrenberg	Low	0.13	0.436	0.52	0.33	0.15
Eunotia sp.	Low	0.12	0.563	0.54	0.42	0.04
Fragilaria crotonensis Kitton	Low	0.12	0.476	0.62	0.38	0
Pinnularia sp.	Low	0.11	0.383	0.5	0.16	0.34
Eucocconeis laevis (Østrup) Lange-Bertalot in Lange-Bertalot and Genkal	Low	0.1	0.314	0.56	0.12	0.32
Diatoma tenuis Agardh	Low	0.08	0.449	0.67	0.27	0.06
Gomphonema gracile Ehrenberg	Low	0.08	0.32	0.63	0.37	0
Reimeria uniseriata Sala, Guerrero et Ferrario	Low	0.08	0.536	0.8	0.09	0.12
Synedra sp.	Low	0.08	0.32	0.58	0.42	0
Tabellaria fenestrata (Lyngbye) Kützing	Low	0.08	0.604	0.55	0.41	0.04
Eunotia bilunaris (Ehrenberg) Souza in Souza and Moreira-Filho	Low	0.07	0.785	0.49	0.43	0.07
Navicula trivialis Lange-Bertalot	Low	0.07	0.913	0.34	0.39	0.27
Puncticulata radiosa (Lemmermann) Håkansson	Low	0.07	0.29	0.73	0.09	0.18
Karayevia laterostrata (Hustedt) Bukhtiyarova	Low	0.06	0.614	0.57	0.2	0.24
Lemnicola hungarica (Grunow) Round et Basson	Low	0.06	0.543	0.83	0.1	0.07
Achnanthidium pyrenaicum (Hustedt) Kobayashi	Low	0.05	0.682	0.5	0.41	0.09
Diatoma sp.	Low	0.05	0.567	0.73	0.18	0.08
Eunotia naegelii Migula	Low	0.03	0.947	0.47	0.12	0.41
Achnanthidium deflexum (Reimer in Patrick and Reimer) Kingston	Medium	0.42	0.146	0.33	0.6	0.06
Rossithidium linearis (Smith) Round et Bukhtiyarova	Medium	0.37	0.066	0.34	0.61	0.05
Gomphonema parvulum (Kützing) Kützing	Medium	0.27	0.784	0.28	0.39	0.33
Cocconeis placentula var. euglypta (Ehrenberg) Grunow	Medium	0.26	0.35	0.17	0.46	0.37
Cocconeis placentula Ehrenberg	Medium	0.23	0.762	0.37	0.4	0.22
Fragilaria vaucheriae (Kützing) Petersen	Medium	0.23	0.882	0.31	0.43	0.26
Karayevia oblongella (Østrup) Aboal	Medium	0.18	0.234	0.08	0.91	0.02
Achnanthidium rivulare Potapova et Ponader	Medium	0.17	0.775	0.4	0.39	0.21
Eunotia pectinalis (Kützing) Rabenhorst	Medium	0.17	0.116	0.15	0.85	0
Navicula cryptocephala Kützing	Medium	0.17	0.682	0.25	0.42	0.33
Fragilaria tenera (Smith) Lange-Bertalot	Medium	0.16	0.196	0.23	0.67	0.11
Eunotia implicata Nörpel, Alles et Lange-Bertalot in Alles, Nörpel and Lange-Bertalot	Medium	0.15	0.176	0.1	0.88	0.02
Navicula capitatoradiata Germain	Medium	0.13	0.158	0.14	0.67	0.2

Taxa	Max Phosphorus Group	Indicator Value	*p*-value	Relative Abundance in Each Phosphorus Group		
				Low	Medium	High
Psammothidium curtissimum (Carter) Aboal in Aboal, Alvarez-Cobelas, Cambra and Ector	Medium	0.11	0.747	0.44	0.4	0.16
Gomphosphenia grovei (M. Schmidt in Schmidt et al.) Lange-Bertalot	Medium	0.09	0.285	0.14	0.86	0
Navicula menisculus Schumann	Medium	0.09	0.274	0.21	0.54	0.25
Navicula radiosafallax Lange-Bertalot	Medium	0.09	0.633	0.32	0.44	0.24
Frustulia vulgaris (Thwaites) De Toni	Medium	0.08	0.592	0.33	0.51	0.16
Staurosirella pinnata (Ehrenberg) Williams et Round	Medium	0.08	0.512	0.28	0.6	0.11
Aulacoseira sp.	Medium	0.07	0.442	0.51	0.49	0
Navicula cari Ehrenberg	Medium	0.07	0.443	0.07	0.68	0.24
Synedra rumpens Kützing	Medium	0.07	0.558	0.32	0.68	0
Achnanthidium latecephalum Kobayashi	Medium	0.06	0.541	0.53	0.47	0
Gomphonema angustatum (Kützing) Rabenhorst	Medium	0.05	0.943	0.38	0.36	0.26
Gomphonema kobayasii Kociolek et Kingston	Medium	0.05	0.958	0.37	0.45	0.18
Nitzschia gracilis Hantzsch in Rabenhorst	Medium	0.05	0.862	0.43	0.47	0.11
Amphora copulata (Kützing) Schoeman et Archibald	Medium	0.04	0.937	0.2	0.41	0.39
Navicula radiosa Kützing	Medium	0.04	0.708	0.34	0.45	0.21
Nitzschia inconspicua Grunow	High	0.77	0.001	0	0.12	0.88
Navicula gregaria Donkin	High	0.67	0.001	0.15	0.14	0.71
Planothidium frequentissimum (Lange-Bertalot in Krammer and Lange-Bertalot) Lange-Bertalot	High	0.53	0.001	0.08	0.27	0.64
Navicula tripunctata (Müller) Bory	High	0.51	0.001	0.07	0.06	0.87
Achnanthes subhudsonis var. kraeuselii (Cholnoky) Cholnoky	High	0.49	0.002	0.04	0.33	0.64
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	High	0.49	0.005	0.28	0.17	0.56
Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	High	0.49	0.015	0.09	0.27	0.64
Amphora pediculus (Kützing) Grunow in A. Schmidt	High	0.46	0.002	0.07	0.21	0.72
Navicula lanceolata (Agardh) Kützing	High	0.46	0.003	0.11	0.24	0.66
Nitzschia sp.	High	0.46	0.001	0.06	0.22	0.71
Nitzschia dissipata (Kützing) Grunow	High	0.43	0.002	0.09	0.18	0.72
Nitzschia amphibia Grunow	High	0.42	0.002	0.13	0.08	0.79
Reimeria sinuata (Gregory) Kociolek et Stoermer	High	0.38	0.028	0.26	0.19	0.54
Navicula cryptotenella Lange-Bertalot in Krammer and Lange-Bertalot	High	0.35	0.01	0.14	0.2	0.66
Nitzschia linearis (Agardh) Smith	High	0.35	0.006	0.13	0.12	0.75
Mayamaea atomus (Kützing) Lange-Bertalot	High	0.33	0.01	0.05	0.02	0.93
Melosira varians Agardh	High	0.33	0.347	0.25	0.28	0.47
Cocconeis pediculus Ehrenberg	High	0.32	0.273	0.33	0.17	0.5
Nitzschia palea (Kützing) Smith	High	0.32	0.134	0.24	0.22	0.54
Cyclotella meneghiniana Kützing	High	0.3	0.055	0.21	0.16	0.63

Taxa	Max Phosphorus Group	Indicator Value	*p*-value	Relative Abundance in Each Phosphorus Group		
				Low	Medium	High
Eolimna subminuscula (Manguin) Moser, Lange-Bertalot et Metzeltin	High	0.29	0.008	0.06	0.11	0.82
Meridion circulare (Greville) Agardh	High	0.27	0.009	0.1	0.15	0.75
Navicula sp.	High	0.25	0.034	0.11	0.18	0.71
Nitzschia frustulum (Kützing) Grunow in Cleve and Grunow	High	0.25	0.014	0.05	0.23	0.71
Nitzschia perminuta (Grunow in Van Heurck) Peragallo	High	0.25	0.005	0.04	0.24	0.72
Achnanthidium exiguum (Grunow in Cleve and Grunow) Czarnecki	High	0.23	0.003	0.04	0.16	0.8
Undetermined Pennate	High	0.23	0.178	0.27	0.24	0.49
Eolimna minima (Grunow) Lange-Bertalot	High	0.22	0.135	0.05	0.2	0.76
Geissleria acceptata (Hustedt) Lange-Bertalot et Metzeltin	High	0.22	0.015	0.01	0.37	0.62
Surirella brebissonii var. kuetzingii Krammer et Lange-Bertalot	High	0.21	0.03	0.35	0.06	0.59
Sellaphora pupula (Kützing) Meresckowsky	High	0.2	0.023	0.11	0.2	0.69
Cocconeis sp.	High	0.18	0.118	0.09	0.4	0.51
Nitzschia fonticola (Grunow) Grunow in Van Heurck	High	0.17	0.173	0.08	0.45	0.47
Platessa conspicua (Mayer) Lange-Bertalot in Krammer and Lange-Bertalot	High	0.17	0.53	0.17	0.48	0.36
Placoneis elginensis (Gregory) Cox	High	0.16	0.036	0.1	0.2	0.7
Psammothidium subatomoides (Hustedt in Schmidt) Bukhtiyarova et Round	High	0.15	0.787	0.11	0.54	0.36
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin et Witkowski	High	0.14	0.091	0.18	0.22	0.6
Caloneis bacillum (Grunow) Cleve	High	0.13	0.232	0.13	0.12	0.75
Staurosirella leptostauron (Ehrenberg) Williams et Round	High	0.13	0.047	0.1	0.14	0.76
Surirella angusta Kützing	High	0.13	0.075	0.12	0.17	0.71
Achnanthidium thienemannii (Hustedt) Lange-Bertalot in Krammer and Lange-Bertalot	High	0.12	0.834	0.36	0.12	0.51
Cocconeis placentula var. lineata (Ehrenberg) Van Heurck	High	0.11	0.396	0.26	0.11	0.63
Diatoma vulgaris Bory	High	0.11	0.243	0.14	0.38	0.47
Navicula antonii Lange-Bertalot in U. Rumrich, Lange-Bertalot and M. Rumrich	High	0.11	0.555	0.32	0.22	0.46
Psammothidium chlidanos (Hohn et Hellerman) Lange-Bertalot	High	0.11	0.194	0.35	0.06	0.6
Cyclotella distinguenda Hustedt	High	0.09	0.197	0.15	0.1	0.76
Navicula cincta (Ehrenberg) Ralfs in Pritchard	High	0.08	0.212	0.1	0.19	0.71
Navicula rhynchocephala Kützing	High	0.08	0.601	0.23	0.31	0.45
Staurosira construens var. venter (Ehrenberg) Hamilton in Hamilton, Poulin, Charles and Angell	High	0.08	0.416	0.31	0.23	0.46
Planothidium dubium (Grunow) Round et Bukhtiyarova	High	0.07	0.384	0.32	0.1	0.58

Taxa	Max Phosphorus Group	Indicator Value	*p*-value	Relative Abundance in Each Phosphorus Group		
				Low	**Medium**	**High**
Geissleria decussis (Østrup) Lange-Bertalot et Metzeltin	High	0.06	0.842	0.22	0.53	0.25
Asterionella formosa Hassall	High	0.05	0.979	0.23	0.48	0.29
Ctenophora pulchella (Ralfs ex Kützing) Williams et Round	High	0.05	0.845	0.01	0.2	0.78
Gomphonema lagenula Kützing	High	0.04	0.951	0.21	0.06	0.73
Gomphonema productum (Grunow) Lange-Bertalot et Reichardt in Lange-Bertalot	High	0.04	0.939	0.46	0.23	0.31
Gomphonema pumilum (Grunow) Reichardt et Lange-Bertalot	High	0.03	0.918	0.24	0.22	0.54
Nupela lapidosa (Krasske) Lange-Bertalot	High	0.03	0.995	0.3	0.26	0.44
Undetermined Centric sp. 1 ?	High	0.03	0.958	0.13	0.28	0.59

Other studies (Danielson 2009; Potapova & Charles 2007; Van Dam et al. 1994) have corroborated the findings that that many of the significant indicator taxa in the high phosphorus level group are typically found in highly productive streams (eutrophic conditions), while many of the significant indicator taxa in the low and moderate phosphorus groups are found in low and moderately productive streams. High levels of nutrients, such as phosphorus and nitrogen, can contribute to the productivity in streams.

Additional sampling and analysis outside of this grant is planned to further study the changes diatom taxa assemblages in response to nutrient enrichment. Ongoing monitoring and research that incorporates the responsiveness of aquatic systems to initial steps to manage phosphorus and nitrogen from NPDES permitted sources as well as the growing emphasis on land-based management practices required under Connecticut's water quality standards will also be helpful to further elucidate specific impacts from nutrients on aquatic life.

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