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Water Quality and Wet Season Diatom Assemblage Characteristics from the Tamiami Trail Pilot Swales Sites (Everglades National Park, Florida, USA)

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Abstract

A pivotal component of hydrological restoration of the Florida Everglades is the improvement of water conveyance to Everglades National Park by the degradation of the current network of canals, roadways and levees. The Tamiami Trail (L29) road/canal complex represents a major barrier to natural water flows into the park and a variety of modification options for flow improvement are currently being explored, including the installation of spreader swales immediately downstream of culverts conveying water under Tamiami Trail from the L29 canal into Everglades National Park. In this study, we evaluated water column chemistry and wet-season diatom community structure to provide baseline information for use in future monitoring activities related to the proposed Tamiami Trail modifications. Water chemistry showed pronounced fluctuations in response to precipitation and anthropogenically mediated hydrological events. Differences in water quality variables among sites were dampened during periods of inundation, and became more pronounced during periods of low canal stage, suggesting the importance of small-scale mechanisms related to isolation of habitat patches. Diatom assemblages were unexpectedly speciose (127 taxa in 40 samples) compared to typical Everglades assemblages, and spatially heterogeneous in sites associated with concentric areas of dense vegetation immediately downstream of culverts. We also observed significant compositional dissimilarities among transects, indicating that culvert pool and north transect assemblages were substantially influenced by propagule input from the canal and areas to the north, while south transect sites were compositionally similar to typical sawgrass prairie diatom communities. Central transect sites were compositionally intermediate to their north and south counterparts. We propose that the position and spatial extent of this "transitional assemblage" is a sensitive indicator of subtle environmental change related to Tamiami Trail modifications.

Key words: Florida Everglades, Comprehensive Everglades Restoration Plan (CERP), diatoms, wetlands, water management

Introduction

The Florida Everglades represent the largest subtropical wetland complex in North America, and also is one of the largest karstic wetland systems in the world (Noe *et al.* 2001, LeHee 2010, Richardson 2010, Lodge 2010, Gaiser *et al.* 2011). Historically, the greater Everglades ecosystem was comprised of a hydrologically continuous network of lakes, rivers and marshes extending from the Kissimmee Lakes in central Florida to the shores of Florida Bay. Until the early 20th century, the Everglades were viewed as a vast, inhospitable swamp, the last refuge of the Miccosukee and Seminole Indians and largely not worth further exploration (Blake 1980, Richardson 2008). During the 20th Century, a wide variety of efforts were made to tame the Everglades for agricultural and urban development (Hollander 2008, Richardson 2010). The result has been the creation of a network of canals, levees and flow control structures that now impede natural water flows theoughout South Florida.

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Waters that once would have flowed unimpeded from their headwaters near the Kissimmee Lakes through the Kissimmee River into Lake Okeechobee, and then overland through a variety of wetlands into what is now Everglades National Park (ENP; Steinman *et al.* 2002, Richardson 2010) now face a myriad of diversions and obstacles (SFWMD 1998). The impacts of impeded water conveyance in the Everglades are now blatantly apparent (Sklar *et al*. 2001). Shortened hydroperiods in the central Everglades sawgrass prairie have led to changes in the distribution and dynamics of plant communities and associated highly endemic periphyton assemblages (Slate and Stevenson 2000, Gottlieb *et al*. 2005, Saunders *et al*. 2006). In addition, elevated phosphorus inputs from canal point sources have impacted algal and plant communities both within the park and in the water conservation areas (WCA) to the north (Rashke 1993, McCormick & O'Dell 1996, Gaiser *et al*. 2006a, McCormick *et al*. 2009). Further south, seawater encroachment has elongated the mangrove ecotone between the freshwater and marine systems (Ross *et al*. 2000, 2001, Stewart *et al.* 2002, Gaiser *et al.* 2006b).

In response to the growing list of impacts to the Florida Everglades, several initiatives have been developed with the objective of preserving the system, and ultimately restoring it to a more "natural" state (Noe *et al*. 2001, Sklar *et al*. 2005). The most recent, and farthest reaching of these plans is the Comprehensive Everglades Restoration Plan (CERP), which aims in part to restore natural waterflows within the Everglades by degrading levees, infilling canals and bridging major roadways (RECOVER 2005). Of these roadways, the Tamiami Trail, a 160 km east-west section of US Highway 41 between Miami and Naples, FL is regarded as the lynchpin of the CERP plan. With only 55 culverts and four major flow control structures to convey water to the southern Everglades along its length, the road and the associated L29 canal act as a major dam and diversion to north-south flows. The modification of Tamiami Trail has been called "the Grand Experiment" by many stakeholders, and several options for maintaining improved water conveyance under the roadway are now being considered within CERP.

One option that has been proposed to increase water flow into the southern Everglades is the construction of swales or spreader canals downstream of culverts in order to diffuse point-source culvert discharge and approximate sheet flow into ENP. The proposed Tamiami swales will be installed 8 m downstream (south) of the Tamiami Trail right of way (Fig. 2). They will be 330 m in length and 10 m in width, with depths determined by the bedrock boundary. Installation of these structures is not without inherent risks. Anticipated impacts of swale creation include increased water column turbidity and total suspended solids due to construction activity, increased pollutant loading and enhanced downstream transport of pollutants into ENP, and the downstream extension of the dense vegetation halos that currently surround culvert pools. We speculate that these halos have developed in response to enhanced point-source phosphorus inputs at the culvert outflows. This initial contribution incorporates a subset of data from a larger pilot project currently being undertaken in order to assess the effects of swale construction on water quality and biological integrity in the area adjacent to the Tamiami Trail culverts.

Here, we examine the spatial and temporal variability of background water quality and wet-season diatom community structure prior to installation of spreader swales at pilot culverts. We test the null hypotheses that water chemistry does not differ significantly among transects or among monthly sampling events. We also evaluate the null hypotheses that diatom taxonomic richness and diversity do not differ significantly among transects and that no significant dissimilarity exists among diatom assemblages from different transects. Furthermore, we provide a synopsis of diatom taxa typically encountered at each transect as a baseline for future monitoring efforts.

Due to their widespread distribution in aqueous environments and their ability to respond sensitively and quickly to environmental gradients, diatoms have been well established as ideal organisms for use in biological assessment (Lange-Bertalot 1979, LeClercq 1988, Round 1991, Dixit & Smol 1993). In the Everglades, diatoms have been shown to respond to several environmental gradients including phosphorus (Rashcke 1993, Gaiser *et al*. 2006) and other nutrients and ions (Cooper *et al*. 1999, Hagerthey *et al*. 2011, Gaiser *et al*. 2011). Where they are well-preserved in sediment records, diatoms and other siliceous microfossils have also been used as indicators of environmental change within the freshwater Everglades

(Slate & Stevenson 2000, Winkler *et al*. 2001). As in other aquatic systems, diatoms can be found ubiquitously throughout the Everglades. Species assemblages, however, shift with changing landscapes. The culvert sites are located in the Northeast Shark slough, a typical ridge and slough type habitat where the characteristic diatom assemblage commonly includes *Brachysira neoexilis* Lange-Bertalot in Lange-Bertalot & G. Moser (1994: 51-54), *Cyclotella meneghiniana* Kützing (1844: 50), *Encyonema evergladianum* Krammer (1997: 193), *Mastogloia smithii* Thwaites ex W. Smith (1856: 65) (we now call this *Mastogloia* cf. *lacustris* (Grunow) Van Heurck (1880: pl. 4, fig. 14)) and *Nitzschia palea* var. *debilis* (Kützing) Grunow in Cleve & Grunow (1880: 96) (Gaiser *et al.* 2011). We expect to encounter these taxa within the southernmost transects of our sites, and assemblages more consistent with the central Everglades habitats of the water conservation areas in closer proximity to the culverts themselves. Childers *et al.* (2003) asserted that waters flowing into Everglades wetlands from canals or agricultural areas were significantly enriched in phosphorus, but waters within the Everglades typically exhibited very low phosphorus concentrations. We expect our results to follow this trend, with phosphorus levels decreasing downstream with distance from the canal.

Methods

Site description and sampling.

Tamiami Trail forms the northern boundary of Everglades National Park. Four culverts passing under the road in Northeast Shark Slough (C43, C44, C47, C51, Fig. 1) were selected by the National Park Service for inclusion in the pilot swales study. Each culvert consists of three 1 m concrete tubes crossing under the road, and conveying water from the L29 canal. Immediately downstream of each culvert is an outflow scour pool approximately 1 m deep and 15 m across. A halo of dense vegetation comprised largely of pond apple (*Annona glabra* L.), coastal plain willow (*Salix caroliniana* Michx.) and leather fern (*Acrostichum danaeifolium* (Langsd.) Fisch.) surrounds the culvert pool concentrically and extends south for approximately 100 m. Beyond the tree halo is a transitional area dominated by *S. caroliniana* and cattail (*Typha domingensis* Pers.), which extends south for another 100 m, where it is replaced by the sawgrass prairie dominated by *Cladium jamaicense* (Crantz) Britt., typical of the southern Everglades. Southern sites were also characterized by extensive periphyton mats composed of a mixture of benthic algae, bacteria, fungi and detritus. These mats are typical of the ridge and slough portions of the Everglades.

At each culvert, we created three east-west transects (north, central and south), with three sites per transect (west, central and east Fig. 2). North transect sites were situated within the vegetation halo approximately 40 m south of the Tamiami Trail right of way. Central transect sites were located directly south of their northern transect counterparts, and positioned latitudinally to ensure that they were situated within the transitional area. Similarly, south transect sites were located due south of their northern and central counterparts, and placed within the sawgrass prairie. The locations of sites were selected to maximize the macrohabitat and vascular plant assemblage similarity of sites within each transect across culverts. We also created three canal sites immediately upstream of each culvert for a total of 12 grab sample sites per culvert. In addition to the transect sites, ISCO Model 6712 Portable Samplers were deployed at the downstream extent of each culvert site, just south of the south central station, in order to continuously monitor the quality of the water flowing through study sites.

Filtered (0.5 µm nitrocellulose) and unfiltered water grab samples were taken monthly at each of the 36 transect sites between December 2009and April 2010. Additionally, triplicate filtered and unfiltered samples were taken from the Tamiami Canal immediately upstream of each culvert as a control. ISCO autosamplers were programmed to sample 250 mL of water every 18 h in order to compile 1 L composite samples every 3 days between October 2009 and April 2010.

Diatom material was collected by removing material to fill a 20 mL scintillation vial from every available substrate type at each site, as well as from substrates within the culvert pools. At north and central sites, floating periphyton, benthos, woody debris and moss were often sampled, while at south sites substrata were primarily limited to benthos and periphyton mats. Diatom sampling took place in November 2009, during a period of relative climatic stability at the end of the 2009 wet season and prior to any potentially disruptive activity within the sites.

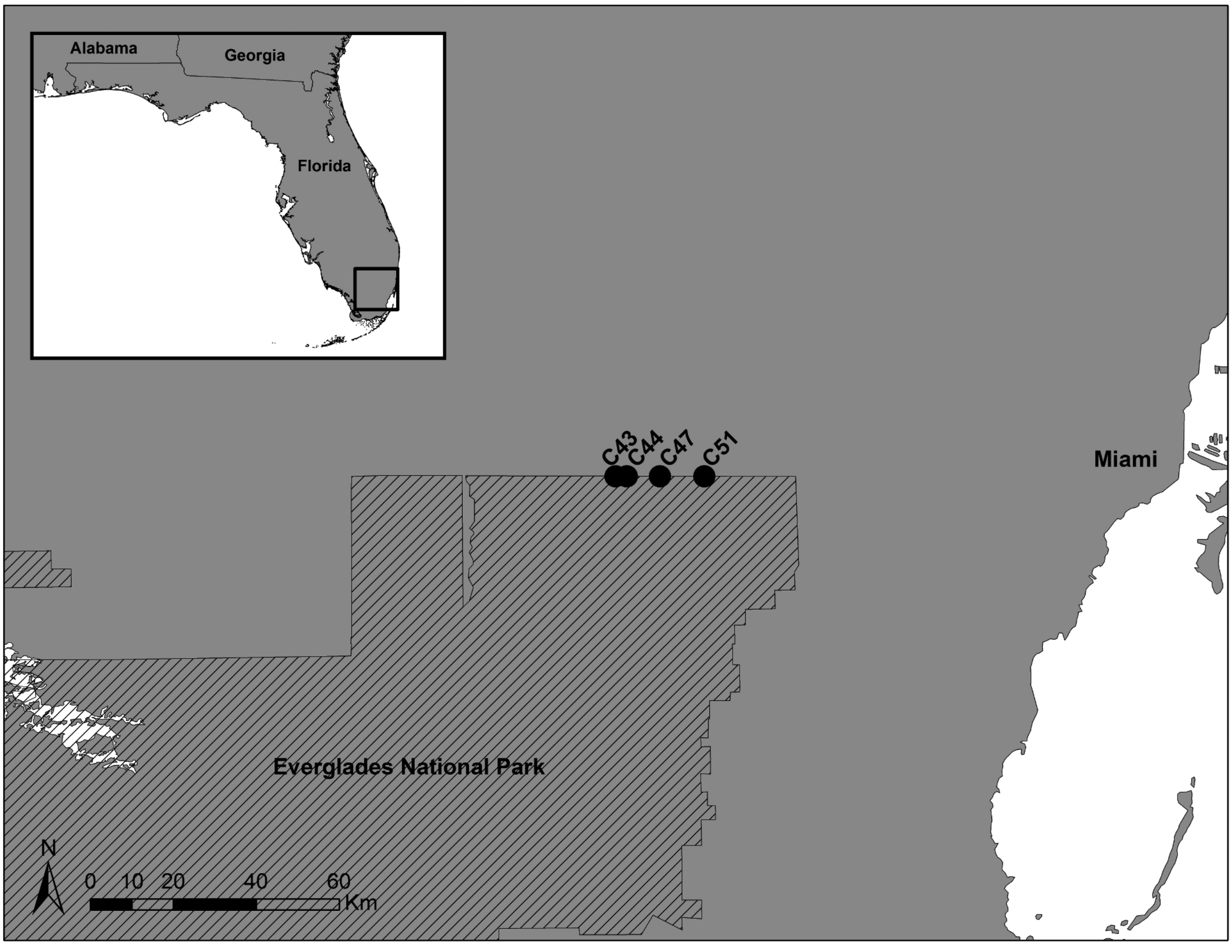

FIGURE 1: Map of South Florida highlighting the Florida Everglades and the northern boundary of Everglades National Park, showing the location of the Tamiami pilot spreader swales culvert sites.

Water Quality Analysis

Unfiltered water grab samples and ISCO autosampler water samples were analyzed for total nitrogen (TN) and total phosphorous (TP), while filtered water grab samples were analyzed for Nitrate/Nitrite (N/N) Dissolved Organic Carbon (DOC), Ammonia (NH_3), and soluble reactive phosphorus (SRP). Total phosphorus was determined following EPA method 365.1, with modified sample preparation methods described by Solózano & Sharp (1980). Inorganic nutrient analyses (TN, NO_2, NO_3, NH_3, SRP) were performed by simultaneous wet chemical analysis using a four-channel Alpkem RFA-300 Rapid Flow Analyzer according to EPA methods 353.2 (N+N, NO_2), 350.1 (NH_4) and 365.1 (SRP).

Diatom Enumeration

Composite samples were created for each site by combining 5 mL of sample slurry from each substrate within the site. Diatom material was cleaned using a hot nitric / sulphuric acid digestion and subsequently subjected to five cycles of distilled water rinsing and centrifugation. Cleaned diatom material was dried onto coverslips and mounted to light microscope (LM) slides with Naphrax® high resolution mountant from Borael Sciences Ltd.. Diatom valves were identified to the lowest possible taxonomic level (species or lower) and counted within random fields of view on each slide until either the end of the field of view in which the 200th valve of the most abundant taxon was encountered, or until the end of the 20th field of view. This technique typically produced counts of 250–500 valves per slide (as per Bramburger et al 2004). Diatom slides and material are currently housed at the St. Lawrence River Institute of Environmental Sciences, Cornwall, ON. Slide numbers Swales-001 to Swales-080.

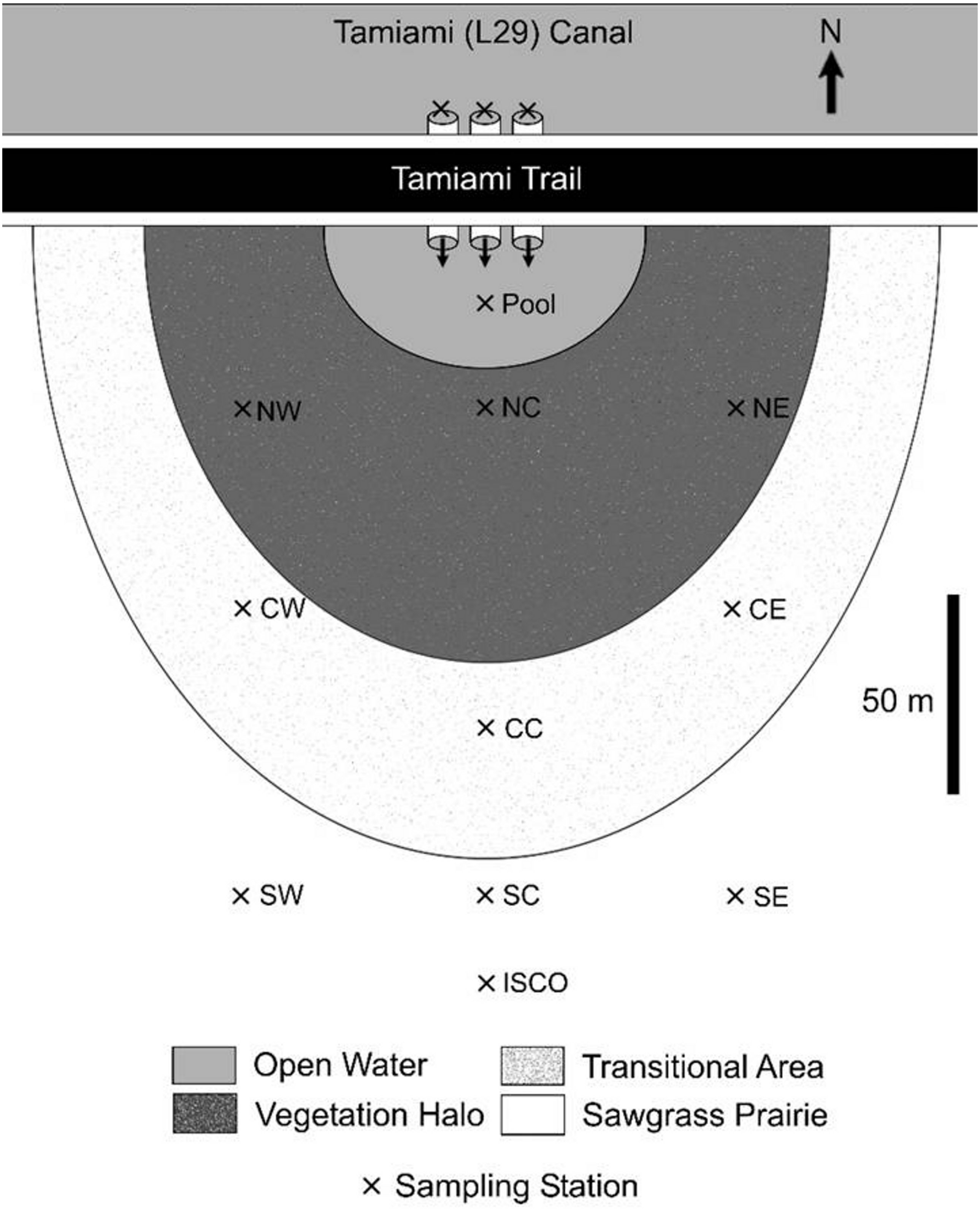

FIGURE 2: Stylized layout of a typical culvert site showing Tamiami Trail, the culvert and associated scourpool, the vegetation halo, transitional area, and locations of transect sampling sites and ISCO autosampler.

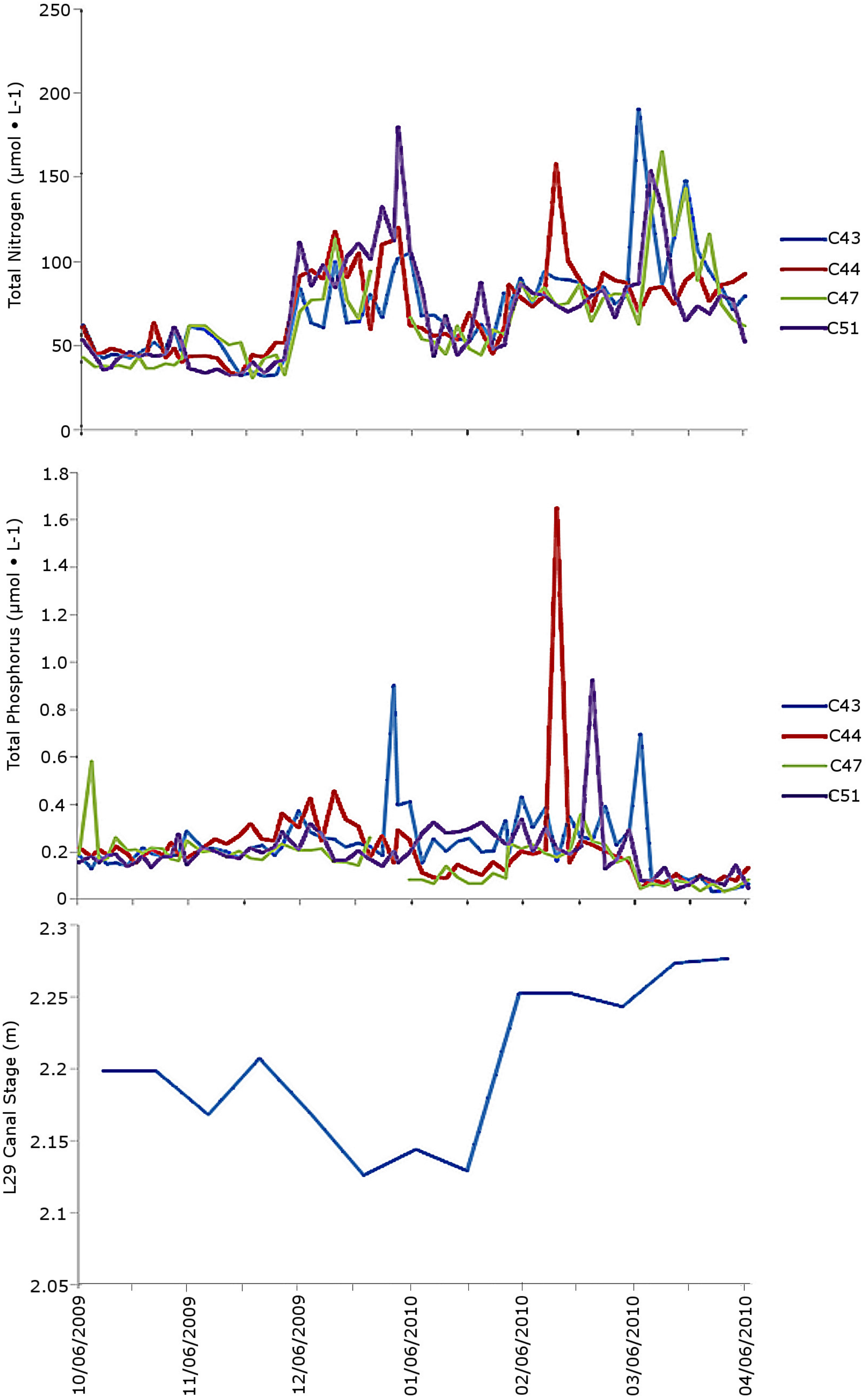

FIGURE 3: Trends in water column nutrient concentration and Tamiami canal stage during the study period from October 2009 through April 2010. 3a: Trends in total nitrogen concentration (µmol · L^{-1}) at ISCO autosampler sites. 3b: Trends in total phosphorus concentration (µmol · L^{-1}) at ISCO autosampler sites. 3c: Trends in Tamiami canal stage between S333 and S334 water control structures (South Florida Water Management District Data).

Statistical Analysis

Water quality data were normalized and Non-metric Multidimensional Scaling (NMDS) and a Two-way Analysis of Similarity (ANOSIM) were used to explore patterns of similarity among water samples by transect (canal, north, central, south) and by sampling event (Dec. 2009 - Apr. 2010), with Euclidean distance as the similarity matrix metric. In addition, Multivariate Dispersion Analysis (MVDISP) was used to examine cohesiveness of sample groups. Analyses were carried out using PRIMER 6 software. Diatom count data were used to calculate species richness (*r*) and Shannon's Index (H') (Shannon 1948) for each station. A series of One-way Analyses of Variance (ANOVA) with post-hoc Bonferroni testing were used to evaluate differences in mean *r* and H' among transects (pool, north, central, south) using the SPSS 16 statistical package. Further NMDS, MVDISP and ANOSIM analyses were used to examine patterns of diatom assemblage similarity among transects, using a Bray-Curtis similarity matrix.

Results

Water Quality

A total of 241 composite water samples were taken by the ISCO autosamplers between October 23, 2009 and April 9, 2010. Total Nitrogen values ranged from 31.22 µmol · L^{-1} (C47 Dec. 5, 2009) to 190.49 µmol · L^{-1} (C43 Mar. 13, 2010) and TP ranged from 0.03 µmol · L^{-1} (C47 Apr. 3 2010) to 1.69 µmol · L^{-1} (C44 Feb. 20, 2010). Between late October and mid-December, 2009, TN fluctuated around a mean of 50 µmol · L^{-1} with strong concordance among autosampler sites (Fig. 3a). In December 2009, TN levels rose across by about 50 µmol · L^{-1} at all culverts, and temporal fluctuations in TN values became more pronounced until a return to pre-December levels in late January 2010. This period corresponded to a drop in water levels as indicated by L29 canal stage measurements reported by the South Florida Water Management District (Fig. 3c). Despite fluctuations at all sites, a coarse temporal congruence was maintained until a period of high-stage water fluctuations beginning in March 2010. Total phosphorus remained low (< 0.40 µmol · L^{-1}) across all sites throughout the sampling period. Some brief fluctuations occurred late in the sampling period concurrently with the high-stage water level fluctuation mentioned above.

TABLE 1: A summary of water quality characteristics from the Tamiami pilot spreader swales transect sampling sites.

	Mean	**S.D.**	**Max.**	**Min.**
Total Nitrogen (µmol · L^{-1})	68.19	26.82	162.23	26.03
Total Phosphorus (µmol · L^{-1})	0.40	0.31	3.88	0.11
Nitrate + Nitrite (µmol · L^{-1})	3.54	3.33	13.22	0.03
Nitrogen as Nitrate (µmol · L^{-1})	3.37	3.24	12.73	-0.04
Nitrogen as Nitrite (µmol · L^{-1})	0.17	0.13	0.63	0.08
Nitrogen as Ammonia (µmol · L^{-1})	3.00	3.43	23.62	0.19
Dissolved Organic Carbon (µmol · L^{-1})	1829.62	376.99	3020.00	260.25
Soluble Reactive Phosphorus (µmol · L^{-1})	0.06	0.05	0.33	0.01

A total of 214 filtered and 214 unfiltered water grab samples were taken between December 2009 and April 2010. Total Nitrogen ranged from 26.06 µmol · L^{-1} (C44SW Feb 2010) to 162.23 µmol · L^{-1} (C44NW Apr. 2010, Fig. 4a). Total phosphorus values from the same samples ranged from 0.11 µmol · L^{-1} (C51SE Feb. 2010) to 3.88 µmol · L^{-1} (C43NC Dec. 2009, Fig. 4b). Water quality variables were broadly homogeneous across sites, with increased TP being consistently observed closer to the park boundary (canal and north transect samples). A summary of water quality characteristics is provided in Table 1. NMDS ordination of water samples based on all measured water quality parameters at all sites showed a general interspersion of all groups (Fig. 5) and a One-way ANOSIM demonstrated that there were no significant dissimilarities among water quality grab samples from culvert to culvert (Global $R = -0.008$, $p > 0.05$). This result indicates that the

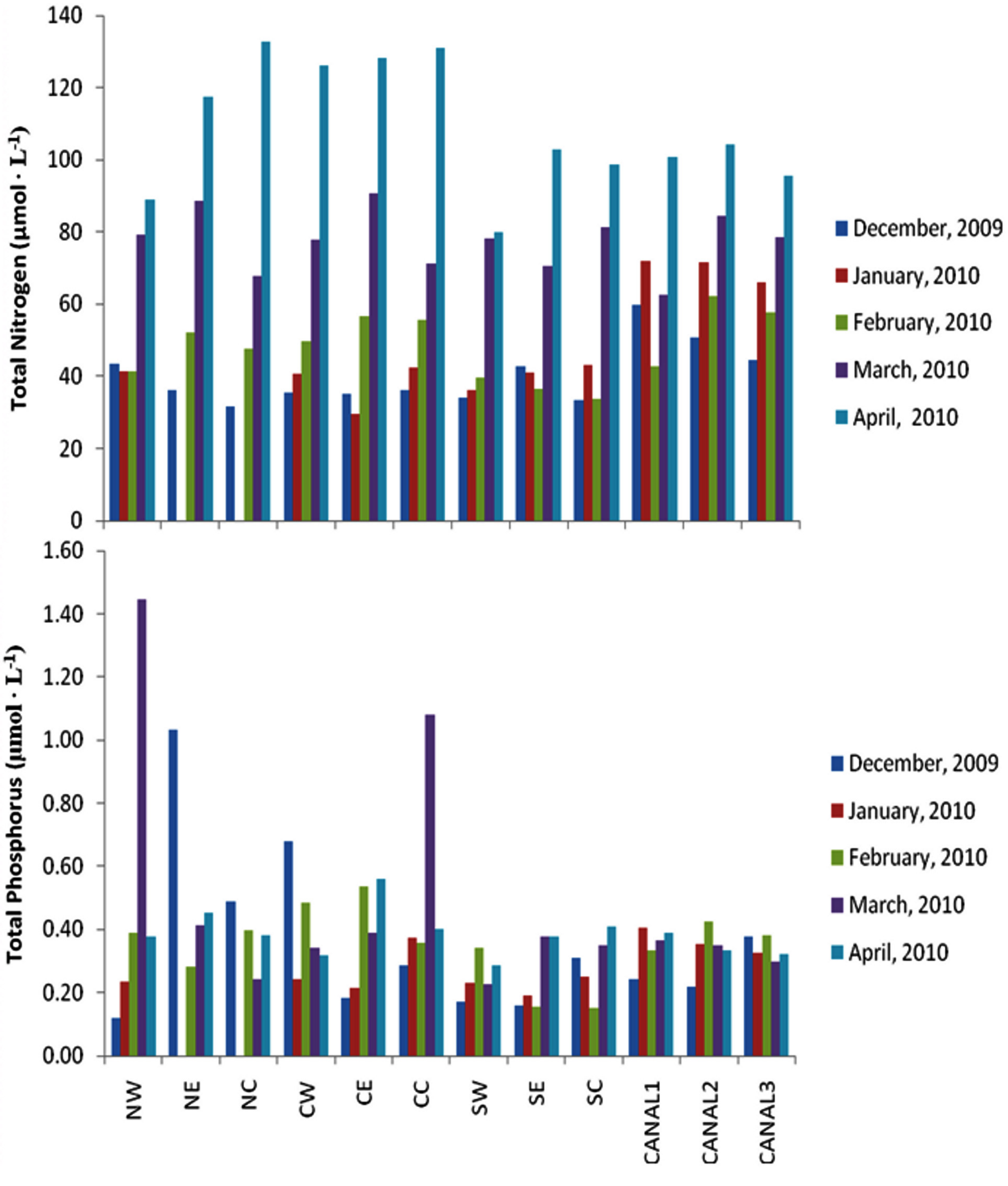

FIGURE 4: Example of water column nutrient concentration from transect station water grab samples at culvert C47. 4a: Total nitrogen concentrations. 4b: Total phosphorus concentrations. Site names are represented by transect and location initials. For example NC is North transect, Central location.

four culverts chosen were appropriate replicates from a water quality standpoint. Multivariate Dispersion Analysis (MVDISP) showed that the south transect samples represented the most spatially cohesive transect group among culvert sites (dispersion = 0.812) followed by the central transect sites (dispersion = 0.888) In NMDS, the southern transect sites clustered centrally on both axes, with some January samples clustered outside the main group. Conversely, the north transect samples were the most widely scattered spatial group (dispersion = 1.235). Within the north, central and south transects, samples clustered roughly according to sampling month. Temporally, the samples taken during the December 2009 and January 2010 sampling events represented the most heterogeneous groups (MVDISP, December dispersion = 1.438 January dispersion = 1.332), while samples taken during the February, March and April 2010 sampling events were more homogeneously clustered (dispersion = 1.153, 0.708, 0.589, respectively). ANOSIM analyses showed that both transect (Global R = 0.146, p < 0.001) and sampling event (Global R = 0.436, P < 0.001) exerted significant effects on water sample similarity. Further pairwise Bonferroni tests demonstrated that samples within each transect differed significantly from those within all other transects (0.075 < R < 0.239, p < 0.002, Table 2a) with the exception that the south transect samples were not distinguishable from the canal samples (R = 0.260, p = 0.10, Table 2a). Similarly, samples taken within each sampling event differed significantly from those within all other sampling periods (0.146 < R < 0.534, p < 0.001, Table 2b).

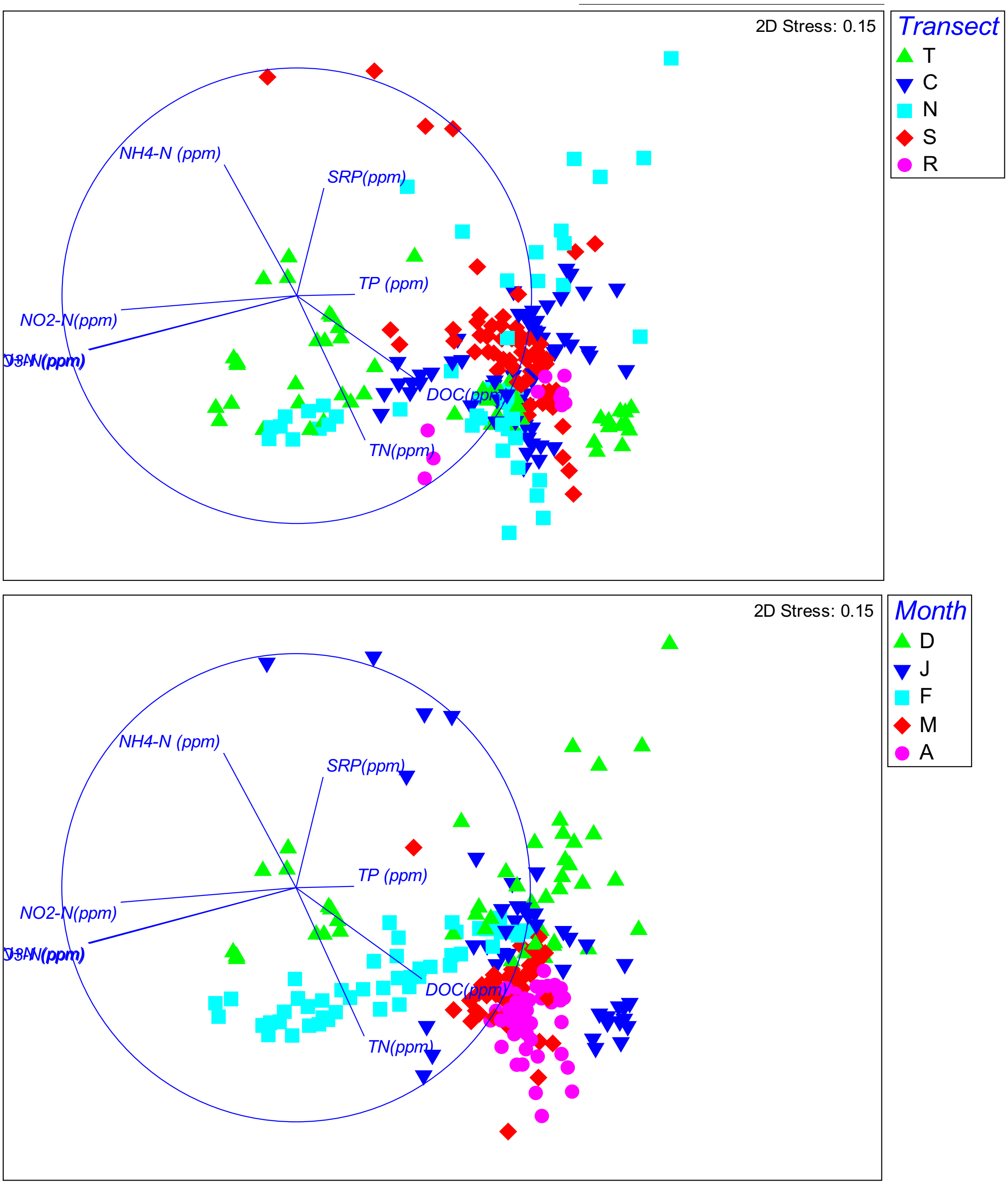

FIGURE 5: Non-metric Multidimensional Scaling ordination plot for water column chemistry similarity among. 5a) Ordination plot with symbols representing sample transects. T represents Tamiami Canal, N represents North, C represents Central, S represents south and R represents reference. 5b) Ordination of samples according to sampling month, beginning with December 2009 (D). Euclidean distance is the distance metric for both plots.

TABLE 2a: Water quality ANOSIM results by transect. Asterisk denotes significant dissimilarity ($p < 0.05$).

	North	Central	South
Canal	R = 0.102 p = 0.002 *	R = 0.175 p < 0.001 *	R = 0.260 p = 0.10
North		R = 0.102 p < 0.001 *	R = 0.239 p < 0.001 *
Central			R = 0.075 p < 0.001 *

TABLE 2b: Water quality ANOSIM results by month of sampling. Asterisk denotes significant dissimilarity ($p < 0.05$).

	January	February	March	April
December	R = 0.146 p < 0.001 *	R = 0.351 p < 0.001 *	R = 0.348 p < 0.001 *	R = 0.567 p < 0.001 *
January		R = 0.534 p < 0.001 *	R = 0.319 p < 0.001 *	R = 0.584 p < 0.001 *
February			R = 0.546 p < 0.001 *	R = 0.780 p < 0.001 *
March				R = 0.325 p < 0.001 *

Diatom Community Characteristics

We encountered 127 diatom taxa (Table 4) in the 40 composite samples from the swales study area. Culvert pool sites exhibited visible diatom films upon sampling and were dominated numerically by an unnamed *Achnanthes* (*Achnanthes ftsp. 13*), *Encyonema evergladianum*, and *Nitzschia amphibia* var. *amphibia* Grunow (1862: 574). North transect sites typically supported sparse diatom communities with thin films comprised primarily of *Achnanthes ftsp. 13*, *Eunotia ftsp. 09*, *Eunotia ftsp. 10* and *N. amphibia* var. *amphibia.* Diatom communities of the central sites were characterized by denser biofilms than north transect sites and were dominated by *Eunotia monodon* Ehrenberg (1843: pl. 2/5, fig. 7), *Fragilaria synegrotesca* Lange-Bertalot (1993: 49-50), *Mastogloia smithii* and *Nitzschia semirobusta* Lange-Bertalot (1993: 149-150). Southern transect sites frequently supported very dense periphyton mats containing profuse diatom communities, and counts of over 100 valves per field of view were not uncommon. These communities consisted almost exclusively of *M. smithii*. *Encyonema evergladianum* and *F. synegrotesca* were the secondarily dominant taxa in these assemblages.

Taxonomic richness (*r)* ranged from 8 (C44 SC) to 38 (C51 NW) and mean *r* differed significantly among transects (Table 3, one-way ANOVA, $F = 15.96$, $p < 0.001$). Post-hoc Bonferroni testing demonstrated the south transect sites to be significantly less rich than the north and central sites (North-south Mean Difference = 15.175, $p < 0.001$; Central-south Mean Difference = 15.674, $p < 0.01$, Fig. 6a). Shannon's Index ranged from 0.40 (C44 SC) to 3.01 (C43 CE) and similarly to taxonomic richness, differed significantly among transects (Table 3, One-way ANOVA, $F = 17.77$, $p < 0.001$). Mean H' was significantly less at the south transect sites that at all other transects (Pool-south Mean Difference = 0.880, $p = 0.028$, North-south Mean Difference = 1.474, $p < 0.001$; Central-south Mean Difference = 1.081, $p < 0.001$; Fig. 6b).

An NMDS ordination conducted to illustrate differences between diatom assemblage structure at transect sites showed pool sites largely interspersed with north transect sites (Fig. 7). Central transect sites clustered intermediately to north and south transect sites, and south transect sites formed a tight cluster with only minor overlap with a few central transect sites. Subsequent ANOSIM analysis of the same data revealed significant dissimilarities among transects (Global R = 0.557, $p < 0.001$). Post-hoc Bonferroni tests illustrated that pool sites were significantly dissimilar to central and south transect sites (Pool-central R = 0.41, $p = 0.009$; Pool-south R = 0.98, $p < 0.001$). North transect sites were also significantly dissimilar to central and south transect sites (North-central R = 0.25, $p = 0.002$; North-south R = 0.945, $p < 0.001$), and central transect sites were significantly dissimilar to south transect sites (R = 0.402, $p = 0.003$). Despite the significant dissimilarities among transects, NMDS ordination shows central sites as being modestly interspersed with both north and south transect sites. MVDISP analysis revealed that the diatom assemblages of the South transect sites were the most cohesive (dispersion = 0.464), while north and central sites were the most heterogenous (dispersion = 1.138 and 1.308, respectively).

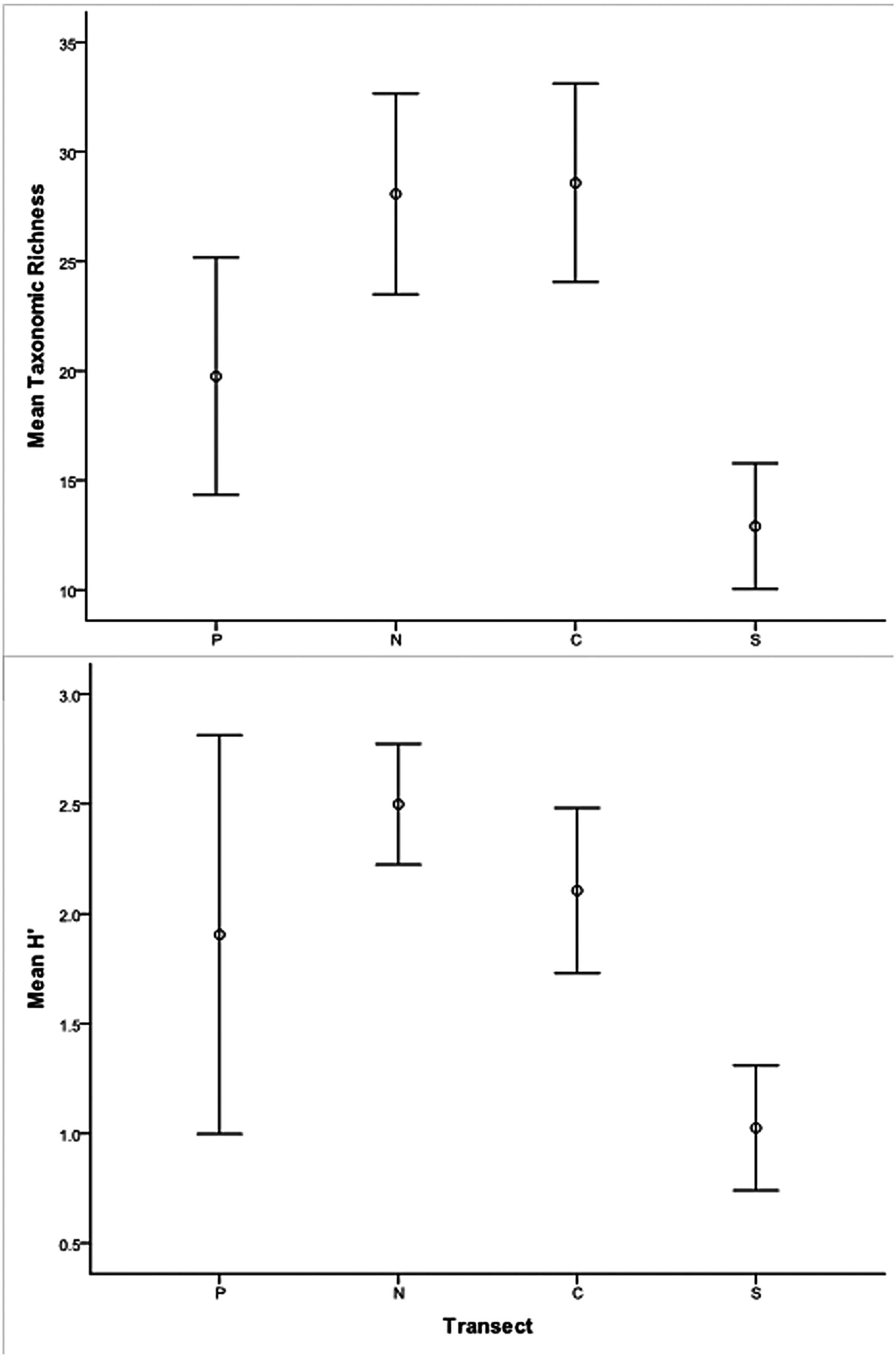

FIGURE 6: 6a: Mean taxonomic richness (*r*) by transect. Error bars denote 95% confidence interval. 6b: Mean Shannon Index (H') by transect. Error bars denote 95% confidence interval. Letters denote pairwise differences indicated by ANOVA.

TABLE 3: Diatom species richness (*r*), Shannon's Diversity Index (*H'*), maximum possible diversity (H_{max}), and Evenness (*E*) for each sample site. Site names are given as the culvert number followed by transect (Pool, North, Central, South) and location (East, Central, West) initials. For example C43NW represents culvert 43, northern transect, western location.

Site	*r*	H'	Hmax	E
C43P	23	2.389	3.135494	0.761921
C43NW	12	2.334	2.484907	0.939271
C43NC	24	2.894	3.178054	0.91062
C43NE	25	2.494	3.218876	0.774805
C43CW	30	2.006	3.401197	0.589792
C43CC	14	0.8	2.639057	0.303139
C43CE	28	3.008	3.332205	0.902706
C43SW	14	0.945	2.639057	0.358082
C43SC	9	0.797	2.197225	0.36273
C44P	15	1.113	2.70805	0.410997
C44NW	33	2.787	3.496508	0.797081
C44NC	33	2.761	3.496508	0.789645
C44NE	21	1.752	3.044522	0.57546
C44CW	29	2.271	3.367296	0.674428
C44CC	34	2.215	3.526361	0.628126
C44CE	32	2.3	3.465736	0.66364
C44SW	9	0.482	2.197225	0.219368
C44SC	8	0.401	2.079442	0.19284
C44SE	22	1.492	3.091042	0.482685
C47P	20	1.875	2.995732	0.62589
C47NW	29	2.838	3.367296	0.842813
C47NC	35	2.898	3.555348	0.81511
C47NE	24	1.755	3.178054	0.552225
C47CW	37	2.322	3.610918	0.64305
C47CC	22	1.856	3.091042	0.600445
C47CE	31	2.793	3.433987	0.81334
C47SW	14	1.128	2.639057	0.427425
C47SC	14	1.831	2.639057	0.693808
C47SE	9	0.992	2.197225	0.451479
C51P	21	2.244	3.044522	0.737061
C51NW	38	2.829	3.637586	0.777714
C51NC	31	2.615	3.433987	0.761505
C51NE	32	2.029	3.465736	0.585446
C51CW	20	1.558	2.995732	0.520073
C51CC	27	1.645	3.295837	0.499115
C51CE	39	2.497	3.663562	0.681577
C51SW	13	0.905	2.564949	0.352833
C51SC	12	0.901	2.484907	0.362589
C51SE	18	1.402	2.890372	0.485059

Discussion

As efforts to restore the Florida Everglades to a more natural flow regime progress, Tamiami Trail and the associated L29 canal pose a major obstacle to improved water conveyance into the southern Everglades. Several alternatives have been proposed with the aim of overcoming this obstacle, including the installation of spreader swales immediately downstream of culverts under the road right of way. The objective of this study was to provide pre-impact water quality and wet-season diatom community data to be used as a baseline for monitoring efforts post-swale installation and to assess the viability of diatoms as an assessment tool for future monitoring.

Our results demonstrated that the water quality characteristics of the northern portion of Everglades National Park can exhibit substantial spatial and temporal variability, which may be regulated both directly and indirectly by stage in the Tamiami Canal. Water column TP remained consistently low (~ 0.40 µmol · L^{-1}) across all sites, and showed little variability in time or space. These results are consistent with Gaiser *et al.* (2006a; 0.36 µmol · L^{-1} < TP < 3.6 µmol · L^{-1} for WCAs and ENP) and Childers *et al.* (2003; ~ 0.3 µmol · L^{-1}) and support assertions that periphyton TP is a better indicator of phosphorus loading and fate in the Everglades than water column TP (Gaiser *et al.* 2004). Water column TN, on the other hand, exhibited substantial temporal and spatial diversity, which often was driven by fluctuations in precipitation or Tamiami Canal stage. TN concentrations from the ISCO samples almost tripled during a period of low stage in the L29 canal in December 2009 and January 2010. Water quality at grab sample sites also showed its greatest spatial variability during the low stage period as indicated by MVDISP analysis and NMDS ordination (Fig. 5b). These results suggest that the spatial patchiness of water quality characteristics is regulated by canal stage through inundation of downstream habitats by canal water inputs. During periods of inundation (i.e. March, April 2010), water column chemistry is regulated largely by inputs from the Tamiami Canal, and water quality at sites essentially is homogeneous (Fig. 5b). During periods of low canal stage (i.e. December 2009, January 2010), areas downstream of the culverts are no longer completely inundated, and water chemistry is regulated by small-scale mechanisms operating within isolated parcels of water. This phenomenon was most pronounced at the north and central transect sites, while south transect sites remained relatively homogeneous throughout the sampling period.

Like the water, the diatom communities within the swales sample area exhibit a substantial degree of spatial heterogeneity. One hundred twenty-seven diatom taxa were encountered in this study, and while this represents a high taxonomic diversity for such a small area in the Everglades, the richness is consistent with other studies that examined a similar variety of habitat types (138 taxa from 125 samples ranging from Lake Okeechobee to the oligohaline ecotone; CERP 2005 unpublished data). Diatom diversity, expressed both as species richness and as Shannon's index, was highest in the north and central transect sites. This elevated diversity is reflective of the increased structural complexity of the available habitat within the vegetation halo and surrounding area, as we were able to sample three different substrate types (benthos, periphyton, woody debris) in all of the north and central transect sites, but only two at the southern sites. These results are consistent with patterns observed elsewhere in the Everglades (CERP 2005 unpublished data) and with relationships between structural habitat complexity and taxonomic diversity demonstrated in other systems (MacArthur & MacArthur 1961, Connell & Orias 1964, Pianka 1967, Johnson & Simberloff 1974, Taniguchi & Tokeshi 2004, Bramburger *et al.* 2008).

General NMDS patterns illustrated that pool diatom assemblages had a high degree of overlap with north transect assemblages (Fig. 7) at the end of the wet season. Although these assemblages bear a strong resemblance to those observed in WCA2 and WCA3 (Gaiser et al. 2006, McCormick and O'Dell 1996), and the overlap observed here is probably a phenomenon driven by propagule flow, increased MVDISP dispersion among north and central sites emphasizes the influence of habitat complexity on these assemblages. Contrastingly, diatom assemblages at the south transect sites were identified by ANOSIM as being distinct to all other groups within the study, and exhibited lower dispersion among sites than north and central transect sites, demonstrating the effects of lower structural habitat complexity, longer periods of inundation, and the self-stabilizing nature of the unique periphyton mats commonly observed in the southern Everglades (Donar *et al.* 2004, Gaiser *et al.* 2011). Although diatoms were sampled during an inundated period at the end of the wet season prior to the initiation of construction activities at the swales sites, patterns of assemblage similarity were reflective of water quality patterns observed during periods of low water depth in December 2009 and January 2010. Taken together, these findings illustrate the importance of habitat heterogeneity and occasional isolation of habitat patches via drying in the maintenance of diatom community diversity in Everglades National Park.

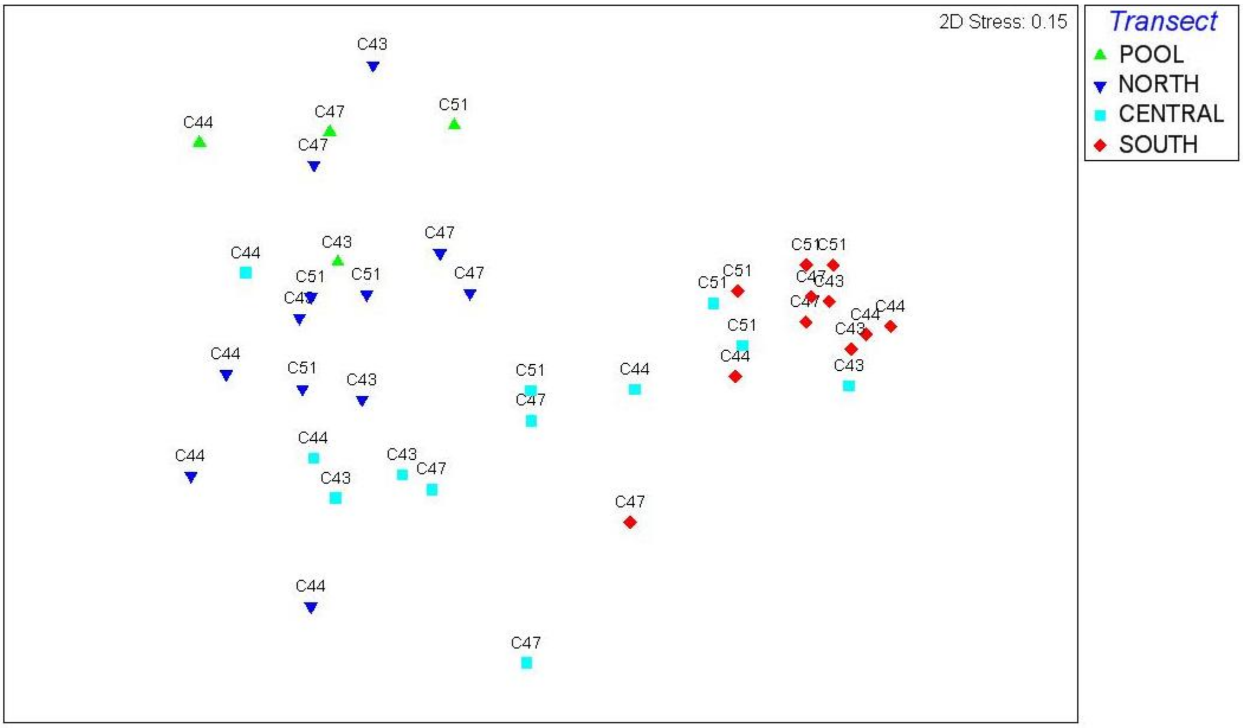

FIGURE 7: Non-metric Multidimensional Scaling ordination plot for diatom assemblage similarity among transect sites. Bray-Curtis similarity is the distance metric. Two dimensional stress = 0.15.

This study highlights the importance of monitoring and adaptive management as the Tamiami Trail modifications continue. Our data suggest that water column chemistry is prone to frequent fluctuations in response to weather patterns and anthropogenically-regulated hydrology, and is perhaps too confounded to serve as an ideal indicator of the effects of spreader swale installation. Diatom assemblages, on the other hand, are relatively unaffected by short-term changes in precipitation and hydrological management, but appear to be sensitive indicators of changes in environmental parameters associated with long-term change (Pan et al 2000, Gaiser et al 2006, Bramburger et al 2008). The composition of assemblages within the transitional area (central transect) is of particular interest, and shifts in the composition of these sites towards assemblages more characteristic of either the northern or southern transects could help to elucidate the effects of spreader swale installation on subtle habitat characteristics. Multi-variable models such as NMDS based on diatom community data will provide a useful means of monitoring compositional trends post-swale installation.

From a management perspective, it is important to be clear about the desired outcome of flow regime modifications. This study suggests the importance of habitat diversity in the maintenance of spatially and taxonomically diverse diatom assemblages, consistent with currently and classically accepted paradigms of structural complexity supporting biodiversity (MacArthur & MacArthur 1961, Pianka 1967). It is possible that the proposed hydrological modifications, which should result in continuous inundation at our north and central transect sites, will result in decreased spatial heterogeneity in the north and central transect diatom assemblages, and a shift to assemblages more characteristic of the southern sawgrass prairie. Alternatively, improved water conveyance into the park could increase propagule pressure, and result in a southward expansion of assemblages typically reported from the water conservation areas north of Tamiami Trail. The importance of a sensitive monitoring program and adaptive management strategies for projects improving water conveyance to Everglades National Park cannot be overstated. This study suggests that wetland diatom assemblages are sensitive, assimilative indicators of long-term trends, and may provide evidence complementary to traditional water quality analysis.

TABLE 4: A list of diatom taxa reported from the swales water grab transect sites.

Taxon	Number of Occurrences	Mean Relative Abundance when Present
Achnanthes exigua var. *constricta*	1	< 0.01
Achnanthes exigua var. *heterovalva*	10	0.02
Achnanthes ftsp 01	1	0.01
Achnanthes ftsp 07	7	0.09
Achnanthes ftsp 13	28	0.17
Achnanthes linearis f. *curta*	5	0.01
Achnanthes minutissima var. *gracillima*	19	0.02
Achnanthes minutissimum	2	0.01
Amphora ftsp 04	1	0.01
Amphora lybica	9	0.02
Amphora sulcata	7	0.01
Amphora veneta	1	0.01
Aulacoseira islandica	12	0.02
Aulacoseira italica	7	0.05
Bacillaria paxilifer	4	0.01
Brachysira neoacuta	13	0.01
Brachysira neoexilis	33	0.03
Caloneis bacillum	14	0.02
Caloneis sp. 1	1	< 0.01
Cyclotella meneghiniana	12	< 0.01
Cymbella ftsp 02	11	< 0.01
Cymbella ftsp 03	1	0.01
Cymbella ftsp 04	1	0.01
Cymbella ftsp 05	1	< 0.01
Cymbella laevis	1	< 0.01
Diploneis oblongella	16	0.02
Diploneis parma	26	0.01
Encyonema evergladianum	35	0.06
Encyonema ftsp 01	5	< 0.01
Encyonema ftsp 02	7	0.01
Encyonema ftsp 04	1	0.04
Encyonema ftsp 10	8	0.01
Encyonema ftsp 11	4	0.02
Encyonema silesiacum var. *elegans*	18	0.01
Encyonema sjsp 03	2	0.01
Encyonopsis ftsp 02	2	0.01
Encyonopsis microcephala	2	0.01

......*continued on the next page*

TABLE 4. (Continued)

Taxon	Number of Occurrences	Mean Relative Abundance when Present
Eunotia ftsp 01	4	0.01
Eunotia ftsp 03	1	< 0.01
Eunotia ftsp 09	18	0.05
Eunotia ftsp 10	28	0.10
Eunotia ftsp 11	1	0.01
Eunotia ftsp 12	3	0.03
Eunotia monodon morph 1	1	0.01
Eunotia monodon morph 2	20	0.03
Eunotia naegeli	11	0.04
Fragilaria delicatissima	7	0.04
Fragilaria filiformis	1	< 0.01
Fragilaria ftsp 07	1	< 0.01
Fragilaria ftsp 15	3	0.08
Fragilaria geocollegarum	11	0.04
Fragilaria synegrotesca	29	0.07
Fragilaria ulna	21	0.02
Gomphonema affine	16	0.02
Gomphonema affine var. *rhombicum*	2	0.01
Gomphonema auritum	1	0.01
Gomphonema clavatulum (cf)	1	0.01
Gomphonema contraturris	3	0.03
Gomphonema ftsp 18	1	0.01
Gomphonema gracile	6	0.01
Gomphonema intricatum	2	0.01
Gomphonema intricatum var. *vibrio*	11	0.01
Gomphonema parvulum	1	< 0.01
Gomphonema parvulum var. *exilissium*	2	0.01
Gomphonema parvulum var. *lagenula*	20	0.02
Gomphonema pratense	1	0.02
Gomphonema vibrioides (cf)	16	0.02
Gyrosigma obscurum	6	0.01
Lemnicola hungarica	1	0.03
Mastogloia lanceolata	1	< 0.01
Mastogloia asperuloides	1	< 0.01
Mastogloia smithii	24	0.44
Mastogloia smithii var. *lacustris*	10	0.02
Navicula brasiliana	1	< 0.01
Navicula constans	3	0.01
Navicula cryptocephala	17	0.01
Navicula ftsp 01	2	0.05
Navicula ftsp 02	4	0.01
Navicula ftsp 05	12	0.02
Navicula ftsp 06	6	0.01
Navicula ftsp 15	1	< 0.01
Navicula ftsp 17	3	0.02

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TABLE 4. (Continued)

Taxon	Number of Occurrences	Mean Relative Abundance when Present
Navicula ftsp 20	2	< 0.01
Navicula ftsp 25	2	0.01
Navicula ftsp 26	1	0.01
Navicula ftsp 29	2	0.03
Navicula integra (cf)	2	0.01
Navicula oblonga	1	0.01
Navicula pusilla (cf)	1	< 0.01
Navicula radiosa	32	0.03
Navicula radiosafallax	3	0.01
Navicula sjsp 01	7	0.01
Navicula stroemii	1	0.09
Navicula subtilissima	2	0.01
Nitzschia acicularis	1	0.01
Nitzschia amphibia f. *frauenfeldi*	3	0.01
Nitzschia amphibia	23	0.06
Nitzschia amphibia var. *rostrata*	8	0.01
Nitzschia ftsp 02	2	0.01
Nitzschia ftsp 06	1	< 0.01
Nitzschia ftsp 09	1	0.01
Nitzschia ftsp 24	1	0.01
Nitzschia nana	23	0.02
Nitzschia palea var. *debilis*	13	0.02
Nitzschia scalaris	13	0.01
Nitzschia semirobusta	29	0.06
Nitzschia serpentiraphe	2	0.01
Pinnularia acrosphaeria	5	0.01
Pinnularia ftsp 01	3	< 0.01
Pinnularia ftsp 10	1	0.01
Pinnularia ftsp 13	5	0.01
Pinnularia ftsp 20	2	0.03
Pinnularia gibba	1	< 0.01
Pinnularia microstauron	9	0.01
Pinnularia stryptoraphe	1	< 0.01
Pinnularia viridiformis	1	0.01
Pleurosigma salinarum	5	0.01
Rhopalodia gibba	10	0.01
Sellaphora pupula	10	0.01
Sellaphora pupula var. *rectangularis*	1	0.01
Stauroneis anceps	1	0.01
Stauroneis phoenicenteron	4	0.01
Stauroneis producta (cf)	1	< 0.01
Staurosirella pinnata	1	0.01
Thalassiosira bramaputrae	5	< 0.01
Thalassiosira ftsp 01	1	< 0.01
Terpinsöe musica	2	0.01

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