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The scaled chrysophyte flora from the Pinelands National Preserve of southern New Jersey, U.S.A.

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With 3 figures and 2 tables

Abstract: The distributions of scaled chrysophytes relative to physical and chemical conditions are described for waterbodies of the Pinelands National Preserve in southern New Jersey, U.S.A. The Pinelands represent the northern end of the Atlantic Coastal Plain and contain waterbodies that are largely shallow, acidic, poorly buffered, dilute and highly colored from high concentrations of iron and dissolved organic matter. The Pinelands sites are rich in scaled chrysophytes with 55 species representing the six genera, *Mallomonas*, *Synura*, *Chrysodidymus, Chrysosphaerella, Spiniferomonas* and *Paraphysomonas*. On average, 19 species were found per waterbody and several localities harbored 22 or more scaled chrysophyte taxa. Although the genus *Mallomonas* contained the most organisms with 41 species, scale counts of *Mallomonas* and *Synura* taxa were equally abundant. *Synura echinulata*, followed by *Chrysodidymus synuroideus, Synura sphagnicola, Mallomonas punctifera, Synura petersenii* and *Synura spinosa* were the most abundant species, each found in over 80 % of the study sites. Many of the species found in the Pinelands sites, including *Mallomonas acaroides* var. *muskokana*, *M. canina, M. calceolus, M. hindonii, M. paludosa, M. pugio* and *M. wujekii*, are acidobionts known to inhabit acidic localities. Taxa in the genera *Chrysosphaerella, Spiniferomonas* and *Paraphysomonas* were present, but rare. The biogeographies of selected taxa are discussed relative to other regions along the Atlantic Coastal Plain.

Key words: Pinelands National Preserve, New Jersey, scaled chrysophytes, biogeography, Pine Barrens

Introduction

Scale-bearing Chrysophyceae and taxa in the Synurophyceae (hereafter referred to as the scaled chrysophytes), are freshwater planktonic flagellates composed of overlapping siliceous scales (Nicholls & Wujek 2003; Siver 2003). Each taxon produces scales that bear unique designs and serve to distinguish between species and sub-specific taxa. Many species of scaled chrysophytes have been shown repeatedly to inhabit waters with specific chemical and physical characteristics resulting in their use as bioindicators (Kristiansen 1986, Siver 1995). As a result, the siliceous remains of scaled chrysophytes have been utilized successfully in reconstructing historical lake-water conditions (Smol 1995), including pH (e. g. Charles & Smol 1988, Siver & Hamer 1989, Cumming et al. 1992, Siver et al. 1999), specific conductance (Siver 1993), trophic conditions (Siver & Marsicano 1996), and the effects of landuse change on lake water chemistry (Siver et al. 1999).

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A primary goal of our research program is to document and inventory siliceous algae, including scaled chrysophytes and diatoms, in ponds and lakes along the eastern coast of North America with an emphasis on acidic waterbodies. To date, we have analyzed collections from over 300 waterbodies ranging from Florida to Newfoundland from which we have described over 30 new taxa, including nine *Mallomonas* taxa (Siver 1994, 1999, 2002a, 2002b, 2003, Siver & Marsicano 1993, Siver & Lott 2006), a new diatom genus *Brevilinea* (Siver et al. 2008) and new species in the diatom genera *Brachysira* (e.g Shayler & Siver 2004), *Eunotia* (Siver et al. 2006), *Frustulia* (Siver & Baskette 2004), *Neidium* (Siver et al. 2003), *Nupela* (Siver et al. 2007) and *Stenopterobia* (Siver & Camfield 2007). We have also proposed new combinations, emended numerous other descriptions of siliceous algae based on scanning electron microscopy observations and will soon report on a unique and new species of *Synura* from Newfoundland (unpub. data). Most of the new taxa were described from low pH localities, reflecting the acidic nature of many of our study sites (Siver 2001, Siver & Lott 2006, Lott & Siver 2005, Siver et al. 2004, 2005). Collectively, these efforts indicate that despite being a heavily studied region of the world, further exploration is warranted in order to fully describe and elucidate the biogeography of the microalgal flora.

To date, we have investigated approximately 60 waterbodies representing sites along the southern (Siver & Lott 2006) and middle (Lott & Siver 2005) portions of the Atlantic Coastal Plain bordering the east coast of North America. The purpose of this investigation is to report on the scaled chrysophyte flora from a suite of ponds and lakes in the Pinelands National Preserve of southern New Jersey which represents the northern end of the Atlantic Coastal Plain. The work represents not only the first survey of scaled chrysophytes from The Pinelands National Preserve, but also the first in depth study of these organisms from New Jersey.

Site description

The Pinelands National Preserve represents a 4.45 x 10^5 hectare mosaic of forests, wetlands, ponds, streams and farms situated on the outer Atlantic Coastal Plain in southern New Jersey (Zampella et al. 2001). Although historically the Pinelands, also known as the Pine Barrens, experienced significant human disturbance, today the region is approximately 75 % forested, sparsely populated with scattered areas of wetland and upland agriculture (Zampella et al. 2001). Pines, cedars and oaks dominate the porous, acidic sandy soils and the understory consists largely of members of the heath family, including blueberries, laurels and huckleberries (Boyd 1991). The Pinelands were extensively harvested for timber during the 1700's and 1800's and the region once supported thriving bog iron and glass manufacturing industries (Boyer 1931, Boyd 1991). Today, despite its close proximity to Philadelphia and New York City, the region is surprisingly devoid of human influence with the exception of blueberry and cranberry farming in selected acidic wetland areas.

The Pinelands lie atop the Cohansey Aquifer, which delivers acidic and nutrient poor water to the many lakes, small ponds, wetlands and streams (Johnson & Watt 1996, Zampella et al. 2001). Waters draining the forested landscapes are typically darkly colored and low in divalent base cations, phosphorus and nitrogen (Morgan & Good 1988, Zampella 1994). The dark reddish color of the water is caused by a combination of high iron concentration and elevated colored dissolved organic matter derived from the cedar and pine forests. Most waterbodies have a pH below 5.0 and range in specific conductance between 23–76 $\mu S \cdot cm^{-1}$ (Morgan & Good 1988, Zampella 1994, 1991). Waterbodies receiving runoff from agricultural or residential lands usually have higher pH, calcium, magnesium and nutrient concentrations. Using a combination of only pH and specific conductivity, Zampella (1991) was able to explain 79 % of the variability in landuse draining the regions streams.

The Pinelands represent the northern or southern distributional limit for numerous terrestrial plants (Boyd 1991). *Sphagnum* dominates many of the waterbodies, along with macrophytes within the genera *Scirpus*, *Eleocharis*, *Nymphaea*, *Nuphar*, *Utricularia*, *Sarracenia* and *Drosera*

(Zampella 1991). According to Hastings (1984), the fish flora is characteristic of acidic waters and contains many native taxa that are restricted to the region. In addition to the scaled chrysophytes, we have documented the diatom flora of the study lakes and will report on them in a later publication. Briefly, the diatom flora is dominated largely by species within the genera *Eunotia* and *Frustulia*, with lesser contributions from *Pinnularia*, *Aulacoseira*, *Neidium*, *Nupela*, *Brachysira*, *Kobayasiella* and *Stenopterobia*.

Methods

Twelve shallow waterbodies in the Pinelands National Preserve in southern New Jersey were sampled for plankton, periphyton and surface sediment samples in June 2004. Plankton samples were made with a 10 µm mesh net from the center of each waterbody. Representative periphyton samples were taken from microhabitats around the perimeter of each lake and stored in whirl-pack bags. For this study, aliquots from each periphytic collection were combined into a single mixed sample. Surface sediments were taken from the deep point of each lake using a Glew gravity corer (Glew 1989) and sectioned on site with a mechanical extruder into one cm sections (Glew 1988). Water samples for chemical analysis were taken at a depth of 1 m from the center of each waterbody. The Secchi disk depth and geographic coordinates were taken with a 20 cm black and white disk and a Trimble Geoexplorer GPS unit, respectively.

Chemical analyses followed the procedures of Ahrens & Siver (2000). Briefly, pH was measured on the same day of collection with a Fisher Acument 640-A pH meter. Conductivity and temperature were measured with a Hydrolab DataSonde 4A. Alkalinity was measured in tripicate by the Gran titration method (Wetzel & Likens 1991) using Fisher reagent-grade 0.02N acid titrant. Chlorophyll-*a* was extracted in acetone and estimated using the trichlorometric method (APHA 1985). Total phosphorus was determined using the stannous chloride-ammonium molybdate colorimetric assay after a persulfate digestion (APHA 1985). For total nitrogen, samples were first digested using the alkaline persulfate oxidation method (D'Elia 1977) and then analyzed using the N-(1-napthyl)-ethylenediamine dihydrochloride method (U.S. EPA method 353.2, 1983). Sulfate and chloride were estimated with anion chromatography using a Dionex IC 2000 (U.S. EPA 1983). Base cations were measured using flame atomic absorption spectroscopy with a Perkin Elmer 2380 spectrophotometer. Water color was determined by the platinum-cobalt method (APHA 1985). Aerial photographs, on-site images and chemical conditions at the time of collection for all sites can be found at http://silicasecchidisk.conncoll.edu.

Approximately 1 ml of each plankton sample tow was air dried onto heavy duty aluminum foil the day of collection. The surface sediment samples (top one-cm section) and mixed periphyton samples were oxidized with a sulfuric acid-potassium dichromate solution according to Marsicano & Siver (1993), and aliquots of each resulting slurry were air dried onto both glass coverslips and heavy duty aluminum foil. The aluminum foil samples were used for observation with scanning electron microscopy (SEM) according to the procedures of Siver (1987). Essentially, samples were attached onto an aluminum stub with Apiezon® wax, coated with a gold and palladium mixture for one minute with a Polaron model E5100 sputter coater and observed with a Leo 982 SEM or a Leo 435V SEM. Glass coverslips were mounted onto glass slides with Naphrax mounting medium and analyzed with a Leica DMR or an Olympus BH51 light microscope.

All samples were used to identify, record and image scaled chrysophytes with SEM. Approximately 300 scales were enumerated for each sample using the surface sediment glass slide preparations with light microscopy (LM) after the sample was first thoroughly examined with SEM. In this manner identifications were confirmed with SEM. Percentages of scales for each sample can be found at our web site. For the purposes of this paper, we used the scale abundances to score each taxon as dominant, abundant, common, rare or very rare in each sample using the following criteria: Dominant = scale abundance >39.9 %; Abundant = 20–39.9 %; Common= 5–19.9 %;

Rare = 1–4.9 % and; Very Rare = <1 %. Taxa in the genera *Paraphysomonas* and *Spiniferomonas* were not included in the counts, but their presence and absence were noted at each site (Table 2).

Results

Chemical and physical characteristics

The waterbodies of the Pinelands are largely shallow, acidic, poorly buffered, dilute and contain high concentrations of colored dissolved organic matter (Table 1). With the exception of two sites, Indian Mills and Atco, the remaining eleven ponds and lakes were highly acidic and had a small range in pH from only 4.1 to 6.3. Unlike the other localities, Indian Mills is situated on the western edge of the Pine Barrens within a watershed that has been heavily altered and contains numerous residential homes. Except for Indian Mills, Atco and Paradise all of the study sites were poorly buffered with alkalinity valves below 53 µeq $\cdot$ L^{-1}. Indian Mills had an alkalinity of 378 µeq $\cdot$ L^{-1} and also contained significantly higher concentrations of base cations relative to the other sites indicating the influence of residential land use on water chemistry.

The waterbodies were low in dissolved salts with specific conductance values ranging from 28 to 209 µS $\cdot$ cm^{-1} (Table 1). Again, except for the Indian Mills and Atco sites, the specific conductance of all sites was below 75 µS $\cdot$ cm^{-1}. In general, sodium and chloride were the dominant cation and anion in the study lakes with concentrations ranging from 0.07 to 0.65 meq $\cdot$ L^{-1} and 0.12 to 0.91 meq $\cdot$ L^{-1}, respectively (Table 1). Dissolved sulfate concentrations ranged from 0.08 to 0.48 meq $\cdot$ L^{-1}. Given the poorly buffered conditions of most of the waterbodies, it is not surprising that the concentrations of calcium and magnesium are low (Table 1).

Except for Indian Mills, Absegami and Fred's, the waterbodies are highly colored ranging from 64 to 251 Pt-Co units (Table 1). Eight of the sites had Pt-Co readings above 100 and had a characteristic deep reddish color presumably derived from the cedar and pine forests in the surrounding forests. As a result of the highly humic-stained waters, light penetration is low in the Pinelands waterbodies resulting in low Secchi disk depths (Table 1). Nine of the sites had Secchi disk depths below 1.0 meters.

Despite relatively high measured concentrations of TN, TP and chlorophyll-*a*, growth of phytoplankton as observed in water samples and plankton tows was low and the high concentrations are most likely the result of the high concentrations of dissolved organic matter. This same condition was observed in waterbodies from the central Atlantic Coastal Plain in North Carolina (Lott & Siver 2005).

Scaled chrysophytes

A total of 55 species of scaled chrysophytes representing the six genera, *Mallomonas*, *Synura*, *Chrysodidymus*, *Chrysosphaerella*, *Spiniferomonas* and *Paraphysomonas*, were observed in the suite of 12 waterbodies in the Pinelands National Preserve (Table 2; Figs 1–3). The number of taxa uncovered per site ranged from 9 to 30, with a mean of 19 per locality. An impressive 30 species were present in Atco and three other sites, Atsion, Batsto and Indian Mills, each had over 22 scaled chrysophytes, marking these as the four localities with the highest species diversity. Indian Mills, the site with the highest pH and nutrient concentrations, contained many of the rarer species in the Pineland sites and represented the only locality where *Mallomonas elongata*, *M. lelymene* and *M. schwemmlei* were found. As is commonly observed, the majority of species belong to the genus *Mallomonas*, with 41 representatives, but the scale counts were equally dominated by both *Mallomonas* and *Synura*.

Table 1. *Physical and chemical data for 12 waterbodies in the Pinebarrens of New Jersey.*

Name	Latitude	Longitude	pH	Spec. Cond. (µS/cm)	Secchi (meters)	Color (Pt-Co Units)	Total P (µg/L)	Total N (mg/L)	CHL-*a* (µg/L)	Sodium (meq/L)
Absegami	N 39° 37 35.90	W 74° 25 33.70	4.3	66	1.2	47	9	0.31	2	0.36
Atco	N 39° 40 14.71	W 74° 49 32.36	6.5	150	0.4	271	57	3.63	14	0.53
Atsion	N 39° 44 23.39	W 74° 43 52.52	4.5	47	0.7	251	14	0.79	22	0.24
Batsto	N 39° 38 48.55	W 74° 39 11.69	5.8	47	0.7	188	14	0.72	3	0.2
Chatsworth	N 39° 48 54.91	W 74° 32 45.28	4.2	49	0.4	239	33	0.7	39	0.15
Egg Harbor	N 39° 33 29.15	W 74° 36 29.38	4.2	60	1.4	102	8	0.43	5	0.18
Fred	N 39° 23 39.29	W 74° 31 47.99	5.1	65	bottom	47	5	0.51	2	0.28
Harrisville	N 39° 39 53.14	W 74° 31 27.21	4.4	40	1	63	11	0.3	5	0.12
Indian Mills	N 39° 47 44.52	W 74° 44 32.57	6.8	209	bottom	50	42	2.99	7	0.65
Oswego	N 39° 44 08.64	W 74° 29 10.44	4.3	41	0.5	109	10	0.41	34	0.14
Paradise	N 39° 41 14.26	W 74° 43 45.67	6.3	75	0.8	102	14	0.9	2	0.33
Pilgrim	N 39° 37 37.23	W 74° 26 42.05	4.5	29	1	64	12	0.22	3	0.11

Table 2. Scaled chrysophyte observations from 12 New Jersey Pineland waterbodies. VR = very rare; R = rare; C = common; A = abundant; DDD = dominant and X = noted in SEM observations. See text for details.

	Absegami	Atco	Atsion	Batsto	Chatsworth	Egg Harbor	Fred	Harrisville	Indian Mills	Oswego	Paradise	Pilgrim
Chrysodidymus synuroideus	C	R	R	C	R	C	R	C	R	R		C
Chrysosphaerella brevispina		V								R		
Mallomonas acaroides var. muskokana			R	R	C			R	V	C	R	V
M. akrokomos				R			V	V	V		R	
M. annulata		V										
M. binocularis						R		C		R		
M. calceolus		V	V	V			R					
M. canina	R		R	V	V	C				C		V
M. caudata	C	R										
M. cratis		V										
M. cristata	R	V		V			R		V		V	V
M. cyanthellata var. kenyana			A	V	A							
M. delanciana			R									
M. doignonii		V										
M.elongata									V			
M. favosa							R					
M. guttata		V										
M. guttata f. simplex											V	
M. hamata							V			V		
M. heterospina		R					V					
M. hindonii	R	V	R			C		C			V	
M. insignis		V		V		V			R			V
M. lelymene									V			
M. lychenensis		V										
M. mangofera		R	R	V	C			V	V	V	R	V
M. matvienkoae			V	V		R	R		R		R	
M. multisetigera	R		V								V	
M. ouradion			V					C		R		
M. paludosa	C		R			V	V	R		V		C
M. papillosa		R		R					R		R	
M. parvula		V									V	
M. pillula		V		V								
M. pugio	R		V	V		R		V				R
M. pumilio		V							V			
M. punctifera	R	V	C		R	R	V	V	V	C	V	C
M. rasilis				V								V
M. retifera		V							V			
M. schwemmlei									V			
M. striata		V										
M. tonsurata		V							R			
M. torquata group	R	R	C	R	R			R	V	R		
M. transsylvanica				V								
M. wujekii	R		C					R		C		R
Paraphysomonas vestita			X	X			X					
Spiniferomonas abei			X									
Sp. bourrellyi						X						
Sp. takahashii			X									
Sp. triangularis		X							X			
Sp. trioralis	X	X	X			X	X	X		X		X
Synura echinulata	A	D	A	D	A	A	D	D	D	A	D	A
S. lapponica			V	V				V				C
S. petersenii	C	R	V	R		C	R	R	C	R	C	C
S. sphagnicola	C	R	C	C	R	C	R	C	V	C	C	R
S. spinosa		R	V	R		R	C	V	C	V	C	R
S. uvella		R	R	R			R		C		C	
55 = Total Number of species	15	30	26	23	9	15	17	18	22	17	16	17

An impressive 24 and 17 species were recorded in greater than 25 % or 50 % of the samples, respectively (Table 2). These include taxa such as *M. cristata*, *M. insignis* and *M. wujekii* that are not usually reported among the more common scaled chrysophytes in studies from North America. Six species, *Chrysodidymus synuroideus*, *Mallomonas punctifera*, *Synura echinulata*, *Synura sphagnicola*, *Synura petersenii* and *Synura spinosa*, were found in over 80 % of the localities and were the most abundant taxa in the Pineland sites (Table 2). *Synura echinulata* was by far the most important species, being either the dominant organism or a co-dominant in all of the sites. *Synura sphagnicola* was a co-dominant in seven localities, while *C. synuroideus* and *S. petersenii* were well represented at five sites.

Other important representatives of the scaled chrysophyte flora in Pinelands waterbodies included a suite of species commonly reported from acidic localities such as *Mallomonas acaroides* var. *muskokana*, *M. canina*, *M. calceolus*, *M. hindonii*, *M. paludosa*, *M. pugio* and *M. wujekii*. Collectively, these acidic species accounted for a significant component of the flora and were

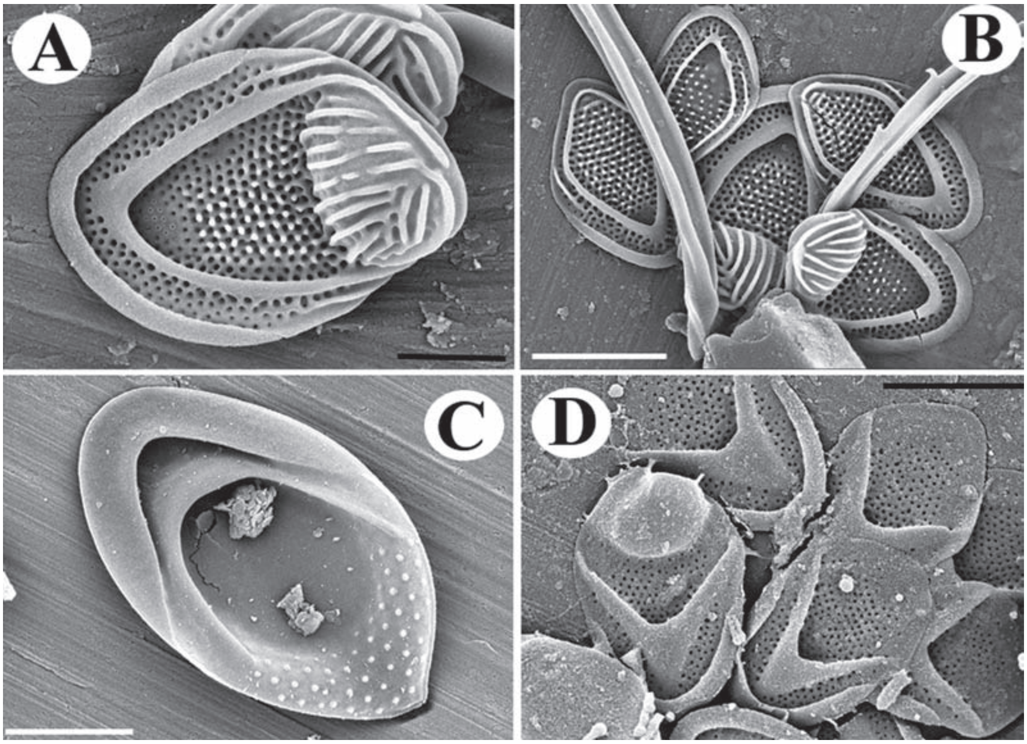

Fig. 1. Scaled chrysophyte scales from the Pinelands that are rarely found. A) Domed scale of *Mallomonas wujekii*. Scale bar = 1 µm B) *Mallomonas wujekii* scales, domed and domeless. Scale bar = 2 µm C) *Mallomonas insignis* scale. Scale bar = 2 µm D) *Mallomonas cristata* scales. Scale bar = 2 µm.

co-dominants in most sites. In addition, the Pineland sites harbored a number of cosmopolitan species often reported from a wider variety of conditions, including *Mallomonas akrokomos*, *M. matvienkoae*, *M. torquata*, *Spiniferomonas trioralis*, *Synura spinosa* and *S. uvella*. In general, these taxa were both less abundant than previously noted species and more common in the sites with higher pH or nutrient concentrations (e. g. Fred's and Indian Mills).

Discussion

The Pinelands National Preserve represents the northern boundary of the Atlantic Coastal Plain that within the United States stretches from Florida to southern New Jersey. As has been reported from other studies along the Atlantic Coastal Plain in northern Florida (Greis 1985, Siver & Lott 2006), South Carolina (Gaiser & Johansen 2000) and North Carolina (Lott & Siver 2005), waterbodies in the Pinelands are shallow, highly acidic, dilute and often significantly humic-stained. Likewise, the ponds are low in dissolved salts, especially divalent cations, with Na^+ and Cl^- representing the most abundant cation and anion species, respectively. In addition, all of the waterbodies surveyed along the Atlantic Coastal Plain lack significant winter ice, are classified as warm monomictic and are situated in non-glaciated regions. Thus, from a physical and chemical point of view, it would not be surprising to find elements of similarity between the

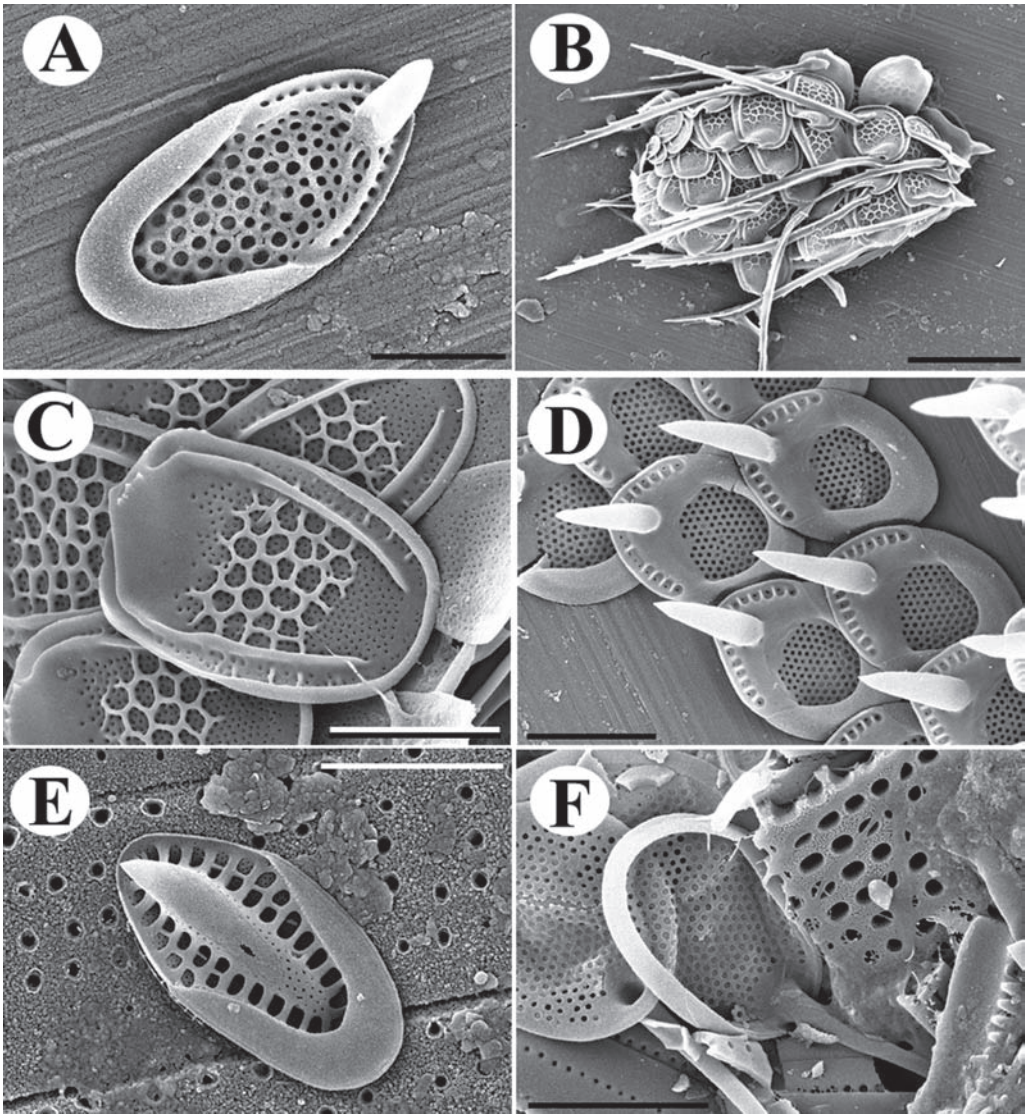

Fig. 2. Commonly occurring scaled chrysophytes in the Pinelands study. A) *Chrysodidymus synuroideus* scale. Scale bar = 1 µm B) Whole cell of *Mallomonas punctifera*. Scale bar = 5 µm C) Close up of a *Mallomonas punctifera* scale. Scale bar = 2 µm D) *Synura echinulata* scales. Scale bar = 2 µm. E) *Synura petersenii* f. *kufferathii* scale. Scale bar = 2 µm. F) *Synura sphagnicola*. Scale bar = 2 µm.

scaled chrysophyte flora of the Pinelands and ones reported from Florida (Siver & Lott 2006) and North Carolina (Lott & Siver 2005).

It is well known that pH is a primary factor governing the distribution of scaled chrysophytes at the species and sub-specific levels and that many taxa are found to be differentially distributed along a pH gradient (Siver 1989). As was reported from other regions along the Atlantic Coastal Plain (Siver & Lott 2006, Lott & Siver 2005), the scaled chrysophyte flora of the Pinelands were

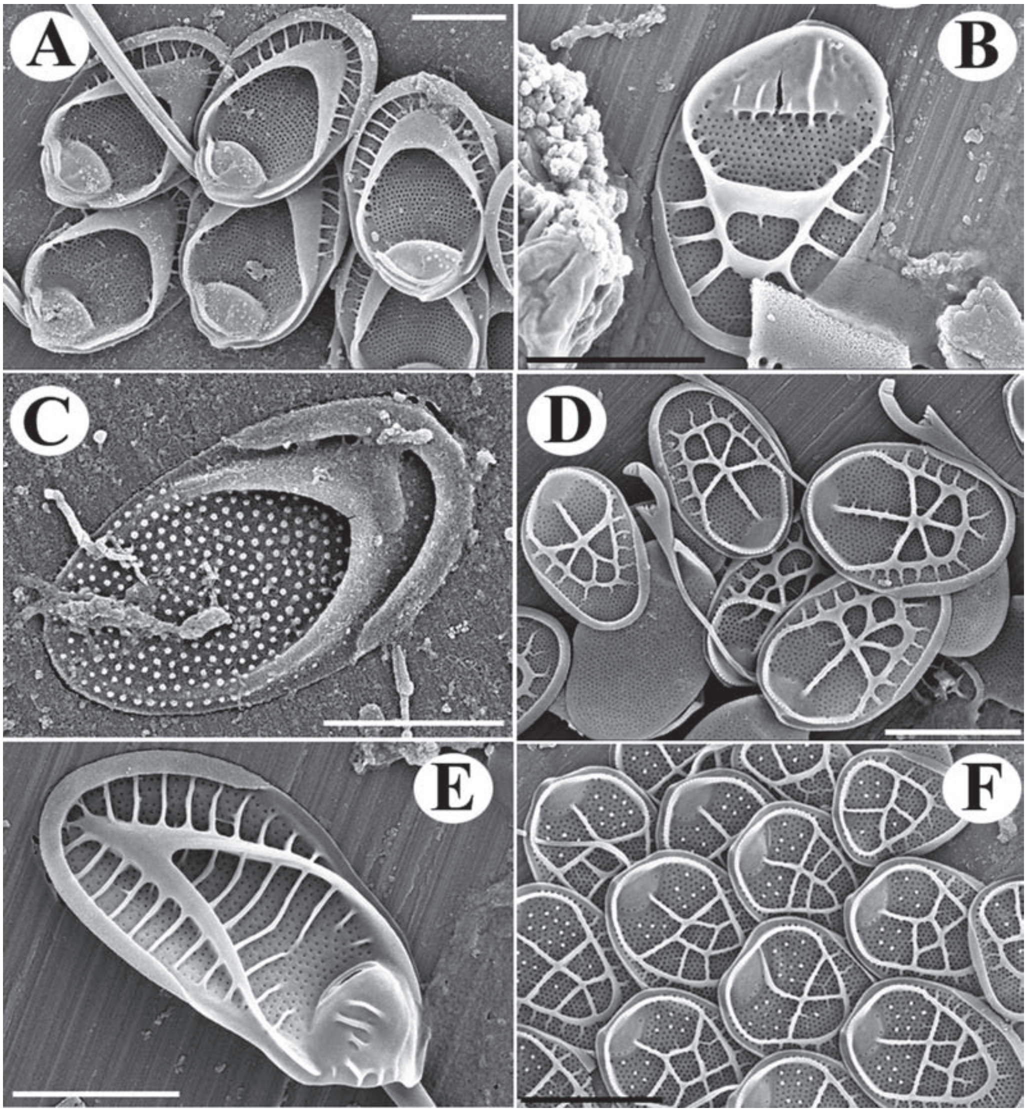

Fig. 3. Species commonly occurring in acidic habitats. All scale bars = 2 µm. A) *Mallomonas acaroides* var. *muskokana* body scales. B) *Mallomonas pugio* scale. C) *Mallomonas calceolus* scale. D) *Mallomonas hindonii* scales and bristles. E) *Mallomonas paludosa* scale. F) *Mallomonas canina* scales.

also clearly dominated with taxa known to inhabit acidic localities. Many of the most abundant species, including *Chrysodidymus synuroideus*, *Mallomonas acaroides* var. *muskokana*, *M. canina*, *M. hindonii*, *M. paludosa*, *M. pugio*, *Synura echinulata* and *S. sphagnicola*, are all acidbiontic species with low abundance weighted mean pH values (Siver 2003 and references therein). In fact, based on an extensive review of the literature, Siver (2003) noted that this group of species typically co-occur in acidic localities and are especially abundant below a pH of 6. With the exception of *Mallomonas punctifera* and *Synura spinosa*, common and widespread taxa representing the mid-pH and high-pH categories as outlined by Siver (2003) were very rare or noticeably absent from the Pine Barren localities, further emphasizing the importance of pH in explaining the composition of the flora.

Three additional species, *M. wujekii*, *M. mangofera* and *M. binocularis*, are noteworthy in regards to their distribution in predominately acidic waterbodies. *Mallomonas wujekii* was originally described from the Ocala National Forest where it was reported from over 70 % of the localities examined and to have an AWM pH of 4.9 (Siver 1994, Siver & Lott 2006). It was subsequently found to be an important component of ponds in coastal North Carolina with pH below 5 (Lott & Siver 2005), consistent with our current findings where it was observed in five Pine Barren lakes ranging from pH 4.3 to 4.5 (Table 1). Based on our collective efforts, *M. wujekii* is clearly among one of the most acidobiontic scaled chrysophytes known. *Mallomonas binocularis* was also originally described from the Ocala National Forest (Siver 2002b) where it was found in acidic waterbodies with pH below 5.3. Like *M. wujekii*, *M. binocularis* has since been found in acidic localities from North Carolina and now the Pinelands, indicating that both taxa are probably widely distributed over the Atlantic Coastal Plain, especially in acidic environments. *Mallomonas mangofera*, a cosmopolitan taxon widely distributed in North America, South America and Europe (Kristiansen 2002), was especially abundant in acidic localities of the Pinelands as it was in other regions of the Atlantic Coastal Plain (Siver & Lott 2006, Lott & Siver 2005) indicating that it too probably prefers acidic conditions.

Besides pH, specific conductance and the concentration of dissolved humic substances have also been shown to influence the distribution and abundance of scaled chrysophytes and these factors are undoubtedly influencing the flora in waterbodies of the Pinelands. Although a few exceptions have been noted, the diversity and importance of scaled chrysophytes are typically highest in dilute localities low in specific conductivity (Roijackers & Kessels 1986, Siver & Hamer 1989). In fact, Siver and Hamer (1989) found specific conductance to be as important as pH in explaining species distributions and noted a maximum diversity in waterbodies near 40 $\mu S \cdot cm^{-1}$. Historically, scaled chrysophytes have also routinely been reported to prefer humic-stained waters (e. g. Dürrschmidt 1980, Kristiansen 1981, Cronberg 1989) and this probably accounts for the observation that these organisms also prefer smaller forest ponds (Siver 2003). Interestingly, Siver (2003) reported that the number of species found at any site tends to decline as the pH drops below 5, a situation not evident in the Pineland sites. However, the studies summarized by Siver (2003) included numerous data representing clearwater lakes where the pH declined below 5 as a result of acidic deposition and few data from naturally acidic, humic-stained waterbodies similar to sites in the Pinelands. High species diversity in our study sites is most likely a combination of the preference of scaled chrysophytes for high levels of dissolved humic matter (Wee & Gabel 1989, Siver & Wujek 1993, Eloranta 1995), coupled with low pH and low specific conductance.

Now that we have information from the southern (Siver & Lott 2006), central (Lott & Siver 2005) and northern portion (this study) of the Atlantic Coastal Plain, several patterns regarding the biogeography of selected scaled chrysophyte species are noteworthy. Including the Pinelands sites, *Mallomonas wujekii* has now been documented as one of the most abundant species along the entire Atlantic Coastal Plain. This is of special interest since *M. wujekii* is not known from any other region worldwide, including ones that have been intensely investigated from nearby southern New England (Siver 1991, Siver 2001). Two other less abundant species, *M. binocularis* and *M. delanciana*, have the same restricted distribution as *M. wujekii* and are also conspicuously lacking in more northern waterbodies. Several other species, *Mallomonas galeiformis* and *Chrysosphaerella longispina*, are distributed in just the opposite manner where they are important constituents of the floras in northern glaciated regions (Nicholls 1988, Siver 1991, 1993, Kristiansen 2002), but have not been observed anywhere along the Atlantic Coastal Plain. Even though *Mallomonas wujekii* is readily distinguished from *M. galeiformis*, these species share many features. Perhaps these two taxa became geographically isolated during past glaciations and have since evolved into separate species. Like *C. longispina*, *Synura lapponica* is a taxon common in temperate lakes across northern Europe and North America most often found during colder months of the year (Siver & Hamer 1992). The Pinelands represents the southern most distribution of this species based on verification with electron microscopy.

Nicholls (1982) and Kristiansen (1982) described *M. hindonii* and *M. canina* from acidic localities in Ontario, Canada and Denmark, respectively. Although the presence of shield papillae and hooked bristles are the best means of distinguishing these species, some scales of *M. canina* have few papillae or lack them altogether making identification of isolated scales problematic. As part of this study, we had the opportunity to examine numerous scales of both taxa and consistently found that on scales of *M. hindonii* two or three primary ribs originated from the center of the transverse rib on the posterior side, confirming original observations made by Nicholls (1982) and serving as another means to separate scales of the two species. Interestingly, *M. hindonii* was common in waterbodies of the Pinelands, but was not present in either North Carolina or Ocala and was rare in southern New England (Siver 1991, Siver 2001). The Pineland sites and those in Ontario studied by Nicholls (1982) that harbor *M. hindonii,* share characteristics of being acidic and humic-stained. Lastly, the biogeographic pattern of another North American endemic, *Mallomonas duerrschmidtiae*, is worth mention. This species is widely distributed in southern New England (Siver 1991, 2001), in the Ocala National Forest and we have found it to be one of the dominant scaled chrysophyte species in waterbodies from Maine, Nova Scotia and Newfoundland (unpublished data). However, it is conspicuously absent in the North Carolina and Pinelands localities, possibly due to the extreme acid content coupled with the unusually high levels of dissolved humic content. Further work is necessary to elucidate the combination of factors that control the distribution of this important planktonic species.

Several common and globally widespread scaled chrysophyte taxa were very rare or noticeably absent from our study sites. *Mallomonas caudata* and *M. crassisquama*, both considered among the most widespread and common species within the genus (Siver 1991, Kristiansen 2002), were rare or lacking from the Pinelands sites. Other commonly reported *Mallomonas* species, including *M. tonsurata*, *M. striata* and *M. pseudocoronata*, were likewise poorly represented. In addition, the genera *Spiniferomonas* and *Paraphysomonas* were rare in the New Jersey Pine Barrens. Even though we recorded five species of *Spiniferomonas*, including the rarely reported *S. triangularis*, *S. trioralis* was the only one found in more than two sites. Two *Spiniferomonas* species, *S. abei* and *S. takahashi*, are known acidic organisms (Nicholls 1981, Siver 1988), but each was observed in only one site. It was also surprising to only record one species of *Paraphysomonas*, despite an intensive search with SEM. However, it is not surprising that the one species we did find was *P. vestita* since this is by far the most widely and reported taxon within the genus. It is possible that with additional efforts that include spiking incubated water samples with organic compounds, additional species of *Paraphysomonas* would be observed.

In summary, the waterbodies of the Pinelands National Preserve harbor a diverse scaled chrysophyte flora that is especially indicative of acidic, poorly buffered localities. On average, the number of species observed per waterbody was highest in Pinelands sites relative to other regions examined along the Atlantic Coastal Plain. Despite differences in species diversity, elements of the Pinelands flora are clearly similar to other the other regions investigated along the Atlantic Coastal Plain.

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