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Cyanobacteria Dominance in the Oligohaline Waters of Back Bay, Virginia

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ABSTRACT Back Bay and its flora have historically been influenced by the interaction of freshwater flow in combination with frequent intrusion of saline water into its basin. These events have resulted in a dynamic environmental setting influencing the abundance and composition of its phytoplankton community. Dominating these oligohaline waters is a diverse representation and high abundance of freshwater filamentous and colonial cyanobacteria. These include the nonheterocystous *Planktolyngbya contorta, Planktolyngbya limnetica*, and *Pseudanabaena limnetica*, taxa implicated as bloom producers in Bay waters with N:P molar ratios ranging from 23:1 to 74:1.
Key Words: algal blooms, Back Bay, cyanobacteria, N:P ratios, Virginia.

INTRODUCTION Back Bay is a shallow (ca. 2 m deep), oligohaline body of water, located along the Virginia Atlantic Coastal Plain and separated from the Atlantic Ocean by a narrow barrier land complex having a high residential population (Figure 1). The Bay has a surface area of ca. 77.7 km^2 and a watershed of ca. 27,000 ha (Mann and Associates, Inc. 1984). Freshwater inflow comes from several creeks along its western and northern borders, and during major storms or hurricanes oceanic water can enter along its eastern flank. There are occasions when wind-driven estuarine waters enter at its southern border from Currituck Sound (Norman and Southwick 1991a). These intrusions have periodically influenced the salinity levels in the Bay with its highest mean salinity (11.4 parts per thousand [ppt]) noted following an August 1933 hurricane. However, the highest recorded reading in Back Bay was in March 1962 when oceanic waters breached the eastern barrier dune complex, resulting in a salinity of 26.0 ppt (Norman and Southwick 1991a). As freshwater continues to enter Back Bay from its bordering creeks, the increased saline conditions gradually are reduced (e.g., <5.0 ppt). Human disruption to the Bay's salinity also was common during the 1970s with the pumping of coastal waters into the Bay. This action at the request of recreational interests resulted in increased salinities and the loss of what were once extensive stands of Eurasian milfoil (*Myriophyllum spicatum* L.) in Back Bay that to this date have not fully recovered. When Comegys (1977) conducted the initial phytoplankton study of Back Bay, the annual salinity ranged from 0.89 to 3.77 ppt. He reported cyanobacteria and chlorophytes were the dominant algae, with diatoms and cryptophytes as subdominant components. In a subsequent phytoplankton study, Marshall (1991) reported salinity ranged from 1.9 to 4.9 ppt in 1986 and 1.4 to 3.8 ppt in 1987. During this period there was the continued dominance by cyanobacteria, along with an array of diatoms, chlorophytes, and a prominent autotrophic picoplankton (cyanobacteria) population. Two subsequent Back Bay reports also have reported cyanobacteria dominance during the autumn/winter period, along with increased presence of diatoms and chlorophytes during those colder months (Marshall 2006, Bowman and Marshall 2009). There has been no major intrusion of coastal waters into Back Bay in recent years, with waters from Currituck Sound continuing to be only a limited and periodic source of saline waters entering Back Bay.

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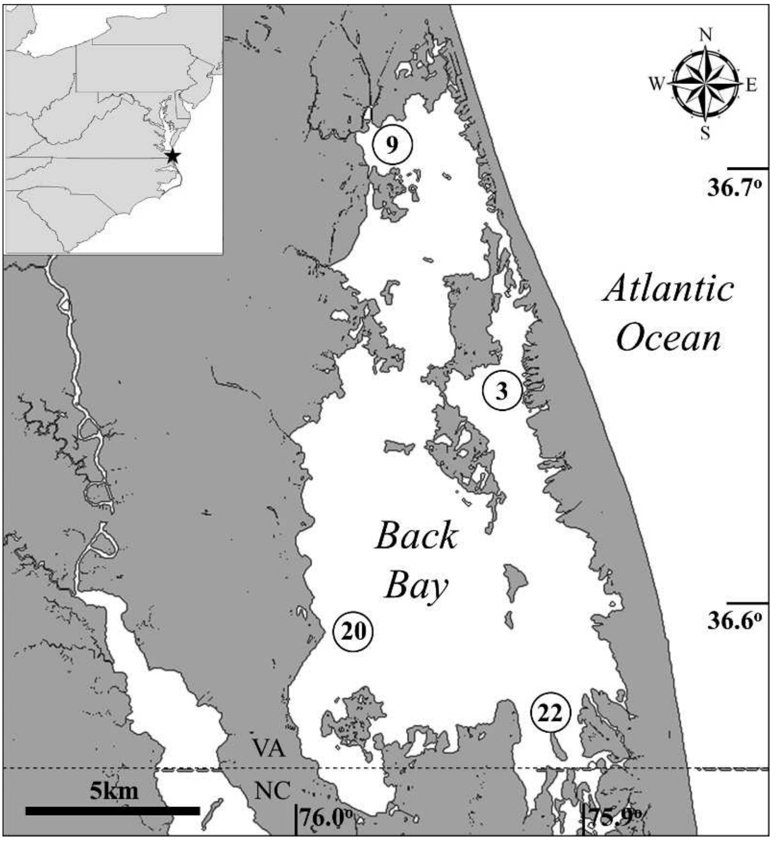

Figure 1. Location of collection sites (stations 3, 9, 20, and 22) for phytoplankton and water quality analysis in Back Bay, Virginia, during 2006 and 2007.

The objectives of this study were to identify and review the present phytoplankton status in Back Bay in relation to current water quality variables. Potential toxin producing algae in Back Bay are also identified.

METHODS Surface (<0.5 m) water samples were taken for phytoplankton analysis at Stations 3, 20, and 22 on 19 September 2006; Stations 3, 9, and 20 on 22 May 2007; and Stations 3, 20, and 22 on 25 September 2007 (Figure 1). These stations represented a broad expanse of the Bay and were also water quality monitoring sites visited by the Virginia Department of Environmental Quality. At each station, a series of 10 replicate water samples (100 ml each) were taken to provide a 1,000-ml composite, which was preserved with Lugol's solution (2 ml) on station. In the laboratory, each composite sample was passed through a series of settling and siphoning steps to produce a 20-ml concentrate that was placed in a settling chamber and examined using a Zeiss inverted plankton microscope (300×, 600× magnification) following a modified Utermöhl procedure (Marshall 1991). For each sample, a minimum of 200 cells (or filaments) in 10 random fields were examined for determining species identity and abundance. From these concentrations of filaments and cells, their numbers per ml were calculated (Venrick 1978). The cyanobacteria were divided into two categories; the filamentous taxa counted by the number of filaments ml^{-1}, and the nonfilamentous cyanobacteria and other algae by their cells ml^{-1}. When on station, surface (<0.5 m) water samples also were taken by personnel from the Virginia Department of Environmental Quality (VDEQ) for water quality measurements. Standard water quality procedures were fol-

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lowed for these determinations as proscribed by the VDEQ. Wind speeds were obtained from the Norfolk Air Station Oceana data records.

RESULTS AND DISCUSSION Throughout the study the waters sampled were oligohaline (<5.0 ppt) having a mean of 1.68 ppt and ranging from 1.1 to 3.2 ppt, with water temperatures fairly similar during each collection period at between 23.5°C and 25.7°C. (Table 1). The mean pH was 7.7, with a range from 6.0 to 8.4. Chlorophyll station values were from a low of 10.0 μg L^{-1} in May 2007 at station 20 to a high of 58.4 μg L^{-1} at station 22 in September 2007. The mean oxygen concentration for September 2006 and May 2007 was 7.8 mg L^{-1} (no oxygen readings were taken in September 2007). Total nitrogen and total phosphorus ranged from 0.85–2.34 and 0.04–0.08 mg L^{-1} respectively. The mean N:P ratio (molar equivalents) for all stations and collection dates was 53:1. Norman and Southwick (1991b) indicated that sources of nutrients into these waters would include runoff from adjacent agriculture sites, campsites, and from sediment introduced to the water column during periods of wind-induced turnover events. The mean station N:P ratios for September 2006, May 2007, and September 2007 were 46:1, 36:1, and 72:1, respectively (Table 1). The higher N:P ratio corresponded to the higher chlorophyll concentrations, plus higher salinity, total nitrogen, and pH values in September 2007. Secchi readings varied from 0.3 to 0.6 m, and Nephelometric Turbidity Units (NTU) ranged from 9.4 to 19.7. The prevailing winds during each collection date were steady and strong enough to disturb the water's surface and induce turnover within the water column. The mean wind speeds were 14.0, 9.1, and 10.1 km h^{-1} for 19 September 2006, 29 May 2007 and 27 September 2007, respectively. In general, these data characterize the collection period in waters that were oligohaline with higher chlorophyll values during autumn than late spring. They also had a moderate pH range and oxygen values, with warm temperatures and high N:P ratios. Light penetration was evident within the upper 0.6 m, with suspended solids and algae greatly reducing its passage in the water column beyond this depth. Comegys (1977) previously considered Back Bay's trophic status as between mesotrophic to early eutrophic, whereas Marshall (1991) considered its status mesotrophic.

A total of 76 phytoplankton taxa were identified in the Bay water samples (Table 2). These were typically freshwater species, with the assemblage lacking any major presence, or development of estuarine or coastal algae. These included 41 cyanobacteria, 16 chlorophytes, 13 diatoms, 3 cryptophytes, and 3 euglenophytes. The euglenophytes were seldom present in the water samples and were

Table 1. Water quality variables at stations (3, 9, 20, 22), in Back Bay, Virginia 19 September 2006, 29 May 2007, and 27 September 2007. Sal (salinity), DO (dissolved oxygen), NTU (nephelometric turbidity units), Sec (Secchi depth m), Chl (chlorophyll *a* μg L^{-1}), TN (total nitrogen mg L^{-1}), TP (total phosphorus mg L^{-1}), N:P (nitrogen:phosphorus molar ratio)

	°C	Sal	pH	DO	NTU	Sec	Chl	TN	TP	N:P
19 September 2006										
3	23.8	1.3	7.8	8.5	13.2	0.5	16.6	1.08	0.05	46:1
20	23.5	1.1	7.4	8.2	14.6	0.5	19.3	1.16	0.05	51:1
22	24.2	1.4	8.3	8.4	9.9	0.6	23.8	0.94	0.06	34:1
Mean	23.8	1.3	7.8	8.4	12.6	0.5	19.9	1.06	0.05	46:1
29 May 2007										
3	25.3	1.2	7.6	8.1	15.4	0.5	11.3	1.00	0.05	44:1
9	25.7	1.1	6.0	6.1	—	0.4	21.1	1.10	0.04	61:1
20	24.8	1.2	7.4	8.0	9.4	0.5	10.0	0.85	0.08	23:1
Mean	25.3	1.2	7.0	7.4	12.4	0.5	14.1	0.98	0.06	36:1
27 September 2007										
3	25.2	2.1	8.0	—	18.2	0.3	49.5	2.23	0.07	70:1
20	25.2	2.6	8.4	—	19.7	0.4	36.7	2.33	0.07	73:1
22	25.5	3.2	8.4	—	15.0	0.4	58.4	2.34	0.07	74:1
Mean	25.3	2.6	8.3	—	17.6	0.4	48.2	2.3	0.07	72:1

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Table 2. Phytoplankton taxa identified in Back Bay, Virginia (2006–2007)

Cyanobacteria
Anabaena circinalis Rabenhorst
Anabaena sp. Bory
Anabaena viguieri Denis & Fremy
Anabaenopsis elenkinii Miller
Aphanizomenon flos-aquae (L.) Rabenhorst
Aphanizomenon issatschenko (Usacev) Proskina-Lavrenko
Aphanocapsa delicatissima West & West
Chroococcus dispersus (Keissler) Lemmermann
Chroococcus limneticus Lemmermann
Chroococcus turgidus (Kützing) Naegel
Coelsphaerium kuetzingianum Nägeli
Cylindrospermopsis raciborskii West
Glaucospira laxissima West
Gomphosphaeria aponina Kützing
Jaaginema neglecta Anagnostidis & Komárek
Limnothrix redekei (Van Goor & Skuja) Anagnostidis & Komárek
Lyngbya birgei G.M. Smith
Merismopedia glauca (Ehrenberg) Nägeli
Merismopedia punctata Meyen
Merismopedia smithii De Toni
Merismopedia tenuissima Lemmremann
Microcystis aeruginosa (Kützing) Kützing
Nostoc commune Vaucher
Nostoc sp. Vaucher
Oscillatoria lacustris (Klebahn) Geitler
Oscillatoria limosa (Roth) C.A. Agardh
Oscillatoria princeps Vaucher
Oscillatoria sp. Vaucher
Planktolyngbya contorta (Lemmermann) Anagnnostidis & Komárek
Planktolyngbya limnetica (Lemmamann) Komárková-Legnerová & Cronberg
Planktolyngbya talligii Komárek & Kling
Planktothrix agardhii (Gomont) Anagnostidis et Komárek
Pseudanabaena limnetica Komárek
Rhabdogloea smithii (R. & F. Chodat) Komáek
Raphidiopsis curvata Geitler
Snowella lacustris (Chodat) Komárek & Hindák
Snowella litoralis (Hayren) Komárek & Hindák
Spirulina laxa G.M. Smith
Spirulina weissii Drouet
Synechococcus sp. Nägeli
Woronichinia naegeliana (Unger) Elenkin
Chlorophytes
Ankistrodesmus falcatus (Corda) Ralfs
Ankistrodesmus falcatus v. *mirabilis* (West & West) West
Chlorella vulgaris Beyerinck
Crucigenia quadrata Morren
Desmodesmus quadricauda (Turpin) Hegewald
Kirchneriella lunaris (Kirchner) Moebius
Kirchneriella sp. Schmidle
Quadrigula closteriodes (Bohlin) Printz
Quadrigula chodatii (Tanner-Füllemann) G.M. Smith
Quadrigula lacustris (Chodat) G.M. Smith
Scenedesmus dimorphus (Turpin) Kützing
Scenedesmus obliquus (Turpin) Kützing
Tetraedron minimum (A. Braun) Hansgirg
Tetraedron muticum (A. Braun) Hinsgirg
Tetraedron regulare Kützing
Westella linearis G.M. Smith
Diatoms
Amphora sp. Ehrenberg
Aulacoseira distans (Ehrenberg) Simonsen
Closterium setaceum Ehrenberg
Closterium sp. Nitzsch
Cocconeis sp. Ehrenberg
Cyclotella meneghiniana Kützing
Cyclotella sp. Kützing
Fragilaria crotonensis Kitton
Navicula sp. Bory
Nedium sp. Pfitzer
Nitzschia acicularis W. Smith
Nitzschia closterium (Ehrenberg) W. Smith
Nitzschia sp. Hassall
Cryptophytes
Cryptomonas erosa Ehrenberg
Cryptomonas marsonii Skuja
Rhodomonas sp. Karsten
Euglenophytes
Euglena sp. Ehrenberg
Trachelomonas hispida (Perty) Stein
Trachelomonas volvocina Ehren.

not major contributors to the algal biomass in these collections.

The dominant algae throughout the Bay stations were cyanobacteria, with chlorophytes and diatoms generally background species in much lower concentrations (Table 3). During September 2006, May 2007, and September 2007, the cyanobacteria represented 80.9, 88.5, and 98.7% respectively of the mean total algal abundance at these stations. Most prominent were filamentous cyanobacteria that included *Aphanizomenon flos-aquae, Planktolyngbya contorta, P. limnetica,* and *Pseudanabaena limnetica*. The dominant colonial cyanobacteria consisted of *Chroococcus dispersus, C. limneticus, C. turgidus, Merismopedia punctata,* and *M. tenuissima*. September bloom concentrations (2006, 2007) for *Planktolyngbya limnetica* occurred both years with a mean abundance of 19,163 filaments ml^{-1}. Among the colonial cyanobacteria, *C. dispersus* and *C. limneticus* were most abundant throughout the sampling with mean concentrations of 8,607 and 7,197 cells ml^{-1}, respectively, with another colonial taxon, *Merismopedia punctata*, at 5,102 cells ml^{-1}. Each of these concentrations are considered bloom status at these sites for these species. Throughout the sampling, diatoms, chlorophytes, or euglenophytes did not

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Table 3. Phytoplankton concentrations as numbers per ml at stations (3, 9, 20, 22) in Back Bay, Virginia on 19 September 2006, 29 May 2007, and 27 September 2007

	Cyanobacteria (filamentous)	Cyanobacteria (nonfilamentous)	Chlorophytes	Diatoms	Cryptophytes	Total
19 September 2006						
3	51,777	57,440	2,668	9,093	2,767	123,745
20	9,951	30,328	22,320	558	2,418	65,575
22	73,312	51,862	406	348	24,302	150,137
Mean	45,013	46,543	8,465	3,326	9,829	113,152
29 May 2007						
3	8,972	10,189	1,169	208	0	20,529
9	11,905	58,787	7,283	3,896	1,159	83,030
20	4,080	16,052	417	0	46	20,595
Mean	8,319	28,343	2,953	1,368	402	41,385
27 September 2007						
3	49,449	14,931	417	634	46	65,477
20	85,486	75,864	790	174	0	162,341
22	124,551	82,824	3,168	232	0	210,775
Mean	86,428	57,873	1,458	347	15	146,198

exceed 10^3 cells ml^{-1}. Comparison to cyanobacteria concentrations from the two earlier studies in Back Bay cannot be made because different counting protocols were used for colonies and filaments. Comegys (1977) counted cyanobacteria filaments and colonies, whereas Marshall (1991) counted cells for both categories. Comegys' highest filament count occurred June 1975 with 2,746 ml^{-1}, which is considerably lower than the abundance levels included above for *Planktolyngbya limnetica*. The most prominent filamentous cyanobacteria in Back Bay from Comegys' samples included a variety of *Oscillatoria* species, with the prominent colonial cyanobacteria consisting of *M. tenuissima* and *M. glauca*, plus the chlorophytes *Chlorella* sp., and *Desmodesmus* (*Scenedesmus) quadricauda*. A diverse representation of chlorophytes represented this codominant group. The dominant cyanobacteria during Marshall's (2006) Back Bay study were colonial species such as *C. limneticus* and *Merismopedia* spp., with the dominant filamentous taxon *Planktolyngbya (Lyngbya) limnetica*, which also was recorded as a dominant form during the present study. Less abundant were the chlorophytes and diatoms, with other algal groups rare or absent.

The dominant Back Bay cyanobacteria reported here are more commonly associated with freshwater habitats rather than oligohaline waters (Wehr and Sheath 2003). The past representation and dominance of these algae in the Bay's low saline waters has not only continued, but has increased in representation and abundance when compared to studies by Comegys (1977) and Marshall (1991). Comegys reported 28 cyanobacteria taxa in a yearly study, and Marshall (1991) noted 36, whereas in this analysis 41 taxa were in a less extensive survey of the year's flora. In addition, over the time period of these studies an apparent increase in the filamentous cyanobacteria also has occurred. This degree of cyanobacteria dominance was not present in another saline pond and lake in the region. Also located as part of Virginia's barrier island series, these sites both contained a greater representation of marine rather than freshwater algae in waters that often reached mesohaline status (Marshall 1980, 1983). However, these sites also experienced lesser amounts and lower frequency of fresh water input compared to salt water intrusion.

Back Bay algae are exposed to a variety of changing environmental conditions. Directly south of station 22, a channel extends to the higher saline waters of Currituck Sound (ca. mean 3.5 ppt), through which wind-driven waters can enter into Back Bay. This location represents the most common entry of saline water into the Bay. Station 22 typically is the location for higher salinity levels in the Bay (Table 1), with prevailing winds a mechanism for spreading these waters within the Bay. Along its western and northern border, besides overland drainage, several streams bring

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fresh water into the Bay. In general, the Bay's water depth is relatively shallow (ca. 2 m) throughout its extent, with little submerged vegetation to stabilize the sediment. The prevailing winds often are consistently strong enough to induce periods of turnover in the water column within this shallow system. This disturbance to the water column is interspaced by periods of reduced turbulence and an increased surface presence of the more buoyant cyanobacteria. However, during periods of turnover, increased levels of suspended solids and nutrients entered the water column, compromising the degree of light available to the algae. Such turnover action has been associated with contributing to a more homogeneous mixture among the algae (Liu and Dickhut 1998), which generally was observed in the replicate samples taken in this study, and apparently favored the cyanobacteria presence in contrast to other algal components.

In Back Bay, the mean N:P ratios were above the Redfield ratio of 16:1 throughout the collection period (Redfield 1958). Ratios above this level are typically associated with chlorophyte and diatom development rather than the cyanobacteria dominance that was extensive in Back Bay (Smith 1983, Levich 1996, Bulgakov and Levich 1999). Cyanobacteria development commonly occurs under low N:P ratios and warm water temperatures (Smith 1983, Tilman and Kiesling 1984, Levich 1996). In contrast to this relationship, cyanobacteria were the dominant flora (in abundance and biomass) in Back Bay over a range of high N:P ratios. There was no major development of chlorophytes or diatoms at any of the stations. Several investigators (Thompson and Rhee 1944, Tilman et al. 1986, Paerl 1988, Levine and Schindler 1999) have discussed environmental factors other than the Redfeld ratio as influencing phytoplankton growth and succession. These conditions include existing temperatures, turnover or stratification of the water column, nutrient uptake relationships with associated light availability, nutrient saturation levels, degree of algal buoyancy, and the prevalence of nitrogen-fixing, or nonnitrogen-fixing cyanobacteria. Partial pressure of CO_2 (pCO_2) has also been linked to cyanobacteria N_2 fixation potential and other growth interactions (Hutchins et al. 2007). Jensen et al. (1994), Levich (1996), and Xie et al. (2003) also emphasized phosphorus concentrations as a major determiner of cyanobacteria development. In Back Bay, the phosphorus levels were not low or considered to be at algal growth-limiting levels, and varied from 0.04 to 0.08 mg L^{-1} during periods of high bloom development. Geider and LaRoche (2002) have stressed the importance of nutrient concentrations regarding optimal growth conditions for algae that might be contrary to the Redfield ratio. They stress that there are varying degrees of plasticity in this ratio depending on excess levels of N or P available to the algae. This plasticity also might be maintained with high nutrient levels present, and a continuous source of nutrients made available to the algae for their uptake. Klausmeier et al. (2004) consider the Redfield ratio as not an optimal relationship, but an average value where species variability occurs and is influenced by existing environmental conditions. Havens et al. (2003) have reported non-nitrogen-fixing filamentous cyanobacteria dominating the algae in a subtropical Florida lake under turbid and low irradiance conditions. Similar conditions were often noted in Back Bay with Secchi depth typically $<$0.5 m and with mean station turbidity 12.4 to 17.6 NTU. In Back Bay, several of the dominant and common filamentous cyanobacteria were those that lacked heterocysts (*Planktolyngbya limnetica, Jaaginema neglecta, Limnothrix redekei, Pseudanabaena limnetica, Planktolyngbya contorta, Glaucospira laxissima, Planktothrix agardhii*). In contrast, Levine and Schindler (1999) reported that heterocystous cyanobacteria were associated with low light intensities and low N:P ratios. Reynolds (1999) stressed that if both N and P are in ample supply, then neither can be considered a limiting growth factor as indicated by the N:P ratio. The extensive cyanobacteria development in Back Bay is considered a response not only to high N:P ratios, but to the ability of these taxa to outcompete (Tilman et al. 1986, Reynolds 1999, Klausmeier et al. 2004) the other taxa for space and development in the more favorable existing conditions for its growth in this habitat.

This assemblage of cyanobacteria also has been associated with a more surface-dominat-

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ing presence (Wehr and Sheath 2003). This status might be attributed to morphological features that enhance their buoyancy and reduce their sinking rates (e.g., cell size, gelatinous colony formation, etc.). Although a stable water column might enhance their presence in the surface layers, turnover conditions also could provide these taxa broad vertical distribution and extended exposure to light and nutrients in the water column. Other algal components either did not compete effectively for the available nutrients, space, etc. with the cyanobacteria, or found these same environmental conditions counterproductive to their growth requirements. This left a less competitive assemblage of other algae, along with the cyanobacteria which continued to grow and become the dominant algal component in Back Bay.

Algal group comparisons indicated that both autumn dates had greater total levels of mean algal abundance than spring. This was mainly the product of lower numbers of filamentous cyanobacteria, and to a lesser degree, lower concentrations among the nonfilamentous cyanobacteria and other taxonomic groups during the spring collections. Filamentous and colonial cell counts had comparable levels in September 2006, with greater filament abundance during September 2007, and less in May 2007 compared to the nonfilamentous cyanobacteria (Table 3). However, if cells per filament were considered, these relationships would differ considerably. For instance, cyanobacteria filaments can vary in length having 6–15 cells (or more) per filament. The greatest abundance of cyanobacteria occurred in September 2007, with mean concentrations of cyanobacteria at 86,428 filaments ml^{-1} and the nonfilamentous cyanobacteria with 57,873 cells ml^{-1}, indicating an algal bloom in progress. The other taxonomic groups had minor representations in comparison.

Trophic status of water habitats may be inferred by phytoplankton composition, or more specifically with reference to nutrient levels and other water quality conditions that are present. (Busch and Sly 1992). The previous references to Back Bay's trophic status by Comegys (1977) and Marshall (1991) described a mesotrophic stage, generally in transition to becoming eutrophic and supported by the characteristic flora associated with that trophic state. However, using the water quality data available during this study, Back Bay would be classified as eutrophic (Table 1). This would be according to the following mean water quality values determined for total nitrogen (>0.6 mg L^{-1}; Vollenweider 1968, Forsberg and Ryding 1980), total phosphorus (>0.02 mg L^{-1}; Bachmann 1980, Chapra and Dobson 1981), Secchi depth (<2.5 m; Forsberg and Ryding 1980), and chlorophyll *a* (>10 μg L^{-1}; Chapra and Dobson 1981). However, these relationships and values can vary seasonally and, because these are based on a limited monthly data base, fluctuations in these parameters would likely occur, and possibly could influence this interpretation of trophic status.

Of note, among the dominant flora, were five potentially harmful cyanobacteria that have been identified as both toxin and bloom producers (Cronberg et al. 2003). These taxa and associated toxins they are reported to produce are *Aphanizomenon flos-aquae* (anatoxin, PSP toxin), *Limnothrix redekei* (microcystins), *Microcystis aeruginosa* (microcystins), *Planktothrix agardhii* (anatoxin, microcystins), and *Snowella lacustris* (hepatotoxins) (Cronberg et al. 2003). Marshall et al. (2008) reported *A. flos-aquae, M. aeruginosa, P. agardhii,* and *S. lacustris* in Chesapeake Bay estuaries, in addition to *A. flos-aquae, L. redekei*, and *M. aeruginosa* in several inland lakes of Virginia (Marshall, unpubl. data). To date, none of the Back Bay species have been associated with a toxic event.

SUMMARY The waters of Back Bay are subject to periods of saline water intrusion and frequent periods of wind-induced turnover associated with its shallow depth. These more-turbulent periods are interspaced by relatively calm conditions and reduced water column disturbance. Fresh water entry comes from several creeks that enter the Bay, plus precipitation. However, the Bay waters have maintained a moderate oligohaline status, with salt water entry common, but sporadic. High N:P ratios have prevailed in recent decades, with nutrient entry from surrounding agricultural and residential sources, plus the Bay's sediment during periods of frequent turnover. The present water quality variables indicate a eutrophic status for Back Bay. The

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Bay's phytoplankton consists of predominantly freshwater cyanobacteria, with no coastal or estuarine species established in these waters. The dominant flora represented a combination of colonial and mainly nonheterocystous filamentous taxa, with other algal categories less abundant and diverse. The classical association of chlorophyte and diatom dominance with high N:P ratios was not displayed in Back Bay. In contrast, the cyanobacteria exhibited quantitative dominance approaching bloom status over the other algal components. This disconnect has persisted since the study by Comegys (1977), and cyanobacteria have become more common in abundance and diversity. Rather than high N:P ratios being a deterrent to cyanobacteria development, the existing nutrient levels and environmental conditions were favorable to their development, in contrast to the other algal components.

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