Stormwater Influence on Phytoplankton Composition and Dynamics in Lake Joyce, Virginia

Lewis F. Affronti Jr. and B. Thomas Duquette
Departments of Science and Math, Norfolk Academy
Norfolk, Virginia 23502-5591

ABSTRACT
A three year study of Lake Joyce, Virginia revealed relationships between the timing, duration, and amount of stormwater runoff and phytoplankton abundance and composition. Major phytoplankton taxa were identified and cyanophytes dominated during periods of decreased rainwater input and increased lake water retention times. Increased freshwater input was associated with the growth of a diverse assemblage of both chlorophytes and diatoms. Phytoplankton dynamics as a result of significant rain events (i.e., hurricanes Floyd and Irene, 1999) were documented and specific taxa involved in nuisance algal blooms were identified.

INTRODUCTION
Lake Joyce, located in Virginia Beach, Virginia (36° 54' 44" Lat., 76° 7' 19" Long.) is a 60.7 hectare freshwater lake with an average depth of 1.1 meters. Lake overflow empties to the lower Chesapeake Bay via Pleasure House Creek and the Lynnhaven River. Because the lake is surrounded by residential housing, a major nutrient nonpoint source results from urban stormwater runoff (United States Environmental Protection Agency 1983). Local changes in the seasonal periods of precipitation will influence the amount of this surface runoff that will enter Lake Joyce. The lake is an unstratified, hyper-eutrophic system with reports of nuisance algal blooms documented since 1978 (Roger K. Everton, Virginia Department of Environmental Quality, Tidewater Region, personal communication). While once a water reservoir for the City of Norfolk, Virginia, its current use is now recreational and includes boating, fishing and water skiing.

The objectives of this study were: 1) identify phytoplankton composition and abundance within Lake Joyce, and 2) compare phytoplankton population dynamics to precipitation data over the three year study period.

METHODS
Three replicate surface grab samples (125 milliliters (ml)) were collected weekly from a pier in Lake Joyce over a 36 month period (May 4, 1999 to May 20, 2002). All samples were preserved with buffered glutaraldehyde to yield a final concentration of 2% (American Public Health Association 1998). Phytoplankton abundance was determined using the mean cell concentrations from two replicate samples and mean autotrophic picoplankton abundance from all three replicate samples. Five to ten ml subsamples were drawn on to a 0.2 micrometer (µm) Nuclepore filter stained in Irgalan Black using a mechanical pump at pressures less than 10 centimeters (cm) of Hg to prevent cell rupture. A Zeiss Axioslab Microscope equipped with a 50 watt
Identification of dominant nanoplankton and microplankton species was verified using a Zeiss 450-490 excitation filter, 510 barrier filter and Zeiss 546 excitation filter, FT580 dichromatic mirror and 590 barrier filter. For each replicate sample, four randomly chosen fields were examined for the representative nanoplankton, microplankton and autotrophic picoplankton components (Affronti and Duquette, 2002). A full filter scan was performed to identify other non-dominant phytoplankton species present in the sample. A one way Model I ANOVA was performed on total phytoplankton abundance data with year as a treatment (1st year - May 4, 1999 to May 1, 2000, 2nd year - May 8, 2000 to May 7, 2001 and 3rd year - May 14, 2001 to May 20, 2002) to determine if there were significant differences in phytoplankton abundance. Average phytoplankton abundance was compared to weekly precipitation data (National Oceanic and Atmospheric Administration/National Climatic Data Center 1999-2002).

RESULTS

Average total phytoplankton and autotrophic picoplankton abundance over the three year period is shown in Figure 1. Cell abundance ranged from 3.70 to 7.75 x 10^6 cells per Liter (L) with onset growth occurring in late spring and early summer. Seasonal maximum abundance varied the three years with numbers generally decreasing into winter. Results of the one way Model I ANOVA indicated total phytoplankton abundance was affected by year (F<0.0001). Tukey's a posteriori tests verified all pair-wise comparisons of abundance by year were significantly different (1st and 2nd years: P<0.05, 1st and 3rd years: P<0.05, 2nd and 3rd years: P<0.05). Phytoplankton abundance for the second year was less than the first and third years of the study where an extended and greater growth period was observed from May 14, 2001 to May 20, 2002 (Figure 1).

Throughout the study, Lake Joyce flora consisted primarily of cyanophytes, chlorophytes and diatoms. Cyanophytes dominated total phytoplankton abundance and ranged from 0.00 to 7.71 x 10^6 cells L^-1. Peak abundance occurred in late summer and often associated with bloom events (Figure 2). Three dominant cyanophyte groups were observed. These included filamentous forms (Anabaena sp. and Lyngbya sp.) colonial taxa that included the temporarily identified Aphanothece holsatica (Affronti and Duquette 2002) as described by Komárek and Anagnostidou (2000), plus Gloeocapsa sp., Gomphosphaeria sp., and Merismopedia sp. Unicellular forms included Synochococcus sp. and individual cells of Aphanothece holsatica, both of which dominated the autotrophic picoplankton component which ranged from 1.98 x 10^6 to 2.14 x 10^6 cells L^-1. Chlorophytes were the most diverse phytoplankton group observed and ranged in abundance from 3.16 x 10^6 to 6.06 x 10^6 cells L^-1. Growth periods varied over the study with peak abundance occurring in late autumn and an increase in numbers beginning each spring (Figure 2). Representative forms were Ankistrodesmus sp., Closterium sp., Cosmarium sp., Cosmarium sp., Crucigenia rectangularis, Crucigenia tetrapedia, Desmidium sp., Kirkneriella sp., Oocystis sp., Pediasstrum duplex, Pediasstrum simplex, Quadrigula sp., Scenedesmus almeranns, Scenedesmus dimorphus, Desmodesmus quadricauda, Staurastrum sp., and Tetraedron sp.. Unidentified chlorophyte cells <2μm also contributed to autotrophic picoplankton abundance.

The diatoms consisted of centric and pennate forms that included Asterionella sp., Cyclotella sp., Leptocylindricus minimus, Nitzschia sp., and Skeletonema potamos. Increased abundance occurred during early spring and again in late autumn, with reduced concentrations during winter (Figure 2). Diatom abundance varied from 0.00 to 2.69 x 10^6 cells L^-1. Additional phytoplankton groups were observed, but did not contribute significantly to overall abundance. These included dinoflagellates (e.g. Amphidinium sp., Ceratium hirundinella), euglenoids and chrysophytes (Synura sp. and Dinobryon sp.).

Weekly rainfall for this region ranged from 0.00 to 18.64cm over the three years (Figures 3-5). Precipitation and phytoplankton data were compared for each year. Two significant rain events occurred in September and October 1999 (16.66cm and 18.64cm, respectively) resulting in substantial freshwater input to the lake. Also, there were significant periods (i.e., 12 consecutive weeks from February to May 2000) without rain. Average phytoplankton abundance the first year had a single peak in June/July, then decreased with an increase in precipitation during autumn and remained low into winter and early spring (Figure 3). The opposite was true the second year as maximum precipitation occurred during summer and phytoplankton abundance remained low in summer and during a second rainfall peak the following spring (Figure 3).
FIGURE 2. Comparison of phytoplankton phyla patterns. Patterns are a result of moving average best fit trend lines of representative data series.

FIGURE 3. Comparison of total phytoplankton abundance (diamond) and precipitation (square) for first year of study. Polynomial best fit lines are used for each data series.

4) The third year of the study was the driest with total precipitation 19.05 cm lower than year two, which was the wettest year (118.95 cm). Maximum phytoplankton growth occurred during this period of reduced precipitation and surface runoff, and was dominated by *Aphanocapsa holsatica* and *Anabaena* sp. into late autumn.

**DISCUSSION**

Numerous studies have implicated phytoplankton abundance and diversity being influenced by the complex interaction of many variables that include physical, chemical and environmental factors (Harris 1986; Padisák et al. 1988; Ochs et al. 1995 and Chen et al. 2003). Because a major source of freshwater input to Lake Joyce includes stormwater runoff, rain events also have an important influence on lake dynamics. Timing, duration, and amount of rainwater input for Lake Joyce not only influenced lake depth and nutrient input, but influenced phytoplankton abundance and composition. Total phytoplankton abundance during the second year of the study was significantly lower than years one and three when total rainfall during this period was high. Likewise, the inverse relationship between phytoplankton abundance and rainfall input during autumn of the first year implied periods of increased freshwater input influenced phytoplankton abundance and composition. As a result of rain events, increased flushing rates and simple dilution of organism abundance would be expected. Over 35.3 cm of rain as a result of hurricanes Floyd and Irene provided these conditions during September and October of 1999 which decreased phytoplankton abundance.

Timing of freshwater input to Lake Joyce also influenced phytoplankton dynamics. Most rainfall during the first year occurred from late summer into autumn and resulted in a decline of established phytoplankton growth. However, the major rain events
during the second year occurred from late spring into summer where phytoplankton growth responded to this input. Most likely, this response was related to nutrient input which in conjunction with other environmental factors promoted phytoplankton growth (United States Environmental Protection Agency 1983). During periods of reduced precipitation and runoff, residency time within the lake was increased allowing for greater phytoplankton development (Figure 5).

Over the study period, changes in phytoplankton composition were associated with the amount of precipitation. During the second year, high rainfall in late spring resulted in more chlorophyte and diatom growth compared to years one and three where cyanophytes dominated phytoplankton composition. The third year was the driest of the study, with only 99.90 cm of rainfall measured. During this year, the lake became stagnant, resulting in increased residency time and favorable conditions for cyanophyte growth. The dominant phytoplankton species during this period were *Aphanocapsa holsatica* and *Anabaena* sp. Both are common forms that thrive in nutrient rich warm waters and have been involved in bloom development (Edson and Jones 1988; Tsujimura and Okubo 2003). Humphries and Lyne (1988) report cyanophytes are able to out-compete other phytoplankton in part because of their increased nutrient uptake kinetics and ability to control cell buoyancy.

Prior to the hurricane events, rainfall input in spring and early summer of 1999 was minimal when phytoplankton composition was dominated by cyanophytes. After the hurricanes and resulting input of a significant amounts of freshwater, cyanophytes continued to thrive and bloom conditions resulted. In a study of urban lakes, reservoirs and ponds, Olding et al. (2000) reported cyanophytes dominating phytoplankton abundance as a result of high water retention times. The autotrophic picoplankton abundance reported in this study is conservative compared to those values reported by Affronti and Duquette (2002) where a different filter set was used (Zeiss 546 excitation filter). However, the patterns of autotrophic picoplankton abundance are similar and followed precipitation patterns. In their study, Affronti and Duquette (2002) suggested the composition of autotrophic picoplankton in Lake Joyce was influenced by freshwater input as the colonial cyanophyte *Aphanocapsa holsatica* disaggregated into individual cells within the picoplankton size range (0.2 – 2.0 μm).

**CONCLUSION**

Lake Joyce is an enclosed natural resource with restricted outflow where rainfall events have a significant impact on lake dynamics. Rainwater is not the only factor influencing phytoplankton growth, but data from this study indicated their abundance and composition were affected by the timing and duration of freshwater input. Similar results were reported by Edson and Jones (1988) in a study of Lake Fairfax, Virginia where differences in stormwater runoff influenced phytoplankton community structure. Phytoplankton composition and abundance was more diverse with increased freshwater input that resulted in lower water retention times and less nuisance bloom conditions.
Because stormwater quality entering the lake is influenced by a variety of sources common in residential areas (i.e., lawn fertilizer, lawn debris, pet waste, sediment erosion), lake water quality can be managed partially by focusing on these sources.

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LITERATURE CITED


