Seasonal Patterns of Stratification, Nutrient Concentrations, and Chlorophyll in a Shallow Mid-Atlantic Pond

by

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A Thesis
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Master of Science
Environmental Science and Policy

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Date: July 15, 2004

Spring Semester 2004
George Mason University
Fairfax, VA

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Acknowledgements

I express my sincere gratitude to my advisor, Dr. R. C. Jones, for his guidance, patience, and support in developing this thesis. I would also like to thank the other members of my committee Dr. Don Kelso and Dr. Ron Stewart for their support and guidance. Laura McGee, Leslie Orzetti, Jennifer Cordrey, and Tess Conner provided field and lab assistance as well as moral support throughout the duration of my project. Finally I am especially grateful to my parents, Arnette and Herbert L. Wheat Jr., for their undying love and support. I dedicate this thesis to my family and thank them for their encouragement during my academic endeavors.

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ABSTRACT

SEASONAL PATTERNS OF STRATIFICATION, NUTRIENT CONCENTRATION, AND CHLOROPHYLL IN A SHALLOW MID-ATLANTIC POND

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Polymictic lakes are shallow, wind exposed lakes in warmer regions. Stratification in polymictic lakes can be established and destroyed repeatedly by daily temperature variations or episodic storm events. The temperature changes are often influenced more by cooling of the surface at night and warming during the day rather than by distinctive seasonal changes.

Patterns of stratification, hypoxia, nutrient concentrations, and chlorophyll were examined in a small polymictic pond on the campus of the NASA Goddard Space Flight Center in Greenbelt, MD. Thermal stratification had a major impact on the depth distribution of several parameters. Dissolved oxygen was distinctly depth-stratified for much of the season. The onset of hypoxia was observed in mid-June and continued through July. Total phosphorus generally increased with depth throughout the sampling season. Soluble reactive phosphorus values reached a maximum in April and then steadily declined, resulting in undetectable levels in upper waters during August. pH was

more variable in surface than in bottom waters due to the greater variability in the photosynthetic processes compared with those of respiration.

Ammonia and nitrate nitrogen followed a seasonal pattern with a maximum in May and a decline throughout the remainder of the season. Chlorophyll *a* showed a distinct seasonal pattern in the upper waters with values below 5 ug/L in April and May increasing to approximately 200 ug/L in early June.

Continuous temperature measurements at 0.25 m intervals indicate that two patterns of mixing occurred in the pond. In the first pattern the surface water cooled to the temperature of a mid-depth or bottom layer resulting in mixing. In the second pattern mixing was induced by wind action, often following a limited degree of surface cooling. Continuous temperature profiling also reveal that changes in the lower depths are more gradual and infrequent than in upper waters. Water chemistry parameters exhibited uniform values with depth immediately following mixing events, but stratified patterns were reasserted within a matter of days following mixing.

Introduction and Literature Review

Stratification Patterns

Polymictic lakes are shallow, wind exposed lakes in warmer regions. Stratification in polymictic lakes can be established and destroyed repeatedly by daily temperature variations or storm events. These lakes are often small, shallow and in tropical or at least warmer climates or at higher altitudes. The temperature changes are often influenced more by cooling of the surface at night and warming during the day rather than by distinctive seasonal changes (Wetzel 2001).

Thermal stratification is one of the most significant physical events in a mid-latitude lake's annual cycle. If the lake is deep enough, three distinct layers will form during stratification: the epilimnion, the metalimnion, and the hypolimnion. The breakdown and reformation of these layers and their associated nutrient concentrations has major implications for water quality and biological communities (Horne 1994). Over the years, limnologists have used vertical temperature profiles to observe changes in the summer heating periods of lakes. As the season advances, the epilimnion deepens, the metalimnion gradient becomes steeper, and the temperature increases at all depths (Bachmann and Goldman 1965).

Hambright et al. (1994) describe the presence of a seasonal thermocline as the core of a lake's character. The depth of the thermocline and volume of the epilimnion influence the dynamics of an energy budget, nutrient recycling, and primary production (Hambright et al. 1994, Hutchinson 1957, Wetzel 1983).

The induction of stratification in the spring is controlled by many factors. According to Wetzel (2001) small, shallow lakes, if protected by the wind like that of the lake detailed in this study, may circulate only briefly during the spring. The process often occurs only for a few days and this period of circulation may allow the temperature of the water to increase more than 10° C.

Prior to the start of thermal stratification in summer, isothermal conditions exist. This isothermal status leads to mixing and an even distribution of chemical and biological components (Nurnberg 1984). The distribution of nutrients such as carbon dioxide and oxygen provides information as to the general nature and trophic state of the lake.

Thermal lake structure influences practically all biological and chemical processes. These processes include primary and secondary production, nutrient cycling, oxygen depletion, and water movement (Mazumder and Taylor 1994, Schindler 1971, Cornett and Rigler 1980, Quay et al. 1980, Gliwicz 1980).

Stratification in temperate lakes isolates hypolimnetic water from contact with atmospheric oxygen. Biomass produced by primary productivity in the epilimnion settles into the hypolimnion and decomposes, resulting in oxygen depletion. Since hypolimnetic water is no longer in contact with the atmosphere and is below the photic zone, oxygen is rapidly depleted causing hypoxia or anoxia. These anoxic conditions at the sediment-water interface cause a release of phosphate, ammonia, and metal components from sediments (Schladow and Fishcer 1995).

As a lake mixes or destratifies, nutrients that have accumulated in the hypolimnion return to the epilimnion. This restructuring has a profound impact on nutrient concentrations and forms. For example, fixed nitrogen in freshwater is present largely as NO_3^- ions. When the hypolimnion of a eutrophic lake becomes hypoxic, bacterial nitrification of ammonia ceases. Oxidation at the water-sediment interface is also lost, reducing the absorptive capacity of the sediments for NH_4-N. An increase in the release of NH_4^+ from the sediments occurs and consequently the concentration of NH_4-N in the hypolimnion increases (Wetzel 2001).

Water Quality Parameters

Nutrient loading to a lake includes inputs from sources such as surface runoff and precipitation. Other sources that are part of the lake's nutrient budget are dryfall (wind inputs), groundwater, and nitrogen fixation by cyanobacteria (Downing 2000).

Oxygen, or the lack thereof, is an essential element concerning biological and chemical processes in aquatic environments. The concentration of oxygen in an aquatic environment is a function of photosynthesis, respiration, water movement, and temperature (Horne 1994). Limnologists suggest that in order to fully understand a lake, knowledge of its oxygen regime is necessary (Nurnberg 1984). Dissolved oxygen (DO) is necessary for the metabolism of all aquatic organisms that have aerobic respiratory biochemistry. Its properties of solubility and distribution are essential to an understanding of the growth of aquatic organisms (Stefan et al., 1995). At low levels the microbial community is greatly affected by small changes in dissolved oxygen which substantially alter redox conditions and associated chemical speciation.

Hypolimnetic oxygen depletion is increased by nutrient enrichment of the lake's system (Cornett 1989). Schadlow and Fischer (1995) found that extended periods of thermal stratification suppress the vertical transport of dissolved oxygen. However, sedimentation of organic production from the lake's upper layers continues. These conditions lead to anoxia in the hypolimnion and initiate serious water quality implications.

Nitrogen is a major nutrient that affects the productivity of fresh waters. In fresh waters nitrogen occurs in many forms, including molecular nitrogen (N_2), organic nitrogen, ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). External sources of fixed nitrogen to lakes include surface land drainage, groundwater, atmospheric dry deposition, and precipitation (Wetzel 2001). Lakes play an important role as nitrogen sinks in the aquatic path from land to ocean (Bernasconi 1997, Billen et al. 1991). The most common forms of inorganic nitrogen dissolved in water are ammonium ion (NH_4^+) and nitrate ion (NO_3^-).

The distribution of ammonium in lakes varies greatly regionally, seasonally, and spatially within lakes. This distribution is mainly attributed to the level of productivity and the degree of pollution from organic matter (Wetzel 2001). Studies by Liao and Lean (1978) found that because ammonium is readily absorbed by plankton and nitrified to nitrate, concentrations in well-oxygenated zones are usually low. They also observed low ammonium concentrations in unproductive oligotrophic waters, the trophogenic zones of most lakes, and in most lakes after periods of circulation. Additionally, they noted a marked increase of ammonium release from the sediments when the hypolimnion of eutrophic lakes becomes anoxic.

Nitrate is the most common form of inorganic nitrogen entering fresh waters from drainage basins, ground water, and precipitation. The assimilation of nitrate and its incorporation by green plants are dominant processes in the trophogenic zones of fresh waters. The ratio of NO_3-N to NH_4-N in lakes varies with regards to natural and polluted waters (Wetzel 2001).

Several studies have been conducted to determine the seasonal distribution of various forms of nitrogen in temperate lakes (Wetzel 2001, Domogalla et al., 1926, Domogalla and Fred 1926, Barica 1970). These studies concluded that low autumnal nitrogen concentrations in the epilimnion gradually increase in late fall and peak in late winter and summer. In the oxygenated upper waters, nitrate decreased during the spring maximum from increases in plankton production. After the onset of thermal stratification, notable decreases in nitrification were observed in the tropholytic zone due to hypoxia in the hypolimnion (Downing 2000).

Phosphorus is generally recognized as the most limiting nutrient in temperate fresh waters (Carignan and Planas 1994, Schindler 1977, 1978). Phosphorus directly limits the abundance of phytoplankton (Horne, 1994). In lakes, during seasons of active biological production, the concentration of phosphate ion often drops below the detection limit of standard methods (Guildford and Hecky 2000, Hecky et al. 1993, Meybeck, 1993). Studies of nutrient concentrations in polymictic lakes found that major storm events resulted in high fluxes of phosphorus and sediment to the lake (Downing et al., 2000).

Lakes are often surrounded by terrestrial and urban ecosystems that introduce nutrients in fixed organic forms, either in solution or as particles (Guildford and Hecky 2000, Hecky et al. 1993, Meybeck, 1993). Futhermore, most phosphorus within lakes is tied up in biomass. As a result, limnological studies often emphasize total phosphorus (TP). TP includes dissolved organic and inorganic phosphorus plus particulate forms rather than simply inorganic forms (Guildford 2000, Vollenweder 1968, Dillon and Rigler 1974). TP concentration is used as a measure of water quality because it strongly correlates with variables such as chlorophyll, nitrogen, and anoxia (Nurnberg 1998).

Sunlight, temperature, nutrients, and wind all affect algae numbers and therefore chlorophyll *a* concentrations. A strong wind may mix the water in a lake, causing an immediate decrease in surface chlorophyll *a* concentrations, as the algae become mixed throughout the water column. An associate increase in surface nutrients may result from mixing with high nutrient bottom waters. The wind also may cause a release of nutrients into the water system by stirring up nutrient-laden bottom sediments. Then, after the wind dies down, the number of algae and the chlorophyll *a* concentrations may increase (Horne 1994).

Algae populations, and therefore chlorophyll a concentrations, also vary greatly with water depth. Algae must stay within the top portion where there is sunlight to be able to photosynthesize and grow. As they sink below the sunlit portion, they have a negative energy balance and will start to die. The increase in nutrients caused by pollution usually results in more algae, assuming light is not limited (Horne 1994).

Guilford and Hecky (2000) found that the northern temperate lakes in their studies exhibited a direct correlation between TP and chlorophyll *a* (Chl *a*). Other studies by freshwater limnologists have determined a dependence of algal biomass on TP as determined by chlorophyll *a* (Dillion and Rigler 1974, Pridemore et al. 1974, Guilford et al. 1994).

A hypothesis concerning the relationship between chlorophyll *a* and phosphorus (Sakamoto 1996) suggests that chlorophyll is both a simple and accurate estimate of phytoplankton standing crops. This hypothesis is now used more widely than cell volume or cell count as an approximation of standing crops (Dillon and Rigler 1974).

Case Study

Rock Creek Lake is a recreational polymictic lake in Jasper, Iowa. Rock Creek Lake has a surface area of 199 ha, a mean depth of 2.3 m, and a mean Secchi disk depth of 0.50 m. A baseline study of Rock Creek Lake in Iowa was conducted from March 1998 to June 1999. This survey indicated that Rock Creek Lake was eutrophic, based on a combination of several parameters including: total phosphorus, dissolved ortho-phosphorus, inorganic nitrogen, Secchi disk measured water clarity, chlorophyll *a*, and dissolved oxygen. Data were collected at three depths, from two stations, one established in the deepest point in Rock Creek Lake, and another at a point of marsh influx into Rock Creek Lake. (Downing 2000).

During the 1998-1999 season, the lake was stratified through May and June, mixed at the end of June, stratified through July and August, mixed during September through November, stratified in early December, mixed in late December, stratified under ice in January, then circulated again in spring. The polymictic thermal regime led to rapidly changing oxygen conditions. During periods of stability, accumulation of silt and sediments led to lowered oxygen concentrations in bottom waters. Polymixis also caused pH to vary through the water column and across the season. During periods of water column stagnation, bottom waters declined to low values of DO due to decomposition in deeper waters (Downing 2000).

Conductivity patterns across the seasons showed a general trend of high conductivity in spring and declining conductivity in summer and autumn. This pattern may have been due to the high rate of import of dissolved substances washed from the watershed in spring, that progressively declined as they were removed throughout the season by chemical and biological processes (Downing 2000).

Seasonal patterns in nutrient concentrations were found to be driven principally by nutrient flux from the watershed in the spring, followed by nutrient regeneration from sediments during periods of summer stagnation. During this stagnant period nutrients accumulate in the hypolimnion, while oxygen accumulates in the epilimnion. Inorganic nitrogen in the water column was high during spring during run-off and was drastically reduced during the summer as nitrogen was absorbed by the biotic community. Phosphorus concentrations in Rock Creek varied from a low of 43 μg/L to a high of over

600 μg/L, making the lake hypereutrophic when viewed from a nutrient chemistry standpoint (Downing 2000).

Objectives

To examine the interaction between stratification, nutrients, and phytoplankton in a small suburban reservoir.

- To observe the sequence of stratification and mixing of the water column over the growing season
- To determine how long after stratification hypoxia and other chemical changes occurs
- To quantify nutrient concentrations as a function of depth and the development of stratification