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DIEL PATTERNS OF DISSOLVED OXYGEN AND SELECT CHEMICAL PARAMETERS IN THREE LAKES WITHIN HOOSIER NATIONAL FOREST THAT HAVE EXPERIENCED RECENT FISH KILLS

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ABSTRACT. Three lakes in Hoosier National Forest, Perry County, southern Indiana, were studied for changes in dissolved oxygen, temperature, pH, oxidation-reduction potential, salinity, specific conductance, and total dissolved solids because they have experienced recent fish kills. These lakes were evaluated for patterns in their chemical limnology over a 24–hr period during September 2005. The shallow nature of these three lakes has caused dramatic shifts in pH, dissolved oxygen, oxidation-reduction potential, and specific conductance. The largest changes in dissolved oxygen and pH occurred at dawn and dusk when aquatic plants switched from photosynthesis to respiration. Changes in oxidation-reduction and specific conductance were the result of the loss of dissolved oxygen in the lake sediment microzone. As the lake substrate changed from a reducing environment to an oxygenated environment, total dissolved solids and specific conductance increased as these materials were released into the water column. Low night-time dissolved oxygen levels and associated chemical stressors associated with aquatic plant respiration could explain the recent fish kills.

Keywords: oxidation-reduction, physio-chemical limnology, reservoirs, water quality

INTRODUCTION

Oxygen is an important attribute that is necessary for sustaining life. The decrease in dissolved oxygen during critical periods of species life history or during diel periods may cause stunting, a loss of reproductive capacity by adults, or mortality as a result of summer or winter kill (Brett 1979; Chapman 1986; Wesolowski 1996). Chapman (1986) found that prolonged exposures to less than 60% oxygen saturation may result in altered behavior, reduced growth, adverse reproductive effects, and mortality. Exposure to less than 30% saturation (~ 2 mg/L at summer temperatures) for one to four days causes mortality to most biota, especially during summer months, when metabolic rates are high. Stresses that can occur in conjunction with low dissolved oxygen (e.g., exposure to hydrogen sulfide or ammonia) may cause as much, if not more, harm to aquatic biota than exposure to low dissolved oxygen concentration alone (Chapman 1986). In addition, aquatic populations exposed to low dissolved oxygen concentration may be more susceptible to adverse effects of other stressors (e.g., disease, toxic substances) (Evans et al. 2004).

As biological assemblages of lakes are confronted with oxygen deficits during seasonal changes that may be due to increased temperature during summer, decreased depth due to lake eutrophication, and diel changes resulting in lower oxygen concentration because of plant respiration, known changes in assemblage structure are effected (Wetzel 2001). Numerous studies have shown that lower dissolved oxygen concentrations affect species composition, relative abundance, growth, maturation, and reproductive capacity.

Hoosier National Forest has experienced a series of summer fish kills (Anne Timm, U.S.

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Forest Service, personal communication). The exact causes of these fish kills were unknown; however, evidence did not suggest a species-specific effect since all species and all sizes were observed among the mortality.

Our objective was to describe the changes occurring in select chemical characteristics of three reservoirs in southern Indiana. Knowledge of this information influences our understanding of many aspects of the biota and many of the indices of productivity. This survey was designed to collect data on the chemical characteristics of three reservoirs in the Hoosier National Forest and to determine possible explanations for the fish kills.

MATERIALS AND METHODS

Description of the Study Area.—This study was conducted in the littoral zone of three lakes on Hoosier National Forest (Simon submitted). Measurements were made over a 24-hr period near the boat launch of Lakes Celina, Indian, and Tipsaw, Perry County, Indiana. Many of the lakes in southern Indiana were created by the damming of small streams and moderate sized rivers. These artificial systems were formed when steep valley ridges were closed and stream channels naturally flooded these areas. Maximum depths of the lakes (IDEM, 1996) range from 15 feet (Tipsaw Lake) to 38 feet (Celina Lake). The area is part of the Mitchell Plain (Schneider 1966) of the Interior Plateau Ecoregion (Omernik & Gallant 1988). The area is primarily natural and without anthropogenic impact, and is managed by the U.S. Forest Service, Hoosier National Forest.

Water Parameter Measurement and Study Design.—All measurements were made at the terminal end of the boat dock for each lake. Boat docks were well marked and were easy to navigate to in the dark. By providing a consistent position we ensured that the sample would be made at the same exact location throughout the study period. Since multiple crews were involved in the data collection it was necessary to ensure that measurements were comparable. The reservoirs of Hoosier National Forest comprise the only significant lakes occurring in Perry County. Measurements were made at the lake surface every two hours beginning at 15:00 on September 16, 2005 and concluding at 14:00 on September 17, 2005. Crews were divided into two-person units and were assigned specific times that the circuit would be collected. Lakes were sampled beginning at Lake Celina, then Indian Lake, and concluding at Lake Tipsaw. Each crew provided training and oversight of the crew following to ensure comparability and quality assurance of the information.

Water chemistry.—Two of the three lakes were too shallow to develop a stratified profile. Since most portions of each lake are less than 2 m in maximum depth it was not necessary to evaluate changes occurring in the deepest portion of the lake. These areas would have not been used by fish assemblages.

A digital meter (Dow Corning, Inc, Pocket Meter M90) was used to measure dissolved oxygen (precision and accuracy DO 0.0-20.00 $\pm$ 0.1 mg/L), temperature (-0.5 °C to 100 °C $\pm$ 0.1 °C), pH (0 to 14 $\pm$ 0.1 SU), salinity (0 to 20 $\pm$ 0.1 ppt), specific conductance (0.0 to 1999 $\pm$ 1 µS), and total dissolved solids (TDS; 0.0 to 1000 $\pm$ 0.1 mg/L). The oxidation-reduction potential (E_h) was measured using a digital meter (LaMotte, Inc, ORPTestr, -200 to 1100 $\pm$ 5 mv). Dissolved oxygen was calibrated using a Winkler titration (American Public Health Association 1989). Water samples were taken along shore near the boat launch within each lake.

RESULTS AND DISCUSSION

Patterns in Temperature and Oxygen.—Dissolved oxygen levels were highest during the late morning in Lake Celina and mid-afternoon in Lakes Tipsaw and Indian (Figures 1–3). Supersaturated dissolved oxygen levels were observed during mid-morning in Lakes Tipsaw (102% saturation at 9:45) and Celina (110% saturation at 10:08). The levels of dissolved oxygen generally followed predictable relationships with temperature, but differed during late afternoon in Lake Celina when saturation levels declined to 55.8% saturation during nocturnal periods (measured at 4:06). Indian Lake showed the lowest concentrations of dissolved oxygen with levels near or less than 50% saturation from midnight to dawn periods. Levels of dissolved oxygen followed predictable patterns with temperature for Lake Tipsaw. The lowest dissolved oxygen level was measured from Indian Lake from 2:06 to 3:10 when levels measured 0.8 mg/L.

Temperature and dissolved oxygen profiles typically show declining dissolved oxygen levels with increasing temperatures (Wetzel 2001). There are a variety of complex reasons that can

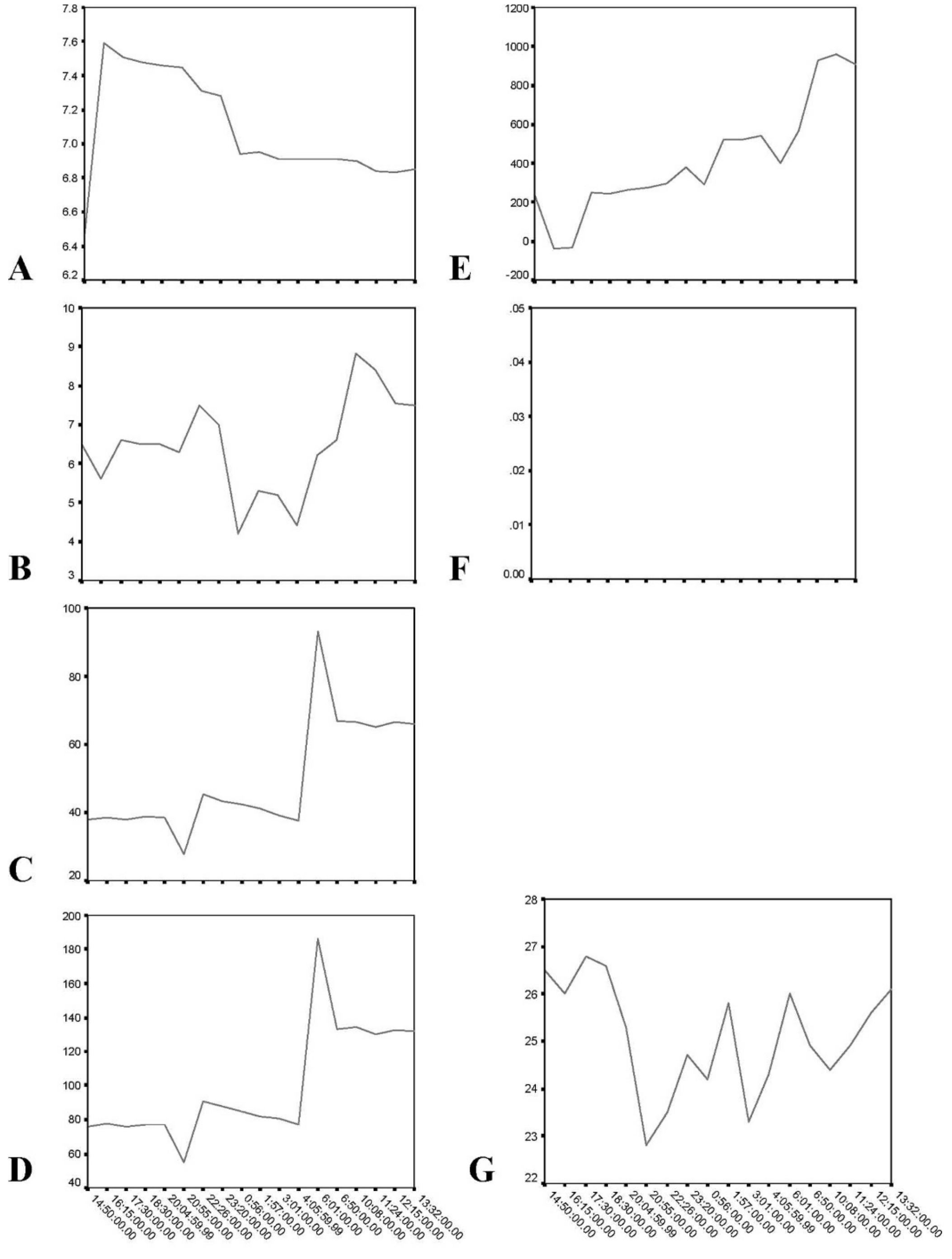

Figure 1.—Diel profiles for seven water quality variables in Lake Celina in September. A. pH (standard units), B. Dissolved oxygen (mg/L), C. Total dissolved solids (mg/L), D. Specific conductance (µS), E. oxidation-reduction potential (E_h), F. Salinity (ppt), and G. temperature (°C).

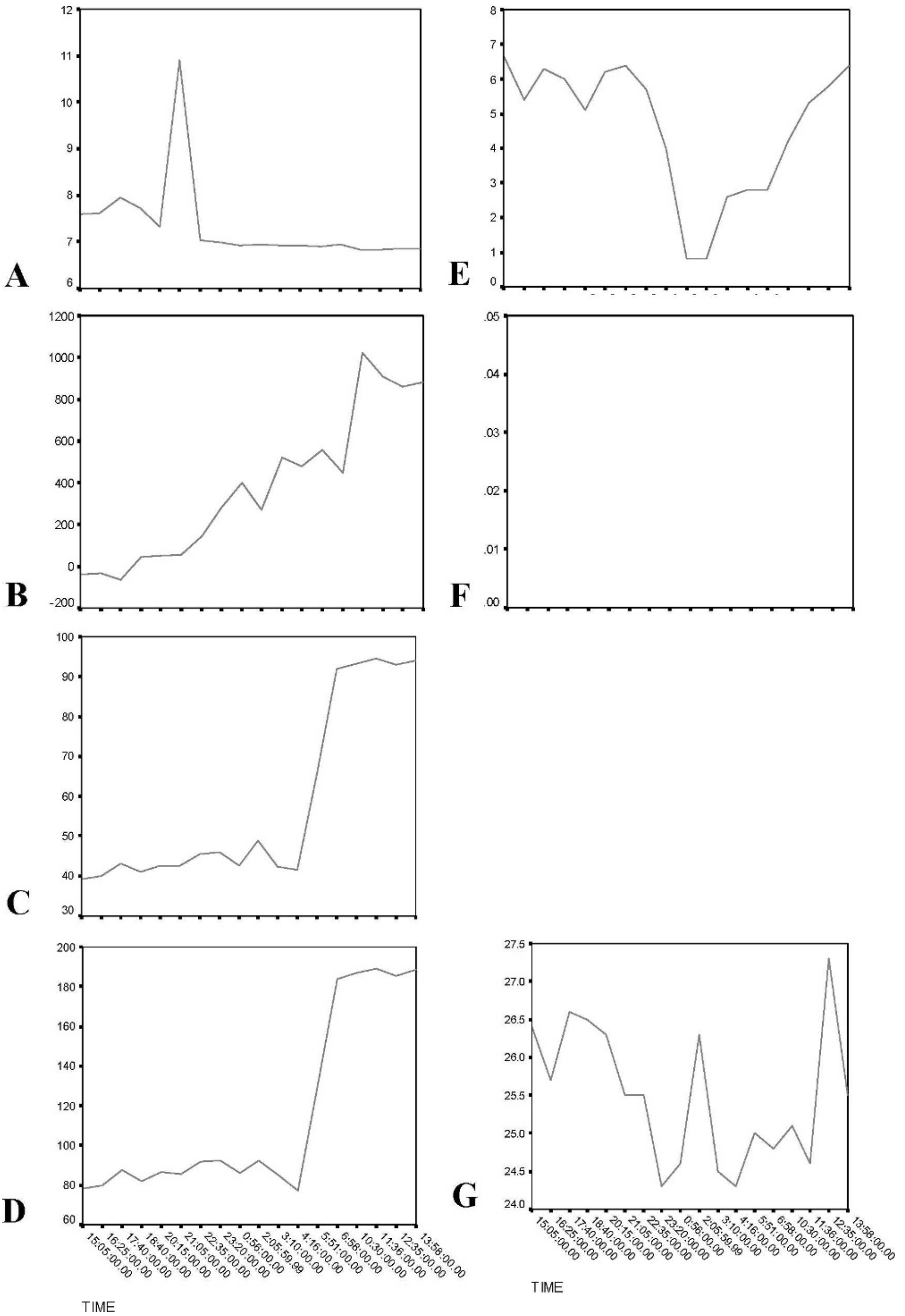

Figure 2.—Diel profiles for seven water quality variables in Indian Lake in September. A. pH (standard units), B. Dissolved oxygen (mg/L), C. Total dissolved solids (mg/L), D. Specific conductance (µS), E. oxidation-reduction potential (E_h), F. Salinity (ppt), and G. temperature (°C).

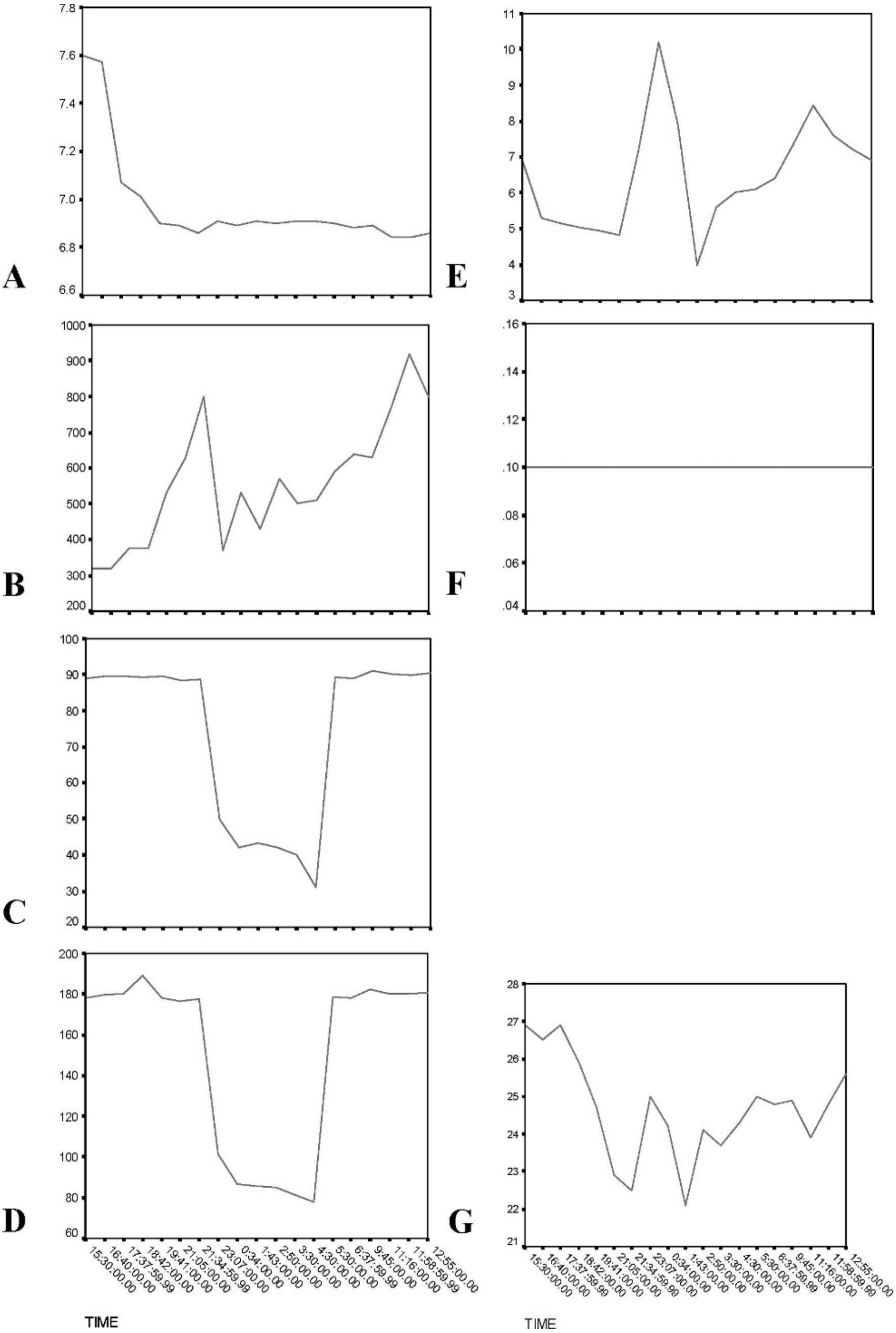

Figure 3.—Diel profiles for seven water quality variables in Tipsaw Lake in September. A. pH (standard units), B. Dissolved oxygen (mg/L), C. Total dissolved solids (mg/L), D. Specific conductance (µS), E. oxidation-reduction potential (E_h), F. Salinity (ppt), and G. temperature (°C).

explain dissolved oxygen profiles being significantly lower than predicted from temperature. These can be a result of increasing chemical or biological oxygen demand, chemical contaminants, biological respiration or a combination of these factors. Respiration of aquatic plants causes the greatest declines during nocturnal periods and increasing levels of dissolved oxygen levels during the peak photosynthetic periods. These dissolved oxygen patterns seem to follow most closely the patterns predicted by aquatic plant respiration. Phytoplankton levels are usually quite low in these lakes (IDEM, 1996), so macrophytic vegetation may be more important in regulating the diel variations.

During the 24-hr diel study, temperatures ranged from 24.3 to 27.3 °C in Indian Lake, 22.8 to 26.8 °C in Lake Celina, and 21.8 to 26.9 °C in Tipsaw Lake. The lowest temperature was measured during nocturnal periods in Indian Lake (4:16) and Tipsaw Lake (6:38), and dusk periods in Lake Celina (20:55). The highest temperature was measured during late afternoon in Lake Celina (17:30) and Tipsaw Lake (15:30 to 17:38), and mid-afternoon in Indian Lake (12:35).

Patterns in pH, Oxidation-Reduction Potential, Total Dissolved Solids, Specific Conductivity, and Salinity.—Diel variations in pH levels were observed in all three lakes (Figs. 1–3) with highest pH levels observed in all three lakes during mid-afternoon on 16 September and declining to lowest levels during the nocturnal and dawn periods. A single pH spike was observed in Indian Lake during dusk period (21:05) with a recorded pH of 10.91. This extreme measurement is not considered an outlier since measurements later dropped to normal pH levels by midnight. Standard units of pH ranged from 6.82 (10:30) to 7.95 (17:40) in Indian Lake, 6.84 (11:16 to 11:59) to 7.57 (16:40) in Tipsaw Lake, and from 6.46 (14:50) to 7.59 (16:15) in Lake Celina.

Oxidation-reduction potential (E_h) is an index of the exchange activity of electrons among elements in solution. A positive potential indicates oxidizing conditions in the water; a negative potential indicates reducing conditions, which determines the valence state of metals (Hem 1985). Reducing conditions were measured in all three lakes (Figures 1–3). The lowest reducing condition during the longest period of time was measured in Tipsaw Lake with reducing conditions during mid-afternoon to dusk periods (16:40–23:07). Reducing conditions were measured during late-afternoon in both Lake Celina (16:15–17:30) and Indian Lake (16:25–17:40). It is not known why extreme alkaline pH conditions were measured in Indian Lake; however, this corresponded to the change from reducing to oxidized conditions during dusk to nocturnal periods. This shift from reducing to oxidized conditions may have caused a valence change and a release of autochthonous materials from the sediment-water interface.

Specific conductance is a measure of the ability of a substance to conduct electricity across a unit length at a specific temperature. Dissolved substances increase the conductivity of water; measurements of specific conductance provide an indication of the amount of dissolved substances in water (Hem 1985). Specific conductance and total dissolved solids increased in Lake Celina (Fig. 1) and Indian Lake (Figure 2) from dawn to mid-afternoon and declined during dusk to dawn periods in Tipsaw Lake (Figure 3).

Salinity did not show any diel changes in any of the three lakes during this study (Figs. 1–3). Salinity was stable during the entire measurement period and showed no variability.

CONCLUSIONS

Three lakes in Hoosier National Forest, Perry County, southern Indiana, were studied for diel changes in dissolved oxygen, temperature, pH, oxidation-reduction potential, salinity, specific conductance, and total dissolved solids during the fall of 2005. The shallow nature of these three lakes has caused dramatic shifts in pH, dissolved oxygen, oxidation-reduction potential, and specific conductance. The largest changes in dissolved oxygen and pH occurred at dawn and dusk when aquatic plants switched from photosynthesis to respiration. Changes in oxidation-reduction and specific conductance were the result of the loss of dissolved oxygen in the lake sediment microzone. As the lake substrate changed from a reducing environment to an oxygenated environment, total dissolved solids and specific conductance increased as these materials were released into the water column. Low dissolved oxygen levels and associated chemical stressors associated with aquatic plant respiration could have been responsible for recent fish kills observed in the lakes.

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LITERATURE CITED

American Public Health Association. 1989. Standard Methods for the Examination of Water and Wastewater. 16th edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation, Washington, D.C.

Brett, J.R. 1979. Environmental factors and growth. Pp. 677–743. *In* Fish Physiology. Volume VIII. Bioenergetics and Growth (W.S. Hoar, D.J. Randall & J.R. Brett, eds.). Academic Press, New York, NY.

Chapman, G. 1986. Ambient water quality criteria for dissolved oxygen. EPA 440/5-86-003. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Evans, J.J., C.A. Shoemaker & P.H. Klesius. 2004. Effects of sublethal dissolved oxygen stress on blood glucose and susceptibility to *Streptococcus agalactiae* in nile tilapia *Oreochromis niloticus*. Journal of Aquatic Animal Health 15:202–208.

Hem, J.D. 1985. Study and interpretation of the chemical characteristics of natural waters, 3rd edition. U.S. Geological Survey Water Supply Paper 2254. 263.

Indiana Department of Environmental Management. 1996. Indiana lake water quality update for 1989–1993. Clean Lakes Program, Indianapolis, IN. 58 p.

Omernik, J.M. & A.L. Gallant. 1988. Ecoregions of the upper Midwest states. EPA 600/3-88/037. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR.

Schneider, A.F. 1966. Physiography. Pp. 40–56. *In* Natural Features of Indiana (A.A. Lindsey, ed.). Indiana Academy of Science, Indianapolis, Indiana. 597 p.

Simon, T.P. submitted. Distribution and condition of fish assemblages in Hoosier National Forest, Perry County, Indiana, with emphasis on lake condition assessment. Proceedings of the Indiana Academy of Science.

Wesolowski, E.A. 1996. Simulation of wastewater effects on dissolved oxygen during low streamflow in the Red River of The North at Fargo, North Dakota, and Moorhead, Minnesota. U.S. Geological Survey Fact Sheet FS-235-96.

Wetzel, R.G. 2001. Limnology. 3rd Ed. W.B. Saunders, Philadelphia, Pennsylvania.

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