JOURNAL OF THE TENNESSEE ACADEMY OF SCIENCE 71(2):36-40 APRIL 1996

PHYTOPLANKTON PRODUCTION IN WEST SANDY BAY, KENTUCKY LAKE

JEFFERSON G. LEBKUECHER, CHRISTOPHER J. CHABOT,
AND TIMOTHY D. NEVILLE

Department of Biology and The Center for Field Biology, Austin Peay State University, Clarksville, TN 37044

ABSTRACT—In support of a program to encourage improved water quality in the West Sandy Creek watershed of Henry Co., Tennessee, measurements of impacted water quality of West Sandy Bay, Kentucky Lake, were undertaken. Vertical profiles of photosynthetic photon flux density and in situ primary-productivity and respiration rates were determined at mid-bay during the photoperiod of 5 August 1993. On this date, West Sandy Bay had a high vertical extinction coefficient (2.15), a shallow yet productive euphotic zone (1.9 m; mean maximum gross-productivity rate = 116 mg carbon $mg^{-3}h^{-1}$), low water-column gross productivity (230 mg carbon m^{-2}surface day^{-1}), and high respiration rates (mean = 14.9 ± 0.6 *SE* mg carbon $m^{-3}h^{-1}$); these are characteristics indicative of poor water quality. These results help demonstrate the negative impact of the poor-quality water of the West Sandy Creek watershed on the water quality of West Sandy Bay.

Kentucky Lake is the largest impoundment of the Tennessee River with a surface area of 64,873 ha at full pool (Tennessee Valley Authority, 1995). Bays of such large river impoundments often have poor water quality as a result of nutrient and sediment loading from tributary streams (Baxter, 1977). West Sandy Bay of Kentucky Lake is an arm of Big Sandy Bay (Fig. 1) and has a history of poor water quality as a result of the polluted water it receives from West Sandy Creek (Finley and Hamilton, 1991).

The West Sandy Creek watershed drains 240 km^2 of Henry Co., Tennessee, including the city of Paris. The water quality of the West Sandy Creek watershed is poor as determined by the analyses of sediment and water chemistry and macroinvertebrate-community compositions (Finley and Hamilton, 1991). Nonpoint source pollution (i.e., many different pollutants entering waterbodies from diffuse sources) is the major contributor to the poor water quality (Finley et al., 1992). Streams that drain the West Sandy watershed pick up dissolved and particulate pollutants from agricultural, silvicultural, and urban sources.

The water-quality problem within the West Sandy watershed is exacerbated by the large number of stream reaches that are channelized. Although channelization may be an effective means of flood control, it often greatly increases the rate of sediment transport and decreases water quality (Hupp, 1992). The water quality of West Sandy Bay, especially in terms of transparency, is adversely affected by the West Sandy pumping station located at West Sandy river mile 3.0. This facility is operated by the Tennessee Valley Authority and is designed to control water levels in the lower sections of the West Sandy watershed. The station pumps water laden with dissolved and particulate matter into West Sandy Bay, primarily during April, May, and June (Finley and Hamilton, 1991).

Many aspects of water quality influence phytoplankton productivity which provides the base for lentic food webs. The purpose of this study was to examine the in situ phytoplankton-productivity and respiration rates of the water of West Sandy Bay. The research is a supplement to the evaluation of the ecological impacts of nonpoint source pollution within the West Sandy Creek watershed by the Tennessee Department of Agriculture, Nonpoint Source Pollution Program, and The Center for Field Biology of Austin Peay State University.

MATERIALS AND METHODS

A vertical profile of photosynthetic photon flux density (PPFD) of West Sandy Bay was determined on 3 August 1993 at 1300 h under clear skies to determine the best depth intervals for productivity determinations. The PPFD levels were measured with a spherical underwater quantum sensor coupled to a Li-Cor quantum meter. On 5 August 1993, the same day of the productivity determinations, vertical profiles of PPFD were determined at mid-bay at least every 2 h from dawn to dusk. These data were used to determine the depth of the euphotic zone and the vertical extinction coefficient (n"). Calculation of n" was based on the PPFD data from 1130 h and the following formula (Lind, 1979): $n'' = (\ln PPFD_{surface} - \ln PPFD_{3\text{ - m depth}})/PPFD_{3\text{ - m depth}^{2}}$.

Phytoplankton productivity was examined in situ at mid-bay on 5 August 1993 using the bottle-oxygen method (Gaardener and Gran, 1927). Procedures followed standard methods (Clesceri et al., 1989). The bottle-oxygen method was chosen because it provides community metabolism estimates of gross-productivity, net-productivity, and whole-sample (including bacteria, zooplankton, and phytoplankton) respiration rates. Although underestimation of primary productivity is assumed due to the consumption of oxygen by nonphotosynthetic organisms during incubation of the sample bottles, this method is preferred in eutrophic waters if long incubation periods are utilized to examine photoperiod productivity (Vollenweider, 1971; Reynolds, 1990).

Two replicate water samples, taken from two replicate submersions of a Van Dorn sampler, were retrieved from depths of 0.05 (surface), 0.25, 0.50, 1.00, 2.00, and 3.00 m. Each sample from each depth was transferred to three borosilicate-glass bottles with ground-glass stoppers: a clear bottle; a darkened bottle; a bottle used to determine the initial dissolved-oxygen concentration. Transfers utilized a rubber delivery tube to prevent aeration.

Clear and darkened sample-containing bottles were suspended at the same depth from which the samples were collected. To eliminate

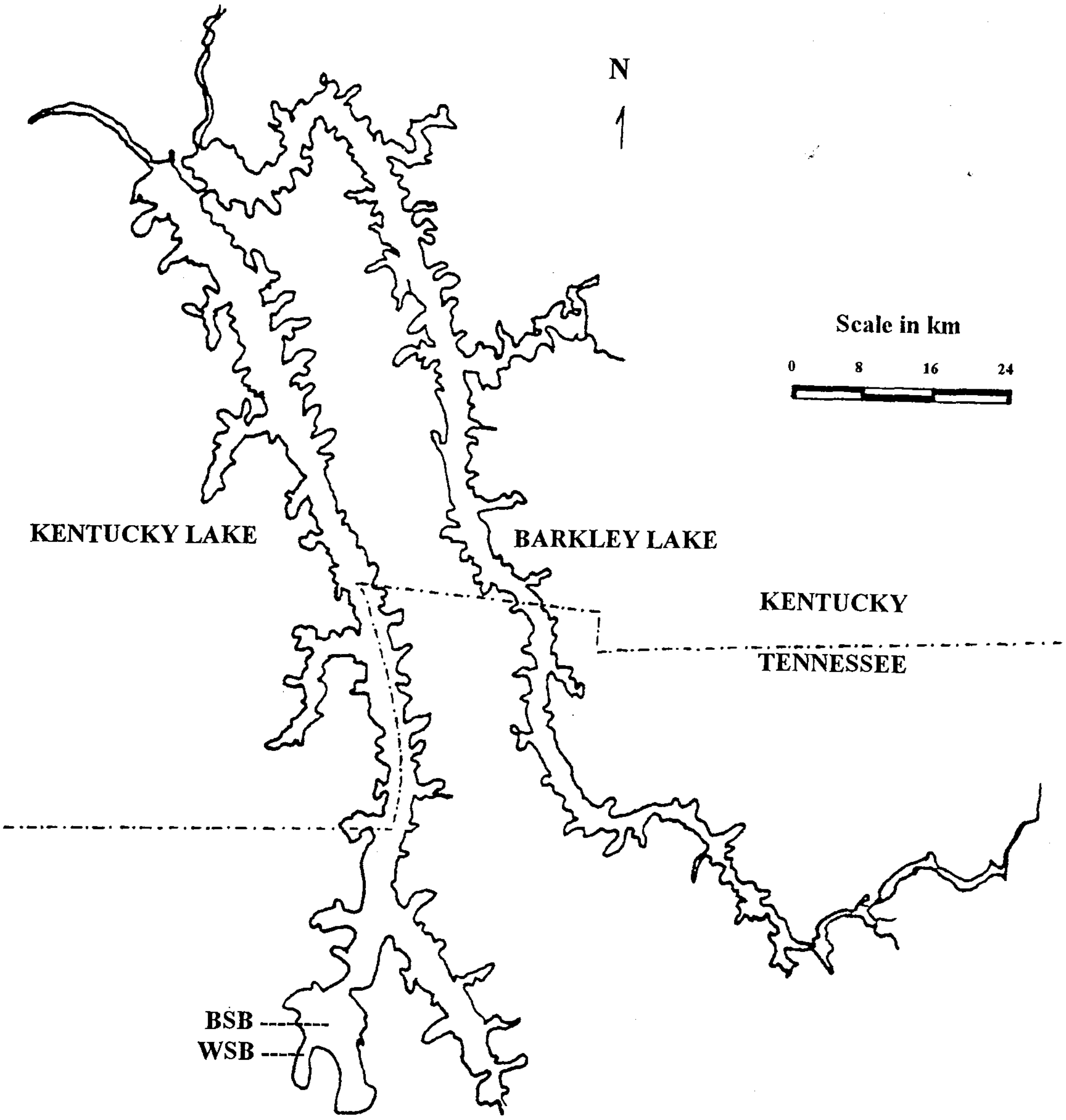

FIG. 1. Map showing localities of West Sandy Bay (WSB) and Big Sandy Bay (BSB), Henry Co., Tennessee.

shading effects, clear bottles were suspended in a horizontal position from different lines. At the end of each 5-h incubation period (0530-1030, 1030-1530, and 1530-2030 h), the bottles were retrieved. No air bubble was observed in any of the clear bottles following the three incubation periods. Concentration of bottle dissolved oxygen was determined with an aqueous oxygen system (Hansatech Ltd., Kings Lynn, United Kingdom).

The change in concentration of dissolved oxygen in clear bottles during incubation was used to determine net-productivity rate which, because of the concurrent use of oxygen by respiration, is less than the gross-productivity rate. The loss of dissolved-oxygen concentration during incubation of darkened bottles was used to determine whole-sample respiration rate. Gross productivity was estimated by adding the loss of dissolved oxygen resulting from whole-sample respiration to the net-productivity rate. Gross productivity at each depth for the entire photoperiod was estimated by adding the gross-productivity rates of the three incubation periods. The photoperiod gross productivity of the water column was calculated by determining the area under the gross productivity-depth curve. Rate calculations and conversions from oxygen to carbon followed standard methods (Clesceri et al., 1989).

RESULTS AND DISCUSSION

The exponential rate of light extinction in water results from the absorption of photons by the water itself and suspended and dissolved materials. The PPFD at varying depths and times of the photoperiod (Table 1) and the high vertical extinction coefficient (2.15) reveal the low light-transmission quality of the water of West Sandy Bay on 5 August 1993. The vertical extinction coefficient (n") is an expression of the PPFD-depth slope on a logarithmic axis: the higher the n"-value, the greater the vertical extinction rate. A large majority of light-extinction studies from a wide variety natural freshwater lakes and reservoirs with different morphologies and chemistries report n"-values near 1.3 (Talling, 1971), a value which has been adopted as typical for purposes of comparison (Reynolds, 1990:143). Although the rate of light extinction is affected by water chemistry (Weilenmann and O'Malia, 1989), rates of extinction which are described as high (i.e., n" ≥ 1.8; Megard, 1974) are indicative of high concentrations of suspended matter (Luettich et al., 1990).

The high n" of West Sandy Bay results in a shallow euphotic zone (1.9 m on 5 August 1993), the portion of the water column receiving ≥1% of the surface illumination. For example, the mean (*n* = 6) euphotic-zone depth of Kentucky Lake determined at mid-reservoir during July and August of 1993 was 2.4 ± 0.1 *SE* m (D. Dycus and D. Meinert, pers. comm.). The PPFD-absorption characteristics of West Sandy Bay suggest that water entering the bay contains large amounts of suspended matter. These results support the conclusion of Finley and Hamilton (1991) that erosion of the powdery, readily-eroded, loess soil that predominates West Tennessee is the most significant nonpoint source pollution problem of the area.

The gross- and net-productivity data demonstrate that the euphotic zone of West Sandy Bay is very productive (Table 2), possibly due to nutrient enrichment by the sediment-laden water entering the bay from the West Sandy watershed (Finley et al., 1992). Decreased productivity during the incubation period of 1530-2030 h is apparent, presumably as a result of increased cloud cover (Table 1). High near-surface productivity rates are reported from other bays of Kentucky Lake; however, gross rates >100 mg carbon $m^{-3}h^{-1}$ typically occur only in late spring and early summer (Kipphut, 1992). Photoperiod gross productivity of the water column was only 230 mg carbon m^{-2}surface day^{-1} with 97% occurring within the top 2 m (Fig. 2). The limitation of primary productivity to such shallow depths is not surprising given that irradiance levels at 2-m depths were only 1% of the surface irradiance.

Water-sample respiration rates on 5 August 1993 were high (mean = 14.9 ± 0.6 *SE*; 1.7% of maximum gross-productivity rate). Utilizing a fixed-model, two-factor analysis of variance, no significant effect of depth (F = 1.7, α = 0.05, power = 0.45), incubation time period (F = 0.1, α = 0.05, power = 0.30), or interaction (F = 0.1, α = 0.05, power = 0.94) on respiration rate was detected. Typically, respiration rates are ca. 1.0% or less of the maximum gross-productivity rate (Steel, 1972; Jewson, 1976). That respiration rates were uniform at all depths and incubation periods is consistent with other respiration studies of lentic systems (Harris and Piccinin, 1977).

Gross- and net-productivity rates from 0.25-m depths were consistently higher relative to surface rates despite that irradiance levels at 0.25-m depths averaged only 50% of surface-irradiance levels. Reduced productivity of surface phytoplankton due to photoinhibition is common on sunny days (Harris, 1978). Bright light-induced photoinhibitory damage to photosystem-II centers may commence within minutes of phytoplankton exposure to bright light (Harris and Piccinin, 1977). This damage can severely reduce primary productivity because recovery involves the replacement of damaged photosystem-II centers which requires several hours (Lebkuecher and Eickmeier, 1992). For example, the mean gross primary-productivity rates of water samples retrieved near midday from Anderson Creek Bay, Kentucky Lake, on 11 June 1990 were lower in surface samples (23 mg carbon $m^{-3}h^{-1}$) relative to samples from a depth of 0.25 m (63 mg carbon $m^{-3}h^{-1}$) even though productivity rates were determined following incubation under low-irradiance conditions (150 υmol photons $m^{-2}sec^{-1}$) in a light chamber (D. White, pers. comm.). The effects of photoinhibition on phytoplankton photosynthesis may have a large impact on aquatic productivity. This impact may be especially significant in lentic systems that have shallow euphotic zones and, thus, narrow vertical ranges of optimal PPFD exposure for phytoplankton photosynthesis.

In conclusion, these results demonstrate that, on 5 August 1993, West Sandy Bay had a high vertical extinction coefficient, a shallow yet productive euphotic zone, low water-column productivity, and high respiration rates; these are characteristics indicative of poor water quality. These results help demonstrate the negative impact of the poor-quality water of the West Sandy Creek watershed on the water quality of West Sandy Bay.

TABLE 1. Vertical profiles of photosynthetic photon flux density (micromoles photons per square meter per second) of West Sandy Bay at different times on 5 August 1993.

Time (h)	Percent cloud cover	Depth (m)						
		0.05	0.25	0.50	1.00	2.00	3.00	4.00
0530	0	0	0	0	0	0	0	0
0730	0	550	250	130	34	3	0	0
0930	10	900	350	250	80	5	1	0
1030	10	1,605	995	563	144	12	1	0
1130	0	2,100	1,300	750	190	17	1	0
1330	10	1,300	650	300	90	7	1	0
1530	100	450	250	110	33	2	0	0
1730	100	180	100	59	20	2	0	0
1930	100	20	13	7	3	2	0	0
2030	100	0	0	0	0	0	0	0

TABLE 2. Gross-productivity, net-productivity, and respiration rates during 5-h incubation periods at different depths in West Sandy Bay on 5 August 1993. Values represent mean milligrams of carbon per cubic meter per hour from two replicate samples.

Depth (m)	Assay	Incubation-time period (h) 0530-1030	1030-1530	1530-2030
0.05	Gross productivity	91.8	108.2	49.2
	Net productivity	75.9	91.0	31.5
	Respiration	15.6	17.2	17.7
0.25	Gross productivity	104.9	115.7	59.8
	Net productivity	88.1	96.6	40.9
	Respiration	16.8	19.1	18.9
0.50	Gross productivity	66.2	76.2	24.8
	Net productivity	50.7	59.8	7.6
	Respiration	15.5	16.4	17.2
1.00	Gross productivity	31.9	39.7	11.0
	Net productivity	18.2	26.3	-3.1
	Respiration	13.7	13.4	14.1
2.00	Gross productivity	2.8	4.1	1.1
	Net productivity	-9.1	-8.2	-9.6
	Respiration	11.9	12.3	10.7
3.00	Gross productivity	0.4	0.0	0.0
	Net productivity	-12.1	-11.2	-13.6
	Respiration	12.5	11.2	13.6

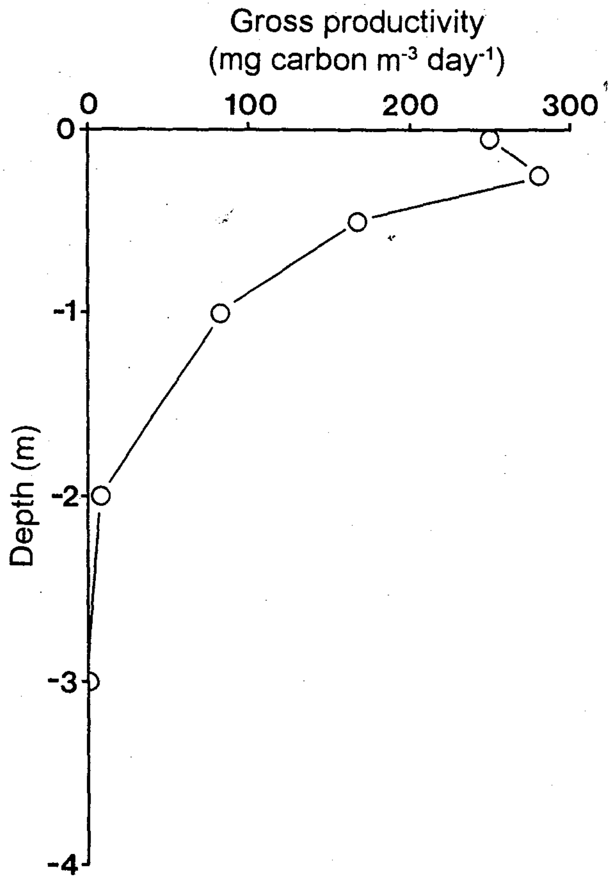

FIG. 2. Vertical profile of photoperiod productivity of West Sandy Bay, Henry Co., Tennessee, on 5 August 1993.

ACKNOWLEDGMENTS

We thank S. Hamilton, M. Finley, O. Yates, J. Breeden, and D. L. Bunting for their suggestions which improved the manuscript. Funding was provided by the Tennessee Department of Agriculture, Nonpoint Source Pollution Program, and The Center for Field Biology of Austin Peay State University.

LITERATURE CITED

BAXTER, R. M. 1977. Environmental effects of dams and impoundments. Ann. Rev. Ecol. Syst., 8:255-283.

CLESCERI, L. S., A. E. GREENBERG, AND R. H. TRUSSELL (EDS.). 1989. Standard methods for the examination of water and wastewater. 17th ed. Amer. public Health Assoc., Washington, DC.

FINLEY, M. T., AND S. W. HAMILTON. 1991. Investigation of nonpoint source water pollution and water resources on Kentucky Lake embayments. The Center for Field Biology, Austin Peay State Univ., Clarksville, Tennessee, AP-47716-92:1-48.

FINLEY, M. T., J. A. GORE, AND S. W. HAMILTON. 1992. Proposed best management practices for improving water quality in the West Sandy watershed. The Center for Field Biology, Austin Peay State Univ., Clarksville, Tennessee.

GAARDENER, T., AND H. H. GRAN. 1927. Investigations of the production of plankton in Oslo Fjord. Rapports Proces-Verbaux Reunions. Conseil Internat. pour l'Exploration Mer., 42:1-48.

HARRIS, G. P. 1978. Photosynthesis, productivity and growth: the physiological ecology of phytoplankton. Ergebnisse Limnol., 10:1-163.

HARRIS, G. P., AND B. B. PICCININ. 1977. Photosynthesis by natural phytoplankton population. Arch. Hydrobiol., 80:405-457.

HUPP, C. R. 1992. Riparian vegetation recovery patterns following stream channelization: a geomorphic perspective. Ecology, 73:1209-1226.

JEWSON, D. H. 1976. The interaction of components controlling net photoplankton photosynthesis in a well-mixed lake (Lough Neagh, Northern Ireland). Freshwater Biol., 6:551-576.

KIPPHUT, G. 1992. Limnology of Kentucky Lake. Reservoir Rev., Murray State Univ., Murray, Kentucky, 2:4-5.

LIND, O. T. 1979. Handbook of common methods in limnology. Second ed. Mosby Company, St. Louis, Missouri.

LEBKUECHER, J. G., AND W. G. EICKMEIER. 1992. Photoinhibition of photophosphorylation, adenosine triphosphate content, and glyceraldehyde-3-phosphate dehydrogenase ($NADP^+$) following high-irradiance desiccation of *Selaginella lepidophylla*. Canadian J. Bot., 70:205-211.

LUETTICH, R. A., D. R. F. HARLEMAN, AND L. SOMLYODY. 1990. Dynamic behavior of suspended sediment concentrations in a shallow lake perturbed by episodic events. Limnol. Oceanogr., 35:1050-1067.

MEGARD, R. O. 1974. Limnology of Lake Minnetonka. Limnol. Res. Center, Univ. Minnesota, Rept., 11:1-61.

REYNOLDS, C. S. 1990. The ecology of freshwater phytoplankton. Cambridge Univ. Press, New York.

STEEL, J. A. 1972. The application of fundamental limnological research in water supply and management. Symposia Zool. Soc. London, 29:41-67.

TALLING, J. F. 1971. The underwater light climate as a controlling factor in the production ecology of freshwater phytoplankton. Mitteilungen. Internatiopnale Vereinigung fuer Theoretische und Angewandte Limnol., 19:214-243.

TENNESSEE VALLEY AUTHORITY. 1995. Aquatic ecological health determinations for TVA Reservoirs—1994. An informal summary of 1994 vital signs monitoring results and ecological health determination methods (D. L. Dycus, ed.). Tennessee Valley Authority, Chattanooga, Tennessee.

VOLLENWEIDER, R. A. 1971. A manual on methods for measuring primary production in aquatic environments. IBP Handbook 12. Blackwell Scientific Publications, Oxford, United Kingdom.

WEILENMANN, U., AND C. R. O'MELIA. 1989. Particle transport in lakes: models and measurements. Limnol. Oceangr., 34:1-18.