PRIMARY PRODUCTIVITY IN AN ILLINOIS RIVER FLOOD PLAIN LAKE

B. J. MATHIS, J. Z. TAYLOR and S. A. MYERS
Bradley University, Peoria; Lamar State College of Technology, Beaumont, Texas; Bradley University, Peoria

ABSTRACT. — Physico-chemical conditions and community metabolism in a shallow flood plain lake of the Illinois River were studied to determine the influence of the river on the lake. When the lake was inundated by the river, planktonic community structure and seasonal succession were disrupted resulting in minimal chlorophyll concentrations and assimilation numbers. Wind created turbidity in the lake appeared to be the major factor limiting primary production between periods of inundation.

Physico-chemical conditions and biota of flood plain lakes adjacent to the Illinois River have been extensively and intensively studied. None of these investigations, however, have reported quantitative studies of community metabolism. Shallow flood plain lakes of the Illinois River can be highly productive. These lakes receive nutrients, especially nitrates and phosphates, from the polluted Illinois River during periods of high flow. In the present study, community metabolism in a shallow flood plain lake was estimated by diel changes in oxygen concentration.

DESCRIPTION OF STUDY AREA

Worley Lake is a shallow flood plain lake of the Illinois River. It is located on the east bank of the river in Tazewell County approximately four miles south of Peoria, Illinois (Fig. 1). The lake covers an area of 156 hectares and has a maximum depth of one and one-half meters when at full capacity. Average depth is 0.7 m at full capacity. The bottom of the lake consists of soft flocculent material that has been deposited by the river during periods of inundation. Rooted vegetation and floating leaf vegetation is absent.

PROCEDURES

Community metabolism was estimated by methods described by Odum and Hoskin (1958) and Odum and Wilson (1962). Diurnals were conducted on clear days at stations located at opposite ends of the lake (Fig. 1). The distance between stations was approximately 1,200 m. Duplicate water samples were taken every two hours in daylight and every three hours at night at both stations and analyzed for oxygen by the Alsterberg (Azide) modified Winkler method (APHA, 1965).

Physico-chemical conditions were determined at weekly intervals during the summer and monthly intervals during other seasons except for January and February of 1968 when the lake was frozen over. Chlorophyll *a* concentration was determined by filtering 100 ml aliquots through

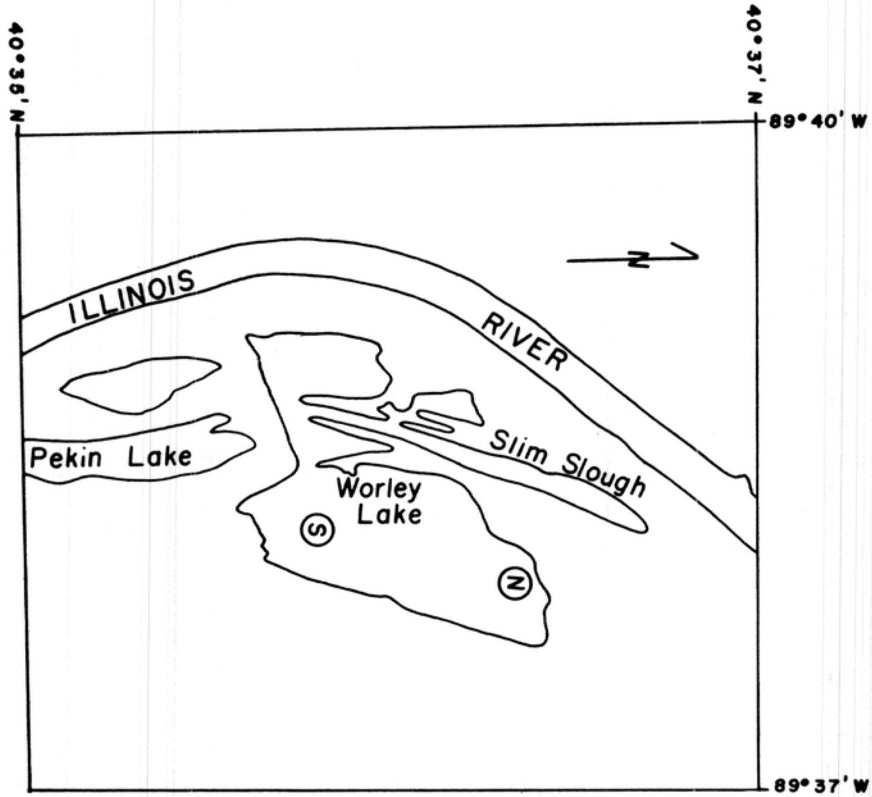

FIGURE 1. Map of Worley Lake and the adjacent Illinois River. S = South Station; N = North Station.

membrane filters of 0.45 micron pore size. The residues were extracted in 10 ml of 90% acetone and refrigerated in the dark at approximately 5 C for 24 hours. Upon removal, the samples were centrifuged and optical density of the liquid was determined with a Bausch and Lomb Spectronic 20 photoelectric colorimeter with a 2.54 cm cuvette at 430 and 665 millimicrons.

The methods of Odum, McConnell and Abbott (1958) were used to estimate chlorophyll *a* concentration where chlorophyll *a* in mg/liter (gr/m^3) of 90% acetone = 13.4 d_{665}. After correction for acetone and sample volume this equation became: Chlorophyll *a* in mg/liter = 1.34 d_{665}. Volumetric values were multiplied by depth of the euphotic zone to convert to an areal basis.

Water temperature and alkalinity were measured in the field according to standard methods. Turbidity was determined in the laboratory with a Bausch and Lomb Spectronic 20 photoelectric colorimeter with a 2.54 cm cuvette at d_{450}. The pH was measured in the field by means of a portable Sargent pH meter. Specific conductance was determined with a

TABLE 1. — Mean Annual Physico-Chemical Conditions.

Station	Turbidity (ppm)	Specific Conductance (umhos/cm)	ALKALINITY HCO_3 (ppm)	CO_3 (ppm)	pH
South	95	501	138	5	8.4
North	102	491	130	9	8.6

YSI Model 31 conductivity bridge while the depth of the euphotic zone was measured with a G. M. Mfg. Instrument Corporation submarine photometer.

Suspended organic matter was determined by filtering 100 ml aliquots through membrane filters of 0.45 micron pore size. After filter and residue had been dried in an oven, they were cooled, weighed, and ashed at red heat in a muffle furnace. After cooling and weighing the ash, the weight of the ash and filter paper was subtracted from the dried weight to determine weight of suspended organic matter.

RESULTS AND DISCUSSION

Physico-Chemical Conditions

Differences in mean annual physico-chemical conditions between stations were slight (Table 1). Turbidity varied from 25 to 275 ppm while pH varied fom 7.9 to 9.5. Specific conductance varied from 338 to 700 micromhos and was lowest

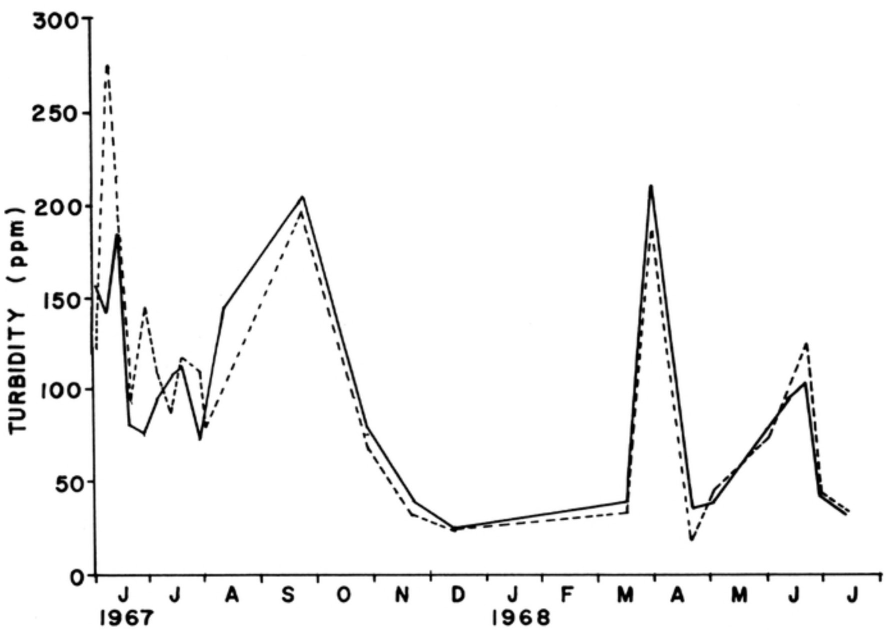

FIGURE 2. Turbidity conditions in Worley Lake. (——) = South Station; (- - -) = North Station.

after dilution by river water. The loss of water from the lake by evaporation at low flow periods of the lake apparently concentrated ions responsible for specific conductance measurements.

Water in Worley Lake is extremely turbid, especially when the water level is less than full capacity (Fig. 2). Turbidity ranged from 25 ppm to 205 ppm at the South Station and from 33 ppm to 275 ppm at the North Station.

The euphotic zone, considered to be that depth at which light penetration is 1% of surface intensity, varied considerably during the study but was generally deepest when the river was connected to the lake (Table 2). The deepest penetration of the euphotic zone into the lake occurred on 12 July 1968 while the river was in a prolonged flood stage. At that time the maximum water depth was 2.5 m. In their study of Lake Chautaugua, Jackson and Starrett (1959) found that turbidity tended to vary with wind velocity during low water periods if vegetation or ice cover was absent. A similar situation was noted in Worley Lake. When water level in the lake was low, wave action kept the turbidity high.

TABLE 2. — DEPTH OF EUPHOTIC ZONE IN METERS

Date	Station South	North
14 June 1967	.38	.41
22 June 1967	.55	.55
1 July 1967	.44	.55
23 July 1967	.65	.60
31 July 1967	.54	.54
14 Dec. 1967	1.00	1.00
16 Mar. 1968	.65	.78
29 Mar. 1968	.18	.16
19 Apr. 1968	.71	.71
2 May 1968	.51	.56
3 June 1968	.75	.67
12 June 1968	.46	.53
18 June 1968	.41	.41
21 June 1968	.38	.38
28 June 1968	.91	.91
12 July 1968	1.13	1.04
Mean	.60	.61

Chlorophyll and Suspended Organic Matter

Highest chlorophyll concentration observed was 0.64 mg/1 in March at the South Station and 0.75 mg/1 in April at the North Station (Fig. 3). According to Bartsch and Allum (1957), Odum et al. (1958) and Wright (1960) chlorophyll concentration is dependent upon the amount of available nutrients. Nutrient levels were apparently high at this time since large numbers of

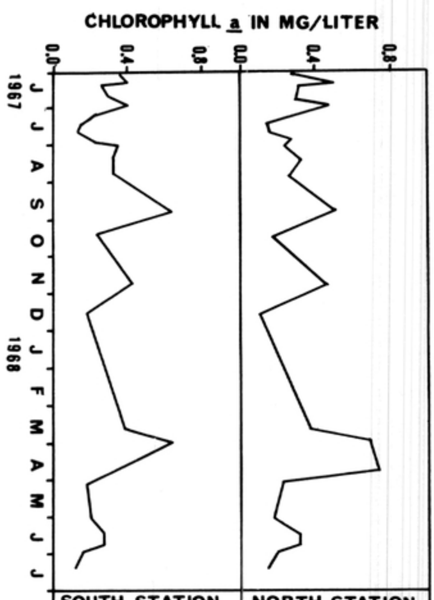

FIGURE 3. Chlorophyll *a* concentration in Worley Lake.

Table 3. — Summer Chlorophyll *a* and Suspended Organic Matter.

Station	Chlorophyll *a*				Suspended Organic Matter	
	Range (g/m^3)	Mean±SD (g/m^3)	Range (g/m^2)	Mean±SD (g/m^2)	Range (g/m^3)	Mean±SD (g/m^3)
South	0.12-0.63	0.30±0.12	0.08-0.20	0.16±0.05	22.1-60.0	33.4±10.1
North	0.15-0.52	0.28±0.16	0.08-0.26	0.16±0.05	16.2-65.1	38.0±16.4

dead fish were observed in and around the lake. These fish were apparently killed during late winter when the lake was ice covered. Suspended organic matter and chlorophyll *a* concentration for the summer are presented in Table 3. The large standard deviation for both suspended organic matter and chlorophyll *a* reflects the wide range of concentrations present in the lake.

Chlorophyll *a* concentrations in the Illinois River during summer are comparable to those found in Worley Lake during summer (Mathis, Root and Weiman, 1968). They reported that chlorophyll *a* concentration ranged from 0.03 to 0.50 mg/1. These concentrations are of the level found in ecosystems receiving large quantities of organic wastes.

Chlorophyll and Assimilation Numbers

The ratio of oxygen production to chlorophyll is referred to as the assimilation number (Odum et al., 1958). Assimilation numbers ranged from 0.2 to 10.7 g 0_2/g chlorophyll $m^{-2}hr^{-1}$ (Table 4). No consistent relationship between the assimilation number and chlorophyll concentration could be discerned in this study. In general, however, assimilation numbers were lowest during and immediately following pe-

Table 4. — Changes in the Relationship Between the Assimilation Number and Chlorophyll *a*

Date	South Station		North Station	
	Assimilation Number	Chlorophyll *a* (g/m^2)	Assimilation Number	Chlorophyll *a* (g/m^2)
6/14/67	0.3	.14	0.2	.17
6/25/67	7.1	.20	7.4	.23
6/30/67	2.2	.15	3.7	.18
7/22/67	2.8	.08	2.7	.09
7/31/67	2.8	.12	3.7	.15
12/14/67	0.9	.19	0.4	.12
3/29/68	0.7	.12	0.6	.11
5/4/68	1.7	.10	1.4	.13
6/3/68	2.5	.16	4.1	.13
6/18/68	2.6	.11	2.4	.12
6/21/68	2.4	.11	2.1	.11
7/12/68	10.6	.14	8.3	.15

riods of high river flow. The high assimilation number obtained in July, 1968, can be attributed to high productivity that occurred after the river had reached and maintained a stable flood stage for two weeks.

Other investigators have found a direct correlation between assimilation numbers and chlorophyll concentration. Copeland, Minter and Dorris (1964) in their study of oil refinery effluent holding ponds reported that assimilation numbers decreased as chlorophyll concentrations increased. Wright (1959) in his study of a natural community and Cooke (1967) in his study of laboratory microcosms reported similar observations. Late successional stages probably occur infrequently in flood plain lakes because frequent floods and high turbidity depress optimal growth conditions. Fluctuations in immature systems are more closely related to abiotic factors while more mature systems fluctuate because of changes in biotic factors (Margalef, 1963a; Hannan, 1967).

The ratio of plant pigment absorbancies (D_{430}/D_{460}) has been suggested by Margalef (1963a,b) as a means of determining succession. Margalef pointed out that the index increases as succession advances. Cooke (1967) reported an increase from an initial level of 2.3 to a maximum of 3.3 after which the index declined to 2.3 again. In Worley Lake, this index ranged from 2.76 to 3.38 at the South Station and from 2.67 to 3.71 at the North Station (Fig. 4). High indices in November and May suggest that the community was proceeding toward stabilization during periods of relative quiescence. The occurrence of

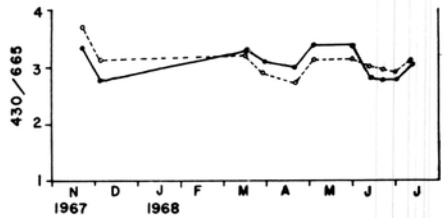

FIGURE 4. Variation in the Margalef pigment ratio in Worley Lake. (——) = South Station; (---) = North Station.

unstable conditions in December disrupted succession, however, and the index decreased. Repetitive disturbances in June kept the index lower than 3.00 at both stations. During July, 1968, however, the index increased when prolonged flood conditions kept the lake at a high but stable level. This suggests that succession was proceeding normally.

Community Metabolism

Primary production and community respiration are plotted for days with clear or nearly clear skies in figure 5. Gross photosynthesis ranged from 4.20 g 0_2m^{-2} day^{-1} in winter to 34.6 g $0_2m^{-2}day^{-1}$ in summer at the South Station. Community respiration varied between 4.4 g 0_2m^{-2} day^{-1} in winter and 23.6 g 0_2m^{-2} day^{-1} in summer.

At the North Station, gross photosynthesis exceeded community respiration slightly more often than at the South Station. Gross photosynthesis at the North Station ranged from 1.2 g 0_2m^{-2} day^{-1} in winter to 30.6 g $0_2m^{-2}day^{-1}$ in summer. Community respiration ranged from 1.5 g 0_2m^{-2} day^{-1} in winter to 23.6 g 0_2m^{-2} day^{-1} in summer. Similar ranges of community metabolism have been reported in other studies (Table 5).

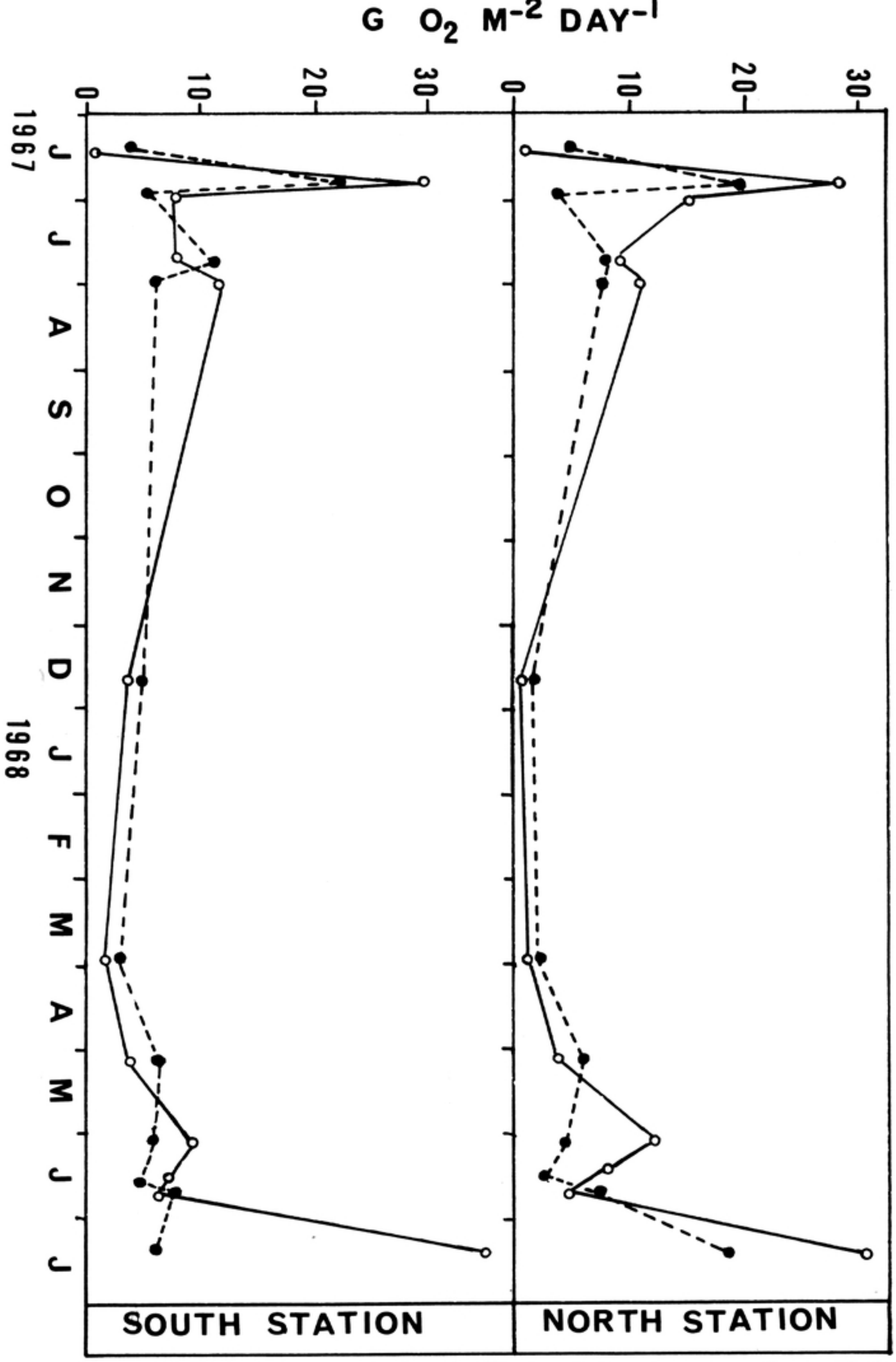

FIGURE 5. Community metabolism in Worley Lake. (——) = Gross Photosynthesis (- - -) = Community Respiration.

TABLE 5. — Community Metabolism in Selected Aquatic Communities Calculated from Diurnal Oxygen Curves

Source	Reference	g O_2/m^2/day Photosynthesis	Respiration
Unpolluted			
Blue River, Okla.	Duffer and Dorris (1966)	1.5-48.0	6.1-19.9
San Marcos River, Texas	Hannan (1967)	2.5-27.4	4.1-19.9
Polluted			
Skeleton Creek, Okla.	Baumgardner (1966)	2.8-60.4	4.9-81.8
Oil Refinery Effluent Holding Ponds, Okla.	Copeland and Dorris (1964)	0.0-29.2	2.1-50.5
Worley Lake, Illinois	Present Study	0.6-34.6	1.5-23.6

The variability exhibited by gross photosynthesis during summer can be attributed mainly to variations in turbidity and river level. Gross photosynthesis was highest during July, 1968, at the South Station when the river was at flood stage and connected to the lake. Water in the lake was extremely clear with the euphotic zone reaching to a depth of 1.13 m. Chlorophyll *a* concentrations during this particular diurnal, however, were not maximal. This suggests that light penetration into the water is the major factor limiting primary production in shallow lakes of this type, especially during spring and summer. Nutrient levels in the lake, especially phosphates and nitrates, are replenished each time the river overflows into the lake. Large quantities of sewage and industrial wastes are dumped into the Illinois River each day by cities and industries located within the drainage basin. As a result, the Illinois River has one of the highest phosphorus concentrations of any major waterway in the United States (Public Health Service Water Surveillance System, 1963).

The ratio of primary productivity to respiration (P/R ratio) ranged from 0.11 to 5.80 during the study (Fig. 6). This parameter also reflected unstable environmental conditions in the lake. When photosynthesis exceeds respiration (P/R ratio greater than unity) the community is autotrophic, and when photosynthesis is less than respiration (P/R ratio less than unity) the community is heterotrophic (Odum,

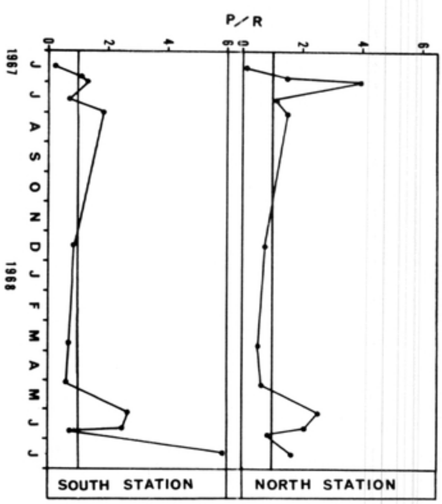

FIGURE 6. Photosynthesis/Respiration ratios of community metabolism in Worley Lake.

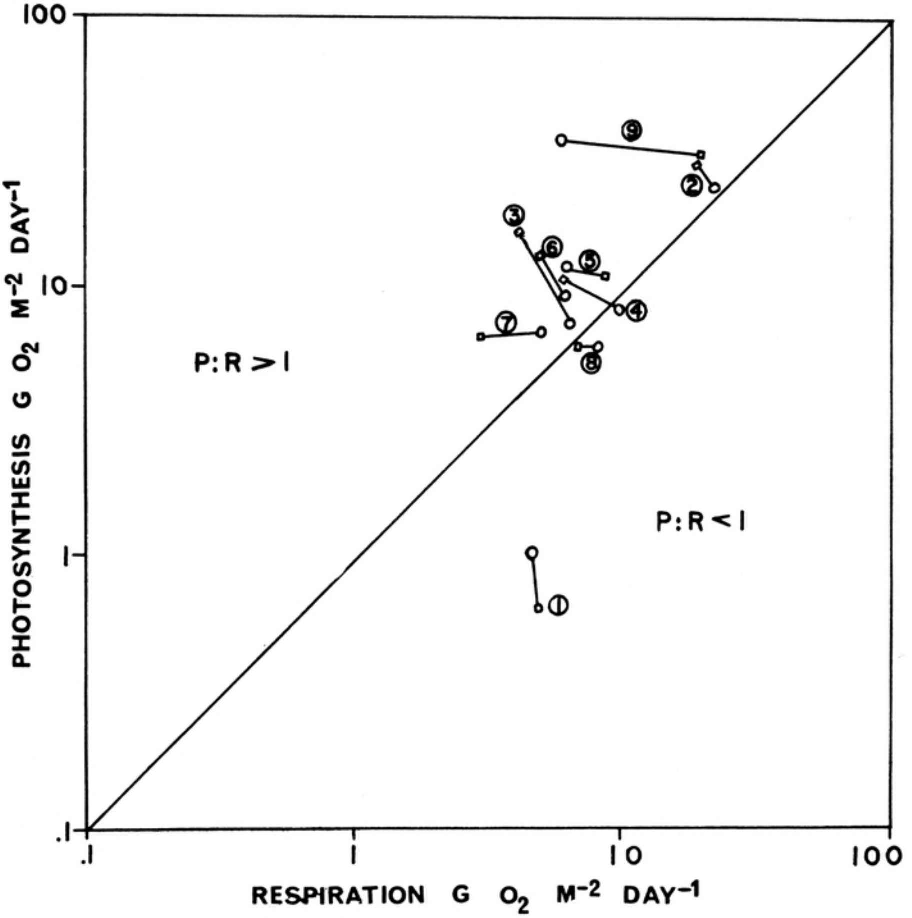

FIGURE 7. Range and relative dominance of autotrophic and heterotrophic metabolism in Worley Lake during summer. (1) = River in flood stage; (2) = Stable; (3) River approaching flood stage; (4) Stable; (5) Stable; (6) Stable; (7) Stable; (8) Stable but extremely turbid; (9) River in Third week of flood stage. (o) = South Station; (□) = North Station.

1959). During summer, the P/R ratio was usually greater than unity and productivity exceeded respiration at both stations except when the community was disturbed by winds or flood conditions (Fig. 7). Community metabolism, as indicated by the P/R ratio, may also serve as an indicator of the degree of community stability (Odum, 1959). In a study of autotrophic succession in the San Marcos River, San Marcos, Texas, Hannan (1967) reported a range from 0.59 to 1.50 in the P/R ratio. In the immature community, fluctuation in light intensity caused greater fluctuation in the P/R ratio than in the more mature community.

ACKNOWLEDGMENTS

This study was supported by NSF grant GY-3097 and by a Bradley University Faculty Research Grant.

LITERATURE CITED

AMERICAN PUBLIC HEALTH ASSOCIATION. 1965. Standard methods for the examination of water and waste water. A.P.H.A. 12th Ed. 769 pp.

BARTSCH, A. A. and M. O. ALLEN. 1957. Biological factors in the treatment of raw sewage in artificial ponds. Limnol. Oceanog., 2:77-84.

BAUMGARDNER, R. K. 1966. Oxygen balance in a stream receiving domestic and oil refinery effluents. Unpublished Ph.D. Thesis, Oklahoma State Univ., 70 pp.

COOKE, G. D. 1967. The pattern of autotrophic succession in laboratory microcosms. Bioscience, 717-721.

COPELAND, B. J. and T. C. DORRIS. 1964. Community metabolism in ecosystems receiving oil refinery effluents. Limnol. Oceanog., 9:431-447.

————, K. W. MINTER and T. C. DORRIS. 1964. Chlorophyll *a* and suspended organic matter in oil refinery effluent holding ponds. Limnol. Oceanog., 9:500-506.

DUFFER, W. R. and T. C. DORRIS. 1966. Primary productivity in a southern great plains stream. Limnol. and Oceanog., 11:143-151.

HANNAN, H. H. 1967. Macrophyte standing crop and metabolism in a constant temperature river. Unpublished Ph.D. Thesis, Oklahoma State University, 47 pp.

JACKSON, H. O. and W. C. STARRETT. 1959. Turbidity and sedimentation at Lake Chautauqua, Illinois. Journal of Wildlife Management, 23 (2):157-168.

MARGALEF, R. 1963a. On certain unifying principles in ecology. Am. Naturalist, 97:357-374.

————. 1963b. Succession in marine populations. Advancing Frontiers of Plant Science, 2:137-138. R. Vira (ed.). Institute for the Advancement of Scientific Culture, 222 Hauz Khas Enclave, New Delhi - 16, India.

MATHIS, B. J., R. J. ROOT and G. W. WEIMAN. 1968. Chlorophyll *a* in the Illinois River. Transactions of the Illinois State Academy of Science. (In press).

ODUM, H. T. and C. M. HOSKIN. 1958. Comparative studies on the metabolism of marine waters. Publ. Inst. Mar. Sci., Texas, 5:16-46.

————, W. McCONNELL and W. ABBOTT. 1958. The chlorophyll "A" of communities. Publ. Inst. Mar. Sci., Texas 5:65-96.

———— and R. F. WILSON. 1962. Further studies on reaeration and metabolism of Texas Bays. Pub. Inst. Mar. Sci., Texas, 8:23-55.

ODUM, E. P. 1959. Fundamentals of Ecology. 2nd. Ed. W. B. Saunders Co., Philadelphia. 546 pp.

PUBLIC HEALTH SERVICE WATER POLLUTION SURVEILLANCE SYSTEM. 1963. Annual compilation of data—upper Mississippi River basin. U.S. Dept. of Health, Education and Welfare, 6:112 pp.

WRIGHT, J. C. 1959. Limnology of Canyon Ferry Reservoir II. Phytoplankton standing crop and primary production. Limnol. Oceanog., 4:235-245.

WRIGHT, J. C. 1960. Limnology of Canyon Ferry Reservoir III. Some observations on the density dependence of photosynthesis and its cause. Limnol. Oceanog., 5:356-361.

Manuscript received December 23, 1968.