Transactions of Illinois Academy of Sciences
(1982), Volume 75, 1 and 2, pp. 29-39

SEDIMENT OXYGEN DEMAND—FINGERNAIL CLAM RELATIONSHIP IN THE MISSISSIPPI RIVER KEOKUK POOL

Thomas A. Butts
Ralph L. Evans
Water Quality Section
Illinois State Water Survey
Peoria, IL
61652

Richard E. Sparks
Havana Laboratory
Illinois Natural History Survey
Havana, IL
62644

ABSTRACT

The Water Quality Section of the Illinois State Water Survey has developed equipment and methods for measuring *in-situ* benthic oxygen usage in streams. An open-bottom, batch-type respirometer is seated in the stream enclosing a known water volume. Dissolved oxygen (DO) usage is measured by circulating water across the face of a galvanic cell oxygen probe implanted in the chamber. The DO drop is referred to as sediment oxygen demand (SOD) and can be utilized in conjunction with quantitative and qualitative benthos information to assess the degree of pollution of bottom sediments. Benthos collections and SOD measurements were made in the Keokuk pool, a reach of the Mississippi River having a large fingernail clam population which, in some areas, appears to be under some environmental stress. The SOD rates were comparable to those measured in semi-polluted to polluted Illinois streams. Fingernail clam respiration was the principal cause of SOD at one station and was significant at three others; overall, the primary cause was microbial.

INTRODUCTION

Sediment oxygen demand can be broadly defined as the use of dissolved oxygen in the overlying water by benthic organisms. In stream waters, it results from the biochemical oxygen demands of micro- and macroorganisms. The principal micro-demand is due to bacteria; diatoms, protozoa, and aquatic fungi may contribute also. Macro-demand is caused by both aufwuch communities and burrowing fauna. Worms, insect larvae and nymphs, leaches, snails, and mussels are the principal burrowing types. Periphyton, or organisms which grow on or are attached to underwater substrates, represent an important source of SOD in some streams. Slime bacteria, such as *Sphaerotilus* and *Leptomitus*, form filamentous streamers on the bottoms of many shallow organically enriched streams and exert significant oxygen demands. Attached filamentous green algae may also represent a demand. Inorganic chemical oxidation reactions can exist, but rarely do so in streams. The identification and determination of this type of demand are difficult.

The Illinois State Water survey (SWS) made *in-situ* sediment oxygen demand (SOD) measurements in the Keokuk pool of the Mississippi River on 14, 15, and 16 July 1976. The measurements were made to supplement data the Illinois Natural History Survey (NHS) biologists have been generating on fingernail clam population dynamics in the pool since 1973 (Illinois Natural History Reports, 1977) and to establish an SOD data base for use in assessing future benthic conditions.

The objectives of measuring SOD *in-situ* in the pool were 1) to measure gross benthic oxygen demands for use in establishing the polluted state of the sediments and, 2) to identify and quantify the benthos for making inferences as to the nature and sources of the demands. The second goal was partially achieved with respiration rates of fingernail clams derived from NHS bench studies, the results of which are presented in this paper.

Qualitative evaluation of sediment conditions can be made with sediment oxygen demand data. Sediment oxygen demand, resulting from benthal respiration, is a good indicator of organic enrichment of benthic sediments and bottom substrates. Generally, high SOD rates are indicative of organic pollution and biologically unstable bottoms. Organic benthic material is stabilized through biological oxidation processes; consequently, the measurements of benthic oxygen usage can aid in defining the polluted condition of sediments, i.e., the degree of sediment pollution can be indirectly determined by measuring oxygen uptake.

The pool is a long, wide navigational pool extending 85.25 km from Lock and Dam 19 (milepoint 364.5) at Keokuk, Iowa, to Lock and Dam 18 (milepoint 410.5) at Burlington, Iowa. However, the primary study area extends only 23 km above the Keokuk dam, a reach historically serving as a host to the greatest concentration of diving ducks in the Mississippi Flyway during spring and fall migrations. These diving ducks, composed principally of scaup (bluebills), depend upon the fingernail clam for food during migrations. Natural History Survey biologists are concerned about the ability of the pool to sustain large, viable clam populations.

MATERIALS AND METHODS

The equipment, methods, and procedures used to perform *in-situ* SODs in the pool are basically those of Butts (1974). Succinctly, it involves containing a known volume of water over a given river bottom area with a half cylinder, bell-type sampler and measuring the DO drop with a galvanic cell oxygen probe implanted in the sampler. The half cylinder consists of a 0.61 meter length of 14-inch nominal diameter steel pipe cut in half with 5/16-inch semi-circular plates welded to the ends. The sampler volume is 30.27 liters, covers a flat bottom area of 0.217 square meters, and weighs 54 kilograms. Steel angle irons of nominal size 2″ x 2″ x 3/16″

(2.54 cm x 2.54 cm x 0.074 cm) are welded completely around the bottom for use as cutting edges and for sealing. Extension flanges can be installed on the angles to prevent excessive settlement in extremely fluid bottoms. Water circulation is accomplished using a 12-volt DC operated pump rated at 148 liters per minute at 1.5 meters of suction lift. The pump and DO meter are operated from a boat equipped with a winch and small crane for raising and lowering the sampler. Circulation lines consist of ¾"-inch heavy duty garden hose with a short clear section of plastic tubing placed at the discharge end of the pump for observation purposes.

Dissolved oxygen readings were taken every 1 to 2 minutes initially and then at 5- and 10-minute intervals after the sediments, disturbed during set-up operations, had resettled. Total sampling times ranged from 60 to 82 minutes, the length depending on the time required for the DO usage to become stabilized at a linear rate. The beginning of an SOD curve usually resembles an exponential curve because of the initial bottom disturbance and the subsequent resettlement. Temperature readings are taken at the beginning and the end of a run with a thermister attached to the DO probe.

Benthos samples were collected with a 23-cm Ponar dredge and were washed in a Wildco model 190 plastic bucket equipped with a No. 30 sieve. Residue retained on the sieve were preserved in quart (1.13 1) Mason jars with formaldehyde. Only one dredge sample for biological analysis is taken at any one sampling station in any SOD study undertaken by the SWS.

Approximately 65 to 75 g of sediment was obtained at each station for determining percent volatile and dried solids. The volatile solid parameter serves as a general indicator of organic content. The percent dried solids parameter is a general indicator of constituency, i.e., the degree of solidity or liquidity of the sediments. This parameter is determined by decanting the supernatant from the top of a refrigerated sample, thoroughly mixing the residue, and oven drying it at 103°C. The oven dried residue weight divided by the decanted wet residue weight, times 100, represents the percent dried solids. Very watery, loose sediments usually represent poor benthological substrates. The volatile solids were determined by incineration according to Standard Methods (American Public Health Association 1975).

SOD measurements, benthos, and sediment samples were taken at or near seven established NHS sampling stations. The stations and sampling mile points (MP) were: 3 (389.0), 4 (376.0), 5 (375.0), 6 (374.0), 7 (370.3), 8 (369.3), and 9 (364.8).

Field observations were obtained in terms of mg/l/min and are converted to areal rates using the formula: SOD = KS; where SOD is the areal rate in g/m^2/day, S is the linear slope of the SOD curve in mg/l/day, and K is the sampling system constant which is dependent upon the bottom area covered and the total water volume contained by the sampler, pump, and hoses. For this study K equaled 233.

The *in-situ* measurements taken at ambient water temperatures were corrected to 25°C using the formula $SOD_T = SOD_{20} (1.047^{T-20})$ as suggested by Velz (1970); where SOD_T is the SOD rate at any temperature, T, and SOD_{20} is the SOD at 20°C.

RESULTS

The SOD curves are shown as Figures 1a-1g, and they exhibit a number of deflection points (Table 1) which represent time sequences. The underlined values designate the liner or stabilized values which normally occurred at or near the end of a run. Zero or small rate changes for periods of approximately 30 minutes usually signaled the need for terminating a run. Depending upon the biological make-up in the sediments, some curves exhibited a continuous curvilinear relationship resembling an exponential function. Most macroinvertebrate respiration rates are a function of the dissolved oxygen levels remaining at a given time, i.e., respiratory activity is indirectly proportional to the dissolved oxygen saturation deficit. This fact, however, does not appear to hold true for some facultative macroorganisms and for most bacteria.

The macroorganisms found at each station are presented in Table 2. The *Chironomidae* and *Tubificidae* were not identified down to species. Because of the time and expense involved in doing so, species identification of these taxa is not routinely done for most generalized water quality studies.

DISCUSSION

Overall the Keokuk pool SOD curves exhibit two characteristics atypical of most SOD data generated for other Illinois streams and lakes between 1972 and 1979 (Butts, 1974; Lee, et al., 1976; Butts and Evans, 1978, 1979). First Keokuk pool curves, particularly those for stations 3, 4, 6, and 8, display considerable irregularity. Most curves in the referenced studies are relatively smooth; in this study only the data for station 7 approximates a typical curve.

The irregular nature of the curves may reflect the relatively large and somewhat diverse benthic biomass at these stations compared with that for most interior Illinois streams and lakes. The second atypical characteristic is the lack of very large initial disturbance rates. Although the disturbance rates (Table 1) are significantly higher than the more stabilized end rates, they are relatively low compared with those which normally occur. As an example, Butts (1974) measured disturbance rates ranging from 15.9 to 47.5 g/m^2/day at 22 locations on the Illinois River. Disturbance rates as high as 93.6 g/m^2/day have been recorded for Lake Meredosia, a heavily silted Illinois River backwater lake (Lee et al, 1976). The low disturbance rates in the Keokuk pool are attributed to sediments at station 3 through 8 being semi-compacted to compacted gray silt-clay; the sediment at station 9 immediately above the dam is a gray gelatinous muck streaked with black silt.

Typical loose benthic sediments (Butts, 1974; Lee et al, 1976; Butts and Evans, 1978, 1979) were composed principally of water, having moisture contents greater than 50%. By contrast, the water content of the Keokuk pool sediments ranged from only 29.7 to 49.6%. The volatile portion of the solids content ranged from a low of 3.2% at station 3 to a high of 6.4% at station 5. The volatile solids are a rough indicator of organic pollution, and the percentage values for the Keokuk pool indicate moderate organic enrichment. Polluted bottoms are usually flocculent having volatile solid percentage compositions grater than 10%. The aforementioned Lake Meredosia sediments are polluted; the water content of the lake sediments ranged between 65 and 70% while the solids fraction was approximately 10% volatile.

Butts and Evans (1978) categorized the polluted state of sediments using 89

SOD measurements made in widely diverse bottoms in northeastern Illinois streams (Table 3). The biomass of macroorganisms was generally low, therefore, bacterial demand accounted for most of the oxygen usage. Five study area stations have SOD rates (as represented by the underlined values in Table 1) indicative of pollution, one indicative of moderate pollution, and the other indicative of slight degradation. However, the high values for stations 3 and 4 and possibly for stations 7 and 8 may partially be caused by the relatively large benthos biomass found during the sample runs.

Research at the NHS Havana field station on the respiration rate of fingernail clams provided information for correcting the gross SOD rates for fingernail clam oxygen usage. Figure 2 depicts a respiration rate curve derived for 3 to 5 mm shell length fingernail clams, the predominant size encountered. Using data from this curve in conjunction with the estimated clam biomass measured at each station, adjusted SOD rates were computed (Table 4).

Slightly less than half of the SOD at station 3 is attributable to fingernail clam respiration. Lesser, but significant contributions to SOD are made by the clams at stations 4, 7, and 8. However, even with the exclusion of the clam oxygen usage the SOD rates at stations 4, 7, and 8 are still greater than 3.0 g/m^2/day indicating additional large biomass respiration or high microbial usage. The correlation coefficient relating the total macroorganisms per square meter (Table 2) to SOD rates underlined in Table 1, is 0.60, a significant value for even a small sample of seven; however, it explains only about 36% of the variability in SOD between stations. Consequently, by deduction benthic microorganisms appear to be the single most important contributor to the SOD in most areas studied. The exception appears around station 3 where 45% of the SOD is attributable to the clams alone; the additional 3,674 macroorganisms per square meter at station 5 probably account for over 5% of the remaining SOD, leaving microorganisms accountable for less than 50%.

CONCLUSIONS

The range of sediment oxygen demand values in the Keokuk pool are comparable to those measured in slightly degraded to polluted Illinois streams and lakes.

Fingernail clam respiration is, principal cause of sediment oxygen usage in one localized area of the pool, is a significant contributor in at least three other areas sampled. The primary cause of SOD in the pool overall is microbial.

REFERENCES

American Public Health Association. 1975. Standard methods for the examination of water and wastewater, 14th ed.

Butts, T. A. 1974. Measurements of sediment oxygen demand characteristics of the upper Illinois waterway. Ill. St. Water Survey Report of Investigation 76, 32 pp.

Butts, T. A., and R. L. Evans. 1978. Sediment oxygen demand studies of selected northeastern Illinois streams. Illinois State Water Survey Circular 129, 178 pp.

Butts, T. A., and R. L. Evans. 1979. Sediment oxygen demand in a shallow oxbow lake. Illinois State Water Survey Circular 136, 28 pp.

Illinois Natural History Survey. 1977. Natural History Survey Reports. Feb. No. 164.

Lee, M. T., J. B. Stall, and T. A. Butts. 1976. The 1975 sediment survey of Lake Meredosia, Ill. State Water Survey report, pp. 8-29.

Velz, C. J. 1970. Applied stream sanitation. John Wiley & Sons, Inc., New York, N.Y. p. 168.

Table 1. SOD rates in the Keokuk pool, Mississippi River.

NHS station number	Time interval (minutes)	SOD rates (q/m²/day (@ 25°C)
3	0-12	5.92
	12-27	7.38
	27-37	6.12
	37-62	5.47
4	0-37	5.10
	37-47	2.59
	47-72	4.34
5	0-10	10.89
	10-40	3.90
	40-65	1.61
6	0-17	6.74
	17-82	5.99
7	0-5	12.04
	5-60	5.84
8	0-8	11.39
	8-23	2.68
	23-29	9.87
	29-65	5.63
9	0-7	9.17
	7-43	7.42
	43-78	2.99

Table 2. Numbers per square meter of macroorganisms in the Keokuk pool, Mississippi River.

Organism	Natural History Survey Sampling Station						
	3	4	5	6	7	8	9
Chironomidae (midge fly larvae)	364	3,100	19	19	115	325	1,741
Dina anoculata (leach)		19					
Erpobdella trannulata (leach)					191		
Glossiphonia complanata (leach)	19						
Helobdella elongata (leach)				19			
Hexagenia limbata (mayfly nymph)	555	134	306		96	134	38
Lymnaea sp (snail)			57		134		
Sphaerium transversum (fingernail claim)	44,719	3,636	1,665	1,894	5,932	10,754	134
Stenelmis sp (beetle)	19					19	
Tubificidae (sludge worms)	2,583	1,914	153	306	12,151		306
Viviparus sp (snail)	134	38		38		57	19
Total number of organisms	48,393	8,822	2,219	2,276	18,619	11,289	2,238

Table 3. Generalized benthic sediment conditions categorized by SOD rates measured in northeastern Illinois streams.

Generalized benthic sediment condition	SOD range g/m^2/day @ 25°C
Clean	<0.5
Moderately Clean	0.5-1.0
Slightly Degraded	1.0-2.0
Moderately Polluted	2.0-3.0
Polluted	3.0-5.0
Heavily Polluted	5.0-10.0
Sewage Sludge	<10.0

Table 4. Gross SOD rates adjusted for fingernail clam oxygen usage.

NHS Station	Clam biomass g/m^2	Avg. DO% saturation in sampler	Clam DO use @ 25°C		% SOD due to clams	Clam adjusted SOD $g/m^2/day$
			mg/g/day	$g/m^2/day$		
3	3,374	41	0.80	2.70	45	2.77
4	274	79	2.08	1.19	26	3.15
5	125	51	1.03	0.13	8	1.48
6	143	66	1.53	0.22	4	5.77
7	447	81	2.15	0.96	16	4.88
8	811	61	1.33	1.03	17	4.60
9	10	64	1.45	0.02	1	2.97

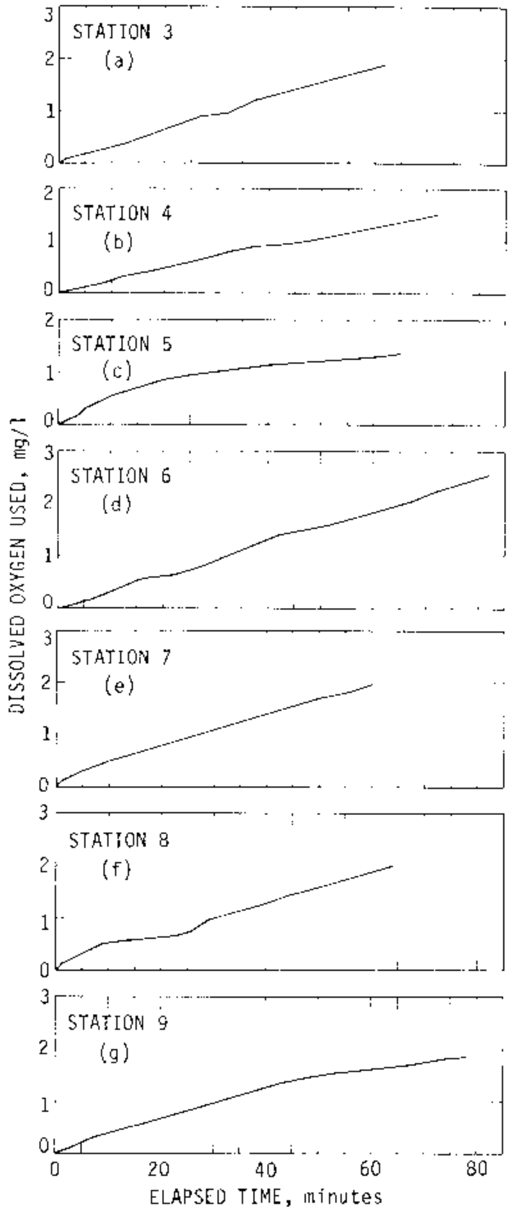

Figure Numbers and Title

FIGURE 1. Field generated sediment oxygen demand curves in the Mississippi River Keokuk Pool

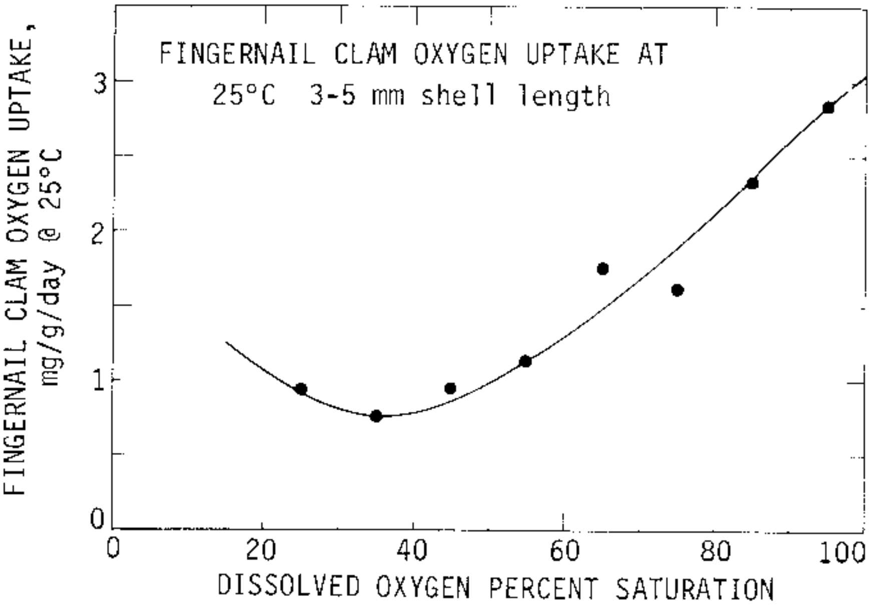

FIGURE 2. Fingernail clam oxygen uptake at 25°C; 3-5 mm shell length.