Effects of Lake Depth on Hypoxia in Agricultural Lakes

Jason Payne and Justin Murdock, Department of Biology, Tennessee Tech University

Introduction

- Oxbow lakes in the Mississippi River Alluvial Plain commonly experience hypoxia (low oxygen, < 2 mg/L) and anoxia (no oxygen) conditions that lead to fish kills, with shallower lakes typically experiencing hypoxic events more often[1].
- Ambient dissolved oxygen (DO) values are the result of oxygen production through algal gross primary productivity (GPP), and oxygen consumption dominated by algal and bacterial respiration (R). Net primary productivity (NPP) is the balance between GPP and R; NPP = GPP – R.
- Because these lakes are shallow and well-mixed, whole-lake DO concentrations, i.e., NPP, is driven by both water-column and lake bottom oxygen production and consumption.
- However, the factors the drive NPP are unclear. Agricultural runoff delivers excessive sediment that blocks light that can depress algal growth, but also introduces excessive nutrients that can fuel algal growth[2].
- Additionally, water availability (i.e., lake depth) is becoming an issue as regional water demand for agriculture is increasing, and rainfall is becoming more variable with climate change.

STUDY OBJECTIVE:

- Determine what factors drive oxygen production and consumption, and assess how changes in lake depth will alter the relative contribution of water-column and sediment to whole-lake DO concentrations

Methods

- Three sample sites were established in Roundaway Lake in the Yazoo River watershed in northwest Mississippi (Figure 1).
- Sampling was conducted seasonally on 9/12/2015, 10/18/2015, 11/20/2015, 5/17/2016, and 7/12/2016.

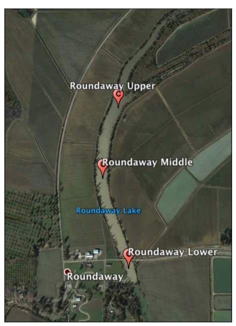


Figure 1: Map of Roundaway Lake and sample sites.

- At each site, 3 integrated water-column samples and 15 core sediment samples were collected. Cores were collected across a depth (i.e., distance-to-shore) gradient in clear polyvinylchloride pipes (Figure 3).
- All samples were analyzed in the lab for NPP, GPP, and R, and algal biomass (as chlorophyll *a*). Photosynthetic-Irradiance curves were created to relate light availability to NPP and used to estimate water column NPP.
- Integrated estimates were calculated from metabolism rates incorporating water column geometry and light attenuation.

Results – Water Column

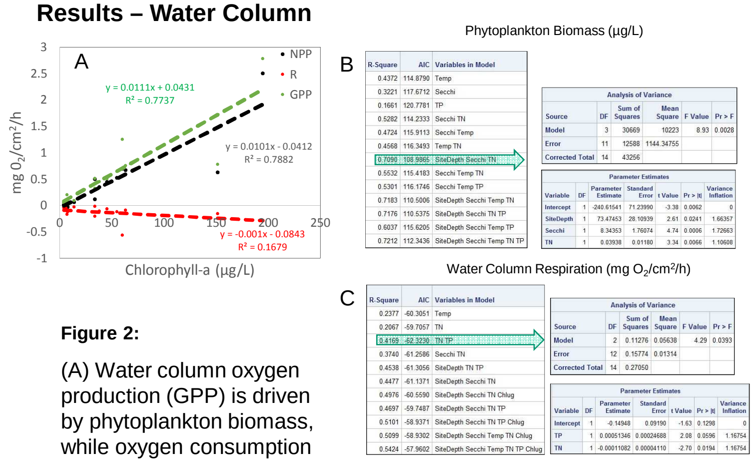


Figure 2:

(A) Water column oxygen production (GPP) is driven by phytoplankton biomass, while oxygen consumption (R) is not.

(B). Phytoplankton biomass is correlated with greater lake depth, suspended sediment (turbidity) and Total Nitrogen (TN).

(C) Water column oxygen consumption (R) is correlated with nutrients, decreasing with TN and increasing with Total Phosphorus (TP).

Results – Sediment

(A) Algal biomass on lake sediments was lower in shallow areas (near the shore) across seasons.

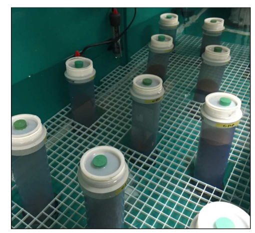
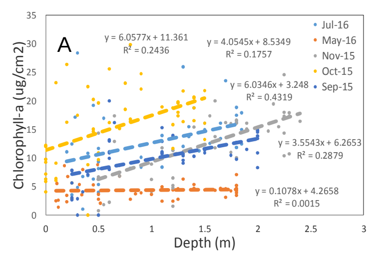


Figure 3: Core samples in incubation tanks



(B) Sediment metabolism rates were weakly correlated with sediment algae biomass.

(C) Despite more algae in deeper sites, sediment algae function is greater in shallow areas.

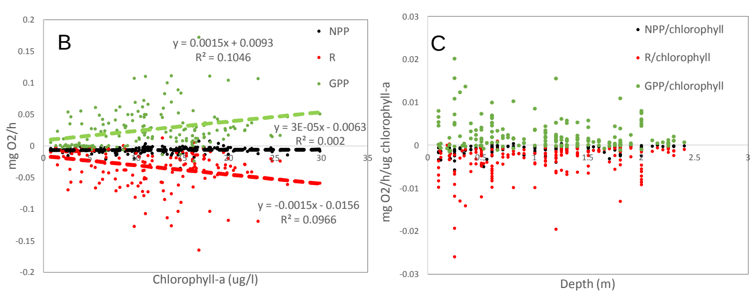


Figure 4: Sediment chlorophyll *a* (A), Metabolism (B), and Metabolism/Chlorophyll (C).

Results – Integrated Water/sediment Estimates

Table 1: Total areal oxygen production (per square meter of lake surface) at each site calculated at full sun conditions. Depths are given at the top of each column.

	Sep-15			Oct-15				Nov-15			May-16		
Total Lake Depth	1.4 m	2.0 m	2.0 m	0.8 m	1.5 m	1.25 m	Depth (m)	1.8 m	2.3 m	2.25 m	1.2 m	1.8 m	1.8 m
Depth (m)	Down	Mid	Up	Down	Mid	Up		Down	Mid	Up	Down	Mid	Up
							0.10		16.5	-12.9			
							0.20		-3.6	-17.3			
							0.30		-5.1	-17.3			
							0.40		-5.3	-17.3			
							0.50		-76.3	-17.3			
							0.60	30.1	-76.3	-17.3		26.4	35.8
							0.70	12.6	-76.3	-17.3		-16.7	-4.7
							0.80	10.4	-76.3	-17.3		-20.4	-9.8
							0.90	10.2	-76.3	-17.3		-20.9	-10.5
							1.00	-12.9	-76.3	-17.3		-21.0	-10.6
							1.10	-12.9	-76.3	-17.3		-24.4	-10.6
							1.20	-12.9	-76.3	-17.3	5.6	-24.4	-12.8
							1.30	-12.9	-76.3	-17.3	-44.1	-24.4	-12.8
							1.40	-12.9	-76.3	-17.3	-51.7	-24.4	-12.8
							1.50	-12.9	-76.3	-17.3	-52.7	-24.4	-12.8
0.25		296.0	616.8				1.60	-12.9	-76.3	-17.3	-52.8	-24.4	-12.8
0.50		-34.2	154.2				1.70	-12.9	-76.3	-17.3	-54.2	-24.4	-12.8
0.75	500.4	-140.7	-13.3		932.9		1.80	-12.9	-76.3	-17.3	-54.2	-24.4	-12.8
1.00	119.6	-155.8	-13.3		346.9	634.7	1.90	-12.9	-76.3	-17.3	-54.2	-24.4	-12.8
1.25	-21.8	-164.5	-13.3	946.3	67.5	322.2	2.00	-12.9	-76.3	-17.3	-54.2	-24.4	-12.8
1.50	-49.8	-239.6	-13.3	382.7	10.1	105.8	2.10	-12.9	-76.3	-17.3	-54.2	-24.4	-12.8
1.75	-54.2	-239.6	-13.3	157.3	1.7	61.9	2.20	-12.9	-76.3	-17.3	-54.2	-24.4	-12.8
2.00	-54.8	-239.6	-13.3	95.6	-1.7	54.2	2.30	-12.9	-76.3	-17.3	-54.2	-24.4	-12.8
Sediment	-213.2	-311.4	-387.7	-238.3	-147.2	-201.2	Sediment	-83.2	-69.4	-89.0	-25.9	-22.1	-31.1
Total NPP (mg $O_2/m^2/h$)	**226.3**	**-1229.2**	**303.6**	**1343.7**	**1210.3**	**977.6**		**-200.3**	**-1516.1**	**-483.1**	**-600.9**	**-391.5**	**-195.5**

Discussion/Conclusions

- Phytoplankton can increase oxygen much more than they consume it.
- Increasing lake depth could increase phytoplankton, but not if rising water is accompanied with more sediment and TN.
- The sediment algae in deep areas is likely composed of settling, dying phytoplankton.
- Sediment algae in shallow areas, which may be receiving more light, is more productive than deeper sediment algae. However, increases in lake DO is mainly dependent on water column phytoplankton due to low light penetration.
- Because large sections of the water column do not receive light and is a net consumer of oxygen, reducing lake depth may decrease the net oxygen demand of the combined water/ sediment and increase overall lake DO (Table 1).
- Dissolved oxygen can also be increased by removing sediments and TN from runoff.
- Future work will determine lake depth and water clarity thresholds for switching to net positive DO production.

References

(1) Goetz D., Miranda L. E., Kröger R., and Andrews C. 2015. The role of depth in regulating water quality and fish assemblages in oxbow lakes. Environmental Biology of Fishes 98:951-959.

(2) Killgore J.K., Hoover J.J., Murphy C.E., Parrish K.D., Johnson D.R., Myers K.F. 2008. Restoration of Delta Streams: A Case History and Conceptual Model. Ecosystem Management and Restoration Research Program Technical Notes Collection (ERDC TN-EMRRP-ER-OS), US Army Engineer Research and Development Center, Vicksburg, MS.

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