Ecosystem metabolism in an effluent-derived, arid-land river estimated from diurnal dissolved-oxygen profiles

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Introduction

Effluent is used frequently as a source of water to restore (or create new) aquatic ecosystems degraded by water diversion. The application of effluent has typically immediate, profound, and highly visible effects on ecosystem structure, but less clear is the response of ecosystem function.

One of the largest wastewater treatment plants (WWTPs) in the region is located in the far West Valley along the Salt River. This large plant receives water from several municipalities, and is capable of treating up to 120 million gallons of wastewater per day. A portion of the effluent is provided to the Buckeye Irrigation District to support agricultural operations. For this purpose, effluent is discharged to the dry Salt River where it flows for approximately 10 km before it is diverted to a canal network.

The free-flowing section of the otherwise dry Salt River below the 91st Avenue WWTP provides an opportunity to assess ecosystem processes in an effluent-driven system.

Questions

Primary production and respiration (R) are fundamental ecosystem processes. We estimated gross primary production (GPP) and R at several points downstream of the WWTP to address the following questions:

(1) Are ecosystem processes (GPP and R) restored in an effluent-driven system, and do they reflect patterns characteristic of a 'natural' lotic system?

(2) Given the extreme chemical properties of effluent (e.g., exceptionally high nutrient concentration, distinctly urban signature), which environmental factors influence relative rates of GPP and R?

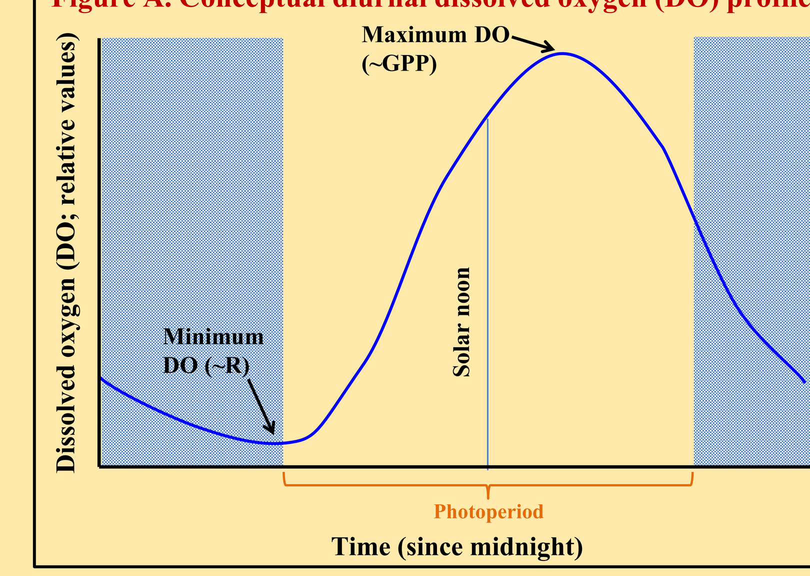
Methods

Water-chemistry data were collected at three points below the WWTP at irregular intervals during the period July 2000 through August 2006. Measurements included diurnal (24-h) profiles of dissolved oxygen (DO) concentration.

Because DO reflects the contribution of photosynthesis and removal through respiration, we are able to estimate GPP and R from the maximum (daytime) and minimum (nighttime) DO concentrations, respectively, during a 24-h period.

We compared maximum and minimum DO concentrations to other water-chemistry data collected at the same dates & locations, and corresponding atmospheric and hydrologic conditions.

Figure A. Conceptual diurnal dissolved oxygen (DO) profile



Results: patterns of GPP and R

The diurnal DO profile (DDO) immediately below the WWTP (Figure B) is notably flat but dramatic spikes or declines, likely reflecting plant operations, are common. The DDO near PIR (~ 4.9 km below the WWTP; Figure C) exhibits diurnal highs and lows more characteristic of a 'natural' lotic system (*see Methods* Figure A). The DDO at the most downstream sampling location (Buckeye ~ 4.4 km below PIR; Figure D) also exhibits patterns similar to a more 'natural' system. Maximum DO (Figure E), particularly, and minimum DO (Figure F) are significantly (maximum, $p < 0.001$; minimum, $p = 0.003$) greater at Buckeye relative to PIR.

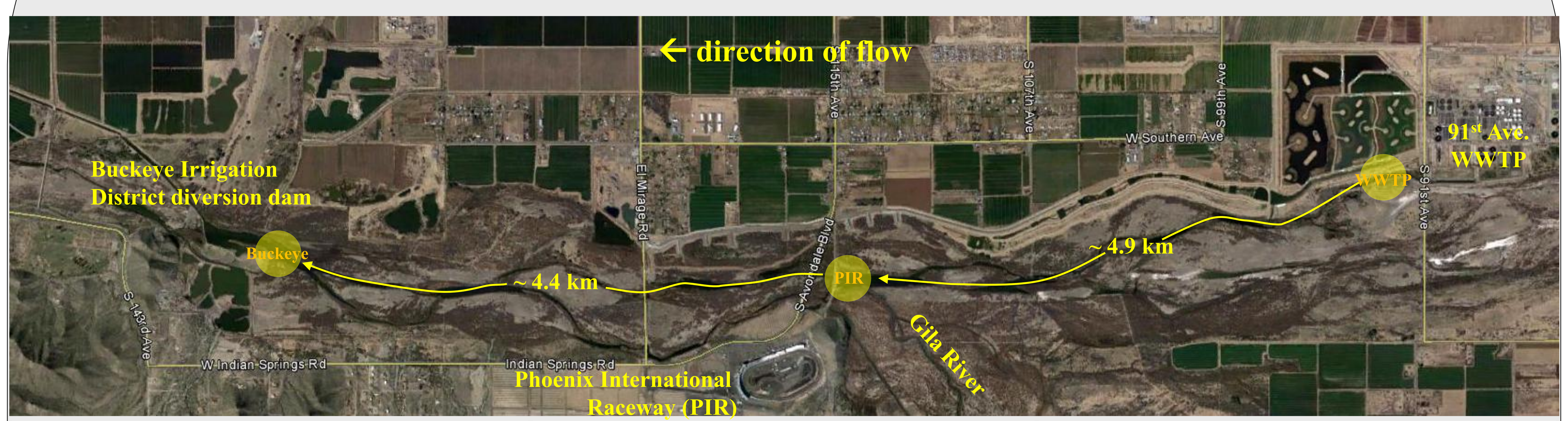


Figure D. Buckeye: diurnal DO profile

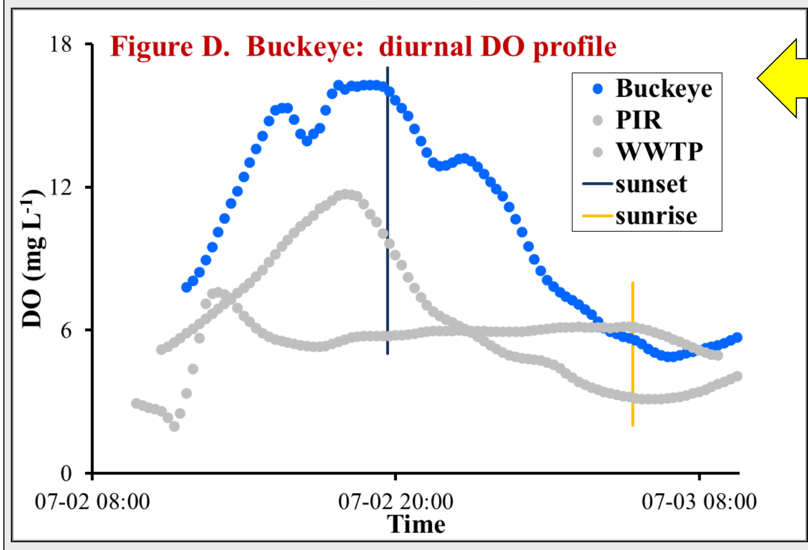


Figure C. PIR: diurnal DO profile

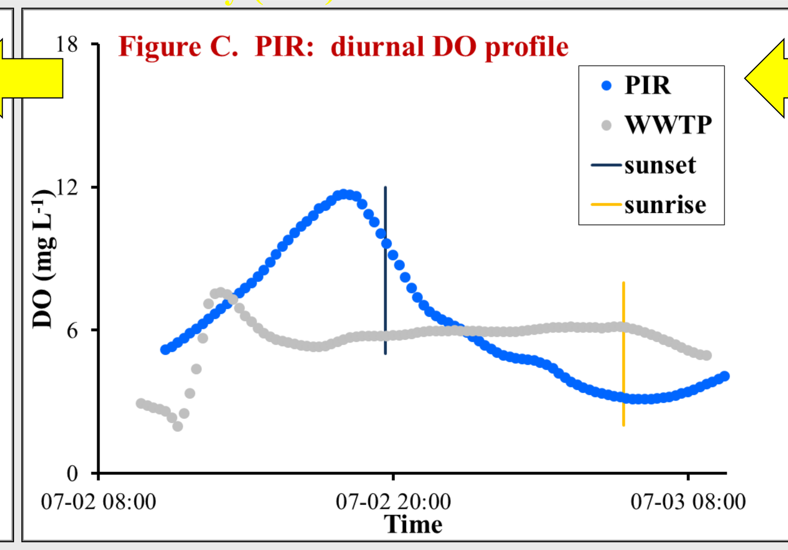


Figure B. WWTP: diurnal DO profile

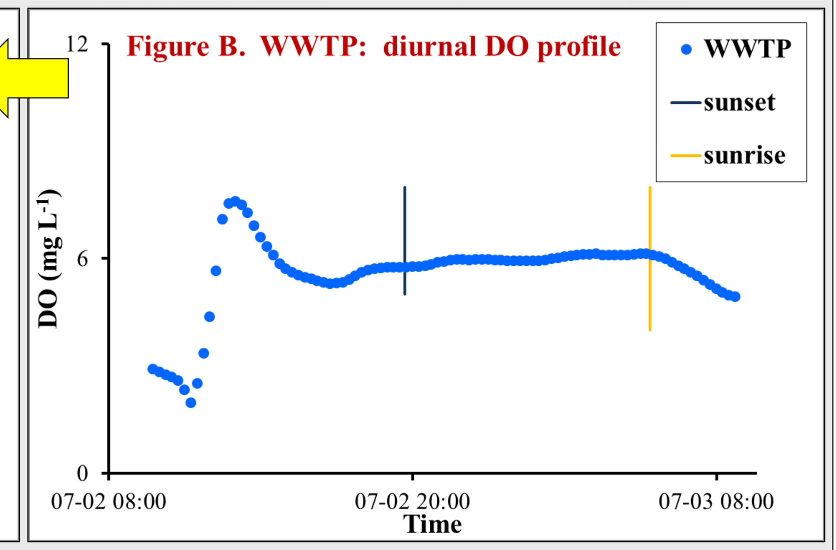


Figure E. Maximum DO (Buckeye:PIR)

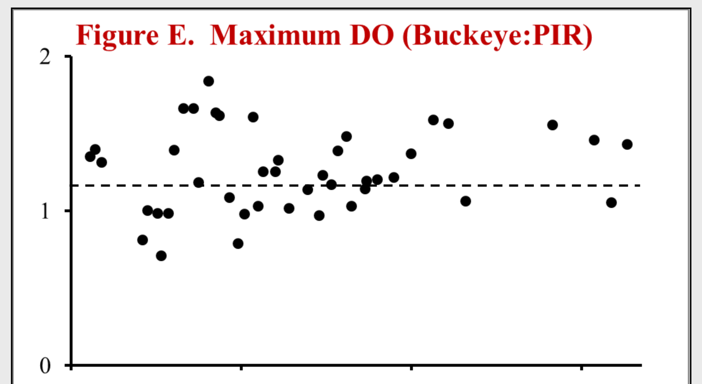
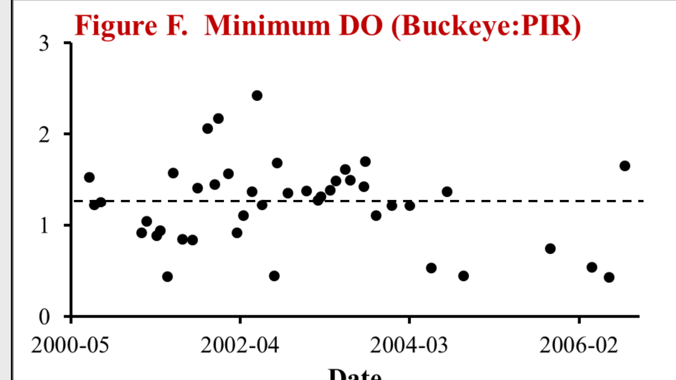


Figure F. Minimum DO (Buckeye:PIR)



Results: environmental controls

While minimum DO concentration was relatively consistent throughout the year, maximum DO concentration exhibited a distinct seasonal pattern at both PIR (Figure G) and Buckeye (Figure H). Correspondingly, maximum DO concentration at both sites was correlated significantly with atmospheric conditions (Figures I and J, Table A). Maximum DO concentration was correlated with discharge (Table A), but discharge also was correlated with atmospheric conditions (results not shown). A few weak correlations among maximum DO concentration and water-chemistry were evident, and only one significant correlation among minimum DO concentration and water chemistry (Table A).

Figure G. Min. and Max. DO: PIR

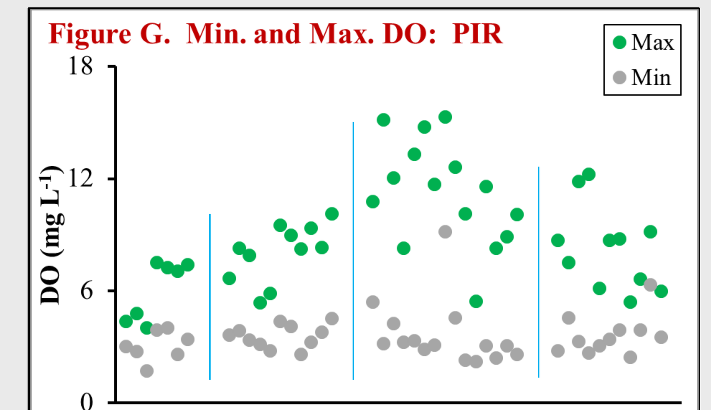


Figure H. Min. and Max. DO: Buckeye

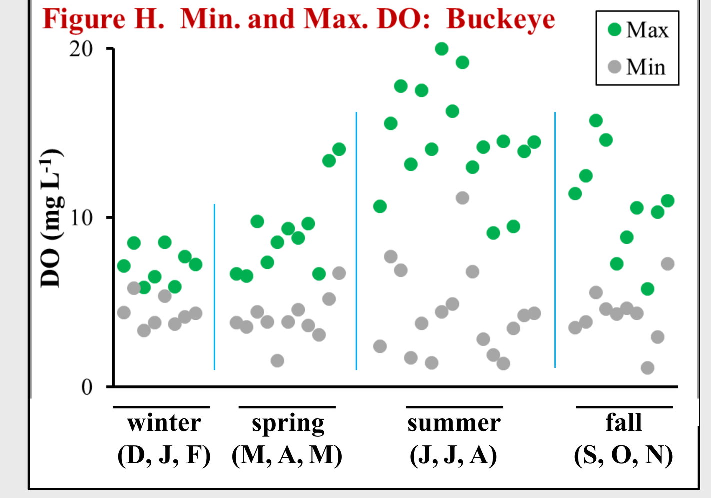


Figure I. Maximum DO vs. Air Temperature

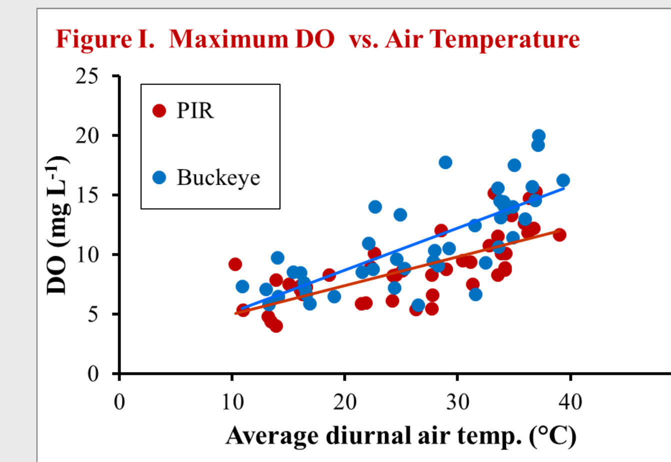


Figure J. Maximum DO vs. Bar. Press.

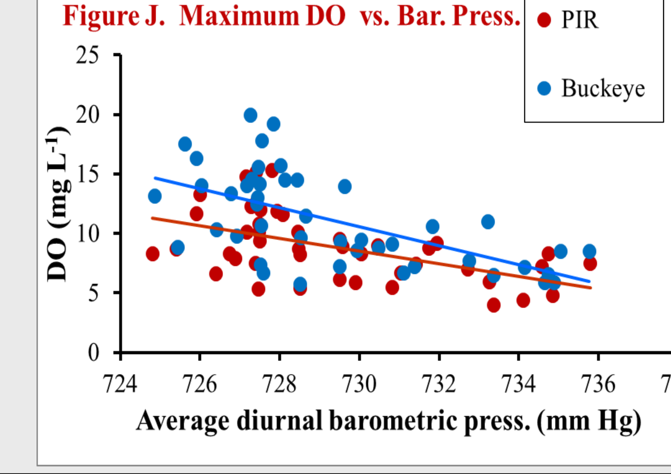


Figure K. Maximum DO vs. ammonium

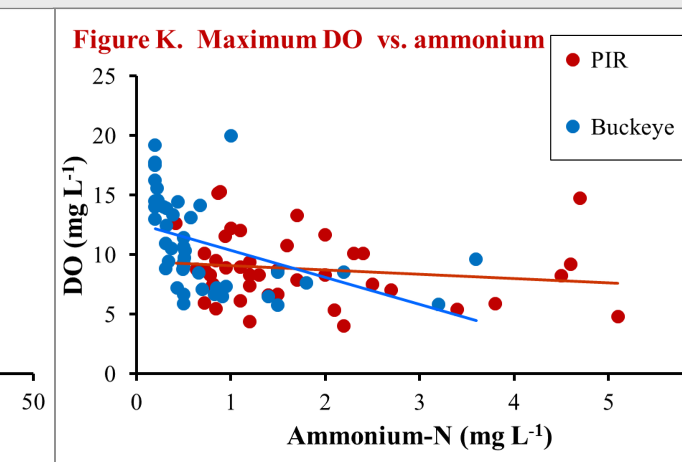


Figure L. Maximum DO vs. TDS

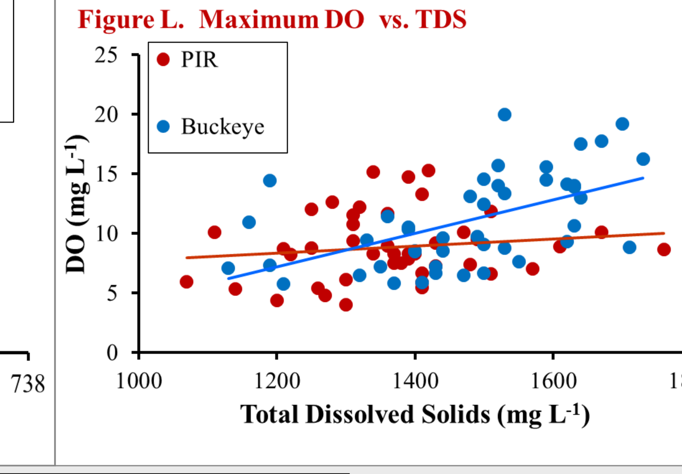


Table A. Correlation matrix of select environmental variables (statistically significant ($p < 0.05$) correlates are highlighted in yellow)

	Minimum DO (R)						Maximum DO (GPP)					
	PIR			Buckeye			PIR			Buckeye		
analyte	n	*p*	*r*	n	*p*	*r*	n	*p*	*r*	n	*p*	*r*
Ammonium	43	0.253	-0.178	44	0.083	-0.264	43	0.326	-0.149	44	0.003	-0.425
Nitrate-Nitrogen	43	0.584	-0.086	43	0.936	-0.013	43	0.002	-0.444	43	0.045	-0.297
Nitrite-Nitrogen	43	0.855	-0.029	43	0.143	-0.227	43	0.761	-0.047	43	0.520	-0.097
Total Kjeldahl Nitrogen	44	0.195	-0.199	45	0.268	-0.169	44	0.608	-0.078	45	0.159	-0.209
Dissolved Phosphrus	42	0.916	0.017	43	0.882	-0.023	42	0.243	0.178	43	0.812	-0.036
Total Phosphorus	43	0.715	0.057	44	0.961	-0.008	43	0.206	0.182	44	0.708	-0.057
Total Dissolved Solids	44	0.987	0.003	45	0.227	0.184	44	0.332	0.148	45	0.000	0.524
Suspended Solids	44	0.004	0.423	45	0.078	0.265	44	0.168	0.206	45	0.775	0.043
Avg. diurnal air temp.	44	0.520	-0.100	45	0.885	0.022	44	0.000	0.721	45	0.000	0.740
Avg. dirunal bar. press.	44	0.805	0.038	45	0.589	-0.083	44	0.000	-0.533	45	0.000	0.603
Avg. diurnal discharge	42	0.084	-0.269	43	0.052	-0.298	42	0.000	-0.680	43	0.000	-0.651

Summary & Conclusions

These preliminary analyses suggest that ecosystem function responds quickly (but not immediately) to effluent addition. Though the DDO exhibited a pattern resembling a more natural system by ~5 km below the WWTP, the significantly higher maximum and minimum DO concentrations at Buckeye relative to PIR suggest the system was still equilibrating.

Not surprising for this hot, cloud-free region, maximum DO concentration was correlated strongly with atmospheric conditions and exhibited a distinct seasonal pattern. However, reaeration (gas exchange at the air-water interface) also is influenced by atmospheric conditions, and further analyses are required to isolate the influence of physical and biological factors. Also not surprising given the high ambient nutrient concentration in effluent, maximum and minimum DO concentrations were not generally related to nutrient availability (and/or opposite in expected direction).

Overall, the results suggest broadly predictable ecosystem responses to effluent addition (e.g., primary producers capitalize quickly on favorable conditions), but suggest also more subtle, complex dynamics (e.g., controls on ecosystem function may be fundamentally different in effluent-driven systems).

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