Diel and Seasonal Changes of Dissolved Oxygen and pH in Relation to Community Metabolism of a Shallow Reservoir in Southeast Missouri

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ABSTRACT

Diel changes of dissolved oxygen (DO) and pH were measured during 1981-1982 in Pool 1, a shallow reservoir in southeast Missouri. Diel changes in spring and fall were about half those of summer when extensive macrophyte biomass apparently had a strong influence on dynamics of DO and pH. During summer, daily pulses averaged 5.45 mg/L DO and 0.88 pH units, and extreme diel changes were 10-14 mg/L DO and 2-3 pH units. Ambient values of DO and pH were directly related to each other as was the magnitude of their daily changes because in the low alkalinity water of Pool 1, pH as well as DO responded to photosynthesis and respiration. Magnitudes of DO and pH changes at night were strongly related to fluctuations during the day, suggesting that community respiration was in a steady state relationship with photosynthesis over time.

INTRODUCTION

Diel changes of dissolved oxygen (DO) and pH in aquatic systems have long been linked to photosynthesis of plants and collective respiration of aquatic biota as measures of community metabolism (Odum 1956, Verduin 1956). Generally, the magnitude of diel change is greatest in shallow systems in the tropics and subtropics (Talling 1965, Dunn 1967, Melack and Kilham 1974, Dye et al. 1980), although large diel changes have been recorded in the littoral zone of lakes at higher latitudes (Kairesalo 1980, Philip 1927).

The purpose of this paper is to report diel changes of DO and pH in a shallow Missouri reservoir, discuss their relation to each other, describe seasonal patterns, and compare values to those documented from other shallow aquatic systems.

SITE DESCRIPTION

Pool 1 is a 700 ha reservoir located in Duck Creek Wildlife Management Area (Missouri Department of Conservation) on the border of Bollinger and Stoddard counties (37°00' N, 90°10' W) in southeast Missouri (Fig. 1). This study was part of a limnological investigation of several aquatic sites in the area during 1981-1983 (Wylie 1985, 1987, Wylie and Jones 1986).

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Pool 1 has a mean depth of 1.5 m with depth increasing from 0.5 m at the north end to 3 m at the south end. A dike delimits the perimeter of Pool 1 and restricts allochthonous inputs. The borrow ditch along the inner edge is 1 m deeper than offshore areas. Rainfall and direct runoff are the major source of water for Pool 1, which is relatively low in alkalinity and dissolved solids, but is eutrophic (Forsberg and Ryding 1980) as judged by nitrogen, phosphorus, and chlorophyll a concentrations (Table 1). Macrophytes grow from late May to late September over the entire surface area of the reservoir in zones generally determined by depth (Fig. 1). Average yield of macrophytes (dry weight) was 2700 kg/ha and yield by species was 3600 kg/ha for Nelumbo lutea, 1000 kg/ha for Nitella, 900 kg/ha for Myriophyllum spicatum, 1100 kg/ha for Ceratophyllum demersum, and 2300 kg/ha for Brasenia schreberi (Wylie and Jones 1986).

Table 1. Mean values and ranges of chemical characteristics of Pool 1. Summer is June-August 1981-1982, Fall is September-December 1981-1982, and Spring is March-May 1982.

	Season		
Measurement	Summer	Fall	Spring
Total P (mg/L)	0.05 (0.02-0.09)	0.04 (0.01-0.10)	0.06 (0.01-0.13)
Total N (mg/L)	0.7 (0.2-1.6)	0.7 (0.1-1.6)	0.8 (0.2-3.3)
Chl. a (ug/L)	21.0 (3.3-78.7)	13.8 (2.0-61.3)	17.4 (3.8-63.5)
Alkalinity (mg/L calcium carbonate)	32 (26-41)	30 (18-45)	31 (15-108)
Conductivity (mS/m @ 25 C)	7.9 (6.3-12.0)	8.2 (6.2-11.6)	8.3 (5.1-24.2)
Dissolved Solids (mg/L)	63 (47-91)	53 (29-108)	74 (44-157)

MATERIALS AND METHODS

Diel changes of DO and pH were recorded in spring (March-May, N=18), summer (June-August, N=39), and fall (September-December, N=38) from June 1981 to December 1982, using consecutive evening-dawn-evening (ca 0600 and 1800 h) measurements of DO and pH, after Welch (1968). Triplicate surface samples (0.2 m depth) were taken from three locations along the east, west, and south edges of the reservoir (Fig. 1). In addition, samples were taken at 0.5 m intervals to the bottom at the south location. Samples for DO were fixed in the field and titrated on the day of collection according to the modified Winkler method using Hach reagents (Hach Chemical Co. 1978). Values of DO were corrected to percent of saturation concentration according to ambient temperatures (Mortimer 1956) and reported as mg/L at 25 C (100% saturation=8.12 mg/L). A Radiometer PHM 26 meter was used to determine pH as soon as possible after sampling.

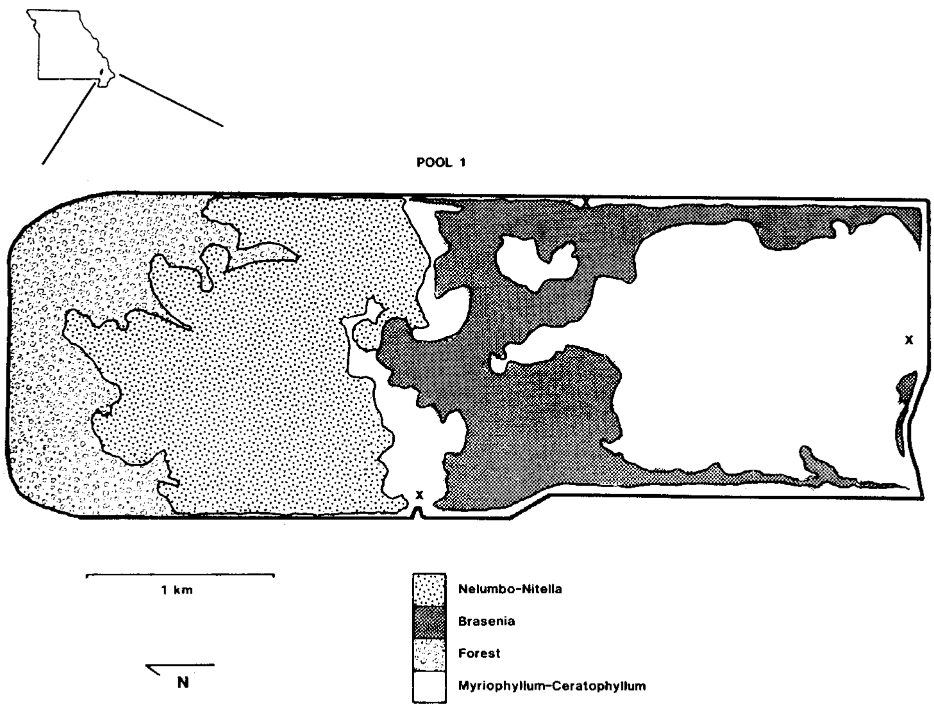

Figure 1. Map of Pool 1 showing vegetative zones and sampling locatiions (X's).

Triplicate samples for chlorophyll a were taken (0.2 m depth) at the three sampling locations during midday of the diel sampling period. Water was filtered through Gelman Type A-E glass fiber filters, and samples were stored frozen over desiccant. Chlorophyll a was extracted with 90% acetone and measured trichromatically (Strickland and Parsons 1972).

Data were combined across years and divided into values by seasons for statistical analysis and discussion of general trends. Data were used in regression and correlation analysis and analysis of variance procedures (SAS 1982). Statistical significance levels were determined at $p<0.05$ (*), $p<0.01$ (**), and $p<0.001$ (***).

RESULTS AND DISCUSSION

High rates of photosynthesis and respiration during summer resulted in large diel fluctuations that averaged 5.45 mg/L DO and 0.88 pH units. During summer we measured a wide range of ambient values of 0-215% saturation for DO and 6.52-10.05 for pH (Table 2, Fig. 2). Diel changes were generally similar among sites and were most extreme during five sampling periods in summer when DO fluctuated by 10-14 mg/L and pH changed by two to three units (Fig. 2). During spring and fall the magnitude of diel fluctuation of DO and pH was about half that of summer (Table 2, Fig. 2). In spring absolute values of DO were 27-138% saturation and pH values were 7.20-8.80. During fall absolute values were 43-138% saturation for DO and 6.78-9.05 for pH.

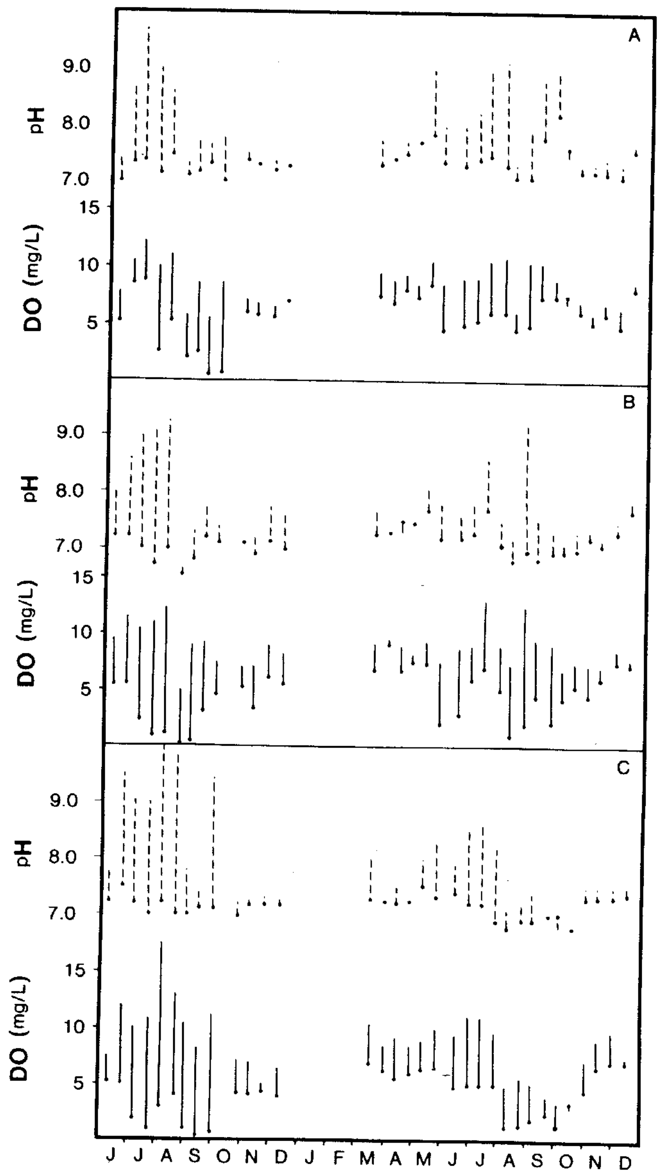

Figure 2. Diel change of dissolved oxygen (DO) (▬▬▬) and pH (▬ ▬ ▬) at the south, east, and west sampling locations (A, B, and C, respectively). Dawn values are represented by dots. Evening values are at opposite ends from dots, and are averages of two consecutive measurements.

Within each season, the magnitude of nighttime decreases in DO and pH were positively related to consecutive increases in these parameters during the day (Fig. 3). This relation between night and day fluctuations was strongest during summer when rates of community metabolism were high and nighttime decreases of greater than two pH units and six mg/L DO were generally matched by commensurate daytime increases (Fig. 3). When averaged over all seasons, losses from respiration at night from all components of the aquatic community (within the resolution of our data) were nearly offset by net photosynthesis during the day, with a background respiratory demand of 0.5 mg/L/day DO. Equality between night and day fluctuations of DO and pH has also been reported from other water bodies (Jackson and McFadden 1954, Verduin 1956, Welch 1968, Dye et al. 1980, Kairesalo 1980, Fontaine and Ewel 1981, Reddy 1981, Marzolf and Saunders 1984). Their observations, together with those of this study, suggest that many shallow aquatic ecosystems over time have a near steady state balance between community respiration and photosynthesis.

Water in Pool 1 was relatively low in alkalinity, and photosynthetic consumption of carbon dioxide during the day and its production by community respiration at night largely determined pH levels by shifting carbonate equilibria. This relation in Pool 1 is in contrast to measurements taken in some well-buffered systems where pH changes little with diel changes in DO (Halstead and Tash 1982). Because photosynthesis and respiration affected both DO and pH in Pool 1, the magnitude of diel DO change was strongly related to the magnitude of diel pH change during summer ($r=0.82^{***}$), when rates of community metabolism were high. This finding is similar to DO-pH relations in Florida lakes (Dye et al. 1980, Reddy 1981). The relation was less strong in fall ($r=0.67^{***}$) and spring ($r=0.52^{**}$) when rates

Table 2. Statistical summary of diel changes in dissolved oxygen (DO) and pH in Pool 1. Summer is June-August 1981-1982, Fall is September-December 1981-1982, and Spring is March-May 1982.

		Day Change DO (mg/L)	Night Change DO (mg/L)	Day Change pH	Night Change pH
Summer (N=39)					
	$\bar{X}$	5.18	5.62	0.88	0.88
	s	3.02	3.03	0.87	0.83
	C.V.	58%	54%	99%	94%
	range	1.40-14.11	1.54-15.22	-0.13-2.90	-0.02-3.05
Fall (N=38)					
	$\bar{X}$	2.79	2.50	0.30	0.29
	s	2.73	2.44	0.41	0.42
	C.V.	98%	98%	137%	145%
	range	-0.33-10.49	0.07-10.56	-0.12-2.40	-0.20-2.30
Spring (N=18)					
	$\bar{X}$	2.39	2.17	0.36	0.22
	s	1.42	1.09	0.35	0.28
	C.V.	59%	50%	97%	127%
	range	0.24-5.41	0.86-4.94	-0.02-1.18	-0.10-0.88

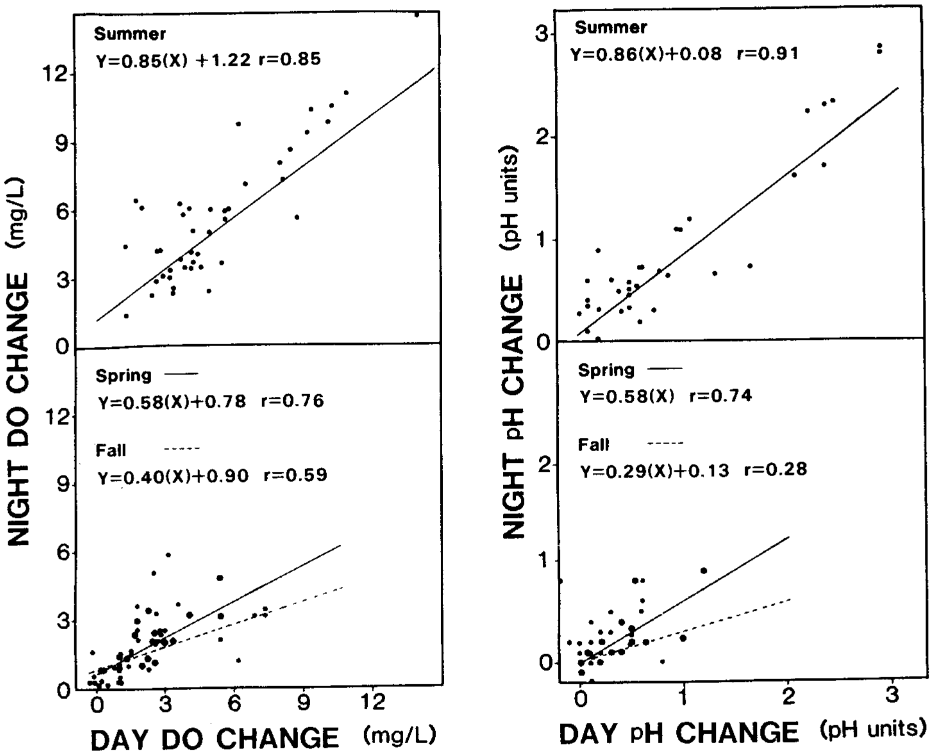

Figure 3. Seasonal relations between consecutive night and day changes in dissolved oxygen (DO) and pH. In lower panels, large and small dots denote spring and fall data, respectively. Data combined over all seasons yield the relations:
Night DO Change = 0.85(Day DO Change) + 0.48, and
Night pH Change = 0.84(Day pH Change) + 0.04
(r=0.85*** and r=0.88***, respectively).

of community metabolism were lower and weather events occasionally had a marked effect on DO and pH. For example, on 6 October 1981 wind and rain increased DO and decreased pH during the day, and after rain on 13 April 1982, pH remained constant overnight while DO decreased.

In general, when we measured low concentrations of DO, pH values were also low. Conversely, when concentrations of DO were high, pH values were high. The relation between ambient values of DO and pH in Pool 1, however, was not a linear function. A plot of paired measurements of these variables shows the relation is positive, but curvilinear (Fig. 4). Inflection of the DO-pH curve is near DO of 100% saturation (8.12 mg/L), below which, on the average, DO changes 5.47 mg/L and above which DO changes 1.81 mg/L per unit pH. This inflection may result from evolution of oxygen from surface water at supersaturated conditions which would reduce the apparent rate of change of DO with pH at DO concentrations above saturation. Loss of oxygen from the system limits the diel change technique as an estimator of

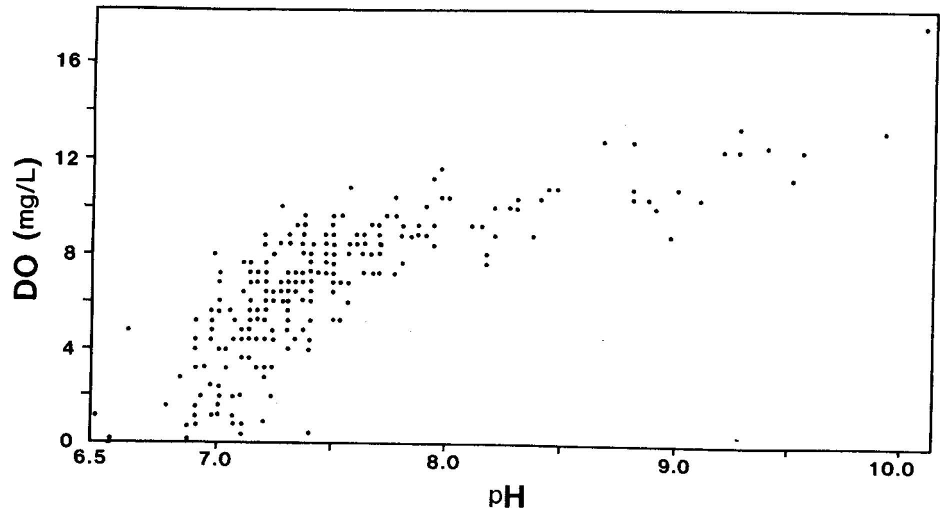

Figure 4. The curvilinear relation between simultaneous measurements of dissolved oxygen (DO) and pH over all sampling periods. Linear regressions are DO=5.47(pH)-34.2, r=0.65***, for DO less than saturation (8.12 mg/L), and DO=1.81(pH)-4.77, r=0.75***, for DO greater than or equal to saturation.

community metabolism (Melack and Fisher 1983), as does lacunal retention of metabolic gasses (Hartman and Brown 1967), and indicates that using summer values of DO change in Pool 1 would result in underestimates of net production.

Typically, either phytoplankton or macrophytes and their epiphytes dominate the metabolism of shallow systems (Fitzgerald 1969, Goulder 1969, Canfield et al. 1983, Jones et al. 1983). We do not have the data to quantitatively assess the relative contribution of phytoplankton and macrophyte-epiphyte associations to total community metabolism, but our evidence suggests that macrophytes and their epiphytes are the driving force for diel changes of DO and pH in Pool 1. If we extrapolate from average chlorophyll a concentrations to phytoplankton biomass and productivity using average values from Reynolds (1984), we calculate that production of phytoplankton biomass is less than 25% of macrophyte yield during summer (630 kg/ha compared to 2700 kg/ha). In addition, we observed the largest fluctuations of DO and pH during summer when macrophyte biomass was high. Phytoplankton biomass during this period, as measured by chlorophyll a concentrations, was negatively related to the magnitude of diel DO changes (r=-0.42**). Only in spring, when macrophyte biomass was low, were concentrations of chlorophyll a positively related to DO changes (r=0.75***); chlorophyll a values were not significantly related to the magnitude of diel pH change in any season.

Pool 1 was usually thermally stratified during summer, in part because macrophyte growth provided mechanical resistance to water movement which enhanced thermal density gradients (Buscemi 1958). Subsurface anoxia during late summer 1981 coincided with stratification when macrophytes reached maximum biomass. During this period diel changes were restricted to surface water where DO concentrations were often less than 30% saturation at dawn, but increased by afternoon (Figs. 2, 5), while water below 0.5 m remained at or near anoxia (Fig. 5). This subsurface anoxia, similar to DO profiles measured in an Elodea stand by Buscemi (1958), may have been the result of shading by macrophytes at the surface which limited photosynthesis in deeper water where respiration and decomposition depleted DO. Mixing of oxygenated surface water with lower layers was precluded by thermal density gradients at ambient temperatures (Fig. 5). During summer 1982, cool, rainy weather in August overcame these barriers, destratified Pool 1, and mixed DO through the water column when compared to the sampling period in July (Fig. 5).

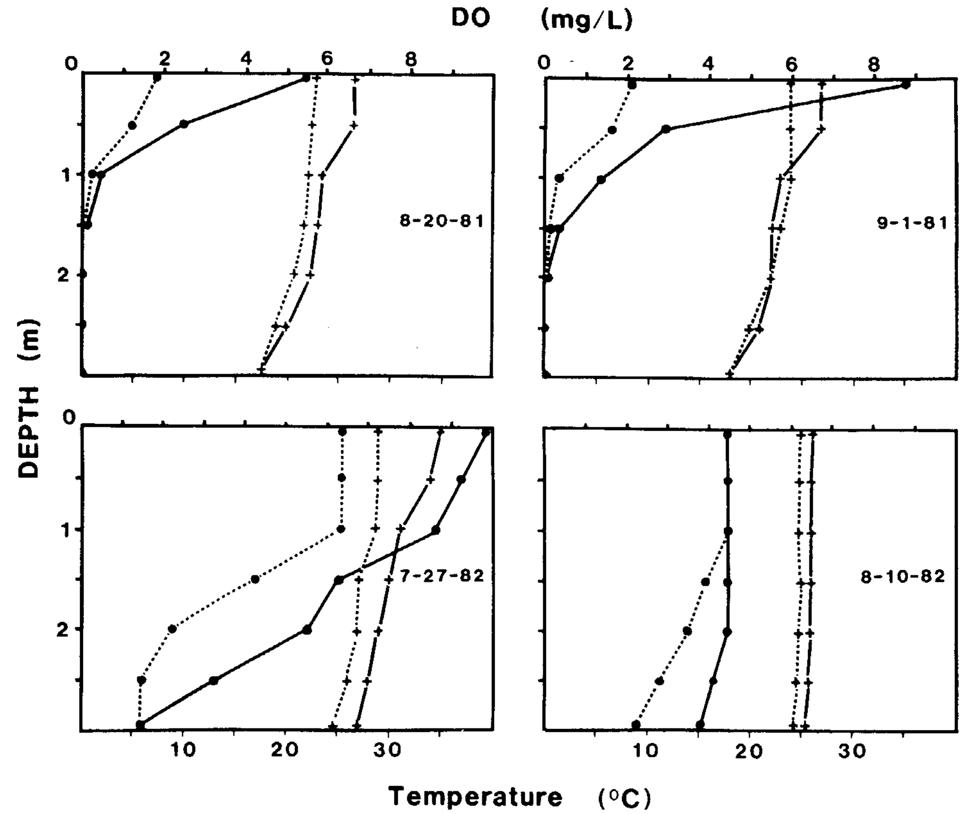

Figure 5. Vertical profiles from the south end of Pool 1 showing stratification of dissolved oxygen (DO) (●) and temperature (+) at dawn (..........) and early evening (————) in summer 1981 and 1982.

Pool 1 functions entirely as a productive littoral zone with relatively high summer values of diel change in DO and pH that are consistent with the large annual yield of macrophyte biomass (Wylie and Jones 1986). Despite periods of low DO concentrations and rapid daily shifts of several pH units, Pool 1 also supports an annual harvest of 120-160 kg/ha of sportfish, among the highest fish harvest values for the state (Missouri Department of Conservation, unpublished data). Fluctuations of DO and pH within Pool 1 are in the upper range of values from a broad range of productive sites in both temperate and tropical regions (Table 3). Annual productivity, however, is likely higher at lower latitudes because of a longer growing season.

Table 3. Diel changes in dissolved oxygen (DO) and pH from aquatic habitats at various locations.

Location	Maximum Diel DO Change (mg/L/day)	Maximum Diel pH Change (units/day)	Reference
Pool 1, MO	14.0	3.0	this study
Lake Paajarvi, Finland (littoral)	3.2	2.0	Kairesalo 1980
Crystal Lake, MN (littoral)	---	2.2	Philip 1927
Florida sites:			
Lake Kissimmee	5.0	1.5	Dye et al. 1980
Lake Conway	5.3	---	Fontaine and Ewel 1981
Egaria pond	10.0	3.0	Reddy 1981
Lake Apopka	6.0	1.4	
Lago Calado, Brazil	4.0	---	Melack and Fisher 1983
Fish pond, Malaysia	9.7	2.5	Dunn 1967
Alkaline vleis, South Africa	---	3.5	Schutte and Elsworth 1954
India sites:			
Microcystis pond	26.0	---	Marzolf and Saunders 1984
Melakkal Lake	2.5 (cloudy)	---	
	12.7 (sunny)	---	
Swamy Pond	6.5	---	
Naini Lake	6.0	0.4	George 1961
Peer-ghaib Tal	22.7	0.7	Khan et al. 1970

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