



RESEARCH LETTER

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Key Points:

- Small ponds demonstrate substantial increases in dissolved oxygen overnight
- Oxygen increases due to convective cooling and increased gas exchange
- Implications for biogeochemical measurements and understanding pond ecology

Supporting Information:

- Supporting Information S1

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Substantial overnight reaeration by convective cooling discovered in pond ecosystems

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Abstract Trends in freshwater dissolved oxygen (DO) reflect whole-ecosystem properties and influence organismal survival and behavior. Here we show that small ponds have unique oxygen dynamics that differ from larger lakes. We discovered that ponds undersaturated in DO experienced substantial increases in oxygen concentration overnight. Nighttime increases in DO occurred on 45% of the nights sampled and resulted in DO saturation increasing 12-fold (22% saturation) on average. Oxygen spikes were likely to occur when ponds became at least 1.8°C warmer than the air and later in the season when oxygen levels were low (<31% saturation) and the air was warm ($\geq 5.8^\circ\text{C}$). We demonstrate that overnight increases in surface water DO resulted from atmospheric oxygen invasion as opposed to internal production. Convective cooling enhanced turbulence and air-water gas exchange, leading to intense bursts of oxygen invasion during nighttime hours. This mechanism has not been demonstrated before and has important implications for the biogeochemistry of these systems, as well as understanding how organisms survive in hypoxic small ponds.

1. Introduction

Dissolved oxygen (DO) dynamics have long been studied in aquatic systems to understand ecosystem processes and function [Odum, 1956]. In lakes, DO concentrations inform overall trophic state, carbon, nitrogen, and sulfur cycling, as well as food web dynamics [Dodds and Cole, 2007; Tank et al., 2010; Riley and Dodds, 2013]. Oxygen concentrations are controlled mainly by two processes: the biological balance of photosynthesis that produces DO and respiration that consumes it, and the rate of physical air-water gas exchange, which is determined by the air-water concentration difference and the amount of surface turbulence. The balance of these processes has been well studied in streams, rivers, and medium- to large-sized lakes. This focus has left smaller ponds less characterized, despite the fact that small ponds (<0.01 km²) comprise a majority of lakes and ponds by number [Downing et al., 2006; Verpoorter et al., 2014] and support high local and regional biodiversity, including many sensitive species (e.g., plants, invertebrates, and amphibians) [Williams et al., 2003; Scheffer et al., 2006].

There is good reason to believe that oxygen dynamics in ponds differ from larger lakes. While most freshwaters are net heterotrophic due to inputs of terrestrial carbon [Cole et al., 2000; Duarte and Prairie, 2005], small ponds may be especially sensitive to these inputs. Small ponds have a high edge relative to surface area and shallow water, meaning that terrestrial carbon inputs are great relative to water volume and can overwhelm the pond's ecosystem metabolism [Rubbo et al., 2006; Holgerson, 2015]. It follows that respiration of allochthonous carbon could also drive oxygen dynamics, explaining the low levels of DO in small, forested ponds [Skelly et al., 2002]. Furthermore, the physics controlling air-water gas exchange is thought to be quite different in small ponds. In larger lakes with greater fetch, wind generates turbulence at the air-water interface increasing the gas transfer velocity, k [Wanninkhof et al., 1985]. However, the relationship between wind speed and k breaks down under low-wind conditions (<3 m s⁻¹) characteristic of small, sheltered ponds [Clark et al., 1995; Cole and Caraco, 1998; Read et al., 2012]. While gas exchange has not been adequately sampled in very small ponds, it stands to follow that k is low and helps maintain low DO concentrations.

In this study, we evaluated the seasonal oxygen dynamics in three small (<0.001 km², <1 m deep), temporary, forested ponds in Connecticut, USA. During our sampling, we observed frequent and substantial increases in surface water oxygen concentrations overnight. In this study, we (1) document this previously undescribed pattern of nighttime increases in oxygen, (2) examine the environmental conditions that permit the increases to occur, (3) identify the source of DO, and (4) discuss implications for pond biogeochemistry and ecology.

Table 1. Characteristics of the Three Study Ponds in 2013

	Atwood Pond	Blacksmith Pond	Long Pond
Latitude	41.9652	41.9549	41.9668
Longitude	−72.1523	−72.1236	−72.1509
Maximum surface area (m ²)	459	604	847
Maximum depth (cm)	51	47	72
Surface water temperature range (°C) ^a	5.3–24.3	5.7–25.7	6.4–25.8
Dissolved oxygen range (%) ^b	1.1–63.2	0.6–50.1	0.0–40.8

^aTemperature was taken from thermistors located 10 cm below the water's surface at the deepest point in the pond from 15 April to 31 July 2013.

^bDissolved oxygen measurements from the periods of time when loggers were deployed. Loggers were located 10 to 20 cm below the pond's surface at the deepest point in the pond.

2. Methods

2.1. Study Sites

The three study ponds (Atwood, Blacksmith, and Long Ponds) are located in Yale Myers Forest, a 3213 ha research forest in Tolland and Windham Counties in Connecticut, USA (Table 1). Additional details of the three ponds can be found elsewhere [Holgerson, 2015]. Briefly, the ponds are located in mixed coniferous-deciduous forest with minimal human development. Ponds are temporary and typically filled with autumn rain, freeze over the winter, thaw in March or April, and dry by late summer. While we did not measure wind speed in our study, similar small ponds in the same forest had average wind speeds of 0.33 m s^{-1} and maximum wind speeds of 4.3 m s^{-1} (unpublished data), indicating that wind speeds are low. All three ponds were consistently undersaturated in oxygen (<64% saturation), and a previous study demonstrated that high respiration rates drove the ponds to be net heterotrophic [Holgerson, 2015].

2.2. Data Collection

Dissolved oxygen was measured from mid-April to July 2013. In the two ponds (Atwood and Long Ponds), we measured DO every 2 weeks for 24–48 h (YSI ProODO meter, Yellow Springs Instrument, Yellow Springs, Ohio, USA), with one biweekly measurement (6 May) missing. In the third pond (Blacksmith Pond), we measured DO similarly for the first two sampling rounds (23 April and 6 May) and then measured DO continuously from 10 May to 21 May and from 19 June to 12 July (YSI 6600 Sonde, Yellow Springs Instrument, Yellow Springs, Ohio, USA). Dissolved oxygen and temperature were sampled 10 to 20 cm below the pond surface at the pond's deepest point, and measurements were recorded every 15 min. Air temperature and incident light were also recorded every 15 min right above the pond surface at the center of each pond (HOBO pendant loggers, Onset Computer Corporation, Bourne, Massachusetts, USA).

After we observed overnight increases in DO, we deployed thermistors (Tidbit temperature logger, Onset Computer Corporation, Bourne, Massachusetts, USA) either every 10 cm (Atwood and Blacksmith Ponds, $n = 5$ thermistors) or every 15 cm (Long Pond, $n = 4$ thermistors) at the deepest part of the pond to measure pond temperature profiles. Temperature was recorded every 15 min from 10 June to 29 July 2013.

In 2014, we monitored benthic DO in Blacksmith Pond (miniDOT oxygen logger, Precision Measurement Engineering, Inc., Vista, California, USA) 10 cm above sediments from 26 June to 21 July 2014. Dissolved oxygen and temperature were recorded every 5 min.

2.3. Nighttime DO Increases

We analyzed DO measurements in percent saturation to account for changing saturation levels in the water due to temperature fluctuations. We focused on nighttime oxygen levels, operationally defined as times when loggers detected zero incident light. However, our analysis includes oxygen spikes that occurred within a few hours of sunrise ($n = 10$), when it would be unlikely to observe marked DO increases from photosynthesis (Table S1 in the supporting information).

We assumed that nighttime changes in oxygen were due to respiration (decreases DO), internal mixing (lateral or vertical), or atmospheric gas exchange (increases DO due to pond undersaturation). For each sampling night, we classified whether or not a DO spike occurred, defined as an overnight increase in DO by at least 5% saturation (always > 1.2-fold increase). Spikes occurred rapidly (1–3 h) and were clearly distinguishable

from background noise. Our definition of an overnight DO spike is conservative as we likely missed small increases in DO that were difficult to distinguish from background noise. We excluded DO spikes that occurred late morning (past 09:00), as we could no longer exclude the possibility that DO increased due to photosynthesis.

We calculated change in oxygen concentration overnight. If no nighttime oxygen spike occurred, the oxygen change was the difference between sunset and sunrise. If an oxygen spike occurred, the oxygen change was the difference in concentration between the minimum and maximum peak values. It is important to note that oxygen invasion events are actually larger than our reported values because oxygen is consumed overnight due to respiration, making our observed increases a net increase.

We used a decision tree analysis to evaluate predictors of DO spikes. Decision trees identify nonlinear associations and interactions among predictor variables that may be correlated, nonnormally distributed, or have missing values [Breiman et al., 1984; De'ath and Fabricius, 2000]. Predictor variables included mean nighttime pond temperature, mean nighttime air temperature, maximum difference between nighttime pond and air temperature, change in nighttime pond temperature between sunset and sunrise, change in air temperature between sunset and sunrise, and sunset DO concentration. We used classification trees to predict whether or not a spike occurred and regression trees to predict changes in DO. Decision trees were run in R using the rpart package 4.1-4 [Therneau et al., 2013]. The decision trees were pruned to optimal size by minimizing classification error.

2.4. Estimating Gas Exchange

We calculated gas exchange velocity, k_{600} , assuming that reaeration explained overnight increases in DO. Physical gas exchange between the water and atmosphere is described by

$$F = k \times (DO_{\text{measured}} - DO_{\text{saturated}}), \tag{1}$$

where F is gas flux ($\text{g O}_2 \text{ m}^2 \text{ d}^{-1}$), k is the gas transfer coefficient (m d^{-1}), DO_{measured} is the measured DO concentration (mg L^{-1}), and $DO_{\text{saturated}}$ is atmospheric equilibrium (mg L^{-1}). We calculated k for each 15 min interval in which DO increased on nights where DO spikes were detected using the equation adapted from Wanninkhof et al. [1987]:

$$k = \frac{h}{\Delta t} \ln \frac{O_{2 \text{ measured}, t} - O_{2 \text{ saturated}, t}}{O_{2 \text{ measured}, t+1} - O_{2 \text{ saturated}, t+1}}, \tag{2}$$

where h is the average depth of the pond (m), Δt is change in time in 15 min intervals, $O_{2 \text{ measured}}$ is measured DO (mg L^{-1}), and $O_{2 \text{ saturated}}$ is the oxygen concentration if water were in equilibrium with the atmosphere (mg L^{-1}) at time t and $t + 1$. As we could not estimate changes in DO due to respiration, we assumed that all changes in DO were due to atmospheric exchange and as such, our estimates are conservative (because ponds were undersaturated during the study).

We normalized k as measured for DO to k_{600} using the equation [Jähne et al., 1987]

$$k_{600} = k_{\text{DO}} \times \left(\frac{600}{Sc_{\text{DO}}} \right)^n \tag{3}$$

Where k_{DO} is the calculated gas exchange rate for DO, 600 is the Schmidt number for k_{600} , Sc_{DO} is the Schmidt number for DO, and the exponent n depends on the processes driving gas exchange and can be assumed to be -0.67 for low-wind conditions [Jähne et al., 1987]. To calculate Sc_{DO} , we used third-order polynomial fits to temperature [Wanninkhof, 1992].

2.5. Estimating Turbulent Diffusivity

Thermal structure was used to define turbulent diffusivity of the pond system. In these ponds, the thermal structure can be considered one-dimensional since the effects of advection are minimal (although will, to some extent, modify the variables). We therefore define an *apparent* turbulent eddy diffusivity, k_T , which is composed of a diffusive and an advective component:

$$k_T = \frac{Q}{\rho c_p} \left(\frac{dT}{dz} \right)^{-1}$$

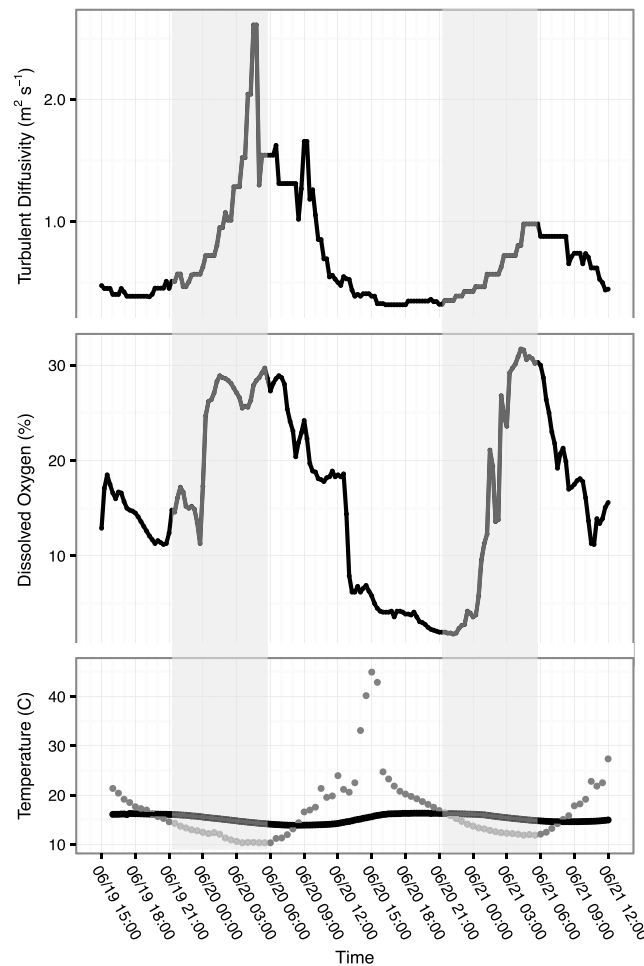


Figure 1. Two representative nighttime DO spikes from Blacksmith Pond, 19–21 June 2013 showing diffusivity, DO (% saturation), and temperature (°C) of the pond (solid black line) and air (dashed gray line). Nighttime hours are shaded grey.

decreased before the spike occurred to $5.2 \pm 1.1\%$ (range: 0.4–25.1) % saturation, and increased on average by 21.5 ± 1.7 (range: 6.2–46.1) % saturation, reaching an average maximum of 26.7 ± 2.01 (range: 6.6–50.1) % saturation (Table S1). Spikes occurred rapidly, within 1 to 3 h, and transformed the pond oxygen environment (Figure 1, Table S1, and Figure S1).

Classification trees identified two predictors of nighttime DO spikes: the difference in air-water temperature and average air temperature (Figure 2a). DO spikes were more likely to occur when the pond was warmer than the air ($\geq 1.8^\circ\text{C}$) and air temperatures were warm ($\geq 5.8^\circ\text{C}$). The classification tree predicted spikes with 85% accuracy. The regression tree also identified two predictors for the extent to which DO saturation changed overnight: DO at sunset and the difference in air-water temperature (Figure 2b). If sunset DO was $\geq 31\%$ saturation, ponds lost DO overnight due to respiration; however, oxygen generally increased overnight when sunset DO was lower. Oxygen increased the most (by 22% saturation) when sunset DO was $< 31\%$ saturated and ponds were at least 1.8°C warmer than the air.

There were 11 nights where DO was measured in more than one pond, representing 25 of the 60 pond nights (Table S1). On three of the 11 nights, study ponds exhibited different responses in terms of whether or not a DO spike occurred. On all three nights (19 May, 20 May, and 30 June), the pond-air temperature difference was $< 1.8^\circ\text{C}$, which would not predict a DO spike (Figure 2a). However, the ponds that experienced spikes had average overnight pond temperatures that were warmer than or similar to the air, while ponds that

where Q is the surface energy budget (see Text S1), ρ is the density of water, c_p is the specific heat of water, and dT/dz is the temperature gradient in the water. If the heat flux and temperature profile are known, k_T can readily be evaluated.

Estimates of k_T were calculated for all events, with the linear gradient estimated from the temperature measured every 10 to 15 cm from 0.1 m to 0.5 m through the full water column. The heat flux is independent of depth since the profiles span only 0.5 m. Estimates of k_T are confined to the times when the surface energy budget is negative or convectively cooling. Estimates could not be made on three nights when the pond was fully mixed (see Figure S2, Atwood Pond: 28 and 29 July; Blacksmith Pond: 19 June) because we could not detect a temperature gradient within the accuracy of the thermistors ($\pm 0.2^\circ\text{C}$).

3. Nighttime DO Increases

We discovered frequent and substantial increases in surface water oxygen concentrations during nighttime hours. We observed overnight DO spikes on 45% of pond nights sampled (27/60 pond nights), during which DO saturation increased an average of 12.0 ± 1.9 (± 1 SE) fold. When DO spikes occurred, sunset DO averaged 7.9 ± 1.6 (range: 0.5–29.6) % saturation,

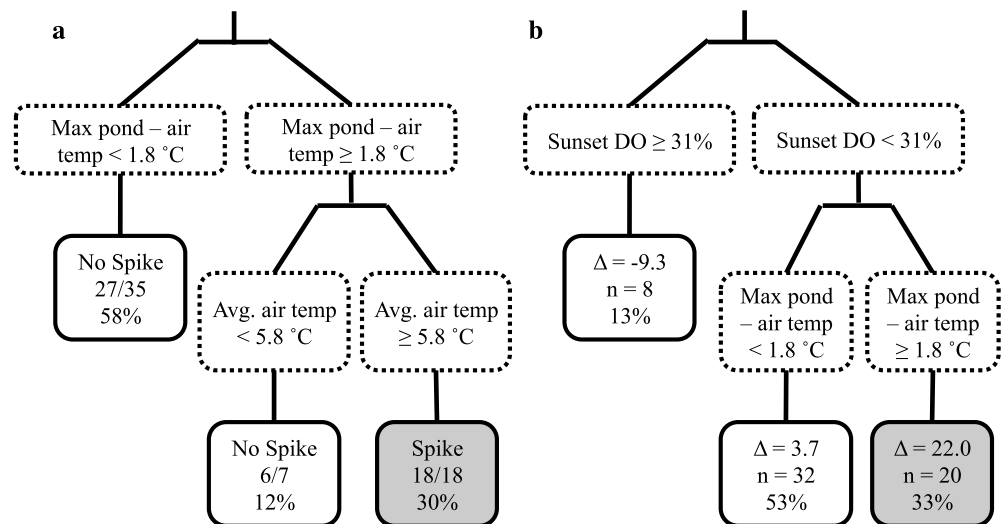


Figure 2. (a) Classification tree predicting when dissolved oxygen spikes occur in ponds and (b) regression tree predicting the extent to which DO percent saturation changed ($n = 60$ pond nights). Dashed boxes represent splits in the classification tree; solid boxes represent whether or not a spike occurred. In Figure 2a the solid boxes include if ponds are predicted to have a spike or not, the fraction of ponds accurately classified, and the percent of total ponds included in the classification. In Figure 2b the solid boxes include the predicted change in overnight DO and the number and percent of total ponds included in the classification.

did not experience spikes were cooler than the air (Table S1). Therefore, we hypothesize that the discrepancy among ponds is explained by differences in pond temperatures relative to the air.

4. Atmospheric Reaeration Causes DO Spikes

These results clearly demonstrate a linkage between cooling temperatures and increases in DO concentrations, which may relate to pond mixing [MacIntyre and Melack, 2009]. Evaluation of temperature-depth profiles of the ponds obtained for 38 pond nights where data were available demonstrated that partial or complete mixing occurred on 10 of the 13 pond nights with DO spikes (Figure S2). On nights when no DO spike was detected ($n = 25$), the ponds remained stratified. This mixing could lead to increases in surface water DO by either (1) increasing air-water gas exchange by significantly enhancing turbulence [Melack and Fisher, 1983; Schladow et al., 2002; MacIntyre et al., 2010], (2) mixing potentially DO-rich benthic waters into the water column [Van de Bogert et al., 2007], or (3) lateral mixing due to spatial heterogeneity in DO [Van de Bogert et al., 2012; Crawford et al., 2015]. We measured benthic DO in Blacksmith Pond and found no evidence that benthic production produced nighttime DO spikes. Benthic production was low: we discerned midafternoon DO increases on only five of the 24 days (20.8%), and on those days benthic DO only increased by an average of $11.1 \pm 3.9\%$ saturation. In contrast, nighttime benthic DO spikes occurred on 13 of the 25 nights (52%), increased DO by an average of $23.0 \pm 2.0\%$ saturation, and coincided with pond mixing (Figure S3). The low benthic productivity coupled with overnight benthic spikes in DO provides evidence against benthic-sourced DO.

Lateral heterogeneity in DO could contribute to observed DO increases during mixing events [Van de Bogert et al., 2007; Van de Bogert et al., 2012]. While we did not evaluate lateral DO heterogeneity in our study ponds, it seems unlikely that this mechanism played a significant role. A previous study in Blacksmith Pond found that spatial variation in surface DO was $< 18\%$ saturation during April 1999, when the mean DO ranged from 31 to 40% saturation across the study dates [Freidenburg, 2003]. As we did not observe DO spikes until later in the season when ponds had lower DO ($< 30\%$ saturation at sunset), it is unlikely that horizontal heterogeneity would be great enough to cause the extreme nighttime increases in the DO we observed (average increases of 22% saturation or 12-fold increase). Additionally, anoxic conditions and the precipitous decline in DO following spikes (Figures 1 and S1) indicate that respiration rates are high, which make it unlikely that pockets of DO that persisted would be high enough to induce DO spikes. Therefore, the observed DO spikes were likely driven by the invasion of atmospheric oxygen during periods of increased turbulence and gas exchange.

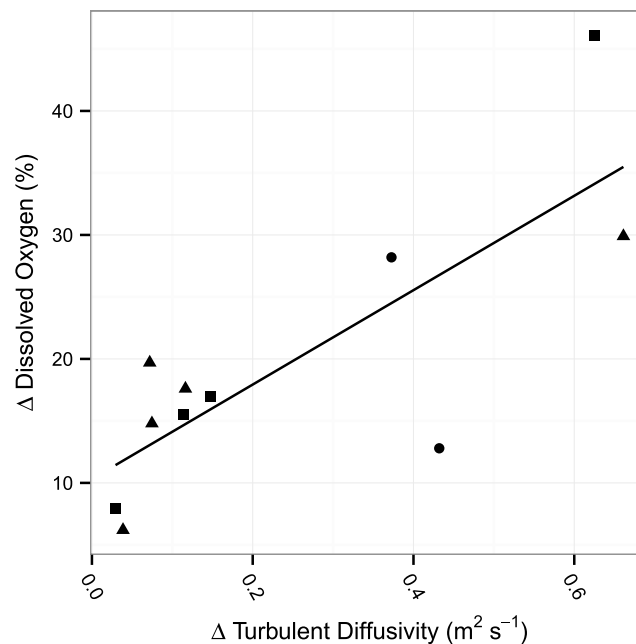


Figure 3. Relationship between change in overnight eddy diffusivity delta and change in dissolved oxygen for nights when oxygen spikes occurred for all three ponds ($n = 11$; Atwood Pond ($n = 2$): circles; Blacksmith Pond ($n = 5$): triangles; Long Pond ($n = 4$): squares). Only nights where diffusivity estimates were available and spikes occurred are included.

Although wind often drives turbulence in large water bodies, turbulence can be largely influenced by convection in sheltered and low-wind ponds [Eugster et al., 2003; MacIntyre et al., 2010; Read et al., 2012]. For convection to create the observed overnight DO spikes, we calculated that nighttime k_{600} (during periods when DO increased) would need to average $4.3 \pm 0.3 \text{ cm h}^{-1}$ (with 15 min intervals ranging from 0.004 to 34.7 cm h^{-1}). This range is higher than the mean k_{600} reported for small lakes 0.3 to 15 ha (1 to 7 cm h^{-1}) [Clark et al., 1995; Cole and Caraco, 1998; Cole et al., 2010; Read et al., 2012] but plausible, considering that values up to 20 cm h^{-1} have been observed during periods of heat loss [MacIntyre et al., 2010]. Short, dramatic increases in k due to convection have not been described before but may be a widespread phenomenon given that the majority of the world's lentic freshwaters are small.

Pond temperature profiles also indicated that nighttime cooling drove buoyant convection in these small, sheltered systems, which led to considerable surface turbulent eddy diffusivity and elevated k . The pond temperature stratification followed a warming and cooling cycle that was slightly out of phase by a few hours with the surface energy budget. The surface energy budget was dominated by solar radiation (positive into the pond) during the day and by evaporation (negative out of the pond) at night. The warming peak in the surface energy budget occurred midafternoon, whereas the peak water temperature occurred at dusk. The temperature stratification that developed during the day was typically broken down overnight (Figure S2). We used this thermal structure to model turbulent diffusivity of the pond system. Turbulent eddy diffusivity increased overnight (due to negative surface energy flux) following the peak in diurnal temperature (Figure 1). Turbulent diffusivity typically peaked right before daybreak at the diurnal temperature minimum and decreased with solar warming (positive surface energy flux), which set up the stratification that diminished the turbulence and the cycle repeats.

On nights where DO spikes occurred and diffusivity was estimated, the average turbulent eddy diffusivity significantly increased the maximum k_{600} ($r^2 = 0.64$, $p = 0.003$, $n = 11$). In turn, these short bursts of increased k_{600} drove large reaeration events and overnight increases in DO ($r^2 = 0.80$, $p < 0.001$, $n = 11$). Because the extent of DO undersaturation at sunset (i.e., air-water concentration difference) was not related to overnight increases in DO ($r^2 = 0.003$, $p = 0.88$, $n = 11$), turbulent diffusivity significantly predicted overnight increases in DO when spikes occurred ($r^2 = 0.63$, $p = 0.003$, $n = 11$, Figure 3). In contrast, there was no significant relationship between turbulent diffusivity and changes in DO on nights when no spike was observed ($r^2 = 0.33$, $p = 0.30$, $n = 24$, Figure S4). These relationships indicate that turbulence is a necessary condition for overnight DO increases, but other factors may also influence the magnitude of change (e.g., turbulence from wind).

While reaeration is a well-known phenomenon in undersaturated water bodies, particularly following lake turnover [Gelda et al., 1996], we are unaware of other field studies demonstrating that convective cooling can drive dramatic oxygen invasion. Oxygen invasion was documented year-round in Lake Calado, a large ($2\text{--}8 \text{ km}^2$), DO-undersaturated floodplain lake in Brazil [Melack and Fisher, 1983]. Lake Calado had periods of positive and negative changes in DO during both day and night, which the authors attributed to wind-induced diffusion, convective cooling, and internal mixing [Melack and Fisher, 1983]. Convective cooling

was proposed to explain increased nighttime CH₄ emissions from a boreal wetland, and the authors called for further research to explore the physical controls of this process [Godwin *et al.*, 2013]. Our study provides critical evidence that convective cooling can induce frequent, rapid, and intense gas exchange, and directly links increased gas exchange to convection.

It is worth noting that because our ponds were always undersaturated in oxygen, reaeration would occur constantly. It is possible that we did not detect DO spikes when ponds had higher initial DO saturation because there was a smaller air-water concentration difference, making it difficult to observe smaller oxygen fluxes. This could indicate that increases in k go unnoticed, or perceived as anomalies, in systems with more oxygen.

5. Implications for Pond Biogeochemistry and Ecology

Overnight reaeration events have important implications for understanding small inland waters. Most calculations of ecosystem metabolism use overnight changes in DO to estimate respiration [Cole *et al.*, 2000]. If short periods of increased gas exchange are unaccounted for, respiration will be underestimated and metabolism may be grossly miscalculated [Kemp and Boynton, 1980]. Additionally, in ponds where DO spikes are significant and initial DO is close to zero, accurate respiration estimates may not be possible using traditional DO techniques.

Nighttime increases in gas exchange may also have important implications for global carbon cycling. Small ponds of this size are hot spots for carbon cycling [Torgersen and Branco, 2008; Holgerson, 2015] and may account for 15% of all CO₂ and 41% of diffusive CH₄ emissions from lakes and ponds globally [Holgerson and Raymond, 2016]. Yet gas flux is often estimated from daytime gas concentrations and wind speed, or from daytime static chamber measurements. If convection and increased nighttime gas exchange are not considered, CO₂ and CH₄ emissions from these systems may be highly underestimated. Indeed, other studies have found that CO₂ or CH₄ emissions are highest at night when lakes [Eugster *et al.*, 2003; Podgrajsek *et al.*, 2015], reservoirs [Liu *et al.*, 2016], oceans [McGillis *et al.*, 2004], and wetlands [Godwin *et al.*, 2013] cool. Nighttime sampling or flux towers may be useful methods to assess the prevalence of increased nighttime gas exchange and the importance to global carbon emissions [Godwin *et al.*, 2013; Liu *et al.*, 2016].

Overnight reaeration may transform how small pond ecosystems function. Small temporary ponds are low-oxygen environments [Moore, 1970; Skelly *et al.*, 2002; Rubbo *et al.*, 2006], and it is assumed that oxygen has little chance to be replenished once seasonal depletion occurs [Moore, 1970]. These hypoxic conditions have prompted speculation that residents must be adapted to persistent hypoxia. But most observations have been made during the daytime, and we found that nighttime DO spikes were 2–3 times greater than daytime peaks. It is possible that overnight reaeration reduces oxygen stress for pond animals. For example, increased oxygen at night may reduce energetically costly behaviors such as amphibians bobbing for air and increase their time spent foraging [Feder, 1984]. Added oxygen may also increase filtering rates and survival in zooplankton and macroinvertebrates [Moore and Burn, 1968; Heisey and Porter, 1977]. Future research should evaluate the extent to which overnight reaeration affects pond consumers.

6. Summary

Overall, we discovered that small ponds are subject to frequent and substantial overnight invasion of atmospheric oxygen. Reaeration results from increased gas exchange due to turbulence generated by convective cooling, coupled with initially low DO. Without accounting for overnight reaeration, our understanding of ecosystem metabolism, carbon cycling, and habitat quality in small ponds is incomplete.

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