Short-term variation in benthic phosphorus transfer due to discontinuous aeration/oxygenation operation

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Background

Sandmining for landfilling projects has left substantial borrow pits in littoral regions in Japan. These borrow pits often causes anoxia, and nitrogen, phosphorus, and sulfide accumulate in high levels in the hypolimnion.

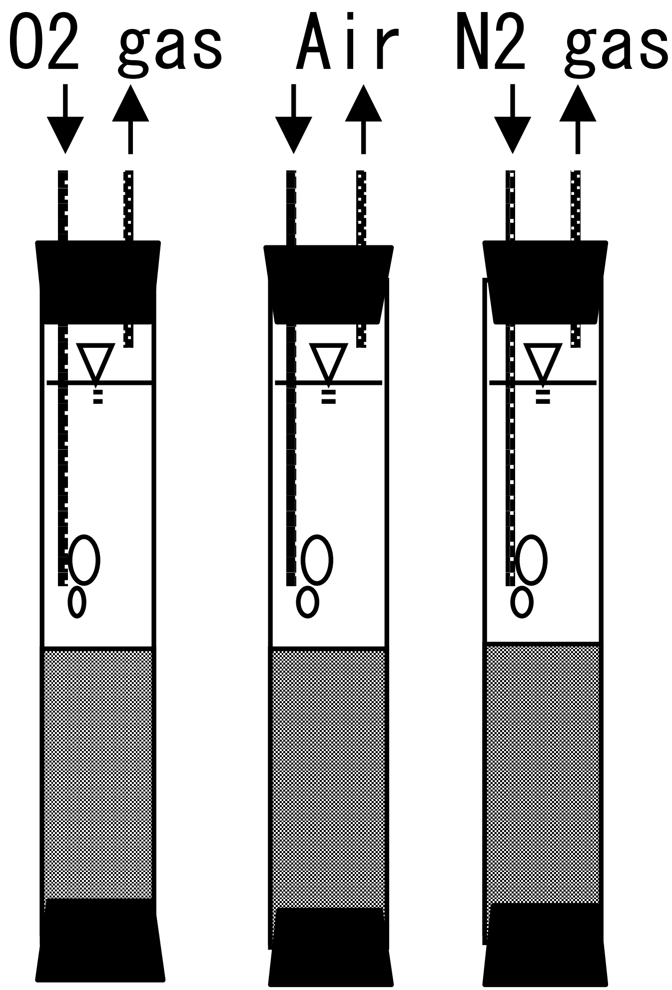
As benthic phosphorus release directly relates to the oxidation-reduction potential in the sediment surface, hypolimnetic aeration and oxygenation are expected to be the most effective approaches to reducing benthic phosphorus release. However, from a mid-long term viewpoint, there is no clear evidence that hypolimnetic oxygenation permanently suppresses benthic phosphorus release.

On the other hand, short-term phosphorus dynamics due to fluctuations in the oxidation-reduction conditions should be given attention from an operational viewpoint.

Objective

1. Short-term dynamics of phosphorus transfer across the sediment-water interface within one week of starting or stopping aeration and oxygenation were investigated through laboratory experiments using intact sediment cores from a borrow pit in a brackish lake.
2. To compensate for the rather rough spatial and temporal resolution in the experiments, more precise examinations were conducted using a numerical diffusion model, and the results were compared with the laboratory experimental results.

Method _ Laboratory experiment



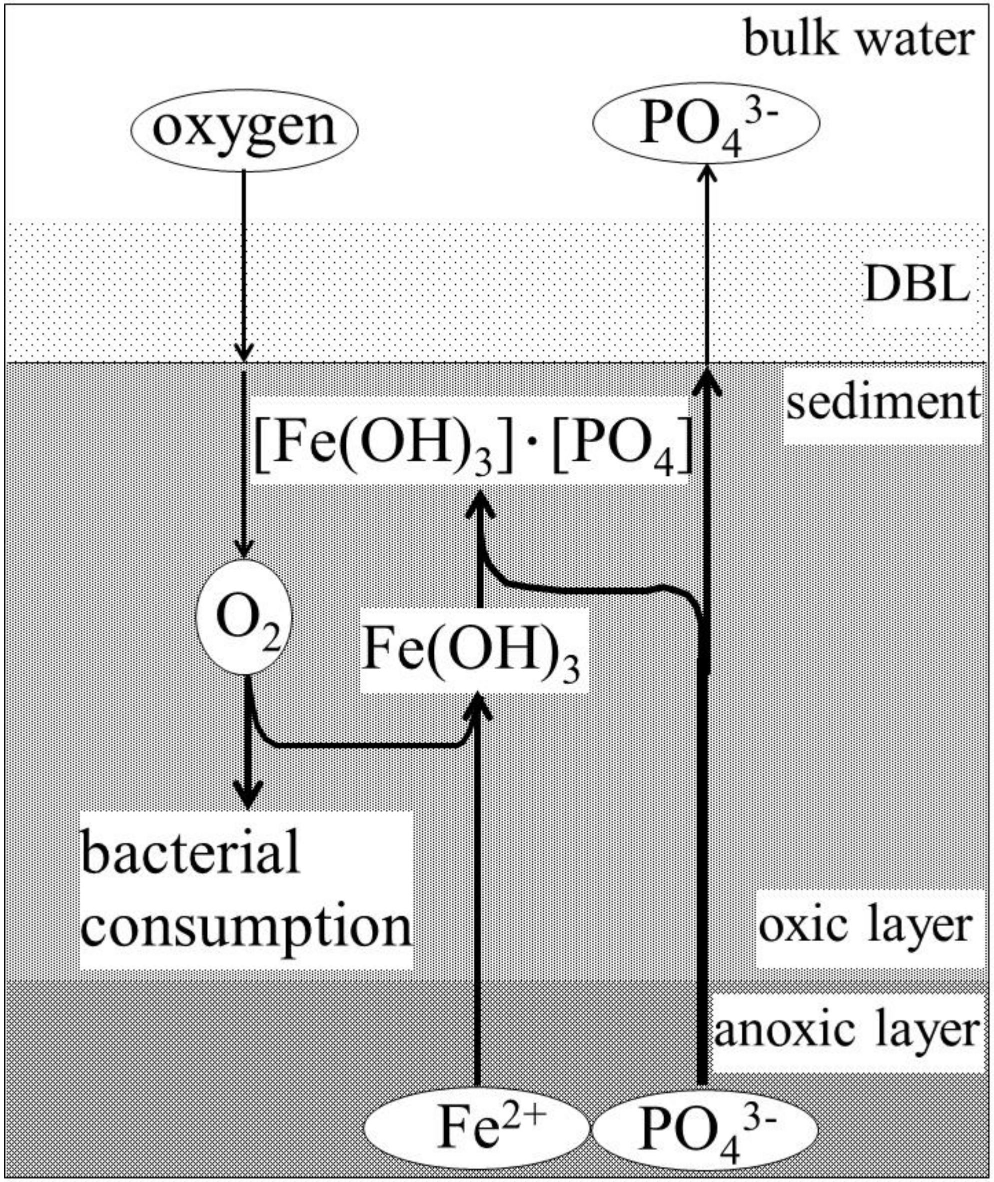
The O_2 concentration in the overlying water was controlled by N_2, air, or O_2 bubbling.

After one day of pre-incubation, Ex #1 was started and continued for 1 day.

After Ex #1 was completed, air or O_2 bubbling was changed to N_2 bubbling and Ex #2 commenced and continued for 5 days.

core No.	water height (cm)	bubbling medium Ex#1	bubbling medium Ex#2
1	23.4	O_2	N_2
2	25.2	O_2	N_2
3	21.0	O_2	N_2
4	25.8	air	N_2
5	24.5	air	N_2
6	24.6	air	N_2
7	24.9	N_2	N_2
8	23.3	N_2	N_2
9	25.0	N_2	N_2

Method _ Analytical model _ Concept



The model employed herein considers the dynamics of ferric hydroxide-bound phosphate.

In this model, O_2 is supplied from the overlying water to the sediment by diffusion, after which it is consumed by biological respiration and oxidation of ferrous iron in the sediment.

Phosphate in the pore water is supplied by desorption from sediment particles and is adsorbed to ferric hydroxide under oxic conditions, while it is supplied by desorption from ferric hydroxide under anoxic conditions.

Method _ Analytical model _ Basic equations

$$\phi \frac{\partial C_O}{\partial t} = \phi D_{zO} \frac{\partial^2 C_O}{\partial z^2} - \frac{1}{4} \phi k_{OF} C_O C_F - k_B C_O$$

$$\phi \frac{\partial C_P}{\partial t} = \begin{cases} \phi D_{zP} \frac{\partial^2 C_P}{\partial z^2} - k_{ad} C_P - k_{de} \{C_P - C_P(-\infty)\} & (C_O > 0) \\ \phi D_{zP} \frac{\partial^2 C_P}{\partial z^2} + k_{de} P_P - k_{de} \{C_P - C_P(-\infty)\} & (C_O = 0) \end{cases}$$

$$\frac{\partial P_P}{\partial t} = \begin{cases} + k_{ad} C_P & (C_O > 0) \\ - k_{de} P_P & (C_O = 0) \end{cases}$$

$$\phi \frac{\partial C_F}{\partial t} = \phi D_{zF} \frac{\partial^2 C_F}{\partial z^2} - \phi k_{OF} C_O C_F - \frac{1}{\alpha} k_{de} \{C_P - C_P(-\infty)\}$$

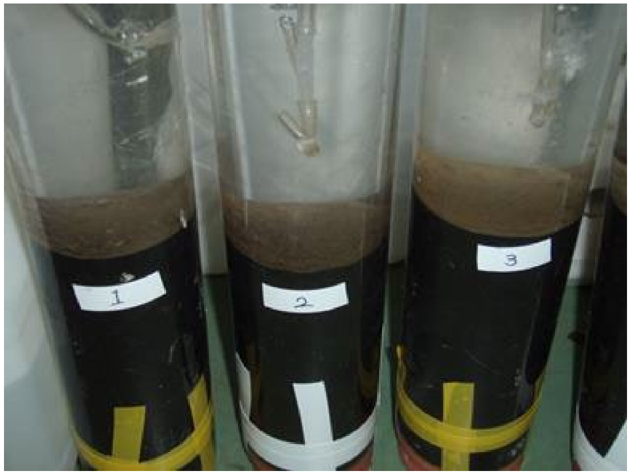
The mass balance equations were formulated as shown here:
The benthic system is basically expressed as 1-dimensional vertical diffusion equations, with some reaction terms.

Method _ Analytical model _ Parameters

- Some volume-known portions of the quarried sediment were used to measure the volume specific oxygen consumption, phosphate adsorption, and desorption rates of the sediment.

parameter	notation	value	unit
porosity	ϕ	0.96	-
rate constant of ferrous iron oxidation	k_{OF}	1.71×10^{6}	$mm^3\ mmol^{-1}\ s^{-1}$
rate constant oxygen respiration	k_{B}	5.00×10^{-11}	s^{-1}
rate constant of SRP adsorption	k_{ad}	6.62×10^{-4}	s^{-1}
rate constant of SRP desorption	k_{de}	1.56×10^{-5}	s^{-1}
mole ratio of adsorbed SRP to iron	α	84.2	-

Results _ Laboratory experiment _ Ex#1

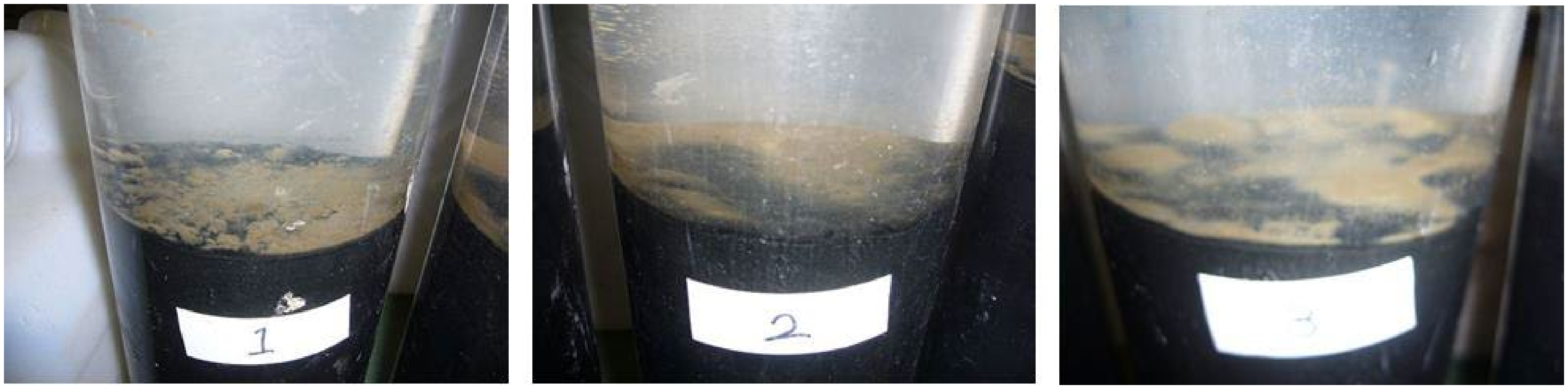


O2 bubbling

air bubbling

N2 bubbling

Results _ Laboratory experiment _ Ex#2



Ex-O2-bubbled cores

Ex-air-bubbled cores

1 day after Ex#2 commenced.

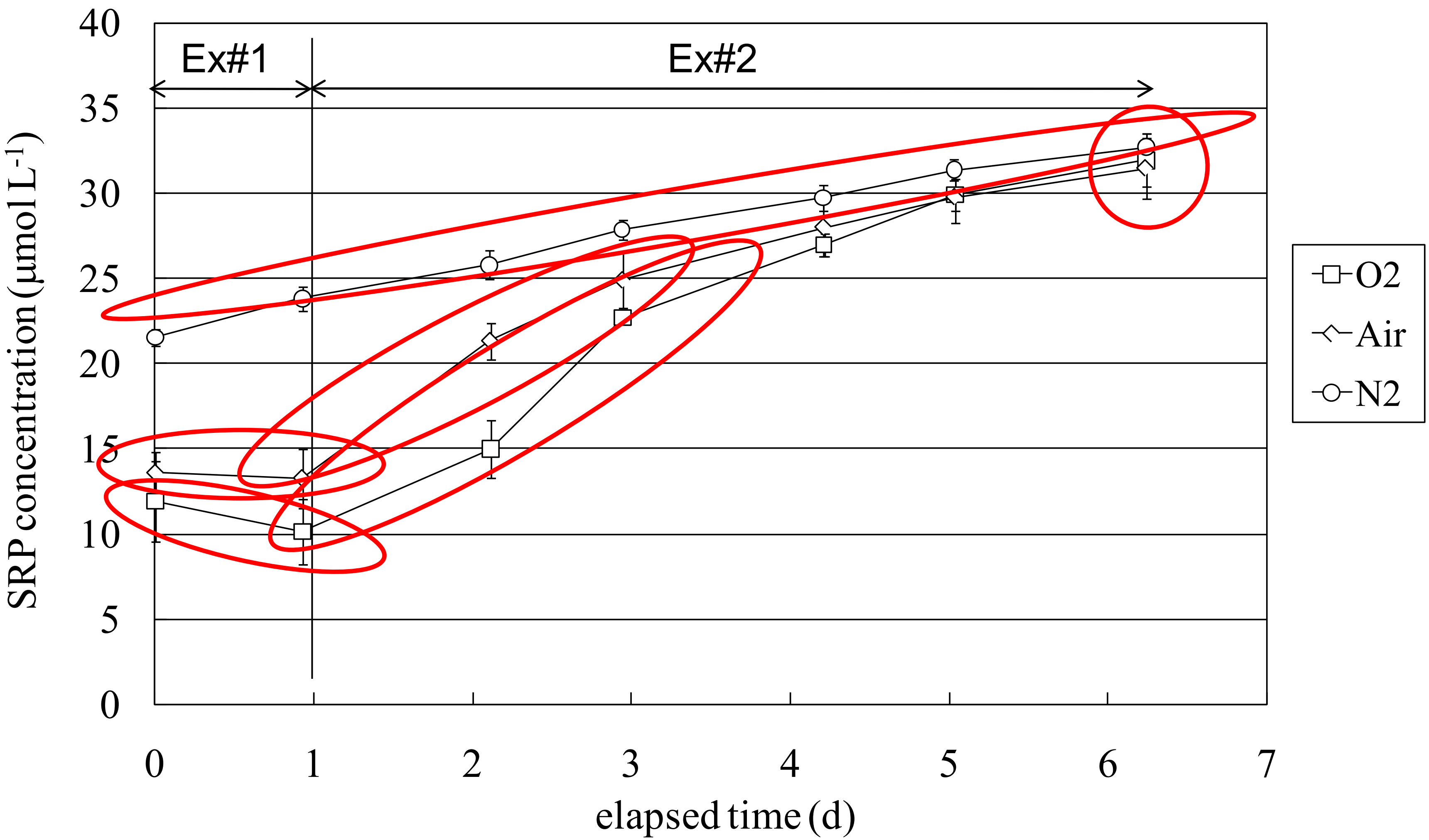
Results _ Laboratory experiment _ Ex#2

Ex-O2-bubbled cores

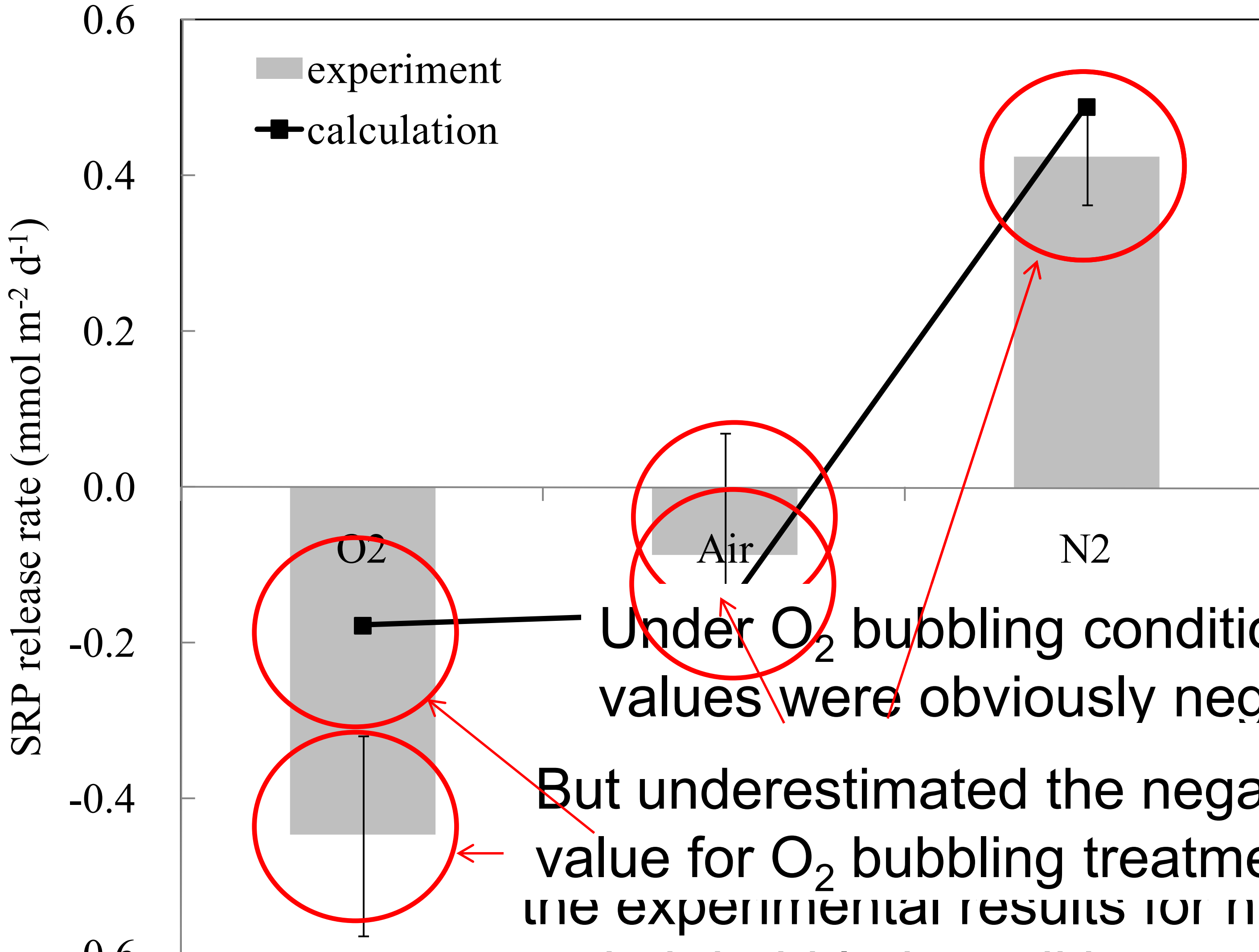
Ex-air-bubbled cores

2 day after Ex#2 commenced.

Results _ Laboratory experiment _ time course of phosphate



Results _ Laboratory experiment _ phosphate release rate Ex#1



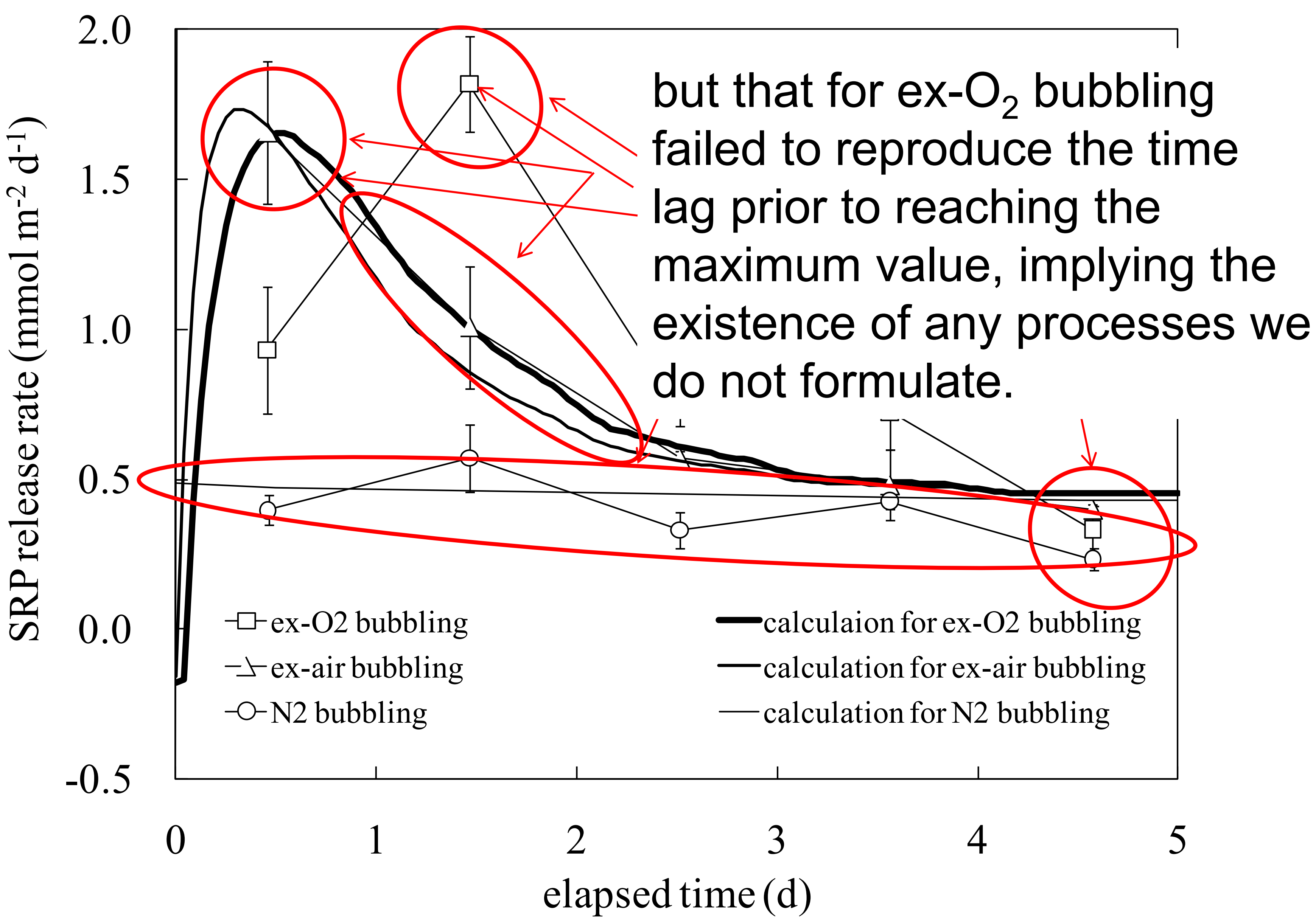
Under O_2 bubbling conditions, the values were obviously negative (-

But underestimated the negative value for O_2 bubbling treatment.

the experimental results for nitrogen n

and air bubbled conditions. t.

Results _ Laboratory experiment _ phosphate release rate Ex#2



Conclusions

short-term dynamics of SRP transport across the sediment surface due to discontinuous aeration/oxygenation were investigated by experimental and analytical methods.

Hypolimnetic aeration and oxygenation are temporally effective approaches to suppression of phosphate release from the sediment.

However, the effects will not be maintained without aeration/oxygenation operations, and the accumulated phosphorus in the sediment surface during hypolimnetic aeration and oxygenation will be drastically released within a few days of the discontinuance of operation.

Spatially and temporally local phenomena have substantial effects on the phosphorus balance at the sediment-water interface. Therefore, more detailed and frequent observations will be required to enable a quantitative understanding of the phosphorus cycle in the field.