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THE TIDAL/DIURNAL CYCLES OF THE NUTRIENTS EVOLUTION FOR MICROPHYTOBENTHOS ACTIVITY

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ABSTRACT: The objectives of this study were to investigate, the evolution of porewater nutrients in intertidal sediments over tidal and diurnal cycles, and the concentrations of nutrients to which the microphytobenthos are exposed during their vertical migration in the sediment. While porewater concentrations and their oscillation over tidal cycles have previously been measured, in our study we have included a high sampling frequency (2 hours) over a 2 day period. The tidal/diurnal cycle of dissolved inorganic nitrogen (nitrate+nitrite, ammonium), microphytobenthic biomass (Chl-a) and environmental parameters (temperature, light intensity, water depth) were studied on an intertidal flat in the Nakdong River estuary. We showed clear evolutions in the two nutrients which were significantly linked to the tidal cycle. Nitrate+nitrite showed an increasing trend in all depths during submersion periods, in contrast ammonium decreased, this resulted from the varying influence of diffusion and advection of overlying water. The microphytobenthos showed a normal migratory rhythm linked to the tidal cycle. Our result suggests that the evolution of porewater nutrients is mainly influenced by tidal cycle and the MPB activity may influence the nutrients evolution during emersion periods.

Keywords: Porewater nutrients evolution, microphytobenthos, tidal/diurnal cycle, intertidal flat.

INTRODUCTION

Coastal ecosystems are generally high productive areas which function as a buffer zone in the transport of nutrients between the land and the sea (sundback et al., 2000). In this area, the nutrients exchange between the sediment and overlying water of intertidal sediments is an essential process for nutrient cycling (Kristensen, 1993).

While several studies have focused on nutrient fluxes in tidal sediments, it has been difficult to obtain accurate estimations. This is due to the dramatic short-term temporal changes of environment factors induced by tidal variations and also the methodological problems of high frequency sampling (Sakamaki et al., 2006). The study of short-term (hourly or daily) fluctuations is an important for our understanding of nutrient cycling in tidal sediment, but most studies have focused on monthly or seasonal variations, using sediment intact cores or in situ chambers (Reay et al., 1995; Rysgaard et al., 1995).

The concentration of nutrients in sediment porewater is influenced by physical and chemical factors such as sediment type, temperature, salinity, hydrodynamic conditions, the concentration of nutrient in the overlying water, biological and biochemical factors such as macrofaunal activities, nutrient uptake and oxygen production by microphytobenthic activities, mineralization of organic matter, nitrification and denitrification (Jensen et al., 1990; Klump and Martens, 1989; Kristensen, 1993). Microphytobenthos (MPB) are recognized as essential primary producer in coastal ecosystems (Underwood and Kromkamp, 1999). They are widely distributed in areas where they can utilize light for photosynthesis. MPB in the tidal flat can control nutrient fluxes at the sediment surface and nutrient concentrations in superficial sediments due to nutrient assimilation and photosynthetic oxygen production (Henriksen et al., 1980; Krom, 1991). The MPB migrate vertically in the sediment. They move up to the surface during light times to photosynthesis and go down into deeper zones during submersion periods or night time (Underwood et al., 2005). This migration of MPB is able to influence the evolution of nutrients in the sediment due to the changes of nutrient concentration by MPB uptake and change of oxygen penetration depth by

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Fig. 1. The Nakdong estuary on southestern coast of South Korea.

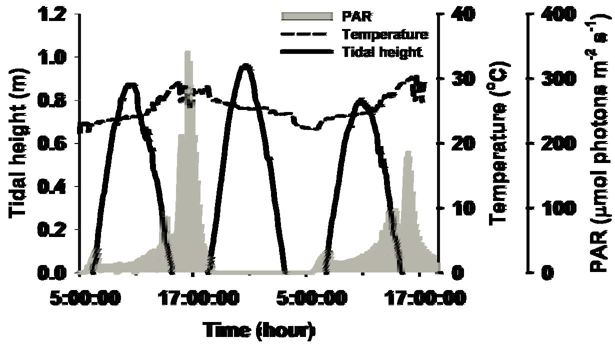

Fig. 2. The vlaue of environmental parameters (PAR : gray filled, temperature : solid line, tidal height : dotted line) during study periods.

photosynthetic oxygen production. The migration of MPB will influence their exposure to different concentrations of nutrients which can change rapidly in the first layers of the sediment.

The objectives of this study were to investigate the evolution of porewater nutrients with depth in the sediment over tidal and diurnal cycle and to study the influence of MPB migration on the evolution of nutrient concentration.

MATERIAL AND METHOD

Study area : Study area, the Nakdong River estuary (35 ° 05' N, 128 ° 55' E) is located on the southern east of the South Korea (Fig. 1). The Nakdong River is the second biggest river in South Korea, which has a catchment area 23,817 km^2. In 1987, a big estuarine barrage was constructed at the river mouth to regulate the water discharge. The intertidal flat is widely formed on the coastline.

Field experiments: Sampling was carried out on 16 and 17 August 2007 to analyze porewater nutrient concentrations (nitrate+nitrite, ammonium), Chl-a concentrations in the sediment, and environmental parameters (temperature, PAR, water depth). Porewater was sampled every 5 mm depth from the interface to 25 mm with three cores, using the rhizon-method (Seeberg-Elverfeldt et al., 2005). Sediment for Chl-a analysis was sampled with 6 cores at each time period, using a converted version of the cryolander-method (Wiltshire et al., 1997). Environmental parameters such as temperature and water depth were measured every minute during the sampling period, using a Hydrolab-Data Sonde 4(HYDROLAB, TX, USA), and Light values was measured using a Hobo Light Intensity Probe (Onset Computer Corp.).

RESULT

Environmental Characteristics

The sediment type of the study site was muddy sand. The fluctuation of the water level by the tide throughout the study period was approximately 0.95 meter, and the submersion period was approximately 6 hours during one of tidal cycles (Fig. 2). The temperature of the water and sediment surface was 21~30 ℃ and 25~33 ℃, respectively, and the diurnal fluctuation throughout study period was approximately 8~9 ℃ (Fig. 2). The photosynthetically available radiation (PAR) at the sediment surface, which influences the photosynthesis of MPB, had an average value of 58 μmol photon m^{-2} s^{-1} during emersion periods after sunrise and 20 μmol photon m^{-2} s^{-1} during submersion periods and a maximum value of 339 μmol photon m^{-2} s^{-1}.Thus environmental parameter was clearly influenced by the the tidal and diurnal cycles

The Evolution of Porewater NO_x (Nitrate+Nitrite)

The evolution of porewater NO_x concentrations in sediment showed a clear oscillation with the tidal variations (Fig. 3), and showed a significant correlation with tidal height (r=0.655, $p<0.01$), which increased during submersion periods and decreased during emersion periods. It is estimated that NO_x increased due to diffusion and advection by water which has higher NO_x concentration than porewater during submersion period, and decreased due to MPB uptake and denitrification during the emersion period (see discussion).

Table. 1. Pearson's corellation between tidal height (m) and concentrations of nutrients in the porewater and Chl-a in the sediment(SPSS, Version 12.0). .(** = p<0.001, .* = p<0.05)

	Nitrate+Nitrite	Ammonium		Chl-a
Depth(mm)	r^2	r^2	Depth(mm)	r^2
0	.642**	-.734**	0.2	-.433
5	.646**	-.738**	1	-.460
10	.613**	-.664**	3	.432
15	.647**	-.435**	5	.328
20	.698**	-.382*	10	.620*
25	.193	-.350*	20	.347

Statistical analysis of the correlation between tidal height and NO_x concentration with depth using Pearson's correlation coefficient showed the influence of tidal height was the highest at the surface and reduced with depth below the surface (Table.2). In order to analysis statistically the relation between environmental parameters and NO_x concentration with depth, the data were tested using a 2-way ANOVA, with tidal height and depth, PAR and depth and surface temperature and depth as main factors. The evolution of NO_x concentration showed a significantly different depth patterns with tidal variation (tidal height x depth, $p<0.01$), but the interaction with PAR and with the temperature of the sediment surface showed no significant correlations (PAR x depth, temperature x depth, all $p>0.05$).

The Evolution of Porewater Ammonium

The evolution of porewater ammonium

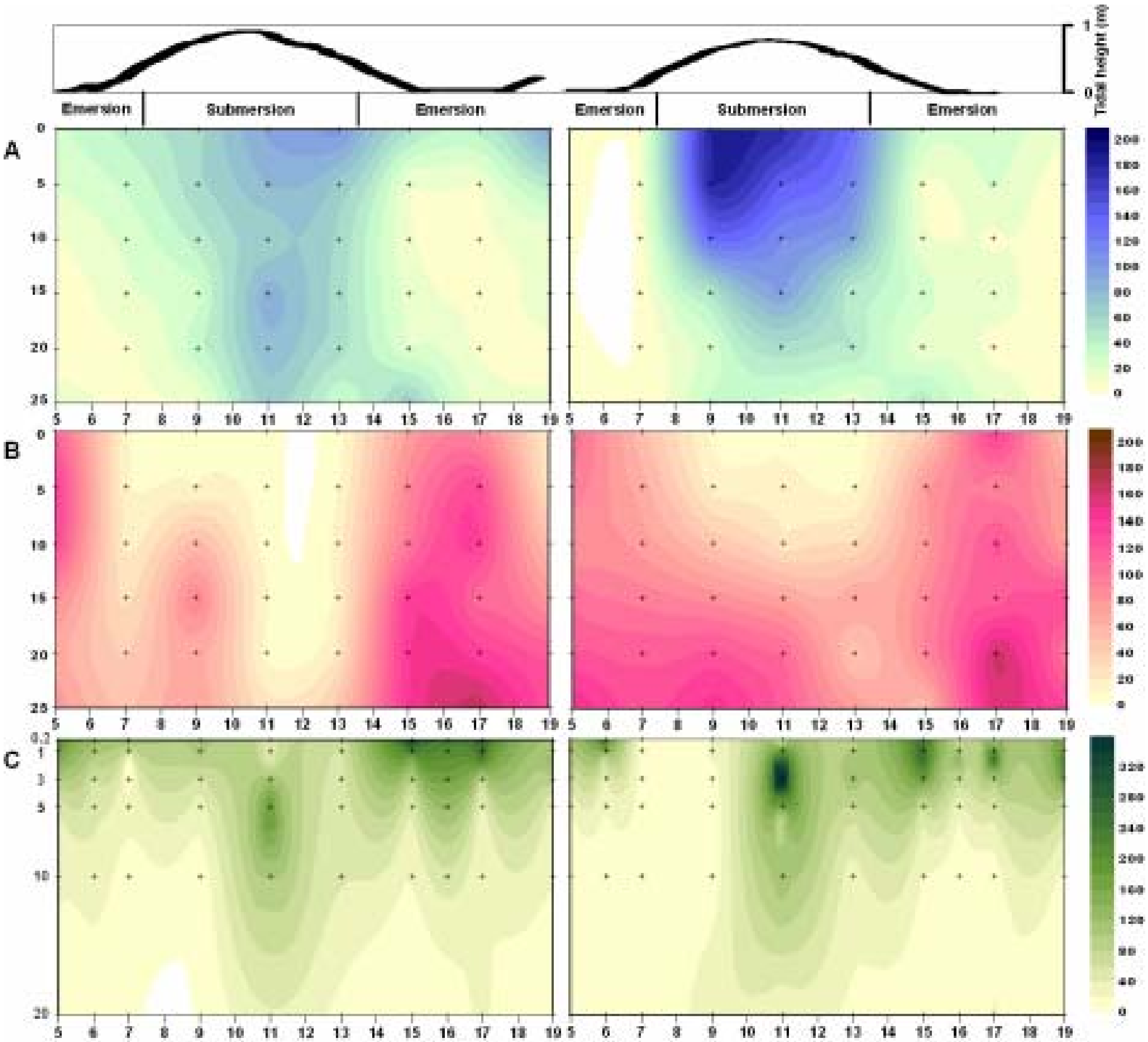

Fig. 3. The profiles of porewater nutrients and Chl-a concentration (A: nitrate+nitrite, B: ammonium, C:chl-a), figure was modified from Longphuirt *et al*, 2009.

concentrations in the sediment also showed an obvious oscillation with tidal variation like NOx, but the pattern was reversed (Fig. 3). The ammonium concentration showed a significant negative correlation with tidal height ($r=-0.623$, $p<0.01$), which decrease during submersion periods and increase during emersion periods. It is estimated that ammonium decreased due to dilution by advection of water which has lower ammonium concentration than porewater, into the sediment during submersion period, and increased due to mineralization of organic matter during emersion period (see discussion).

The influence of tidal height on ammonium concentrations with depth, portrayed using statistical analysis, was the highest at the surface and was lower with depth in the sediment similar to NO_x (Table.2).

As a result of the relation between environmental parameters and ammonium concentration with depth (2-way ANOVA), ammonium concentration showed a significantly different depth patterns with tidal variation (tidal height x depth, $p<0.01$). The interaction with PAR and with sediment surface temperature showed no significant correlations (PAR x depth, temperature x depth, all $p>0.05$).

The Evolution of Chl-a Concentration in Sediment

The evolution of Chl-a concentrations in the sediment showed no obvious oscillation for tidal variation similarly to result of DIN ($r=0.104$, $p>0.05$), but observed diurnal cycle with light condition (Fig. 3). The light condition change due to submersion and emersion by tidal variation was related with the migration of MPB represented by Chl-a concentration. We observed that the Chl-a concentration reflects the migration of MPB as the concentration was high at the surface during diurnal emersion periods and at about 3~10 mm depth during diurnal submersion periods.

Tidal height showed no overall correlation with Chl-a concentration with depth, but a significant correlation which observed at 10 mm depth. This reflects an obvious influence of the tide /light cycles on the MPB migration ($r=0.620$, $p<0.01$) (Table. 2). As a result of the relation between environmental parameters and Chl-a concentration with depth (2-way ANOVA), Chl-a concentration represented a significantly different depth patterns with tidal variation and with PAR (tidal height x depth, PAR x depth, $p<0.01$), but the interaction with temperature of sediment surface showed no significant correlations (temperature x depth, $p>0.05$).

DISCUSSION

What controls the evolution of DIN (dissolved inorganic nitrogen)?

Generally, the factors which influence the evolution of DIN concentration are biological factors such as nutrient uptake of MPB, nitrification and denitrification of bacterial activities, and physical factor such as emersion and submersion by the tidal cycle (Kemp et al., 1990).

In our results, the evolution of NO_x concentrations was clearly influenced by emersion and submersion. Among the biological factors, nitrification is a process whereby ammonium is oxidizes to nitrate by bacterial activity, and this is influenced by in situ temperature and ammonium concentration (Rysgaard et al., 1995; An and Joye, 2001). MPB are primary producer which uptake ammonium and nitrate and have photosynthetic activity related to light conditions. Their activities influence nitriification due to the changes of ammonium concentration. Thus, nitrification is closely connected with the activities of MPB. Although this study didn't measure the values of these two parameter (nitrification and MPB activity) directly, the relation between these processes was investigated using NO_x concentration as the index for nitrification and Chl-a concentration as the index for MPB activity. As a result of comparing NO_x with sediment temperature, PAR, and Chl-a, the temperature and NO_x and PAR and NOx showed no significant correlation, but Chl-a and NO_x showed positive significant correlation ($r=0.457$, $P<0.01$). The NO_x and Chl-a have generally negative correlation when nitirification is high, due to the inhibition of nitrification by ammonium uptake of MPB and the continuous decrease of NO_x production. But in our result of the positive correlation between two parameters, it is estimated that the activity of MPB doesn't influence nitrification. Denitirification is a process whereby nitrate is reduced to nitrogen gas by bacterial activity in anaerobic environments. This process, removal factor of nitrate, is influenced by the aerobic and anaerobic layers and thus with the distribution of oxygen in the sediment. Low concentrations of NO_x was observed in the deep layer during emersion period was estimated to be a result of thepromotion of denitrification in the extended anaerobic layer with decrease of oxygen penetration depth (Blackburn et al., 1983).

The evolution of porewater ammonium concentrations, as $NO_{x,}$ was also significantly influenced by emersion and submersion like. As described above, nitrification is a biochemical process related to ammonium and the removal of nitrate. Ammonium and nitrate generally represent a negative correlation (Rysgaard et al., 1995). In our results, this pattern was clearly represented ($r=-0.734$, $p<0.01$), but the main factor contributing to this is dilution by overlying water water with low ammonium and high NOx concentrations during submersion. So while nitrification might influence ammonium concentrations, in this case at clear influence was not in evidence.

The Effect of Microphytobenthic Activity

It has been reported that the photosynthetic oxygen production and nutrient uptake processes of MPB are important when considering biogeochemical cycling in intertidal sediments (van Luijin et al., 1995; Sigmon and Cahhon, 1997). This study estimated the biomass of MPB with depth in the sediment using the Chl-a concentration. Further the relation between the distribution of MPB and both environmental parameters and the evolution of DIN concentration by MPB activity was investigated. Although direct comparisons of ammonium and Chl-a showed no significant correlation ($r=-0.230$, $p>0.05$), the correlation between NO_x and Chl-a($r=0.457$, $p<0.01$) and the interaction with depth of PAR were significant.

MPB are generally related to light conditions due to their photosynthetic activity. In the case of DIN, it is estimated that the effect of emersion and submersion significantly influenced the evolution of DIN concentration, and this effect was obviously represented in our result The physical effect of water must influence the biomass of MPB, but it appears for the statistical results the effect of light condition change by emersion and submersion was larger. As a result of analysis of comparison between Chl-a and environmental parameters in order to investigate above estimation, the tidal height, with emersion and submersion, and Chl-a showed significant correlation, and the correlation between Chl-a and PAR was significantly represented. It is estimated that the distribution of MPB in sediment was greatly influenced by the effect of light condition change compared to DIN which was influenced by chemical and physical factor with emersion and submersion, because although NO_x and Chl-a showed a correlation, the degree was not large, and the correlation between Chl-a and ammonium which is preferred by MPB was not represented.

CONCLUSIONS

This study investigated the evolution of porewater DIN and MPB with depth in intertidal sediment during short-term diurnal periods, and studied the process and factors which influence their oscillations.

There are 2 important results from this study:

(1) It was shown that the emersion and submersion caused by the tidal cycle, is the factor which controls the evolution of DIN concentrations with depth. The NO_x concentration increased with diffusion and advection from overlying water containing higher concentrations than porewater during the submersion period and decreased as a result of nutrient uptake of MPB and denitrification during the emersion period. The evolution of the ammonium concentration showed a reverse pattern compared to NO_x. Ammonium decreased due to the dilution effect by the advection of water having lower ammonium concentration than porewater into the sediment during the submersion period, and increased due to mineralization of organic matter during the emersion period.

It was shown that nitrification, as a biochemical factor did not clearly influence the evolution of the DIN concentration as tidal oscillations hence physical factors were far more important on this short timescale. The effect of denitrification, as a biochemical factor related to NO_x, is estimated to influence on NO_x concentration at deep layer in sediment during emersion period.

(2) As a result of the estimation of MPB biomass using Chl-a concentration, we showed that the migration of MPB in the sediment represented a normal migratory rhythm which went down during submersion period and night time and went up to surface during the diurnal emersion period. The distribution of Chl-a concentration showed an obvious influence of emersion and submersion, the reason of this result is estimated due to light condition change by emersion and submersion compared with DIN which was influenced by chemical and physical effect of water. MPB did not appear to influence the DIN concentrations, again as the tidal cycle was the overriding factor.

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