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Estimating Denitrification in Sediments of the Parker River Estuary, Massachusetts

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Nitrogen cycling plays a major role in determining the level and pattern of estuarine productivity, because most coastal ecosystems are nitrogen limited (1, 2). The fate of inorganic nitrogen entering an estuary is key to understanding estuarine nitrogen dynamics. Denitrification, an anaerobic respiration process in which nitrate is reduced to N_2 gas by bacteria (1, 2, 3), is an important nitrogen sink in estuarine systems. Nitrate for denitrification in the sediments comes from two sources: diffusion of NO_3^- into the sediment from the water column (direct denitrification), or NO_3^- produced from the oxidation of ammonium (NH_4^+) released by the degradation of organic matter (coupled denitrification) (1, 4, 5).

The purpose of this study was to investigate sediment denitrification at an oligohaline site in the Parker River Estuary, Massachusetts. Our objectives were to compare (1) three methods of estimating coupled denitrification, (2) rates of denitrification with several NO_3^- concentrations in the overlying water, and (3) denitrification rates in intertidal and subtidal sediments.

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Table I

Sediment-water fluxes of DIC, O_2, NH_4^+, and NO_3^-, sediment NH_4^+ production, and estimates of denitrification for the Parker River Estuary (mean ± standard error). Fluxes are in mmoles·m^{-2}·d^{-1}, and denitrification estimates are in mmoles N·m^{-2}·d^{-1}. Negative fluxes are directed into the sediment. Ambient nitrate concentrations were ~9 μM.

Treatment: Site:	+0 μM NO_3^-[a] Intertidal Flux ± SE	+0 μM NO_3^-[a] Subtidal Flux ± SE	+5 μM NO_3^-[a] Subtidal Flux ± SE	+25 μM NO_3^-[b] Subtidal Flux ± SE
NH_4^+ flux	2.64 ± 0.41	2.02 ± 0.10	3.69 ± 1.35	2.32 ± 0.37
O_2 flux	−35.53 ± 1.01	−27.01 ± 0.54	−44.47 ± 10.41	−38.47 ± 4.90
O_2:N ratio	13.86 ± 6.01	13.40 ± 0.74	12.74 ± 2.40	17.30 ± 4.92
Coupled denitrification	2.73 ± 0.56	2.05 ± 0.18	3.03 ± 0.22	3.49 ± 1.03
DIC flux	65.71 ± 5.30	18.62 ± 0.55	32.14 ± 4.11	23.55 ± 6.98
C:N ratio	25.85 ± 6.01	9.24 ± 0.74	9.59 ± 2.40	9.92 ± 1.53
Coupled denitrification	7.28 ± 1.21	0.79 ± 0.19	1.16 ± 0.73	1.24 ± 0.68
NH_4^+ production[c]	8.48 ± 1.94	5.37 ± 1.95	5.37 ± 1.95	5.37 ± 1.95
Coupled denitrification	5.84 ± 1.98	3.35 ± 1.95	1.69 ± 2.37	3.05 ± 1.99
NO_3^- flux	−0.48 ± 0.14	0.00 ± 0.04	−0.87 ± 0.49	−2.38 ± 0.40
Direct denitrification	0.48 ± 0.14	0.00 ± 0.04	0.87 ± 0.49	2.38 ± 0.40
Total denitrification[d]	3.20–7.76	0.79–3.35	2.03–3.89	3.62–5.87
% direct denitrification[e]	6–15%	0%	22–43%	41–66%
% N denitrified[f]	50–73%	50–62%	26–47%	32–59%

Notes: [a]n = 2; [b]n = 3; [c]n = 9; [d]calculated as a range for coupled + direct; [e]calculated as a range of percent of total denitrification; [f]calculated as a range of percent remineralized N denitrified.

Intact sediment cores were collected from a subtidal and an intertidal site and incubated to determine exchange rates of oxygen (O_2), dissolved inorganic carbon (DIC), NH_4^+, and NO_3^- between the sediment and the overlying water. NH_4^+ production in the sediment was determined by the increase of NH_4^+ (6, 7) in separate cores incubated anaerobically. Direct denitrification was measured by NO_3^- uptake from the overlying water. Coupled denitrification was estimated by comparing measured NH_4^+ release to several expected NH_4^+ release rates calculated from estimates of sediment metabolism based on O_2 uptake, DIC release, and anaerobic NH_4^+ production (7, 8). The expected NH_4^+ release was calculated by assuming C:N and O_2:N ratios of 6.625, based on the Redfield ratio (7, 9).

Estimated rates of denitrification ranged from 0.79 to 7.76 mmoles $N \cdot m^{-2} \cdot d^{-1}$ (Table I), which is in good agreement with other estuarine studies (1, 5, 10). Overall, the various methods did not differ significantly ($P > 0.05$), although for subtidal cores, estimates based on DIC release were lower than estimates based on both NH_4^+ production and O_2 consumption ($P < 0.05$). For the intertidal cores, estimates based on O_2 consumption were lower than estimates from NH_4^+ production ($P < 0.05$). Between 25% and 75% of the nitrogen regenerated in the sediments was estimated to have been denitrified (Table I), indicating that denitrification is a significant sink for nitrogen in Parker River Estuary.

Coupled denitrification did not significantly change with increasing NO_3^- concentration ($P > 0.05$). Direct denitrification, however, did increase with nitrate addition (Flux = $0.0841[NO_3^-] - 0.46$; $P < 0.05$). Whereas NH_4^+ oxidation was the major source of nitrate for denitrification under our ambient conditions (1), denitrifying bacteria were able to take advantage of higher nitrate concentrations.

The estimates of denitrification based on DIC release and NH_4^+ production were higher at the intertidal site than the subtidal site ($P < 0.05$), and there was evidence of direct denitrification in the intertidal cores at ambient NO_3^- levels (Table I). Higher rates of organic matter remineralization indicate higher rates of metabolism at the intertidal site during our investigation. Oxygen uptake did not reflect the higher rate of metabolism (Table I), possibly due to the storage of reduced sulfur compounds from anaerobic sulfate reduction (7). The differences between intertidal-subtidal metabolism and oxidation-reduction capacity warrant further research.

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