

(HUANJING KEXUE)

ENVIRONMENTAL SCIENCE

第39卷 第9期

Vol.39 No.9

2018

中国科学院生态环境研究中心 主办

斜 学 出 版 社 出版



ENVIRONMENTAL SCIENCE

第39卷 第9期 2018年9月15日

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我国典型潮间带沉积物-水界面无机氮源汇效应

聂家琴^{1,2}, 王东启^{1,2*}, 陈杰^{1,2}, 李杨杰^{1,2,3}, 陈妹^{1,2}, 陈振楼^{1,2}

(1. 华东师范大学地理科学学院, 上海 201100; 2. 地理信息科学教育部重点实验室, 上海 201100; 3. 国家海洋局第二海洋研究所, 杭州 310012)

摘要: 以中国东部沿海 12 个典型潮间带为研究对象,通过室内模拟测定了潮间带沉积物-水界面硝酸盐(NO_3^-)和氨氮(NH_4^+)的源汇通量,分析了沉积物对上覆水体无机氮源汇效应的空间分布特征,以及环境因子的影响。结果发现:① NO_3^- -N的总通量范围是 $-2.91 \sim 3.34$ mmol·($m^2 \cdot h$) $^{-1}$, NH_4^+ -N的总通量范围是 $-4.36 \sim 2.34$ mmol·($m^2 \cdot h$) $^{-1}$. 12° C和 35° C温度下,无机氮的平均值是 -0.04 mmol·($m^2 \cdot h$) $^{-1}$,我国东部典型潮间带沉积物表现为氨氮和硝氮的有效汇库。② 潮间带的硝氮和氨氮通量存在纬度分异。 12° C时,纬度越高,氨氮硝氮通量值越大; 25° C和 35° C时,潮间带硝氮通量值大小随纬度的变化为, $25^{\circ} \sim 35^{\circ}$ N $<15^{\circ} \sim 25^{\circ}$ N $<35^{\circ} \sim 45^{\circ}$ N. 而氨氮通量值, $25^{\circ} \sim 35^{\circ}$ N $>15^{\circ} \sim 25^{\circ}$ N $>35^{\circ} \sim 45^{\circ}$ N. ③ 温度通过影响硝化反硝化的耦合作用影响无机氮通量。潮间带的 NO_3^- -N通量随温度的增加而减小, $15^{\circ} \sim 25^{\circ}$ N 和 $35^{\circ} \sim 45^{\circ}$ N 地区 NO_3^- -N通量随温度 先升高再降低, $25^{\circ} \sim 35^{\circ}$ N 地区 NO_3^- -N通量随温度一直减小。每个纬度区,温度越高, NH_4^+ -N通量值越低。④ 上覆水体的盐度、沉积物总有机碳(TOC)、总氮(TN)含量,孔隙水氨氮、硝氮浓度,容重等环境因子对通量没有单一的显著影响,协同影响 NO_3^- -N、 NH_4^+ -N在潮滩沉积物水界面的空间分异。

关键词:潮间带;无机氮通量;空间分布;温度;沉积物水界面

中图分类号: X52 文献标识码: A 文章编号: 0250-3301(2018)09-4199-07 DOI: 10.13227/j. hjkx. 201712094

Simulation of Inorganic Nitrogen Fluxes at the Sediment-water Interface in a Typical Intertidal Zone, Eastern China

NIE Jia-qin^{1,2}, WANG Dong-qi^{1,2*}, CHEN Jie^{1,2}, LI Yang-jie^{1,2,3}, CHEN Shu^{1,2}, CHEN Zhen-lou^{1,2} (1. School of Geographic Sciences, East China Normal University, Shanghai 201100, China; 2. Key Laboratory of Geographic Information Science of the Ministry of Education, East China Normal University, Shanghai 201100, China; 3. Second Institude of Oceanography, State Oceanic Administration, Hangzhou 310012, China)

Abstract: Taking 12 typical intertidal zones along the eastern coast of China as the research object, indoor tide simulation experiments were conducted to measure exchange fluxes of nitrate nitrogen (NO_3^--N) and ammonia nitrogen (NH_4^+-N) between overlying water and sediments, to investigate their spatial distribution, and to clarify controlling factors such as salinity, temperature, and organic matter. Results showed that the total NO_3^--N flux was -2.91-3.34 mmol·($m^2\cdot h$)⁻¹, while the total flux of NH_4^+-N was -4.36-2.34 mmol·($m^2\cdot h$)⁻¹. The average flux, at 12° C and 35° C, was -0.04 mmol·($m^2\cdot h$)⁻¹, indicating that typical intertidal zone sediment is an effective sink for ammonia nitrogen and nitrate nitrogen. There was a significant difference in the spatial distribution of nitrate and ammonia nitrogen fluxes. At 12° C, the higher the latitude, the greater the ammonia nitrogen flux; results for the $25^{\circ}-35^{\circ}N$ intertidal nitrate flux were as follows: $<15^{\circ}-25^{\circ}N <35^{\circ}-45^{\circ}N$ at 25° C and 35° C, while the flux of ammonia nitrogen was $25^{\circ}N-35^{\circ}N > 15^{\circ}-25^{\circ}N > 35^{\circ}-45^{\circ}N$. The fluxes of the three intertidal zones decreased with increase in temperature, which controls the coupled nitrification-denitrification taking place in the upper layer of sediment and at the bottom of overlying water. NO_3^--N fluxes first increased and then decreased with temperature at $15^{\circ}-25^{\circ}N$ and $35^{\circ}-45^{\circ}N$, while NO_3^--N fluxes at $25^{\circ}-35^{\circ}N$ always decreased with temperature. At each latitude, the higher the temperature, the lower the NH_4^+-N flux. There was no single significant effect of environmental factors on fluxes. Salinity, sediment organic carbon (OC), sediment total nitrogen (TN), concentrations of ammonia nitrogen and nitrate nitrogen in pore water, and bulk density synergistically affected the spatial distribution; temperature; sediment-water interface

潮间带是海陆交替的过渡地带之一,在削减人海径流的营养元素的过程中扮演重要角色[1].同时由于污染而不断累积和元素再循环,潮滩沉积物又可能变成次生污染源,加剧海岸带和河口区的富营养化[1~3].近年来,随着人口和经济迅猛增长,我国河口和近海区水体富营养化加剧,许多学者在我国各个河口和潮间带开展了大量的氮素循环研

究^[1,4~6],分析和讨论了环境因子,如 TOC、TN、盐度、季节、沉积物形态、温度等的影响,以及控制

收稿日期: 2017-12-12; 修订日期: 2018-03-13

基金项目: 国家自然科学基金项目(41473094, 41671467); 科技部

科技基础性工作专项(2014FY210600)

作者简介: 聂家琴(1992~), 女, 硕士研究生, 主要研究方向为湿地生物地球化学, E-mail;770459396@ qq. com

* 通信作者,E-mail:dqwang@geo.ecnu.edu.cn

机制^[7~10],其中沉积物-水界面氮通量是评价潮滩 削减或增加水体污染的重要指标.

陈振楼等^[4]对长江口不同地区潮间带的研究发现,河口区上下游沉积物-水界面NO₃-N通量的季节变化明显,且无机氮通量受 TOC、沉积物粒度、水温等因素的综合影响。王东启等^[5]研究崇明东滩沉积物不同盐度上覆水体发现,盐度影响潮滩沉积物中微生物的生理活动,进而影响NH₄⁺-N的通量变化。Koomklang等^[6]对日本的 Shido Bay 研究发现,沉积物表层会向上覆水体释放更多NH₄⁺-N,温度越高,沉积物越表现为上覆水体释放更多NH₄⁺-N,温度越高,沉积物越表现为上覆水体NO₃⁻-N的汇,NH₄⁺-N的源。Hopkinson等^[12]对 Massachusetts 和 Cape Cod 海湾的研究发现,温度和呼吸作用是影响沉积物水界面无机氮通量的主要因素,而不是有机碳、沉积物类型等其他环境因素。

本文选取了中国东部典型海岸带潮间带为研究 对象,通过实验室微环境模拟,探讨了不同温度条 件下,中国东部海岸不同纬度地区潮间带沉积物-水界面无机氮交换特征,分析了对不同纬度潮间带 沉积物对上覆水体无机氮的源汇特征,以及温度、 盐度、沉积物类型等环境因子的影响,以期对不同 纬度地区潮滩的污染治理、环境管理和生态保护提 供数据支持.

1 材料与方法

1.1 样品的采集

沿着中国东部海岸线由北向南分别选取了12 个典型潮间带, 辽宁大辽河口(LH)、天津汉沽涧 河河口(HG)、山东东营黄河口(DY)、山东青岛大 沽河(QD)、江苏盐城浅滩(YC)、上海崇明岛东滩 (DT)、浙江慈溪(CX)、福建福州闽江口(FZ)、厦 门九龙江口(JL)、广东珠江口(ZJ)、广西英罗湾 (YL)、海南东寨港(DZ). 选定滩面底质类型相对 均匀、潮间带完整、人为扰动较小且相对稳定的潮 间带区域进行取样. 各采样区域分布如图 1 所示, 12个典型潮间带南北纬跨度大,包含温带季风气 候区和亚热带季风气候区. 综合了沉积物类型、发 育特点、植被类型的典型潮间带, 每个潮间带区域 设1~4个采样站, 总共26个采样站, 每个采样站 2~3个平行样,使用自制的螺旋盖有机玻璃管采 集了沉积物原位柱样样品 67 个, 并用盐度计(YSI 30) 现场测定上覆水体的盐度.

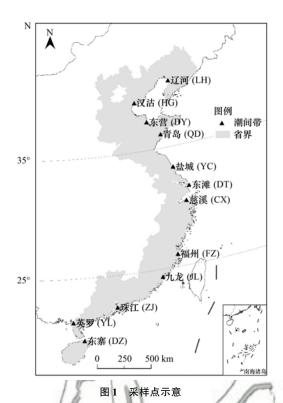


Fig. 1 Map showing distribution of sampling sites

1.2 实验室培养

野外样品采集后在实验室冷藏保存,并根据各 地海水的实测盐度值配置人工海水(氯化钠、氯化 镁、硫酸镁、氯化钙、碳酸氢钠、氯化钾),同时使 用硝酸钠(NaNO₃)和氯化铵(NH₄Cl)将人工海水氮 浓度配置为硝酸盐氮(NO3-N)2 mg·L-1 和氨氮 (NH₄+-N)0.5 mg·L⁻¹. 使用恒温培养箱,设定了3 个温度的培养(12、25、35℃). 在每个温度下,用 新配置的海水模拟潮汐淹没和出落过程, 首先对柱 样进行预培养2d(以6h为间隔,人工向培养管中 注入和倒出人工海水,操作过程中控制水流,减少 柱样表层的扰动. 2 d 后,向每个培养管里注满对 应盐度的海水,测定培养初始的水体溶解氧(DO) 数值后盖上丁基胶塞, 使之没有气泡, 再拧上双螺 旋盖子. 并采集各培养管对应的海水作为初始水样 50 mL. 培养6 h 后, 打开密封盖, 测定培养后水体 DO 值, 然后从每个培养管中采集培养后水样各 50 mL. 培养的初始水样和培养后水样经 0.45 μm 滤 膜过滤后编号储存聚乙烯瓶中冷冻(-20℃)保存, 用以测定 NO; 和 NH; 浓度. 培养后的沉积物柱样 按照1 cm 分层切片, 其中一根柱子的每个分层样 品放入100 mL 离心管,加入50 mL 超纯水振荡混 合后离心, 再经过 0.45 μm 滤膜过滤后编号储存聚 乙烯瓶中冷冻(-20℃)保存, 用以测定和计算孔隙 水中 NO_3^- 和 NH_4^+ 浓度; 再取一根柱子按照 1 cm 分层切片后 60° 烘干, 干湿分别称重测含水率、容重, 烘干土样研磨过筛后待测 TOC 与 TN.

1.3 样品分析和计算

1 /n/

水样 NO_3^- 浓度用流动化学分析仪 (INTEGRAL FUTURA, ALLIANCE 公司, 美国) 测定, 用次溴酸盐氧化法测定水体中 $NH_4^{+[13]}$. 沉积物总有机碳和总氮用元素分析仪(Elementar vario MICRO cube, 德国) 测定. 沉积物-水界面氮交换通量根据上覆水体培养前后 N 浓度的变化计算得出扩散通量:

$$F = \frac{M_t}{S \times t}$$

式中, F 是在 t 时间段内平均测得的沉积物-水界面扩散通量[mmol·(m²·h) -1]; S 是有机玻璃管中沉积物的截面积(m²); t 是引起上覆水体中物质浓度差的时间(h). M_t 是 t 时间段内上覆水体物质的变化量(mmol),可通过上覆水体浓度变化计算 M_t :

$$M_{t} = V_{t} \cdot (c_{t} - c_{0})$$

式中, c_t 是经过 t 时间后上覆水体中物质的浓度 (mmol·L⁻¹), c_0 是上覆水体中物质的初始浓度

(mmol·L⁻¹), V, 是上覆水体的体积(L).

沉积物容重用一定容积的土壤烘干后的重量与 同容积水重的比值表示.

2 结果与分析

2.1 潮滩沉积物和上覆水体的理化性质

中国东部海岸线绵长,盐度差异较大,盐度最大值在青岛大沽河和海南东寨港,最低值在上海崇明东滩;同一片潮滩不同的样站盐度也不尽相同,差异最大的是青岛大沽河,同一潮间带两个样站的盐度差达到 29%。各潮滩表层 5 cm 沉积物的有机碳含量迥异,其中平均值在 5%以下和 10%以上的各有 3 个河口,分别是黄河口、盐城、慈溪,天津涧河河口、九龙江口和珠江口,相差最大的是在福州闽江口,差 5.36%。,除闽江口、崇明东滩外其它同一潮间带不同样站间的有机质差异都小于 2%。平均容重约为1.17 g·cm⁻³,大部分容重处于0.9~1.1 g·cm⁻³和1.3~1.5 g·cm⁻³之间,容重和有机质之间呈现负相关关系。在 35℃条件下沉积物孔隙水中氨氮和硝氮平均浓度高于 15℃条件下.潮间带沉积物的具体理化参数见表 1.

表 1 潮间带沉积物的理化性质1)

61	100	l)	Table 1	Physicochemical pro	operties of sedin	nents		~ J
亚 米上	盐度/%。	TOC /6/	TENL (CL.	OVE	孔隙水池	程度/mg·L⁻¹	V /	容重
采样点	鱼)支/%0	TOC/‰	TN/‰	氨氮(15℃)	氨氮(35℃)	硝氮(15℃)	硝氮(35℃)	/g·cm ⁻³
LH-1	24. 6	9. 94	0. 23	ND ND	ND	ND	0.36	1. 05
LH-2	11.0	8. 00	0. 34	0. 04	0. 20	0. 10	ND	1. 36
HG-1	24. 5	10.04	0. 40	0.04	ND	0. 12	ND	0.76
HG-2	16. 6	10. 57	0.60	0.05	0.01	0. 20	0.37	0.83
DY-1	22. 2	3.43	0.06	0. 01	0.01	0. 07	0.11	1.46
DY-2	26.0	2. 19	0.09	0. 03	0.05	0. 15	0.32	1.40
QD-1	11.0	8.06	0.40	0. 17	0. 39	0. 22	ND	1.06
QD-2	40.0	9. 88	0.65	0. 20	0. 28	0. 16	0.17	1. 27
YC-1	25.0	2. 59	0.08	0. 16	0. 18	0.08	ND	1.02
YC-2	25.0	3. 29	0.08	0. 36	ND	0. 28	ND	1.43
YC-3	25.0	6. 73	0.04	0. 35	ND	0.08	ND	1.69
DT-1	1.0	10. 12	0.38	ND	ND	0. 16	0.03	0.96
DT-2	5.0	8. 23	0.42	ND	ND	0.08	ND	1.34
DT-3	5.0	7. 87	0.42	ND	0.03	0.08	0.02	1.37
DT-4	10.0	11. 73	0.42	0. 23	ND	0.08	ND	0. 26
CX-1	10.0	3. 33	0.47	ND	ND	0.01	0.07	1.30
CX-2	10.0	4. 79	0. 27	ND	ND	0. 03	0.04	1.38
CX-3	10.0	5. 94	0. 27	ND	ND	0. 11	0.05	1.41
FZ-1	20.0	5. 95	0.06	ND	0.48	0. 24	ND	1. 37
FZ-2	18. 3	11. 31	0.71	0.01	0.01	0. 18	0.87	1.02
JL-1	29. 3	12. 82	0. 70	ND	ND	0. 20	ND	1. 03
JL-2	16. 4	11. 53	0.64	ND	ND	0. 25	1.52	0.90
ZJ-1	16. 3	12. 98	0. 89	ND	0.82	1. 34	0. 18	0. 91
ZJ-2	16. 3	13. 07	0.90	ND	0.04	ND	ND	0. 94
YL	29. 3	7. 09	0. 12	0.06	0. 15	0. 16	1.76	1. 43
DZ	40. 0	6. 67	0. 18	0. 09	0. 23	0. 16	0.55	1. 52

¹⁾ ND 表示低于仪器检测限, 未检出

根据中国东部海岸带纬度跨度,将12个潮间 带区域按纬度由北到南分成3个区域(LH、HG、 DY、QD 采样站在 35°~45°N 纬度带内, YC、DT、 CX、FZ 采样站在25~35°N 纬度带内, JL、ZJ、YL、 DZ 采样站在 15°~25°N 纬度带内). 本研究表明培 养温度为 12℃时, 各采样点的NO; -N通量范围是 -1.83 ~ 2.65 mmol·(m²·h)⁻¹, 平均值是 0.39 mmol·(m²·h)⁻¹, 沉积物主要表现为NO₃-N的源, 但其中 YC-2、YC-3、CX-3、JL-1 和 ZJ-2 样站沉积 物是上覆水体的汇. 总体来看, 纬度越高通量值越 大, 沉积物越表现为上覆水体NO, -N通量的源(图 2). 培养温度为25℃时和12℃一样, 沉积物主要表 现为上覆水体的源,其中平均通量大小为 0.54 mmol·(m²·h)⁻¹, 各采样点的通量在 - 1.29 ~ 3.34 mmol·(m²·h)⁻¹之间,通量值显示在 25°~35°N 区 间最低,其他两个纬度区间的NO;-N通量平均值相 比于 12℃和 35℃都较高. 35℃平均通量为 - 0.13 mmol·(m²·h)⁻¹, 沉积物表现为上覆水体NO₃-N通 量的汇. 各采样点的通量变化范围是 - 2.91 ~ 0.14 mmol·(m²·h)⁻¹, 其中LH-1、YC-2、YC-3、DT-1、 CX和JL的潮滩沉积物是上覆水体NO, -N通量 的汇.

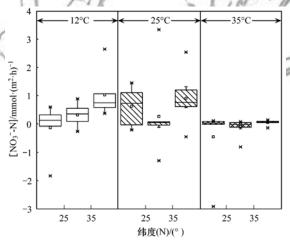


图 2 硝氮通量与温度和纬度的关系

Fig. 2 Relation between NO_3^- -N flux and temperature and latitude

2.3 潮间带沉积物-水界面NH₄ -N通量

培养温度为 12° C 时,各采样点的 NH_4^+ -N通量范围是 $-0.80 \sim 2.34 \text{ mmol} \cdot (\text{m}^2 \cdot \text{h})^{-1}$,平均值是 $0.33 \text{ mmol} \cdot (\text{m}^2 \cdot \text{h})^{-1}$,沉积物主要表现为 NH_4^+ -N的源,但 $15^{\circ} \sim 25^{\circ}$ N 纬度区内除 DT 样站外其他样站的沉积物都表现为水体的汇. 低纬度区 $15^{\circ} \sim 25^{\circ}$ N

(图 3)间的潮间带沉积物总体表现为上覆水体的汇,35°~45°N和25°~35°N纬度带内的潮间带沉积物表现为上覆水体的源.25℃时由于样品量较少,主要测的是盐城浅滩、崇明东滩和杭州湾,各采样点的通量在 $-0.65~0.24~\text{mmol}\cdot(\text{m}^2\cdot\text{h})^{-1}$ 之间,平均值为 $-0.31~\text{mmol}\cdot(\text{m}^2\cdot\text{h})^{-1}$,除 CX的2个样站外,其它样站都表现为 NH_4^+ -N通量的汇.35℃各采样点的通量大多是负通量,变化范围在 $-4.36~1.72~\text{mmol}\cdot(\text{m}^2\cdot\text{h})^{-1}$ 间,平均交换通量为 $-0.71~\text{mmol}\cdot(\text{m}^2\cdot\text{h})^{-1}$,沉积物基本表现为 NH_4^+ -N的汇,只有FZ的样站沉积物依旧表现为上覆水体的源.35°~45°N和25°~35°N纬度区的潮间带的 NH_4^+ -N通量都从正值变成负值,也就是沉积物的角色随着温度的升高由源向汇转变.

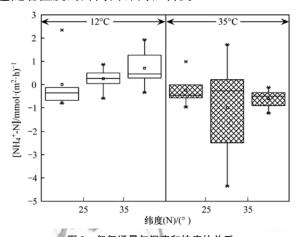


图 3 氨氮通量与温度和纬度的关系

Fig. 3 Relation between NH₄⁺-N flux and temperature and latitude

2.4 潮间带沉积物对上覆水体无机氮源汇效应

以水体 NO_3^- 和 NH_4^+ 之和作为溶解无机氮, 12° 和 35° 下 的 界 面 总 平 均 值 为 -0.04 mmol· $(m^2 \cdot h)^{-1}$,表明我国东部 12 个典型潮间带沉积物总体上是水体无机氮的有效汇库. 其中 NO_3^- -N通量平均值是 0.12 mmol· $(m^2 \cdot h)^{-1}$,潮间带沉积物表现为上覆水体 NO_3^- -N的源, NH_4^+ -N通量平均值是 -0.19 mmol· $(m^2 \cdot h)^{-1}$,潮间带沉积物表现为上覆水体 NO_3^- -N的源, NH_4^+ -N通量的源,平均值是 -0.36 mmol· $(m^2 \cdot h)^{-1}$; 35° 时潮间带沉积物是上覆水体 NO_3^- -N和 NH_4^+ -N通量的汇,平均值是 -0.42 mmol· $(m^2 \cdot h)^{-1}$. 温度越高,潮间带沉积物越表现为上覆水氨氮和硝氮通量的汇,不仅潮间带间沉积物水界面 NO_3^- -N和 NH_4^+ -N通量空间差异很大,同一潮间带不同潮滩样站 NO_3^- -N和 NH_4^+ -N通量值和变

化也不同步, 界面迁移变化十分复杂.

由图 2、图 3 可见潮间带的NO $_3^-$ -N和NH $_4^+$ -N通量空间分布都存在显著分异. 12℃时,纬度越高,潮间带NH $_4^+$ -N、NO $_3^-$ -N通量值越大;25℃和35℃时,NO $_3^-$ -N通量值随纬度变化表现为25°~35°N < 15°~25°N <35° N,而NH $_4^+$ -N通量值是25°~35°N > 15°~25°N 和35°~45°N,在不同温度下,15°~25°N 和35°~45°N 纬度区潮间带的NO $_3^-$ -N通量随温度先升高再降低,25°~35°N 地区潮间带NO $_3^-$ -N通量值随温度一直减小,各个纬度区的NH $_4^+$ -N通量均表现为温度越高,通量值越低;35℃时,35°~45°N 纬度区潮间带通量值降低最多. NH $_4^+$ -N通量和NO $_3^-$ -N通量最小值均出现在盐城苏北浅滩,说明苏北浅滩潮间带沉积物是上覆水体无机氮的高汇.

3 讨论

3.1 典型潮间带无机氮交换通量和其他河口潮间带对比

本研究中得出的通量值落于各个潮滩通量值范

围内,数量级相同(表2),和已有的相关研究结果进行对比可知,崇明东滩的NH₄⁺-N通量范围最小值是陈振楼等^[4]研究的 3 倍,NO₃⁻-N通量范围和他们的范围较为一致;黄河口地区的NH₄⁺-N、NO₃⁻-N通量都在李玲玲^[14]的数据范围内,且都是表现为NO₃⁻-N偏向于源,氨氮是低汇;闽江口潮间带的通量略高于林贤彪等^[7]的研究,且NH₄⁺-N、NO₃⁻-N都表现为低源;珠江口潮间带的研究结果和本实验数据基本一致.不同的潮间带无机氮通量值差异较大(表2),同一潮间带盐度、容重、有机质含量等环境条件也存在差异(表1),需控制变量,研究单一因子的影响.同时不同潮间带横向比较时,量化部分环境条件数值.

3.2 温度对潮间带无机氮交换通量的影响

温度可以促进微生物的成长与代谢,也会影响上覆水体中的含氧量. 刘素美等[19] 研究发现有氧条件下有机质的降解作用消耗很少的 NH_4^+ ,产生大量 NO_3^- ;缺氧条件下有机质的分解作用消耗大量 NO_3^- ,产生少量 NH_4^+ . Koriyama 等[18] 和 Ozkan 等[20] 的研究发现硝化和反硝化的耦合可能发生在

表 2 世界各地河口潮间带沉积物-水界面无机氮通量对比/mmol·(m²·d)⁻¹
Table 2 Comparison of exchange fluxes of inorganic nitrogen at the sediment-water interface between different intertidal zones and estuaries across the world/mmol·(m²·d)⁻¹

地点	NH ₄ -N	NO ₃ -N	NO ₂ -N	文献
黄河口, 中国	- 9. 16 ~6. 94	− 22. 80 ~ 144. 00	-1.20 ~2.10	[14]
长江口,中国	−18.45 ~10.65	−32.82 ~24.13	− 1. 15 ~ 2. 82	[4]
闽江口,中国	-4. 11 ∼ 0. 44	<i>−</i> 2. 17 <i>~</i> 1. 44	- 0. 15 ~ 0. 17	[7]
珠江口, 中国	<i>−</i> 1. 32 <i>~</i> 0. 99	$-0.56 \sim 0.47$	-1.52 ~0.14	[15]
胶州湾, 中国	$-0.41 \sim 48.00$	$-2.00 \sim 2.80$	<i>−</i> 0. 05 <i>∼</i> 6. 20	[16]
St. Lawrence Estuary, 加拿大	0. 65 ~ 2. 18	-2.29	~0. 69 ¹⁾	[11]
Douro River estuary, 葡萄牙	0. 67 ~ 23. 47	0. 96 ~ 19. 44	$0.02 \sim 3.07$	[17]
Shido Bay, 日本	0. 075 ~ 9. 83	/2)	/	[6]
Northern Galician Rias, 西班牙	$-0.132 \sim 3.01$	- 0. 95 ∼ 1. 16	$-0.006 \sim 0.21$	[18]
12 个东部潮间带,中国	<i>−</i> 52. 32 ~ 28. 08	− 34. 92 ~ 40. 08	/	本研究

1) "-2.29~0.69"表示"NO₃-N+NO₅-N"的通量总和; 2) "/"表示文章中没有该数值

沉积物的上层. 程勋亮等^[21]的研究发现温度、上覆水体盐度、孔隙水中氨氮和有机质显著影响 NH₄* 界面通量,温度和孔隙水中NO₃-N浓度显著影响 NO₃* 界面通量. 温度的升高直接带来溶解氧的减少^[21],而硝化和反硝化过程都依赖于温度^[22, 23].

室内模拟实验结果表明,温度和无机氮通量呈负相关关系(图 4), NH_4^+ -N通量和温度的关系最为显著,其他因素和通量之间没有显著相关性,这与Hopkinson等[12]的研究结果一致. 12° 时硝化微生物的活性较低,使得沉积物呈现为上覆水体 NH_4^+ -N

通量的弱源. 培养温度为 25℃时,有机质的矿化作用虽在增强^[18],但硝化细菌的活性增强仍使得硝化作用起主要影响;温度再增加微生物活性进一步增强,NH₄⁺-N主要转化成为NO₂⁻-N和NO₃⁻-N的形式^[24],最终随着温度的升高,NH₄⁺-N通量降低甚至变成负值,沉积物由源变成上覆水体的NH₄⁺-N通量汇.

NO₃-N的界面通量和反硝化作用密切相关,受到硝化-反硝化耦合的影响^[7,25].温度可以通过改变微生物活性而抑制或加速沉积物中不同形式氮的

释放速率^[25],反硝化作用随着温度升高,溶解氧降低,微生物活性增强,通量低温时高,高温时低^[9,20]. 12° 温度较低时,沉积物氧化层和上覆水体的底部会迅速发生硝化反应产生中间产物 NO_2^- -N,进而产生 NO_3^- -N^[26]. 随着温度的升高,溶解氧(OD)的减少^[26],反硝化作用越来越强,最终沉积物变成上覆水体的汇^[4]. 35° C时各纬度 NO_3^- -N通量都趋近于 0,因高温促进反硝化作用,温度越高,上覆水体的溶解氧含量越低^[27,28],厌氧环境又会抑制硝化反应的进行。其中 25° ~ 35° N 地区 NO_3^- -N通量平均值远远低于其他两个纬度区的 NO_3^- -N通量。目前全球变暖的背景下,海岸带可能对于去除上覆水体氮负荷具有更大的潜力和贡献。

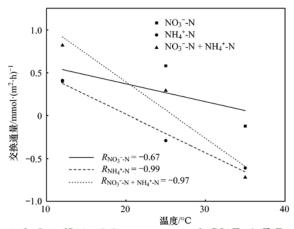


图 4 沉积物-水界面无机氮交换通量与温度的相关性 Fig. 4 Correlation between temperature and NO₃⁻-N, NH₄⁺-N and NO₃⁻-N+NH₄⁺-N flux across the sediment-water interface

4 结论

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- (1) 中国东部海岸带潮间带沉积物-水界面 NO_3^- -N 的 总 通 量 范 围 是 $-2.91 \sim 3.34$ $mmol\cdot(m^2\cdot h)^{-1}$, NH_4^+ -N的总通量范围是 $-4.36 \sim 2.34$ $mmol\cdot(m^2\cdot h)^{-1}$. 潮间带沉积物表现为上覆水体无机氮的有效汇库 -0.04 $mmol\cdot(m^2\cdot h)^{-1}$.
- (2)无机氮通量存在明显的空间分异,纬度位置越高,无机氮通量值越大,其中25~35°N潮间带沉积物可能受人类活动影响较大,因此无机氮的通量变化更为复杂.
- (3)温度是影响潮间带无机氮通量的决定性因素,温度越高,沉积物越表现上覆水体无机氮通量的汇.其他环境因素如沉积物容重、孔隙水氨氮硝氮、溶解氧、总氮、总有机碳、盐度各影响因素综合作用使得无机氮空间差异明显.

致谢:感谢课题组汪萌、陈璐娟、许运凯、常思

琪、俞林等在采样和实验方面提供的指导和帮助. 参考文献.

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Environmental Science (monthly)

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