Denitrification in tidal flat sediment, Yangtze estuary

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Sediment denitrification rates at six Yangtze River estuary tidal flat locations (mudflats and salt marshes) were measured from July 2003 to October 2004. In winter and summer, spatial distribution of denitrification rates was not great in the Yangtze estuary, while in spring and autumn, denitrification rates had a great spatial distribution because of the human activity effect. The temporal change of denitrification rates was greater. They ranged from 0.2 to 36.4 μmolN·m−2·h−1, and were higher in the summertime. The annual average of sediment denitrification rate was 18.2±12.3 μmolN·m−2·h−1 in the middle tidal flat and 15.1±9.45 μmolN·m−2·h−1 in the low tidal flat in the Yangtze estuary. Data analysis indicated that the temperature was the primary factor controlling the process of denitrification (significant positive correlation, P<0.01); at the same time, the content of sediment total nitrogen (TN) and the molar ratio of sediment carbon and nitrogen (C/N) had significant positive correlation (P<0.05) and negative correlation (P<0.05) with denitrification rates, respectively. In the Yangtze estuary, increasing of water salinity had no significant inhibition of denitrification because of the wide change range of water salinity.

Yangtze estuary, tidal flat sediment, denitrification, effect factors

Nitrogen is one of the most important elements in life-cycle processes, and a necessary nutrient of natural biology. Since the advent of the industrial revolution, the biogeochemical cycling of nitrogen has changed significantly. Nitrogen emitted from combusting fossil fuels and utilizing synthetic nitrogen fertilizers is as great as the nitrogen fixed by bacteria in natural ecosystems[1]. Nitrogen created as a result of human activities has increased nine-fold between 1890 and 1990, with most of that increase taking place in the second half of the century in association with increased use of fertilizers. Since 1960, the amount of reactive (biologically available) nitrogen in global ecosystems has increased sharply[2]. A recent study of global human contributions to reactive nitrogen flows projected that flows will increase from approximately 1.65×1014 g of reactive nitrogen in 1999 to 2.70×1014 g in 2050[3]. Nitrogen cycling imbalance has become a serious environmental problem in the world, with some researchers reporting that the biodiversity of grass land ecosystem has decreased quickly because of nitrogen pollution[4], and it would be even preignite the sixth biology extinguishment[5].

Denitrification is a key process of nitrogen recycling, taking place in the condition of anoxia when denitrifying bacteria convert nitrate (NO3−), one of the main activity nitrogen, into biologically unavailable nitrogen (N2) and a small proportion of nitrous oxide (N2O). Because the end product of the denitrification process is N2, a gas that is abundant in the earth’s atmosphere, denitrification may be considered the most desirable means to removing nitrate pollution from the environment and plays a key role in keeping nitrogen balanced among the lithosphere, hydrosphere, biosphere, and atmosphere. Fur-
thermore, because denitrification removes NO$_3^-$ from the environment as N$_2$, a gas which is abundant in the earth’s atmosphere and is inert, chronic N inputs will not cause this sink to become saturated with nitrogen$^6$.

Global flux of nitrogen to estuarine and coastal areas increases year by year, and growing nitrogen loads lead to eutrophication in these areas. Riverine transport of nitrogen into estuaries and coastal seas is widely recognized as a concern$^7$. Especially in the northern hemisphere, the level of nitrogen transported into estuaries has increased several times$^3$. Estuarine wetlands are a natural barrier in purifying terrestrial pollutants and attenuating riverine pollution loads to the sea$^8$. Estuarine wetlands are a key role in controlling marine eutrophication and global nitrogen recycling$^9$. It has been estimated that estuarine sediment could eliminate 10%—60% of terrestrial nitrogen$^{10}$, with denitrification as an especially important process achieving this reduction$^{11}$.

In the past decades, accompanying extensive economic development, a great deal of point and non-point nutrients has been transported into estuarine areas by Yangtze River flow. NO$_3^-$ concentrations have increased several times. In 1963, the NO$_3^-$-N concentration of Yangtze estuary water was only about 16 µmol/L$^{12}$, while in 1980 it reached 65 µmol/L. Although NO$_3^-$-N concentration fluctuated in the past twenty years, it also increased as a whole during the past twenty years$^{13}$. Especially in recent years, NO$_3^-$-N concentrations have increased steadily$^{14}$, and average nitrogen concentrations in coastal water (NO$_3^-$-N: 129.74 µmol/L; NH$_4^+$-N: 16.39 µmol/L; NO$_2^-$-N: 3.12 µmol/L) were higher than estuary water because of civil sewage discharges$^{10}$. The frequency and area coverage of algal blooms, an indicator of eutrophication have increased year after year$^{15}$. Many researches had taken on the nitrogen flux of Yangtze River flows$^{16}$. They were focused on nitrogen exchange fluxes through the sediment-water interface$^{10}$, the geochemical behavior of sediment nitrogen$^{17}$, and the effect of environmental factors$^{18}$, bio-factors$^{19}$, tidal flat sediment resuspension processes$^{20}$, and coastal reclamation efforts$^{21}$ on the nitrogen exchange behavior at the sediment-water interface in Yangtze estuarine tidal flats. While there have been a few reports considering denitrification in Chinese coastal zones$^{22,23}$, the research of tidal flat sediment denitrification within the Yangtze estuary has just been launched$^{11,24}$. In this paper, several representative tidal flats were selected as research locations in order to: (i) investigate the temporal and spatial characteristics of denitrification in tidal flat sediments; (ii) analyze the effect of environmental factors on the rate of denitrification; and (iii) enlarge the range of the nitrogen denitrification and nitrogen biogeochemical cycling theory research work in Chinese estuarine and coastal areas.

1 Materials and methods

1.1 Study locations and sampling

Every year, several hundred million metric tonnes of sediment is transported into the Yangtze estuary, and because of this abundant sediment supply, the delta-front continues to extends seaward rapidly at an average rate of tens to hundreds of meters per year, forming estuarine islands and expanding tidal flats. Natural geomorphy and depositing zones are distinct. High, middle, and low tidal flats develop from the land to the sea. Usually, Phragmites communis thrives on the high tidal flat (marsh). On the middle tidal flat (marsh), Scirpus maritimus and Scirpus triqueter are the dominant plants, with continuous distribution across the ground. The low tidal flats are bare of macrophytes$^{10}$.

Six sampling locations were selected on both the north and south banks and island of the Yangtze estuary. Those locations were Yin-yang (YY), Chong-ming island (CM), Giu-lu (GL), Bai-long-gang (BLG), Chao-yang (CY), and Lao-gang tidal flat (LG) (see Figure 1). Samples were collected at all of the six locations in July 2003 and July 2004 to investigate the spatial distribution character of sediment denitrification. In addition, from July 2003 to July 2004, sampling was undertaken every two months on the CM tidal flat, and in winter, spring, summer, and autumn in 2004 at YY, GL, and BLG, respectively, in order to study the temporal (seasonal) change character of sediment denitrification. Two sampling sites were located at CM, CY, and LG; one was set on the middle tidal flat (salt marsh) as CM-M, CM-L, LG-M, and the other on the low tidal flat (bare flat) as CM-L, CY-L, LG-L. At the YY, GL, and BLG sites there were only low tidal flat (bare flat) sampling sites, because the salt marsh had disappeared due to coast reclamation.

Nine small intact sediment cores were collected at every sampling site, using perspex tubes, and sealed