Fate of Riverine Nitrate Entering an Estuary: I. Denitrification and Nitrogen Burial

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ABSTRACT: Fate of riverine nitrate entering a well defined turbid estuary receiving discharges from the Atchafalaya River, a distributary of the Mississippi River, was determined. Seasonal distribution of NO₃ and its transformations were measured in Four League Bay (9,300 ha). Denitrification was estimated by incubating wet samples in the presence of acetylene and monitoring N₂O production. The annual sediment accumulation of N was also determined within the bay and within the adjacent marshes. Nitrogen accumulation ranged from 6.0 to 23 gN per m² per yr on the marsh and 6.1 to 11.2 gN per m² per yr in the bay. Denitrification in this system was controlled by the availability of NO₃⁻ with fluxes ranging from 2 to 70 ngN per g per hr. The annual (N₂O + N₂)⁻N emission was equivalent to 142 and 120 µg per g or 2.1 and 1.7 gN per m² from the 5 bay and 5 marsh stations, respectively. Approximately 1.95 × 10⁶ kgN, predominantly as N₂, is being returned to the atmosphere via denitrification. We estimate this to be equivalent to 50% of the riverine NO₃⁻ entering this estuary. A significant amount was also assimilated within the estuary.

Introduction

The growth of the Atchafalaya delta is a major event in the development of the Mississippi River deltaic system. The delta growth has resulted from the steady diversion and capture of the Mississippi River flow by the Atchafalaya River (Van Heerden and Roberts 1980a, 1980b). Emergence of the delta has caused dramatic changes in the wetlands, inland waters and in the nearshore Gulf of Mexico. A small, high turbidity estuarine bay, Four League Bay, with well defined boundaries and extensive marshes, on the eastern side of Atchafalaya Bay was chosen for this study. Seasonal weather patterns, Gulf of Mexico tides, and riverine discharge are the dominant physical factors influencing this estuary. During the late fall and winter when wind direction is predominantly northerly, Four League Bay is under a freshwater influence. Gulf of Mexico waters play a more dominant role in the bay in the summer and early fall when the riverine discharge is decreased and southerly winds predominate, thereby increasing the salinity of the estuary.

Nitrogen occurs in estuarine waters in the form of NH₄⁺, NO₃⁻ and a wide range of organic species (Kemp et al. 1982). The ionic species NH₄⁺ and NO₃⁻ tend to predominate, and the intermediate NO₂⁻ is generally found only at low concentrations and is often undetectable. The objective of this study was to quantify the flux of riverine NO₃⁻ and determine the fate of NO₃⁻ in Four League Bay ecosystem. We hypothesize that denitrification is a major mechanism for NO₃⁻ removal from shallow turbid estuaries receiving riverine nitrate and that sedimentation serves as a major nitrogen sink. The magnitude of NO₃⁻ loss due to denitrification was estimated by monitoring N₂O production in the presence of acetylene. In addition we identify the role of the aggradation process of vertical accretion in serving as a nitrogen sink in the Four League Bay ecosystem.
Materials and Methods

STUDY AREA

The study was conducted in the bay and marshes surrounding Four League Bay, Louisiana, a shallow coastal bay with an area of approximately 9,300 ha. The bay is connected to the Gulf of Mexico at its southern end via Oyster Bayou and the northern end (Halter Island) opens into the northeastern section of Atchafalaya Bay (Fig. 1). Four League Bay receives riverine discharge from the Atchafalaya River, which carries approximately 30% of the lower Mississippi River flow into Atchafalaya Bay. The Atchafalaya River has been actively building a delta in the upper section of this bay since early 1970 (Roberts et al. 1980). As a result of the delta growth, an estimated $3 \times 10^9$ m$^3$ per yr of riverine water and suspended sediment flows into Four League Bay. Five sampling stations were established within the bay and on the adjacent marshes along a transect extending from Halter Island to Oyster Bayou (Fig. 1).

Sedimentation rates at each sampling station were determined using $^{137}$Cs dating (DeLaune et al. 1978). Total N content of the dated sediment profile was determined by Kjeldahl digestion (Bremner 1965). Density was determined from the weight of oven-dry sediment in the known volume of each section. The net accumulation of N was calculated from mean dry weight, concentration of N, the sedimentation rate and the bulk density (Hatton et al. 1982).

In the laboratory the effect of NO$_3^-$ concentration in the water on NO$_3^-$ disappearance and total denitrification was determined on a mixed sediment sample obtained from the 5 bay stations. Thirty grams wet sediment (12 g dry wt) was incubated with 60 cm$^3$ of 70 $\mu$M or 35 $\mu$M KNO$_3$ solution in the presence of 10 kPa acetylene. The initial concentrations of NO$_3^-$ in the incubation system were 50 and 25 $\mu$M, respectively. Total denitrification was determined by the acetylene inhibition technique (Smith and DeLaune 1983; Sorensen 1978a). Two cubic centimeters of acetylene saturated distilled water were injected at five locations in the sediment, while slowly withdrawing the needle through the sediment (Sorensen 1978b). The jars were sealed and acetylene gas (10% vol/vol) was added to the air space. The samples were destructively sampled after incubation for 2, 4, 8, 16, and 24 h at 25°C. Sampling consisted of shaking the samples for 10 min on a wrist arm shaker to allow equilibration of the N$_2$O dissolved in the water and the headspace gases. The headspace gases were immediately analyzed for N$_2$O on a Varian 3700 gas chromatograph equipped with a $^{63}$Ni electron capture detector (Smith and DeLaune 1983). The controls were a separate series of samples amended with acetylene but not incubated. Total denitrification was determined as the net N$_2$O production in acetylene amended samples. When the gas sampling was completed, the sediment in each incubation vessel was filtered and NO$_3^-$ in the filtrate determined spectrophotometrically following cadmium reduction (Strickland and Parsons 1972). All incubations were performed in triplicate.

Denitrification at each sampling station was estimated in the laboratory at 4–6 week intervals between March 1982 and May 1983 by incubating 30 g wet (12–15 g dry wt) surface (0–3 cm) sediment and 60 cm$^3$ of bay water. Surface sediment was obtained from the bay stations with a Peterson dredge.