Sources and History of Heavy Metal Contamination and Sediment Deposition in Tivoli South Bay, Hudson River, New York

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ABSTRACT: Persistent inorganic constituents preserved in sediments of aquatic ecosystems record temporal variability of biogeochemical functioning and anthropogenic impacts. $^{210}$Pb and $^{137}$Cs dating techniques were used to study the past variations of heavy metals (Pb, Cu, and Zn) and accumulation rates of sediments for Tivoli South Bay, in the Hudson River National Estuarine Research Reserve ecosystem. South Bay, a tidal freshwater embayment of the Hudson, may play an important role in the sediment dynamics of this important river. The measured sedimentation rate range of 0.59 to 2.92 cm yr$^{-1}$ suggests that rapid accumulation occurred during the time period represented by the length of the cores (approximately the past 50 yr). Direct measurements of sediment exchange with the Hudson River reveal high variability in the sediment flux from one tidal cycle to the next. Net exchange does not seem to be adequate to explain sediment accumulation rates in the bay as measured by $^{210}$Pb and $^{137}$Cs. The difference may be supplied from upland streams or the Hudson River during storm events. Concentrations of the metals Pb, Cu and Zn were found to be well correlated with each other within individual cores at five of six sites tested. This suggests a common proximate source for the three metals at a specific site. The evidence is consistent with mixing in some environmental compartment before delivery to the bay. While metals self-correlate within individual cores, absolute concentrations, depth distribution patterns, and ratios of the metals to each other vary among the cores collected at different locations within the bay. Organic matter, Fe content, and particle size distribution of sediments do not account for the intercore variations in metal concentration. It is likely that cores collected from different sites may have derived metals from different sources, such as watershed streams and tidal exchange with the Hudson River.

Introduction

Because of the complexity of biogeochemical cycling at the land-sea interface, our understanding of the behavior of contaminants in estuaries is far from complete. A better knowledge is desirable, since a large human population is concentrated in the narrow zone adjacent to the coast, making this an area of high ecosystem stress. Development within watersheds increases erosion and generates and mobilizes pollutants (Howarth et al. 1991). A key determinant of the fate of materials transported by streams and rivers is the behavior of detritus and particle-associated contaminants. Fine-grained
sediments control the transport and fate of toxic heavy metals and detrital organic carbon in estuarine ecosystems. For the Hudson River, little is known about the short-term dynamic behavior of these solids, and especially the potentially important role played by sediment exchange between shallow embayments and the river's main stem. Fine sediments are critical to estuarine ecosystem structure and function because of their role in blocking light, carrying toxic contaminants, and transporting detrital carbon, a key component of estuarine trophic webs.

Eroded and transported sediments are significant, not only because they are vectors of particle-reactive contaminants, but also because their accumulation in tidal embayments leads to shoaling that may require periodic dredging to maintain navigational channels. The commonly observed linkage between contaminants and fine-grained sediments can be especially problematic, since safe disposal of dredged materials is made more difficult. Understanding sediment dynamics in tidal systems such as wetlands and small embayments is important because they have been suggested as sites where natural purification of waters occurs through removal of suspended sediments, particle-associated contaminants, and nutrients.

The purpose of this investigation was to study the dynamics of sediment and associated metal contaminants deposited in Tivoli South Bay, Hudson River National Estuarine Research Reserve (Fig. 1). Prior research on pollutants in Hudson River sediments (Peller and Bopp 1986; Stevenson et al. 1986) has indicated that concentrations of trace metals have declined in recent years, but are still significantly above pre-industrial levels. Fringing marshes and shallow embayments are especially worthy of study, since they account for a disproportionate share, on an areal basis, of the accumulation of fine-grained sediments and the contaminants they carry. The current investigation benefits from, and contributes to, intensive research conducted at this site over the years. The geomorphology of Tivoli South Bay facilitates mass balance studies of material fluxes to shallow embayments since it connects to the main stem of the Hudson River through only three narrow openings. With the assistance of 210Pb and 137Cs dating techniques, we establish a chronology for sediments and associated pollutant metals, evaluate sediment accumulation rate and mixing processes, and provide understanding of transport of sediments and associated metals at this site.

**Study Site**

The Tivoli Bays are two neighboring tidal freshwater embayments of the Hudson River located approximately 160 km (100 miles) north of lower Manhattan, New York (Fig. 1). Each of the embayments is part of the Hudson River National Estuarine Research Reserve System. The south embayment, which is the focus of this study, covers approximately 113 ha along the east shoreline of the Hudson River. The average tidal range at the site is 1.2 m. Large areas of mudflats are exposed at the lowest tides, while a system of channels is always inundated. Tidal flow comprises approximately 90 percent of the annual water balance at the site (Lickus and Barten 1990). The principal source of non-tidal surface water inflow to South Bay is the Saw Kill, a stream which has a drainage area of approximately 68 km² and includes a broad range of land use-land cover categories (forested, wetland, agricultural, transportation, residential, and commercial).

Prior to and during early European settlement, the west side of Tivoli South Bay was open to the Hudson River. In 1851, construction of the East Shore line of the New York Central Railroad was completed (Carey and Waines 1984). The freight