

# Declining metal levels at Foundry Cove (Hudson River, New York): Response to localized dredging of contaminated sediments

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*Dredging of a hotspot of metal-contaminated sediment is associated with a recognizable local and river-wide decline in cadmium in the Hudson River, New York.*

## Abstract

This study examines the effectiveness of remediating a well-recognized case of heavy metal pollution at Foundry Cove (FC), Hudson River, New York. This tidal freshwater marsh was polluted with battery-factory wastes (1953–1979) and dredged in 1994–1995. Eight years after remediation, dissolved and particulate metals (Cd, Co, Cu, Pb, Ni, and Ag) were found to be lower than levels in the lower Hudson near New York City. Levels of metals (Co, Ni, Cd) on suspended particles were comparatively high. Concentrations of surface sediment Cd throughout the marsh system remain high, but have decreased both in the dredged and undredged areas: Cd was 2.4–230 mg/kg dw of sediment in 2005 vs. 109–1500 mg/kg in the same area in 1983. The rate of tidal export of Cd from FC has decreased by >300-fold, suggesting that dredging successfully stemmed a major source of Cd to the Hudson River.

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## 1. Introduction

The potential hazards of metal contaminants to humans and ecological systems are well-recognized (Gochfeld and Burger, 1998; Jarup, 2003; US EPA, 2004) and have promoted large-scale remediation efforts in a range of ecosystems. For example, in the United States, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as the “Superfund Act” of 1980, has focused attention and resources on identifying contaminants, their associated risks, and on developing technologies for cleaning and containing hazardous waste. However, while 25 years have passed since the inception of CERCLA, there is still

a small amount of objective data on the efficacy of remediation projects. These data are essential to guiding future projects, and for increasing our understanding of how chemical parameters affect biotic systems.

Remediation of benthic systems is primarily accomplished by dredging-removal of contaminated sediments with or without sediment replacement. The determined recovery status of a remediated site reflects both the particular system dynamics and response variables measured (Kelaher et al., 2003; Kemble et al., 2000; Schuwerack et al., 2001; Voie et al., 2002; Zajac and Whitlatch, 2001). Dredging itself is considered a major ecological disturbance to the benthic community and may affect sediment structure, and species diversity and richness (Kelaher et al., 2003). In many cases, this immediate ecological effect will be outweighed by the primary goal of removing pollutants from a locale where they pose a threat to human health.

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This study examines the effect of dredging on metal concentrations in Foundry Cove (FC), in the Hudson River, just south of Cold Spring, NY. Waste effluents containing large amounts of cadmium (Cd), cobalt (Co) and nickel (Ni) were released into the Cove by a battery factory from 1953 to 1979. Prior to remediation FC was the most Cd-polluted riverine site known (Förstner, 1984; Moore and Ramamoorthy, 1984). Large areas of the cove had sediment Cd concentrations of 10,000 mg/kg (Knutson et al., 1987). Contaminated sediments were removed without replacement from FC during two clean-up campaigns. In 1972–1973, 90,000 m<sup>3</sup> of sediments were removed by dredging, however, Cd concentrations were not significantly altered (Knutson et al., 1987). In 1994 under the auspices of the 1980 Superfund Act, the U.S. Environmental Protection Agency (EPA) began a larger-scale clean-up. The upper 30 cm of sediment was removed from across the entire main body of FC (an area referred to as ‘Eastern Foundry Cove’ in reports); the highly contaminated factory outfall was dredged and capped with gravel (US EPA, 1989, 1998).

Considering both the direct ecological impacts and considerable financial costs of dredging operations, further studies are required to document the effectiveness of this strategy in removing toxicants, as well as resulting ecosystem effects. The unusual history of FC has made it a useful site for studying the ecological and genetic effects of Cd toxicity (Klerks and Levinton, 1989; Levinton et al., 2003; Martinez and Levinton, 1996) and the ecological and evolutionary effects of removing contaminated sediments (Kelaher et al., 2003; Levinton et al., 2003).

The objectives of the present study were to determine the concentrations of metals in the water column at FC, 10 years after environmental remediation, and to compare these values to other locations within the Hudson and other rivers. Total dissolved and suspended particulate concentrations of a suite of metals (Cd, Co, Cu, Pb, Ag, and Ni) were measured in the water column at FC. Concentrations of Cd in surficial sediments at FC were determined, including samples within the dredged location and neighboring non-dredged areas. If dredging has resulted in comprehensive removal of heavy metals, we would expect low metal levels in FC, relative to other areas in the Hudson River and to pre-dredging values. Alternatively, elevated metal levels may persist in FC due to incomplete remediation or transport from other sources. If high concentrations of metals other than those discharged by the battery plant are detected in the Cove, this may indicate the presence of additional sources of metals into FC and the Hudson River.

## 2. Methods

### 2.1. Study area

Foundry Cove is situated on the eastern side of the Hudson River south of the village of Cold Spring, and 90 km north of The Battery, New York City, NY. The main body of water of Eastern FC is 12 ha and is bordered to the north, east, and south by cattail marsh (Fig. 1). Localized exchange of water between FC and the Hudson River occurs through a ca. 20-m wide opening, beneath a railroad trestle (Knutson et al., 1987). Although FC is tidally

influenced, salinity only reaches 3–6 psu during periods of low freshwater flow (Bower et al., 1978).

### 2.2. Water samples

Surface water samples were collected from FC ( $n = 11$ ) in August 2002. Sampling was conducted over two half ebb tides and a complete flood tide (Appendix 1). Unfiltered and filtered water samples were collected 1 m below the surface through acid-washed Teflon tubing into acid-cleaned polyethylene (LDPE) bottles. Filtered samples were passed through an acid-cleaned polyethylene filter cartridge (0.45  $\mu\text{m}$ ) attached to the pump system. The unfiltered and filtered samples were acidified to  $\text{pH} < 2$  using quartz-distilled hydrochloric acid and stored for 3 months prior to analysis. Most of the metals attached to suspended particles as well as those bound to dissolved organic ligands are released by this passive acid-digestion protocol (Sañudo-Wilhelmy et al., 1996). The accuracy of this digestion protocol is suggested by the fact that distribution coefficients ( $K_d$ ) between the particulate and dissolved metal pools calculated using this digestion protocol are indistinguishable from those calculated using a strong acid-digestion (Sañudo-Wilhelmy et al., 1996). Therefore, the particulate fraction of the samples ( $>0.45 \mu\text{m}$ ) was calculated as the difference between the unfiltered and the filtered ( $<0.45 \mu\text{m}$ ) dissolved fractions. Water samples were preconcentrated with an APDC/DDDC organic extraction (Bruland et al., 1985). Samples were analyzed for Cd, Co, Cu, Pb, Ni, and Ag using a Thermo-Finnegan Element2 Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Analytical procedures yielded full recoveries of all trace metals measured within the Canadian National Research Council standard reference material for trace metals (CASS-3) and relative standard deviations of  $<10\%$  for replicated analyses of samples. Analytical detection limits were 15 pM for Pb, 0.60 pM for Ag, 0.15 nM for Cu, 0.20 pM for Cd, 0.60 nM for Ni and 0.10 nM for Co.

The opening beneath the railway trestle provides the single major water connection between FC and the main Hudson River. Metal fluxes (the product of metal concentration, water velocity, and area of water movement between FC and the Hudson River) were estimated assuming a 1 m water column depth and 20 m width, approximately matching the dimensions of the opening. The export term for each metal, based on sampling of one tide, was determined by calculating the difference in areas of flux curves of the incoming and outgoing tide. Areas were determined by summing trapezoids of flux plots. Water velocity (cm/s) was measured with the aid of a stopwatch (0.1 s accuracy) at the surface using a free-moving float moving past a fixed 2 m floating rod, at 11 time points (with 10 replicates during each period) throughout the tidal cycle. Estimated velocities at metal sampling times were not made simultaneously as water samples were collected, but inferred via graphical interpolation. The Mann–Whitney–Wilcoxon (MWW) test, assuming independence of data points, was used to test whether flux of an element was consistently higher on either the incoming or outgoing tide. Significance was estimated from a two-tailed distribution of the  $T$  statistic. Probability values of  $<0.05$  were considered significant.

Pre-dredging tidal transport data are available for Cd only (Hazen and Kneip, 1980; J. Levinton, unpublished data). We estimated water column-based metal transport between FC and the Hudson River for Cd following a previously published method: the difference between the mean influx and efflux concentrations of Cd in one tidal cycle was multiplied by 125,000 m<sup>3</sup>, the estimated volume of water exchanged per tidal cycle (Hazen and Kneip, 1980).

### 2.3. External reference site for measurement of trace metals

Water samples from one location in the Lower Hudson River were collected and analyzed for comparison with levels measured at FC. This site (referred to as ‘LHR’), is 19 miles north of The Battery, in a highly urbanized drainage system receiving a range of anthropogenic-source toxicants. Wastewater emissions from the nearby North River Wastewater Treatment Plant (DEP NY, 2006) appear to contribute to the elevation of some metals (Ag, Ni, Cu) (Sañudo-Wilhelmy and Flegal, 1992). Water samples ( $n = 5$ ) were collected at LHR during one complete ebb tide and two half flood tides, and corresponded to the maximum and minimum current speeds during the

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