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Regional variability in bed-sediment concentrations of wastewater compounds, hormones and PAHs for portions of coastal New York and New Jersey impacted by hurricane Sandy

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ABSTRACT

Bed sediment samples from 79 coastal New York and New Jersey, USA sites were analyzed for 75 compounds including wastewater associated contaminants, PAHs, and other organic compounds to assess the post-Hurricane Sandy distribution of organic contaminants among six regions. These results provide the first assessment of wastewater compounds, hormones, and PAHs in bed sediment for this region. Concentrations of most wastewater contaminants and PAHs were highest in the most developed region (Upper Harbor/Newark Bay, UHNB) and reflected the wastewater inputs to this area. Although the lack of pre-Hurricane Sandy data for most of these compounds make it impossible to assess the effect of the storm on wastewater contaminant concentrations, PAH concentrations in the UHNB region reflect pre-Hurricane Sandy conditions in this region. Lower hormone concentrations than predicted by the total organic carbon relation occurred in UHNB samples, suggesting that hormones are being degraded in the UHNB region.

1. Introduction

Tidal surge associated with Hurricane Sandy inundated low-elevation coastal areas in New Jersey and New York in late October 2012. Most, if not all, bays along the New Jersey shore, New York/New Jersey Harbor, and the southern shore of Long Island were impacted by tidal surge and/or, to a lesser extent, river flood-waters (Schubert et al., 2015; Hall and Sobel, 2013). Residential structures, industrial manufacturing and storage facilities, and wastewater-treatment facilities were affected by this flooding. Storm-related damage to buildings and infrastructure had the potential to release a variety of contaminants that could subsequently be transported to local rivers and bays. In some cases, this damage persisted for several weeks, with untreated or partially treated wastewater released from wastewater-treatment facilities that failed as a result of disruptions in electrical service and flooding of treatment works. Sewage overflows totaled 19.7 billion liters (L) in New York and 19.3 billion in New Jersey (Kenward et al., 2013). Public-health agencies responded to address acute effects (such as damaged homes and spills) of Hurricane Sandy, but the potential long-term human and ecological effects caused by the introduction of contaminants from compromised infrastructure, weathering debris, and redistribution of previously contaminated sediments are unknown.

Persistent organic pollutants, including polychlorinated biphenyls (PCBs), dibenzo-*p*-dioxins/furans (PCDD/Fs), and polycyclic aromatic hydrocarbons (PAHs), are widespread in bed sediments in New York Harbor and Newark Bay bed sediments. These contaminants are primarily from historical sources, have been decreasing through time, and have been monitored long-term by several programs (Adams, 2003; Lodge et al., 2015).

Additional studies have evaluated the impact of short-term inputs of organic pollutants into New York Harbor. For example, the impact of the September 11, 2001 (9/11) destruction of the World Trade Center on the occurrence and distribution of persistent organic pollutants has also been assessed by Litten et al., 2003 and Lauenstein and Kimbrough, 2007. Litten et al. (2003) did not find a substantial impact on the presence of PCBs, PCDD/Fs and other persistent organic pollutants in sediments in the New York Harbor after 9/11, with only 5% of the PCBs in sediment in the vicinity of Manhattan attributable to the 9/11 destruction; Lauenstein and Kimbrough (2007) similarly did not find any substantial changes in PCBs or PAHs in sediments after 9/11.

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Other extreme events, including large storms, can affect estuarine conditions that control the distribution of contaminants in sediments. Estuaries trap and retain much of the sediment material inputs to them by the surrounding watershed (Meade, 1969; Chapman and Wang, 2001). Local maximums of sediment deposition rates typically occur at or near the brackish-freshwater interface where particle settling is enhanced (Meade, 1969). Thus, sediment deposition dynamics can depend in part on salt-water intrusion. Storms can increase bed stress and cause re-suspension of sediments in many estuaries including New York Harbor. For example, Tropical Storms Irene and Lee significantly increased discharge in the Upper Hudson River, but turbidity maximums and sediment dynamics in the estuary were the result of sediment re-suspension rather than new fluvial sediment delivery (Ralston et al., 2013). Sediment re-suspension can alter contaminant distributions because concentrations of some contaminants, including trace metals, PCB, and PAHs have been declining with time and thus can be higher in areas with deeper sediments (Bopp et al., 1993). However, recent work in Jamaica Bay, NY has shown that concentrations of some emerging, sewage-associated contaminants have been increasing over the past five decades and the highest concentrations are in surface sediments (Lara-Martín et al., 2014). Thus, it is difficult to predict how storm surge, sediment re-suspension, and significant sewage outflows resulting from failed infrastructure might affect the concentration and distribution of historical (e.g. PCBs, PAHs) and emerging (e.g. hormones, personal care and domestic use products) contaminants.

Emerging contaminants (including but not limited to hormones, antimicrobials, surfactants, and fragrances) associated with wastewater discharges have not been widely assessed in the sediments in the New York Harbor or surrounding areas. To our knowledge, no regional assessment of hormones and other emerging contaminants has been undertaken in urbanized estuaries in the United States. By contrast, recent research in large urban areas in China (Zhang et al., 2014; Chang et al., 2011), and Europe (Matic et al., 2014; López de Alda et al., 2002) have demonstrated the presence of these contaminants in bed sediments in estuaries adjacent to large urban areas. Recent investigations of wastewater associated organic contaminants including estrogens, androgens, plant and animal biochemicals (PABs), fragrances, and antimicrobial compounds indicate that sewage inputs can be an important source of contaminants (Phillips et al., 2012; Cantwell et al., 2010; Nilsen et al., 2014; Gorga et al., 2015). A few studies have included emerging contaminants in sediments in the New York Harbor area (Reddy and Brownawell, 2005; Benotti and Brownawell, 2009; Ferguson et al., 2003; Lei et al., 2009; Lara-Martín et al., 2014) but these studies have 1) largely focused on surfactants, and have generally not included analyses for hormones (especially androgens), and 2) mostly focused on the Jamaica Bay portion of the study area and have not included sampling south in New Jersey or in eastern New York (i.e. Long Island).

Emerging contaminants that can sorb to sediments can affect fish health, sexual characteristics of fish, fish reproduction, and potentially affect the health of benthic invertebrates (Jobling et al., 1996; Sumpter and Johnson, 2005; Richardson and Kimura, 2016). Given the widespread damage of wastewater infrastructure, release of large amounts of untreated and partially treated sewage during Hurricane Sandy (Kenward et al., 2013), and the propensity of these contaminants to be associated with wastewater, the assessment of emerging contaminants post-Sandy is particularly relevant. However, emerging contaminants have not been sampled in this area prior to Hurricane Sandy; therefore, it is impossible to provide a regional assessment of the impact of Hurricane Sandy on these contaminants. Given these constraints, the purpose of this study was to 1) document post-Sandy occurrence of emerging contaminants, including hormones, plant and animal biochemicals, and fragrances in coastal New Jersey and New York area; 2) use ratios of analytes to determine potential sources of contaminants; and 3) analyze relationships between hormones and other compounds as a means to explore the distribution of hormones in coastal New York and New Jersey.

2. Methods

2.1. Sample network, land use analysis, and data availability

Sediment samples were collected from 79 sites distributed among six coastal regions from southern New Jersey to eastern New York (Table S01, Fig. S01). The study area was divided into 6 study regions on the basis of hydrologic divides and similar patterns of land use to evaluate differential impacts associated with Hurricane Sandy. The 6 regions are based on aggregation of 13 regions described by Fischer et al., 2015 (Table S02 gives the equivalent regions used in this paper and Fischer et al., 2015). Land use estimates for the regions are based on the 2011 National Land Cover database for New York and New Jersey obtained from the USDA NRCS Geospatial Data Gateway (*http://datagateway.nrcs.usda.gov/*), and mosaicked to provide continuous coverage of the study area. The areas inundated during the storm surge are based on models incorporating field-based observations of high-water marks and monitoring data from stream, tide and surge monitors (Federal Emergency Management Agency [FEMA], 2013). Land use was summarized to Level I Anderson classes. Additional details on sample network and land use analysis are provided by Fischer et al., 2015. The proportion of each region and inundated portion of the region in high-intensity developed land use is given in Fig. S02.

All the data used for the analysis in this paper are available in Fischer et al., 2015, where data tables are provided in a spreadsheet form.

2.2. Sample collection and handling

Bed-sediment samples were collected from boats using grab samplers during June–October 2013; all sites were sampled once. Samples were collected using standard US Geological Survey (USGS) or US Environmental Protection Agency methods described in Hladik et al., 2009; Radtke, 2005; Lauenstein and Cantillo, 1993, and US Environmental Protection Agency, 2001. Sediment samples were collected using either an Ekman sampler, Petite Ponar sampler, or a modified Van Veen type sampler depending on sampling conditions (for example, sediment texture, or presence of shells or vegetation). The upper 2 cm of sediment was retained for analysis to standardize sample collection among sites in an attempt to obtain samples representative of sediment-quality conditions after Hurricane Sandy. Additional details of sediment sampling and handling are given in Supplemental Materials and in Fischer et al. (2015).

2.3. Analytical methods

Estuarine sediments collected at each site were analyzed for more than 75 organic chemical constituents. Analytical results for these samples are given in Fischer et al., 2015. Two USGS methods were used to analyze compounds, and are referred to as 1) the wastewater method and 2) the hormone method. A summary of these methods is provided below, with more detail available in Supplemental Material and Fischer et al. (2015).

The wastewater method includes analysis for 57 compounds that include surfactants, fragrances, antioxidants, disinfectants, food additives, plastic components, industrial solvents, PAHs, PABs, phosphate flame retardants, and high-use domestic pesticides using a method described by Burkhardt et al. (2006). Because this method largely focuses on compounds often associated with wastewater, it is referred to here as the wastewater method. Analytes were extracted from sediment by pressurized solvent extraction, further isolated by solid-phase extraction, and determined by gas chromatography/mass spectrometry. Reporting levels ranged from 50 to 1000 μg/kg (micrograms per kilogram) for a 10 g (gram) sample, and were adjusted based on the mass of the sample.

The second method, referred to as the hormone method, was used to analyze for 20 compounds, including 9 estrogens, 6 androgens, two