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Potential effects of sediment contaminants on diatom assemblages in coastal lagoons of New Jersey and New York States

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ABSTRACT

Sediment samples from the coastal lagoons and estuaries of New York and New Jersey were used to investigate the influence of contaminants on diatom assemblages. Multivariate analyses demonstrated correspondence between composition of diatom assemblages and concentrations of several metals and total PAH. The effects of the individual contaminants were difficult to disentangle because of the considerable correlations between their concentrations. The most conspicuous trend was the increase in the relative abundance of small centric planktonic diatoms in response to contamination and the corresponding decrease in the benthic flora. The high relative abundance of planktonic species on contaminated sediments apparently resulted not so much from their tolerance to pollution, but from the paucity of benthic species. A comparison of the assemblages on the surface and at the depth of approximately 8–10 cm revealed a statistically significant temporal change in community composition towards planktonic diatoms.

1. Introduction

Diatoms are commonly used as indicators of various environmental characteristics, especially salinity, pH, and nutrients (Smol and Stoermer, 2010). Diatoms are also known to be sensitive to toxic substances, such as metals (Cattaneo et al., 2008, Duong et al., 2008; Morin et al., 2012) and organic contaminants (Moisset et al., 2015). Classic toxicological approaches, such as testing the effects of contaminants on single species or monoclonal cultures in the laboratory conditions demonstrated effects of individual contaminants and of their mixtures on both freshwater (*e.g.*, Adams and Stauber, 2004; Araújo et al., 2010; Larras et al., 2012,) and marine (*e.g.*, Fan and Reinfelder, 2003; Hagenbuch and Pinckney, 2012; Joux-Arab et al., 2000; Moreno-Garrido et al., 2003, 2007) diatoms. While the traditional tests typically measured growth or survival rates of various species depending on the dosage and length of the exposure to contaminants, a number of recent studies attempted to investigate mechanisms of toxicity by estimating gene expression (Kim Tiam et al., 2012; Moisset et al., 2015) and enzyme activities indicating which cell functions are affected (Bonet et al., 2012; Crespo et al., 2013). Laboratory and field experiments were also crucial for investigating effects of contaminants on the composition (Morin et al., 2010; Ricart et al., 2010) and diversity (Ricciardi et al., 2009) of algal communities and the function of the river biofilm ecosystems (Barral-Fraga et al., 2015). Several researchers used mesocosms and artificial streams to study freshwater diatom community composition changes in response to contaminant exposure (Pérès et al., 1997; Kim Tiam et al., 2015). Ivorra et al. (1999) and Morin et al. (2014) documented the effect of zinc exposure on lotic diatom communities using *in situ* translocation experiments. While experimental work is indispensable for establishing causal relationships between pollutants and organisms, field surveys are important for detecting potential effects of contaminants on whole communities *in situ* and for observing the ecosystem-level effects. Cattaneo et al. (2004, 2008) showed how diatom community composition changed with time as a result of metal pollution in several Canadian lakes with sensitive planktonic species declining in abundance and more tolerant benthic species surviving heavy pollution. Medley and Clements (1998) combined field observations with experiments to study the effects of metals on diatom community composition in Colorado streams and determined which diatom species were either sensitive or tolerant to various metals. The effects of contaminants on the species composition and diversity of benthic algae including diatoms were demonstrated in field studies of rivers in Spain (Sabater, 2000; Guasch et al., 2009; Brix et al., 2012) and in Northern Canada (Spencer et al., 2008). In comparison to freshwaters, relatively little is known about patterns of benthic diatom distribution in relation to sediment contaminants in marine environment. The effects of hydrocarbons and metals on subtidal sediment diatom assemblages were studied in Antarctica using field survey

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(Cunningham et al., 2005) as well as field experiments (Cunningham et al., 2003). In the temperate zone no field studies of subtidal diatom assemblages along gradients of contaminants have been done yet.

The present investigation is an attempt to reveal potential effects of contaminants on diatoms in surface sediments in the coastal waters of New York and New Jersey. This investigation is part of a survey aimed at assessing the presence of sediment contaminants after Hurricane Sandy and their effects on biota conducted by USGS in 2013. Unfortunately, no baseline data on spatial and temporal variation of surface sediment diatom assemblages in the area was available. The closest location where diatoms from sediment core samples have been analyzed was conducted in Long Island Sound (Cooper et al., 2010; Varekamp et al., 2010). An increase of planktonic to benthic diatom ratio and a decrease in species diversity and abundance of diatoms starting from 1850s were reported, but detailed data on species composition in Long Island Sound samples have yet to be published. Our study is thus the first report on the patterns of distribution of subtidal sediment diatoms in the near-shore locations of New York and New Jersey and their possible links to contaminants.

2. Materials and methods

2.1. Study area, sampling, and laboratory analyses

Surface sediment samples were collected from 50 sites in the lagoons and estuaries along the Atlantic coastline in New York and New Jersey, from Cape May, NJ and along the southern shore of Long Island to its eastern end (Fig. 1). The samples were collected by USGS and USEPA staff in June–October 2013 as part of the USGS post-Hurricane Sandy assessment of sediment contaminants. The samples were collected from boats using Ekman, Petite Ponar, or Van Venn grab samplers. The upper top 2 cm of the each grab sample was analyzed for grain size, contaminants and diatoms, while only diatom subsamples were collected from the base of the grab samples. All analytical methods used to determine contaminant concentrations, TOC and particle size of the sediments are described in Fischer et al. (2015) and were performed by the USGS staff. Surface water salinity data were collected by various agencies and retrieved from Water Quality Data Portal (http://waterqualitydata.us/).

About 1 g of wet sediment from each sediment sample was used for diatom sample processing. The organic component was oxidized

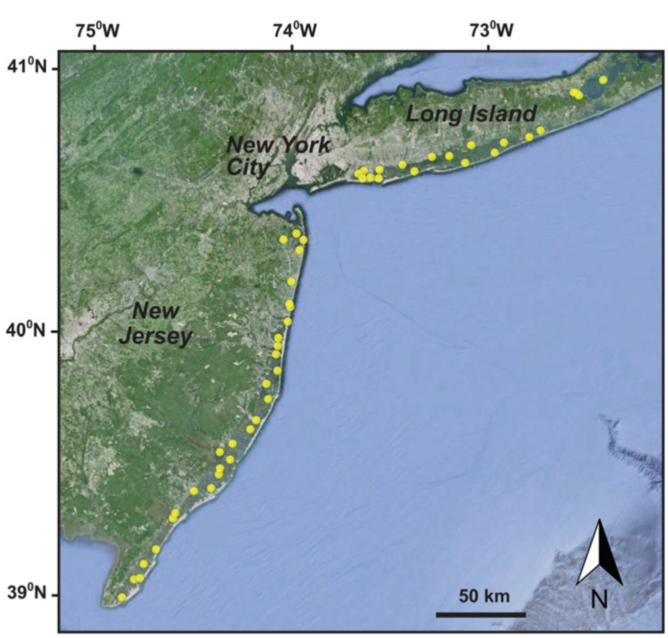

Fig. 1. Map of the study area showing sampling locations.

with 70% nitric acid while heated for 1.5 h. Diatoms were repeatedly allowed to settle for 24 h and the supernatant was decanted until it reached a neutral pH. A measured amount of digested sample was dripped onto a microscope cover slip and dried. Cover slips were then mounted onto slides using a high refractive index mounting medium (Naphrax™). Diatoms were counted and identified using a Nikon Eclipse 80i microscope equipped with DIC optics. Five hundred valves were counted for each slide at 1000× magnification. For Scanning Electron Microscopy (SEM) diatom suspensions were air-dried on aluminum stubs. The samples were then sputter-coated with Pt–Pd and observed with a Zeiss Supra 50 scanning electron microscope under 10 kV accelerating voltage.

2.2. Data analyses

Among various contaminants analyzed in the samples sediments, we chose metals and polycyclic aromatic hydrocarbons (PAHs) to investigate as potential stressors affecting diatom assemblages. The reason that other parameters, such as PCBs, were excluded from this study was that they comprised a relatively high number of non-detects in the dataset. In addition to individual concentration of metals and PAH species, we used two summary variables. The first represented the sum of all PAH species (total PAH). A summary variable reflecting the toxicity of metals was constructed based on the same principle that was used by Clements et al. (2000) to study the response of biota to multiple metal contamination in rivers. Clements et al. (2000) suggested using a summary variable, which they called the "compound variable cumulative criterion unit", or CCU. To calculate CCU, it is first necessary to calculate the ratio of each observed metal concentration to the concentration known to cause negative effects on invertebrates. The sum of all calculated ratios is the CCU. Such summary variables were subsequently applied to evaluate the effect of toxic substances on freshwater diatom assemblages by Morin et al. (2012) and Guasch et al. (2009). While Clements et al. (2000) used critical values of water concentrations of metals, we use here the sediment concentrations and the sediment quality guidelines published by Long et al. (1995), who summarized a large number of studies of the impact of sediment contaminants on aquatic invertebrates. Two concentrations for nine metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Ag and Zn) provided by Long et al. (1995) are called Effect Range-Low (ERL) and Effect Range-Medium (ERM). These thresholds correspond to the 10% and 50% incidence of the toxic effects of the corresponding metals on invertebrates. The ERL is used here because the largest majority of observations were below the ERM level. The variable that we call CCU following Clements et al. (2000), is calculated as $CCU = \Sigma (m_i/ERL_i)$, where m_i is the concentration of each metal and ERL is its Effects Range-Low level as given by Long et al. (1995). The particle or grain size is represented by a single variable, which is the sum of sand and gravel percentages.

To explore the structure of contaminant data used in this study, the Principal Component (PCA) analysis was used. The values of environmental variables were standardized. Detrended Correspondence Analysis (DCA) was carried out to identify major gradients in diatom data and to relate them to measured environmental parameters, such as contaminants, sediment particle size, total organic carbon (TOC), and water salinity. To test the significance of the contaminants' effect on diatom assemblages, a series of partial Canonical Correspondence Analyses (CCA) with Monte Carlo permutation tests were carried out. Environmental variables that are known to be important determinants of diatom assemblage composition, such as salinity, grain size and total organic carbon (TOC) were used as covariates in CCAs to ensure that only the portion of variability on diatom data attributable to contaminants is estimated. An option of "downweighting of rare species" was chosen in DCA and CCA analyses. To test for differences in diatom assemblage composition between top and bottom sediment layer samples we used a partial redundancy analysis (RDA). Sampling sites were used as covariates to control for the effect of the site. Species relative