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A survey of benthic sediment contaminants in reaches of the Columbia River Estuary based on channel sedimentation characteristics

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HIGHLIGHTS

- We modeled sedimentation patterns in three reaches in the Columbia River Estuary.
- Sediment transport model is used to guide bottom sediment sample allocation.
- Organic carbon levels are correlated with predicted sedimentation patterns.
- Sediment contaminants are correlated with predicted sedimentation patterns.
- Longitudinal contaminant trends comport to trends in resident bird and fish tissues.

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ABSTRACT

While previous studies have documented contaminants in fish, sediments, water, and wildlife, few specifics are known about the spatial distribution of contaminants in the Columbia River Estuary (CRE). Our study goal was to characterize sediment contaminant detections and concentrations in reaches of the CRE that were concurrently being sampled to assess contaminants in water, invertebrates, fish, and osprey (*Pandion haliaetus*) eggs. Our objectives were to develop a survey design based on sedimentation characteristics and then assess whether sediment grain size, total organic carbon (TOC), and contaminant concentrations and detections varied between areas with different sedimentation characteristics. We used a sediment transport model to predict sedimentation characteristics of three 16 km river reaches in the CRE. We then compartmentalized the modeled change in bed mass after a two week simulation to define sampling strata with depositional, stable, or erosional conditions. We collected and analyzed bottom sediments to assess whether substrate composition, organic matter composition, and contaminant concentrations and detections varied among strata within and between the reaches. We observed differences in grain size fractions between strata within and between reaches. We found that the fine sediment fraction was positively correlated with TOC. Contaminant concentrations were statistically different between depositional vs. erosional strata for the industrial compounds, personal care products and polycyclic aromatic hydrocarbons class (Indus–PCP–PAH). We also observed significant differences between strata in the number of detections of Indus–PCP–PAH (depositional vs. erosional; stable vs. erosional) and for the flame retardants, polychlorinated biphenyls, and pesticides class (depositional vs. erosional, depositional vs. stable). When we estimated mean contaminant concentrations by reach, we observed higher contaminant concentrations in the furthest downstream reach with a decreasing trend in the two upstream reaches. Contaminant survey designs that account for sedimentation characteristics could increase the probability that sampling is allocated to areas likely to be contaminated.

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Abbreviations: CRE, Columbia River Estuary; FR–PCB–Pest, flame retardants, polychlorinated biphenyls, and pesticides; Indus–PCP–PAH, fragrances, surfactants, industrial compounds, personal care products, and polycyclic aromatic hydrocarbons; TOC, total organic carbon.

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1. Introduction

Exposure of fish, wildlife, and people to contaminants within the Columbia River Basin has caused concern (USEPA, 2009). Contaminants measured in Columbia River fish included PCBs, dioxins, furans, arsenic, mercury, and DDE, a toxic breakdown product of the pesticide DDT (USEPA, 2009). In 1992, a USEPA contaminants survey suggested a potential health threat to tribal and other people who eat fish from the Columbia River Basin (USEPA, 1992). The consumption survey showed that 92 contaminants were detected in fish with some above levels of concern for aquatic life or human health. More recently, the Oregon Department of Environmental Quality (2012) found concentrations of DDTs and PCBs that grossly exceed DEQ's human health criteria, both in smallmouth bass (*Micropterus dolomieu*) and largescale suckers (*Catostomus macrocheilus*). Exposure of aquatic life to contaminants, including emerging contaminants such as flame retardants, pharmaceuticals, cosmetics, personal care products, hormones, antibiotics, and other drugs, can occur through various routes such as permitted effluent. Since contaminants can affect fish, human, and wildlife health and there are long standing concerns about contaminant exposure in the CRE, a more thorough investigation of contaminants in the CRE is warranted.

Contaminants in sediments and water in the CRE could confound efforts to recover threatened and endangered anadromous salmon and to manage other fish and wildlife species. Current and past industrial discharges into the CRE have resulted in contamination of sediments and water (USEPA, 2009). All anadromous fish species produced in the Columbia and Snake Rivers, many that are listed as endangered or threatened under the Endangered Species Act, have to migrate through the CRE (NMFS, 2014). In a study examining the body burdens of contaminants in juvenile salmon in the CRE, researchers documented exposure levels for some contaminants approaching concentrations that could affect their health and survival and that were among the highest levels measured from Pacific Northwest estuaries (Johnson et al., 2007). Sediment deposition is one way compounds may persist in the aquatic environment and enter the foodweb via benthic organisms (Nakata et al., 2007). Understanding what habitats are contaminated may help identify mitigation opportunities.

While previous studies have documented contaminants in fish, sediments, water, and wildlife, little is known about the specific spatial distribution of contaminants in habitats of the Columbia River and CRE, despite its designation as a priority Large Aquatic Ecosystem (USEPA, 2010). In a 2007 contaminants survey, approximately 16% of the Columbia River estuarine area was in poor condition with respect to sediment contaminants (USEPA, 2007). The USEPA (2007) study employed a design intended to assess the status and trends of ecological resources at a regional scale. Few other probabilistic surveys of sediment contaminants have been conducted in the Columbia River. As part of the Columbia River Toxics Reduction Plan, the USEPA (2010) recognizes the need for a coordinated effort to identify research and monitoring priorities and the integration of water, land, air, sediment and biota monitoring for contaminants in this system.

The goal of our study was to provide a characterization of benthic sediment contaminant detections and concentrations in three reaches of the CRE that were concurrently being sampled to assess contaminants in water, invertebrates, fish, and osprey (*Pandion haliaetus*) (Nilsen and Morace, 2014-in this issue) to provide context to these studies. Our objectives were to develop a survey design based on sedimentation characteristics and then assess whether sediment grain size, total organic carbon (TOC), and contaminant concentrations and detections varied between areas with different sedimentation characteristics and between reaches that were hypothesized to represent a gradient in contamination.

1.1. Study area

The Columbia River is the fourth largest river in the United States (US), draining an area of approximately 670,800 km^2, from Canada to the northwest of the US. The Columbia River is highly affected by dams that have altered the river's hydrograph and sediment load (Naik and Jay, 2011; Gelfenbaum et al., 2001). Our study was conducted in the Columbia River Estuary (CRE), an un-impounded reach of the Columbia River below Bonneville Dam, which is located at river kilometer 378. The entire CRE is affected by ocean tides as well as by a seasonally changing hydrograph.

We chose three river reaches hypothesized to provide a potential gradient of contaminant concentrations (Nilsen and Morace, in this issue). The three reaches selected were the Columbia River near Longview (river kilometer 106), near Columbia City (river kilometer 132), and near Skamania (river kilometer 225) (Fig. 1). Results from contaminant studies using passive samplers, fish tissues, and osprey eggs in 2008–2010 (Henny et al., 2009, 2011; Alvarez et al., 2014-in this issue; Christiansen et al., 2014–in this issue; Nilsen et al., in this issue; Torres et al., in this issue) were used to help select these three study reaches. Sample reaches were made approximately 16 km in length and were located to encompass sampling sites for largescale suckers (Nilsen et al., 2014-in this issue), osprey eggs (Henny et al., 2011), and passive contaminant samplers (Alvarez et al., in this issue).

The Longview reach is located near the Port of Longview that consists of eight marine terminals and waterfront industrial property dominated by forest products and steel industries and has inputs from municipal and industrial sources. The Columbia City reach is located near two small towns in Oregon, Columbia City on the downstream end and St. Helens on the upstream end. The Multnomah Channel, which branches off of the Willamette River, drains into the Columbia River at the upstream end of this site. The Skamania reach is the most upstream reach and is located downstream of Bonneville Dam, and upstream of the urban areas of Portland and Vancouver. Areas immediately upstream of the Skamania reach have been shown to have relatively low levels of contaminants (Fuhrer et al., 1996; Johnson et al., 2007; Morace, 2006).

Fluvial processes, modified by tidal processes, control the hydrodynamics and sediment transport in the CRE. Flow is directed downstream in all three reaches, but slows and even reverses direction with the tides, even as far upriver as the Skamania reach. Even though salt water never reaches this far upriver, the tides still influence water elevation and velocity. The magnitude of flow reversal is a function of seasonally-varying river discharge. The highest river flows occur during the spring freshet while low flows typically occur during late summer. Sediments and contaminants were sampled during late summer — early fall low flow conditions when flow reversals are typically greatest. Sedimentation patterns in the CRE depend spatially on convergences and divergences in sediment transport flux that can occur near river meanders, in side channels, or in embayments. Sedimentation or erosion can also result from temporal changes in the sediment concentration, typically during rapid decreases or increases in river discharge associated with flooding.

2. Material and methods

2.1. Delft3D sediment transport modeling

To investigate physical processes and sediment patterns in the CRE a Delft3D flow and sediment transport model was created that encompasses the Columbia River downstream of Bonneville Dam and includes the estuary, mouth, and open coast to the continental shelf break. The model used in this study is based on a Delft3D hydrodynamic and sediment transport model originally developed specifically for the mouth of the Columbia River and which has been validated for waves and currents against field data (Elias et al., 2012). World-wide case studies indicate that Delft3D is applicable to a wide range of coastal and fluvial environments including ocean, estuary and river settings (Grunnet et al., 2004; Van Maren, 2004; Elias et al., 2006; Lesser et al., 2004; Mulligan et al., 2010). The base model for the CRE has a grid resolution varying between 50 to 100 m^2, with an average of 20 grid cells