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Bioavailability of metals along a contamination gradient in San Diego Bay (California, USA)

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Abstract

San Diego Bay is heavily contaminated with metals, but little is known about their biological availability to local marine organisms. This study on 15 elements showed that concentrations of metals associated with sediment increased from the mouth to the back of the Bay while metals in seawater particulates were similar throughout the Bay. Metal bioavailability was assessed over 8 weeks following transplant of the local brittlestar, *Ophiothrix spiculata* (Ophuroidea, Echinodermata), from outside to inside the Bay. Despite a gradient of contamination, brittlestars accumulated similar levels of metals throughout the Bay, suggesting that metal contamination occurred through dissolved metals as well as through the diet. Sediment transplanted in dialysis tubing in the Bay accumulated metals only when placed on the sea-floor bottom, indicating greater metal bioavailability near the bottom; the level of accumulation was similar between the mouth and the back of the Bay. The results are consistent with a circulation pattern in which a bottom layer of seawater, enriched with metals, drains from the back to the mouth of the Bay. There was a positive correlation between metal concentration in brittlestars and tidal range, suggesting increased metal exposure due to bay-ocean water exchange. For brittlestar arms the correlation was higher at the mouth than the back of the Bay, indicating greater metal accumulation in arms from dissolved metals in seawater than from ingestion of metal contaminated diet. In contrast, for brittlestar disks the correlation was higher at the back of the Bay, indicative of metal accumulation mainly through the diet. The results highlight the importance of considering bioavailability and physical processes in environmental quality assessments.
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Keywords: Field transplant; Contamination; Upwelling; Brittlestar; Echinodermata; *Ophiothrix*; Risk assessment

1. Introduction

San Diego Bay is a semi-enclosed body of water that is the site of intense economic and public activities. It has long been known that, as with other bays acting as harbors and surrounded by a metropolis, San Diego Bay is subject to contamination by various hazardous substances (State Department of Public Health, 1951; Torres, 1988; Environmental Health Services, 1990). Amongst them, metals are some of the most important contaminants, originating from multiple recurring past and present sources mainly linked to military and recreational boating, such as contamination from antifouling

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paint, fuel combustion, and shipyard activities. Contamination of the Bay was particularly intense until 1963, when completion of the San Diego Metropolitan Sewage System allowed a large percentage of municipal and industrial waste to be discharged offshore instead of directly in the Bay (State Department of Public Health, 1951; Torres, 1988; Environmental Health Services, 1990). Today, San Diego Bay harbors many ships and shipyards, the largest component being military. Recreational boating is significant as well, accounting for thousands of vessels, some of them densely packed in marinas around the Bay. All these boats are potential sources of pollution, especially by metals (Federal Water Pollution Control Administration, 1969; Young et al., 1979; Nichols, 1988; Schiff et al., 2004).

San Diego Bay has often been subject to monitoring surveys over the years, with the Bay divided into a northern part (the mouth of the Bay) that opens to the Pacific Ocean and is frequently flushed, and a southern part (the back of the Bay), which is the closed and poorly flushed dead-end of the Bay. Considering also that most shipyard activity takes place towards the back of the Bay, it is not surprising that there is an increasing gradient of metal total concentration in sediment from the mouth to the back of the Bay (Anderson et al., 1996; Fairey et al., 1998). This does not necessarily mean, however, that these metals are biologically available to the local fauna. In fact, only a few studies have assessed the bioavailability of metals in the Bay, then using seawater-filtering organisms as experimental models. Mussels transplanted into sub-surface Bay waters accumulate metals, an indication that metals are bioavailable from seawater and/or seawater particulates (Martin, 1985; Steinert et al., 1998). Yet, there is a lack of knowledge on the actual amount of bioavailable metals in the Bay, as based on the ratio between environmental levels of metals and the quantity actually taken up by organisms. Thus, it is not known to what extent metals present in the Bay can be transferred to the local biota.

Bioavailability depends on multiple environmental factors that affect metal complex formation, including physico-chemical parameters like salinity and the concentration of organic material soluble in the environment, and on biological and/or physiological characteristics of the organism that is exposed to the metal, including digestion and uptake efficiency, storage, and excretion capacities. Bioavailability therefore is a difficult parameter to assess because of the many environmental and species-specific factors that can affect metal uptake and/or accumulation (Luoma, 1983, 1989; Campbell, 1995; Rainbow, 2002).

Brittlestars live in sandy/muddy areas where metals are preferentially concentrated (Clark, 1997), and are thus directly exposed to contamination from dissolved metals in seawater and from metals concentrated in their diet, which consists of sediment and/or organic detritus. For this reason brittlestars, as well as other echinoderms such as seastars and sea urchins, are excellent bioindicators of environmental quality because they can uptake bioavailable contaminants from the surrounding environment (Warnau et al., 1995; Newton and McKenzie, 1998).

This study measured environmental levels of fifteen metals in the marine ecosystem of San Diego Bay and assessed their bioavailability following metal accumulation in brittlestars transplanted from outside to inside the Bay.

2. Materials and methods

2.1. Environmental parameters

This study was performed from June, 14 to August, 9 2001 at four sites (A–D) distributed along the San Diego Bay (Fig. 1); water depth was 16 m for site A, 15 m for site B, and 11 m for both sites C and D. At each site, water temperature, salinity, and turbidity were measured once a week during 7 weeks (week 0, 1, 2, 3, 4, 6, and 8), in parallel with the collection of samples involved in the transplant experiment (Section 2.2). Water temperature was measured from the seafloor bottom using an Oceanic dive computer and from the surface with a standard ASTM certified mercury thermometer (Fisher Scientific) immersed for several minutes before reading. Salinity was measured from subsurface seawater samples using a portable refractometer (Fisher Scientific), while turbidity was estimated from Secchi disk measurements of water clarity. Seawater renewal in the Bay due to tidal mixing and exchange with the open Ocean was estimated for each week of the experiment (except for week 0)

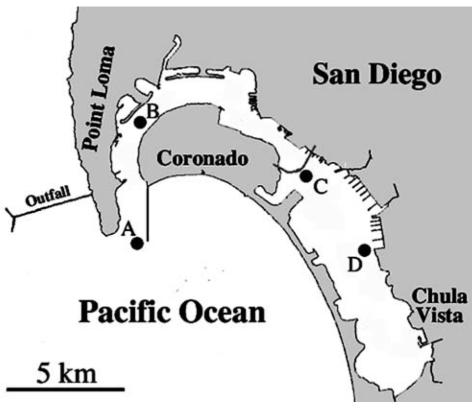

Fig. 1. Location of sites of investigation in San Diego Bay, California. The sites were located near navigation buoys R8 (site A), R16A (site B), G1 (site C) and R34 (site D).

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