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Baseline

Environmental recovery in Sydney Harbour, Nova Scotia: Evidence of natural and anthropogenic sediment capping

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ABSTRACT

Contaminants were assessed in Sydney Harbour during baseline and three years of remediation of a former coking and steel facility. Concentrations of PAHs; PCBs; and lead measured in surface sediments indicate overall spatial distribution patterns of historical contaminants remains unchanged, although at much lower concentrations than previously reported due to natural sediment recovery. Recovery rates were in broad agreement with predicted concentrations; or in some cases lower, despite remediation at the Sydney Tar Ponds (STP) site. Contaminants showed little temporal variability, except for detection of significant increases in PAH concentrations during onset of remediation compared to baseline which represented a short term interruption in the overall long term natural recovery of sediments in Sydney Harbour. Recovery (via "capping") was enhanced following recent harbour dredging activities where less contaminated outer harbour sediments were discharged into a confined disposal facility (CDF) required for a new container in the inner harbour.

Sydney Harbour, Nova Scotia has long been subject to effluent and atmospheric inputs of contaminants, including thousands of tons of metals, PAHs and PCBs, from a large coking and steel plant which operated in Sydney for nearly a century (Lambert et al., 2006). Contaminants comprised of coal tar residues which were discharged from coking ovens into Coke Ovens Brook and a small tidal tributary, Muggah Creek, which in turn discharged into Sydney Harbour (Furinsky, 2002). Numerous studies linked these effluent and atmospheric contaminants to local ecological and human health impacts (Tay et al., 2003), and these particle reactive contaminants became the main pathway of exposure for marine benthic organisms (Stewart et al., 2002). Within Sydney Harbour, the highest chemical contaminant concentrations in sediments were historically reported near Muggah Creek, with concentrations decreasing towards the outer harbour (Lee et al., 2002).

The pollution legacy of contaminants in Sydney Harbour sediments are well documented, and reached their maxima between 1960 and 1980 (Lee et al., 2002). However, a study by Smith et al. (2009) used radionuclide tracers to predict time required for natural recovery (or "capping") of historical contaminants. Smith et al. (2009) estimated Pb concentrations would fall below the highest ranked ecological health risk benchmarks (where chronic effects would be very likely) by 2020, and fall below lowest ranked ecological health risk benchmarks (where chronic effects would be unlikely) by 2050. Concentrations of PAHs and PCBs were predicted to take longer time for natural recovery to fall below their corresponding ecological benchmarks (2060 and 2090) and (2030 and 2060), respectively.

Our study measured current contaminant concentrations in Sydney Harbour sediments to compare them against modelled predictions of natural sediment recovery rates reported by Smith et al. (2009). Monitoring occurred alongside two large scale projects in or adjacent to the harbour. These were remediation of the STPs (Walker et al., 2013a,b, submitted for publication-a,b) and large scale dredging of less contaminated outer harbour sediments (required for a new container terminal development in Sydney Harbour) (Jacques Whitford, 2009).

An Environmental Impact Statement (EIS) conducted by a Joint Review Panel (JRP) concluded that mobilization of contaminated sediments in Muggah Creek poses greatest threats to the marine ecosystem (JRP, 2006). Therefore, immobilizing these contaminated sediments in the STPs using solidification and stabilization (S/S) was identified as the primary source control remediation option to mitigate against continued transport of contaminated sediments from the STPs into Sydney Harbour. Remediation of the STPs began in 2009 and included *in situ* S/S by mixing contaminated tar ponds sediments with Portland cement to reduce contaminant leaching into the surrounding environment (ITRC, 2011). Annual monitoring of sediments began during 2009 baseline (pre-remediation), and three years of remediation (year 1, 2010; year 2, 2011; year 3, 2012) (Fig. 1). Between October 2011

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and December 2012 a trailing suction hopper dredge removed nearly 5 million m^3 of cleaner sediment from a navigation channel in the outer harbour which was subsequently discharged into a CDF located in the inner harbour. Dredging occurred between monitoring years 2 and 3.

Objectives of this study were: (1) to assess effectiveness of STP remedial activities on surface sediments in Sydney Harbour; (2) to measure potential positive impacts of anthropogenic sediment "capping" following dredging and discharge of less contaminated sediments; (3) to confirm modelled predictions of natural sediment recovery reported by Smith et al. (2009); and (4) to establish a new current baseline for marine sediments in Sydney Harbour. A comprehensive suite of other monitored media and parameter concentrations have been reported elsewhere (Walker et al., 2013a,b, submitted for publication-a,b).

Four "areas of assessment" (area 1 – near-field; area 2 – mid-field; area 3 – far-field; and area 4 – Sydney River Estuary) and eleven marine monitoring stations (~10 m deep), were sampled in Sydney Harbour (Fig. 1). Sydney Harbour has modest freshwater and sediment inputs from Sydney River and Balls Creek and provides the main source of natural capping and recovery of contaminated harbour sediments (Petrie et al., 2001). Contaminated sediment effluents have historically been transported from Muggah Creek in Sydney Harbour with highest contaminant concentrations measured in area 1, decreasing across the harbour with increasing distance from Muggah Creek (Smith et al., 2009).

Sediment samples were collected during baseline (2009) and three years of remediation (2010, 2011 and 2012) using an Ekman grab taking care to allow surface seawater to drain away to minimise disturbance of surface sediment before sub-sampling (Walker et al., 2008; Walker and Grant, 2009). Sub-samples of the 0–1 cm horizon were collected to capture the most recently deposited sediment material in consideration of low deposition rates in Sydney Harbour (0.4–0.8 cm yr^{-1}) (Walker et al., 2013b). Samples were analysed for low level total PAHs (18 individual PAH compounds) based on US-EPA 8270C; aroclor PCBs based on US-EPA US-EPA 8082; and Pb based on US-EPA 6020A (US-EPA, 2005). Samples were analysed by Maxxam Analytics Inc. (a Canadian Analytical Laboratory Association (CALA) certified laboratory).

Significant temporal differences between baseline and remediation (or following dredging) were determined by one-way ANOVA followed by Tukey's test; years attributed with same letters were not significant and those with different letters were significantly different ($p < 0.05$ level). Baseline sampling data represents "before" and were compared with subsequent annual monitoring events during remediation, representing "after" treatment. Concentrations of PAHs and PCBs were compared to sediment quality guidelines (SQGs) developed by US National Oceanographic and

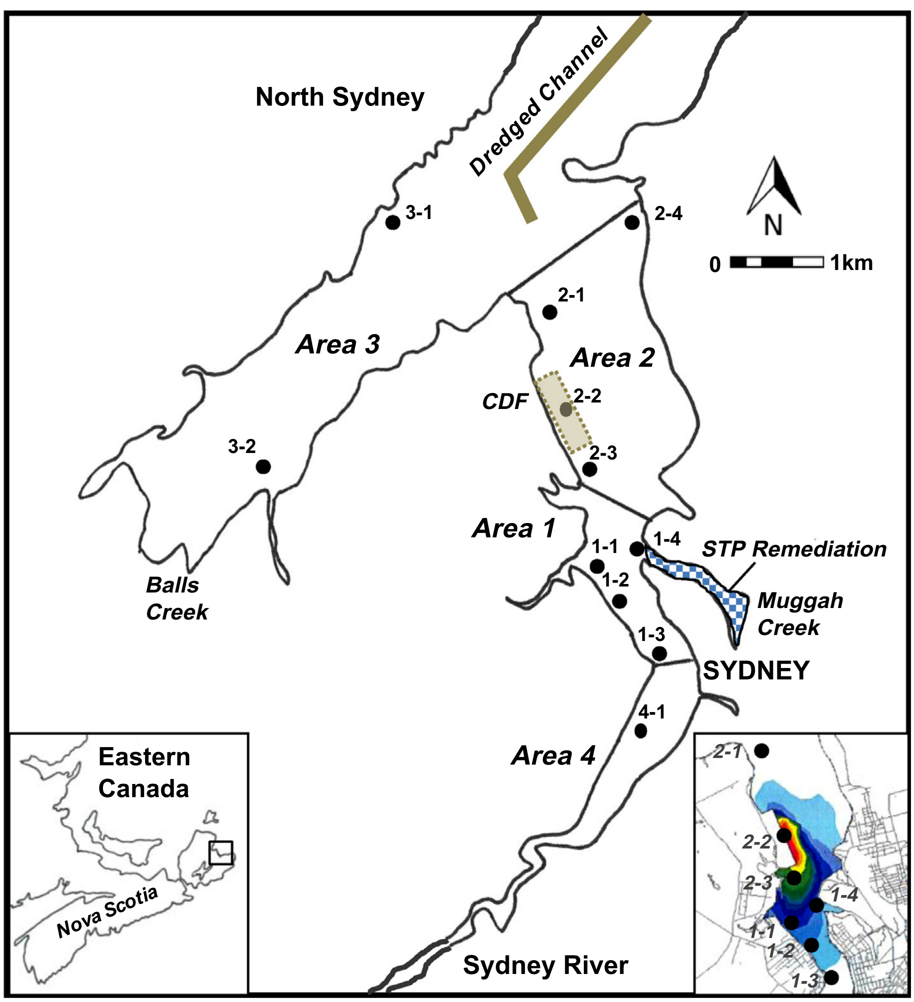

Fig. 1. Marine monitoring stations and assessment areas in Sydney Harbour relative to the STP remediation site and the navigation dredge channel and CDF. (right inset) Dredge plume dispersal and deposition modelling (red, 75–150 cm; yellow, 25–75 cm; green, 7–25 cm; blue, 1–7 cm) (adapted from Jacques Whitford, 2009). Station 2-2 was lost due to infilling at the CDF and could not be sampled in 2012 (year 3). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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