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Effects of coastal managed retreat on mercury biogeochemistry

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ABSTRACT

We investigated the impact of managed retreat on mercury (Hg) biogeochemistry at a site subject to diffuse contamination with Hg. We collected sediment cores from an area of land behind a dyke one year before and one year after it was intentionally breached. These sediments were compared to those of an adjacent mudflat and a salt marsh. The concentration of total mercury (THg) in the sediment doubled after the dyke was breached due to the deposition of fresh sediment that had a smaller particle size, and higher pH. The concentration of methylmercury (MeHg) was 27% lower in the sediments after the dyke was breached. We conclude that coastal flooding during managed retreat of coastal flood defences at this site has not increased the risk of Hg methylation or bioavailability during the first year. As the sediment becomes vegetated, increased activity of Hg-methylating bacteria may accelerate Hg-methylation rate.
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1. Introduction

Coastal wetlands have been subject to dramatic global declines in the past due to dyking and draining for agriculture. However, this practice is now being reversed in many countries because salt marshes are valued as habitats for wildlife and as natural defence against rising sea-levels (Singh et al., 2007). Managed retreat of coastal defences has led to an increase in the number of sites where dykes are breached, agricultural fields are inundated with seawater, sediment is deposited over soils, and new salt marshes are created. Inundation of previously dyked farmland leads to considerable biogeochemical changes, characterised by increased salinity, lower redox potential (Portnoy and Giblin, 1997) and a decaying mat of buried vegetation (Emmerson et al., 2000). There is concern that biogeochemical changes during managed retreat may alter the fate of redox-sensitive contaminants such as mercury (Hg) (Morris et al., 2014).

The Bay of Fundy in Southeastern Canada is renowned for having the largest tidal amplitude in the world, which gives rise to expansive intertidal mudflats and vast areas of salt marsh (Crowell et al., 2011; Desplanque and Mossman, 2004). For centuries the Bay's coastline has been extensively dyked to use the land for agriculture (Wynn, 1979). The land surrounding the Bay of Fundy is designated a 'biological mercury hotspot' due to elevated concentrations of Hg in biota (Evers et al., 2007). The Bay of Fundy itself has been identified as an area of special concern for Hg contamination because the Bay's ecosystem may be critical to concentrations of Hg found in fish, birds and wildlife (Hung and Chmura, 2006).

Mercury enters the Bay of Fundy through seawater inflow and atmospheric deposition (Sunderland et al., 2012). The Hg present in sediments of the Bay of Fundy is strongly associated with organic matter and fine textured sediments (O'Driscoll et al., 2011; Sizmur et al., 2013b). Inorganic Hg in sediments can be converted to methylmercury (MeHg) under anoxic conditions by sulphate-reducing bacteria (Compeau and Bartha, 1985). Methylmercury can biomagnify through food webs (Lavoie et al., 2010) and is a potent neurotoxin affecting higher trophic level animals and humans (Rasmussen et al., 2005).

Increases in MeHg concentrations in sediments and biota have been observed during the decades that follow terrestrial freshwater flooding for dam construction or wetland creation (Kelly et al., 1997; Sinclair et al., 2012). However, little research has been done to assess changes in Hg biogeochemistry after coastal wetland flooding. Terrestrial flooding events, like reservoir or wetland creation, entail a permanent change in sediment redox from oxic to anoxic conditions because the sediments are constantly flooded. However, coastal flooding events subject the land to fluctuating oxic/anoxic conditions due to the tidal cycle. These fluctuations generate an oxic–anoxic interface in the sediment. The temporal

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fluctuations in redox conditions increases the volume of sediment where sulphate reduction and mercury methylation may occur (Heim et al., 2007; Sizmur et al., 2013a). However, there is also frequent tidal flushing of inundated areas which acts as a significant means of removing MeHg from the surface of coastal sediments (Guédron et al., 2012). Therefore, it is not clear if coastal managed retreat will increase or decrease Hg and MeHg concentrations in sediments.

We investigated the effects of managed retreat on mercury biogeochemistry at Beaubassin Research Station where a dyke has recently been breached, allowing the seawater to inundate land previously drained for agriculture.

2. Materials and methods

2.1. Site description

Beaubassin Research Station (Latitude: 45.852195 Longitude: −64.279631) is located on the Chignecto Isthmus between Nova Scotia and New Brunswick, Canada (Fig. 1a). It lies along the Cumberland Basin, a branch of Chignecto Bay, in the Bay of Fundy which is sourced from the Gulf of Maine. The average tidal amplitude at Beaubassin is 11 m (Gordon and Baretta, 1982). Recently, an eroding 150-year-old dyke was replaced with a new dyke built approximately 90 m back from the pre-existing coastline in order to protect transport infrastructure and the historic site of Fort Beausejour from tidal surges. The 40 ha of low lying land between the old dyke and the new dyke (Latitude: 45.851595 Longitude: −64.294379) was flooded in October 2010. Flooding occurred when the old dyke was deliberately breached so that sediment could accumulate to protect the new dyke before the old dyke completely failed (Ollerhead et al., 2011). Tidal re-entry has resulted in the rapid deposition of fresh sediment over the top of the agricultural soil, burying a mat of terrestrial vegetation. At the time of sampling, new salt marsh vegetation was yet to establish.

2.2. Sample collection and preparation

Two 16 cm deep cores were taken in the dyke cell (Fig. 1b) between the new and the old dykes (hereafter referred to as the pre-breach cores) in summer 2009 (before the old dyke was breached in 2010). We returned to the site in summer 2011 to collect cores one year after the old dyke was breached. Three 15 cm deep cores were sampled at four locations: (i) The area previously sampled in the dyke cell between the new and old dykes (hereafter referred to as the post-breach cores), (ii) the mudflat seaward of the dyke cell, (iii) a pre-existing salt marsh adjacent to the dyke cell, and (iv) the field landward of the dyke cell (Fig. 1b). All cores were sampled at low tide using polyvinyl chloride (PVC) cores (10 cm internal diameter) that were dug out with a stainless steel spade.

Pre-breach cores were sliced in 2 cm intervals to a depth of 16 cm, producing a total of eight slices per core. Each of the post-breach, mudflat, salt marsh, and field cores were sliced at 1 cm intervals for the upper 5 cm of sediment and then at 2 cm intervals for the remaining 10 cm, producing a total of 10 core slices per core. Core slices were individually sealed in Ziploc bags at the research station and placed in a dark cooler with ice packs for transport back to the laboratory.

At the laboratory each sediment slice was thoroughly homogenised by hand in the Ziploc bag and frozen as a wet homogenate

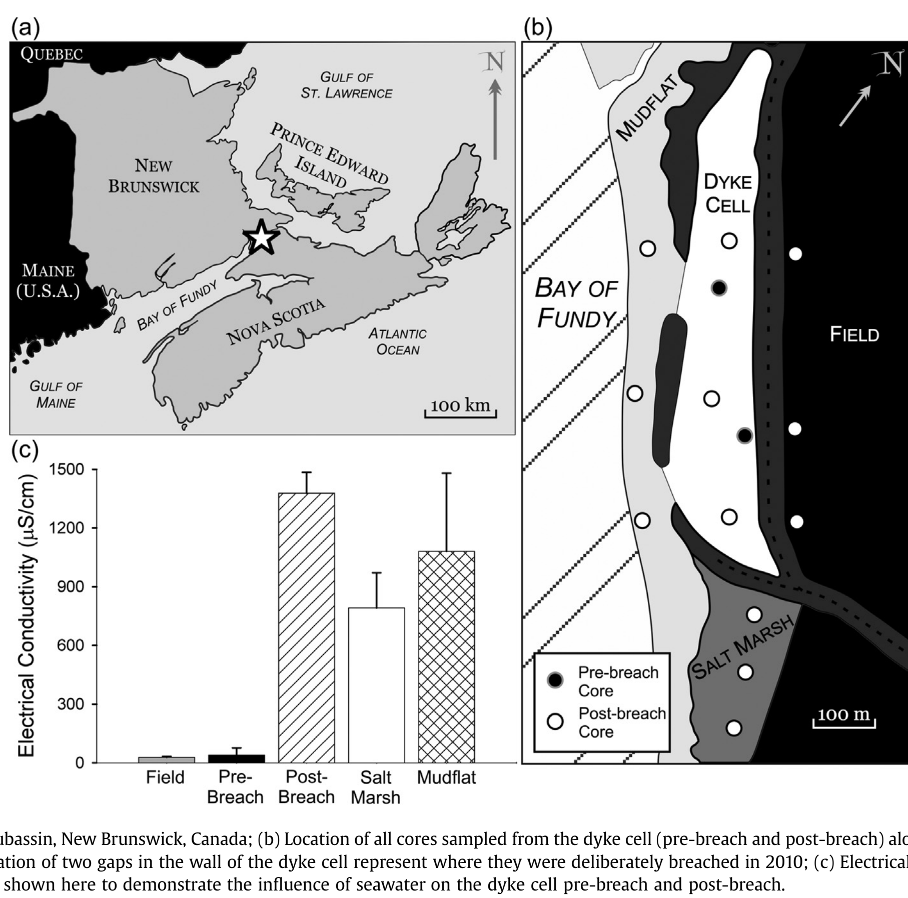

Fig. 1. (a) Site location at Beaubassin, New Brunswick, Canada; (b) Location of all cores sampled from the dyke cell (pre-breach and post-breach) along with adjacent sites (mudflat, salt marsh and field). The location of two gaps in the wall of the dyke cell represent where they were deliberately breached in 2010; (c) Electrical conductivity of sediment cores sampled (averaged 0–15 cm) shown here to demonstrate the influence of seawater on the dyke cell pre-breach and post-breach.

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