Marine Pollution Bulletin xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

A pilot study on remediation of muddy tidal flat using porous pile

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ARTICLE INFO

Article history:
Received 5 July 2016
Received in revised form 7 November 2016
Accepted 10 November 2016
Available online xxxx

Keywords:
Remediation
Muddy tidal flat
Porous pile
Groundwater flow

ABSTRACT

In order to prove that porous piles are effective in remediating muddy tidal flat sediments and increasing the biomass, field experiments were carried out at the tidal flat of a brackish river located in Hiroshima City, Japan. Porous piles with a diameter of 16 cm and height of 50 cm were installed in the muddy sediment that covers the sand layer of the tidal flat. After installation, concentrations of dissolved oxygen in interstitial water in and around the porous piles increased to a maximum concentration of 6 mg/l due to enhancement of the groundwater flow. The increase of dissolved oxygen in the interstitial water produced a decrease in the concentration of ammonia and an increase in the individual number of benthos at the porous pile site. From these results, we concluded that the porous pile is an effective technology for remediation of muddy tidal flats.

1. Introduction

High organic contaminants in the muddy sediments of tidal flats may consume dissolved oxygen in the pore water through oxidative decomposition processes. Under such reduced conditions, ammonia and hydrogen sulfide, both highly toxic to benthic organisms, are generated through anaerobic decomposition processes. These processes may also cause depletion of dissolved oxygen (DO) in the pore water due to oxidation, resulting in the deterioration of tidal flat ecosystems. Since oxygen depletion is fatal to organisms, it sometimes brings great fishery economic losses to the river in terms of fishing. Therefore, it is very important to reduce the concentration of oxygen-reducing substances in sediments so as to maintain healthy ecosystems.

The Ota River divides into 6 branches at northern Hiroshima City, Japan and runs through the City, as shown in Fig. 1. Two flood gates were constructed to control the river discharge in 1960. A huge area of reclamation has been created the river mouth by enclosing and filling tidal flats and shallow coastal space (Fig. 1(b) and (c)). This has led to changes in the hydraulic conditions of the river. Furthermore, constructions of sheet pile have been raised along the riverbank to reduce damage from the disruption of the groundwater flow. These anthropogenic developments have fragmented the tidal flat environment along the rivers, resulting in silt and clay particles (hereafter muddy sediment; content of silt and clay particles are about 40%) being deposited on the sandy tidal flat (Abe et al., 2010). Due to the weak soil hardness and odor of the muddy sediment, inhabitant of Hiroshima City cannot approach this intertidal flat. Thus, it is important to remediate the intertidal flat to restore water front and maintain healthy aquatic ecosystems.

Studies have found that groundwater flow plays an important role in supplying DO in tidal flat sediments (Datry et al., 2004; Chapelle et al., 2012), and that groundwater flow may sometimes enhance erosion of muddy sediment by decreasing critical shear stress (Kim et al., 2009). Permeability of muddy tidal flats is generally very low, and groundwater can be stagnant. Our hypothesis is that installation of high permeability material can lead to an enhancement of groundwater flow and contribute to remediation of organically enriched muddy tidal flats by supplying DO.

In order to prove that the installation of porous piles creates groundwater flow that is effective in remediating muddy tidal flats and increasing biomass, field experiments were carried out at the tidal flat of a brackish river located in Hiroshima City, Japan.

2. Materials and methods

The experimental site was a muddy tidal flat of the Motoyasu River (Figs. 1(c), 2 (a)). This muddy tidal flat is under the influence of both tides and the outflows from the Ota River watershed. In Nov. 2005,

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http://dx.doi.org/10.1016/j.marpolbul.2016.11.019
0025-326X/© 2016 Published by Elsevier Ltd.

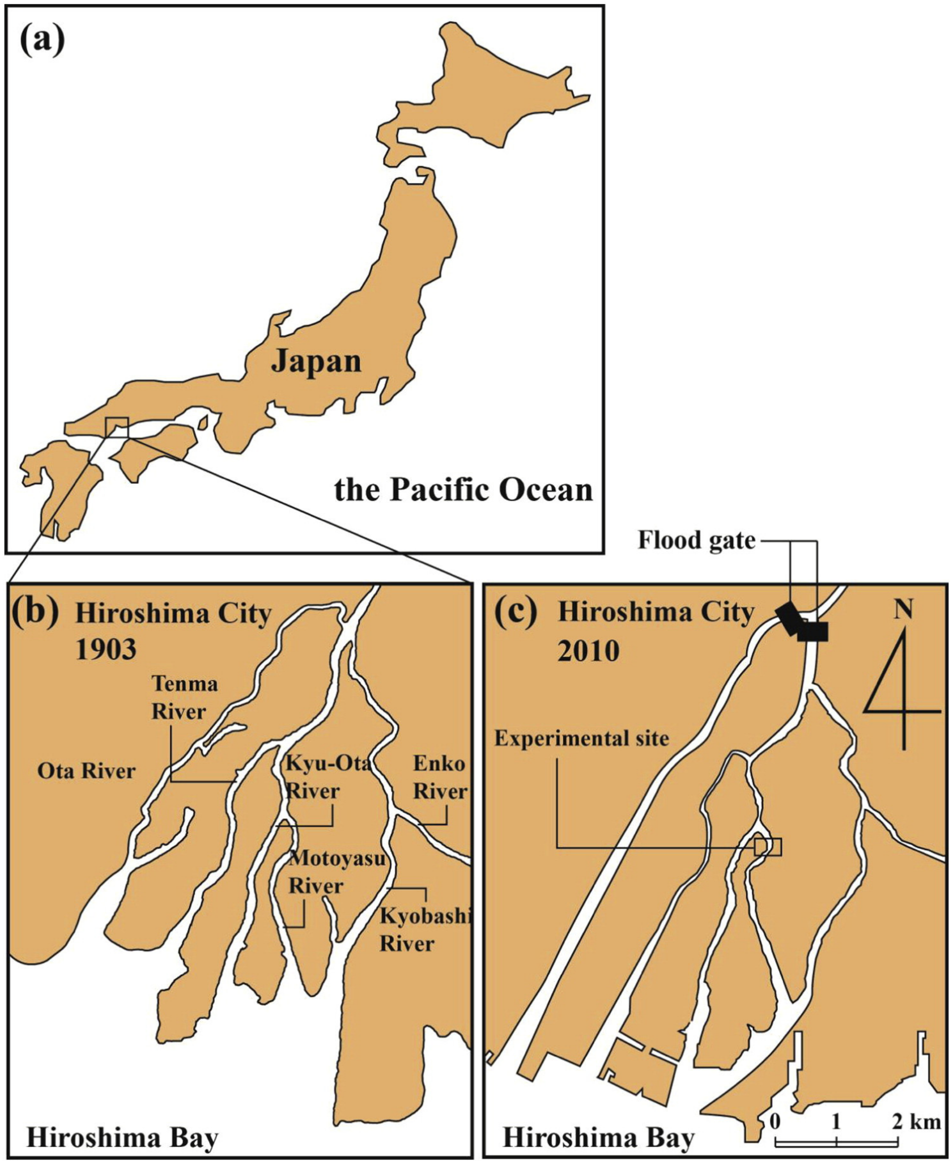

Fig. 1. Map showing (a) the site where the field experiments were carried out and a topographical map of Hiroshima City in (b) 1903 and (c) 2010.

porous piles with a diameter of 16 cm and height of 50 cm were installed in the muddy sediment that covers the sand layer of the tidal flat (Fig. 2(b)), and field observations and samplings were carried out annually from 2005 to 2010 (20 Sep. 2005, 5 Oct. 2006, 21 Sep. 2007, 16 Sep. 2008, 18 Sep. 2009 and 27 Sep. 2010). A total of 36 porous piles (rows of 3×12) were installed in the sediment with intervals of 1.5 m.

Circumference shaped iron nets were installed at a depth of 50 cm from the surface, and sediments in the nets were replaced by Granulated Coal Ash (GCA) porous media. The GCA was a mixture of fly ash and cement, 5–50 mm in diameter (Fig. 3). A control site was left untreated as a reference. Observations of the physical, chemical and biological conditions were carried out every year. The GCA used in this study was provided by the Chugoku Electric Power Co., Inc., Hiroshima, Japan. Chemical composition of GCA was shown in Table 1. The physical and chemical characteristics of the GCA, including the mechanisms of sediment remediation, are described in Asaoka et al. (2009) and Asaoka et al. (2012). It has been reported that the concentrations of heavy metals in the GCA were below the standard levels set for soil pollution environmental criteria in Japan (Asaoka et al., 2008).

A pressure meter (Compact-TD, JFE Advantec Co., Ltd., Kyoto, Japan), water temperature and salinity meter (Compact-CT, JFE Advantec Co., Ltd., Kyoto, Japan) and DO meter (Compact-DOW, JFE Advantec Co., Ltd., Kyoto, Japan) were positioned on the bottom of the porous pile immediately before it was filled with GCA.

Sediment cores ($n = 3$) were collected from the center of each site (T.P. = 0 m) with acrylic pipes ($\Phi = 7.5$ cm, 50 cm long). The oxidation-reduction potential (ORP) of samples was measured (PS-112C, RM1; TOA Electronics, Ltd., Tokyo, Japan), then sediment samples were placed in plastic containers and kept in the dark at a cool temperature during transportation to the laboratory. Content of particles under 75 μm was measured using a laser diffraction particle-size distribution analyzer (Sald-2000, Shimadzu Corporation, Kyoto, Japan).

The interstitial water of the sediment was collected by centrifugation (3000 rpm, 20 min), and the filtered interstitial water was immediately frozen for the later analysis of nutrients. The concentrations of NH_4-N, NO_3-N and NO_2-N were determined by standard methods (American Public Health Association et al., 1989) using an auto analyzer (SWATT; BLTEC).

Please cite this article as: Ryu, S.-H., et al., A pilot study on remediation of muddy tidal flat using porous pile, Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.11.019