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Integrated hazard, risk and impact assessment of tropical marine sediments from Tema Harbour (Ghana)

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HIGHLIGHTS

- Whole-sediment bioassays indicated severe toxicity in Tema Harbour sediments.
- *C. volutator* exhibited greater sensitivity to the sediment toxicity than *H. diversicolor*.
- A logarithmic correlation was observed between sediment Cd concentration and *C. volutator* mortality.
- A linear correlation was observed between sediment Cu concentration and *H. diversicolor* mortality.
- Tema Harbour sediments are not suitable for disposal at sea without remediation.

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ABSTRACT

The potential ecological hazard, risk and impact of tropical marine sediments from the Tema Harbour (Greater Accra, Ghana) was investigated by integrating *Corophium volutator* and *Hediste diversicolor* whole-sediment toxicity bioassays with data on the metals (Cd, Pb, Cr, Ni, Cu, Zn and As) concentrations of the sediments. The whole-sediment toxicity bioassay results showed that sediments of the Tema Harbour are potentially hazardous to marine benthic invertebrates. *C. volutator* exhibited a higher vulnerability to the sediment toxicity than *H. diversicolor*, although the latter showed higher biota-sediment accumulation factors for the investigated metals. Statistically significant correlations were observed between *C. volutator* mortality and sediment Cd concentration ($r = 0.84$, $p < 0.05$; $n = 6$) and between *H. diversicolor* mortality and sediment Cu concentration ($r = 0.94$, $p < 0.05$; $n = 5$). Comparison of metal concentrations with international action levels for contaminated sediment disposal indicates that the Tema Harbour sediments contain potentially hazardous concentrations of Cu and Zn. This study shows that sediments from the Tema Harbour are not suitable for disposal at sea without remediation. There is, therefore, a need to improve environmental management and regulate the disposal of dredged material originating from the Tema Harbour.

1. Introduction

Contaminated sediments can be a source of hazardous contaminants to aquatic organisms, particularly benthic species (Burgess et al., 2007; Birch and Hutson, 2009). These benthic organisms play important roles in the functioning of aquatic ecosystems, such as biogeochemical cycling (Durou et al., 2007) and as a source of food for other species in the aquatic food chain (Burton Jr, 2002; Birch and Hutson, 2009; Carvalho et al., 2011; Gaion et al., 2014). The impact of contaminated sediments on benthic organisms can thus have serious consequences for the entire food chain (Burton Jr, 2002; Gaion et al., 2014) and the proper functioning of aquatic ecosystems. Consequently, sediment contamination is a major issue and information on the associated potential adverse

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ecological impact is of great interest to environmental regulators (Birch and Hutson, 2009; Schipper et al., 2010). Several biological effect-based sediment quality guidelines (SQGs) have been developed as predictive tools for assessing the potential of contaminated sediments to cause adverse biological effects (Burton Jr, 2002; Long et al., 2006; Schipper et al., 2013).

The abilities of SQGs to predict adverse biological effects associated with contaminated sediments are, however, limited since SQGs do not account for: (1) contaminant bioavailability (Schipper et al., 2010); (2) synergistic or antagonistic effects of contaminant mixtures present in sediments under natural conditions (Ciarelli et al., 1998; Forrester et al., 2003; Eisentraeger et al., 2004; Schipper et al., 2010); (3) multiple effects that may be exhibited by a single contaminant (Eggen et al., 2004); (4) chronic effects that may result from long-term exposure to low concentrations of contaminants in sediments (Eggen et al., 2004) and (5) contaminants present in sediments without being measured or identified as toxic or hazardous substances (Eisentraeger et al., 2004; Burgess et al., 2007). Consequently, whole-sediment toxicity bioassays have been recommended for the ecotoxicological characterisation of contaminated sediments to overcome the limitations of the SQG approach (Annicchiarico et al., 2007; Ré et al., 2009; Schipper et al., 2010). Whole-sediment toxicity bioassays involve the exposure of pollution-sensitive benthic invertebrates to contaminated sediments under laboratory conditions (Forrester et al., 2003). Integrating whole-sediment bioassays with the SQG approach can provide valuable insight into contaminants potentially contributing to sediment toxicity.

Marine benthic invertebrates such as *C. volutator* (Stronkhorst et al., 2003; Scarlett et al., 2007; van den Heuvel-Greve et al., 2007; Mayor et al., 2008) and *H. diversicolor* (Moreira et al., 2006; Mayor et al., 2008) are often employed as bio-indicators of pollution in marine and estuarine whole-sediment toxicity bioassays. Preference for *C. volutator* is due to its ease of collection and maintenance under laboratory conditions, availability in the field throughout the year, and tolerance to a wide range of salinities, sediment grain sizes and organic carbon contents (Ciarelli et al., 1998; Roddie and Thain, 2002; Scaps, 2002; Bat, 2005). *H. diversicolor* commonly occurs in intertidal areas, is able to survive in hypoxic and contaminated environments and exhibits tolerance to wide fluctuations in salinity and temperature (Scaps, 2002; Philippe et al., 2008). Both *C. volutator* and *H. diversicolor* have wide geographic distributions across polar, temperate and tropical marine regions (Bat, 2005; Moreira et al., 2006; Uwadiae, 2010; Carvalho et al., 2011). However, standard whole-sediment toxicity bioassay protocols have been developed mainly with temperate *C. volutator* (Roddie and Thain, 2002; Schipper et al., 2006) and *H. diversicolor* (Hannewijk et al., 2004) with mortality as toxic response (endpoint), whereas whole-sediment toxicity bioassays with tropical species are not well developed (Adams and Stauber, 2008). Therefore, studies on the use of *C. volutator* and *H. diversicolor* bioassays to assess the toxicity of sediments from tropical marine environments are scarce.

With over 50% of the world's population living in coastal zones (Petrosillo et al., 2009), the coastal marine environment is characterised by intense anthropogenic activities such as waste disposal, crude oil extraction and oil spills, shipping, fishing, agriculture and industrialisation (Petrosillo et al., 2009; Lepland et al., 2010; Schipper et al., 2010). This is also the case for the tropical marine Tema Harbour in Greater Accra (Ghana). Anthropogenic activities are a source of a wide range of hazardous substances, which adversely impact organisms inhabiting the coastal marine environment (Petrosillo et al., 2009; Lepland et al., 2010; Schipper et al., 2010): previous studies have shown that sediments of the Tema Harbour are contaminated by polycyclic aromatic hydrocarbons and organochlorine pesticide residues (Botwe et al., 2017) and metals (Nyarko et al., 2014; Botwe et al., unpublished results). Since Tema Harbour sediments are dredged periodically with subsequent disposal/storage under seawater, assessment of sediment quality is required to guide sediment management decisions at Tema Harbour and minimise adverse ecological impact. Therefore, the objectives of this study were to investigate: (1) the overall potential toxicity (hazard) of Tema Harbour sediments, (2) the potential risk (toxicity and bioavailability) of metal contamination in the sediments and (3) the potential impact (bioaccumulation) of metal contamination in the Tema Harbour sediments on benthic invertebrates by integrating whole-sediment toxicity bioassays with metal contamination data.

2. Materials and methods

2.1. Study area

The Tema Harbour in Greater Accra (Ghana) is a semi-enclosed coastal marine harbour with a water area of approximately 2 km^2, which forms part of the Gulf of Guinea (Fig. 1). The salinity of the Tema Harbour water ranges from 30 to 35‰. The Tema Harbour is compartmentalised into a Main Harbour, an Inner Fishing Harbour, an Outer Fishing Harbour and a Canoe Basin, which are bound to experience different anthropogenic impacts. The Main Harbour, the Inner Fishing Harbour and the Canoe Basin have been in operation since 1962, while the Outer Fishing Harbour was constructed in 1965. Various ships including oil tankers, bulk carriers, general cargo ships and containerships call at the Main Harbour. The Fishing Harbour provides handling facilities for semi-industrial and industrial fishing vessels such as trawlers, tuna vessels, and deep-sea carriers, while the Canoe Basin is a dedicated artisanal canoe fishing landing site. To ensure safe navigation, the Main Harbour is subject to dredging since 1998, whereas the Canoe Basin was dredged in May 2013. No dredging has yet been conducted in the Fishing Harbour. Located within an industrial setting, the Tema Harbour is subject to contamination not only from maritime operations (e.g. bunkering and refuelling, maintenance and repairs of vessels), but also from industrial activities (e.g. wastewater discharges into the harbour).

2.2. Sediment sampling

Grab sediment samples were collected from thirty stations (1–30) within the Tema Harbour (Fig. 1) in January 2016 using a stainless steel 3.5 L Ekman grab. The grab samples were composited to obtain five samples for analysis. In the Main Harbour, grabs 1–6 were composited to form sample MH1, while grabs 7–12 formed sample MH2. All grabs from the Outer Fishing Harbour (13–18) were composited into sample OFH, grabs from the Inner Fishing Harbour (19–24) formed sample IFH, while grabs from the Canoe Basin (25–30) formed sample CB (Fig. 1). All composite samples were mixed thoroughly with a plastic shovel in acid-washed plastic bowls before taking about 3.5 L portions into 3.78 L FoodSaver® zipper bags. All the samples were sealed air-tight using a hand-held vacuum pump and kept on ice in an ice-cool box in the field and during transportation to the Marine and Fisheries Department laboratory at the University of Ghana (Accra, Ghana), where they were stored overnight in a refrigerator at 4 °C. The samples were kept chilled in an ice-cool box and transported by air to the Systemic Physiological and Ecotoxicological Research laboratory (SPHERE) at the University of Antwerp (Belgium). The samples were kept there in a cold room at 4 °C until the bioassay experiments were conducted within 2 weeks of sample collection (Roddie and Thain, 2002).