Effects of enhanced bioturbation intensities on the toxicity assessment of legacy-contaminated sediments

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1. Introduction

The magnitude of land use and industrialisation within coastal regions is increasing globally, putting aquatic ecosystems under threat from a range of stressors (Borja et al., 2016; Gunderson et al., 2016; Wenger et al., 2016). Sediments act as a sink for a wide range of contaminants, and those located within estuaries represent some of the most degraded ecosystems (Chariton et al., 2010; Clark et al., 2015; Dafforn et al., 2013; Lindgren et al., 2016; Lotze et al., 2006; Perelo, 2010).

The remediation of contaminated sites is often an expensive exercise, leading to monitored natural recovery (MNR) being favoured as a remediation option (Lotze et al., 2006; Reible and Algar, 2014; Pedersen et al., 2016). Natural recovery relies on natural physical, chemical, and biological processes to isolate, destroy, or otherwise reduce the exposure to and bioavailability and toxicity of contaminants (Magar and Wenning, 2006; Perelo, 2010). Consequently, there are both abiotic and biotic processes that will influence whether contaminated sediments will recover naturally, and the rate of recovery. Better understanding of factors influencing ecosystem recovery may enable resource managers to invest in moderate remediation actions that significantly increase recovery rates.
Although the abundance of some benthic organisms, such as polychaetes, may increase in response to contamination (Dafforn et al., 2013), many systems become deprived of other larger bioturbating organisms. The burrowing and feeding activities of these larger benthic organisms are responsible for physically moving considerable amounts of sediments, e.g. bringing deeper sediments to the surface, and facilitating a range of biogeochemical processes, including the degradation of organic matter (Aller et al., 2001; Cadée, 2001; Levinton, 1995). Thus the absence of larger bioturbators will change the dynamics of the ecosystem, influencing the bioavailability and degradation of sediment-bound contaminants directly (Simpson et al., 2002; Ciutat and Boudou, 2003; Josefsson et al., 2010), and indirectly through changes to the behaviour and function of other organisms, including benthic microorganisms and hard substrata organisms immediately above sediments (Branch and Pringle, 1987; Reichardt, 1988; Goni-Urriza et al., 1999; Hill et al., 2013). The disturbance of sediments by bioturbation displaces porewater and modifies fluxes of both dissolved and particulate substances into the overlying waters (Ciutat and Boudou, 2003; Ciutat et al., 2006; Granberg et al., 2008; Josefsson et al., 2010; Amato et al., 2016). This disrupts redox equilibria that influence the sediment-water partitioning of contaminants, including those that influence trace metal bioavailability (Josefsson et al., 2010). The disturbance of sediments by bioturbation also induces release of sediment-bound organic contaminants (poly- partitioning and overlying water chemistry (Atkinson et al., 2007). Bioturbators will change the dynamics of the ecosystem, in ecosystems that have been degraded due to high concentrations of contaminated sediments (0–15 cm depth) were collected from Lake Illawarra and transplanted to bioturbated by the sand prawn Sipunculus nudus (unsegmented marine worm) (Li et al., 2015). Both Granberg et al. (2008) and Josefsson et al. (2010) have reported significant bioturbation-induced release of sediment-bound organic contaminants (poly-chlorinated biphenyls (PCBs) and polybrominated biphenyl ethers (PBDEs)) with the polychaete Marenzelleria spp, but only Josefsson et al. (2010) observed an apparent relationship between bioturbation and accumulation in this species.

When assessing the potential for sediment contamination to cause toxicity to benthic organisms, standard bioassays are used which typically comprise single species within exposure chambers that isolate them from disturbances by other organisms, and also from abiotic processes such as water currents that might cause sediment to be resuspended intermittently in their natural setting (ASTM, 2014; Simpson and Kumar, 2016). It has been clearly demonstrated that sediment disturbance will alter sediment-metal partitioning and overlying water chemistry (Atkinson et al., 2007). Remalli et al. (2016) showed in metal-contaminated sediments, the survival of the bivalve Tellina deltoidalis was higher when cohabiting with the actively bioturbating amphipod Victoriosipa australiensis, compared to bivalve-only communities in the same contaminated sediments. This was attributed to the increased intensity of bioturbation resulting in increased scavenging of dissolved copper by resuspended particulate phases resulting in lower exposure of the bivalve to copper.

The importance of designing tests to adequately mimic exposures and conditions encountered in the field is not a new consideration for sediment quality assessments (Burton et al., 2005, 2012; Mann et al., 2010; Belzunce-Segarra et al., 2015; Costello et al., 2015). However, generally such considerations only extend to the abiotic nature of field conditions (e.g. dissolved oxygen and light conditions, food availability etc.). Few studies consider the importance of organism-organism interactions when assessing contaminant bioavailability or, potentially more importantly, when applying bioassay results to predicting the trajectory of the natural recovery of contaminated sediments.

The present study tested the hypothesis that bioturbation activities of a secondary organism will change contaminant bioavailability to an extent sufficient to alter the outcomes of a chronic sediment toxicity test. The specific objective of this work was to investigate the reproduction of a test amphipod exposed to contaminated sediments in the presence and absence of an active secondary bioturbator. The test species was used the small epibenthic amphipod Melita plumulosa, and the secondary bioturbator was the larger more tolerant endobenthic amphipod V. australiensis. Two sediment types were tested, one primarily contaminated with metals and the second had both metals and petroleum hydrocarbons. The results are discussed in relation to the adequacy in which standardised test procedures replicate the assessment of the environment, and also our understanding of the recovery processes for natural sediments.

2. Materials and methods

2.1. Test media and organisms

Clean seawater was obtained from the southeast coast of New South Wales (NSW), Australia, filtered (1 μm) and analysed prior to use to ensure that the metals of interest were below 1 μg L⁻¹. Sediments (0–15 cm depth) were collected from Lake Illawarra (control, S1), and five contaminated sites: one in Port Kembla, NSW (S2), and four along the south-western foreshore of the Parramatta River, NSW (S3, S4, S5 and S6). Sediment collection, homogenisation and storage (4 °C) were conducted as per Belzunce-Segarra et al. (2015).

The epibenthic amphipod M. plumulosa, endemic to the estuarine tidal mudflats of south-eastern Australia, was used to assess the effects on reproduction. M. plumulosa individuals were obtained from previously established laboratory cultures, maintained as described per Spadaro and Simpson (2016). The bioturbator used in this experiment was the endobenthic, deposit-feeding amphipod V. australiensis (Chilton, 1923; 2–3 cm body length) collected from Lake Illawarra.

2.2. Reproduction bioassay

The 10–day renewed whole-sediment bioassay was conducted according to Spadaro and Simpson (2016), with modifications to incorporate bioturbation intensity as a variable. The toxicity tests were conducted at constant temperature (21 ± 1 °C) within an environmental chamber (Labec Refrigerated Cycling Incubator, Laboratory Equipment) on a 12-h light/12-h dark rotational cycle (light intensity = 35 μmol photons s⁻¹ m⁻²) and aeration provided. Each test comprised of three conditions: (i) with no added organisms (No bioturbation), (ii) with M. plumulosa added (Low bioturbation), and (iii) with both M. plumulosa and the larger bioturbating amphipod V. australiensis added (High bioturbation). The No bioturbation
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