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Uptake and loss of dissolved ^{109}Cd and ^{75}Se in estuarine macroinvertebrates

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Abstract

Semaphore crabs (*Heloecius cordiformis*), soldier crabs (*Mictyris platycheles*), ghost shrimps (*Trypaea australiensis*), pygmy mussels (*Xenostrobus securis*), and polychaetes (*Eunice* sp.), key benthic prey items of predatory fish commonly found in estuaries throughout southeastern Australia, were exposed to dissolved ^{109}Cd and ^{75}Se for 385 h at 30 kBq/l (uptake phase), followed by exposure to radionuclide-free water for 189 h (loss phase). The whole body uptake rates of ^{75}Se by pygmy mussels, semaphore crabs and soldier crabs were 1.9, 2.4 and 4.1 times higher than ^{109}Cd, respectively. There were no significant ($P > 0.05$) differences between the uptake rates of ^{75}Se and ^{109}Cd for ghost shrimps and polychaetes. The uptake rates of ^{109}Cd and ^{75}Se were highest in pygmy mussels; about six times higher than in soldier crabs for ^{109}Cd and in polychaetes for ^{75}Se – the organisms with the lowest uptake rates. The loss rates of ^{109}Cd and ^{75}Se were highest in semaphore crabs; about four times higher than in polychaetes for ^{109}Cd and nine times higher than in ghost shrimps for ^{75}Se – the organisms with the lowest loss rates. The loss of ^{109}Cd and ^{75}Se in all organisms was best described by a two (i.e. short and a longer-lived) compartment model. In the short-lived, or rapidly exchanging, compartment, the biological half-lives of ^{75}Se (16–39 h) were about three times greater than those of ^{109}Cd (5–12 h). In contrast, the biological half-lives of ^{109}Cd in the longer-lived, or slowly exchanging compartment(s), were typically greater (1370–5950 h) than those of ^{75}Se (161–1500 h). Semaphore crabs had the shortest biological half-lives of both radionuclides in the long-lived compartment, whereas polychaetes had the greatest biological half-life for ^{109}Cd (5950 h), and ghost shrimps had the greatest biological half-life for ^{75}Se (1500 h). This study provides the first reported data for the biological half-lives of Se in estuarine decapod crustaceans. Moreover, it emphasises the importance of determining metal(loid) accumulation and loss kinetics in keystone prey items, which consequently influences their trophic transfer potential to higher-order predators.

Keywords: Accumulation; Radionuclide; Biological half-life; Concentration factor; Trophic transfer

1. Introduction

Food web diversity is important in ecosystems. The higher the number of links or levels in a food web, the higher the number of niches organisms can occupy, which in turn creates higher species abundance and biodiversity (Post, 2002; Worm and Duffy, 2003; Bastolla et al., 2005). However, food webs are known to be vectors for contaminant transfer to higher-order predators through bioaccumulation and biomagnification (Gaston et al., 1998; Gray, 2002; Lubetkin and Simenstad, 2004; Seebaugh et al., 2005). Macroinvertebrates form an important component in the resource partitioning and food web energetics of estuarine ecosystems (Carrassón and Cartes, 2002). They are an important food source for higher-order predators, such as fish, and play a key role in bioaccumulation and transfer of metal(loid) contaminants to higher trophic levels (Peters

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et al., 1999). Elevated metal(loid) concentrations in estuaries may have a direct toxic effect on macroinvertebrates and their predators, or have an indirect effect on natural community structure by reducing prey item diversity or reducing competition within a species, resulting in a trophic cascade (Fleeger et al., 2003; Chapman, 2004).

Macroinvertebrates may accumulate metal(loid)s through various environmental pathways, including water, diet and/or sediment (Peters et al., 1999; Wang and Fisher, 1999; Boisson et al., 2003; Selck and Forbes, 2004). The relative importance of each pathway, as well as the bioavailability of the source, will influence the potential transfer factors of metal(loid)s to higher-order predators. Biokinetic models have permitted a better understanding of the relative importance of waterborne and dietary exposure pathways of metal(loid)s in macroinvertebrates and are driven by physiological processes (Wang and Fisher, 1999; Luoma and Rainbow, 2005). These processes include assimilation efficiencies from ingested foods (dietary) and metal(loid) uptake and loss rate constants from the dissolved phase (water).

This study determined the uptake and loss of dissolved ^{109}Cd and ^{75}Se in five species of macroinvertebrates (semaphore crabs, soldier crabs, ghost shrimps, pygmy mussels and polychaetes). The selected macroinvertebrates are among the main dietary items of predatory estuarine fish commonly found in south-eastern Australia (Burthmore et al., 1984; Hindell et al., 2000; Alquezar and Markich, in press). Both Cd and Se are commonly found at elevated concentrations in sediments of urbanised estuaries in southeastern Australia (Irvine and Birch, 1998; Barwick and Maher, 2003) and have a contrasting physicochemistry in water – Se occurs as an anion, whereas Cd occurs as a cation (Byrne, 2002).

2. Materials and methods

2.1. Test organisms

Five macroinvertebrate species; semaphore crabs (*Heloecius cordiformis*), soldier crabs (*Mictyris platycheles*), ghost shrimps (*Trypaea australiensis*), pygmy mussels (*Xenostrobus securis*) and polychaetes (*Eunice* sp.) were collected at Towra Point Nature Reserve in Botany Bay (34°01′S, 151°10′E), 20 km south of Sydney, Australia. The Reserve is a relatively undisturbed sandy marine delta with mangrove forest and is minimally-impacted by metal (loid)s and other contaminants (Spooner et al., 2003). Ten to fifteen individuals of each species, of a predetermined size (semaphore crab carapace width, 11.4–13.9 mm; soldier crab carapace width, 11.1–12.1 mm; ghost shrimp body length, 34.2–35.2 mm; pygmy mussel shell length, 26.1–27.6 mm, and polychaete body length, 60–65 mm), were manually sampled from sediment (0–5 cm depth) at random over a 90 × 10 m intertidal area in November 2004. Animals were transported to the laboratory in insulated containers within 4 h of collection.

2.2. Experimental system

Animals were acclimated to seawater under experimental conditions (pH 8.3 ± 0.1, temperature 18 ± 0.1 °C, salinity 31 ± 1‰, dissolved oxygen 95–100% saturation and a 2 h light/22 h dark photoperiod to mimic natural light conditions (where animals are exposed to sunlight outside of their burrows for only about 2 h each day)) for five days prior to the start of experiments. Six individuals of each species were randomly selected and individually exposed to 0.8 l of filtered (<5 μm) seawater spiked with 30 kBq/l of ^{109}Cd ($T_{1/2} = 463$ days) and ^{75}Se ($T_{1/2} = 120$ days) for 385 h (16 days) in acid-cleaned polycarbonate containers (1.2 l). There was no change in the measured pH of seawater after radionuclide addition. Test waters were renewed daily to maintain constant radionuclide concentrations (<10% depletion) and minimise radionuclide recycling. Test waters were aerated to maintain constant levels of dissolved oxygen (>95% oxygen saturation) throughout the experimental exposure period.

During the uptake phase, six selected individuals of each species were independently sampled at 0 (control), 6, 12, 25, 50, 75, 100, 150, 200, 250, 310 and 385 h and live-counted for radionuclides (see below). Organisms were rinsed thoroughly in radionuclide-free seawater to remove any loosely adsorbed radionuclides, blotted dry and weighed before being placed in 5 ml glass vials prior to radionuclide analyses. Individuals were removed from the experimental waters for no more than five minutes at each sampling time.

At the end of the uptake phase, containers were thoroughly washed in 5% nitric acid (AnalaR, BDH) and then washed twice with deionised water (Milli Q; 18 MΩ/cm) and animals reintroduced with radionuclide-free seawater. During the loss phase, the same six individuals of each species were sampled at 0 (control), 10, 25, 45, 70, 100, 140 and 189 h and live-counted for radionuclides. No mortalities occurred during the experimental exposures. Triplicate water samples (5 ml) were also taken at each sampling time. Macroinvertebrates were not fed during the experiments, to remove the possibility of ingestion of radioactive particles. There was no measured growth or observed moulting in any of the organisms during the uptake and loss experiments.

2.3. Radionuclide analyses

The radioactivities of ^{109}Cd (88 keV) and ^{75}Se (136 keV) in water and macroinvertebrates were counted for 90 s (coefficient of variation < 5%) using a high resolution gamma spectrometer, with a p-type closed end high purity germanium coaxial detector (30% relative efficiency) coupled to a multi-channel analyser (Ortec International). All samples were directly calibrated against mixed radionuclide standards with identical geometry and sample volume (water) and/or mass (whole organism). Additionally, the detector was calibrated over the full energy spectrum every