Available online at www.sciencedirect.com
ScienceDirect
Marine Environmental Research 65 (2008) 264–281
MARINE ENVIRONMENTAL RESEARCH
www.elsevier.com/locate/marenvrev

Effects of settling organic matter on the bioaccumulation of cadmium and BDE-99 by Baltic Sea benthic invertebrates

Maria H. Thorsson [a,b], Jenny E. Hedman [b], Clare Bradshaw [a,b], Jonas S. Gunnarsson [b], Michael Gilek [a,*]

[a] *School of Life Sciences, Södertörn University College, SE-141 89 Huddinge, Sweden*
[b] *Department of Systems Ecology, Stockholm University, SE-106 91 Stockholm, Sweden*

Received 16 April 2007; received in revised form 7 November 2007; accepted 12 November 2007

Abstract

Settling organic matter (OM) is the major food source for heterotrophic benthic fauna. The high sorption affinity of many contaminants for OM implies that OM can influence both the distribution and bioavailability of contaminants. Here, we experimentally examine the role of settling OM of various nutritional qualities on the bioaccumulation of cadmium and the flame retardant BDE-99 by three benthic invertebrates; *Macoma balthica*, *Monoporeia affinis* and *Marenzelleria* sp. Contaminants were associated with three types of OM; a microalgae (*Tetraselmis* spp.), lignin and sediment. Bioaccumulation of Cd was proportional to OM nutritional quality for all three species, and was species-specific in the order *Marenzelleria* > *M. balthica* > *M. affinis*. BDE-99 bioaccumulation was highest in the treatment with the most nutritious OM (*Tetraselmis*). Consequently, both benthic species composition and the nutritive value of organic matter settling to the seafloor can have a substantial effect on the bioaccumulation of both metals and organic contaminants.

Keywords: Bioavailability; Benthos; Deposit feeding; Food quality; Flame retardant; Heavy metal; Sediment pollution; *Monoporeia affinis*; *Macoma balthica*; *Marenzelleria*

1. Introduction

Settling organic matter (OM) plays a major role in coastal marine ecosystems as it is the major food source for heterotrophic benthic organisms below the photic zone. Furthermore, a high sorption affinity of most hydrophobic organic contaminants (HOCs) and metals for organic matter implies that OM can also play a major role in the distribution and bioavailability of contaminants (Lee, 2002; Schlekat et al., 2002). The Baltic Sea is characterized by spatial and temporal differences (both annually and over longer periods owing to eutrophication and climate change) in the amount and type of OM settling to the seafloor. For example, labile organic matter from diatoms and other phytoplankton species reaches the sediment following the annual

* Corresponding author. Tel.: +46 8 608 48 62; fax: +46 8 608 45 10.
E-mail address: michael.gilek@sh.se (M. Gilek).

0141-1136/$ - see front matter
doi:10.1016/j.marenvres.2007.11.004

spring bloom, whereas detritus from cyanobacteria blooms may settle during summer. Other sources of OM to benthic deposit-feeders are resuspended sediment introduced by current and storm events and allochthonous material such as products from terrestrial plants, both of which are generally of lower nutritional quality for deposit-feeding benthic animals. Due to this variation in the quality of the settling OM, it is of great interest to assess how bioaccumulation of contaminants by benthic deposit-feeders is affected by different types of OM inputs.

According to the equilibrium partitioning theory (EPT) bioaccumulation of hydrophobic organic contaminants (HOCs) is inversely proportional to the total organic carbon (TOC) content of the sediment (Lake et al., 1990). However, the EPT theory does not consider either the nutritional quality of the sediment or the feeding strategy of benthic organisms (Gunnarsson et al., 1999a). Several studies have shown that bioaccumulation of HOCs by deposit-feeding benthic animals instead can increase with increasing TOC content of the sediment and reach tissue concentrations well above those predicted by EPT (Gunnarsson et al., 1996; Gunnarsson and Sköld, 1999). In addition, not only may the bioaccumulation of HOCs be proportional to TOC quantity but also to its nutritional quality (Gunnarsson et al., 1999a; Granberg and Forbes, 2006). Gunnarsson et al. (1999a) suggested that when a significant part of the sediment TOC is composed of labile organic matter, the nutritious organic particles may act as vectors of contaminant exposure and increase the uptake of sediment-associated contaminants through their diet. On the other hand, if the sediment TOC is mostly refractory it may act as a dilution matrix and decrease the bioavailability of sediment-associated contaminants. The quality of OM may also affect the sorption kinetics of contaminants to TOC (Kukkonen et al., 2003) and thereby affect the assimilation and bioavailability of OM-associated contaminants to deposit feeders. Bioaccumulation of metals, on the other hand, is more dependent on physico-chemical variables (e.g. chemical speciation, acid volatile sulfides (AVS), salinity, pH, redox conditions) than on TOC alone (Griscom and Fisher, 2004) and consequently, steady state models, such as the free ion activity model (FIAM) and the biotic ligand model (BLM) for metals are more complicated than the EPT (Luoma and Rainbow, 2005). Nevertheless, since many metals partition preferentially to OM particles (Schlekat et al., 2002), organic matter is also of great significance for the bioavailability and hence bioaccumulation of metals. For example, an increased assimilation efficiency and bioavailability of the metal Cd with increased nutritional OM quality has been observed (Maloney, 1996; Wang and Wong, 2003). The failure of many bioaccumulation models to accurately predict the bioaccumulation of HOCs and metals by detritus-feeding organisms highlights the importance of other factors, such as the feeding ecology and physiology of the organisms. Most deposit feeders are selective feeders (Jumars and Wheatcroft, 1989), which means that they selectively choose and ingest nutritious particles such as algal cells, bacteria, and different types of detrital matter (Lopez and Levinton, 1987). This means that contaminant exposure and subsequent bioaccumulation can vary substantially among different species inhabiting the same sediment. Animal morphology as well as physiological and biochemical properties of the digestive system have also been shown to influence the bioavailability of sediment-associated contaminants (Mayer et al., 1996; Chen and Mayer, 1999; Mayer et al., 2001).

The benthic fauna in the Baltic Sea are dominated by only a few invertebrate species. Among the most common are the three species investigated in this study: the deposit-feeding amphipod *Monoporeia affinis*, which burrows in the top-most 5 cm of the sediment (Ankar, 1977), but feeds mainly on surface sediments (Byrén et al., 2002); the facultative deposit-feeding clam *Macoma balthica*, which lives buried a few centimeters down in the sediment and primarily feeds on organic particles deposited on the sediment surface; and the invasive polychaete worms *Marenzelleria* spp. (Zettler et al., 1995) which are also generally considered to be surface deposit feeders (Dauer et al., 1981). Although the ecology of the Baltic benthic food web is relatively well understood (Elmgren and Hill, 1997; Ejdung et al., 2000), the influence of sedimentary organic matter quality on contaminant bioaccumulation by benthic invertebrates is to our knowledge not yet described. In particular, there is a lack of knowledge on how the recent invasion of the polychaete genus *Marenzelleria* spp. will influence trophic transfer of sediment-associated contaminants.

In the present experiment, we investigated how the deposition of OM of various nutritional qualities (the unicellular green algae *Tetraselmis* spp., lignin and surface sediment) on the sediment surface affected contaminant bioaccumulation by the three benthic deposit-feeding invertebrates described above. The various OM were spiked with two radio-labeled contaminants: (a) the metal cadmium (^{109}Cd); (b) a polybrominated diphenyl ether (^{14}C-BDE-99) and added to microcosms to simulate a field situation where different types of OM