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ORIGINAL RESEARCH ARTICLE

Bioaccumulation of microcystins in invasive bivalves: A case study from the boreal lagoon ecosystem☆

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Summary In the current study we present the first report on the bioaccumulation of microcystins (MC) in zebra mussel *Dreissena polymorpha* from the eutrophic brackish water Curonian Lagoon. The bioaccumulation capacity was related to age structure of mussels and ambient environmental conditions. We also discuss the relevant implications of these findings for biomonitoring of toxic cyanobacteria blooms in the Curonian Lagoon and potential consequences for *D. polymorpha* cultivation activities considered for the futures as remediation measure. Samples for the analysis were collected twice per year, in June and September, in 2006, 2007 and 2008, from two sites within the littoral zone of the lagoon. The highest microcystin concentrations were measured in mussels larger than 30 mm length and sampled in 2006 (when a severe toxic cyanobacteria bloom occurred). In the following years, a consistent reduction in bioaccumulated MC concentration was noticed. However, certain amount of microcystin was recorded in mussel tissues in 2007 and 2008, when no cyanotoxins were reported in the phytoplankton. Considering high depuration rates and presence of cyanotoxins in the bottom sediments well after the recorded toxic blooms, we assume mechanism of secondary contamination when microcystin residuals could be uptaken by mussels with resuspended sediment particles.

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1. Introduction

Toxic algal blooms are of a particular concern in eutrophic aquatic ecosystems, where natural or anthropogenically induced nutrient enrichment leads to enhanced algae and cyanobacteria biomass (Sutcliffe and Jones, 1992). About 300 microalgae species were reported as forming so-called algal blooms. Nearly one fourth of these species have a potential to produce toxic compounds (Hallegraeff et al., 2003). Some of algal toxins may bioaccumulate in aquatic organisms and be transferred through a food chain, reaching critically high concentrations at higher trophic levels (Cazenave et al., 2005; Ferrão-Filho and Kozlowski-Suzuki, 2011; Landsberg, 2002; Rhodes et al., 2001). Due to the wide toxicological effects of these compounds, including neurotoxicity, hepatoxicity, cytotoxicity and dermatoxicity, there is a risk of health hazard for humans, domestic animals and wildlife related to the toxic algal blooms in aquatic ecosystems (Carmichael, 2001; Kujbida et al., 2006; Van Dolah, 2000). Among the toxins produced by cyanobacteria microcystins (hepatotoxins) are probably the most hazardous ones in terms of impact on human health (Carmichael, 1994; Chorus and Bartram, 1999; Funari and Testai, 2008). Microcystins (MC) are very stable (Jones and Orr, 1994; Tsuji et al., 1994), not destroyed by the common water treatment methods (Keijola et al., 1988; Rositano and Nicholson, 1994) and therefore considered having high potential for bioaccumulation in aquatic organisms (Figueiredo et al., 2004; Funari and Testai, 2008; Jonasson et al., 2010; Vasconcelos, 1995).

In this study we address the bioaccumulation of microcystins by the invasive zebra mussel *Dreissena polymorpha* (Pallas 1771), widely distributed and being acknowledged as powerful biofilter (Karatayev and Burlakova, 1994; Karatayev et al., 2002; Nicholls, 2001; Vanderploeg et al., 2002; Zaiko and Daunys, 2012). *D. polymorpha* has an intrinsically high clearance rate that is approximately 10 times that of other freshwater filter-feeding bivalves (Vanderploeg et al., 2002). On the other hand, zebra mussel filtration capacity is highly dependent on the environmental conditions and population structure, and may vary in a wide range (Zaiko and Daunys, 2012).

These bivalves can efficiently accumulate micropollutants, are easy to collect in large numbers and are sedentary, reflecting site specific pollution (Bervoets et al., 2005; Hendriks et al., 1998; Voets et al., 2006). Being themselves resistant to a broad range of environmental conditions (Claudi and Mackie, 1993) and to various types of pollution (Bervoets et al., 2005), they are considered as a proper object for biomonitoring studies (Bervoets et al., 2005; Smolders et al., 2003). Their bioaccumulation abilities may imply important ecological consequences. Zebra mussels are important food source for some fish and water birds thus might be an agent for toxic substances transfer through the food web (Tucker et al., 1996; Zimmermann et al., 1997).

Another implication of cyanotoxins bioaccumulation by zebra mussel is related to its potential use for water quality remediation, recently addressed in several studies (Elliott et al., 2008; Goedkoop et al., 2011; Orlova et al., 2004; Reeders and Bij de Vaate, 1990; Stybel et al., 2009). These issues are particularly relevant for the large transitional ecosystems, such as the Baltic Sea brackish lagoons, with a well pronounced anthropogenically induced eutrophication (Chuseve et al., 2012). Such an option is considered for the Curonian Lagoon as well, and possible *pros* and *cons* being analyzed within the Baltic Sea Region Programme project SUBMARINER ("Sustainable Uses of Baltic Marine Resources"). Since the harvested mussel biomass is not suitable for human consumption, it is often advised for utilization in husbandry as chicken feed, fertilizer or aquafeed for fishfarms (Lindahl et al., 2005; Schernewski et al., 2012; Stybel et al., 2009). Therefore it is important to identify and assess the potential risks of transfer of bioaccumulated toxic substances.

In this study, we present the potential of zebra mussel to be used as indicator of toxic cyanobacteria occurrence in a eutrophic brakish water coastal lagoon and relation of its bioaccumulative capcity to the age structure and ambient environmental conditions. We also discuss the possible consequences for other aquatic organisms and relevant implications of these findings for *D. polymorpha* cultivation activities (e.g., utilization of the zebra mussel biomass in husbandry).

2. Material and methods

2.1. Study area and sampling

The Curonian Lagoon is a large (1,584 km^2), shallow (average depth ~3.8 m) and mainly freshwater coastal body connected to the south-eastern Baltic Sea by a narrow (0.4—1.1 km) Klaipeda strait (Fig. 1). The Nemunas River brings 98% of the total freshwater runoff and enters the lagoon in its central area, dividing the water body into two different parts (Gasiūnaitė et al., 2008). The northern part is a transitory riverine-like system transporting fresh water into the sea, where salinity may episodically increase up to 5—6 psu during wind driven short-term inflow events. Seawater inflows of 1—6 days duration are most common and the seawater intrusions are usually restricted to the northern part of the lagoon in rare cases propagating $\geq$40 km into the lagoon. The lacustrine southern part is characterized by a relatively closed water circulation and lower current velocities. Therefore, it serves as a main depositional area of the lagoon (Daunys et al., 2006; Galkus and Jokšas, 1997; Gasiūnaitė, 2000; Pustelnikov, 1983).

Most likely, the zebra mussel *D. polymorpha* was introduced into the Curonian Lagoon in the early 1800s. The molluscs would have been attached to timber rafts transported via the Central European invasion corridor (Olenin et al., 1999). However, it may have spread much earlier. According to palaeontological data, *Dreissena* could have existed in the Baltic Sea area during the last interglacial, later becoming extinct, before being re-introduced in the early 1800s (Buynevich et al., 2011; Starobogatov and Andreyeva, 1994).

Zebra mussels are now very abundant in the Curonian Lagoon. They occupy the hard substrates (boulders, embankments, hydrotechnical structures) and soft bottoms (sand, silt or mud) down to 3—4 m depth (Zaiko et al., 2010). The largest area occupied by a zebra mussel community is located in the central part of the lagoon (Gasiūnaitė et al., 2008; Olenina, 1997; Zaiko et al., 2009).

Zebra mussels (*D. polymorpha*) were collected twice per year, in June and September, in 2006, 2007 and 2008, from two sites within the area of the natural zebra mussel