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Science of the Total Environment 366 (2006) 659–672

Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Humankind

www.elsevier.com/locate/scitotenv

Biomagnification of PBDEs and PCBs in food webs from the Baltic Sea and the northern Atlantic Ocean

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Received 28 October 2005; received in revised form 31 January 2006; accepted 1 February 2006
Available online 31 March 2006

Abstract

Biomagnification of polychlorinated biphenyls (PCBs) and polybrominated diphenylethers (PBDEs) in food webs from the Baltic Sea and the northern Atlantic Sea was investigated. For this, we used PCB and PBDE concentration data, together with data on fish body weight and δ^{15}N of fish and zooplankton as a measure of trophic position. In the Baltic Sea material, consisting of zooplankton, sprat, herring and salmon, we report biomagnification of all PCB congeners but PCB #209 and of PBDEs with 3–6 or 7 bromine atoms. Higher brominated PBDEs and PCB 209 did not biomagnify likely due to their high molecular weights or sizes and subsequent inefficient dietary uptake in fish. If salmon was excluded from the statistical analysis, strong biomagnification of PCB #209 was evident, indicating species differences in biomagnification. In the Baltic Sea material δ^{15}N and body weight covaried. In the Atlantic Sea material, consisting of fish samples (herring and salmon) of larger body sizes, we show positive correlation between concentrations of most PCBs and PBDEs and body weight without increasing δ^{15}N. This shows that biomagnification in some cases depends on body size and not trophic position. We conclude that there probably is trophic position dependence in biomagnification, which was manifested in a food chain from zooplankton to piscivores, but no further trophic position influence on biomagnification in fish at the highest trophic levels. In these fish, there was a body size effect leading to biomagnification, probably due to slower clearance in larger fish. PCB concentrations were generally between 2 and 6 times higher in Baltic Sea salmon than in Atlantic Sea salmon. Higher PBDE concentrations in the Baltic compared to the Atlantic Sea salmon were also found, but with a larger variation between congeners. Nona- to deca-BDEs were found in most investigated samples, which illustrates the bioavailability of these compounds. Unidentified penta-, hexa-, hepta-, and octa- BDEs were found in several samples.

Keywords: Flame retardants; Fish; Ecotoxicology; Food chains; Trophic position; Body size

1. Introduction

Many hydrophobic organic compounds (HOCs) present in the aquatic environment tend to accumulate in aquatic organisms due to their hydrophobicity. Several HOCs, e.g. halogenated HOCs such as polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs), are also very persistent, which, in combination with their high affinity to biological tissues, can lead to harmful concentrations in organisms. PCBs have been considered environmental pollutants for a relatively long time and were banned in most countries in the 1970s. PBDEs are currently

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doi:10.1016/j.scitotenv.2006.02.005

used as flame retardants in large quantities, though some countries have recently banned penta- and octa-BDE products (WHO, 1994; de Wit, 2002). It has been shown that fish efficiently absorb some PBDEs from food (Burreau et al., 1997, 2000). PBDEs might pose a risk to organisms if they accumulate to sufficiently high concentrations, for example through biomagnification. For an overview of PBDEs in the environment including their biomagnification, see de Wit (2002). Biomagnification is in the present study defined as the diet dependent increase of the HOC fugacity ("escaping tendency") in an organism above the fugacity of the same HOC in the food of the organism. In fish, biomagnification of HOCs can occur if the flux of HOCs into the fish via dietary uptake is not compensated by the fluxes out of the fish, e.g. excretion over the gills (Clark et al., 1990). Biomagnification of HOCs can lead to a food chain enrichment with successively higher fugacities of HOCs with higher trophic levels.

A method of quantifying the biomagnification power of HOCs was presented by Broman et al. (1992) and Rolff et al. (1993). The authors used a technique of measuring the stable nitrogen isotope ratios in combination with measuring concentrations of polychlorinated dibenzo-p-dioxins and -furans (PCDD/Fs). In nature, nitrogen occurs as the two stable isotopes, ^{14}N and ^{15}N. The isotopic composition of nitrogen in a sample is often expressed as $\delta^{15}N$ in parts per thousand (‰) which is calculated according to Eq. (1).

$$\delta^{15}\mathrm{N}(‰) = \frac{\left(\frac{^{15}\mathrm{N}}{^{15}\mathrm{N}}\right)_{\mathrm{sample}} - \left(\frac{^{15}\mathrm{N}}{^{14}\mathrm{N}}\right)_{\mathrm{air}}}{\left(\frac{^{15}\mathrm{N}}{^{14}\mathrm{N}}\right)_{\mathrm{air}}} \cdot 1000 \quad (1)$$

In organisms, it has been shown that ^{15}N is enriched compared to ^{14}N with increasing trophic level. Hence, the difference in $\delta^{15}N$-value between organisms at two successive "classical" trophic levels, e.g. "producer" and "1st consumer," is 3.4‰ (Minagawa and Wada, 1984). With this measure, the trophic levels of organisms are expressed with a continuous, ecologically relevant parameter, since it is an exception that an organism feeds on only one trophic level.

2. Materials and methods

According to the biomagnification model described by Broman et al. (1992) and Rolff et al. (1993) the biomagnification of an HOC can be described by Eq. (2), in which c is the concentration of a substance in an organism for which the $\delta^{15}N$ value has been determined. The term A in Eq. (2) is a constant depending on the concentration at the base of the food chain and the B value describes the biomagnification power of the substance.

$$c = A \cdot e^{(B \cdot \delta^{15} N)} \quad (2)$$

A positive B value means that the concentration of the substance is higher at higher trophic levels, i.e. biomagnification has occurred. A negative B value means that the concentration is lower at higher trophic levels, indicating, for example, biotransformation at the higher trophic level. The nitrogen isotope methodology has been applied to quantify the biomagnification of several HOCs, e.g. ΣPCB (Kucklick et al., 1996; Kucklick and Baker, 1998), ΣHCH, ΣDDT and ΣCHB (Kidd et al., 1995; Jarman et al., 1996), ΣPCB, DDE and Mirex (Kiriluk et al., 1995), and individual PCB congeners (Olsson et al., 2000).

In the present study, we investigate the biomagnification of PCBs and PBDEs in organisms from the Baltic Sea and the northern Atlantic Ocean. The sampling areas were chosen to represent two differently polluted areas where the Baltic samples were assumed to have generally higher HOC concentrations than the Atlantic samples. This assumption was based on unpublished results from our lab. The organisms chosen for the study were assumed to represent a wide range of trophic levels and could be sampled in both geographical areas. Using this experimental design, we wanted to investigate whether the biomagnification power of HOCs is independent of HOC background concentrations (the term A in Eq. (2)), which is assumed in the model by Broman et al. (1992) and Rolff et al. (1993). We modified the model described in Broman et al. (1992) and Rolff et al. (1993) by using lipid weight based concentrations instead of dry weight based concentrations, since the relative differences among lipid weight based concentrations is a good approximation of the relative differences in fugacity (Mackay and Fraser, 2000).

2.1. Organism sampling

Zooplankton samples ($n=3$) were taken with a 90 μm mesh size net in the central part of the Baltic Sea in the summer of 1999. In order to avoid sampling of phytoplankton and blue-green algae, samples were collected at least 30 m beneath the water surface. Sprat (*Sprattus sprattus*) ($n=6$), herring (*Clupea harengus*) ($n=5$) and salmon (*Salmo salar*) ($n=10$) were caught with gill nets in the central part of the Baltic Sea in the summer and autumn of 1998.