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Accumulation of organochlorines and brominated flame retardants in estuarine and marine food chains: Field measurements and model calculations

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Abstract

Food chain accumulation of organochlorines and brominated flame retardants in estuarine and marine environments is compared to model estimations and fresh water field data. The food chain consists of herbivores, detritivores and primary and secondary carnivores i.e. fish, fish-eating birds and marine mammals. Accumulation of polychlorinated biphenyls is predicted well by OMEGA for herbi-detritivores and primary and secondary carnivorous fish. Ratios are similar to those found for fresh water species. Accumulation ratios for fish-eating birds and mammals are overestimated by the model, which is attributed partly to biotransformation of *meta–para* unsubstituted congeners. Additionally, birds may feed in other less polluted areas. For brominated diphenylethers (BDE) accumulation patterns are highly species and congener specific. Accumulation depends on both K_{ow} and metabolization capacities. BDE47 is the predominant congener in lower trophic levels. For marine birds and mammals accumulation ratios of BDE99 and 100 are similar to or higher than ratios of persistent PCBs.

Keywords: Bioaccumulation; Brominated flame retardants; Organochlorines; Food chain; Marine environment; Fugacity model

1. Introduction

The last two decades, many chemicals have been identified as potentially hazardous because of their accumulation in food chains. Yet, most of the thousands of substances and species that are of interest for environmental management will not be monitored at all relevant locations and periods, because of financial, practical and ethical constraints. To allow risk assessment for many substances and species at different locations and periods, results from monitoring programs should be checked for consistency with data from other studies. With this goal in mind, we have developed the model OMEGA that estimates accumulation in food chains (e.g., Hendriks et al., 2001; Hendriks and Heikens, 2001). OMEGA has been successfully applied to hazardous substances in fresh water and terrestrial communities. In the present investigation, its applicability to estuarine and marine systems is explored, with special emphasis on organochlorines and brominated flame retardants. A related investigation is carried out for organotins (Veltman et al., 2005).

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The aim of this study is

1. to determine the consistency of available estuarine and marine data sets with patterns of the same or related toxicants in other areas and food chains (diagnostic approach);
2. to test the OMEGA model with estuarine and marine data to allow predictions for other areas, periods, substances and species (prognostic approach).

For this purpose empirical data sets from monitoring surveys on estuarine and marine environments in the Netherlands from the last two decades were collected. These data comprise measured chemical concentrations in marine sediments and/or suspended solids as well as chemical residues in various species belonging to several trophic levels. Accumulation factors were calculated for a number of relevant food chains and results were compared to model estimations. Furthermore, the accumulation patterns of polychlorinated biphenyls (PCBs) and brominated diphenylethers (BDEs) were compared. Similar accumulation patterns were expected for these two groups as PCBs and BDEs are structurally related and have similar octanol–water partition coefficients. For polychlorinated biphenyls calculated accumulation factors were compared to results from fresh water studies. Brominated flame retardants have not been monitored extensively in Dutch fresh water environments, so a comparison could not be made for these compounds.

2. Methods

2.1. The model OMEGA

OMEGA combines classical fugacity theory with allometric regressions in order to predict chemical accumulation in aquatic or terrestrial food chains. The model has extensively been described before (Hendriks, 1995; Hendriks et al., 2001; Hendriks and Heikens, 2001; Van der Linde et al., 2001). Here, only a short explanation of the main processes is given.

The mass of organisms results from four basic flows (Fig. 1)

(1) absorption and excretion of water;
(2) ingestion and egestion of food;
(3) (re)production of mass;
(4) mortality of tissues.

Each of these flows may carry a toxicant into and out of an organism. OMEGA calculates steady-state chemical residues in biota as the sum of influx via water (absorption) and uptake of food (assimilation) divided by elimination (Eq. (1)). Four different routes of elimination exist: efflux via water, food and biomass (growth dilution) and biotransformation. Biotransformation is not explicitly accounted for, but rate constants can easily be added to the model if available.

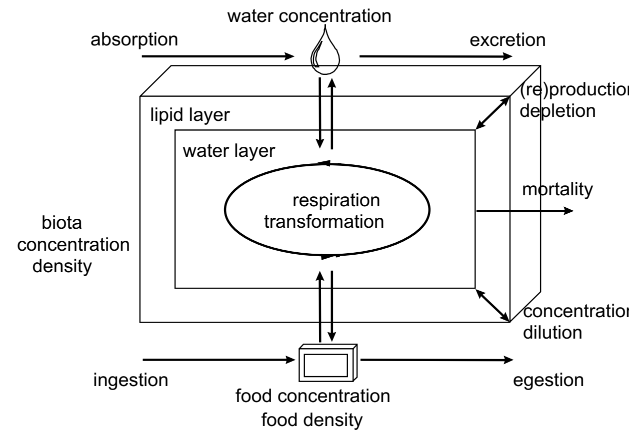

Fig. 1. The densities of organisms and of their food are determined by metabolic flows at rate constants for absorption and excretion of water, ingestion and egestion of food, (re)production, respiration and mortality of mass. The concentrations in organisms and their food are determined by the lipid and water resistance as well as by the metabolic flows that carry substances into and out of organisms.

$$C_{i,x} = \frac{k_{0,x,\text{in}} \times C_{\text{ow},x} + k_{1,x,\text{in}} \times C_{i-1,x}}{\sum_j k_{j,x,\text{out}}} \qquad (1)$$

$C_{i,x}$ = concentration in biota (μg kg^{-1} lipid weight);
$k_{0,x,\text{in}}$ = rate constant for absorption (μg kg^{-1}/μg kg^{-1} d^{-1});
$C_{\text{ow},x}$ = dissolved concentration in water (μg l^{-1});
$k_{1,x,\text{in}}$ = rate constant for assimilation (μg kg^{-1}/μg kg^{-1} d^{-1});
$C_{i-1,x}$ = concentration in food (μg kg^{-1} lipid weight);
$k_{j,x,\text{out}}$ = rate constants for elimination (d^{-1}).

The different rate constants are a function of the octanol–water partition coefficient of the chemical and the size and trophic level of the species i.e. they depend on resistances that substances encounter in the water and lipid layers of organisms and on metabolic flows that carry substances into and out of these organisms (Fig. 1). The adjacent coefficients and exponents needed to determine the various rate constants have been calibrated on hundreds of rate constants from laboratory studies and are extensively described in Hendriks et al. (2001).

2.2. Accumulation and biomagnification

Accumulation is defined as the net process by which the chemical concentration in an organism achieves a level exceeding that in water as a result of chemical uptake through all possible routes of exposure (water and food) and elimination from all possible routes (Gobas