Supporting Information

The effect of microplastic on chemical uptake by the lugworm *Arenicola marina* (L.) under environmentally relevant conditions

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Table S1. PCB concentration added to the sediment of the different treatments at start of the bioassay. PCB concentrations are on a dry weight (DW) basis. The 0% PE A treatment has similar background quantities spiked for all ten congeners. The 0% PE B treatment has elevated concentrations of five of the ten congeners spiked to the sediment. These five congeners are also extra spiked to the 0.05% DW PE treatment and 0.5% DW PE treatment, to compensate for the anticipated chemical dilution by the PE, thus representing the infinite source scenario.

| PCB Congener µg/kg DW | Scenario          | Treatment       |
|-----------------------|-------------------|-----------------|
|                       |                   | 0% PE A | 0% PE B | 0.05% PE | 0.5% PE |
| PCB 28                | Chemical dilution | 0.92   | 3.87   | 1.31     | 3.83    |
| PCB 52                | Chemical dilution | 0.97   | 4.07   | 1.38     | 4.03    |
| PCB 101               | Chemical dilution | 0.92   | 4.90   | 1.41     | 4.86    |
| PCB 153               | Chemical dilution | 0.80   | 4.76   | 1.28     | 4.71    |
| PCB 180               | Chemical dilution | 0.93   | 5.65   | 1.50     | 5.61    |
| PCB 31                | Infinite source   | 0.92   | 0.97   | 1.01     | 0.96    |
| PCB 44                | Infinite source   | 0.94   | 0.99   | 1.03     | 0.98    |
| PCB 118               | Infinite source   | 0.94   | 0.98   | 1.02     | 0.98    |
| PCB 138               | Infinite source   | 0.94   | 0.99   | 1.03     | 0.98    |
| PCB 170               | Infinite source   | 0.94   | 0.98   | 1.02     | 0.97    |

Table S2. Partitioning coefficients used for calculations and comparisons.1–5

| PCB Congener | Van Noort et al. 2010 Log K<sub>OW</sub> | Hawthorne et al. 2009 Log K<sub>POM</sub> L/kg | Seth et al. 1999 Log K<sub>KOM</sub> L/kg | Lohmann et al. 2012 Log K<sub>PE</sub> L/kg | Velzeboer et al. 2014 Log K<sub>PE</sub> L/kg |
|--------------|----------------------------------------|---------------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| PCB 28       | 5.58                                   | 5.68                                        | 4.99                                   | 5.85                                   | 6.23                                   |
| PCB 31       | 5.58                                   | 5.51                                        | 4.96                                   | 5.81                                   | 6.05                                   |
| PCB 44       | 6.02                                   | 5.65                                        | 5.01                                   | 5.87                                   | 6.03                                   |
| PCB 52       | 6.02                                   | 5.65                                        | 5.07                                   | 5.94                                   | 6.04                                   |
| PCB 101      | 6.42                                   | 5.90                                        | 5.56                                   | 6.50                                   | 6.55                                   |
| PCB 118      | 6.51                                   | 6.32                                        | 5.85                                   | 6.83                                   | 6.30                                   |
| PCB 138      | 6.82                                   | 6.50                                        | 6.01                                   | 7.01                                   | 6.74                                   |
| PCB 153      | 6.82                                   | 6.64                                        | 6.08                                   | 7.09                                   | 7.59                                   |
| PCB 170      | 7.21                                   | 6.54                                        | 6.36                                   | 7.41                                   | 8.03                                   |
| PCB 180      | 7.21                                   | 6.67                                        | 6.49                                   | 7.56                                   | 7.94                                   |
Table S3: Relative importance (%) of the various PCB uptake pathways for *A. marina* at a realistic (0.05%) and a high (0.5%) PE concentration in marine sediment.\textsuperscript{a)}

| IS Scenario PCBs | CD Scenario PCBs |
|------------------|------------------|
|                  | PCB 28 | PCB 52\textsuperscript{b)} | PCB 101 | PCB 153 | PCB 180 | PCB 31 | PCB 44 | PCB 118 | PCB 138 | PCB 170 |
| Environmentally realistic dose of 0.05% PE |
| Uptake from Water  | 96.2 | n.a. | 77.7 | 32.6 | 16.6 | 95.3 | 89.4 | 56.1 | 34.4 | 18.9 |
| Sediment ingestion | 3.6 | n.a. | 21.6 | 64.4 | 80.7 | 4.6 | 10.3 | 40.7 | 63.5 | 78.5 |
| Plastic Ingestion  | 0.1 | n.a. | 0.7 | 3.0 | 2.8 | 0.1 | 0.3 | 3.2 | 2.2 | 2.6 |
| High dose of 0.5% PE |
| Uptake from Water  | 95.8 | n.a. | 75.5 | 26.2 | 10.7 | 95.6 | 89.5 | 49.7 | 28.4 | 12.9 |
| Sediment ingestion | 1.9 | n.a. | 11.1 | 27.4 | 27.7 | 2.4 | 5.4 | 19.1 | 27.8 | 28.2 |
| Plastic Ingestion  | 2.3 | n.a. | 13.4 | 46.4 | 61.6 | 2.0 | 5.1 | 31.2 | 43.8 | 58.9 |

\textsuperscript{a)} Based on evaluation of the first three terms in Eq. 1 of the main manuscript. The model used variable values from the actual experiments, established default parameters for uptake from water and sediment,\textsuperscript{6–9} and optimized parameters for ingestion rate (IR) and plastic-gut fluid exchange coefficient $k_1$.

\textsuperscript{b)} Omitted due to detection problems.
Figure S1. Schematization of the four treatments. $\sum$PCB concentrations are the sum of 5 congeners representing the respective scenario, in µg/kg DW. Concentrations per congener can be found in Table S1. 0% PE A: no plastic and a similar concentration of the PCB congeners representing the CD and IS scenario. 0% PE B: no plastic, a low concentration of PCB congeners representing the CD scenario (PCB 28, 52, 101, 153 and 180) and a higher concentration of PCB congeners representing the IS scenario (PCB 31, 44, 118, 138 and 170). 0.05% PE: 0.05% polyethylene, a low concentration of PCB congeners representing the CD scenario and a higher concentration of PCB congeners representing the IS scenario to compensate for dilution by the 0.05% PE. 0.5% PE: 0.5% polyethylene, a low concentration of PCB congeners representing the CD scenario and a higher concentration of PCB congeners representing the IS scenario to compensate dilution by the 0.5% PE. The extra spike in the 0.5% PE IS scenario is higher than in the 0.05% PE IS scenario to compensate for the higher anticipated dilution effect at 0.5% PE compared to 0.05% PE.
Figure S2. Schematic visualization of the compartments and metrics used in the study design. The main transport pathways of PCBs are indicated with arrows. $C_{lip}$, $C_{PW}$, $C_{OM}$, and $C_{PE}$ are the PCB concentration in respectively the lugworm lipids, the porewater, the organic matter (OM) and the plastic (PE) in the sediment. $K_{OM}$, $K_{OM-PE}$, and $K_{PE}$ are the equilibrium partitioning coefficients between porewater, OM and PE. The biota to sediment accumulation factor is calculated as: $BSAF = C_{lip} / C_{OM}$. The bioaccumulation factor is calculated as: $BAF = C_{lip} / C_{PW}$. The biota to plastic accumulation factor is calculated as $BPAF = C_{lip} / C_{PE}$. Chemical transfer according to equilibrium partitioning theory (EPT) and including realistic feeding in the treatments are shown. The relative importance of feeding pathways in Panel B, D and E is indicated with the thickness of the blue arrows. Panel A – EPT 0% PE: Hypothetical equilibrium partitioning between the compartments lipids, porewater and OM. Panel B – 0% PE: Partitioning as in Panel A, but now with realistic feeding included. Panel C – EPT 0.05% PE: Hypothetical equilibrium partitioning between the compartments of Panel A, but now including 0.05% plastic. As the addition of plastic is the introduction of an extra hydrophobic sorption domain, this causes transport of PCBs from the porewater, OM and lipids towards the plastic. The resulting dilution of PCB concentrations in the compartments other than plastic, is referred to as the ‘chemical dilution’ (CD) scenario. In the ‘infinite source’ (IS) scenario, extra PCBs are spiked to overcome this dilution effect and thus represent oceanic conditions with excess PCB availability from surrounding sediment. Panel D – 0.05% PE: Partitioning as in Panel B, but now with realistic feeding included. Feeding on OM leads to higher than equilibrium steady state PCB concentrations in lipids, leading to BSAF and BPAF values higher than 1-2. Panel E – 0.5% PE: Feeding inclusive steady state partitioning as in Panel C, but now with a higher PE concentration (0.5%). Feeding on OM can lead to higher than equilibrium steady state PCB concentrations in lipids, leading to BSAF and BPAF values higher than 1-2.
Figure S3. Physiological endpoints. Panel A: Average fraction of lugworms surviving the 28 day exposure assay. Panel B: Average feeding activity during the 28 day exposure assay in number of faeces heaps produced per organism per day. Panel C: Average total mass of faeces heaps produced on day 28 of the exposure assay per surviving individual. Panel D: Average AFDW in the faeces heaps produced on day 28 of the exposure assay. White markers: percentage of all material (OM+PE) that burned at 600 °C. Black markers: percentage of OM estimated as AFDW minus the nominal percentage of PE. Panel E: Average percentage wet weight loss of lugworms during the 28 days exposure assay. Panel F: Average lipid weight as percentage of the lugworm DW after the 28 day exposure assay.
Figure S4. $C_{PW}$ values ± SE 0.009 – 0.179 (not shown) at $t=28$ days, calculated with Eq. S2.

Figure S5. Agreement of $C_{PW,t=28}$ with $C_{PW,t=0}$ (1:1 line drawn for comparison) over four orders of magnitude, used to support the assumption of constant aqueous exposure during the 28 d exposure assay.
Figure S6. Sorption of PCB congeners to organic matter (Log K_{OM}) in sediment of the 0% PE A (Regression line: \( \log K_{OM} = 1.34 \times \log K_{OW} - 2.98 \), \( R^2 = 0.97 \)) and the 0% PE B treatment with elevated PCB concentration (Regression line: \( \log K_{OM} = 1.29 \times \log K_{OW} - 2.94 \), \( R^2 = 0.98 \)) as a function of their hydrophobicity (Log \( K_{OW} \)). For comparison \( K_{OM} \) values according to the formula by Seth et al. are given.\(^3\)

Figure S7. Sorption of PCB congeners to polyethylene (Log K_{PE}) as a function of PCB hydrophobicity (Log \( K_{OW} \)). Regression line 0.05% PE treatment: \( \log K_{PE} = 1.33 \times \log K_{OW} - 2.23 \), \( R^2 = 0.94 \). Regression line 0.5% PE treatment: \( \log K_{PE} = 1.51 \times \log K_{OW} - 3.34 \), \( R^2 = 0.98 \).
Figure S8. Average PCB concentration on PE in the sediment-PE mixture. **Panel A:** at t=0. **Panel B:** at t=28 days. At t=0 these PCB concentrations on the PE were calculated from the concentration in the porewater, determined using triplicate POM passive samplers that equilibrated with the sediment mixture, $K_{POM}$ and $K_{PE}$. At t=28 d the PCB concentrations on the PE ± SE were calculated from the concentration in the sediment, which was for each treatment in quintuplicate, $K_{OM}$ and $K_{PE}$ by Eq. S2-5. Where error bars are invisible they are small and thus lie behind the markers.
Figure S9. Average PCB concentrations ± SE in lugworms (lipid normalized) after exposure to the different treatments and their background PCB concentrations before start of the exposure assay. Left panels: PCB congener spiked equally in all treatments representing the CD (chemical dilution) scenario. Right panels: PCB congener extra spiked in the treatments with PE and the 0% PE B treatment to correct for the dilution mechanism representing the IS (infinite source) scenario. Where error bars are invisible they are smaller than the markers.
Supporting information - Materials and methods

**Materials.** Polyethylene (PE, green fluorescent UVPMS-BG, spherical, diameter 10 – 180 µm, density 0.94 kg/L) was purchased from Cospheric, Santa Barbara, USA. PE polymer identity was confirmed by FTIR (ThermoFisher, iN10 MX). For microscope images and particle size distributions of the PE the reader is referred to the publication by Velzeboer et al. Polyethylene sheets (POM, 76 µm thickness) from CS Hyde Co (Lake Villa, IL, US) were used as passive samplers as in earlier studies. PCB congeners 28, 31, 44, 52, 101, 118, 138, 153, 170 and 180 were obtained from Dr. Ehrenstorfer GmbH (Augsburg, Germany). Acetone and n-hexane (picograde) were obtained from Promochem (Wesel, Germany), diatomaceous earth from Dionex (Camberly, UK) and isooctane from Acros (Geel, Belgium). Silicia gel 63 – 200 mesh was obtained from Merck KGaA (Darmstadt, Germany) and activated overnight at 180 °C. Aluminium oxide super was obtained from ICN Biomedicals (Eschwege, Germany) and deactivated with 10 mass% Barnstead™ nanopure water. Before use, copper powder, 99.7 %, from Merck KGaA (Darmstadt, Germany) was Soxhlet-extracted with hexane for 4 h.

**Sediment sampling and pre-treatment.** The sediment was sampled from the Eastern Scheldt (Location ‘Oesterput’, The Netherlands) and had an average density of 1.8 kg/L (wet weight; WW) and organic matter (OM) content of 1.15 % DW. It was sieved in order to remove objects >2mm before usage. The sediment was divided in four portions, one for each treatment. PE was added to the sediment, accomplishing plastic concentrations of 0, 0.05 and 0.5 % DW, which are within and above the range found in the marine environment, respectively. Subsequently, the sediment-plastic mixture was spiked with the PCB congeners. After addition of PE and PCBs, the sediment was mixed for six weeks. Mixing was performed on a roller apparatus (Willemsen Proefinstallaties, Spijk, The Netherlands). During the last four weeks of mixing, three POM passive samplers (≈ 0.3 g each) were added to each PE-sediment mixture for determination of porewater PCB concentrations. Six and four weeks have been shown sufficient to reach chemical equilibrium between sediment porewater, and 10-180 µm PE particles and POM passive samplers, respectively. The mass ratio of OM to POM was 300 to 1, which implies that passive sampling occurred under negligible chemical depletion conditions, that is, POM extracted less than 1.6% of each PCB congener present in the sediment.

**Test organisms.** A. marina were collected by a professional bait collector (Lugworm wholesale business Rotgans, Hippolytushoef, The Netherlands) in the southern Wadden Sea. The lugworms contained background concentrations of PCBs, representing Dutch estuarine conditions.
(Fig. 2, S8, left markers). The lugworms were acclimatized at experimental temperature and the ‘digging-in’ speed of the organisms in clean sediment was tested, to select fit, fast digging organisms. The organisms were pooled randomly. The n=5 pool weights averaged 18.2 ± 1.4 g. Three pools were directly stored at -18 °C for determination of initial PCB concentrations.

**Maintenance.** Three times a week, dissolved oxygen (DO) saturation, temperature, pH and salinity were measured with a HACH HQd Field Case. Reagent kits from Aquamerck (Darmstadt, Germany) were used to monitor NH$_4$$^+$ and NO$_2^-$ (kit range 0.5 - 10 mg/L and 0.025 - 0.5 mg/L respectively). Averages were DO 9.7 mg/L (95 % saturation), temperature 14.2 °C, pH 8.1, salinity 33.8 ‰, NH$_4$+ 0.7 mg/L and NO$_2^-$ 0.05 mg/L. Evaporation was compensated by adding demineralized water. The overlying water was continuously aerated and about 30 L was refreshed with Eastern Scheldt water three times a week, after the water quality measurements.

**Calculation of $C_{PW,t=28}$, $K_{OM}$, $K_{PE}$, $C_{PE}$, $C_{OM}$, BSAF, BPAF and BAF**

Concentrations of PCBs on polyoxymethylene passive samplers ($C_{POM}$) were used to determine porewater concentrations of PCBs ($C_{PW,t=0}$), at the start of the experiment. This was done by using the partitioning coefficients to POM in table S2 ($K_{POM}$) from Hawthorne et al.\(^1\) and Eq. S1:

$$C_{PW,t=0} = \frac{C_{POM}}{K_{POM}}$$ \hspace{1cm} \text{Eq. S1}

From the concentrations in the sediment and the porewater in the 0% PE treatments at the start of the experiment, respectively $C_{SED,total}$ and $C_{PW,t=0}$, the partitioning coefficient to OM ($K_{OM}$) could be calculated by using Eq. S2:

$$K_{OM} = \frac{C_{SED,total}}{C_{PW}} \times \frac{1}{f_{OM}}$$ \hspace{1cm} \text{Eq. S2}

in which $f_{OM}$ is the fraction OM in the 0% PE treatments at t=0.
Similarly, from the concentrations in the sediment and the porewater in the treatments with PE at the start of the experiment, respectively $C_{SED,\text{total}}$ and $C_{PW,t=0}$ the partitioning coefficient to PE ($K_{PE}$) could be calculated by using Eq. S4:

$$K_{PE} = \left( \frac{C_{SED,\text{total}}}{C_{PW,t=0}} - f_{OM} \times K_{OM} \right) \times \frac{1}{f_{PE}} \tag{Eq. S3}$$

in which $f_{OM}$ is the fraction OM in the treatments with PE at $t=0$, $K_{OM}$ is the partitioning coefficient to OM as calculated in Eq. S2 and $f_{PE}$ is the fraction PE in the sediment of the treatments with PE.

The above equations show how from measured concentrations in sediment and porewater at $t=0$ d, equilibrium partition coefficients for OM ($K_{OM}$) and PE ($K_{PE}$) can be derived. Now we use the reversed calculation at $t=28$ d, that is, porewater concentrations after 28 d ($C_{PW,t=28}$) are calculated using the measured concentration in sediment after 28 d ($C_{SED,\text{total}}$) and the aforementioned values for $K_{OM}$ and $K_{PE}$. This assumes that these partition coefficients remain constant during 28 d of exposure. The calculation is done following Eq. S4:

$$C_{PW,t=28} = \frac{C_{SED,\text{total}}}{(f_{OM} \times K_{OM} + f_{PE} \times K_{PE})} \tag{Eq. S4}$$

in which $C_{SED,\text{total}}$ is the concentration of PCBs in the total sediment mixture, including organic matter (OM) and polyethylene (PE) at $t=28$ d. To verify whether porewater concentrations were sufficiently constant during the 28 d assay, we compare $C_{PW,t=28}$ (Eq. S4, Fig. S3) with $C_{PW,t=0}$ (Eq. S1, Fig. 1). The constant partitioning between sediment organic matter, PE and sediment porewater over 28 d was confirmed by the excellent agreement between $C_{PW,t=0}$ and $C_{PW,t=28}$ as illustrated in Fig. S4.

The PCB concentration on the PE, $C_{PE}$ can be calculated at $t=0$ and $t=28$ with Eq. S5:

$$C_{PE} = C_{PW} \times K_{PE} \tag{Eq. S5}$$
with \( C_{PW} \) being the concentration of PCBs in the porewater at either \( t=0 \) or \( t=28 \) (Eq. S1 or S4) and \( K_{PE} \) the partitioning coefficient to PE (Eq. S3). Similarly, the PCB concentration on the OM, \( C_{OM} \) can be calculated with Eq. S6:

\[
C_{OM} = C_{PW} \times K_{OM} \quad \text{Eq. S6}
\]

with \( C_{PW} \) being the concentration of PCBs in the porewater at either \( t=0 \) or \( t=28 \) (Eq. S1 or S4) and \( K_{OM} \) the partitioning coefficient to OM (Eq. S2).

After the 28 days exposure assay, PCB concentrations in the tissue of the lugworms were determined and normalized on the lipid concentration in the tissue (\( C_{lip} \)). Biota to sediment accumulation factors (BSAFs) normalized on lipids and sediment OM were subsequently calculated by using Eq. S7:

\[
BSAF_{lip, OM} = \frac{C_{lip}}{C_{OM}} \quad \text{Eq. S7}
\]

in which \( C_{OM} \) is the PCB concentration in OM of the sediment, calculated before by Eq. S6. Likewise, the new metric; biota plastic accumulation factor (BPAF), was calculated by using Eq. S8:

\[
BPAF_{lip, PE} = \frac{C_{lip}}{C_{PE}} \quad \text{Eq. S8}
\]

with \( C_{PE} \) being the PCB concentration on PE, calculated by Eq. S5. Correspondingly, bioaccumulation factors were calculated from the PCB concentration in the lipids, \( C_{lip} \), and in the porewater, \( C_{PW} \), with Eq. S9:

\[
BAF = \frac{C_{lip}}{C_{PW}} \quad \text{Eq. S9}
\]
Biodynamic model for leaching of chemicals from plastic

The model description below follows the description provided by Koelmans et al.\textsuperscript{8}

Koelmans et al.\textsuperscript{7,8} modelled bioaccumulation of hydrophobic chemicals (dC\textsubscript{B,t}/dt; \(\mu g \times g^{-1} d^{-1}\)) from an environment containing plastic as a mass balance of uptake and loss processes:

\[
\frac{dC_{B,t}}{dt} = k_{derm}C_{PW} + IR(S_{FOOD}a_{FOOD}C_{FOOD} + S_{PL}C_{PLR,t}) - k_{loss}C_{B,t} \tag{Eq. S10}
\]

The first term in Eq. 10 quantifies dermal (including gills) uptake from ambient water. The second term quantifies uptake from ingested food and exchange with plastic particles. The third term quantifies overall loss due to elimination and egestion. The first and third term are parameterised following traditional approaches with \(C_{PW}\) (\(\mu g/L\)) being the concentration in the ambient water and \(k_{derm}\) (\(L \times g \times d^{-1}\)) and \(k_{loss}\) (\(d^{-1}\)) are first order rate constants for dermal uptake and overall loss through elimination and egestion. Following Hendriks et al.,\textsuperscript{6} \(k_{loss}\) is a minimum value, excluding possible biotransformation. In the second term, \(IR_t\) (\(g \times g^{-1} \times d^{-1}\)) represents the mass of food ingested per unit of time and organism dry weight, \(a_{FOOD}\) is the absorption efficiency from food, \(S_{FOOD}\) and \(S_{PL}\) are the mass fractions of food and plastic in ingested material respectively (\(S_{FOOD} + S_{PL} = 1\)) and \(C_{FOOD}\) is the chemical concentration in food. The product \(a_{FOOD} \times C_{FOOD}\) quantifies the contaminant concentration that is transferred from food, i.e. prey species, to the organism during gut passage. Note that for species like fish, weight usually is expressed as wet weight (WW), in which case \(IR_t\) also is based on wet weight. The transferred concentration from plastic during gut passage (GP), \(C_{PLR,t}\) (\(\mu g/g\)) is dynamically modelled using (see Koelmans et al.\textsuperscript{7} for detailed derivation):

\[
C_{PLR,t} = \frac{k_1 C_{PL} - k_2 C_{LT}}{k_1 + \frac{M_{PL}}{M_L} k_2} \left(1 - e^{-\left(k_1 + \frac{M_{PL}}{M_L} k_2\right) GRT}\right) \tag{Eq. S11}
\]

In which \(k_1\) and \(k_2\) (\(d^{-1}\)) are forward and backward first order rate constants describing the transport between plastic and biota lipids, GRT is gut residence time (d), \(C_{PL}\) and \(C_{LT}\) (\(\mu g/g\)) are the chemical concentrations in the ingested plastic particle and the biota lipids at the moment of ingestion (i.e. \(C_{LT} = C_{B,t}/f_{lip}, \mu g/g\)), and \(M_{PL}\) and \(M_L\) are the mass of plastic and lipids in the organism respectively (g). Eq. 11 can be rewritten as:\textsuperscript{8}
\[ C_{PLR,t} = A_{PL}k_1C_P - A_{PL}k_2C_{L,t} \]  
\[ A_{PL} = \frac{1 - e^{-\left(\frac{M_{PL}k_2}{M_L}\right)GRT}}{k_1 + \frac{M_{PL}k_2}{M_L}} \]  

in which

If GRT is constant, also \( A_{PL} \) is constant over time. Combination of equations 10, 12 and 13 and using \( C_{L,t} = C_{B,t}/f_{lip} \), yields the mass balance equation for bioaccumulation:\(^8\)

\[
\frac{dC_{B,t}}{dt} = k_{derm}C_W + IR \times S_{FOOD}a_{FOOD}C_{FOOD} + IR \times S_{PL}A_{PL}k_1C_{PL}
\]
\[
-(IR \times S_{PL}A_{PL}k_2/f_{lip} + k_{loss})C_{B,t}
\]  

for which the following steady state solution (body burden at steady state, \( C_B^{SS} \)) can be calculated:

\[
C_B^{SS} = \frac{k_{derm}C_W + IR(S_{FOOD}a_{FOOD}C_{FOOD} + S_{PL}k_1C_{PL}A_{PL})}{IR \times S_{PL}A_{PL}/f_{lip} + k_{loss}}
\]  

The steady state concentration thus reflects the balance between rates for dermal uptake, uptake by food and uptake by plastic (‘carrier’) all in the numerator, versus ‘cleaning’ by plastic ingestion and chemical loss, which are covered by the denominator. The analytical solution to Eq. 14 is (Koelmans et al, 2014):\(^8\)

\[
C_{B,t} = \left(C_{B,t=0} - C_B^{SS}\right) \times e^{-\left(\frac{IR \times S_{PL}A_{PL}k_2/f_{lip} + k_{loss}}{t}\right)} + C_B^{SS}
\]  

The time required to reach 95% of steady state (\( t_{SS} \)) can be approximated as three times the time constant of the system (1-e\(^{-3}\)):

\[
t_{SS} = 3 / \left( IR \frac{S_{PL}k_2A_{PL}}{f_{lip} + k_{loss}} \right)
\]
We modeled bioaccumulation at 28d using the analytical solution of Eq. S10 and measured values for $C_{PW}$, $C_{SED}$, $C_{PL}$ $S_{SED}$ and $S_{PL}$. The relative share of an uptake pathway (either term 1, 2 or 3 in Eq. S10) was quantified as the ratio of the magnitude of that term, and that of the sum of all three uptake terms.

**Parameters**

Parameters and variables for the experimental treatments 0 % PE B, 0.05% PE and 0.5% PE, were taken from the experimental data and literature and are provided in Table S4.
**Table S4 A. Model input**

0 % PE B (no plastic)

| Parameter | IS scenario PCBs | CD scenario PCBs | unit | Description & source |
|-----------|------------------|------------------|------|----------------------|
|           | PCB 31           | PCB 44           |      |                      |
| W         | 3.09E-03          | 3.09E-03          | kg   | species wet weight (a) |
| k         | 0.25             | 0.25             |      | rate exponent [8]      |
| pH2O,j    | 0.0028           | 0.0028           | d x kg⁻¹ | water layer diffusion resistance [8] |
| pCH2,j    | 68               | 68               |      |                      |
| LogKow    | 5.58             | 6.02             |      |                      |
| ρH2O, j   | 0.0028           | 0.0028           | d x kg⁻¹ | water layer diffusion resistance [8] |
| ρH2O, j   | 68               | 68               |      |                      |
| dw        | 0.14             | 0.14             | g    | dry weight individual organism (a) |
| LogKCM    | 4.37             | 4.76             |      | OM normalised partition coefficient (a) |
| fOC       | 4.11E-03          | 4.11E-03          | g/kgDW | ingestion rate per dw organism (a) |
| fOM, nom  | 0.010            | 0.010            |      |                      |
| fOM, sed  | 0.443            | 0.443            |      |                      |
| IR        | 9.978            | 9.978            | g    | dry weight individual organism (a) |
| fOM       | 0.013            | 0.013            |      |                      |
| KOM       | 3.80E+05          | 1.05E+06          |      | lipid-water partition coefficient [7] |
| LogKw     | No plastic present |                |      |                      |
| kSBP      | 3.80E+05          | 1.05E+06          | g/kgDW | ingestion rate per dw organism (a) |
| kw        | 7.48E-04          | 2.76E-04          |      |                      |
| Mw/Miw    | No plastic present |                |      |                      |
| kG        | 0.0142           | 0.0142           | d    | Food egestion coefficient [8] |
| GRT       | 0.135            | 0.135            |      | gut residence time [7] |
| kGFD      | 0.0149           | 0.0145           | d/kg | total loss rate into water (kFD + kG) |
| kS, OM    | 3.70             | 3.70             | L x g x d⁻¹ | dermal absorption rate constant from water [8] |
| Cw t=0    | 4.77E-03          | 3.87E-03          | µg/L | concentration in water at t=0 d (a) |
|                   | Cw t=28 | SFOOD  | SFOOD  | SFOOD  | SFOOD  | SFOOD  | SFOOD  | SFOOD  | SFOOD  | µg/L concentration in water at t=28 d (a) |
|------------------|---------|--------|--------|--------|--------|--------|--------|--------|--------|------------------------------------------|
| SFOOD           | 1       | 1      | 1      | 1      | 1      | 1      | 1      | 1      | 1      | mass fraction food (a)                   |
| AFOOD           | 0.15    | 0.15   | 0.15   | 0.15   | 0.15   | 0.15   | 0.15   | 0.15   | 0.15   | absorption efficiency food [8]           |
| Csed t=28       | 1.09E-03| 1.86E-03| 2.41E-03| 2.78E-03| 4.67E-03| 1.12E-04| 4.14E-06| 2.43E-04| 2.70E-04| µg x g⁻¹ chemical concentration in sediment at t=28 d (a) |
| Sn               | 0       | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | mass fraction plastic (a)               |
| k₁               | 5.5E-06 | 2.0E-06| 6.5E-07| 3.2E-07| 1.3E-07| 5.5E-06| 2.0E-06| 8.0E-07| 3.2E-07| d⁻¹ Forward rate constant for plastic to lipid transport (b) |
| C₇₅              | No plastic present | No plastic present | No plastic present | No plastic present | No plastic present | No plastic present | No plastic present | No plastic present | No plastic present | µg x g⁻¹ concentration in plastic (a) |
| A₇₅              | 0.118   | 0.118  | 0.118  | 0.118  | 0.118  | 0.118  | 0.118  | 0.118  | 0.118  | absorption coefficient from plastic [6,7] |
| k₂               | 0.0875  | 0.0479 | 0.0320 | 0.1099 | 0.0126 | 0.0090 | 0.0000 | 0.0517 | 0.1495 | d⁻¹ Backward rate constant for lipid to plastic transport [7] |
| CB₇₅₀           | 0.0875  | 0.0479 | 0.0320 | 0.1099 | 0.0126 | 0.0090 | 0.0000 | 0.0517 | 0.1495 | µg x g⁻¹ Chemical concentration in biota lipid at t=0 (a) |

(a) Measured data
(b) Fitted
### Table S4 B. Model input

**Treatment 0.05% PE**

| Parameter | IS scenario PCBs | CD scenario PCBs | unit | Description & source |
|-----------|------------------|------------------|------|-----------------------|
| w         | 3.21E-03         | 3.21E-03         | kg   | species wet weight (a) |
| k         | 0.25             | 0.25             | -    | rate exponent [8]      |
| pH2O,j    | 0.0028           | 0.0028           | d x kg⁻¹ | water layer diffusion resistance [8] |
| pH2O,j    | 68               | 68               | d x kg⁻¹ | lipid layer permeation resistance [8] |
| LogKow    | 5.58             | 6.02             | -    | octanol- water partition coefficient |
| Y0        | 200              | 200              | kg x d⁻¹ | water absorption-excretion coefficient [8] |
| DW        | 0.14             | 0.14             | -    | species dry weight fraction(a) |
| LogKow    | 4.37             | 4.76             | g    | OM normalised partition coefficient (a) |
| fOC       | 3.64E-03         | 3.64E-03         | -    | sediment organic carbon fraction (a) |
| fom,om    | 9.10E-03         | 9.10E-03         | -    | fraction organic matter in sediment (a) |
| dw        | 0.46             | 0.46             | g    | dry weight individual organism (a) |
| IR(co2)   | 5.51             | 5.51             | g/g DW x d⁻¹ | ingestion rate per dw organism (b) |
| fsp       | 0.0207           | 0.0207           | -    | lipid fraction (a) |
| Ksp       | 3.80E+05         | 1.05E+06         | -    | lipid-water partition coefficient [7] |
| LogKcl    | 5.22             | 5.63             | -    | plastic - water partition coefficient (a) |
| kcLP      | 2.30             | 2.44             | Plastic-lipid partition coefficient [7] |
| kc         | 4.66E-04         | 1.72E-04         | Depuration coefficient [8] |
| Mf/Mc     | 0.018            | 0.018            | g    | Plastic-lipid mass ration in the organism [7] |
| k         | 7.82E-03         | 7.82E-03         | Food egestion coefficient [8] |
| GRT       | 0.135            | 0.135            | d    | gut residence time [7] |
| KCO2      | 8.29E-03         | 7.99E-03         | Total loss rate into water (kₐₐₚ + kₐ) |
| kₘₙₖₚₜₚₜₚ      | 3.67             | 3.72             | L x g x d⁻¹ | dermal absorption rate constant from water [8] |
| kₘₙₖₚₜₚₜₚ      | 9.44E-04         | 7.57E-04         | µg/L | concentration in water at t=0 d (a) |
| Cw t=28   | 7.83E-04         | 5.68E-04         | µg/L | concentration in water at t=28 d (a) |
| Sfocco    | 0.9995           | 0.9995           | -    | mass fraction food (a) |
| Parameter            | Value       | Unit         | Description                                                                 |
|----------------------|-------------|--------------|-----------------------------------------------------------------------------|
| $A_{\text{food}}$    | 0.15, 0.15, 0.15, 0.15, 0.15, 0.15, 0.15, 0.15, 0.15 | $\mu g \times g^{-1}$ | absorption efficiency of food [8]                                             |
| C$_{\text{sed}}$ at t=28 | 1.67E-04, 2.94E-04, 2.24E-04, 3.10E-04, 4.96E-04, 5.55E-05, 1.00E-06, 1.68E-04, 1.51E-04, 2.21E-04 | $\mu g \times g^{-1}$ | chemical concentration in sediment at t=28 d (a)                             |
| $S_{PL}$             | 0.0005, 0.0005, 0.0005, 0.0005, 0.0005, 0.0005, 0.0005, 0.0005, 0.0005, 0.0005 | - | mass fraction plastic (a)                                                   |
| $k_1$                | 8.04E-02, 8.04E-02, 8.04E-02, 8.04E-02, 8.04E-02, 8.04E-02, 8.04E-02, 8.04E-02, 8.04E-02, 8.04E-02 | $d^{-1}$ | Forward rate constant for plastic to lipid transport (c)                    |
| $C_{PL}$             | 0.129, 0.244, 0.489, 0.291, 0.450, 0.057, 0.001, 0.148, 0.192, 0.211 | $\mu g \times g^{-1}$ | concentration in plastic (a)                                                |
| $A_{PL}$             | 0.135, 0.135, 0.135, 0.135, 0.135, 0.135, 0.135, 0.135, 0.135, 0.135 | - | absorption coefficient from plastic [6,7]                                   |
| $k_2$                | 3.5E-02, 3.3E-02, 1.8E-01, 9.6E-02, 8.5E-02, 3.6E-02, 4.8E-02, 3.4E-02, 1.4E-01, 1.0E-01 | $d^{-1}$ | Backward rate constant for lipid to plastic transport [7]                   |
| C$_{B_{0}}$          | 8.75E-02, 4.79E-02, 3.20E-02, 1.10E-01, 1.26E-02, 8.99E-03, 0.00E+00, 5.17E-02, 1.50E-01, 1.43E-02 | $\mu g \times g^{-1}$ | Chemical concentration in biota lipid at t=0 (a)                             |

(a) Measured data
(b) Calibrated value for the treatment without plastic (0% PE B)
(c) Fitted
Table S4 C. Model input

### Treatment 0.5% PE

| Parameter | IS scenario PCBs | CD scenario PCBs | unit | Description & source |
|-----------|------------------|------------------|------|-----------------------|
| w         | 2.65E-03         | 2.65E-03         | kg   | species wet weight (a) |
| k         | 0.25             | 0.25             | -    | rate exponent [8]      |
| pH20,j    | 2.80E-03         | 2.80E-03         | d x kg -k | water layer diffusion resistance [8] |
| ρCH2,j    | 68               | 68               | d x kg -k | lipid layer permeation resistance [8] |
| LogKow    | 5.58             | 5.62             | -    | octanol-water partition coefficient |
| YD        | 200              | 200              | g x d⁻¹ | water absorption-excretion coefficient [8] |
| DW        | 0.14             | 0.14             | -    | species dry weight fraction (a) |
| LogKORM   | 4.37             | 4.76             | -    | OM normalised partition coefficient (a) |
| fDC       | 4.22E-03         | 4.22E-03         | -    | sediment organic carbon fraction (a) |
| fOM,OM    | 0.0105           | 0.0105           | -    | fraction organic matter in sediment (a) |
| dw        | 0.38             | 0.38             | g    | dry weight individual organism (a) |
| IRfood    | 3.32             | 3.32             | g/ℓ DW x d⁻¹ | ingestion rate per dw organism (b) |
| flip      | 0.02             | 0.02             | -    | lipid fraction (a)     |
| Kf        | 3.80E+05         | 1.05E+06         | -    | lipid-water partition coefficient [7] |
| LogKn     | 5.14             | 5.58             | -    | plastic-water partition coefficient (a) |
| Ks,pl     | 2.76             | 2.77             | g    | Plastic-lipid equilibrium partition coefficient [7] |
| k0        | 4.96E-04         | 1.83E-04         | g    | Depuration coefficient [8] |
| Mn/Mlip   | 0.110            | 0.110            | g    | Plastic-lipid mass ration in the organism [7] |
| kG        | 9.64E-03         | 9.64E-03         | g    | Food egestion coefficient [8] |
| GRT       | 0.135            | 0.135            | d    | gut residence time [7]  |
| kLOSS     | 1.01E-02         | 9.82E-03         | g    | Total loss rate into water (kG + kG) |
| kwater    | 3.85             | 3.90             | L x g x d⁻¹ | dermal absorption rate constant from water [8] |
| Cw t=0    | 2.31E-03         | 1.37E-03         | µg/L | concentration in water at t=0 (a) |

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|                  | Cw t=28 | SFOOD | AFOOD | SED t=28 | SPl | k1 | Cpl | APl | CBt=0 |
|------------------|---------|-------|-------|----------|-----|-----|------|------|-------|
|                  | 1.32E-03 | 0.995 | 0.15  | 2.61E-04 | 0.005 | 0.27 | 0.181 | 0.133 | 8.75E-02 |
|                  | 7.14E-04 | 0.995 | 0.15  | 3.43E-04 | 0.005 | 0.27 | 0.270 | 0.133 | 4.79E-02 |
|                  | 9.51E-05 | 0.995 | 0.15  | 2.89E-04 | 0.005 | 0.27 | 0.401 | 0.133 | 3.20E-02 |
|                  | 3.93E-05 | 0.995 | 0.15  | 3.05E-04 | 0.005 | 0.27 | 0.407 | 0.133 | 1.10E-01 |
|                  | 2.15E-05 | 0.995 | 0.15  | 3.75E-04 | 0.005 | 0.27 | 0.663 | 0.133 | 1.26E-02 |
|                  | 1.40E-04 | 0.995 | 0.15  | 2.17E-05 | 0.005 | 0.27 | 0.022 | 0.133 | 8.99E-03 |
|                  | 0.00E+00 | 0.995 | 0.15  | 3.37E-05 | 0.005 | 0.27 | 0.000 | 0.133 | 0.00E+00 |
|                  | 2.89E-05 | 0.995 | 0.15  | 2.81E-05 | 0.005 | 0.27 | 0.034 | 0.133 | 5.17E-02 |
|                  | 3.39E-06 | 0.995 | 0.15  | 2.78E-05 | 0.005 | 0.27 | 0.040 | 0.133 | 1.50E-01 |
|                  | 1.36E-06 | 0.995 | 0.15  | -        | 0.005 | 0.27 | 0.052 | 0.132 | 1.43E-02 |

- **Cw t=28**: µg/L concentration in water at t=28 d (a)
- **SFOOD**: mass fraction food (a)
- **AFOOD**: absorption efficiency food [8]
- **CED t=28**: chemical concentration in sediment at t=28 d (a)
- **SPl**: mass fraction plastic (a)
- **k1**: Forward rate constant for plastic to lipid transport (c)
- **CPl**: concentration in plastic (a)
- **APl**: absorption coefficient from plastic [6,7]
- **k2**: Backward rate constant for lipid to plastic transport [7]
- **CBt=0**: Chemical concentration in biota lipid at t=0 (a)

(a) Measured data
(b) Calibrated value for the treatment without plastic (0% PE B)
(c) Fitted
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