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BIOACCUMULATION OF CHLORINATED HYDROCARBONS BY THE MAYFLY (*HEXAGENIA LIMBATA*) IN LAKE ST. CLAIR

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ABSTRACT. Concentrations of six PCB congeners, octachlorostyrene, and penta- and hexachlorobenzene were measured in sediments and in resident in situ *mayfly populations* (Hexagenia limbata) *at a location in Lake St. Clair from July to September, 1987. Observed mayfly/sediment concentration ratios varied from 0.14 for pentachlorobenzene to 0.71 for PCB-153, and were linearly correlated with K_{OW} when expressed on a logarithmic basis. A chemical equilibrium model of sediment-organism interactions predicting a mayfly/sediment concentration ratio of 0.5 is shown to be in good agreement with the field observations, particularly for the higher K_{OW} compounds. A dynamic model gives a more realistic description of organic chemical uptake and bioaccumulation in the mayfly. However, when calibrated by rate constants derived from laboratory experiments, this model tends to overestimate mayfly/sediment concentration ratios by approximately a factor of 10.*
ADDITIONAL INDEX WORDS: Benthos, benthic environment, bioaccumulation, mathematical models.

INTRODUCTION

In aquatic environments, hydrophobic organic chemicals show a tendency to partition into sediments, thus reaching concentrations in sediments which are several fold higher than those in water. Benthic invertebrates, such as the mayfly nymph *Hexagenia limbata*, which dwell in the sediments and feed on sediment associated matter, are thus exposed to relatively high concentrations of sediment-associated organic substances. As a first step in an assessment of the potential risk of sediment-associated organic substances to benthic invertebrate communities, the actual exposure of the organism needs to be determined.

Various authors have addressed the uptake of organic substances in benthic invertebrates in the laboratory and in the field. For example, Landrum (1988) and Eadie *et al.* (1983) determined the kinetics of some aromatic hydrocarbons in the amphipod *Pontoporeia hoyi* in the laboratory and in the field. Oliver (1984, 1987) demonstrated uptake and accumulation of various organochlorines in oligochaete worms (*Limnodrilus hoffmeisteri* and *Tubifex tubifex*). Recently, Landrum and Poore (1988) reported laboratory measurements of the uptake and depuration kinetics of some aromatic hydrocarbons in the mayfly (*Hexagenia limbata*), which is a dominant benthic species in Lake St. Clair.

The objective of this study is to investigate the mechanism of organic chemical uptake and bioaccumulation in the mayfly under typical field conditions in Lake St. Clair. The study investigates the relationship between chemical concentrations in sediments and *in-situ* mayflies for chemicals of varying hydrophobicity (1-octanol-water partition coefficient) and it develops models and correlations for exposure assessments of hydrophobic organic substances in benthic invertebrates.

THEORETICAL

To describe the exchange of organic chemicals between sediments and mayflies, models of various complexity can be proposed. We will briefly present two models, which to various degrees have been discussed before (Pavlou and Weston 1984, Reuber *et al.* 1987, Landrum and Poore 1988, Gobas *et al.* 1988). The models will be treated as

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hypotheses, which will be tested experimentally in the field. This approach is believed to improve insights into the mechanism of chemical exchange between sediments and benthic invertebrates such as the mayfly.

Model I

The simplest approach toward describing chemical interactions between sediments and the mayfly is to assume that the chemical in the mayfly is in chemical equilibrium with that in the sediment. This equilibrium condition can be characterized by equal fugacities of the chemical in the sediment and in the mayfly:

$$f_S = f_B \tag{1}$$

where f_S and f_B are the fugacities (Pa) in respectively the sediments and the organism. To test if this equilibrium condition applies in real situations requires the measurement of f_S and f_B in the field. Unfortunately, f_S and f_B can not be directly measured. However, Mackay and Paterson (1981, 1982) have shown that chemical fugacities in sediments and organisms can be determined from the chemical concentrations in the sediment (C_S) and the organism (C_B) if the chemical fugacity capacity of the sediments (Z_S) and that of the organism (Z_B) are known, i.e.

$$f_S = C_S/Z_S \tag{2}$$

$$f_B = C_B/Z_B \tag{3}$$

The fugacity capacities Z_S and Z_B (mol/m^3 · Pa) of a chemical can be determined as

$$Z_S = K_S \cdot d_S/H \tag{4}$$

$$Z_B = K_B \cdot d_B/H \tag{5}$$

where K_S is the sediment-water partition coefficient (L/kg), K_B is the organism-water partition coefficient (L/kg), d_S and d_B are the densities (kg/L) of respectively the sediment and the organism, and H is the Henry Law constant (Pa.m^3/mol).

Karickhoff *et al.* (1979) and Karickhoff (1981) have demonstrated that for hydrophobic organic chemicals at low concentrations, which are often encountered in the environment, K_S can be viewed as the product of the organic carbon fraction of the sediment (on a mass fraction basis) X_S (kg/kg) and the organic carbon partition coefficient K_{OC} i.e. K_S equals $X_S \cdot K_{OC}$. DiToro (1985) has suggested that, within experimental error, the organic carbon partition coefficient K_{OC} equals the 1-octanol-water partition coefficient K_{OW}, i.e.

$$K_{OC} = K_{OW} \tag{6}$$

It then follows that Z_S can be determined as

$$Z_S = X_S \cdot K_{OW} \cdot d_S/H \tag{7}$$

Gobas *et al.* (1989) have shown that the organism-water partition coefficient K_B is controlled by the lipid content (on a mass fraction basis[1]) of the organism L_B (kg/kg) and K_{OW}. It can thus be expressed as

$$K_B = L_B \cdot K_{OW} \tag{8}$$

The fugacity capacity in the organism Z_B can thus be determined as

$$Z_B = L_B \cdot K_{OW} \cdot d_B/H \tag{9}$$

It thus follows from equations 2, 3, 7, and 9 that if there is a chemical equilibrium between sediments and mayflies (i.e., $f_S = f_B$) the ratio of chemical concentrations in the organism and the sediment should equal:

$$C_B/C_S = (L_B \cdot K_{OW} \cdot d_B/H)/(X_S \cdot K_{OW} \cdot d_S/H) = L_B \cdot d_B/X_S \cdot d_S \tag{10}$$

This demonstrates that at equilibrium the organism/sediment concentration ratio C_B/C_S is determined only by organism and sediment characteristics, namely L_B, d_B, X_S, and d_S. The nature and properties of the chemical (e.g., K_{OW}) should not influence C_B/C_S. In other words, if the equilibrium assumption applies in real field situations, C_B/C_S should be similar for all organic chemicals, i.e., $L_B \cdot d_B/X_S \cdot d_S$.

Model II

The equilibrium model outlined above treats the mayfly as a single homogenous phase, which is in thermodynamic equilibrium with the sediments. It ignores the actual physiological processes of chemical exchange between the organism, the sediments, and other relevant compartments such as

[1]The density of the wet weight organism is approximately 1.0 kg/L

the water (i.e., pore and overlying water). The second model that we will discuss views chemical uptake and bioaccumulation as a result of a balance between the rates of chemical uptake (i.e., from water and sediments) and depuration. Chemical uptake is from the water (i.e., via the gills) and the ingestion of contaminated sediments (i.e., via the gastro-intestinal tract). Depuration is through direct chemical elimination to the water (via the gills), elimination into egested "faecal" matter (via the gastro-intestinal tract), and metabolic transformation (i.e., for metabolizable chemicals). The organism is thus defined as the whole organism excluding the contents of the gastrointestinal tract.

The expression describing simultaneous exchange of chemical between the benthic organism and water, the organism and ingested sediment particles, and metabolic transformation, can be expressed as

$$dC_B/dt = k_W \cdot C_W - k_E \cdot C_B + k_S \cdot C_S - k_F \cdot C_B - k_M \cdot C_B \quad (11)$$

where C_B, C_W, and C_S are the chemical concentrations (mol/m^3) in respectively the organism, the water, and the sediments and t is time (h). The first order rate constants k_W, k_E, k_S, k_F, and k_M refer to respectively chemical uptake from the water (via the gills), elimination to the water (via the gills), uptake from ingested sediment associated matter (via gastro-intestinal tract), elimination in egested matter (via the gastro-intestinal tract), and metabolic transformation.

Under field conditions, where organisms have been continuously exposed to approximately constant chemical concentrations in the water and sediments, it seems reasonable to assume that the chemical concentration in the organism is at steady state with that of the sediments and the water in its immediate environment. In other words, there is no net uptake in, or loss of chemical from the organism, i.e., dC_B/dt is zero. Equation 11 can thus be simplified to:

$$C_B = (k_W \cdot C_W + k_S \cdot C_S)/(k_E + k_F + k_M) \quad (12)$$

Rearranging equation 12 gives the following expression for the organism/sediment concentration ratio C_B/C_S:

$$C_B/C_S = \{k_W \cdot (C_W/C_S) + k_S\}/(k_1 + k_1 + k_M) = \{(k_W \cdot C_W/C_S) + k_S\}/k_T \quad (13)$$

where k_T is the total depuration rate constant, i.e., $(k_E + k_F + k_M)$. Equation 13 demonstrates that the relationship between organism and sediment concentrations (i.e., C_B/C_S) is predominantly the result of a balance between uptake and elimination rate constants. It thus reflects organism and chemical dynamics.

METHODS

Mayfly and Sediment Collection

One-year-old mayfly nymphs (*Hexagenia limbata*) and sediment samples were collected simultaneously with a Peterson grab from a specific site in Lake St. Clair (Latitude N : 42.30'.00", Longitude W : 82.42'.25") in July, August, and September of 1987. This site was chosen because it maintained a continuous population of nymphs throughout the season.

Mayflies were separated from the substrate with a 625 μm mesh sieving bucket (in the field) and they were held with the sediment and overlying lake water for transport. In the laboratory, nymphs were separated from the sediment with a 250 μm mesh sieve, wrapped in hexane-rinsed aluminum foil, and stored at -20°C until further analysis. Samples were processed within 3 to 4 hours after collection to minimize contaminant losses. Sediment samples were stored in amber glass jars at -20°C until analysis.

Mayfly Analysis

Extraction and contaminant analysis were performed as described previously by Pugsley *et al.* (1985) and Ciborowski and Corkum (1988). Briefly, individual mayflies were homogenized in 120 mL of acetonitrile and 40 mL water for 1.5 min. with a polytron blender. The homogenate was filtered under vacuum through a sintered glass filter. The residue on the filter was resuspended in 50 mL acetonitrile and then filtered again. This procedure was repeated twice with 20 mL acetonitrile. After adding 1 mL of concentrated sulphuric acid the combined filtrate was extracted, respectively once with 150 mL and twice with 75 mL petroleum ether. The combined extract was washed with 200 mL distilled water. To remove dissolved water the extract was passed through a 15 g anhydrous sodium sulphate column. Clean-up of the extracts was performed on 0.40 × 0.02 (I.D.) m glass columns containing from top to bottom 2 g anhydrous sodium sulphate and 20 g of Florisil.

Columns were eluted with approximately 200 mL petroleum ether. After clean-up, extracts were concentrated by evaporation to 10 mL, and then analyzed by gas chromatography. Because of experimental difficulties with spiking mayflies, recovery efficiencies of the test chemicals were determined using mussel tissue and ranged from 75 to 85%. The lipid content of the mayflies was determined by evaporating all solvent from dried mayfly extracts, after which the lipids were determined by weight.

Sediment Analysis

Of each sediment sample two 5-g sediment subsamples were ovendried at 106°C, then weighed and extracted individually by soxhlet-extraction with 300 mL 1:1 acetone:hexane (v/v) for 16 hours. The extract was concentrated by evaporation to approximately 50 mL and passed through a 15 g anhydrous sodium sulphate column to remove water. Clean-up of the extract was similar to that used for the mayflies, but hexane was the eluting solvent. The extract was then concentrated by evaporation to approximately 5 mL and treated with activated copper (i.e., copper powder treated with a 5% nitric acid solution, then washed with distilled water, acetone, and hexane). This solution was diluted to 10 mL and analyzed by GC. Recovery efficiencies of the entire sediment extraction procedure for the individual chemicals and PCB congeners were determined with spiked sediments. They ranged from 79 to virtually 100%.

The organic fraction of the sediments was determined, independent of the chemical analysis, by measuring the reduction in mass of an oven-dried 5-g sediment subsample after overnight heating at 550°C to burn off organic matter. This method, which determines the volatile organic matter content, has been suggested to overestimate to some extent the "actual" organic carbon content of the sediment, which is more correctly measured by an organic carbon analyzer (P. F. Landrum, Great Lakes Environmental Research Laboratory, NOAA, 1989, personal communication).

Gas Chromatographic Analysis

All samples were analyzed on a Hewlett-Packard 5790A gas chromatograph equipped with a ^{63}Ni-electron capture detector at 300°C, a splitless injector at 250°C, a 25 m J&W Scientific DB5 fused silica capillary column (film thickness: 0.25 μm), and a Hewlett-Packard 3390A integrator. Carrier gas was ultra-high-pure-grade helium at a flow rate of 1.5 mL/min. Makeup gas, i.e., ultra-high pure 5% methane-argon, was applied at a flow rate of 35 mL/min. The temperature program for GC analysis was: 50°C for 0.5 min., then increasing to 255°C at 3°C/min., at which the temperature remained constant for 15 min. Standards used for qualitative identification (i.e., retention times) and quantification were prepared from >98% pure commercially obtained substances and individual PCB congeners. GC analysis was performed for pentachlorobenzene (QCB), hexachlorobenzene (HCB), Octachlorostyrene (OCS), and the polychlorinated biphenyl (PCB) congeners 87, 101, 118, 138, 153, and 180.

Statistical Analysis

Standard deviations are reported in parentheses. Confidence intervals are reported in square brackets and have a 95% probability.

RESULTS AND DISCUSSION

Sediment and Mayfly Characteristics

The sediment at our field site was predominantly silt-clay with a density of 1.4 kg/L. The organic content of the sediment (X_S) was determined to be 3.62 ($\pm$ 0.54)%. The lipid content (L_B) of the mayflies was 2.54 ($\pm$ 0.58)% when expressed on a wet weight, whole organism basis.

Bioaccumulation in the Mayfly

The observed concentrations of six PCB congeners, octachlorostyrene, pentachlorobenzene, and hexachlorobenzene in the mayfly and in the sediments throughout the July-September period are listed in Table 1. During this period, the variability in the mayfly and sediment concentrations was relatively small. The mean values of the mayfly and sediment concentrations are thus believed to adequately represent the chemical concentrations during the July-September period. For each substance, the mayfly/sediment concentration ratio was determined by dividing the mean chemical concentration in the mayfly by the mean concentration in the sediments. These concentration ratios are listed in Table 1 and plotted versus the 1-octanol-water partition coefficient (K_{OW}) in Fig. 1. Figure 1 demonstrates that C_B/C_S varies from 0.14 for pentachlorobenzene to 0.71 for PCB-153 and tends to follow a linear relationship with K_{OW} when expressed on a logarithmic basis, i.e.:

TABLE 1. Concentrations of pentachlorobenzene, hexachlorobenzene, octachlorostyrene, and six PCB congeners in the mayfly (in ng/g wet weight) and in the sediments (in ng/g dry weight) in Lake St. Clair from July to September. Standard deviations are in parentheses.

	Pentachloro-benzene	Hexachloro-benzene	Octachloro-styrene	PCB-101	PCB-87	PCB-118	PCB-153	PCB-138	PCB-180
July:									
Mayfly	0.50	8.8	5.4	1.7	0.70	0.87	0.94	ND	0.62
(n = 4)	(0.07)	(0.8)	(1.2)	(0.4)	(0.42)	(0.59)	(0.66)		(0.31)
Sediments	6.0	73.2	17.6	2.9	1.20	2.1	1.82	2.36	0.83
(n = 2)	(0.13)	(18)	(0.8)	(0.6)	(0.32)	(0.6)	(0.65)	(0.87)	(0.28)
August:									
Mayfly	1.2	14.0	8.2	1.7	0.7	1.1	1.3	1.22	0.94
(n = 2)	(0.3)	(0.97)	(0.7)	(0.2)	(0.01)	(0.1)	(0.2)	(0.04)	(0.02)
Sediments	6.1	135	17.2	3.8	1.6	2.6	2.0	2.8	1.0
September:									
Mayfly	1.13	11.4	6.6	2.3	1.1	1.5	2.5	1.7	1.5
(n = 2)	(0.45)	(0.73)	(0.8)	(0.7)	(0.3)	(0.5)	(0.2)	(0.5)	(0.5)
Sediments	5.9	51.7	16.3	5.3	1.7	3.2	2.2	3.0	2.8
(n = 2)	(0.5)	(7.4)	(1.3)	(0.5)	(0.5)	(0.6)	(0.1)	(0.2)	(0.5)
C_B/C_S	0.14	0.14	0.37	0.46	0.54	0.41	0.71	0.54	0.62
	(0.08)	(0.09)	(0.11)	(0.27)	(0.34)	(0.27)	(0.51)	(0.29)	(0.65)
Log K_{OW}	5.03[a]	5.45[a]	6.29[b]	6.40[c]	6.50[c]	6.40[c]	6.90[c]	7.00[c]	7.00[c]

(a) from Miller *et al.* 1985, (b) from Veith *et al.* 1979, (c) from Shiu and Mackay 1986.

$$\log(C_B/C_S) = 0.37\ [\pm\ 0.09] \cdot \log K_{ow} - 2.76\ [\pm\ 0.17]$$
$$n = 9,\ r^2 = 0.93. \qquad (14)$$

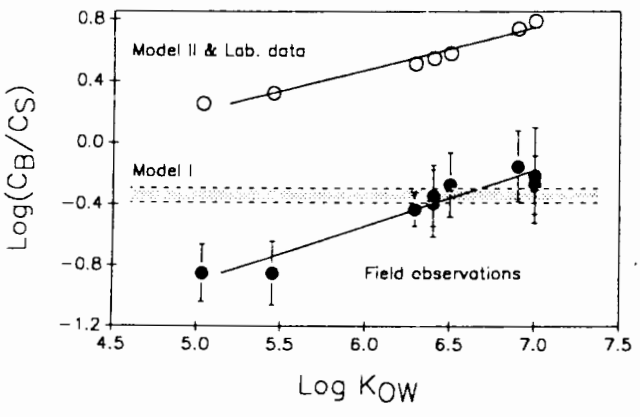

FIG. 1. Logarithms of observed mayfly/sediment concentration ratios of selected organochlorines in Lake St. Clair (closed circles) with their 95% confidence intervals versus log K_{ow}. The shaded area represents predictions of a sediment-organism chemical equilibrium model (i.e., model I). The open circles are predicted values from a dynamic sediment-mayfly model (i.e., model II), calibrated by laboratory data from Landrum and Poore (1988).

This correlation indicates that when chemical concentrations in sediments are the same, higher K_{ow} chemicals tend to achieve higher concentrations in the mayfly.

Sediment-Mayfly Interaction

To obtain a better understanding of the actual mechanism of uptake and accumulation of hydrophobic organic substances in the mayfly under field conditions, the experimental data in Table 1 are used to test the models I and II discussed earlier. This is illustrated in Tables 2 and 3.

Model I demonstrates that if there is a chemical equilibrium between the mayfly and the sediment, C_B/C_S for each non-metabolized chemical should equal $L_B \cdot d_B/X_S \cdot d_S$. In our particular field situation this ratio is $0.025 \times 1.0/(0.036 \times 1.4)$ or 0.50 ($\pm$ 0.09). Figure 1 and Table 1 illustrate that within the margins of experimental uncertainty the

TABLE 2. Parameters for mayfly-sediment chemical equilibrium model (i.e., Model I).

Mayfly:	Density:	1.0 kg/L
	Lipid Content:	2.54 ($\pm$ 0.58) %
Sediment:	Density:	1.4 kg/L
	Organic Content:	3.62 ($\pm$ 0.54) %

TABLE 3. Parameters for the dynamic mayfly-sediment model (i.e., Model II) and model calculations.

Chemical	k_S (h^{-1})	k_T[a] (h^{-1})	C_B/C_S[b] model II	C_B/C_S observed
QCB	0.049	0.027	1.8	0.14
HCB	0.049	0.023	2.1	0.14
OCS	0.049	0.015	3.3	0.37
PCB-101	0.049	0.014	3.5	0.46
PCB-87	0.049	0.013	3.8	0.54
PCB-118	0.049	0.014	3.5	0.41
PCB-153	0.049	0.009	5.5	0.71
PCB-138	0.049	0.008	6.1	0.54
PCB-180	0.049	0.008	6.1	0.62

(a) Calculated from K_{OW} (Table 1) according to $k_T = -0.0099.\log K_{OW} + 0.077$
(b) Calculated as k_S/k_T

observed C_B/C_S ratios for the higher K_{OW} substances (i.e., log $K_{OW} > 6$) in Lake St. Clair agree with the model I prediction. It should be noted that the C_B/C_S ratio predicted by model I (i.e., $L_B \cdot d_B/X_S \cdot d_S$) is dependant on correct values for L_B and X_S. The methodologies used to derive L_B and X_S are therefore critical.

Although the observed C_B/C_S ratios tend to correspond with the equilibrium value, they are not normally distributed around the equilibrium value. In fact, Figure 1 indicates a correlation between the C_B/C_S ratio and K_{OW}, which can not be readily explained by equilibrium partitioning. We will therefore investigate the applicability and validity of the more "realistic" dynamic model II. This model (i.e., equation 13) considers various rate constants for chemical uptake and elimination in the mayfly, which can not be readily measured in the field. However, laboratory measurements of the uptake and depuration kinetics in the mayfly by Landrum and Poore (1988) have demonstrated that: (i) The metabolic transformation capability of the mayfly for chlorinated hydrocarbons is probably insignificant (i.e., $k_M = 0$). (ii) In laboratory experiments k_S is approximately 0.049 g dry sediment/g mayfly/h and k_S is not dependent on K_{OW}. And (iii) the depuration rate constant (i.e., k_T in h^{-1}) tends to drop with increasing K_{OW} (i.e., $k_T = -0.0099.\log K_{OW} + 0.077$). In addition, the authors estimated that under typical field conditions chemical uptake in the mayfly from water is insignificant relative to uptake from sediment. This suggests that the $k_W \cdot C_W$-term in equations 11 and 12 may be insignificant under field conditions, such that model II (i.e., equation 13) can be simplified to

$$C_B/C_S = k_S/k_T = k_S/(k_E + k_F). \qquad (15)$$

Based on the laboratory measurements of k_S (i.e., 0.049 g/g/h), k_T (i.e., $k_T = -0.0099.\log K_{OW} + 0.077$), and K_{OW}, equation 15 can be used to predict the C_B/C_S ratios in the field. Figure 1 and Table 3 illustrate the observed and predicted values.

Figure 1 demonstrates that the combination of equation 15 and the laboratory kinetic data by Landrum and Poore (1988) correctly predicts the K_{OW} dependence of C_B/C_S, i.e., the slopes of the correlations between predicted and observed log C_B/C_S values and log K_{OW} are approximately similar. This suggests that the increase in the observed C_B/C_S values with K_{OW} may be due to a drop in the total depuration rate constant when K_{OW} increases. This drop in the depuration constant is possibly due to the lower tendency of higher K_{OW} chemicals to "partition" from the mayfly to the water. This indicates that chemical uptake in the mayfly, and thus C_B/C_S, is the result of a dynamic process in which chemicals are taken up from the sediment at a constant rate and are eliminated to the water (k_E) and to egested "faecal" phases (k_F). The lower K_{OW} chemicals, which have higher depuration rate constants to the water, thus have a lower C_B/C_S. But when K_{OW} increases and the depuration rate constants to the water (k_E) drops, chemical elimination to the water becomes a less significant depuration route, thus allowing the mayfly and sediment to approach chemical equilibrium or k_S/k_F. It should be stressed, however, that this interpretation of model II is only valid if the water is an insignificant source of chemical uptake in the mayfly. This may correspond with a situation in which water and sediments are not in chemical equilibrium, but f_S exceeds f_W.

The large difference of C_B/C_S ratios between model/laboratory predictions and field observations, which is approximately a factor of 10, is puzzling and may reflect either experimental error or a real laboratory-field difference. To explain this large difference between laboratory and field observations, Landrum (1989) has suggested that, as a result of a longer contact time between chemical and sediment in the field, sediment-associated chemicals in the field are less "extractable" (or bioavailable) by organisms than those in laboratory experiments which generally have had a short contact time. The same phenomenon may also

affect the ratio of chemical concentrations in ingested sediments and gill extracted water. Due to a longer sediment-chemical contact time in the field, the C_W/C_S ratio in the field may be lower than that in laboratory experiments. This could result in a more important contribution of chemical uptake from the water (i.e., the $k_1 \cdot C_W$-term in equation 11) to the total body burden of the mayfly in the laboratory than in the field. Further research is required to resolve this issue.

CONCLUSION

It can be concluded that at our field location in Lake St. Clair organochlorine concentrations in mayflies and sediments tend to be at or near chemical equilibrium. This study suggests that at a first approximation the relationship between mayfly and sediment concentrations can be expressed by a simple equation, i.e., $C_B = C_S \cdot L_B \cdot d_B/X_S \cdot d_S$, which only requires information of the lipid content of the mayfly, the organic carbon fraction of the sediments, and the densities of the sediment and the mayfly at a particular site. However, a constant C_B/C_S ratio for all chemicals, such as predicted by the chemical equilibrium model, has not been observed. The C_B/C_S ratio tends to increase with increasing K_{OW}. A dynamic model, which treats uptake and bioaccumulation in the mayfly as a balance of the rates of chemical uptake from water and sediments and depuration to water and other (e.g., "faecal") phases, may thus give a more realistic and accurate description of organochlorine exposure to mayflies. However, when calibrated with rate constants derived from laboratory experiments this model correctly predicts the K_{OW}-dependence of the C_B/C_S ratio but overestimates the actual C_B/C_S ratios by approximately a factor of 10. This indicates that at this stage observations of chemical bioaccumulation in the field and in the laboratory are inconsistent and that further research is required to enable reliable predictions of chemical concentration in mayflies in the field.

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