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Presentation of a general algorithm for effect-assessment on secondary poisoning. II terrestrial food chains.

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Summary

In an earlier report, a simple algorithm for effect-assessment on secondary poisoning of birds and mammals was presented. This algorithm (MAR = NOEC/BCF) was drawn up by analyzing an aquatic food chain. In the present study it was tested whether this algorithm can be used equally well for effect-assessment on terrestrial food chains.

The pathway soil - earthworm - bird/mammal was used as an example for a terrestrial food chain. Literature data on both bioconcentration factors ($BCF_{soil\text{-}worm}$) and toxicity data ($NOEC_{birds/mammals}$) for six compounds (lindane, dieldrin, DDT, PCP, cadmium and mercury) were studied. As in the aquatic food chain, BCFs can be determined both with experimental data and QSARs. However, important differences were found between BCFs for this terrestrial pathway and BCFs for the aquatic pathway analyzed in the previous report. BCFs for the terrestrial pathway are frequently < 1 and rarely above 10, though for the aquatic pathway BCFs upto 10^4 were found for the same compounds. BCFs for the terrestrial pathways seem to depend on soil properties rather than on compound related properties. Therefore, Maximum Acceptable Risk levels (MAR) can only be calculated for defined situations. By calculating MARs for a standard situation and comparing these to MARs for soil organisms, it was concluded that secondary poisoning could be a critical pathway for cadmium and methyl-mercury. For methyl-mercury secondary poisoning in an aquatic food chain (fish-eating birds and mammals) was also a critical pathway. Secondary poisoning of fish-eating birds and mammals is not likely to occur for cadmium at levels in water below the MAR calculated for aquatic organisms.

It was concluded that the simple algorithm can only be used for effect-assessment on terrestrial food chains if details on soil parameters are available.

1. INTRODUCTION

At the National Institute of Public Health and Environmental Protection (RIVM) methods are being developed to predict and assess risks to the environment created by the production and use of new chemicals. This is carried out within the frame of the project "Evaluation system for new chemical substances" (BNS). In an earlier report (Romijn et al., 1991) a general algorithm was presented for effect-assessment on secondary poisoning of birds and mammals. This algorithm was used to calculate Maximum Acceptable Risk levels (MARs) for a set of compounds in surface water. By subsequently comparing these MARs to MARs calculated for aquatic ecosystems (Van de Meent et al., 1990), a conclusion was drawn on the importance of secondary poisoning. It was found that for some of the compounds secondary poisoning was a critical pathway. For these compounds secondary poisoning should be considered when quality criteria for surface waters are set. The algorithm ($MAR = NOEC_{fish\text{-}eater} / BCF$) was drawn up by analyzing an aquatic food chain. The present study was carried out to assess whether the proposed algorithm can equally well be applied to make effect-assessments on secondary poisoning in terrestrial food chains. An extension of the applicability of the algorithm to terrestrial food chains would provide a useful tool for the integrated criteria setting (INS) project.

2. MATERIAL & METHODS

In the previous report (Romijn et al., 1991) the food chain water - fish - fish-eating bird or mammal was used to draw up the algorithm. An equally simple pathway will be used here as an example of a terrestrial food chain:

Soil - earthworm - worm-eating bird or mammal

This implies that we are modelling a pathway in which birds and mammals are exposed to chemicals exclusively through their diet, and that this diet consists for 100% of earthworms. Earthworms accumulate chemicals from the soil.
For the algorithm presented for effect assessment on secondary poisoning only 2 parameters are used: 1. the bioconcentration factor (BCF), which in this case constitutes the quotient of the concentration in the earthworm and the concentration in the soil. 2. the no-observed effect concentration (NOEC) for birds and mammals, in this case called the $NOEC_{worm\text{-}eater}$.

In analogy to the aquatic food chain, a number of chemicals were selected to analyze the availability of data on these parameters. These compounds are lindane, dieldrin, DDT, cadmium, mercury (both anorganic and methyl-mercury) and pentachlorophenol (PCP). For the aquatic food chain, two PCB congeners (153 and 118) were included in this set, because next to organochlorine-pesticides and heavy-metals, PCBs were considered to be a group of major concern when food chain effects are analyzed. However, insufficient data on both bioconcentration factors and toxicity could be obtained for these PCB congeners to make them valuable for analyzing the pathway. Hence, the PCBs were excluded from the set of compounds for the terrestrial food chain. DDT and PCP have been used instead.

2.1. BCF

Values for the BCF can be estimated in 2 ways:
1. By using data from literature on laboratory and field experiments with earthworms.
2. By using QSARs.

2.1.1. Experimentally derived BCFs

Reviews and original literature were screened for studies reporting on paired measurements of concentrations in soil and earthworms. Both laboratory and field experiments were selected (appendix 1). BCF values were calculated from these data. It was found that $BCF_{soil\text{-}worm}$ values for the selected compounds are showing a large variation. This variation could be due to a great number of factors:

Factors in worms
- Species differences
- Ratio dry : wet weight (1:4 to 1:6)

Factors in soil
- Organic matter content (%OM)
- Acidity (pH)

- Cation exchange capacity (CEC)
- Clay content (%clay)
- Concentration of the chemical (C_s) and the fraction which is bioavailable
- Source of contamination (natural soil or by applying sewage sludge)
- Ratio dry : wet weight (% humidity)

Factors in analytical-procedure

- Pretreatment of worms (emptying digestive tract)
  (dislocation of digestive tract)
  (rinsing in distilled water)
- Extraction from soil (EDTA, 0.1N HCl, 1N HCl, nitric-perchloric acid, radio-labelling, $HN0_3$)

An attempt was made to reduce this variation by standardizing the data:

- BCF values from literature were listed per species. A subdivision of species into groups on the basis of their burying behaviour (Bouche, 1977) was considered, but this proved not to be feasible.
- Wet weight = 5 * dry weight was used as a standard for transforming data on concentration in worms given as mg/kg dry weight into mg/kg wet weight, unless the actual ratio was reported in the study.
- For every compound, a regression analysis was made between the BCF and the soil parameters %OM, pH, CEC, %Clay, and C_{soil}. Details on these regressions are given in appendix 2. The purpose of this exercise was to indentify the soil parameter to which BCF showed the highest correlation. The results were compared with research in literature.
- For organic compounds it was decided to standardize BCF values to the % OM in soil, because Connell & Markwell (1990) found a strong correlation between BCF and %OM for a large set of organic chemicals. This correlation was confirmed by the results of the regression analysis (appendix 2) for dielrin and DDT. The %OM for a standard situation was in analogy to "Desire for levels" (Van de Meent et al., 1990) set on 10. Standarization was carried out by:

$$BCF_{standard} = BCF_x * \%OM/10 \qquad (1)$$

For cadmium BCF values were standardized to a soil with pH = 6.5, because Ma (1982) showed the BCF for cadmium to be highly correlated to soil pH (in the range 4.7-7.1). The results obtained by the regression analyses in this report neither support nor reject Ma's hypothesis. From Ma's study the following relation can be derived:

$$BCF_{standard} = BCF_x * e^{-4.89+0.752*pH} \qquad (2)$$

For mercury no standardization was carried out, because of the lack of information on correlations between BCF and soil factors, either in the literature or from data listed in the present study (appendix 2).

- 20% Humidity was used as a standard to transform data on concentrations in soil expressed as mg/kg wet weight to a mg/kg dry weight value.
- Studies in which the digestive tract was dislocated prior to analysis of the concentration in the worm were excluded from the list.
- BCF values used in this report will be expressed as the concentration in worm (C_w, wet weight) / concentration in soil (C_s, dry weight).

The availability of data to carry out these standardizations was used to subdivide studies into categories of reliability (appendix 1). A $BCF_{standard}$ was derived from category 1 studies only.

2.1.2. QSAR estimated BCFs

BCF values can also be estimated using QSAR's. For organic chemicals a QSAR is reported by Connell and Markwell (1990) in which BCF can be estimated using K_{ow}, as was done for BCFs in the aquatic food chain:

$$BCF = (Y_L \;/\; x * f_{oc}) * K_{ow}^{b-a} \qquad (3)$$

In which: Y_L = the lipid fraction of earthworms.
- x = a constant, estimate to be 0.66 by Rao & Davidson (1980)
- f_{oc} = the organic carbon fraction of the soil. The OC content of a soil can be calculated from the organic matter content by dividing through 1.7. Since values for organic compounds will be standardized for a 10% OM soil, %OC can be set to equal 5.9.
- K_{ow} = the octanol - water partition coefficient, for which values can be derived from the MEDCHEM ClogP data base.
- b-a = b and a are both non-linearity constants. a for the soil to soil water partitioning and b for the soilwater to earthworm partitioning. b-a was estimated by Markwell et al. (1989) to equal 0.07 for earthworms.

Connell & Markwell (1990) state that the factor b-a is close to zero, and therefore that the BCF is only weakly dependent on the K_{ow}. Hence, the lipid fraction of the worm (Y_L) and the organic carbon fraction in the soil (f_{oc}) determine the BCF. This hypothesis can be underpinned by considering the uptake of chemicals by earthworms from soil as a 3 compartment partition process:

soil ==== soilwater ==== earthworm

In this process earthworms take up chemicals directly from the water phase. Earthworms could therefore be considered as aquatic organisms. The distribution of chemicals between soil and soilwater can, if an equilibrium situation is assumed, be described using the (linear) partition coefficient K_p ($K_p = C_{soil} \;/\; C_{soil\text{-}water}$). The uptake of chemicals by earthworms from water can be described with a BCF for aquatic organisms ($BCF_{water\text{-}worm} = C_{worm} \;/\; C_{water}$). The overall process can be described as:

$$BCF_{soil\text{-}worm} = BCF_w \;/\; K_p \qquad (4)$$

For neutral chemicals both K_p, and BCF_w can, at least at lower concentrations, be related to K_{ow}:

K_p: Karickhoff (1981) carried out a linear regression analysis between the organic carbon normalized soil-water partition coefficient K_{oc} and K_{ow}. He found that $K_{oc} = 0.411 * K_{ow}$, and since $K_{oc} = K_p \;/\; \%OC * 100$, K_p can be set equal to $0.00411 * K_{ow} * \%OC$. This regression is, however, based on a limited data set containing only polycyclic hydrocarbon compounds. Furthermore, Karickhoff listed paired measured K_{oc} and K_{ow} values for a large number of compounds (65), representing a number of different organic compound groups. A linear regression carried out on these data results in:

$K_{oc} = 0.29 * K_{ow}$ (n = 65, $r^2 = 0.61$); hence: $K_p = 0.0029 * K_{ow} * \%OC$.
In the RIVM report "Desire for levels" (Van de Meent et al., 1990) a simplification is made, leading to the relation: $K_p = 0.5 * f_{oc} * K_{ow}$ for all non-dissociating organic chemicals which equals:

$$K_p = 0.005 * \%OC * K_{ow}. \qquad (5)$$

$BCF_{water\text{-}worm}$: $BCF_w = 0.05 * K_{ow}$ (Mackay, 1982). The value of 0.05 is based on a average 5% lipid content of fish. Hence this QSAR can be expressed as:

$$BCF_{water\text{-}worm} = Y_L * K_{ow}. \qquad (6)$$

From (4)(5) and (6) follows:

$$BCF_{soil\text{-}worm} = Y_L * K_{ow} / 0.005 * K_{ow} * \%OC. \qquad (7)$$

From this formula K_{ow} can de deleted:

$$BCF_{soil\text{-}worm} = Y_L / 0.005 * \%OC \qquad (8)$$

This indicates that the bioconcentration factor is dependent on %OC and Y_L and independent of K_{ow}. This has an important consequence since K_{ow} is the only compound-related parameter in the formula. Hence $BCF_{soil\text{-}worm}$ is a feature of worm and soil properties and not of compound properties. This distinguishes $BCF_{soil\text{-}worm}$ from BCFs in water, for $BCF_{water\text{-}worm}$, as was shown in the earlier report (Romijn et al., 1991), is a compound-related property.
Rao & Davidson (1980) report an average lipid content for earthworms equal to 0.84%, which is in agreement with analyses carried out at the University of Utrecht which gave values ranging from 0.63 to 2% (Belfroid et al., 1991). In this report Y_l will be considered a constant for all species equal to 1%. The BCF can then be calculated to be set equal to 0.01 / 0.005 * 5.9 (10% OM = 5.9% OC) = 0.34 for all organic compounds in a standard (10% OM) soil. This indicates that when a simple *algorithm for terrestrial food chains is drawn up, the BCF should be made dependent on soil and* worm properties rather than on compound properties, as was the case for BCF in aquatic food chains (Romijn et al., 1991). However, to avoid oversimplification QSAR estimates for the organic compounds in this study were made following (3), thus including a small compound-specific factor.

For cadmium the regression line found by Ma (1982), BCF = $2722 * e^{-0.752 * pH}$, can be used as a QSAR. The BCF data in Ma's study were, however, expressed on a dry to dry weight basis and should be compensated for the dry to wet weight ratio (1:5) in earthworms,

$$BCF_{soil\text{-}worm} = 544 * e^{-0.752 * pH} \qquad (9)$$

No QSAR's were found for estimating BCFs for mercury.

2.2. $NOEC_{worm\text{-}eater}$

Single species toxicity data for the selected compounds were obtained from the literature. Only studies reporting on effects on survival, reproduction or growth reduction were used. The method for derivation of chronic single species NOEC values from the literature are given in the previous report (Romijn et al., 1990). NOECs for all birds and/or mammals can be derived from these single species toxicity data, using extrapolation methods:

1. A preliminary value for the NOEC for birds and mammals can be derived by a modified EPA extrapolation method, in which safety factors (10, 100, 1000) are applied on single species data, depending on the quality and quantity of the available data.
2. If a sufficiently large data set is available a more refined extrapolation method can be used to derive NOEC values for birds and/or mammals. This method was developed by van Straalen & Dennemann (1989) and modified at the RIVM by Aldenberg & Slob (1991). It can be used to calculate a concentration in the environment (or food) at which the NOEC level of no more than 5% of the species concerned will be exceeded (HC5), based on a logistic distribution of toxicity data.

Details on these extrapolation methods are given in the previous report (Romijn et al., 1991).

3. RESULTS

Table 1. Geometric mean and maximum $BCF_{standard}$ values from experimental data, and QSAR estimates.

	experimental data		QSAR
	geometric mean	maximum	
lindane	.	.	0.46
dieldrin	0.33	1.50	0.51
DDT	0.27	0.51	0.72
PCP	1.48	12.80	0.28
cadmium	2.70	39.51	4.10
inorganic mercury	0.36	0.39	.
methyl-mercury	8.28	8.31	.

3.1. Availability of data

3.1.1. Lindane

Raw data from the literature on bioconcentration factors of all compounds are given in appendix 1. All the available data on lindane lack details on soil parameters. Therefore, no standardized BCF value can be calculated from these data. K_{ow} for lindane equals 3.61. Hence, a value for BCF equal to 0.46 can be calculated for a standard (10% OM) soil. Since no $BCF_{standard}$ can be derived from experimental data, only this QSAR value will be used (table 1).

Data on the acute and chronic single species toxicity of lindane to birds and mammals are given in table 2a. Data are presented as they were reported in literature, and converted into a mg/kg food value. Conversion factors are also given in table 2a. A list of common names for the species used in toxicity testing is given in appendix 3. For every species a single toxicological value was selected (the lowest one). These data were used to calculate NOEC values for all birds and /or mammals (table 3). The EPA extrapolation method was used for the separate data sets on birds and mammals. For the combined data set of birds and mammals the Aldenberg & Slob method could be used. From the extrapolated NOEC values it can be concluded that birds seem to be much more susceptible to lindane than mammals.

Table 2a. Oral and dietary toxicity data of lindane to birds and mammals. Values are listed as reported in the literature, and converted into a mg/kg food value. LC50= (sub-)acute mortality, NOEC= no observed effect concentration (effect recorded is specified).

Parameter	species	exposure period	reported value	converted value	reference
LC50	**Birds**				
	Coturnix c. japonica	5 days	425	425	Hill et al. 1975
	Phasianus colchicus	5 days	561	561	Hill et al. 1975
	Colinus virginianus	5 days	882	882	Hill et al. 1975
	Anas platyrhynchos	5 days	>5000	>5000	Hill et al. 1975
	mammals				
	Peromyscus polionotus	4 days	1000	1000	Wolfe & Esher 1980
NOEC	**Birds**				
(mo)	Gallus domesticus	27 days	16	1.6(2)	Harrison et al. 1963
(re)	Anas platyrhynchos	8 weeks	200	100(1)	Chakravarty et al. 1986
	Mammals				
(re)	Mus musculus	9 days	30(3)	25(2)	Frohberg & Bauer 1972
(re)	Oryctolagus cuniculus	12 days	10(3)	33(2)	Palmer & Lovell 1971
(re)	Rattus norvegicus	90 days	5(3)	100	Trifonova et al. 1970
(mo)	Rattus norvegicus			141	geometric mean value
	,,	2 years	400	400	Fitzhugh et al. 1950
	,,	90 days	50	50	Van Velsen 1984

Legends table 2a-f:
(mo)= mortality, (re)= reproduction, (gr)= growth.
(1)= NOEC value derived by applying a factor of 2 on the lowest concentration tested, which caused <20% effect relative to the control group, or a factor 3 on the lowest concentration which caused 20-50% effect relative to the control group.
(2)= NOEC derived by applying a factor of 10 on the value obtained from the literature to compensate for the uncertainty in establishing a (chronic) NOEC from short time (<1 month) studies.
(3)= value reported in the literature in mg/kg body weight. These values were converted into a mg/kg food value with a body weight / daily food intake factor: 40 (Canis domesticus), 33.3 (Oryctolagus cuniculus), 20 (Macaca spec. + Rattus norvegicus), 8.3 (Microtus spec. + Mus musculus), 5.7 (Saimura sciureus).
(4)= Value reported in the literature in mg/l drinking-water, converted into a mg/kg food value by applying a factor of 2 (= daily water intake / daily food intake) for Gallus domesticus.
(5) = reported value was not compensated for the relative contribution of the CH_3Hg group to the molecular weight of the compound with which the study was carried out.
(6)= Species name not specified, hence treated as a species of quail different from Coturnix coturnix japonica or Colinus virginianus.

3.1.2. Dieldrin

For dieldrin a large data set on bioconcentration factors is available. A standardized BCF value could be calculated for three species. Differences between these 3 species are relatively small. The geometric mean and maximum $BCF_{standard}$ values for dieldrin are given in table 1. The ClogP data base recommended K_{ow} value for dieldrin equals 4.32, from which a QSAR estimated $BCF_{standard}$ can be calculated equal to 0.51. Hence, the QSAR estimate is in good agreement with the experimental data.
Single species toxicity data for dieldrin are given in table 2b. Large data sets are available for both birds and mammals. The Aldenberg & Slob method could be used in all cases. Extrapolated $NOEC_{worm-eater}$ values are given in table 3. The extrapolated values indicate that birds and mammals are equally sensitive to dieldrin.

Table 2b. Oral and dietary toxicity data of dieldrin to birds and mammals.

Parameter	species	exposure period	reported value	converted value	reference
LC50	**Birds**				
	Numida meleagris	5 days	107	107	Wiese et al. 1969
	Colinus virginianus	5 days	166	166	Hill et al. 1975
	Coturnix c. japonica	5 days	278	278	Hill et al. 1975
	Phasianus colchicus	5 days	570	570	Hill et al 1975
	Anas platyrhynchos	5 days	1500	1500	Hill et al. 1975
	Mammals				
	Microtus canicaudus	30 days	40(3)	333	Cholakis et al. 1981
	Microtus orchrogaster	30 days	105(3)	872	Cholakis et al. 1981
NOEC	**Birds**				
(mo)	Quail(6)	162 days	0.5	0.5	DeWitt 1956
(re)	Anas platyrhynchos	>1 year	1.6	0.8(1)	Lehner & Egbert 1969
(mo)	Numida meleagris	21 months	1.5	1.5	Wiese & Basson 1967
(re)	Phasianus colchicus	breeding period	2.0	2.0	DeWitt 1956
(mo)	Colinus virginianus	34 weeks	2.5	2.5	Fergin & Schafer 1977
(re)	Numida meleagris	21 months	5.0	5.0	Wiese & Basson 1967
(re)	Gallus domesticus	13 months	10	10	Brown et al. 1974
(mo,re)	Coturnix c. japonica	18 weeks	10	10	Walker et al. 1969
(re)	Colinus virginianus	34 weeks	10	10	Fergin & Schafer 1977
	Mammals				
(mo)	Mus musculus	2 years	1	1.0	Hunt et al. 1975
(re)	Macaca mulatta	6 years	1	1.0	Wright et al. 1978
(re)	*Rattus norvegicus*	*life time*	1.25	1.25	*Harr et al. 1970*
(re)	Mus musculus	6 generations	3	3.0	Keplinger et al. 1970
(mo)	Blerina brevicauda	14 days	50	5.0(2)	Blus 1978
(gr)	Canis domesticus	25 months	0.2(3)	8.0	Fitzhugh et al. 1964
(mo)	Canis domesticus			8.9	geometric mean value
	,,	25 months	0.2(3)	8.0	Fitzhugh et al. 1964
	,,	270 days	10	10	Treon & Cleveland 1955
(mo)	Rattus norvegicus	2 years	10	10	Fitzhugh et al. 1964
(mo)	Damaliscus dorcas p.	90 days	15	15	Wiese et al. 1973

(see table 2a)

3.1.3. DDT

BCF values for DDT are calculated on the basis of total DDT (DDT + DDE + DDD) content in both soil and earthworms. This reduces the variation in bioconcentration factors due to differences in metabolism and degradation. A large data set on BCF for DDT is available, containing data for a number of different species. However, details on organic matter content of soils are often lacking. So $BCF_{standard}$ can only be determined for Lumbricus terrestris and Apporectodea caliginosa. A geometric mean $BCF_{standard}$ was calculated on data for these two species (table 1). In the study of Bailey et al. (1974), the species with which the study was carried out is not specified, so, these values were not used for calculating the geometric mean $BCF_{standard}$ in table 1. A value for $BCF_{standard}$ can, however, be calculated from these data. The geometric mean $BCF_{standard}$ from Bailey's study equals 0.13, which is a factor of 2 lower than the value obtained from data on L. terrestris and A. caliginosa. Using K_{ow} = 6.36, a QSAR estimated value for $BCF_{standard}$ is found equal to 0.72. This value is somewhat higher than the maximum value found for $BCF_{standard}$ derived from experimental data. Single species toxicity values for DDT are given in table 2c. The Aldenberg & Slob method could be used for both the separate as well as the combined data set for birds and mammals (table 3). Birds and mammals seem to differ considerably in their susceptibility to DDT. This difference is expressed in the $NOEC_{worm\text{-}eater}$ values for both groups (table 3) which differ by more than an order of magnitude.

Table 2c Oral and dietary toxicity data of DDT (total) to birds and mammals.

Parameter	Species	exposure period	reported value	converted value	reference
LC50	**birds**				
	Cyanocitta cristata	5 days	415	415	Hill et al. 1971
	Passer domesticus	5 days	415	415	Hill et al. 1971
	Phasianus colchicus			500	geometric mean value
	,,	5 days	311	311	Hill et al. 1975
	,,	5 days	804	804	Stickel & Heath 1964
	Richmondena car.	5 days	535	535	Hill et al. 1971
	Coturnix c. japonica	5 days	568	568	Hill et al. 1975
	Agelaius phoeniceus	10 days	1000	1000	Dewitt et al. 1963
	Colinus virginianus			1015	geometric mean value
	,,	5 days	881	881	Stickel & Heath 1964
	,,	5 days	1170	1170	Hill et al. 1971
	Anas platyrhynchos			1279	geometric mean value
	,,	5 days	875	875	Stickel & Heath 1964
	,,	5 days	1869	1869	Hill et al. 1975
	Rallus longirostris	5 days	1612	1612	Van Velzen & Keitzer 1975
	mammals				
	no data found				
NOEC	**birds**				
(re)	Streptopelia risoria	8 days	10	0.5(1,2)	Peakall 1970
(re)	Gallus domesticus			0.6	geometric mean value
	,,	10 weeks	<0.1	0.05(1)	Sauter & Steele 1972
	,,	2 months	7.5	7.5	Smith et al. 1970
(mo)	Molothrus ater	13 days	<100	3.3(1,2)	Van Velzen et al. 1972
(re)	Anas platyrhynchos	2 years	3.3	3.3	Heath et al. 1969
(re)	Coturnix c. japonica	12 weeks	10	10	Davison et al. 1976
(mo)	Colinus virginianus	63 days	50	17(2)	Coburn & Treichler 1946
(gr)	Colinus virginianus	5 days	200	20(1)	Hill et al. 1971
(re)	Phasianus colchicus	8 weeks	<100	50(1)	Genelly & Rudd 1956
	mammals				
(re)	Rattus norvegicus	7 months	20	20	Clement & Okey 1974
(re)	Mus musculus	6 generations	25	25	Keplinger et al. 1970
(mo)	Saimura sciureus	6 months	5(3)	28.4	Cranmer et al. 1972
(mo)	Microtus pennsyl.	31 days	1000	100(1)	Coburn & Treichler 1946
(mo,gr)	Macaca mulatta	7.5 years	200	200	Durham et al. 1963
(mo)	Canis domesticus	4 years	400	400	Lehman 1965

(see table 2a)

3.1.4. PCP

Two studies have recently been carried out on bioconcentration of PCP in earthworms. Both studies give details on soil parameters. From these data a $BCF_{standard}$ can be calculated for 4 different species of earthworms. The geometric mean and maximum $BCF_{standard}$ for these 4 species is given in table 1. The K_{ow} value for PCP is dependent on the pH, and varies between 3.3 and 4.8 at pH values between 1.2 -13.5. At pH = 6.5, which is used as a standard in this report, K_{ow} = 3.56 (WHO 1987). Based on this value a QSAR estimate is found equal to 0.28. This QSAR estimate is considerably lower than the geometric mean $BCF_{standard}$ from experimental studies. A possible explanation for this can be found in the influence of the pH on the experimental values, for no standardization for pH was carried out on these data.

Data sets on the toxicity of PCP to birds and mammals are limited (table 2d). Reliable NOEC values are available for only 1 bird and 2 mammalian species. LC50 values are at hand for 4 different species of birds, but these values were obtained with low purity (40%) PCP. In the study it is not stated whether the impurity consists of other chlorophenols, or a carrier compound. Hence, these data are not considered to be reliable. Only preliminary values for $NOEC_{worm\text{-}eater}$ could be derived (table 3).

table 2d Oral and dietary toxicity data of pentachlorophenol to birds and mammals

Parameter	Species	exposure period	reported value	converted value	reference
LC50	**Birds**				
	Colinus virginianus	5 days	3400	3400	Hill et al. 1975
	Phasianus colchicus	5 days	4331	4331	Hill et al. 1975
	Anas platyrhynchos	5 days	4500	4500	Hill et al. 1975
	Coturnix c. japonica	5 days	5204	5204	Hill et al. 1975
	Mammals				
	no data found				
NOEC	**Birds**				
	Gallus domesticus			245	geometric mean value
(re)	,,	8 weeks	100	100	Stedman et al. 1980
(re)	,,	8 weeks	600	600	Prescott et al. 1982
	Mammals				
(re)	Rattus norvegicus			55	geometric mean value
	,,	5 months	50	50	Exon & Koller 1982 & 1983
	,,	3.5 months	60	60	Welsh et al. 1987
(gr)	Rattus norvegicus			100	geometric mean value
	,,	3 months	2.5(3)	50	Knudsen et al. 1974
	,,	8 months	100	100	Goldstein et al. 1977
	,,	8 months	100	100	Kimbrough & Linder 1978
	,,	2 years	10(3)	200	Schwetz et al. 1978
(gr)	Mus musculus	2 years	200	200	NTP 1989
(mo)	Mus Musculus	6 months	600	600	NTP 1989

(see table 2a)

3.1.5. Cadmium

The uptake of cadmium (Cd) by earthworms is well documented. BCF values are reported to be dependent on many soil parameters (Ma, 1982) as well as on the presence of other metals in the soil (Beyer et al., 1982). The strongest correlation is suggested between the BCF and soil pH. pH-standardized data on the BCF are given in appendix 1. From the analysis carried out on the obtained data on cadmium it was found that BCF is not constant, but seems to decline at increasing Cd concentrations in soil (appendix 2). Thus, although a single geometric mean value for $BCF_{standard}$ is given in table 1, important deviations from this value are expected in reality. This is stressed by the extremely high value found for the maximum $BCF_{standard}$, which was measured at a relatively low soil Cd concentration. This geometric mean BCF value from experimental data is close to the value obtained by QSAR estimation (table 1).

Data on single species toxicity of cadmium are given in table 2e. The Aldenberg & Slob method could be applied on both the separate as well as the combined data sets for birds and mammals. Based on the derived $NOEC_{worm\text{-}eater}$ values, mammals seem to be considerably less susceptible to cadmium than birds.

3.1.6. Mercury

In the report on secondary poisoning of fish-eating birds and mammals (Romijn et al., 1991) a large difference was found between both bioconcentration factors and toxicity of anorganic and organic mercury. It was found that fish concentrate organic (methyl-)mercury to a much higher extent than inorganic mercury.

Table 2e Oral and dietary toxicity data for cadmium to birds and mammals.

Parameter	species	exposure period	reported value	converted value	reference
LC50	**Birds**				
	Gallus domesticus	20 days	562	562	Pritzl et al. 1974
	Phasianus colchicus	5 days	767	767	Hill et al. 1975
	Coturnix c. japonica	5 days	1584	1584	Hill et al. 1975
	Anas platyrhynchos	5 days	>3065	>3065	Hill et al. 1975
	Mammals				
	no data found				
NOEC	**Birds**				
(gr)	Meleagris gallopavo	2 weeks	2	0.2(2)	Supplee 1961
(re)	Anas platyrhynchos	90 days	1.6	1.6	White et al. 1978
(mo,re)	Gallus domesticus	48 weeks	12	12	Leach et al. 1978
(gr)	Coturnix c. japonica	6 weeks	75	38(1)	Richardson et al. 1974
	Mammals				
(gr)	Macaca mulatta	3 years	3	3	Nomiyama et al. 1987
(gr)	Ovis amon aries	191 days	15	15	Doyle et al. 1974
(gr)	Rattus norvegicus			20	geometric mean value
	"	2 years	10	10	Loeser 1980
	"	90 days	42	42	Prigge 1978
(mo)	Rattus norvegicus			21	geometric mean value
	"	6 months	45	45	Fitzhugh & Meiller 1941
	"	41 weeks	10	10	Sugawara & Sugawara 1974
(gr)	Bos primigenius taurus	12 weeks	40	40	Powell et al. 1964
(gr)	Sus scrofa domesticus			45	geometric mean value
	"	5 months	40	40	Kranjc et al. 1986
	"	6 weeks	50	50	Cousins et al. 1973

(see table 2a)

Moreover, it was shown that methylation of inorganic mercury by methanogenic bacteria prior to uptake by fish is a common process. Based on these facts, a simplification was made assuming all mercury to exist as methyl-mercury. Validation with field data indicated that this simplification did not lead to a large overestimation of methyl-mercury concentrations in fish. MARs for secondary poisoning of mercury were therefore calculated exclusively on data for methyl-mercury.
Methanogenic bacteria also occur in terrestrial environments. In a field study it was shown that more than one-third of the total amount of mercury applied to the field was methylated (Beckert et al., 1974). Bull et al. (1977) found only 8-13% methyl-mercury in earthworms exposed to inorganic mercury in soil. These studies do not present a clear picture of the extent of methylation occuring in terrestrial ecosystems. Field data on concentrations in soil and earthworms, which could be used for validation, are not available. Therefore, the availability of data on both inorganic and methyl-mercury was analyzed here separately.
Several studies on bioconcentration of inorganic (or total) mercury are available. No standardization

for soil parameters was carried out on these data because no information on correlation between BCF and soil parameters is available from the literature. A subdivision in reliability categories was, however, made. The study by Adema et al. (1987) was not considered to be suitable for deriving reliable BCF values, because the soil was treated with various cleaning agents, the influence of which is not known. The untreated control plot in this study was considered unsuitable for derivation of a reliable BCF study because the concentration in soil was extremely high. From the study by Helmke et al. (1979) BCF values can only be calculated using nominal concentrations in soil, and are hence considered to be less reliable. The study by Siegel et al. (1975) is carried out with lava. The applicability of the BCF value from this study to other soils is not known. Hence, only the study by Bull et al. (1977) was classified as a category 1 study. A geometric mean value for BCF from this study is given in table 1. This BCF value is only based on 2 values from 1 study, so the uncertainty is high. However, if a geometric mean BCF is calculated on the lower category studies, a value of 0.54 is found, which is near to the BCF value from this study (0.36).

Beyer et al. (1985) report on accumulation of mercury by earthworms from a methyl-mercury treated soil. The experiment carried out at the highest concentration in soil in this study was considered to be less reliable for determining the BCF because, in the very same study it was stated that this concentration was toxic to earthworms. The geometric mean BCF from this study is given in table 1. The derived BCF value for methyl-mercury is more than an order of magnitude higher than the BCF for inorganic mercury.

Single species toxicity data for both inorganic and methyl-mercury are listed in table 2f. Data sets on inorganic mercury are limited and therefore only preliminary $NOEC_{worm\text{-}eater}$ values were determined. For methyl-mercury the Aldenberg & Slob method was used on the separate as well as the combined data sets (table 3). There are no large differences in susceptibility to methyl-mercury between birds and mammals.

3.2. Derivation of Maximum Acceptable Risk Levels (MAR)

The values for BCF and $NOEC_{worm\text{-}eater}$ given in table 1 and 3 can be used to calculate MARs for secondary poisoning.

$$MAR_{secondary\ poisoning} = NOEC_{worm\text{-}eater} / BCF_{standard} \quad (10)$$

$MAR_{secondary\ poisoning}$ values for the selected compounds are given in table 4.

Values have been derived for birds, mammals and a combined data set, using both a geometric mean and a maximum value for $BCF_{standard}$. When no $BCF_{standard}$ could be derived from experimental studies, the QSAR estimated value is used. For all the values calculated with the Aldenberg & Slob method, except the value for birds on cadmium, uncertainties are relatively small, the 95% lower limit to the HC5 value being within 2 orders of magnitude of the HC5 value.

The fact that a standardized value for BCF is used, implies that the calculated MARs are also standardized values. However, applying (1) or (2) MAR can be calculated for soil with different properties:

for organic chemicals: $$MAR_x = MAR_{standard} * (\%OM / 10) \quad (11)$$

for cadmium: $$MAR_x = MAR_{standard} * e^{-4.89 + 0.752*pH} \quad (12)$$

Table 2f. Oral and dietary toxicity data of mercury to birds and mammals.

Parameter	species	exposure period	reported value	converted value	reference
Inorganic-mercury					
LC50	**Birds**				
	Phasianus colchicus	5 days	2805	2805	Hill et al. 1975
	Anas platyrhynchos	5 days	>3700	>3700	Fitzhugh et al. 1950
	Coturnix c. japonica			4063	geometric mean value
	,,	5 days	4385	4385	Hill et al. 1975
	,,	5 days	3764	3764	Hill & Soares 1984
	Mammals				
	no data found				
NOEC	**Birds**				
(re)	Coturnix c. japonica	1 year	4	4	Hill & Schafner 1975
(re)	Gallus domesticus	3 weeks	100	10(2)	Scott 1977
(mo,gr)	Gallus domesticus	16 weeks	125(4)	250	Parkhurst & Thaxton 1973
	Mammals				
(gr)	Mus musculus	560 days	20	20	Ganser & Kirschner 1985
Methyl-mercury					
LC50	**Birds**				
	Coturnix c. japonica	5 days	40.2	40	Hill & Soares 1984
	Mammals				
	no data found				
NOEC	**Birds**				
(re)	Anas platyrhynchos	3 generations	0.5	0.25(1)	Heinz 1979
(mo,gr)	Anas platyrhynchos	20 days	3.3	0.36(2,5)	Gardiner 1972
(mo,gr)	Phasianus colchicus	20 days	3.3	0.36(2,5)	Gardiner 1972
(mo)	Gallus domesticus			0.56	geometric mean value
	,,	3 weeks	12	0.86(2,5)	Fimreite 1970
	,,	20 days	3.3	0.36(2,5)	Gardiner 1972
(mo)	Coturnix c. japonica	9 weeks	2.0	1.70(5)	Hill & Soares 1984
(mo)	Colinus virginianus	6 weeks	4.3	4.30	Spann et al. 1986
	Mammals				
(gr)	Macaca spec.	52 weeks	0.01(3)	0.22(5)	Kawasaki et al. 1986
(gr,re)	Rattus norvegicus	3 generations	0.5	0.43(5)	Verschuuren et al. 1976
(mo)	Mustela vison	93 days	1.1	1.20(5)	Wobeser et al. 1976
(gr)	Mus musculus	60 days	0.25(3)	2.25(5)	Berthoud et al. 1976

(see table 2a)

Table 3 $NOEC_{worm-eater}$ values extrapolated from single toxicity values on birds, mammals and a combined data set.

	preliminary value (EPA-method)			refined value (Aldenberg & Slob method)		
	birds	mammals	combined	birds	mammals	combined
lindane	0.16	2.50	0.16	-	-	1.16
dieldrin	0.05	0.10	0.05	0.29	0.35	0.38
DDT	0.05	2.00	0.05	0.21	7.31	0.47
PCP	10.0	5.50	5.50	-	-	-
cadmium	0.02	0.30	0.02	0.04*	2.34	0.35
inorganic mercury	0.40	2.00	0.40	-	-	-
methyl-mercury	0.025	0.022	0.022	0.09	0.10	0.12

* = The uncertainty in this value is very high. The 95% lower limit to the HC5 value is more than 2 orders of magnitude lower than the HC5 value.

The MAR value obtained for DDT can be validated with data from a field study by Bailey et al. (1974). In this study, DDT concentrations in soil and earthworms, details on soil parameters and effects on survival of resident birds were monitored. The average %OM in the soil was reported to be 2.4. Using (11) a MAR_{birds} under these conditions can be calculated to be equal to 0.19 mg/kg. The soil concentrations in Bailey's study were reported to be in excess of this value (1.21-2.64 mg/kg). So, the reported individual mortalities of worm-eating birds (blackbirds, thrushes, partridges and pheasants) are in line with the results in the present study. The individual mortalities did not lead to effects on populations of these worm-eating birds.

When $MAR_{secondary\ poisoning}$ values are compared to MAR values derived for soil organisms, a conclusion can be drawn on whether secondary poisoning should be considered when quality criteria are set for the terrestrial environment. $MAR_{soil\ organisms}$ (table 4) values were obtained from the RIVM report "Desire for levels" (Van de Meent et al., 1990). These values were derived by extrapolation from standardized (10% OM, 25% Clay) single toxicity data for soil organisms. The results in table 4 indicate that for cadmium and methyl-mercury secondary poisoning of worm-eating birds and mammals can occur at concentrations in soil below the MAR for soil organisms. This indicates the need to consider secondary poisoning for these chemicals, if environmental quality criteria are set. For all other compounds the MAR for soil organisms constitutes a "safe" level for secondary poisoning effects.

Table 4 MAR (mg/kg) values derived for secondary poisoning using BCF values from table 1 and NOEC values from table 3. $MAR_{soil\ organisms}$ (mg/kg) from "Desire for levels" (Van de Meent et al., 1990). Values for which $MAR_{secondary\ poisoning} < MAR_{soil\ organisms}$ are given in bold printing.

	$MAR_{secondary\ poisoning}$ using a geometric mean BCF_{st}			$MAR_{secondary\ poisoning}$ using the maximum BCF_{st}			$MAR_{soil\ organisms}$
	birds	mammals	combined	birds	mammals	combined	
lindane	0.35	5.43	2.50	-	-	-	0.005
dieldrin	0.88	1.06	1.15	0.19	0.23	0.25	0.05
DDT	0.78	27.07	1.74	0.41	14.33	0.92	0.01*
PCP	6.76	3.72	3.72	0.78	0.43	0.43	0.17
cadmium	**0.015**	0.867	**0.130**	**0.001**	**0.059**	**0.009**	0.17
inorganic mercury	1.11	5.55	1.11	1.03	5.13	1.03	0.20
methyl-mercury	**0.011**	**0.012**	**0.014**	**0.011**	**0.012**	**0.014**	0.1**

* = The $MAR_{soil\ organisms}$ for DDT was not obtained from "Desire for levels" but derived from a standardized LC50 value for <u>Gryllus pennsylvanicus</u> (Harris, 1966) using the EPA extrapolation method.

** = The $MAR_{soil\ organisms}$ for methyl mercury was not obtained from "Desire for levels", but derived from a single NOEC value for <u>Eisenia</u> <u>foetida</u> (Beyer et al., 1985) using the preliminary extrapolation method.

4. DISCUSSION

4.1. BCF

A standardization was carried out on BCF values from the literature because a strong relationship is suggested between the %OM and BCF for organic compounds and the pH and BCF for cadmium (Connell & Markwell, 1990; Ma, 1982). The strong correlation between BCF for organic compounds and %OM in soil is confirmed by the results of the regression analysis for dieldrin and DDT (appendix 2). For PCP, however, this correlation is very weak. The correlation between BCF for PCP and pH is much higher, probably due to the fact that PCP is a dissociating organic chemical. Too few data are, however, available to conclude whether the relation suggested by Connell and Markwell (see above) should be rejected for this compound. For cadmium only a weak correlation between the BCF and pH has been found in this study (appendix 2). Apparently, either the correlation is weaker than indicated by Ma (1982) or the influence of the pH on BCF is not strong enough to rise above the variation in BCF values due to the other factors mentioned in section 2.1.1. Surely, if other soil factors influence the BCF as well, it is not surprising that a better correlation is found between the pH and BCF, if a single experimental method is followed as in Ma's study, than when different studies with different experimental methods are lumped together, as was done in the regression analyses in appendix 2.

For all compounds, except for DDT, a quite strong inverse correlation was found between the BCF and the concentration of the compound in the soil (C_{soil}). Values for the BCF show a decline when concentrations in soil are higher. Thus one might argue that in fact the BCF would not be, as it is regarded in this study, a constant. In this case the simple algorithm used to calculate MARs ($NOEC_{worm\text{-}eater}$ / BCF) is not applicable. However, in this study BCFs were derived from studies in which relatively low concentrations in soil were tested (only studies with no toxic effects on earthworms were selected). That is why the $BCF_{standard}$ values derived here are more or less maximum values. This indicates that the MARs calculated with these BCFs may be conservative estimates. Thus, although a simplification is made when BCF is regarded as a constant, calculating a MAR with the method described above does not lead to an underestimation of the risk presented by a compound. This feature is considered an acceptable shortcoming.

4.2. NOEC

NOECs calculated for non-worm-eating species are used to calculate NOECs for worm-eating species. This can only be done if differences in daily food intake due to differences in energy content of the food are considered to be negligible. In the previous report (Romijn et al. 1991), considering fish-eating birds and mammals it was argued that this could be an important source of uncertainty because fish are known to have a low energy content. Thus, a fish-eating bird has to eat considerably more food, expressed in mg/kg body-weight, to meet its metabolic requirements than e.g. a seed-eating bird of the same weight. It was argued that expressing NOEC on a mg/KJ basis would eliminate this source of variation. Considering the reported low lipid content in earthworms (1%), it is not unlikely that earthworms have an even lower energy content than fish. So, this issue could be of special importance where worm-eating birds and mammals are concerned.

4.3. MAR

In the previous study it was stressed that differences in sensitivity between birds and mammals may be large. Thus, calculating MARs on combined data sets for birds and mammals may lead to values at which >5% of the species of one of these groups might still be affected (Romijn et al., 1991). The question was raised whether the MAR still constitutes an "acceptable risk" level in this case. In the present study the toxicity of two more compounds (DDT and PCP) were analyzed. Calculated $NOEC_{worm\text{-}eater}$ values for the separate data sets (table 3) indicate that for DDT these important differences in sensitivity between birds and mammals are found again (> 1 order of magnitude). These results stress the need for a further discussion on whether or not combining data sets for birds and mammals can be allowed.

It was found that BCFs for terrestrial food chains differ from those in aquatic food chains. The feature found in aquatic habitats, that compounds are accumulating in organisms to concentrations several orders of magnitude higher than in their environment, was shown not to occur in terrestrial habitats. BCFs for terrestrial food chains derived from the literature are frequently below 1 and seldom above 10. This beares consequences on the concept of critical pathways. One might argue that compounds for which secondary poisoning was shown to be a critical pathway in aquatic food chains (Methyl-mercury and PCB153), can be identified as such because they have a very high accumulation potential. A less bioaccumulative chemical like cadmium is less likely to be of importance in aquatic food chains. In terrestrial food chains, however, secondary poisoning was shown to be a critical pathway for cadmium. Apparently, in terrestrial food chains compounds for which secondary poisoning can be a critical pathway are not characterized by a high accumulative potential. A better indication for terrestrial pathways is the toxicity ratio between birds and invertebrates (table 5).

Table 5. Toxicity ratio. ($NOEC_{birds}$ / $NOEC_{soil\text{-}organisms}$)

compound	$NOEC_{birds}$ mg/kg food	$NOEC_{soil\text{-}organism}$ mg/kg soil	toxicity ratio
lindane	0.16	0.005	32
dieldrin	0.29	0.05	5.8
DDT	0.21	0.01	21
PCP	10	0.17	59
cadmium	0.04	0.17	0.2
organic mercury	0.4	0.2	2.0
metyl-mercury	0.09	0.1	0.9

The MARs for secondary poisoning calculated here are derived with a simple 2 trophic levels food chain. It is not clear whether these MARs constitute acceptable levels when larger food chains are considered. Where top-predators (carnivorous birds and mammals) are concerned bioaccumulation factors ($BAF = C_{bird/mammal} / C_{worm}$) become important. Assuming carnivorous birds and mammals to be equally sensitive to metals and organic compounds as worm-eating birds, the MAR values calculated here are no longer valid, when the BAF for a compound reaches values over 1. Moreover, in contrast to BCFs, BAFs may be much more dependent on compound properties, which could mean that different compounds, or compound groups, can be identified again for which secondary poisoning can be a critical pathway.

5. CONCLUSION

The concern of this study was whether the simple algorithm presented to be used for effect-assessment on secondary poisoning of birds and mammals in aquatic food chains (MAR = NOEC/BCF), can be applied for effect-assessment on birds and mammals in a terrestrial food chain as well.
BCFs for terrestrial food chains were shown to be much more dependent on soil parameters than on compound properties. For organic chemicals the organic matter content (%OM) of the soil is the most important factor determining the BCF. For cadmium the acidity (pH) of the soil has a large influence on the BCF. Hence the BCF for these compounds can only be expressed as a constant in a defined situation. Consequently MARs for these compounds are also calculated for standard situations. A standard soil was defined as having 10% OM and a pH = 6.5.
From $MAR_{standard}$ MARs for other soils can be calculated with:

For organic chemicals: $MAR_x = MAR_{standard} * (\%OM / 10)$
For cadmium: $MAR_x = MAR_{standard} * e^{-4.89 + 0.752*pH}$

It was concluded that bioconcentration factors in terrestrial habitats are much lower than in aquatic habitats and are < 1 for many compounds (in standard situations). Based on this, another important difference between secondary poisoning in aquatic food chains and terrestrial food chains was found. Compounds for which secondary poisoning is a critical pathway in terrestrial food chains can not be characterized as being those compounds having a high accumulation potential, as is the case for aquatic food chains. It was shown that for methyl-mercury and cadmium secondary poisoning in terrestrial food chains can be a critical pathway. This result stresses the differences between terrestrial and aquatic food chains, for in the previous report (Romijn et al., 1991) it was concluded that secondary poisoning is unlikely to be important for cadmium in aquatic food chains.
It can be concluded that the use of the simple algorithm (MAR = NOEC / BCF) can only be used for terrestrial food chains if details on soil parameters are available.

Recommendations for further research:

1. A similar study should be carried out on a simple larger food chain to analyze whether MARs calculated here can be considered acceptable levels for top-predators.
2. A research should be carried out on the question whether it is feasible and profitable to express NOECs in mg/KJ. Important pioneering work has already been carried out by Lahr & Van der Valk (1991) and Ruys & Pijnenburg (1991)

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Appendices 1-3

Appendix 1 BCF values (soil - earthworm) for a set of selected compounds. Data were obtained from reviews (criteria documents & WHO/IPCS environmental health criteria) and original literature. All BCF values were calculated by dividing the concentration in earthworm species (on a wet weight basis) to the concentration in soil (on a dry weight basis). Expressing the concentration in earthworms on a wet weight basis was preferred because this facilitated comparing them to toxic concentrations for birds and mammals in toxicity tests. Studies were subdivided into categories of reliability. Studies were placed in category 1 (the category with the highest reliability) if:

- details on soil parameters were available to carry out standardization (see appendix 2)
- the species used were specified.
- *the concentrations tested were not toxic to earthworms.*
- actual concentrations in soil were given (no nominal concentrations were used to calculate BCF)

On category 1 studies a standardisation of the BCF value was carried out to a 10% OM soil for organic chemicals or to pH = 6.5 for cadmium.

LINDANE

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF ww/dw	BCF_{st}	Reference
category 1 studies												
not available												
lower category studies												
L. terrestris	f	-	stony loam	-	-	-	-	0.004	0.0064	1.60	n.a	Wheatley & Hardman '68
A. longa	f	-	,,	-	-	-	-	0.004	0.0060	1.50	-	,,
A. caliginosa	f	-	,,	-	-	-	-	0.004	0.0110	2.75	-	,,
A. chlorotica	f	-	,,	-	-	-	-	0.004	0.0130	3.25	-	,,
A. rosea	f	-	,,	-	-	-	-	0.004	0.0170	4.25	-	,,
O. cyaneum	f	-	,,	-	-	-	-	0.004	0.0076	1.90	-	,,
P. posthuma	l	70 days	-	-	-	-	-	1.000	1.1000	1.38	n.a	Yadav et al. '76
								nominal	(ww)3			
-	f	-	-	-	-	-	-	0.01	0.05	1.00	n.a	Davis & Harrison '66
								0.08	0.30	0.75	n.a	,,
								(dw ?)	(dw ?)			

Appendix 1

DIELDRIN category 1 studies

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
L. terrestris	l	35 days	-	2.6	5.1	-	-	0.63	0.60	0.95	0.25	Lord et al. '80
,,+ 3 others	f	1 years	loam	4	6-7	-	-	average	of 3 conc.	3.75[19]	1.5	Beyer & Gish '80
,,+ 3 others	f	5 years	loam	4	6-7	-	-	average	of 3 conc.	2.00[19]	0.8	,,
,,+ 3 others	f	11 years	loam	4	6-7	-	-	average	of 3 conc.	0.98[19]	0.39	,,
A. caliginosa	l	28 days	peaty loam	30.1	6.3	27	-	3.10	0.23	0.07	0.21	Davis '71
,,	l	28 days	organic loam	6.6	6.9	49	-	2.70	0.78	0.29	0.19	,,
,,	l	28 days	loamy sand	1.3	6.0	11	-	1.70	2.99	1.76	0.23	,,
,,	l	28 days	silty loam	2.8	7.4	25	-	2.20	3.56	1.62	0.45	,,
,,	l	28 days	clay loam	1.7	7.6	52	-	2.00	4.55	2.28	0.39	,,
A. longa	l	35 days	-	2.6	5.1	-	-	0.74	0.63	0.85	0.22	Lord et al. '80

geometric mean BCF_{st} for L. terrestris = 0.58
geometric mean BCF_{st} for A. calignosa = 0.28
geometric mean value for A. longa = 0.22

Geometric mean BCF_{st} for the 3 species = 0.33
Maximum value = 1.5

DIELDRIN lower category studies

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
L. terrestris	l	28 days	compost	high	-	-	-	17	13.3	0.78	-	Davis '71[10]
,,	l	20 days	compost	high	-	-	-	32	13.8	0.43	-	Davis '71
,,	l	28 days	compost	high	-	-	-	17	11.5	0.68	-	Davis '71
,,	f	-	stony loam	-	-	-	-	0.64	1.60	2.50	-	Wheatley & Hardman '68
,,	f	20 days	-	-	-	-	-	25 (nominal)	18.4-24.9 (ww)	1.07	-	Jefferies & Davis '68
A. caliginosa	l	28 days	-	-	-	-	-	17.0	27.5	1.61	-	Davis '71
,,	l	28 days	alluvial	-	7	-	-	5.00	1.17	0.23	-	,,
,,	l	28 days	alluvial	-	6.4	-	-	5.00	1.26	0.25	-	,,
,,	l	28 days	alluvial	-	5.8	-	-	5.00	1.61	0.32	-	,,
,,	l	28 days	alluvial	-	5.4	-	-	5.00	1.27	0.25	-	,,
,,	l	28 days	alluvial	-	4.9	-	-	5.00	1.91	0.38	-	,,
,,	f	-	stony loam	-	-	-	-	0.64	3.80	5.90	-	Wheathley & Hardman '68
A. longa	f	-	stony loam	-	-	-	-	0.64	2.20	3.40	-	Wheatley & Hardman '68
,,	f	-	sandy loam	-	-	-	-	0.003	0.033	11.0	-	,,
,,	f	-	sandy loam	-	-	-	-	0.50	0.70	1.40	-	,,
,,	f	-	sandy loam	-	-	-	-	0.85	1.00	1.18	-	,,
,,	f	-	sandy loam	-	-	-	-	1.10	1.30	1.18	-	,,
,,	f	-	sandy loam	-	-	-	-	1.30	1.30	1.00	-	,,
A. chlorotica	f	-	stony loam	-	-	-	-	0.64	4.60	7.19	-	Wheatley & Hardman '68
,,	f	-	sandy loam	-	-	-	-	0.003	0.028	9.33	-	,,
,,	f	-	sandy loam	-	-	-	-	0.50	1.80	3.60	-	,,
,,	f	-	sandy loam	-	-	-	-	0.85	2.00	2.35	-	,,
,,	f	-	sandy loam	-	-	-	-	1.10	2.90	2.63	-	,,
,,	f	-	sandy loam	-	-	-	-	1.20	2.10	1.75	-	,,
A. rosea	f	-	stony loam	-	-	-	-	0.64	3.90	6.09	-	Wheatley & Hardman '68
O. cyaneum	f	-	stony loam	-	-	-	-	0.64	2.40	3.75	-	Wheatley & Hardman '68
-	f	-	-	-	-	-	-	0.03-0.7	0.06-0.8 (dw ?)	0.89 (dw ?)	-	Davis & Harrison '66

DDT category 1 studies: DDT concentration in both soil and earthworms were determined as total DDT concentrations (= DDT + metabolites) in order to reduce variation caused by differences in metabolism. $C_{DDT} = C_{o,p'-DDT} + C_{p,p'-DDT} + 1.1*C_{p,p'-DDE} + 1.1*C_{DDD}$. The multiplication factors (1.1) for DDE and DDD are applied to compensate for the relative molecular weight of DDT to these metabolites.

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
L. terrestris + 3 others	f	11 years	loam	4	6-7	-	-	average	of 3 conc.	1.28[17]	0.51	Beyer & Gish '80
A. caliginosa	l	4 weeks	clay loam	2	-	45.2	-	2.2-2.6	1.05	0.44	0.09	Davis '71
,,	l	4 weeks	clay loam	3.6	-	45.2	-	2.2-2.6	0.93	0.39	0.14	,,
,,	l	4 weeks	clay loam	6.5	-	45.2	-	2.2-2.6	0.45	0.20	0.13	,,
,,	l	4 weeks	clay loam	11.7	-	45.2	-	2.2-2.6	0.33	0.14	0.16	,,
,,	l	4 weeks	clay loam	21	-	45.2	-	2.2-2.6	0.21	0.09	0.19	,,

Geometric mean BCF_{st} value for L. terrestris = 0.51
Geometric mean BCF_{st} value for A. caliginosa = 0.14

Geometric mean BCF_{st} value for the 2 species = 0.27
Maximum value = 0.51

DDT lower category studies

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
unspecified	f	-	stony loam	2.4	7.6	-	-	3.61	5.30 (dw)	0.29	0.07	Bailey et al. '74
,,	f	-	stony loam	2.4	7.6	-	-	5.38	11:67 (dw)	0.43	0.10	Bailey et al. '74
,,	f	-	stony loam	2.4	7.6	-	-	3.59	10.82 (dw)	0.60	0.14	Bailey et al. '74
,,	f	-	stony loam	2.4	7.6	-	-	3.90	7.67 (dw)	0.39	0.09	Bailey et al. '74
,,	f	-	stony loam	2.4	7.6	-	-	2.16	3.97 (dw)	0.37	0.09	Bailey et al. '74
,,	f	-	stony loam	2.4	7.6	-	-	5.13	7.92 (dw)	0.31	0.07	Bailey et al. '74
,,	f	-	stony loam	2.4	7.6	-	-	4.31	17.55 (dw)	0.81	0.19	Bailey et al. '74

Geometric mean BCF_{st} value for unspecified species = 0.1

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
L. terrestris	f	-	-	-	-	-	-	9.6[11]	59	6.19	-	Barker '58
,,	f	-	stony loam	-	-	-	-	0.96[12]	1.15[12]	1.19	-	Wheatley & Hardman '68
,,	l	4 weeks	compost	high	-	-	-	1	0.18	0.18	-	Davis '71
,,	l	4 weeks	compost	high	-	-	-	4	2.49	0.62	-	,,
,,	l	4 weeks	compost	high	-	-	-	16	12.9	0.80	-	,,
,,	l	4 weeks	compost	high	-	-	-	64	54.9	0.86	-	,,
,,	l	4 weeks	compost	high	-	-	-	17	9.75	0.57	-	,,
L. terrestris	l	6 months	-	-	-	-	-	0.9	4.0[14]	4.44	-	Edwards & Jeffs '74[15]
,,	l	4 months	-	-	-	-	-	1.2 (dw ?)	3.9[14] (ww ?)	3.3	-	,,
L. rubellus	f	-	-	-	-	-	-	9.6[11]	210	21.9	-	Barker '58
O. lacteum	f	-	-	-	-	-	-	9.6[11]	106	11.0	-	Barker '58
H. zeteki	f	-	-	-	-	-	-	9.6[11]	200	20.9	-	Barker '58
H. caliginosa t.	f	-	-	-	-	-	-	9.6[11]	54	5.7	-	Barker '58

DDT lower category studies continued

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
Lumbricus +	f	2 year	organic	high	-	-	-	0.88	0.098	0.11	-	Dimond et al '70
Aporectodea	f	3 year	,,	,,	-	-	-	1.56	0.160	0.10	-	,,
,,	f	6 year	,,	,,	-	-	-	1.21	0.133	0.11	-	,,
,,	f	8 year	organic	high	-	-	-	1.32	0.321	0.24	-	Dimond et al. '70
,,	f	-	,,	,,	-	-	-	3.26	0.435	0.13	-	,,
,,	f	-	control	,,	-	-	-	0.18	0.089	0.49	-	,,
A. longa	f	-	stony loam	-	-	-	-	0.96[12]	1.38[12]	1.44	n.a	Wheatley & Hardman '68
A. caliginosa	f	-	stony loam	-	-	-	-	0.96[12]	2.57[12]	2.67	-	Wheatley & Hardman '68
,,	l	15 days	-	-	-	-	-	5.6	2.35	0.42	-	Davis '71
A. chlorotica	f	-	stony loam	-	-	-	-	0.96[12]	4.72[12]	4.92	-	Wheatley & Hardman '68
A. rosea	f	-	stony loam	-	-	-	-	0.96[12]	2.67[12]	2.78	-	Wheatley & Hardman '68
O. cyaneum	f	-	stony loam	-	-	-	-	0.96[12]	1.28[12]	1.33	-	Wheatley & Hardman '68
P. posthuma	l	10 weeks	-	-	-	-	-	1.00 nominaal(ww)	13	16.3	-	Yadav et al. '76
Various	f	-	loam	-	-	-	-	0.33[12] (dw ?)	3.5 (dw ?)	2.12	-	Davis & Harrison '66
unspecified	f	-	-	-	-	-	-	5.9[11]	30.9	5.23	-	Collet & Harrison '68
,,	f	-	-	-	-	-	-	7.2[11]	13.9	1.93	-	,,

Appendix 1

PCP category 1 studies

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC (mg/kg)	C_{soil} (mg/kg)	C_{worm}	BCF	BCF_{st}	Reference
E. andrei	l	14 days	sandy loam	3.7	4.8	1.4	6.6	32-56	39.6 (dw)	1.06	0.39	Van Gestel & Ma '88
,,	l	14 days	sandy loam	6.1	5.6	2.4	10.0	32-56	40.9 (dw)	0.68	0.41	,,
L. rubellus	l	14 days	sandy loam	3.7	4.8	1.4	6.6	32-56	39.6 (dw)	0.8	0.30	Van Gestel & Ma '88
,,	l	14 days	sandy loam	6.1	5.6	2.4	10.0	32-56	40.9 (dw)	1.6	0.98	,,
A. caliginosa	l	14 days	loam soil	10	6.6	20	-	2.2	17	8.1	8.1	Haque & Ebing '88
,,	l	14 days	loam soil	10	6.6	20	-	11.2	144	12.8	12.8	,,
,,	f	19 weeks	loam soil	2.0	6.8	2.9	8	1.8	11.5	6.3	1.26	,,
L. terrestris	v	19 w	loam soil	2.0	6.8	2.9	8	1.8	40	22.2	4.44	Haque & Ebing '88

Geometric mean BCF_{st} value for E. andrei = 0.40
Geometric mean BCF_{st} value for L. rubellus = 0.54
Geometric mean BCF_{st} value for A. caliginosa = 5.07
Geometric mean BCF_{st} value for L. terrestris = 4.44

Geometrisch mean value for the 4 species = 1.48
Maximum value = 12.8

lower category studies

none

Appendix 1

CADMIUM category 1 studies.

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
L. rubellus	f	-	sandy podzol	5	4.6	-	-	0.1-5.7	20-202 (dw)	7.93[1]	1.89	Ma et al. '83
L. terrestris	f	-	-	-	6.5	-	-	1.0	16 (dw)	2.93[2]	2.93	Wright & Stringer '80
,,	f	-	-	-	6.8	-	-	10	55 (dw)	1.11[3]	1.39	,,
,, (mainly)	f	-	lansdale loam sludge-amended	-	6.2	-	-	3.8	51 (dw)[4]	3.09	2.46	Beyer et al. '82
,, (mainly)	f	-	lansdale loam	2.5	6.4	-	8	0.14	8.6 (dw)[4]	14.13	13.1	,,
,, (mainly)	f	-	lansdale loam sludge-amended	2.8	6.3	-	8	1.9	101 (dw)[4]	12.22	10.51	,,
,, (mainly)	f	-	silt loam	2.6	6.1	-	10	0.09	3.6 (dw)[4]	9.2	6.8	,,
,, (mainly)	f	-	silt loam sludge amended	3.8	6.1	-	11	8.2	118 (dw)[4]	3.3	2.44	,,
,,	f	-	sandy soil	7.3	6.0	-	-	6.0	79 (dw)	2.63	1.81	Ma '87
,,	f	-	sandy soil	10.2	6.5	-	-	9.2	114 (dw)	2.48	2.48	,,
,,	f	-	sandy soil	5.7	4.0	-	-	0.1	19 (dw)	38	5.79	,,
,,	f	-	K-fertilized	-	5.9	-	-	0.29 (0.12)[5]	16.9 (dw)	11.7	7.45	Andersen '79
,,	f	-	sludge amended	-	5.8	-	-	0.65 (0.26)[5]	16.8 (dw)	5.17	3.05	,,
,,	f	-	sludge amended	-	6.0	-	-	0.99 (0.41)[5]	8.8 (dw)	1.78	1.22	,,
,,	f	-	-	-	6.93	-	-	1.04	21.0 (dw)	4.04	5.58	,,
,,	f	-	-	-	6.36	-	-	1.04	23.8 (dw)	4.58	4.12	,,
,,	f	-	-	-	7.08	-	-	0.76	30.8 (dw)	8.11	12.54	,,

CADMIUM category 1 studies continued.

species	field/lab expériment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
L. terrestris	f	-	-	-	6.53	-	-	0.76	15.6 (dw)	4.11	4.2	Andersen '79
,,	f	-	-	-	7.21	-	-	0.72	32.5 (dw)	9.03	15.4	,,
,,	f	-	-	-	6.80	-	-	0.72	19.8 (dw)	5.50	6.89	,,
,,	f	-	-	-	7.4	-	-	0.29	29.1 (dw)	20.1	39.51	,,
,,	f	-	-	-	7.28	-	-	0.45	12.5 (dw)	5.56	9.99	,,
A. calignosa	f	-	-	-	6.5	-	-	1.0	35 (dw)	6.49[3]	6.49	Wright & Stringer '80
,,	f	-	-	-	6.8	-	-	10	63 (dw)	1.29[3]	1.62	,,
,, (mainly)	f	-	loamy soil	5.8	7.1	30	26.3	-	- (dw)	2.46	3.86	Ma '82
,, (mainly)	f	-	loamy soil	6.7	7.0	30	24.5	-	- (dw)	2.14	3.12	,,
,, (mainly)	f	-	loamy soil	8.4	6.9	30	25.1	-	- (dw)	2.26	3.05	,,
,, (mainly)	f	-	loamy soil	2.8	6.6	10	9.4	-	- (dw)	5.24	5.65	,,
,, (mainly	f	-	loamy soil	4.0	7.0	10	10.5	-	- (dw)	6.08	8.85	,,
,, (mainly)	f	-	loamy soil	4.9	7.0	10	12.3	-	- (dw)	3.50	5.1	,,
,, (mainly)	f	-	loamy soil	6.9	5.3	40	26.4	-	- (dw)	3.06	1.24	,,
,, (mainly)	f	-	loamy soil	9.2	5.8	40	28.7	-	- (dw)	2.72	1.61	,,
,, (mainly)	f	-	loamy soil	9.7	5.9	40	28.7	-	- (dw)	3.18	2.02	,,
,, (mainly)	f	-	sandy soil	12.4	4.7	low	20.5	-	- (dw)	22.4	5.79	,,

CADMIUM category 1 studies continued.

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
A. caliginosa (mainly)	f	-	sandy soil	11.2	5.2	low	19.2	-	- (dw)	12.18	4.58	Ma '82
,, (mainly)	f	-	sandy soil	13.6	5.8	low	18.3	-	- (dw)	8.10	4.78	,,
,, (mainly)	f	-	sandy soil	6.4	5.4	low	13.5	-	- (dw)	15.92	6.96	,,
,, (mainly)	f	-	sandy soil	7.4	5.4	low	12.7	-	- (dw)	8.52	3.73	,,
,, (mainly)	f	-	sandy soil	8.1	5.7	low	23.2	-	- (dw)	6.14	3.36	,,
,, (mainly)	f	-	sandy soil	2.8	4.8	low	5.3	-	- (dw)	28.0	7.80	,,
,, (mainly)	f	-	sandy soil	3.7	5.5	low	6.1	-	- (dw)	11.88	5.60	,,
,, (mainly)	f	-	sandy soil	4.3	6.0	low	7.1	-	- (dw)	8.10	5.56	,,
,,	f	-	sludge amended	-	5.8	-	-	0.65 (0.26)[5]	6.9 (dw)	2.12	1.25	Andersen '79
,,	f	-	sludge amended	-	6.0	-	-	0.99 (0.41)[5]	10.9 (dw)	2.20	1.51	,,
,, (= A. tuberculata)	f	-	-	-	6.5	-	-	1.0	19	3.51[3] (dw)	3.51	Wright & Stringer '80
,,	f	3 years	mined slugde amended	-	7.5	-	-	2.0	22 (dw)[2]	3.17[3]	6.72	Pietz et al. '84
,,	f	-	mined nonamended	-	7.9	-	-	0.6	3.8 (dw)[2]	1.34[3]	3.84	,,
,, + L. terr.	f	-	silty loam sludge amended	-	5.9	-	-	3.5	36 (dw)[2]	3.51[3]	2.24	,,
,, + L. terr.	f	-	silty loam nonamended	-	8.0	-	-	1.0	12 (dw)[2]	2.51[3]	7.75	,,
,, (mainly)	f	-	Lansdale loam	-	6.3	-	-	0.06	4.0 (dw)[4]	15.3	13.16	Beyer et al. '82
,, (mainly)	f	-	silt loam	3.0	6.4	-	9	0.18	5.3 (dw)[4]	6.77	6.28	,,

CADMIUM category 1 studies continued.

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
A. chlorotica	f	-	-	-	6.5	-	-	1.0	16 (dw)	2.98[3]	2.98	Wright & Stringer '80
,,	f	-	-	-	6.8	-	-	10	55 (dw)	1.13[3]	1.42	,,
,,	f	-	sludge amended	-	5.8	-	-	0.65 (0.26)[5]	10.9 (dw)	3.35	1.98	Andersen '79
,,	f	-	sludge amended	-	6.0	-	-	0.99 (0.41)[5]	16.2 (dw)	3.72	2.55	,,
A. longa	f	-	-	-	6.5	-	-	1.0	17 (dw)	3.2	3.2	Wright & Stringer '80
,,	f	-	-	-	6.8	-	-	10	39 (dw)	0.803	1.00	,,
,, (mainly)	f	-	silt loam sludge amended	4.9	6.0	-	13	0.91	18 (dw)[4]	4.55	3.12	Beyer et al. '82
,,	f	-	K-fertilizer	-	5.9	-	-	0.29 (0.12)[5]	11.8 (d.w.)	8.14	5.18	Andersen '79
,,	f	-	NPK-fertil.	-	5.7	-	-	0.14 (0.12)[5]	10.0 (dw)	14.3	7.84	,,
,,	f	-	sludge amended	-	5.8	-	-	0.65 (0.26)[5]	5.3 (dw)	1.75	1.03	,,
,,	f	-	sludge amended	-	6.0	-	-	0.99 (0.41)[5]	9.2 (dw)	1.86	1.28	,,
A. rosea	f	-	-	-	6.5	-	-	1.0	17 (dw)	3.25[3]	3.25	Wright & Stringer '80
,,	f	-	-	-	6.8			10	49 (dw)	1.21[3]	1.52	,,
,,	f	-	K-fertilizer	-	5.9	-	-	0.29 (0.12)[5]	26.9 (dw)	18.6	11.84	Andersen '79
,,	f	-	NPK-fertil.	-	5.7	-	-	0.14 (0.12)[5]	21.2 (dw)	30.3	16.60	,,
,,	f	-	sludge amended	-	5.8	-	-	0.65 (0.26)[5]	10.9 (dw)	3.35	1.98	,,
,,	f	-	sludge amended	-	6.0	-	-	0.99 (0.41)[5]	19.6 (dw)	3.96	2.72	,,

CADMIUM category 1 studies continued.

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
E. foetida	l	4 weeks	OECD-grond	17[20]	6.9-7.4	10	10	0.3	1.9 (dw)[7]	0.95	1.55	Ma et al. '91
,,	l	4 weeks	untreated	3.6[20]	7.3-7.6	12.9	9.8	23	47 (dw)[8]	0.31	0.63	,,
,,	l	4 weeks	OECD-soil	17[20]	7.1-7.9	10	10	0.3	1.9	0.95	2.01	,,

Geometric mean BCF_{st} value for L. rubellus = 1.89
Geometric mean BCF_{st} value for L. terrestris = 5.13
Geometric mean BCF_{st} value for A. caliginosa = 3.99
Geometric mean BCF_{st} value for A. chlorotica = 2.15
Geometric mean BCF_{st} value for A. longa = 2.45
Geometric mean BCF_{st} value for A. rosea = 4.16
Geomertic mean BCF_{st} value for E. foetida = 1.25

Geometric mean value for all 7 species = 2.70
Maximum value = 39.51

Appendix 1

CADMIUM lower catagorie studies

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
4 spec.	f	-	silty clay	7.3	6.96	-	-	1.14	10.8 (dw)	1.89	2.67	Gish & Christensen '73
,,	f	-	silty clay	4.96	6.98	-	-	0.64	7.8 (dw)	2.44	3.5	,,
,,	f	-	loamy sand	4.8	6.88	-	-	0.62	7.2 (dw)	2.32	3.09	,,
,,	f	-	loamy sand	6.36	6.96	-	-	0.88	8.7 (dw)	1.98	2.67	,,
,,	f	-	mixed	3.28	6.86	-	-	0.66	3.0 (dw)	0.91	1.19	,,
various	f	-	sandy soil	6.00	6.10	-	-	5.5	62 (dw)	2.3	1.70	Ma et al. '91
,,	f	-	sandy soil	6.00	6.10	-	-	5.5	109 (dw)	4.0	2.96	,,
,,	f	-	sandy soil	8.8	3.5	-	-	1.2	13 (dw)	2.2	0.23	,,
,,	f	-	sandy soil	8.8	3.5	-	-	1.2	38 (dw)	6.3	0.66	,,
Geometric mean BCF_{st} for unspecified species = 1.60												
L. rubellus	f	-	mined	-	-	-	-	2.00	15.0 (dw)	1.50	-	Ireland '79
,,	f	-	sludge amended	-	-	-	-	4.00	4.00 (dw)	0.20	-	,,
,,	f	-	mined	-	-	-	-	4.00	25 (dw)	1.20	-	,,
,,	f	-	-	4.81	-	-	-	0.08	15.05 (dw)	37.63	-	Kruse & Barret '85
,,	f	-	fertilized	5.1	-	-	-	0.29	15.67 (dw)	10.81	-	,,
,,	f	-	sludge amended	5.79	-	-	-	1.29	135.6 (dw)	21.03	-	,,
various	f	-	-	-	-	-	-	29	143.7 (dw)	0.99	-	Martin & Coughtrey '76

CADMIUM lower catagorie studies

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
E. foetida	l	5 weeks	sludge	-	-	-	-	10	46 (dw)	0.78[3]	-	Hartenstein et al. 80
,,	l	5 weeks	,,	-	-	-	-	50	101 (dw)	0.41[3]	-	,,
,,	l	5 weeks	,,	-	-	-	-	100	148	0.29[3]	-	,,
,,	f	26 weeks	sludge	-	-	-	-	12-27	8-46	0.21	-	,,
,,	l	4 weeks	hydroxide-washed	0.34[20]	6.0-5.7	0.4	1.3	3.3	45 (dw)[7]	6.66	-	,,
,,	l	4 weeks	acid-extracted	-	4.1-4.3	-	-	5.4	16 (dw)[6]	0.48	-	,,
,,	l	4 weeks	hydroxide-washed	-	7.0-7.2	-	-	4.6	18 (dw)[8]	0.57	-	,,
,,	l	4 weeks	NTA-washed	2.2[20]	7.4-7.7	1.6	1.8	8.6	36 (dw)[8]	0.63	-	,,
,,	l	4 weeks	acid-extracted	3.1[20]	5.1-5.8	10.3	7.8	5.5	33 (dw)[8]	0.90	-	,,
,,	l	4 weeks	acid-extracted	-	7.1-7.3	-	-	14	44 (dw)[6]	0.50	-	,,
D. veneta	f	-	sludge-amended	-	-	-	-	4.00	7.00 (dw)	0.35	-	Ireland '79
E. tetraedra	f	-	sludge-amended	-	-	-	-	4.00	3.00	0.15 (dw)	-	Ireland '79

Appendix 1

MERCURY category 1 studies:

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
L. terrestris	f	-	-	-	-	-	-	3.81 total	1.29 total[16]	0.33	-	Bull et al. '77
,,	-	-	-	-	-	-	-	0.106 total	0.041 total	0.39	-	,,

Geometric mean BCF for L. terrestris = 0.36

Lower category studies

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
E. foetida	l	4 weeks	untreated	9.9[20]	4.8-5.2	3.5	10.2	159	58 (dw)[8]	0.054	-	Adema et al. '87
Eisenia foetida	l	4 weeks	hydroxide-washed	0.7[20]	6.7-6.1	0.7	3.2	35	65 (dw)[6]	0.30	-	,,
,,	l	4 weeks	flotated	0.2[20]	7.3-7.6	0.5	1.9	1	0.74 (dw)[6]	0.12	-	,
,,	l	4 weeks	acid-extracted	-	3.7-3.9	-	-	62	52 (dw)[8]	0.13	-	,,
A. caliginosa (= A. tuberculata)	f	4-5 years	untreated	-	-	-	-	<0.02 nominal	0.58 (dw)	5.8	-	Helmke et al '79
,,	f	4-5 years	sludge-amended	-	-	-	-	0.06[21] nominal	0.49 (dw)	1.6	-	,,
,,	f	4-5 years	sludge-amended	-	-	-	-	0.10[21] nominal	0.59 (dw)	1.2	-	,,
,,	f	4-5 years	sludge-amended	-	-	-	-	0.19[21] nominal	0.60 (dw)	0.63	-	,,
Lumbricus spec	f	-	Lava	-	-	-	-	14.3 ([10])	387.6 (dw)	5.42	-	Siegel et al. '75

Geometric mean lower category studies = 0.54

Appendix 1

METHYL-MERCURY category 1 studies

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
E. foetida	l	12 weeks	potting soil	high	-	-	-	0.63 (ww)[9]	13	8.25	-	Beyer et al. '85
,,	l	12 weeks	potting soil	high	-	-	-	1.3 (ww)[9]	27	8.31	-	,,

Geometric mean BCF for E. foetida = 8.28

lower category studies

species	field/lab experiment	experimental duration	soil type	%O.M.	pH	%Clay	CEC	C_{soil} (mg/kg)	C_{worm} (mg/kg)	BCF	BCF_{st}	Reference
E. foetida	l	12 weeks	potting soil	high	-	-	-	3.8	85	8.95	-	Beyer et al. '85

BCF_{st} = standardized BCF value
C_{soil} = concentration in soil, based on dry weight unless specified different
C_{worm} = concentration in earthworms based on wet weight unless specified different.
CEC = Cation exchange capacity
dw = dry weight
ww = wet weight
%OM = organic matter content of the soil
\- = not available

species:

A. caliginosa	= Aporrectodea (= Allolobophora) caliginosa (= tuberculata)	H. caliginosa t.	= Helodrilus caliginosa trapezoidus*
A. longa	= Aporrectodea (= Allolobophora) longa	H. zeteki	= Helodrilus zeteki*
A. chlorotica	= Aporrectodea chlorotica	L. rubellus	= Lumbricus rubellus
A. rosea	= Aporrectodea (= Allolobophora) rosea	L. terrestris	= Lumbricus terrestris
D. venta	= Dendrobaena veneta	O. cyaneum	= Octolasion cyaneum
E. foetida	= Eisenia foetida	O. lacteum	= Octolasium lacteum
E. andrei	= Eisenia andrei	P. posthuma	= Pheretima posthuma
E. tetraedra	= Eiseniella tetraedra		

* = these species names do not exist any more. However, correct contemporary names could not be found, hence the names as given by the authors were used.

[1]= Calculated using regression equations with C_{soil} = 1 mg/kg, pH= 4.6 and ww= 5*dw.
[2]= In the study the dry weight of the worms was measured to be 16.7% of the wet weight.
[3] = BCF value listed as given in the article, not calculated by C_w/C_b.
[4] = Dry weight measured to be 23% of the wet weight.
[5] = In the article C_{soil} has been determined using two different extraction methods. The BCF listed here was calculated using the results of the perchloric acid extraction.
[6] = Dry weight of the worms was measured to be 16% of the wet weight.
[7] = Dry weight of the worms was measured to be 14% of the wet weight.
[8] = Dry weight of the worms was measured to be 15% of the wet weight.
[9] = Water content of the soil was measured to be 60 %.
[10]= C_{soil} in this study is given as the biological available (= HCl or HNO_3 extractable) concentration.
[11]= C_{soil} calculated by taking the geometric mean of the measured concentrations in various soil layers.
[12]= Total DDT concentration calculated by $C_{p,p'-DDT}$+ $C_{o,p'-DDT}$ + $1.1*C_{p,p-DDE}$.
[13]= The authors states that C_{DDE} in soil equals 10% of the DDT concentration in soil. Calculation of BCF was carried out using these figures.
[14]= Value estimated from figure !
[15]= Mortality among earthworms occurred at the concentrations tested.
[16]= 8-13% Of the total mercury in the earthworm was methylated. No methyl-mercury was present in the soil.
[17]= Values for BCF calculated by compensating the BCF values in the article (on a dry to dry weight) with the dry to wet weight ratio also given in by the author.
[18]= A. calignosa: dry weight = 28.5% of life weight, L. terrestris: gut content = 11% of w.w.
[19]= In this article a dry to wet weight ratio of 1:4 is assumed.
[20]= %OM calculated by %O.M. = 1.7 * % O.C.
[21]= C_{soil} calculated by data given in the article, not measured as such by the author.

Appendix 2

Influence of soil parameters on BCF values.

In the literature a correlation is suggested between the accumulation in earthworms (and hence the bioconcentration factors) and soil-parameters:

For dieldrin:	$C_{worm} = 1.534pH + 0.486/\%OM - 9.914$	Davis 1971
For organic chemicals:	$BCF = (Y_l / x * f_{oc}) * K_{ow}^{b-a}$	Connell & Markwell 1990
For cadmium:	$BCF = 2.722 * e^{-0.752*pH}$	Ma 1982
	$BCF = 10.5 / C_{soil} + 3.65$	Pietz et al. 1984
	$C_{worm} = 5.5 + 0.66 * LnC_{soil} - 0.4pH$	Wright & Stringer 1980

Regression analyses were carried out on the BCF data found in the literature (appendix 1) to analyze whether these correlations can be confirmed.
For each compound the correlation was analyzed between BCF and: %OM, pH, %Clay, CEC and C_{soil}, both on a linear and log-transformed data.
Below regression lines are given either on linear or log-transformed data, whichever gave the highest correlation. Regressions were only carried out when more than 4 data points were available ($n > 4$).

lindane

BCF-%OM	no data available	
BCF-pH	no data available	
BCF-%Clay	no data available	
BCF-CEC	no data available	
BCF-C_{soil}	$logBCF = -0.63 - 0.41logC_{soil}$	($n = 8$, $r^2 = 0.54$)

dieldrin

BCF-%OM	$BCF = 2.20 - 1.07log\%OM$	($n = 7$, $r^2 = 0.63$)
BCF-pH	$BCF = -1.49 + 0.41pH$	($n = 15$, $r^2 = 0.11$)
BCF-%Clay	$logBCF = 0.40 - 0.4log\%Clay$	($n = 5$, $r^2 = 0.03$)
BCF-CEC	no data available	
BCF-C_{soil}	$BCF = 2.74 - 2.51logC_{soil}$	($n = 33$, $r^2 = 0.67$)

DDT

BCF-%OM	$logBCF = -0.093 - 0.71log\%OM$	($n = 5$, $r^2 = 0.97$)
BCF-pH	no data available	
BCF-%Clay	no data available	
BCF-CEC	no data available	
BCF-C_{soil}	$BCF = 1.81 + 3.23C_{soil}$	($n = 28$, $r^2 = 0.13$)

PCP

BCF-%OM	$BCF = 10.65 - 5.97\log\%OM$	($n = 8$, $r^2 = 0.05$)
BCF-pH	$\log BCF = -3.16 + 0.62pH$	($n = 8$, $r^2 = 0.81$)
BCF-%Clay	$\log BCF = 0.32 + 0.28\log\%Clay$	($n = 6$, $r^2 = 0.07$)
BCF-CEC	$BCF = 8.65 - 0.39CEC$	($n = 6$, $r^2 = 0.005$
BCF-C_{soil}	$\log BCF = 1.14 - 0.03C_{soil}$	($n = 8$, $r^2 = 0.87$)

Cadmium

BCF-%OM	$BCF = 9.21 - 0.21\%OM$	($n = 45$, $r^2 = 0.006$)
BCF-pH	$\log BCF = 1.99 - 0.22pH$	($n = 79$, $r^2 = 0.22$)
BCF-%Clay	$\log BCF = -0.31 + 0.47\log\%Clay$	($n = 14$, $r^2 = 0.21$)
BCF-CEC	$BCF = 9.55 - 0.16CEC$	($n = 28$, $r^2 = 0.04$)
BCF-C_{soil}	$\log BCF = 0.54 - 0.55\log C_{soil}$	($n = 76$, $r^2 = 0.57$)

Mercury

BCF-%OM	not enough data available	
BCF-pH	not enough data available	
BCF-%Clay	not enough data available	
BCF-CEC	not enough data available	
BCF-C_{soil}	$\log BCF = -0.17 - 0.007C_{soil}$	($n = 10$, $r^2 = 0.38$)

Methyl-mercury

BCF-%OM	no data available
BCF-pH	no data available
BCF-%Clay	no data available
BCF-CEC	no data available
BCF-C_{soil}	not enough data available

Appendix 3 Common names to species used in toxicity tests.

Anas platyrhynchos	=	mallard duck
Blerina brevicauda	=	short-tailed shrew
Bos primigenius taurus	=	cow
Colinus virginianus	=	bob-white quail
Canis domesticus	=	dog
Coturnix coturnix japonica	=	japanese quail
Cyanocitta cristata	=	blue jay
Damaliscus dorcas phillipsi	=	blesbuck
Gallus domesticus	=	chicken
Macaca mulatta	=	rhesus monkey
Meleagris gallopavo	=	turkey
Microtus canicaudus	=	gray tailed vole
Microtus orchrogaster	=	prairie vole
Microtus pennsylvanicus	=	eastern meadow vole
Molothrus ater	=	cowbird
Mus musculus	=	domestic mouse
Mustela vison	=	mink
Numida meleagris	=	crowned guinea fowl
Oryctolagus cuniculus	=	rabbit
Ovis amon aries	=	sheep
Passer domesticus	=	house sparrow
Peromyscus polionotus	=	old-field mouse
Phasianus colchicus	=	ring-necked pheasant
Rallus longistris	=	clapper rail
Rattus norvegicus	=	norwegian (laboratory) rat
Richmondena carolinensus	=	cardinal
Saimura sciureus	=	squirrel monkey
Streptopelia risoria	=	ring dove
Sus scrofa domesticus	=	pig

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