Uptake and Accumulation of DDT and PCB by *Ephemera danica* (Ephemeroptera) in Continuous-Flow Systems

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Most aquatic organisms are known to accumulate organochlorine residues (WOODWELL et al. 1967, WURSTER 1969, JOHNSON et al. 1971). The process of magnification of these substances in succeeding trophic levels has been studied by several workers (ROBINSON et al. 1967, MACEK et al. 1970, EBERHARDT et al. 1971, WILKES and WEISS 1971), and different mechanisms have been proposed. Accumulation of persistent residues by aquatic organisms occurs by either direct uptake from the surrounding water, or uptake via the food, or by a combination of both. For certain invertebrates and fish, Hamelink et al. (1971), have shown that the uptake of DDT occurs largely via the water.

In a previous study of a stream ecosystem, we found that nymphs of the mayfly Ephemera danica (Müll.) differed from other organisms studied with respect to storage and degradation of DDT (SÖDERGREN et al. 1972). A closer examination of this species with regard to the kinetics of uptake and degradation of DDT and polychlorinated biphenyls (PCB) was therefore undertaken in continuous-flow systems.

MATERIAL AND METHODS

Nymphs of E. danica, which were used as test organisms, are detritivorous burrowers in the bottom substrates of streams and ponds. Food particles are filtered from the water by the long bristles on the forelegs, and rhytmically brought to the mouth. The length of the nymphs used in the experiments was 21-23 mm, and they were approximately 1.5 years old. It is generally considered that E. danica completes a generation in two years (Landa 1960).

The nymphs were collected in a stream in southern Sweden. The background levels of organochlorine residues in organisms of this stream have been re-

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ported elsewhere (SÖDERGREN et al. 1972).

In order to subject the animals to a medium with a constant residue level, a continuous-flow system was employed. Immediately after having been collected in the stream, some fifty animals were introduced into the system. p,p'-DDT and PCB (Clophen A 50) were dissolved in ethanol and added to the water flowing through the chamber containing the animals, and each day a sample of five animals was drawn for subsequent residue analysis. At the same time, the residue content in the outflowing water was determined. The chamber was aerated by a constant flow of air which before leaving the system was filtered in order to trap organochlorine residues escaping this way (WHEELER 1969). Thus, a complete budget calculation for the substances within the system could be performed.

The experiments were continued for nine days, during which time the animals received no food. Consequently, the uptake of test substances by the animals was exclusively via the gills and integument.

The temperature during the experiments was 14°C (S.D. = 2) and 8°C (S.D. = 3) in the tests with DDT and PCB respectively.

The residue content was determined by means of gas chromatography. Samples of water and air were analyzed according to Södergren (1971); the animal samples were treated following methods described elsewhere (SÖDERGREN et al. 1972).

RESULTS

Uptake and accumulation of DDT and PCB by E. danica followed a similar pattern for both substances (Fig. 1). When the animals had been exposed to either substance for 4-5 days, an apparent constant level was established, indicating equilibrium between uptake and excretion (including degradation) of the substances. The accumulation of residues by the animals as a function of the concentration in the water also showed a similar pattern (Tab. 1).

A kinetic equation of first order is proposed as a model for the uptake of DDT and PCB by the animals. The general expression of this equation is

$$(C_E)_t = C_A(1 - e^{-k \cdot t})$$

where $(C_E)_t$ is the concentration in the animals after t days of exposure, C_A the concentration in the animals at steady state and k rate constant. For DDT and PCB, the rate constant was calculated to 0.20 (S.D. = 0.12) and 0.28 (S.D. = 0.06) respectively.

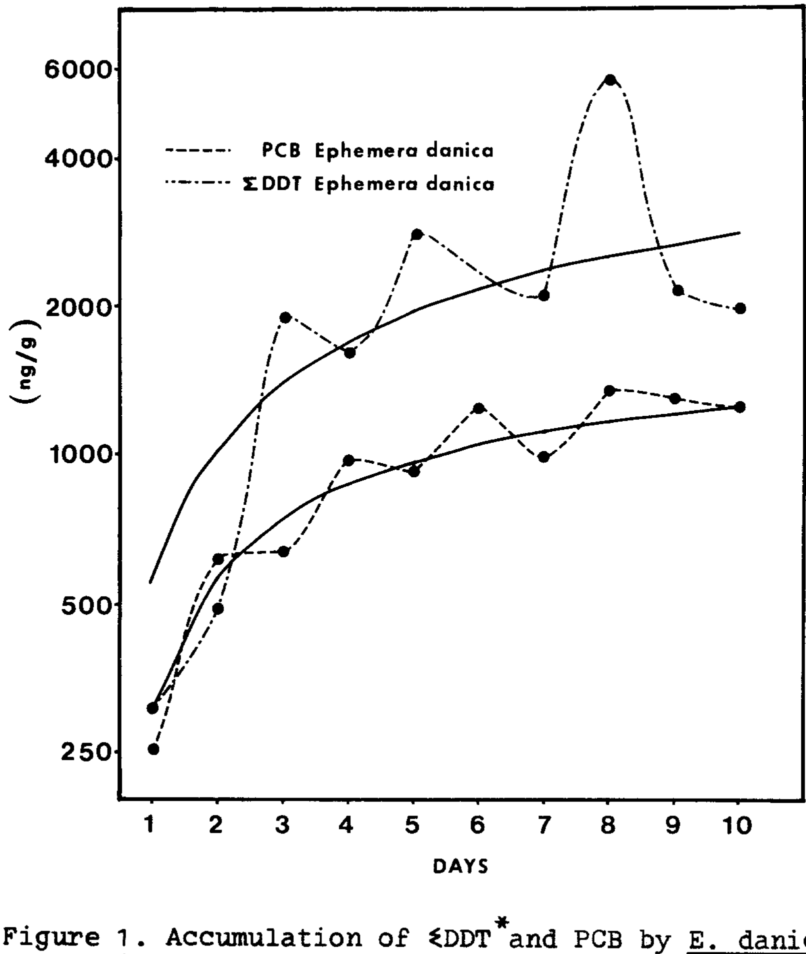

Figure 1. Accumulation of ΣDDT* and PCB by E. danica at continuous-flow conditions. The solid lines show the calculated accumulation according to the equation given in the text. The concentration at steady-state was calculated to 3,100 ng/g and 1,300 ng/g (freshweight) for ΣDDT and PCB respectively.
(*ΣDDT = p,p'-DDT + p,p'-DDE + p,p'-DDD)

TABLE 1

Accumulation by <u>Ephemera danica</u> of ΣDDT and PCB (Clophen A 50) from water during nine days' exposure. Accumulation factor = conc. in the organisms/ water concentration. The water concentration was 761 ng/l (S.D. = 79) and 526 ng/l (S.D. = 102) for ΣDDT and PCB respectively.

Exposure time (days)	Accumulation factor (PCB)	Accumulation factor (ΣDDT)
1	$0,40 \cdot 10^3$	$0,44 \cdot 10^3$
2	$1,34 \cdot 10^3$	$0,61 \cdot 10^3$
3	$1,43 \cdot 10^3$	$2,23 \cdot 10^3$
4	$1,95 \cdot 10^3$	$1,98 \cdot 10^3$
5	$2,44 \cdot 10^3$	$3,06 \cdot 10^3$
6	$2,94 \cdot 10^3$	-
7	$2,05 \cdot 10^3$	$2,90 \cdot 10^3$
8	$2,15 \cdot 10^3$	$8,25 \cdot 10^3$
9	$1,94 \cdot 10^3$	$2,86 \cdot 10^3$

The distribution of the test substances within the system shows that DDT and metabolites are accumulated to a greater extent by <u>E. danica</u> than is PCB (Tab. 2). Consequently, a greater proportion of PCB compared to DDT was recovered in the water and air of the system.

TABLE 2

Budget of ΣDDT and PCB within the continuous-flow system.

	ΣDDT (ng)	ΣDDT (%)	PCB (ng)	PCB (%)
Water	6,899	37	4,668	45
Air	30	1	585	6
<u>Ephemera danica</u>	11,878	63	5,105	49

p,p'-DDT added to the system was rapidly metabolized by the animals. The principal breakdown product found in the nymphs was p,p'-DDE, and only occasionally small amounts of p,p'-DDD were detected. After one day of exposure, the quotient DDE/DDT was low (1.0). However, a higher quotient was observed already on the second day, after which it remained relatively constant (3.2, S.D. = 1.0) until the end of the experiment.

In the test with PCB, no degradation of the parent substance was observed.

The substances were tested at non-lethal levels, and no animals died during the experiment. The values presented are corrected for background levels of residues in the animals.

DISCUSSION. KINETICS OF ACCUMULATION

Accumulation of DDT by living organisms has been proposed to follow a kinetic equation of first order (ROBINSON 1967, EBERHARDT 1971). In our study, this appeared to be the case for both DDT and PCB. Compared with PCB a greater proportion of DDT was accumulated by the animals. We suggest that this reflects the different physical properties of these substances, mainly their solubility in water.

The weight of the animals as well as the content of extractable lipids did not change significantly during the experiments, although no food was available for the organisms. Together with the fact that no animals died during the experiment, this indicates that the nymphs were not subjected to severe starvation or other stress factors. Moreover, the relatively short duration of the experiments as well as the low temperature, probably contributed to the low mortality.

DDE is the major metabolite of DDT found in most organisms. The proportion of DDE to DDT is, however, quite different, depending on exposure, trophic level and age of the organisms. In the field, the quotient DDE/DDT in _E. danica_ differed from all co-existent species examined (SÖDERGREN et al. 1972), which probably indicates divergent metabolic pathways in the degradation of DDT. In the present experiments, the dehydrochlorination of DDT by the animals occurred rapidly, although the quotient DDE/DDT did not reach the same level as in the field. The low value recorded is a result of the continuous exposure of p,p'-DDT to the animals. In the field, exposure to environmental contaminants is believed not to be so uniform as in this experiment.

In the test with PCB, the internal composition of the mixture accumulated by the animals was followed and compared to the parent compounds introduced. No evidence of degradation was found, although the experiment continued for nine days. The results suggest that the degradation of PCB in the animals proceeds very slowly.

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