# DDT and PCB Relocate When Caged Robins Use Fat Reserves

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Organochlorine residues are usually lipophilic and have consequently been found stored in lipid-rich organs and tissues. Migratory birds build up large fat reserves prior to their biannual migrations, and these deposits are used as energy sources for their migratory flights (1, 2, 3, 4). Prior to and during the migratory periods the fat metabolism proceeds at an accelerated rate, and it follows that any organochlorine residues present are relocated when the fat deposits are mobilized (5, 6, 7).

In order to examine the pattern of these relocations during fat mobilization and to study the possible interactions between DDT and PCB, caged robins *Erithacus rubecula L.* were subjected to starvation following a period of administration of 1) DDT, 2) PCB, 3) DDT + PCB in combination.

The results showed that the presence of DDT including metabolites affected the retention of PCB and the pattern of distribution of PCB between different body parts. A transfer of a potentially toxic substance from fat deposits to vital organs, as was observed in the present experiments, can presumably have serious consequences for the individual concerned. Thus, the synergistic effects of different substances taken up in combination must be considered to be of primary importance in future studies of the accumulation of contaminants in ecosystems.

The robins were trapped at Falsterbo Bird Station in south-western Sweden around 1 May, 1971. Scandinavian robins migrate by night to winter quarters which are located mainly in the western part of the Mediterranean region (8, 9). The experimental birds were trapped on their way towards the breeding quarters somewhere in northern Europe. A total of nineteen robins were used in this study.

In the laboratory the robins were kept in opaque plastic containers in a room where temperature and light were close to natural conditions. They were fed meal-worms, minced meat, apples, and water, *ad lib.* After 8 days' acclimatization, the administration of the test substances commenced. In addition to normal food rations, each bird daily was given one meal-worm injected with either 10.5 $\mu$g of p,p'-DDT, or 11.0 $\mu$g of PCB (Clophen A50), or a combination of both these doses. In the course of 15 days, each experimental bird ingested a total of approximately 160 $\mu$g of the test substance, excepting those birds given both compounds which obviously consumed about twice that quantity.

There was a careful check every morning to make sure that the robins had in fact devoured the contaminated meal-worms, and on the same occasions the birds were also weighed. After 8 days' acclimatization and 15 days' administration of the test compounds, some birds were killed, and the remaining ones were deprived of food but had access to water. They died within 48 hours. No non-starvation experiments were performed on birds that had received combined dosages.

Organochlorine residues in the brain, breast muscles, and rest of the body were analyzed separately, using the techniques described in previous reports (10, 11). Following extraction with acetone/hexane (1:1) the contents of extractable lipids (hereafter abbreviated "fat") were also determined.

Samples to which known amounts of test substances had been added were analyzed in order to check the efficiency of the analytical method. Recovery was above 83 per cent, but as is normal in residue analysis, no correction was entered in the calculations.

The brain was removed in its entirety from the skull of the birds, but it proved difficult to remove the breast muscles completely. Therefore a small portion usually had to be left *in situ*. In the following, the term "carcass" refers to the whole body after the brain, (most of the) breast muscles, the feet and tarsi, and the bill had been removed.

Small quantities of p,p'-DDD were occasionally detected. In comparison with other compounds, however, these amounts were negligible and have been included under the designation of $\Sigma$ DDT, which thus stands for p,p'-DDT, p,p'-DDE, and p,p'-DDD.

The average weight of the robins at their arrival at the laboratory was 15.0 g. During the acclimatization period their body weight did not change at all or increased very slightly. During the period of administration of test substances only a very slow weight increase was noted (Table 1, Fig. 1). When deprived of food, the birds lost approximately one quarter of their body weight before dying. No difference with respect to changes in body weight were apparent between birds receiving DDT, PCB, or both in combination.

A comparison was made of the level of extractable fat in birds killed and those dying from starvation. As illustrated in Fig. 1, fat levels increased in the brain during starvation, but decreased in the breast muscles and carcass.

Relevant information about residue levels in nonstarved and starved birds is presented in Table 1 and illustrated in Fig. 2. During starvation, residue levels increased in the brain and in the

Table 1.
**General information about body weight, extractable fat levels, and results of analyses. nst = nonstarved, st = starved birds. Body parts: br = brain, brm = breast muscles, carc = carcass (as defined in text). X = compound not detected. Levels expressed as ppm fresh weight.**

| Bird No. | Comp. adm. | Treat-ment | Weight (g) day 9 | day 23 | post-starv. | % extract. fat br | brm | carc | p, p'—DDT br | brm | carc | p, p'—DDE br | brm | carc | PCB br | brm | carc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | PCB | nst | 17.1 | 17.4 | — | 1.6 | 1.4 | 4.9 | × | × | × | <0.1 | 0.1 | 0.5 | 0.1 | 0.3 | 3.4 |
| 5 | PCB | nst | 16.6 | 17.5 | — | 1.9 | 3.0 | 8.5 | × | × | × | <0.1 | 0.1 | 1.4 | 0.7 | 0.3 | 6.7 |
| 7 | PCB | nst | 15.4 | 14.8 | — | 1.7 | 2.2 | 1.4 | × | × | × | 0.1 | 0.1 | 0.5 | 0.4 | 1.0 | 5.2 |
| 9 | PCB | nst | 14.6 | 16.0 | — | 4.3 | 2.0 | 3.6 | × | × | × | 0.1 | 0.3 | 0.8 | 0.2 | 0.6 | 2.7 |
| 10 | PCB | st | 15.5 | 17.7 | 11.8 | 4.5 | 0.8 | 0.8 | × | × | × | 1.8 | 3.9 | 1.6 | 2.7 | 8.0 | 2.6 |
| 11 | PCB | st | 15.1 | 16.2 | 12.6 | 5.5 | 1.9 | 0.8 | × | × | × | 0.1 | 0.2 | 0.6 | 1.5 | 2.1 | 2.2 |
| 12 | PCB | st | 15.7 | 16.8 | 12.2 | 3.2 | 1.7 | — | × | × | — | 0.1 | 0.1 | — | 0.5 | 0.9 | — |
| 13 | PCB | st | 16.0 | 16.6 | 13.6 | 1.8 | 0.6 | 1.2 | × | × | × | 0.8 | 0.2 | 1.4 | 1.3 | 1.0 | 2.9 |
| 16 | DDT | nst | 16.2 | 16.2 | — | 4.1 | 1.7 | 6.1 | 0.2 | 1.2 | 2.2 | 0.3 | 1.2 | 1.8 | × | × | × |
| 17 | DDT | nst | 17.5 | 16.9 | — | 3.1 | 3.2 | 4.7 | 0.7 | 1.4 | 4.8 | 0.3 | 0.5 | 1.7 | × | × | 1.2 |
| 18 | DDT | nst | 17.6 | 17.4 | — | 7.8 | 3.3 | 4.0 | 0.3 | 0.3 | 4.0 | 0.2 | 0.2 | 1.8 | 0.4 | <0.1 | 0.5 |
| 19 | DDT | nst | 14.1 | 15.8 | — | 6.9 | 8.9 | 6.9 | 0.5 | 1.1 | 3.2 | 0.5 | 0.9 | 2.1 | 0.4 | × | × |
| 22 | DDT+ PCB | st | 15.4 | 15.7 | 13.0 | 8.5 | 2.5 | 1.5 | 1.8 | 1.4 | 2.0 | 2.0 | 1.1 | 1.1 | 13.8 | 12.4 | 6.1 |
| 24 | DDT+ PCB | st | 15.7 | 16.7 | 13.6 | 6.0 | 2.3 | 1.9 | 5.6 | 2.7 | 1.7 | 2.3 | 1.7 | 0.7 | 11.4 | 9.2 | 6.1 |
| 25 | DDT+ PCB | st | 13.4 | 15.6 | 10.6 | 6.5 | 2.2 | 1.3 | 3.8 | 3.2 | 3.0 | 2.7 | 3.2 | 3.2 | 6.6 | 6.3 | 3.8 |
| 26 | DDT+ PCB | st | 15.4 | 17.1 | 12.0 | 9.7 | 2.3 | 1.0 | 3.3 | 2.6 | 1.5 | 1.6 | 2.1 | 1.8 | 5.5 | 7.3 | 2.0 |
| 27 | DDT | st | 16.0 | 18.7 | 13.0 | 6.4 | 3.6 | 4.7 | 0.8 | 2.5 | 3.7 | 0.8 | 1.7 | 2.3 | × | 1.1 | 1.7 |
| 29 | DDT | st | 14.7 | 14.9 | 12.9 | 5.4 | 4.0 | 1.0 | 3.8 | 7.1 | 2.3 | 2.9 | 10.0 | 2.5 | × | 5.2 | 0.2 |
| 30 | DDT | st | 15.6 | 18.1 | 11.0 | 7.8 | 2.1 | 0.8 | 4.3 | 1.3 | 1.9 | 2.3 | 0.5 | 1.9 | × | 1.5 | 0.2 |

breast muscles, in terms of both fresh weight and fat weight. In the carcass an increase of residue levels in terms of fat weight was found in birds given DDT, PCB, and DDT+PCB in combination, but in terms of fresh weight the picture was not so uniform: PCB and p,p'-DDT levels dropped, while the p,p'-DDE level did not change appreciably.

Four birds (see Table 1) were given DDT + PCB in combination and were later subjected to starvation. The distribution of residues within these birds was compared with that observed in birds having received only one or the other of the substances.

As shown in Table 2, levels of p,p'-DDT and p,p'-DDE were very similar between comparable groups of birds. Thus the presence of PCB did not seem to have affected the retention of p,p'-DDT and p,p'-DDE within the body.

In contrast, however, there was a clear indication that the presence of DDT, including metabolites, affected the retention of PCB (see Table 2). In birds that received DDT + PCB in combination, PCB levels were higher in all body parts examined than in birds having received only PCB. In the last mentioned group, one bird (No. 10 in Table 1) deviated strongly from the rest in having exceptionally high levels of all compounds analyzed. The fact that it contained high levels of DDE shows that this bird was already more contaminated than the rest when captured. Therefore, in Table 2, data are presented in which bird No. 10 has been omitted.

The information presented above suggests redistribution of organochlorine residues between different body parts during starvation. To examine this question more closely, data about the distribution of organochlorine residues within the birds have been collected in Table 3 which gives the total content in the various organs (see also Fig. 2).

In birds given DDT, the quantity and the percentage of p,p'-DDT were higher in the brain and in the breast muscles after starvation but were lower in the carcass. At the same time, the total amount of p,p'-DDT in the whole bird decreased appreciably. For p,p'-DDE on the other hand, the post-starvation level in the brain was relatively high, while levels in the breast muscles and in the carcass had not changed appreciably. The total amount of p,p'-DDE was approximately the same before and after starvation.

In birds given only PCB, the pattern of distribution found for this substance closely resembled that described above for p,p'-DDT.

When comparing birds given a combination of DDT + PCB with those given only DDT with respect to their content of p,p'-DDT and p,p'-DDE, no major differences were found. This was true in terms of total quantities as well as distribution between different body parts (Fig. 3). In contrast, however, PCB quantities were consistently higher in birds given DDT + PCB in combination than in those given only PCB (Table 3). The pattern of distribution of PCB also deviated in birds having ingested both substances. Much larger proportions were stored in the brain and the breast muscles than in the case of birds that received only PCB (Fig. 3), consequently a smaller proportion was found in the carcass.

In these experiments the robins were given substances in doses that were calculated not to provoke serious toxic effects. After the final dose, the robins had acquired levels comparable with those found in other species under natural conditions (12, 13). We did not look for possible effects of the test substances on the activity and behaviour of the robins, but in general the birds appeared entirely normal. The background levels of organochlorine residues in robins were examined in a previous report (10).

**Table 2.**
**Levels of p, p'-DDT, p, p'-DDE and PCB in starved robins given p, p'-DDT och PCB (Clophen A50) or both substances in combination. Abbreviations as in Table 1. Bracketed figures show maximum and minimum values.**

**Substance analysed: p, p'—DDT**

| | Substance administered: p, p'—DDT (n = 3) | | | Substance administered: p, p'—DDT + PCB (n = 4) | | |
|---|---|---|---|---|---|---|
| | br | brm | carc | br | brm | carc |
| ppm fresh weight | 3.0<br>(0.8—4.3) | 3.6<br>(1.3—7.1) | 2.7<br>(1.9—3.7) | 3.6<br>(1.8—5.6) | 2.5<br>(1.4—3.2) | 2.0<br>(1.5—3.0) |
| ppm fat weight | 47<br>(13—71) | 102<br>(60—179) | 183<br>(79—241) | 45<br>(21—65) | 108<br>(55—146) | 149<br>(91—227) |

**Substance analysed: p, p'—DDE**

| | Substance administered: p, p'—DDT (n = 3) | | | Substance administered: p, p'—DDT + PCB (n = 4) | | |
|---|---|---|---|---|---|---|
| | br | brm | carc | br | brm | carc |
| ppm fresh weight | 2.0<br>(0.8—2.8) | 4.1<br>(0.5—10.0) | 2.2<br>(1.9—2.5) | 2.2<br>(1.6—2.7) | 2.0<br>(1.1—3.2) | 1.7<br>(0.7—3.2) |
| ppm fat weight | 33<br>(13—53) | 107<br>(25—249) | 175<br>(48—250) | 27<br>(16—41) | 89<br>(46—144) | 134<br>(72—244) |

**Substance analysed: PCB**

| | Substance administered: PCB (n = 4) | | | Substance administered: p, p'—DDT + PCB (n = 4) | | |
|---|---|---|---|---|---|---|
| | br | brm | carc | br | brm | carc |
| ppm fresh weight | 1.5<br>(0.5—2.7) | 3.0<br>(0.9—8.0) | 2.6<br>(2.2—2.9) | 9.3<br>(5.5—13.8) | 8.8<br>(6.3—12.4) | 4.5<br>(2.0—6.1) |
| ppm fat weight | 44<br>(16—71) | 335<br>(54—1003) | 282<br>(244—325) | 113<br>(56—162) | 300<br>(102—496) | 305<br>(203—403) |
| ppm fresh weight | 1.1<br>(0.5—1.5) | 1.3<br>(0.9—2.1) | 2.6<br>(2.2—2.9) | excluding bird No. 10. | | |
| ppm fat weight | 38<br>(16—71) | 112<br>(54—171) | 261<br>(244—278) | | | |

No differences in terms of weight changes were established between birds given different compounds (Fig. 1). This is in contrast to an earlier study, where a significant increase of body weight in ducks given PCB was found (14).

Deprivation of food was used to simulate the stress situation encountered in long migratory flights, sometimes under adverse weather conditions (15). Birds wintering in the north often are exposed to conditions which also require mobilization of fat reserves.

When the carcass lost part of its fat, levels of organochlorine residues decreased in terms of fresh weight. Consequently, due to the low remaining fat content, residue levels in terms of fat weight increased. But in the breast muscles, although the fat content decreased, the residue levels in terms of both fresh and fat weight increased. This agrees with the findings of Findlay and deFreitas (7) who also suggested an explanation of the storage of residues in muscle tissues.

The same pattern of transfer of residues to breast muscles emerges from the data provided by B. Persson (16), using whitethroats *Sylvia communis* Lath.

In contrast to Findlay and deFreitas, who studied the domestic pigeon, we found that a considerable portion of the residues released from the fat reserves was relocated to the brain. Again, the data published by B. Persson (16) reveal a pattern similar to that found in the present experiment. Domestic pigeons like the wild populations of the same species *Columba livia* Gm. are resident birds, while whitethroat and robin are highly migratory species. It would not be unexpected if the patterns of metabolic activity, and thus of residue relocation, differ between ecologically dissimilar species.

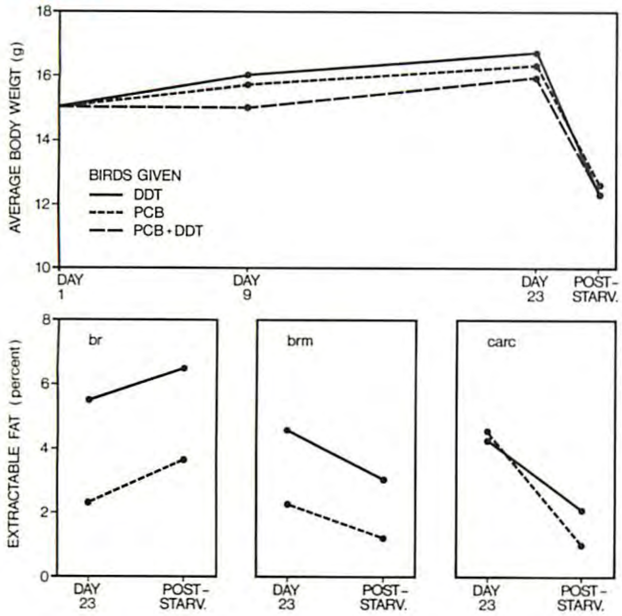
Dindal (17) found that DDT levels in the brain of two wild duck species rose in winter, which is probably another example of relocation of residues during stress conditions.

Harvey (19) found that starlings *Sturnus vulgaris L.* retained less than 25 per cent of the DDT received. We found that in nonstarved robins, approximately 35 per cent of DDT ingested was recovered (including metabolites) after the dietary dosage was discontinued. A similar percentage of PCB was retained (Table 3).

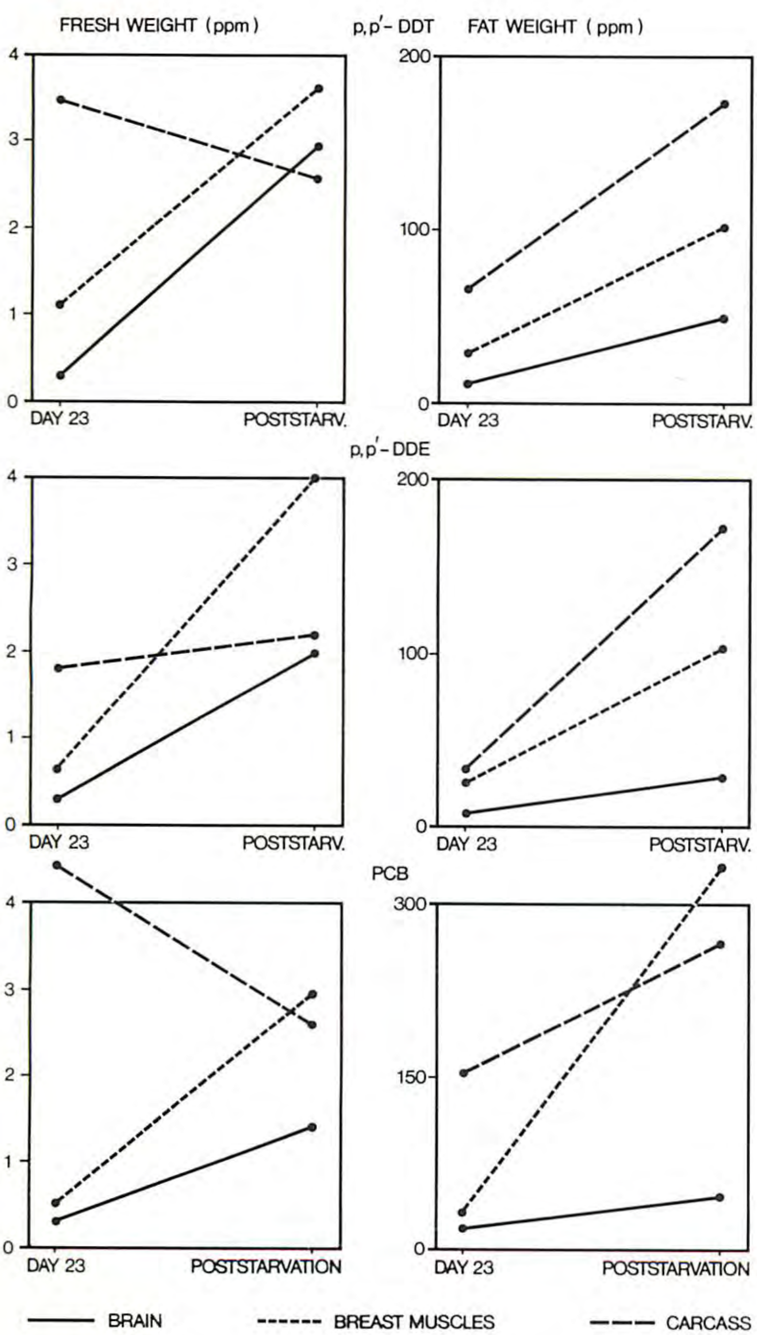
In starved robins, approximately 30 per cent of the total amount of p,p'-DDT administered was recovered, the proportion of p,p'-DDE having increased considerably compared to that in nonstarved birds. The quantity of PCB in starved birds decreased to the same extent as did p,p'-DDT (Table 3).

The present results suggest that the presence of DDT including metabolites affected the retention of PCB, while the presence of PCB did not seem to influence the retention of p,p'-DDT and p,p'-DDE (Table 2). Deichman *et al.* (18) found in beagles that the administration of aldrin strongly affected the retention of $\Sigma$ DDT in blood and fat. They assume, and we agree, that this is related to a reduced excretion

## Figure 1




## Figure 2




## Figure 3

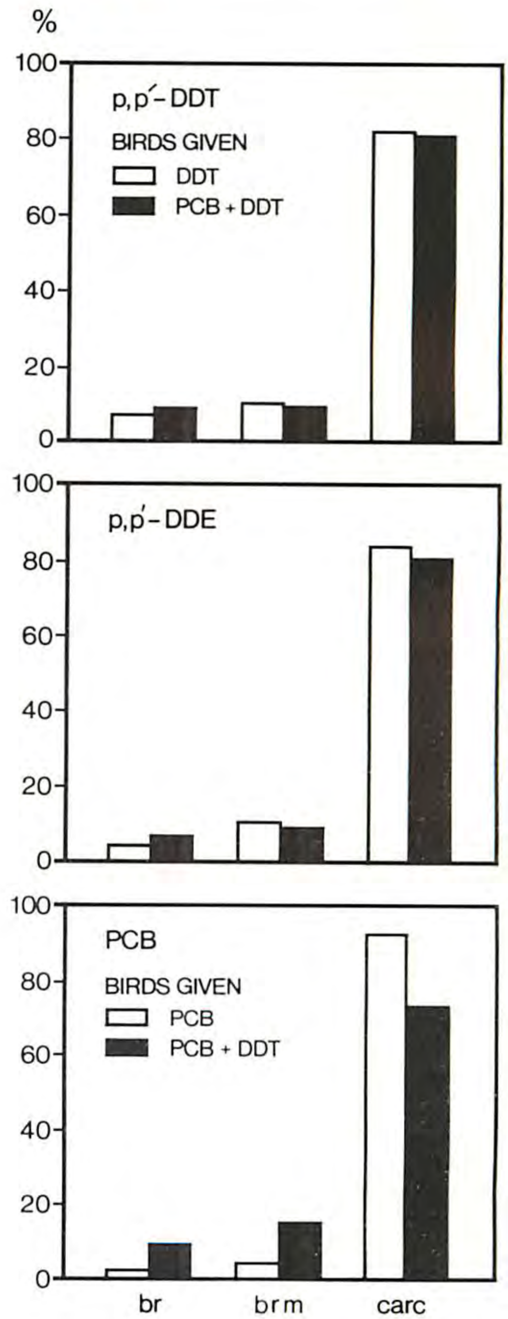



**Figure 1. Weight changes in birds given different test substances and changes in extractable fat content in brain (br), breast muscles (brm) and carcass (carc, as defined in text) during starvation.**

**Figure 2. Changes in levels of p, p'-DDT, p, p'-DDE and PCB in different body parts of caged robins during starvation. Extreme values in brackets.**

**Figure 3. Percentage distribution of p, p'-DDT, p, p'-DDE and PCB in starved robins given p, p'-DDT, PCB, or both these compounds in combination. Extreme values in brackets.**

Table 3.
Quantities and distribution of p, p'-DDT, p, p'-DDE and PCB in starved and nonstarved robins. Abbreviations as in Table 1. Bracketed figures show maximum and minimum values.

**Substance administered: p, p'—DDT**

| Substance analysed | Treatment | br (μg) | brm (μg) | carc (μg) | total (μg) | br (%) | brm (%) | carc (%) |
|---|---|---|---|---|---|---|---|---|
| p, p'—DDT | nst (n=4) | 0.2 (0.1—0.3) | 0.7 (0.2—1.4) | 39.2 (23.9—53.5) | 41.4 (24.7—55.2) | 0.5 (0.3—0.8) | 1.9 (0.5—2.9) | 97.7 (96.7—99.2) |
| | st (n=3) | 1.6 (0.4—2.4) | 2.6 (1.0—4.5) | 22.6 (14.8—35.7) | 26.8 (18.2—38.4) | 7.4 (1.1—13.3) | 10.2 (5.5—19.1) | 82.4 (81.2—93.0) |
| p, p'—DDE | nst (n=4) | 0.1 (0.1—0.2) | 0.5 (0.2—0.7) | 20.2 (19.2—21.3) | 20.8 (19.9—21.7) | 0.8 (0.5—1.6) | 2.2 (0.7—3.4) | 97.1 (96.0—98.8) |
| | st (n=3) | 1.0 (0.4—1.4) | 2.7 (0.4—6.3) | 18.5 (14.8—21.8) | 22.2 (16.5—26.5) | 4.9 (1.7—7.6) | 11.0 (2.6—23.8) | 84.2 (71.0—91.8) |

**Substance administered: PCB**

| Substance analysed | Treatment | br (μg) | brm (μg) | carc (μg) | total (μg) | br (%) | brm (%) | carc (%) |
|---|---|---|---|---|---|---|---|---|
| PCB | nst (n=4) | 0.2 (<0.1—0.4) | 0.5 (0.2—0.8) | 47.9 (27.6—78.6) | 48.5 (28.2—79.3) | 0.4 (0.1—0.5) | 0.9 (0.4—1.8) | 98.7 (97.8—99.3) |
| | st (n=4) | 0.7 (0.6—0.7) | 1.4 (0.8—1.9) | 25.8 (23.1—28.5) | 27.8 (24.6—31.1) | 2.5 (2.2—2.7) | 4.7 (3.4—6.2) | 92.7 (91.6—93.8) |

**Substance administered: p, p'—DDT + PCB**

| Substance analysed | Treatment | br (μg) | brm (μg) | carc (μg) | total (μg) | br (%) | brm (%) | carc (%) |
|---|---|---|---|---|---|---|---|---|
| p, p'—DDT | st (n=4) | 1.7 (1.0—2.6) | 1.8 (1.0—2.1) | 15.6 (12.6—22.3) | 19.1 (16.3—25.9) | 9.2 (6.0—14.5) | 9.7 (6.3—13.3) | 81.2 (74.7—87.6) |
| p, p'—DDE | st (n=4) | 1.0 (0.8—1.1) | 1.5 (0.8—2.1) | 13.3 (5.6—24.0) | 15.8 (8.0—27.1) | 8.4 (4.0—13.7) | 10.5 (7.7—16.2) | 81.1 (70.1—88.3) |
| PCB | st (n=4) | 4.6 (2.7—7.7) | 6.5 (4.2—9.2) | 34.4 (17.3—47.4) | 45.4 (26.1—61.0) | 9.9 (9.0—12.5) | 15.3 (11.1—23.2) | 74.8 (66.3—80.1) |

rate of the substance in question, although the mechanism responsible is not known. The ecological implications of synergism between different organochlorine compounds are very obvious. Continuous exposure to a low level of an environmental contaminant may be believed to lead to a steady-state relationship of the substance in ecosystems. However, the results of Deichman *et al.* and of this study show that potential interactions between substances cannot be ignored. Consequently, the introduction of a new contaminant into ecosystems may disrupt steadystate relationships previously established. The indirect effects caused by the interplay between different substances may thus be added to the direct effects of a newly introduced contaminant on the structure and function of a given ecosystem.

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