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Uses and effects on bird populations of organochlorine pesticides

I NEWTON
Institute of Terrestrial Ecology, Monks Wood Experimental Station

1 Introduction

This paper reviews the uses of organochlorine pesticides in Britain and their effects on bird populations, and makes proposals for future work. It is 35 years since DDT was introduced into British agriculture, and more than 25 years since the more toxic cyclodiene compounds came in. Although the uses of all these chemicals have been reduced since their peak in the 1960s, their effects on wildlife are still apparent.

Of all pesticides still used widely, the organochlorines have had the most harmful effects on wildlife populations, especially of predatory birds, some of which have been exterminated over wide areas (Newton 1979). Besides being toxic, these chemicals have 3 main properties which contribute to their effects. First, they are chemically extremely stable, so that they persist more or less unchanged in the environment for many years. Second, they dissolve in fat, which means that they can accumulate in animal bodies and pass from prey to predator, concentrating at successive steps in a food chain. Predatory birds, near the top of food chains, are thus especially liable to accumulate large amounts. Third, at sublethal levels of only a few ppm in tissues, organochlorines can disrupt the breeding of certain birds. They are also dispersed in air and water currents, or in the bodies of migrant birds and insects, and can thus reach regions far removed from areas of application.

All bird species studied have been found to be susceptible in one way or another to organochlorine

Plate 1. Greater structural or habitat diversity in hedgerows containing trees, as in this Hertfordshire 1980 example, supports a greater variety of breeding species than do low, well-trimmed hedges. (Photograph J H Marchant)

Plate 2. Sustained top trimming of a hedge may result in a loss of structural diversity and degeneration into a series of tree stems of little value to birds, as in this Bedfordshire hedge in 1982. (Photograph R J O'Connor)

Plate 3. Despite almost a half century of herbicide use, there is still a bank of weed seeds in the soil. In this case, charlock, pheasant's-eye, sun spurge and fumitory are shown in a strip of winter wheat which was left unsprayed to help partridge chick survival. (Photograph D Hill)

Plate 4. Red deer in the hills interact in the winter with agriculture, forestry and conservation, when they are forced down from their abundant high-level summer range to lower altitude farmland, plantations and remnants of natural woodland. Where agricultural use of this lower ground intensifies, so does the possibility of conflict through reduction of deer wintering ground. This photograph shows red deer concentrated in a winter feeding site near Loch Laggan in the Cairngorms. (Photograph B Mitchell)

pesticides (Newton 1979). The most marked population declines have occurred in bird feeding raptors, especially the peregrine and sparrowhawk (Ratcliffe 1970, 1980). Lesser or more local declines occurred in other raptor species, such as the kestrel, and in certain seed eaters, such as the stock dove (O'Connor & Mead 1984). Among other animals, various predatory mammals proved particularly vulnerable, including otters, as did several bat species, various amphibia and fish.

2 The chemicals and their uses

DDT came into widespread agricultural use about 1947. It has since been freely used throughout the country against many insect pests of various types of crop, mainly on top fruit (against several pests), brassicas (against flea beetles and caterpillars) and cereals (against leatherjackets). In the physical environment, and in the animal body, most DDT rapidly degrades to DDE. Another organochlorine, γ-BHC (HCH or lindane), came into use at about the same time. It is much less persistent than DDE, and, although often present in bird tissues, it is not known to have had adverse effects on populations.

The more toxic cyclodiene organochlorines, including aldrin, dieldrin and heptachlor, came into wide use after 1955. They were used mainly against pests in the soil, as seed dressings on cereals and other crops, on brassicas against cabbage root fly, on potatoes against wire-worms, and on various minor crops against other pests. Their usage has thus been greater in those (mainly eastern) regions with the greatest proportion of arable land. The active ingredient in dieldrin (HEOD) is also produced in the environment or in the animal body from aldrin. So, on finding HEOD in a bird, it is not possible to tell how much is from aldrin and how much from dieldrin. In the years since 1962, successive Government restrictions have progressively curtailed the use of these cyclodienes. In 1962, they were 'banned' from use on spring sown cereals, in 1965 from sheep dips and other minor uses, and in 1975 from autumn sown cereals. After that date, the remaining uses were chiefly on brassicas and root crops. Heptachlor was used hardly at all after 1964.

The restrictions were not legal bans, but 'voluntary' agreements involving manufacturers, distributors and users, and there was no legal comeback on any farmer who chose to ignore them. Most restrictions did not lead to sudden reductions in usage, but rather to steady declines over a period of years. Thus, although dieldrin had been banned in sheep dips for 15 years, analyses of wool samples showed that some farmers were still using this chemical in 1980 (unpublished data). Similarly, DDT was no longer recommended for use on top fruit after 1976, but orchard surveys revealed extensive usage after this date (Sly 1981), and in 1983 it was still advertized for horticultural use.

Because manufacturers do not disclose their sales, information on organochlorine usage in Britain has resulted chiefly from periodic farm surveys by the Ministry of Agriculture for England and Wales and by the Department of Agriculture and Fisheries for Scotland. These surveys were done on a sampling basis, and gave national estimates of the area of each crop treated with different chemicals. From these figures, the quantities applied were calculated (Table 1, based on Strickland 1966; Wilson 1969; Sly 1977, 1981; Cutler 1981). The surveys revealed a decline in DDT usage during the 1960s, and a further slight decline in the early 70s; in some regions, however, DDT usage increased again between 1974 and 1977 (Cutler 1981). The main point, however, was a continued substantial DDT usage in Britain throughout this period. The same statistics revealed a progressive and marked decline in the use of aldrin and dieldrin between the early 1960s and the late 1970s, and particularly after 1975, following the latest restriction on use on cereals.

Such figures probably reflected the broad trends, but their reliability has been questioned. Among other things, they depend on the honesty of farmers, and there may have been somewhat greater use of organochlorines in recent years than these official data suggest. Only 3 out of 81 brassica growers interviewed independently in Lincolnshire in 1978 did not use DDT (Tait 1983).

Table 1. Estimated annual usage of some organochlorine pesticides in British agriculture/horticulture during different periods (Source: Strickland 1966; Wilson 1969; Sly 1977, 1981; Cutler 1981)

	England & Wales								Scotland			
	1962–64		1966		1971–74		1975–79		1964–66		1975–77	
	Tonnes of active ingredient	Spray hectares*	Tonnes of active ingredient	Spray hectares*	Tonnes of active ingredient	Spray hectares*	Tonnes of active ingredient	Spray hectares*	Tonnes of active ingredient	Spray hectares*	Tonnes of active ingredient	Spray hectares*
All organochlorines†	547	1 475 500	—	1 813 400	131	148 000	166	146 000	76	361 000	60	101 900
DDT	266·2	106 000	—	71 700	78·3	63 800	71·5	60 700	57·8	39 300	33·1	29 600
Aldrin	137·2	91 000	—	45 100	12·8	29 300	18·3	10 300	3·4	1 800	4·5	3 000
Dieldrin	28·4	198 300	—	157 200	11·6	229 700	0·5	5 400	3·4	10 200	0·9	1 300
Heptachlor	5·1	46 500	—	160 300	—	—	—	—	—	—	—	—

*Includes each application separately, so 10 ha sprayed twice would appear as 20 ha.
†Besides those listed below, includes mainly HCH and a few others with minor uses, such as endrin and heptachlor.

A further set of restrictions came into effect in 1981, applicable to all EEC countries, and aimed to phase out completely the use of organochlorines in agriculture, except for very limited purposes for which no reasonably priced alternative was available. In Britain, DDT was still recommended against leatherjackets in cereals and against chafer grubs and cut-worms, while aldrin also had a few small-scale uses. Since then, the recommended use for DDT has been limited to cut-worms. These restrictions are again voluntary, so it remains to be seen how effective they will be on chemicals that can be bought and stockpiled. There are already disconcerting reports of increased DDT use in various parts of Scotland in the last few years. Meanwhile, dieldrin continues to be used in mothproofing and wood preservation.

3 Effects on birds

DDT and its main metabolites are not particularly toxic to birds. However, the main metabolite, DDE, causes thinning of eggshells (Cooke 1973; Newton 1979). Such shells often break during incubation, so that the reproductive rate is lowered. Metabolites of DDT also cause embryo deaths in intact eggs, thus further lowering the breeding rate. Adverse effects on reproduction can be so great as to lead to population extinction. Different taxonomic groups of birds vary in their sensitivity to DDE residues. With 4-5 ppm DDE in their fresh eggs, raptors show more than 15% shell-thinning, whereas herons show about 10% and gamebirds and songbirds less than 1% (Newton 1979). Evidently the latter families are relatively tolerant to DDE. Birds of prey are thus particularly vulnerable, partly because they are more sensitive than some other birds to a given level of DDE (ie they show more shell-thinning), and also because, being predators, they accumulate larger amounts than most other birds. Of course, it is not the DDE in the egg which causes the thinning, but the DDE in the bird, which the egg level reflects.

The more toxic cyclodiene compounds, including aldrin and dieldrin, cause much more direct mortality of adult birds, in some cases leading to population decline. Some of the deaths from these compounds are immediate, others are delayed. As the organochlorine is stored in body fat, a bird may die when its fat is metabolized, and the chemical is released to other, more sensitive, tissues. Birds may die during periods of food shortage or migration, from residues accumulated in the body during previous months. At lower concentration, aldrin, dieldrin and other organochlorines also cause embryo mortality, thus lowering the breeding rate in the same way as DDE, but without the shell-thinning. Many deaths occur around the time of hatch, when remaining yolk is metabolized, and the organochlorine is released into the chick's body.

4 Population trends

The main decline in bird of prey populations occurred in the late 1950s, following the introduction of aldrin, dieldrin and heptachlor as seed treatments. The raptors became contaminated primarily through taking seed eating birds, which had themselves consumed treated grain. Large numbers of finches, pigeons and other seed eaters were found dead and dying around newly sown fields, and many bird of prey carcases were also recovered. Other routes of contamination occurred, however, for all species of birds that were analysed in the 1960s were found to contain organochlorine residues (Prestt & Ratcliffe 1972). Fish were also contaminated, providing a source of residues for herons and other fish eaters.

The bird feeding raptors were most affected, particularly the peregrine and sparrowhawk. The extent of their population decline varied between regions, according to the proportion of land that was tilled, and hence the amount of pesticide applied. In both species, the decline was least marked in the north and west, and most marked in the south-east, the region with most arable land.

In parts of the north and west, some resurgence of the populations of both peregrine and sparrowhawk was evident within 3-4 years after the first restrictions were imposed on the use of aldrin and dieldrin in 1962, and, as the years passed, a recovery became increasingly apparent further south and east. In the peregrine, traditional nest sites throughout the country were well known, and the species has been subject to regular surveys (Ratcliffe 1963, 1965, 1972, 1984). The population probably reached its lowest point in 1963. In that year, survey revealed a population only 44% as great as that present during the standard pre-pesticide period of 1930-39, largely concentrated in Scotland. Only 13% of territorial pairs produced young that year. By 1971, a substantial recovery was apparent, with the population at 54% of its former level and 25% of pairs producing young. By 1981, the recovery was much more marked, with the population at 88% of its former level and 49% of pairs producing young. In most inland areas of the north and west, the recovery was complete, and in some districts numbers were even greater than in the pre-DDT period. However, pairs were still largely absent from eastern coastal districts, and completely absent from the south coast of England, east of Devon. These were areas adjacent to rich arable farmland, where pesticide use was particularly heavy.

The sparrowhawk, too, has largely recovered its numbers, spreading eastward in a wave-like manner from western districts (Newton & Haas 1984). At the time of writing, the species is still absent from that part of the country with the greatest proportion of arable land, embracing Lincolnshire, Huntingdonshire, Cambridgeshire and much of Essex, Norfolk, Suffolk and Kent. To my knowledge, breeding has only recently started again in the first 3 of these counties. Hence, the recovery in both the peregrine and sparrowhawk has so far closely reflected the decline, occurring soonest in the north-west where decline was least severe. It followed the reduced use of aldrin and dieldrin, which would presumably have led to improved survival in the adults. Throughout, however, both species have continued to lay thin-shelled eggs, under continuing DDT contamination. Some of these eggs have broken, so breeding success has been less than normal. Evidently, this has not been sufficient to prevent the populations from producing enough surplus young to fuel the recovery.

In the kestrel, decline was evident only in the most arable districts of south-east England, and here recovery soon followed the 1975 ban on aldrin/dieldrin for use on spring sown cereals. The birds were present in numbers again by 1980. In the heron, no decline in population was apparent that could be attributed to pesticides. Nonetheless, the birds were heavily contaminated, and showed marked shell-thinning and egg breakage. Unlike the raptors, however, they could produce up to several repeat clutches per year if previous ones broke, thus greatly reducing the impact of DDE on productivity.

Almost certainly, several seed eating species also declined in the years around 1960, but the only species for which trends have been well documented is the stock dove, which has also recovered in recent years (O'Connor & Mead 1984).

5 Pesticide residues in bird tissues

Since 1963, carcases of predatory birds have been analysed chemically, at Monks Wood Experimental Station, in an attempt to monitor changes in organochlorine residues, and thus provide a check on the effectiveness of Government regulations. Initially, all species were analysed, but eventually the scheme was reduced to fewer, concentrating on kestrel and sparrowhawk for the terrestrial environment, and heron for fresh water. Birds were received from most parts of the country, in response to advertisements placed periodically in bird journals. All carcases were requested, irrespective of form of death. In practice, most such birds died from accidental causes, and few seemed to have died from pesticide poisoning (Cooke *et al.* 1982; Newton *et al.* 1981). The birds obtained in particular years, or in particular regions, showed enormous variation in the organochlorine residues in their livers. The year-to-year changes in residues were therefore not significant, only some of the longer term trends. Note that the scheme began only after the peak period of organochlorine usage when the main decline in sparrowhawk populations occurred. One consequence was that relatively few birds of this species were obtained from eastern districts where the decline was most marked.

The findings confirmed widespread contamination of all 3 species with organochlorine residues. All birds are included in Figures 1-3, irrespective of year, season or

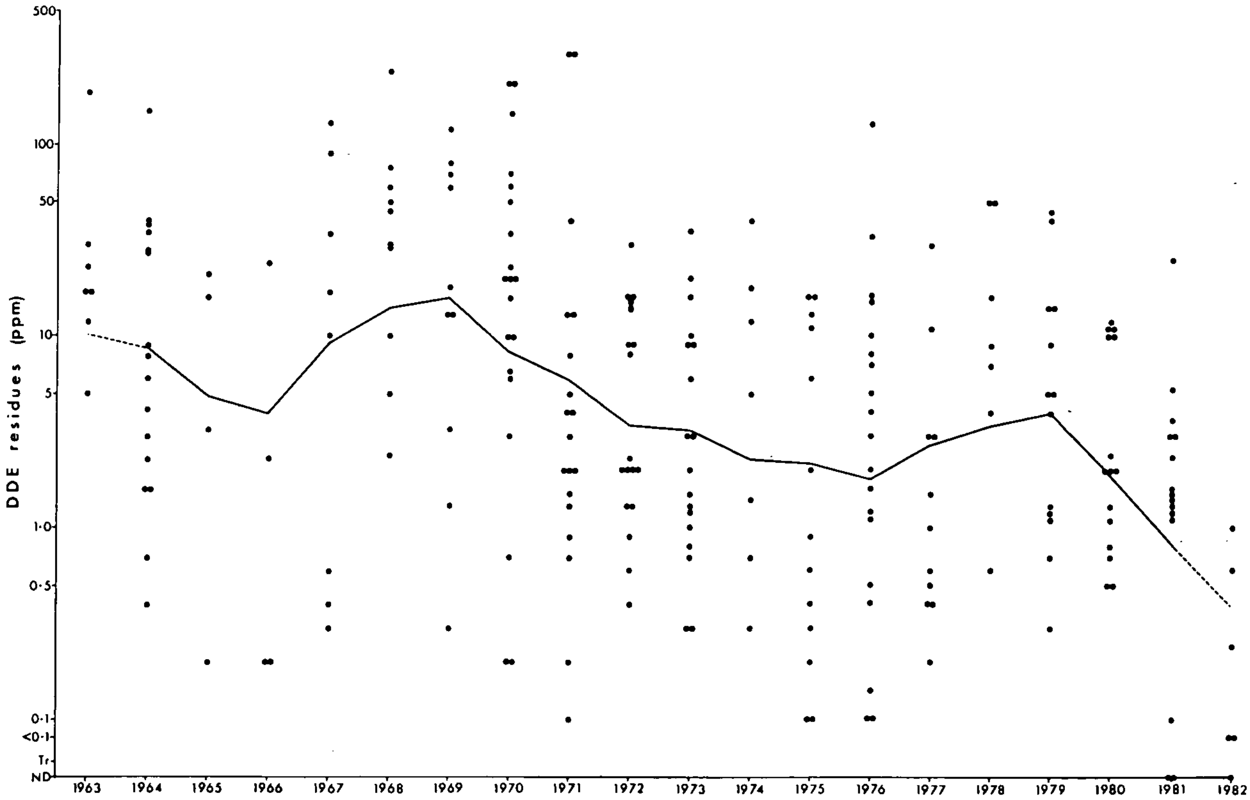

Figure 1a. Levels of DDE in livers of herons received at Monks Wood Experimental Station 1963-82. All herons included, irrespective of region, season or cause of death. Lines show 3-year (– – – 2-year) moving geometric means of residue levels

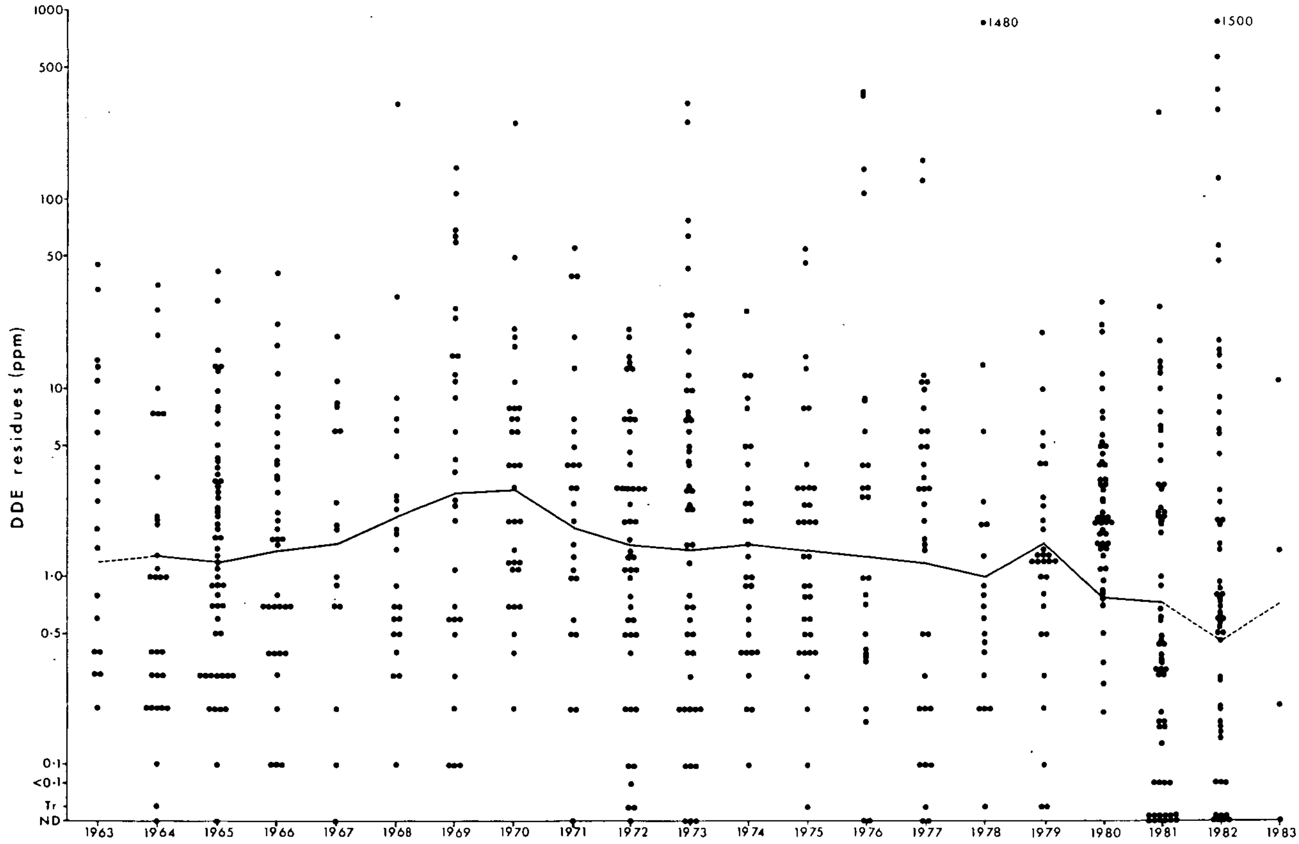

Figure 1b. Levels of DDE in livers of kestrels received at Monks Wood Experimental Station 1963-83. All kestrels included, irrespective of region, season or cause of death. Lines show 3-year (– – – 2-year) moving geometric means of residue levels.

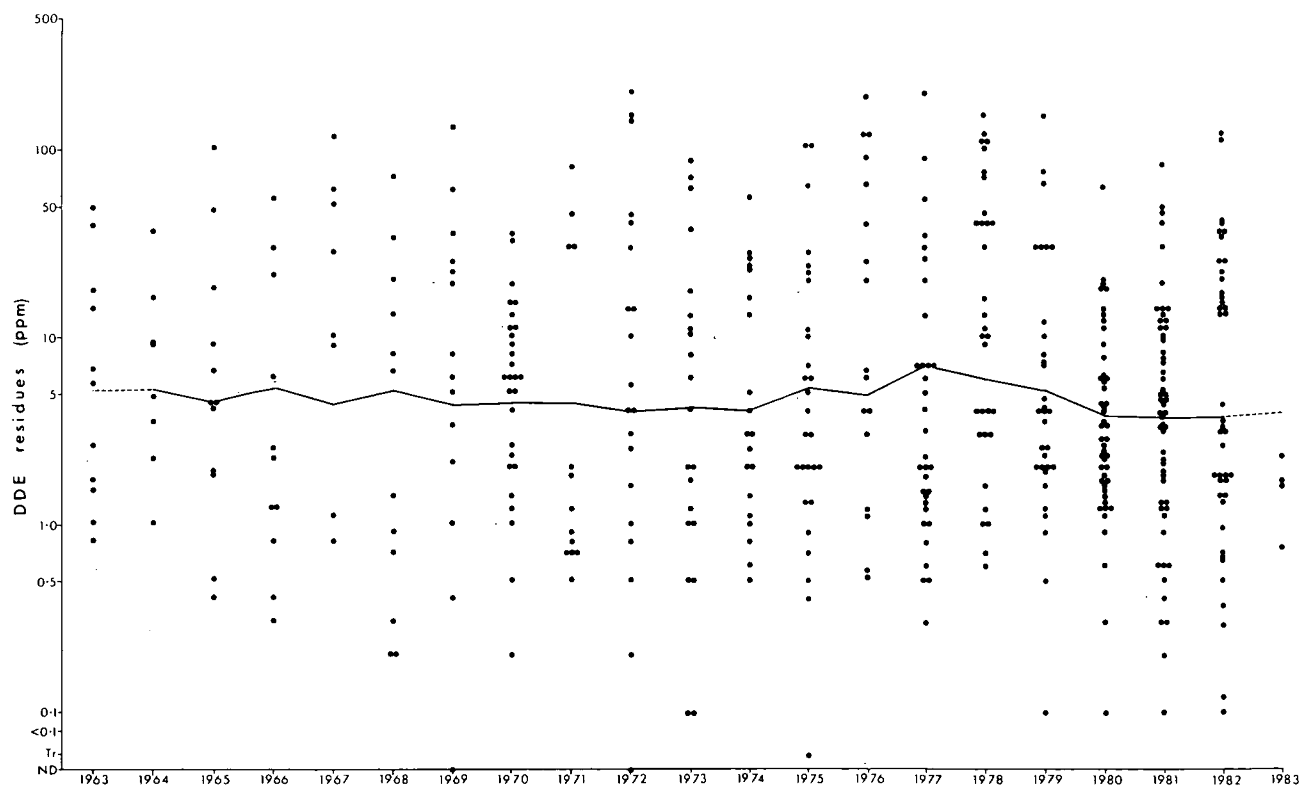

Figure 1c. Levels of DDE in livers of sparrowhawks received at Monks Wood Experimental Station 1963-83. All sparrowhawks included, irrespective of region, season or cause of death. Lines show 3-year (– – – 2-year) moving geometric means of residue levels

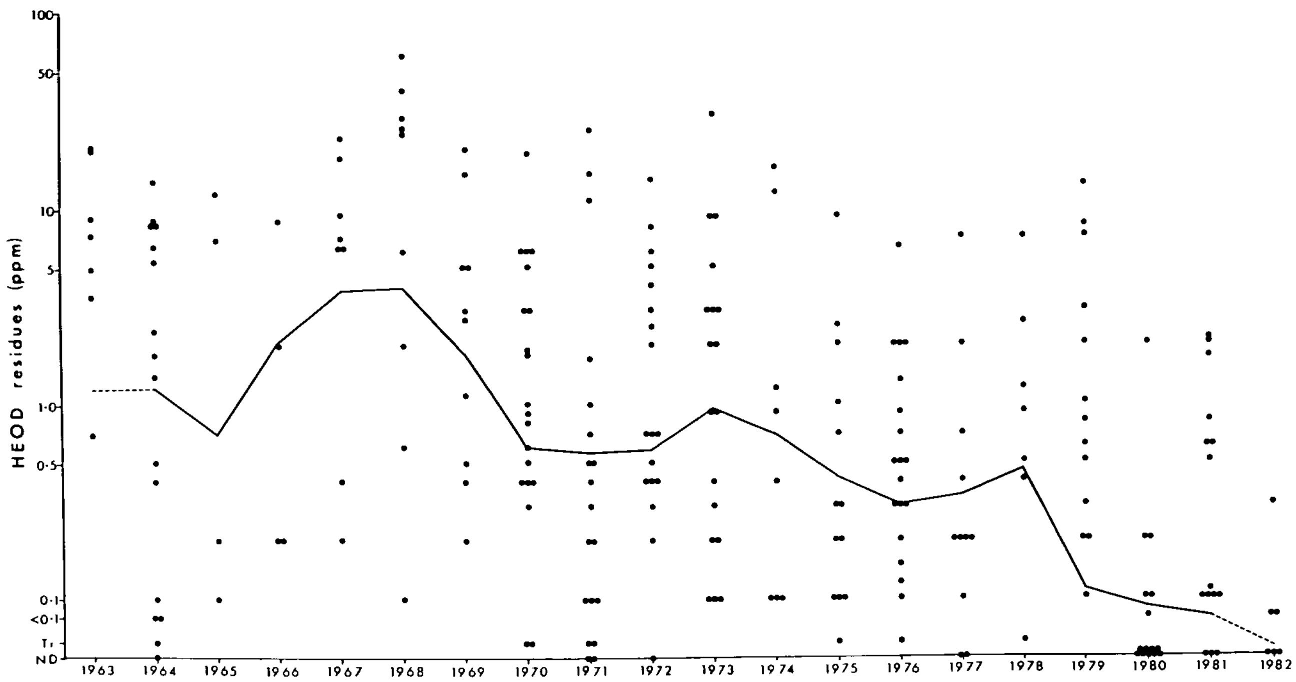

Figure 2a. Levels of HEOD in livers of herons received at Monks Wood Experimental Station 1963-82. All herons included, irrespective of region, season or cause of death. Lines show 3-year (– – – 2-year) moving geometric means of residue levels

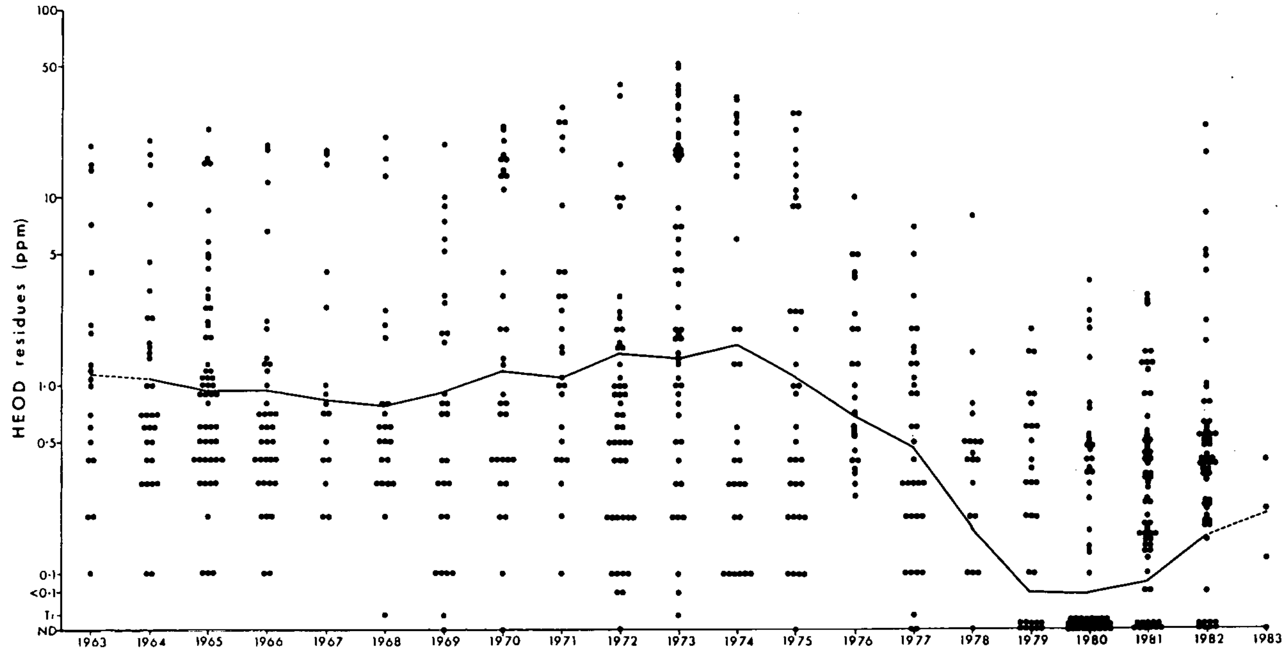

Figure 2b. Levels of HEOD in livers of kestrels received at Monks Wood Experimental Station 1963-83. All kestrels included, irrespective of region, season or cause of death. Lines show 3-year (– – – 2-year) moving geometric means of residue levels

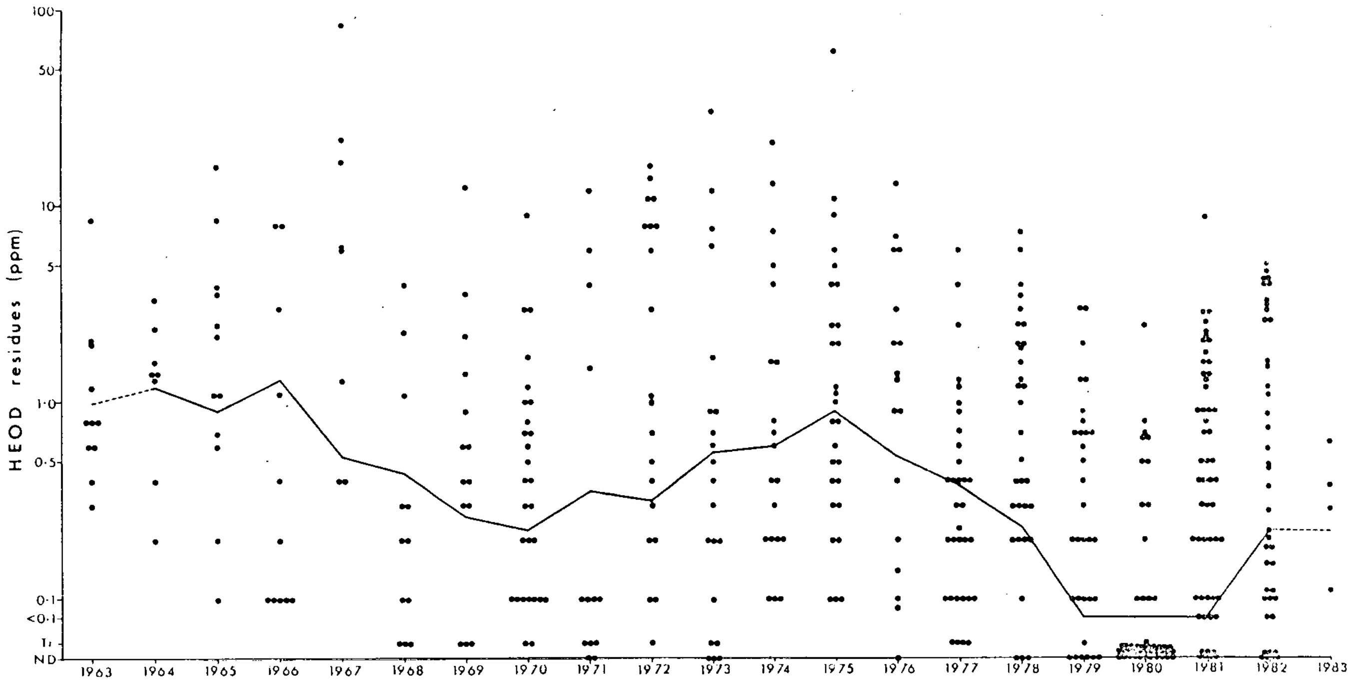

Figure 2c. Levels of HEOD in livers of sparrowhawks received at Monks Wood Experimental Station 1963-83. All sparrowhawks included, irrespective of region, season or cause of death. Lines show 3-year (– – – 2-year) geometric means of residue levels

cause of death. Levels of DDE in livers were generally higher than those of HEOD, not necessarily because of the greater use of DDT than of aldrin/dieldrin (Table 1), but because of the greater persistence and lower toxicity of DDE compared to HEOD, both of which would have led birds to accumulate greater levels of DDE. From most parts of the country, some of the birds contained relatively low levels of these compounds, while other birds had high levels. However, the proportion of individuals with high levels was greater in the east than in the west (Cooke *et al.* 1982). This fitted the geographical trend in tilled land, and thus presumably also the extent of pesticide usage.

In the long-term trends in residues, the 3 species differed somewhat (Figures 1-2). For DDE, the heron showed a slight, but progressive, decline throughout the 20 years concerned, which became particularly marked after 1981. The kestrel showed a decline only after 1977; before this date, all annual geometric mean levels were greater than 1 ppm, whereas after this year only one annual geometric mean (1980) was greater than 1 ppm. The sparrowhawk, in contrast, showed a consistently high level throughout, with no sign of a decline.

For HEOD, the 3 species revealed a similar order of trend. The heron showed a steady decline in residues from the early 1960s to about 1980, and the kestrel and sparrowhawk showed declines chiefly after 1976 following the last main restriction of aldrin and dieldrin as seed treatments. In all 3 species, however, HEOD levels rose again after 1980, presumably reflecting an increase in usage, but no figures on this are available.

These different patterns probably resulted because the 3 species ate different prey, from different food chains. Much of the organochlorine in water is presumably derived from agriculture, with local inputs of HEOD associated with the mothproofing and wood industries. Levels in herons are therefore likely to reflect recent agricultural usage. As residues of organochlorines persist for years in soils, levels in the 2 terrestrial predators are likely to reflect previous usage, as well as very recent usage. Previous usage is particularly likely to affect the sparrowhawk because several of its prey species feed on worms and other organisms which become contaminated by residues in soil. In other words, because of their feeding habits, the 3 species probably differ in the speed with which they reflect declines in usage, in the order heron, kestrel and sparrowhawk respectively. The possibility that sparrowhawks accumulate their own DDE residues from migrant prey now seems, from analyses of prey species, unlikely to be true (unpublished data). The bulk of DDE found in British predatory birds has almost certainly been applied as DDT in Britain.

The greater contamination of the sparrowhawk than the kestrel agrees with findings in other areas, where bird eaters invariably contain higher organochlorine levels than do mammal eaters (Conrad 1977; Henny 1977). This is partly because the mammal eating raptors are living on herbivorous prey (a food chain with 2 steps), whereas the bird eaters are living largely on carnivorous prey (a food chain with at least 3 steps). In addition, mammals in general are better able to metabolize organochlorines than birds (Walker 1983). So, on the same rate of intake, mammals will generally accumulate less than will birds. There are thus 2 reasons why mammal feeding raptors would be expected to become less contaminated than bird feeding raptors.

For herons, the situation differs. Organochlorines are only slightly soluble in water, but fishes, filtering hundreds of gallons of water per day, can rapidly absorb organochlorines through their gills, as well as from their food. So fish, too, are often a major source of residue, and especially oily fish, such as eels, which are favoured by herons, and particularly by otters.

6 Persistence of DDE in soils

Recent analyses of uncultivated orchard soils showed only a negligible decline in DDT-type residues (especially DDE) during 13 years after DDT was last used, and the expected 'half-life', when concentrations in the soil should have decreased to one half, was estimated at 57 years (Cooke & Stringer 1982). Even if use of DDT was stopped tomorrow, soil dwelling organisms would remain a source of residues to prey species for decades to come. HEOD is much less persistent, with a half-life in soil estimated at 4-7 years (Research Committee on Toxic Chemicals 1964; Edwards 1966). Organochlorines can disappear more rapidly from animal bodies than from the physical environment, but, again, DDE lasts longer than HEOD. For example, in pigeons, the 'half-life' of DDE has been estimated at about 240 days, compared with 47 days for HEOD (Walker 1983). These rates vary between species, and with the condition of the individual.

7 Future work

As the most affected species, sparrowhawk and peregrine, have still not completely reoccupied their former range, continued monitoring of populations is desirable, especially in south-east England, where peregrines are still absent, and where sparrowhawks have only recently started to return. Monitoring until populations have fully recovered is desirable not only for conservation reasons, but also to check whether events are fully consistent with organochlorines being the primary cause of population decline. Also, in view of the continuing high DDE residues in these and other species, continued monitoring of residues and shell thickness is also desirable. There is now only one remaining legitimate use for DDT in Britain, but there are worrying signs of increasing use for other purposes. Substantial use will probably continue whilst the chemical remains freely available, and its removal from all lists of recommended chemicals is highly desirable. If its use could be stopped, it would be instructive to find how long it takes for residues to decline to negligible levels in different species, thus providing data on persistence levels in different parts of the environment. The work of Cooke and Stringer (1982) demonstrating the extreme persistence of DDE in soil might usefully be extended, both with more analyses in future years at the same site, and with further analyses at other sites. This extension would help to indicate how widely applicable are the results from this one area, and the extent to which persistence varies with soil type. In general, further monitoring of the physical environment, and of selected animal species, will be required for some further years, whether or not DDT remains available commercially.

On the other hand, I can see little value in further research on the mode of action of DDT or on other physiological aspects, not because these aspects are fully understood, but because the chemical is hopefully being phased out, and further basic research could only be regarded as a luxury rather than a priority. The same applies to dieldrin and other organochlorines. However, because of the extent of our existing knowledge of DDT, it will remain a good chemical on which to make general studies of pollutants and their behaviour in the environment. It is also a good chemical for research into the effects on animals of long-term exposure, including the development and mechanisms of resistance. Indeed, the routine screening of a wide range of animals for their sensitivity to DDT, comparing populations from agricultural and non-agricultural areas, might give some idea of the variety of species which have been affected by this chemical (though it would not tell us how many species have been eliminated completely). Such data are not yet available for any chemical, the information on effects being restricted to the pest species themselves and a few other conspicuous or important species, such as birds and bees.

Another major research need concerns not just the organochlorines, but all chemicals used on farmland. The need is for some assessment of the effects of the collective total of chemical use on the farmland flora and fauna, including soil organisms. To some extent, it is too late for this assessment, because much of the change will have occurred already, but, with the continuing increase in numbers of chemicals and applications, further change in flora and fauna seems inevitable. I believe that such a study could reveal effects far greater and wider ranging than previously imagined, some of which might have repercussions on the long-term maintenance of soil fertility. Projects by the Game Conservancy and MAFF go only part way towards fulfilling this need.

8 Summary

8.1 DDT is held responsible for the widespread shell-thinning and lowered breeding success which have occurred in certain predatory birds from the late 1940s, while aldrin and dieldrin are held responsible for the large-scale mortality and population declines which occurred from the late 1950s. The bird eating peregrine and sparrowhawk were the main species affected.

8.2 Since 1962, successive Government restrictions have progressively reduced the amounts of these chemicals used in agriculture. The decline

in aldrin/dieldrin use was especially marked after 1975, but DDT continued to be used in substantial amounts until beyond 1980.

8.3 Coincident with reductions in aldrin/dieldrin use, peregrines and sparrowhawks have largely recovered in numbers and recolonized areas from which they were eliminated. However, both are still absent from those (intensely arable) parts of their range with heaviest pesticide use. The peregrine is still absent from sea cliffs (near arable land) in southern and eastern England, and the sparrowhawk is largely absent from a region embracing much of Lincolnshire, Cambridgeshire, and parts of Norfolk, Suffolk, Essex and Kent.

8.4 These population recoveries, associated with reductions in aldrin/dieldrin use, have occurred despite continued shell-thinning and reduced breeding success.

8.5 Sparrowhawk, kestrel and heron specimens, analysed chemically, have all shown declines in HEOD residues in their livers, especially after 1975. Kestrel and heron showed declines in DDE levels.

8.6 Recent work implies that DDE is extremely persistent in soils, and therefore likely to remain a problem, at least to sparrowhawks, for years to come, even if its usage is curtailed now.

8.7 The main priorities for future work include (i) continued monitoring of population trends in affected species, and of residue levels in selected species and in soils; (ii) some assessment of the changes in flora and fauna of farmland due to total chemical use.

In addition, DDT would be a good chemical for more general studies of the behaviour of persistent pesticides, and for studies of the development, and mechanisms, of resistance.

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