Pollutants in Merlin eggs and their effects on breeding

I. Newton and M. B. Haas

In view of the declining status of the Merlin *Falco columbarius* in Britain (Bibby & Nattrass 1986; Newton *et al.* 1986), we have continued to analyse unhatched eggs for pollutant residues. The findings from eggs collected to 1980 were given in Newton *et al.* (1982), and in this paper we summarise the results obtained to 1986 and re-examine some aspects on the enlarged samples. The chemicals involved include DDE (from the insecticide DDT), HEOD (from the insecticides aldrin and dieldrin), PCBs (polychlorinated biphenyls from industrial products) and mercury (mainly from agricultural and industrial sources). We demonstrate for the first time a relationship between breeding success and mercury levels in eggs.

As in previous studies, the eggs were collected by observers in different parts of Britain, and sent to Monks Wood Experimental Station for analysis. Most such eggs were either addled or deserted. They were thus not a random cross-section of those laid, but the same sampling method was used throughout. Organochlorine residues were calculated as parts per million (ppm) in egg lipid, and mercury as ppm in dry weight. Shell-indices, reflecting shell thickness, were calculated as shell weight (mg)/ shell length × breadth (mm) (Ratcliffe 1967). To find whether residues affected breeding success, we looked for relationships between residue levels in eggs from particular nests and the number of young produced in those nests. In total, eggs from 173 nests were examined during 1964-86, but the results from no more than one egg per clutch were used in any of the following calculations (see Newton *et al.* 1982 for further details of procedure). The mean lipid content of Merlin eggs was 6.2% and the mean dry matter was 20.0%. The organochlorine values given below could, therefore, be converted to a fresh weight basis by dividing them by 17, and the mercury values by dividing them by 5.

 [*Brit. Birds* 81: 258-269, June 1988]

Results

The Merlin remains the most heavily contaminated of the British raptors. The eggs examined during 1981-86 had geometric mean levels of about 100 ppm DDE, 5 ppm HEOD and 50 ppm PCBs in lipid, and 2 ppm mercury in dry weight. These levels were considerably higher than those in contemporary eggs of the Peregrine *F. peregrinus* from the same regions (fig. 1). The two species share much the same habitat, and both eat birds. Relative to their body weights, however, the smaller Merlin has a greater daily food intake than the Peregrine, and this could at least partly explain the difference in residue burdens.

The mean shell-index of Merlin eggs obtained in 1981-86 was 1.102 ± 0.010, some 12% less than the pre-DDT value of 1.256.

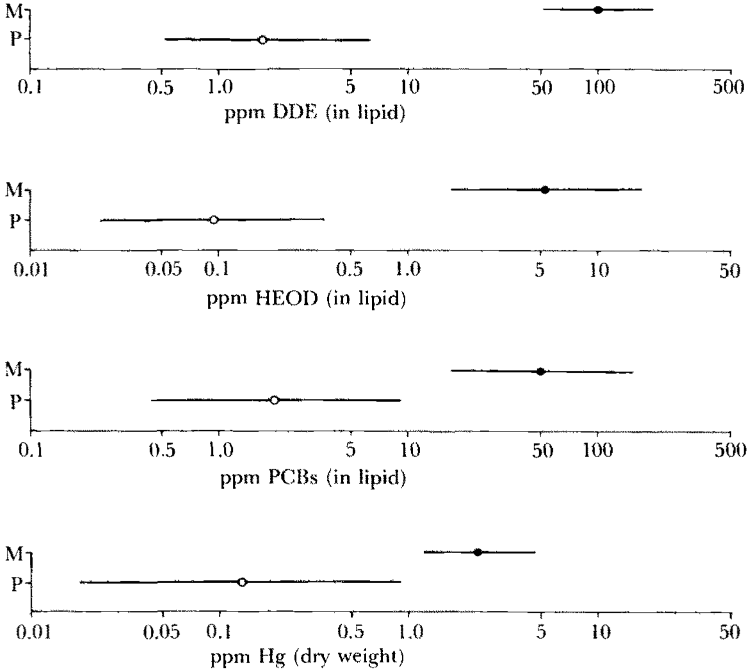


Fig. 1. Comparison of pollutant levels in eggs of Merlins *Falco columbarius* (M) and Peregrines *F. peregrinus* (P) collected in Britain during 1981-86. The figures show geometric mean levels and standard deviations, based on 122 eggs of Merlin and 189 of Peregrine

Geographical patterns in residues

As yet, no Merlin egg examined in Britain has been free of pollutants, and every egg analysed during 1981-86 contained measurable residues of all four chemicals. For each chemical, regional variation was apparent (fig. 2). The pesticides generally tended to be present at lower levels in eggs from the north of Britain than from farther south: DDE levels were lowest in eggs from Orkney and Shetland, and HEOD levels in eggs from Orkney. PCBs showed no obvious north-south trend. Mercury has been measured only since 1980, and the levels in eggs from Orkney and

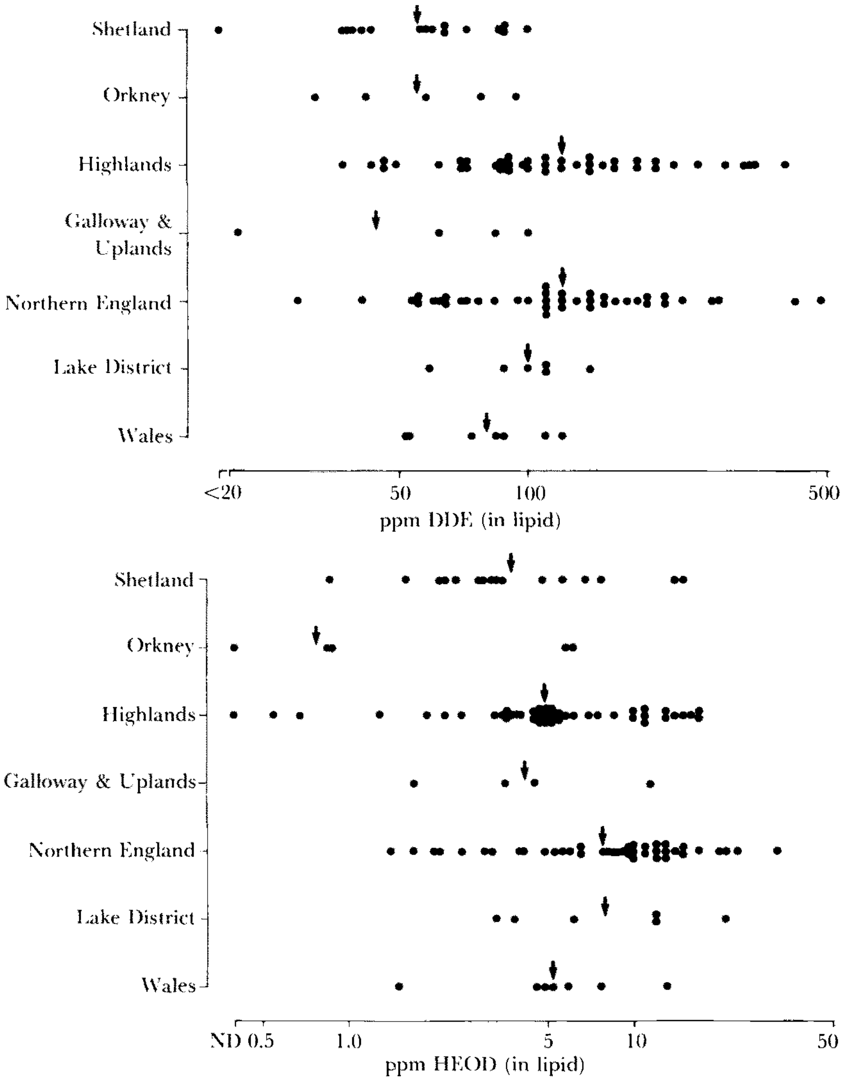
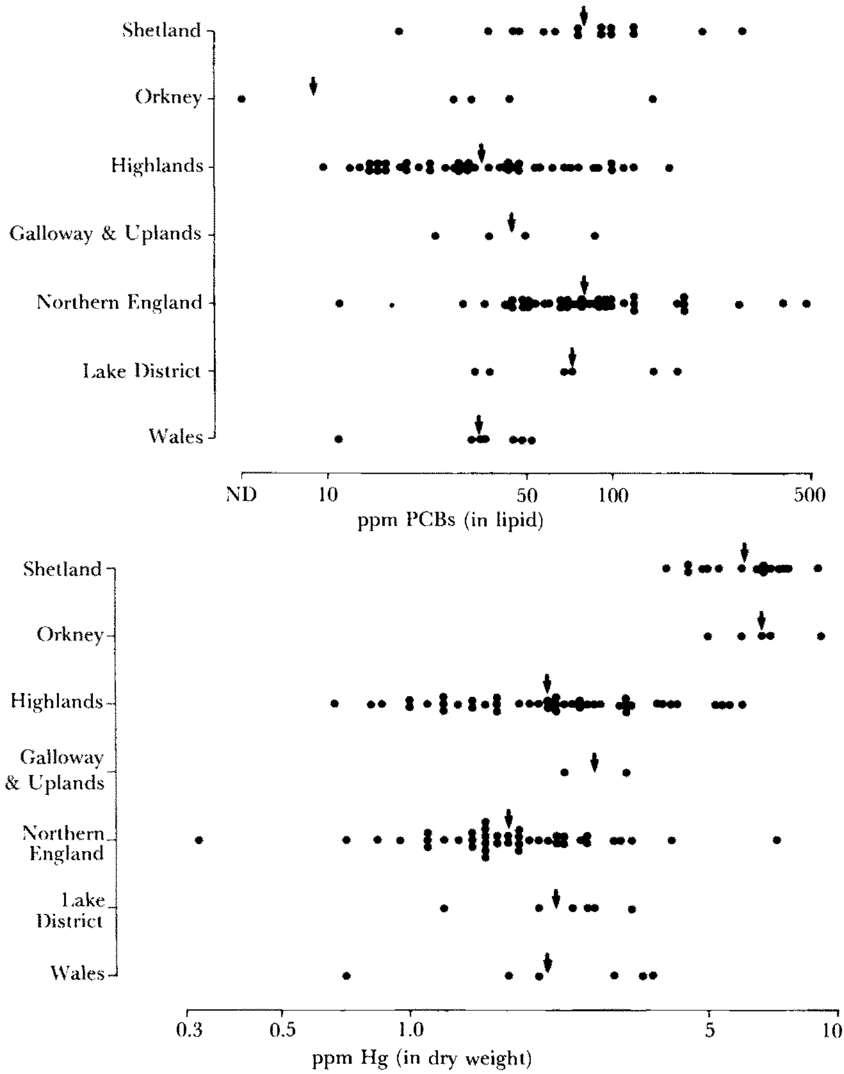


Fig. 2. Pollutant levels in eggs of Merlins *Falco columbarius* from different regions, 1981-86. variation was found: for DDE, $F_{6,116} = 5.90$, $P<0.0001$; for HEOD, $F_{6,116} = 4.14$, $P<0.0008$;

Shetland were strikingly higher than in those from the rest of Britain. The two eggs obtained from Hebridean islands also had high mercury levels, with 5.0 ppm recorded from Mull and 4.1 ppm from Lewis.

Shell-indices were generally higher in the north of Britain than farther south, as expected from the pattern in DDE, the main causal agent of shell thinning (see later).

Eggs laid by two captive females, fed largely on day-old domestic fowl chicks, had much lower residues than eggs from wild Merlins, with about 1.2 and 1.4 ppm HEOD, 0.9 and 1.6 ppm DDE, 2.2 and 2.3 ppm PCB, and



Arrows show position of geometric mean levels. On analysis of variance, significant regional for PCBs, $F_{6,116}$ = 6.15, P<0.0001; for Hg, $F_{6,116}$ = 16.41, P<0.0001

0.1 and 0.1 ppm mercury, respectively. These eggs also had shell-indices that were close to the pre-DDT mean, at 1.26. Evidently, the domestic fowl chicks were very much less contaminated than was the wild prey eaten by Merlins.

Time trends in residues and shell-indices

Since the 1960s, when the first Merlin eggs were analysed, the residues of all three organochlorines have declined significantly (fig. 3). The decline was more marked in HEOD than in DDE and PCBs. Over the same

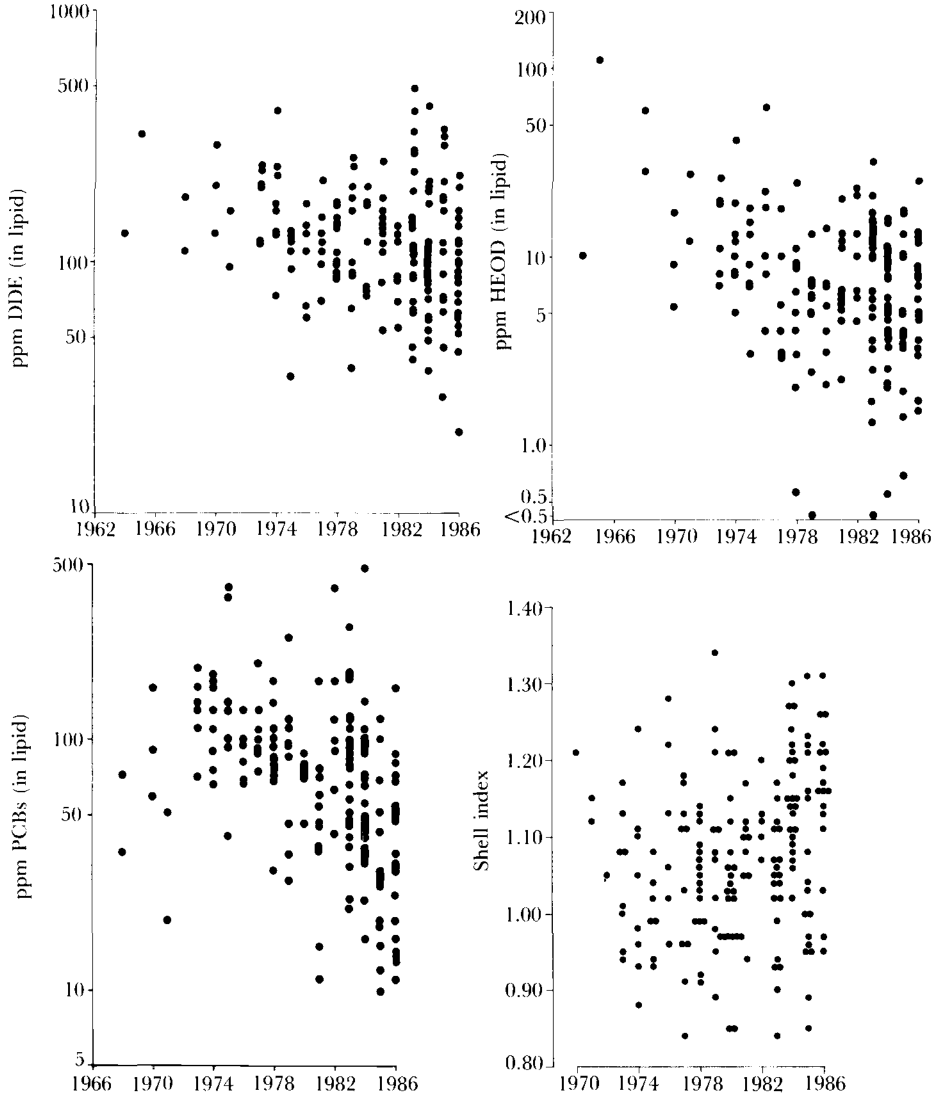


Fig. 3. Time trends in the organochlorine levels and shell-indices of eggs of British Merlins *Falco columbarius* (Orkney and Shetland excluded). On a linear regression of residue level on year, significant declines were found in the levels of all three chemicals: Log DDE = 2.278 − 0.012 year, r = 0.24, $P<0.001$; Log HEOD = 1.312 − 0.027 year, r = 0.30, $P<0.0001$; Log PCB = 2.305 − 0.028 year, r = 0.38, $P<0.0001$. During the same period, shell-indices rose: shell-index = 0.978 + 0.006 year, r = 0.24, $P<0.005$. In all these equations, 1963 is taken as year 1

period, shell-indices improved. In assessing these national trends, eggs from Orkney and Shetland were excluded, because they had somewhat different residue levels from those in eggs from the rest of the country, and were represented only in recent years. No trend in mercury was apparent in the short period that levels were measured.

Significance of residues

The number of young raised by individual Merlin pairs was related to the levels of mercury in their eggs: in general, the more mercury the eggs contained, the less likely were they to produce young. Although significant statistically, this relationship was by no means clear-cut (fig. 4). Some clutches with high mercury levels still managed to produce three or four young, while some other clutches with low levels failed completely (in some cases for reasons other than mercury content). Lack of a clear-cut relationship between residue level and success is common with other types of pollutants (Newton 1979). It results partly because of individual variation in response (as levels which will harm one bird will not affect another), and partly because the effect of a pollutant in eggs may be modified by other variables (such as incubation routines). In general, the data in fig. 4 suggested that productivity fell markedly in clutches where mercury exceeded 3 ppm. Only two out of 18 clutches (11%) with less than 3 ppm mercury failed to produce young, compared with 18 out of 37 (49%) with more than 3 ppm mercury (χ^2 = 5.8, $P<0.02$).

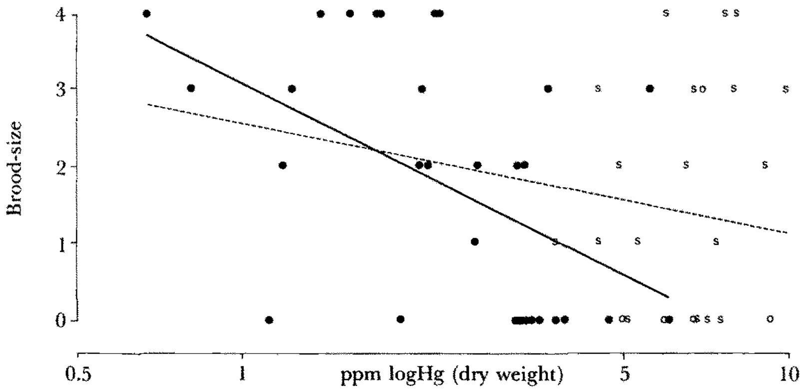


Fig. 4. Number of young raised by individual pairs of Merlins *Falco columbarius* shown in relation to the mercury content of their eggs. Open circles show eggs from Orkney, S eggs from Shetland, and filled circles eggs from elsewhere in Britain. The regression equation, describing the relationship, is as follows, where Pr = the productivity of individual pairs: Pr = 2.49 − 1.37 log Hg, r = 0.28, N = 55, $P<=0.04$ (broken line above). Excluding the records from Orkney and Shetland the relationship becomes: Pr = 2.82 − 2.81 log Hg, r = 0.49, N = 32, $P<0.005$ (solid line above). For Orkney and Shetland alone, no relationship was apparent

Another complication was that, although the relationship between mercury level and brood-size was marked in mainland Britain (and hence in the complete sample), it was practically non-existent in Orkney and Shetland, where mercury levels were highest. We cannot explain this anomaly, but future work will aim to find whether mercury was present in some less toxic form in the island birds than in the mainland ones. The chemical analyses done so far measured elemental mercury alone, and did not distinguish the different compounds involved.

In contrast to the findings on mercury, productivity showed no significant relationship with the levels of DDE, HEOD and PCBs in eggs. Moreover, when these chemicals were included in a multiple regression analysis with mercury, they explained no more of the variance in brood size than did mercury alone. In other words, no evidence was found that the organochlorines (at the levels found) had any influence on productivity. This was in line with earlier findings, based on eggs collected in 1971-80 (Newton *et al.* 1982).

As in previous studies (Hodson 1975; Newton *et al.* 1982), shell-indices were negatively correlated with DDE levels. The relationship was linear with DDE on a log scale, and a revised equation based on all available eggs was as follows:

Shell-index = 1.30 − 0.10 log DDE, r = 0.31, N = 168, $P<0.0001$. Intercept value of 1.30, indicating shell-index with 1 ppm DDE, was close to pre-DDT mean shell-index of 1.26.

Shell-indices showed no significant correlation with HEOD, PCB or mercury. Moreover, when these other chemicals were incorporated in a multiple regression analysis, they explained no more of the variance in shell-index than did DDE alone. This was also in line with previous findings on Merlins and other raptors (Newton 1979; Newton *et al.* 1982), and with experimental evidence implicating DDE as the primary cause of shell thinning (Cooke 1973).

Discussion

The recent results indicate a continuing widespread contamination of

146. Merlin *Falco columbarius*, Clwyd, June 1973 (*Dennis Green*)

British Merlins with organochlorine and mercury residues, together with widespread shell thinning. Progressive reductions in the use of DDT, aldrin and dieldrin over the years (Newton & Haas 1984), however, and almost no usage since 1983, seem to have been accompanied by reductions in residues of DDE and HEOD in Merlin eggs and by a slight improvement in shell-indices.

A slower decline of DDE compared with HEOD in the eggs was presumably because DDE is more persistent in the physical and biotic environment than is HEOD, and was also used in quantity until a later date (Cutler 1981; Sly 1981, 1986; Newton & Haas 1984). The continuing high levels of PCBs parallel the situation in British Peregrines and Sparrowhawks *Accipiter nisus* and presumably result because some PCBs are even more persistent than DDE, and their manufacture and use continues.

Interestingly, those Merlins breeding in the Scottish Highlands, where pesticide use has been slight and localised, were as heavily contaminated with organochlorines and mercury as were those from farther south. This was presumably because a large proportion of the Highland Merlins, together with their various prey species, spend the winter in more contaminated areas.

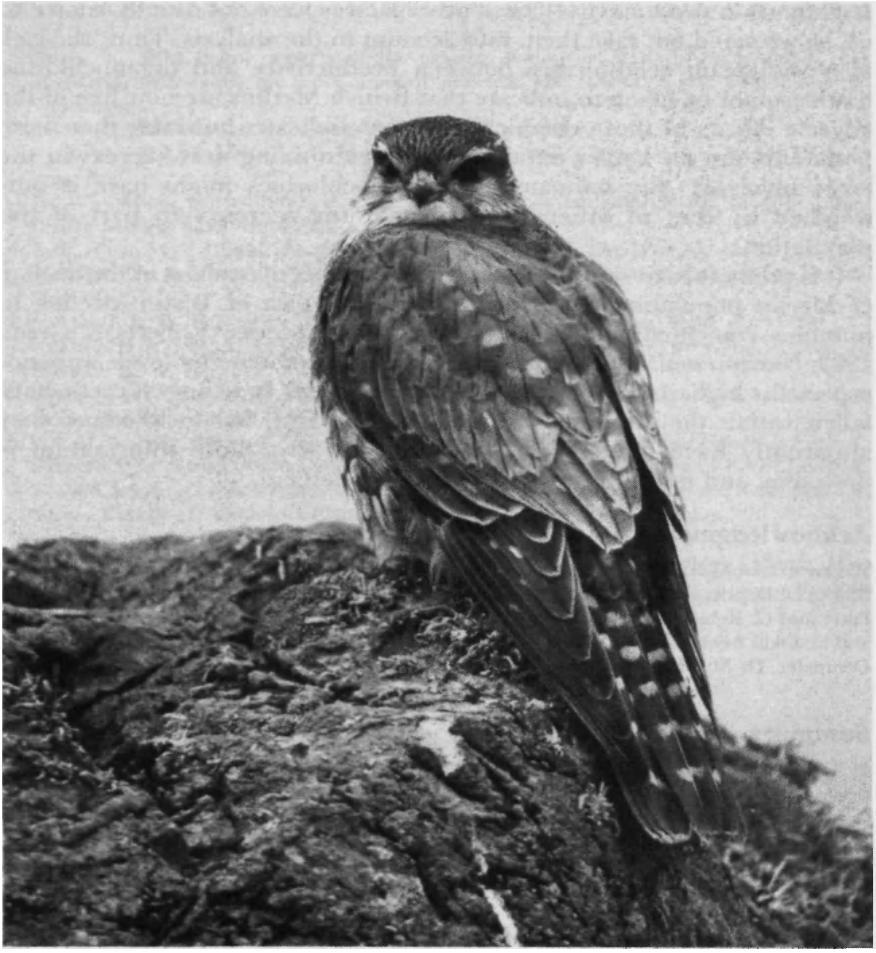
We cannot yet explain the greater levels of mercury found in the Orkney and Shetland eggs. Possibly the Merlins on these islands eat more waders than do Merlins elsewhere, but, if so, this could only be in winter, as it is not apparent in the summer diet, which consists almost entirely of song-birds (E. Meek, D. Okill, unpublished data). Waders generally contain more mercury than do song-birds, presumably because many

147. Merlin *Falco columbarius*, Clwyd, June 1974 (*Dennis Green*)

species feed on contaminated estuaries. To judge from analyses at Monks Wood Experimental Station, song-birds usually contain less than 1 ppm mercury in their livers (dry weight), whereas waders often contain 1-20 ppm (Parslow 1973; Newton *et al.* in press). Hence, if more of the Merlins from Orkney and Shetland than those from elsewhere winter in coastal districts, they would in general pick up more mercury. Relevant ringing recoveries for migrant Merlins are few and inconclusive on this point (Heavisides 1987), but those Merlins which remain on the islands in winter are mostly seen at the coast.

The relationship between brood size and mercury level was highly significant among eggs from mainland Britain, rather less so in the whole sample, and practically non-existent among the island eggs. We do not know why the island Merlins seemed more resistant to mercury, unless, as mentioned above, they contained mercury in a less toxic form than did the mainland birds. This is a distinct possibility, considering that the use of

148. Merlin *Falco columbarius*, Clwyd, May 1974 (*Dennis Green*)



149. Merlin *Falco columbarius*, Gwynedd, April 1977 (*R. J. Chandler*)

organo-mercury in agriculture has been relatively much greater in mainland Britain than on the islands. Interestingly, however, the mercury levels found in Merlin eggs from several regions were within the range found in experiments to reduce the hatchability of the eggs of Pheasants *Phasianus colchicus*. Such levels were recorded as 1.3-2.0 ppm wet weight (= 6.5-10 ppm dry weight) in a Swedish study (Borg *et al.* 1969) and as 0.5-1.5 ppm wet weight (= 2.5-7.5 ppm dry weight) in a Canadian study (Fimreite 1971).

There were probably two reasons why no relationship was found in the complete sample between productivity and either shell-indices or organochlorine residue levels. First, the pesticide residues have now become so low that they probably affected at most a small proportion of the Merlins studied; and, secondly, many other factors besides pollutants cause reductions in productivity. These other factors were not usually known to us, so we could not take them into account in the analysis. Thus, the lack of a significant relationship between productivity and organochlorine levels cannot be taken to indicate that British Merlins are now free of the adverse effects of these chemicals. It does indicate, however, that these pollutants are no longer paramount in determining nest success in the areas involved. Any influence the organochlorines might have is outweighed by that of other factors, including mercury in part of the population.

It is premature to say whether mercury has been involved in the decline of Merlin populations. In Northumbria and part of Wales, decline in numbers coincided with decline in breeding success (Roberts & Green 1983; Newton *et al.* 1986), but in these areas mean mercury levels were not especially high. In Orkney, both numbers and breeding success have fallen within the last ten years (E. Meek *in litt.*), but in Shetland they apparently have not (D. Okill *in litt.*). Clearly, more information is desirable, and not only from Orkney and Shetland.

Acknowledgments

We are grateful to all the observers who contributed eggs for analysis, in particular, Dr C. J. Bibby, D. Doody, A. Heavisides, G. Horne, B. Little, E. Meek, D. Okill, A. D. Payne, S. J. Petty and G. Rebecca. Chemical analyses were done mainly by D. Leach. P. Ellis, E. Meek and D. Okill freely shared their knowledge on the Orkney and Shetland birds, and Dr J. P. Dempster, Dr M. Marquiss and E. Meek commented helpfully on the manuscript.

Summary

1. British Merlins *Falco columbarius* have continued to show widespread contamination with organochlorine pesticides, PCBs and mercury. Shell thinning was also widespread.
2. On a national scale, organochlorine residues in eggs declined during the period 1964-86, and shell-indices improved.
3. Geographical variation was apparent in the egg residues of all the chemicals examined, and eggs from Orkney and Shetland contained much more mercury than did those from elsewhere.
4. The number of young raised by breeding Merlins was inversely related to the levels of mercury in their eggs. This finding was new and unexpected, but it was apparent only in eggs from mainland Britain, not in those from Orkney and Shetland, where mercury levels were highest. In general, organochlorines had no obvious influence on nest success. This was partly because organocblorine levels in most eggs were too low in the years concerned, and probably also because other factors (including mercury in some regions) had much greater influence on success.

References

BIBBY, C. J., & NATTRASS, M. 1986. Breeding status of the Merlin in Britain. *Brit. Birds* 79: 170-185.

BORG, K., WANNTORP, H., ERNE, K., & HANKO, E. 1969. Alkyl mercury poisoning in terrestrial Swedish wildlife. *Viltrevy* 6: 301-379.

COOKE, A. S. 1973. Shell tbinning in avian eggs by environmental pollutants. *Environ. Pollut.* 4: 85-152.

CUTLER, J. R. 1981. *Review of Pesticide Usage in Agriculture, Horticulture and Animal Husbandry 1975-1979.* Survey Report 27. Dept of Agriculture & Fisheries for Scotland, Edinburgb.

FIMREITE, N. 1971. *Effects of Dietary Methyl-mercury on Ring-necked Pheasants.* Canad. Wildlife Serv. Occas. Paper 9: 1-39.

HEAVISIDES, A. 1987. British and Irish Merlin recoveries, 1911-1984. *Ringing & Migration* 8: 29-41.
HODSON, K. 1975. Some aspects of the nesting ecology of Richardson's Merlin (*Falco columbarius richardsonii*) on the Canadian prairies. MSc thesis, Univ. Brit. Columbia, Vancouver.
NEWTON, I. 1979. *Population Ecology of Raptors*. Berkhamsted.
——, BOGAN, J. A., & HAAS, M. B. In press. Organochlorines & mercury in British Peregrine eggs. *Ibis*.
——, ——, MEEK, E., & LITTLE, B. 1982. Organochlorine compounds and shell-thinning in British Merlins *Falco columbarius*. *Ibis* 124: 328-335.
—— & HAAS, M. B. 1984. The return of the Sparrowhawk. *Brit. Birds* 77: 47-70.
——, MEEK, E., & LITTLE, B. 1986. Population and breeding of Northumbrian Merlins. *Brit. Birds* 79: 155-170.
PARSLOW, J. L. F. 1973. Mercury in waders from the Wash. *Environ. Pollut.* 5: 295-304.
RATCLIFFE, D. A. 1967. Decrease in eggshell weight in certain birds of prey. *Nature, Lond.* 215: 208-210.
ROBERTS, J. L., & GREEN, D. 1983. Breeding failure and decline of Merlins on a north Wales moor. *Bird Study* 30: 193-200.
SLY, J. M. A. 1981. *Review of Usage of Pesticides in Agriculture, Horticulture and Forestry in England & Wales 1975-79.* Survey Report 23. Ministry of Agriculture, Fisheries and Food, London.
—— 1986. *Review of Usage of Pesticides in Agriculture and Horticulture in England and Wales 1980-1983.* Survey Report 41. Ministry of Agriculture, Fisheries and Food, London.

Dr I. Newton & Mrs M. B. Haas, Institute of Terrestrial Ecology, Monks Wood Experimental Station, Abbots Ripton, Huntingdon PE17 2LS