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1 Preface and summary

1.1 Introduction

The Wildlife and Pollution contract covers a long-term monitoring programme, the Predatory Bird Monitoring Scheme (PBMS), that examines the levels of certain pollutants in selected wildlife species in Britain. The programme was started in the early 1960s, when there were serious concerns over the effects of organochlorine insecticides and organomercury fungicides on various species of birds and mammals. This early work demonstrated the effects of the organochlorines and eventually contributed to the ban on their use in the UK and abroad. The programme has subsequently assessed the success of these bans by measuring whether there has been a decline in the concentrations of organochlorine pesticides in the livers and eggs of predatory and freshwater fish-eating birds. Investigations have also been made into the levels of industrial polychlorinated biphenyls (PCBs), following their identification as pollutants in 1966. Mercury levels, derived from both agricultural and industrial sources, have also been tracked, although mercury concentrations were not measured in birds collected in 2001. In recent years, investigations have been made into the effects of the newest generation of rodenticides on barn owls *Tyto alba*. Northern gannet *Morus bassanus* eggs are also collected approximately biennially from two colonies and, when available, from other sites; eggs were last collected in 2000.

This programme is now the longest-running of its kind anywhere in the world and the findings stimulate considerable interest internationally, as well as in Britain. Annual reports give an interim summary of results and every three years these annual results are gathered together into a more substantial report in which they are integrated with previous findings. The latest report of this type covers the period up to and including 2000 (Shore *et al*. 2005). Results are published periodically in the scientific literature. This current report presents the results of analyses carried out on material collected in 2001. It also includes a review of long-term trends in second-generation anticoagulant rodenticide residues in barn owls that occurred during the monitoring period up to and including the year 2001.

The Wildlife and Pollution contract was the subject of scientific assessment within JNCC's rolling programme of peer review in autumn 1993 and was further assessed in 1996. As a result of the last two assessments, some monitoring was curtailed. Most notably, common kestrels *Falco tinnunculus* are no longer monitored for organochlorines. However, from 2001 onwards, kestrels will be monitored for second-generation anticoagulant rodenticides following the results from an individual study, carried out as part of the PBMS activities, which demonstrated that this species may be particularly vulnerable to exposure to these compounds (Shore *et al.* 2001). Carcasses and eggs of predatory bird species (such as peregrine falcon *Falco peregrinus*, common buzzard *Buteo buteo*, long-eared owl *Asio otus*, little owl *Athene noctua*, common kingfisher *Alcedo atthis*, great crested grebe *Podiceps cristatus*, and great bittern *Botaurus stellaris*) which do not form the core part of the PBMS, but are sent to the Centre for Ecology & Hydrology (CEH) by volunteers, are not analysed chemically. However, post-mortem examinations are carried out the carcasses, relevant information is recorded and the cause of death is determined (and reported back to the volunteer who submitted the carcass). Samples of the egg contents and body organs for these species, and samples for the species that do form part of the core monitoring, are all archived at -20°C as part of CEH's unique long-term tissue bank, and are often used in specific targeted research studies in subsequent years.

Each section within the Wildlife and Pollution contract is summarised below. Each is dependent on the provision of material from amateur naturalists and other interested parties, and it is not always possible to obtain desired material for analysis, especially from remote areas.

1.2 Organochlorines and mercury in the livers of predatory birds

The main objective of this work is to analyse the bodies of certain predatory and fish-eating bird-species, supplied by members of the public, in order to continue the monitoring of organochlorine and mercury residues in livers. This enables surveillance of the effects of previous withdrawals of permitted uses of some of these chemicals, and to examine geographical variation in residues. For 2001, the livers from 49 Eurasian sparrowhawks *Accipiter nisus* and four grey herons *Ardea cinerea* were analysed. These birds came from various localities in Scotland, England and Wales.

None of the sparrowhawks or herons collected during 2001 had liver concentrations of organochlorine insecticides or PCBs which were clearly indicative of lethal exposure. Average liver concentrations of organochlorine pesticides and PCBs were not significantly different from those recorded in birds that died in 2000, apart from an apparent decrease in liver PCB concentrations in sparrowhawks, although this was within the inter-year variation in liver PCB levels recorded in sparrowhawks since 1980.

1.3 Organochlorines in merlin *Falco columbarius* eggs

Single eggs collected in 2001 from seven merlin clutches from various parts of Scotland were analysed. The results confirm that the eggs of merlins in Britain are still generally contaminated with organochlorine pesticides and PCBs. But concentrations were generally low and below concentrations that are thought to be toxicologically significant.

1.4 Organochlorines in golden eagle *Aquila chrysaetos* eggs

Single eggs from five clutches from Scotland were analysed in 2001; four were from the Western Isles. The DDE and PCB concentrations in the three eagle eggs from Rum and Barra were relatively high compared with those in the other two eggs that were analysed and compared with average concentrations in eagle eggs from west coast eyries in previous years. However, the contaminant levels were below concentrations thought to impair reproduction, and the eggshell indices were within the range of variation observed in other eagle eggs in recent years.

1.5 Organochlorines in northern gannet *Morus bassanus* eggs

No gannet eggs were analysed in 2001. Gannet eggs are usually only analysed every two years.

1.6 Organochlorines in white-tailed eagle *Haliaeetus albicilla* eggs

One failed egg, from Mull, was collected and analysed in 2001. The organochlorine insecticide and PCB concentrations in this egg were amongst the lowest recorded in any of the white-tailed eagle eggs analysed as part of the PBMS, and were below levels thought to be associated with adverse effects.

1.7 Second-generation anticoagulant rodenticides (SGARs) in barn owls *Tyto alba*, common kestrels *Falco tinnunculus*, and red kites *Milvus milvus*

A total of 53 barn owls, 23 common kestrels and the one red kite (a road casualty) were received at CEH in 2001 and analysed for four SGARs, difenacoum, bromadiolone, brodifacoum and flocoumafen. Detectable residues of one or more compound were found in 22 (41.5%) barn owls, 14 (60.9%) kestrels and in the single red kite; difenacoum and bromadiolone were the compounds that were most frequently detected. The proportion of barn owls that contained residues, and (in comparison) the even higher proportion of kestrels that were contaminated, was consistent with findings in previous years. Twelve of the barn owls had liver residues that were in the potentially lethal range of >0.1-0.2 µg/g wet weight, but none of these birds were diagnosed, on the basis of post-mortem examination, to have died from rodenticide poisoning. A large proportion of the kestrels (30.4%) had relatively high liver SGAR residues (>0.2 µg/g wet weight) but, as with the barn owls, post-mortem examination did not reveal signs of haemorrhaging consistent with rodenticide poisoning in any birds.

The long-term monitoring of barn owls for SGARs has demonstrated that there is widespread exposure of barn owls to SGARs throughout Britain. One or more SGAR has been detected in 295 of the 993 barn owls (29.7%) analysed to date during the monitoring period, but the proportion of owls exposed has increased during the monitoring period and the current proportion of owls with detectable residues is approximately 40%. Difenacoum and bromadiolone are the SGARs most frequently detected in the livers of barn owls (19% and 11.5% respectively of all barn owls analysed) and the proportion of owls with detectable residues of both compounds has increased during the monitoring period. However, there is no evidence that the average magnitude of liver residues of difenacoum and bromadiolone in birds with detectable residues has increased progressively over time. Brodifacoum and flocoumafen have been detected less frequently in barn owls (6.4% and 1.0% of all birds, respectively). Between 5% and 10% of barn owls have liver SGAR concentrations (concentrations of multiple compounds in individuals summed) in the “potentially lethal range” of >0.1-0.2 µg/g wet weight but approximately only 1% of all birds examined have been diagnosed as having been directly poisoned by SGARs. There is no evidence that the exposure of barn owls to SGARs is currently causing any population decline.

2 Organochlorines in the livers of predatory birds

2.1 Introduction

The main objective of this work was to analyse the carcasses of predatory birds, supplied by members of the public. The chemicals of interest were dichlorodiphenyldichloroethylene (DDE, from the insecticide DDT), HEOD (from the insecticides aldrin and dieldrin), gamma-hexachlorocyclohexane (g-HCH) and PCBs (polychlorinated biphenyls from industrial products). Mercury concentrations in the liver were not determined in birds collected in 2001. Liver organochlorine concentrations are reported in this section as µg/g wet weight (ww).

The species analysed were the Eurasian sparrowhawk *Accipiter nisus*, representing the terrestrial environment, and the fish-eating grey heron *Ardea cinerea*, which represented the aquatic environment. Carcases of other species (common kestrel *Falco tinnunculus*, peregrine falcon *Falco peregrinus*, common buzzard *Buteo buteo*, long-eared owl *Asio otus*, little owl *Athene noctua*, common kingfisher *Alcedo atthis*, great crested grebe *Podiceps cristatus*, and great bittern *Botaurus stellaris*) were also received during 2001. These were not analysed for organochlorine residues because of the reduction in the scope of the monitoring scheme agreed in 1998. However, post-mortem examinations were carried out on each of these birds, relevant information being recorded and the cause of death determined (and reported back to the volunteer who submitted the carcass). Body organs and tissues from all birds received at CEH in 2001 are archived at -20°C and can be analysed for organochlorines and other contaminants in specific future studies.

2.2 Results

The livers from 49 sparrowhawks and four herons were analysed. All of these birds were found in 2001, with the exception of one bird for which the year in which the carcass was collected is not known. The results from all these birds are listed in Table 2.1 and the geometric means for each chemical (data for birds found dead in 2001 only) are given in Table 2.2. Data from the birds collected in earlier years are given in earlier reports in the present series and by Newton *et al*. (1993).

None of the sparrowhawks collected during 2001 had liver concentrations of organochlorine insecticides which were clearly indicative of lethal exposure. Liver pp'-DDE residues were mostly in the 0.1-20 µg/g ww range, concentrations typically found in sparrowhawks in Britain. However, one bird (13465) had a liver pp'-DDE residue of 194 µg/g ww, which is within the range (approximately >150 µg/g ww) associated with lethality in this species (Newton *et al.* 1992), but lower than the experimentally-defined range of >266 µg/g ww, which was derived from studies on brown-headed cowbirds *Molothrus ater* fed DDE (Blus 1996). All but one sparrowhawk had liver HEOD concentrations of less than 1 µg/g ww (the exception was a bird with a residue of 3.0 µg/g ww) and were below the range associated with mortality (5-85 µg/g ww; Newton *et al*. 1992). Gamma-HCH residues were only detected in nine sparrowhawks, and detected concentrations were all low (<0.04 µg/g ww), some two orders of magnitude below residues associated with mortality (Wiemeyer 1996).

Liver total PCB concentrations in sparrowhawks were typically lower than 20 µg/g ww, but four individuals had higher residues (22-58 µg/g ww). Three of these birds had no visible fat deposits in their bodies, and residues of <100 µg/g ww are not exceptional in starved individuals. The fourth sparrowhawk with a high PCB concentration was diagnosed to have died from as the result of a collision. The biological significance of its liver total PCB residue in birds is uncertain because there is considerable overlap in levels between birds dying from PCB poisoning and those that survive; the toxicological significance of residues is better defined for individual PCB congeners.

The concentrations of organochlorine insecticides and PCBs in the four herons analysed were all low, and not considered to be toxicologically significant.

The only statistically significant difference between liver residues in birds that died in 2001 and those that died in the previous year for the compounds that were analysed was an apparent decrease in liver PCB concentrations in sparrowhawks (Table 2.3). However, liver total PCB concentrations in sparrowhawks have shown considerable inter-year variation since 1980 and the geometric mean concentration of 2.19 µg/g ww for birds that died in 2001 was well within this range (Shore *et al*. 2005).

Table 2.1: Levels of organochlorines (µg/g ww) and in the livers of juvenile (in first year) and adult (older than first year) sparrowhawks and herons received during 2001. * indicates missing data that were either not provided by the sender of the carcass or that could not be obtained from the sample received.

Bird No.	Year found	Location	Age	Sex	pp'-DDE	HEOD	g-HCH	PCB
Eurasian sparrowhawk *Accipiter nisus*								
13451	2001	SW Yorkshire	A	F	0.824	0.179	ND	1.16
13459	2001	West Sussex	J	F	4.07	0.211	0.026	7.82
13462	2001	NE Yorkshire	J	F	2.36	0.168	ND	3.67
13465	2001	Cambridgeshire	J	M	194	0.328	0.023	10.8
13469	2001	Oxfordshire	A	M	6.21	0.123	ND	8.04
13470	2001	East Norfolk	A	F	8.85	0.353	0.025	14.3
13477	2001	S. Northumberland	A	F	0.194	0.090	ND	2.19
13479	2001	Cambridgeshire	A	F	26.2	0.650	ND	14.2
13480	2001	North Devon	A	F	1.44	0.184	ND	1.09
13484	2001	Isle of Wight	A	F	4.99	0.306	ND	5.76
13485	2001	East Cornwall	J	F	2.41	0.197	ND	6.47
13487	2001	East Suffolk	A	F	5.17	0.069	ND	0.883
13491	2001	North Essex	J	F	10.2	0.342	ND	21.6
13493	2001	Hertfordshire	A	M	7.60	0.245	ND	58.3
13501	2001	East Kent	A	M	64.8	3.02	ND	14.6
13502	2001	East Inverness-shire	J	M	6.77	0.191	0.024	11.4
13504	2001	Glamorgan	J	M	5.45	0.344	ND	24.3
13513	2001	Carmarthenshire	J	M	0.827	0.062	ND	1.42
13525	2001	North Somerset	A	F	7.42	0.409	ND	2.60
13529	2001	*	A	M	1.43	0.198	ND	2.23
13531	2001	South Devon	A	M	1.25	0.070	ND	1.72
13557	2001	Cheshire	J	M	0.093	0.033	ND	0.145
13562	2001	South Essex	J	F	0.169	0.047	0.023	0.123
13563	2001	S. Aberdeenshire	J	F	0.245	0.040	ND	0.007
13565	2001	East Norfolk	J	M	1.30	0.286	ND	3.47
13567	2001	Northamptonshire	J	F	1.46	0.116	ND	2.25
13583	2001	East Gloucestershire	J	F	0.409	0.128	ND	0.35
13593	2001	South Lancashire	J	F	0.409	0.037	ND	0.15

Bird No.	Year found	Location	Age	Sex	pp'-DDE	HEOD	g-HCH	PCB
13594	2001	NE Yorkshire	J	F	1.76	ND	ND	0.64
13595	2001	East Suffolk	A	F	4.97	0.123	ND	1.25
13598	2001	Kintyre		F	2.40	0.318	ND	12.5
13600	2001	West Suffolk	J	F	2.64	0.081	ND	16.2
13601	2001	SW Yorkshire	J	M	0.285	0.076	ND	0.762
13616	2001	West Kent	J	F	45.3	0.524	ND	6.88
13619	2001	South Lincolnshire	J	M	0.321	0.068	ND	0.655
13620	2001	Leics (with Rutland)	J	F	0.087	0.051	0.024	0.116
13623	2001	Surrey	J	F	3.88	0.260	ND	32.5
13630	*	Huntingdonshire	J	M	1.84	0.093	ND	2.24
13637	2001	Huntingdonshire	J	M	0.839	0.075	ND	0.144
13638	2001	Huntingdonshire	J	F	0.179	0.048	ND	0.207
13639	2001	South Lancashire	J	M	0.117	0.059	ND	0.640
13643	2001	Berkshire	J	M	0.440	0.040	ND	1.32
13646	2001	South Lincolnshire	J	F	1.62	0.087	0024	1.15
13650	2001	East Sutherland	A	F	0.351	0.109	ND	2.49
13654	2001	Pembrokeshire	J	M	0.305	0.104	0.027	0.56
13657	2001	Warwickshire	J	F	3.49	0.384	0.038	6.60
13658	2001	South Wiltshire	A	F	3.84	0.184	ND	11.9
13661	2001	Buckinghamshire	J	F	4.11	0.124	ND	7.83
13663	2001	Surrey		F	0.571	0.067	ND	2.50
Grey heron *Ardea cinerea*								
3445	2001	Staffordshire	A	F	0.067	0.048	ND	4.88
13536	2001	South Somerset	J	M	0.166	0.068	ND	0.93
13540	2001	Dorset	A	M	0.654	0.075	ND	3.07
13571	2001	North Somerset	J	F	0.339	0.041	ND	2.53

ND is not detected

Table 2.2: Geometric mean levels of pollutants in the sparrowhawk and heron in Table 2.1 (data are only for birds found dead in 2001). GSE=geometric standard error.

	pp'-DDE	HEOD	PCB
Sparrowhawk			
Geometric mean	1.74	0.128	2.19
N	48	48	48
Range of 1 GSE	1.35 – 2.23	0.108 – 0.151	1.68 – 2.85
Heron			
Geometric mean	0.223	0.056	2.44
N	4	4	4
Range of 1 GSE	0.137 – 0.363	0.049 – 0.065	1.72 – 3.46

Data are not given for g-HCH because concentrations were non-detected in most birds.

Table 2.3: Results from student t-test comparison (log_{10} transformed data) of residue levels from birds collected in 2000 and 2001; values for the two years and the statistical t-values are shown. Minus values indicate a decrease and plus values indicate an increase from 2000.

		pp'-DDE	HEOD	PCB
Sparrowhawk				
	2001	1.74	0.128	2.19
	2000	0.977	0.100	3.44
		t_{111} = +1.61	t_{111}= +0.95	t_{111} = -1.40*
Heron				
	2001	0.223	0.056	2.44
	2000	0.865	0.339	1.90
		t_5 = -1.41	t_5 = -1.21	t_5 = +0.13

Significance of difference: *P<0.05; **P<0.01; ***P<0.001

Table 2.4: Trends in pollutant levels in livers of predatory birds during 1963–2001 and 1996–2001. Figures show sample sizes (N) and linear regression coefficients (b) based on log values regressed against year (analyses for PCBs and mercury (Hg) were started in 1967 and 1970 respectively in sparrowhawk and heron)

		1963 – 2001			1996 – 2001		
		N	**b**		**N**	**b**	
Sparrowhawk							
	pp'-DDE	1972	-0.031	***	376	0.048	*
	HEOD	1973	-0.031	***	376	0.032	*
	PCB	1928	0.007	**	376	0.137	***
	Hg	1675	-0.017	***	327	0.116	***
Heron							
	pp'-DDE	818	-0.042	***	34	0.054	ns
	HEOD	808	-0.048	***	34	0.111	ns
	PCB	684	-0.021	***	34	0.119	ns
	Hg	517	-0.019	***	30	0.013	ns

*P=<0.05; **P=<0.01;***P<0.001; ns=not significant

3 Organochlorines in merlin *Falco columbarius* eggs

3.1 Introduction

The eggs of merlins have been monitored since the late 1960s for organochlorine compounds as part of the core PBMS monitoring. The findings from previous analyses of merlin eggs are given by Newton *et al.* (1982), Newton *et al*. (1999a) and Newton & Haas (1988), and also in previous reports in the present series. Those from 7 eggs (one per clutch) collected during 2001 are summarised in Table 3.1.

3.2 Results

As in previous years, the analyses of the eggs collected in 2001 confirm that the eggs of merlins in Britain are still generally contaminated with organochlorine pesticides and PCBs. PCB and DDE residues were detected in all seven eggs and HEOD residues in five. The concentrations of all three contaminants were generally low, and below concentrations that are thought to be toxicologically significant (Blus 1996; Hoffman *et al.* 1996; Peakall 1996).

Together with previous findings, these data indicate a continuing downward trend in DDE and HEOD residues in merlin eggs, but occasional high levels still occur. These declines in organochlorine insecticide residues have been accompanied by an increase in eggshell index and in the numbers of breeding merlins in Britain, although there has been some regional variation in the extent to which populations have recovered (Newton *et al.* 1999a). The long-term pattern of changes in the concentrations of PCBs and mercury (not measured in 2001 merlins) in merlin eggs is less clear and again appears to vary regionally (Shore *et al.* 2005).

Table 3.1: Residue levels of organochlorine insecticides, PCBs and shell indices (SI) for merlin eggs received in 2001. Contaminant concentrations are expressed as µg/g ww (µg/g lipid weight in parentheses). * indicates where shell indices could not be measured because of the poor condition of the eggshell.

Number	Year	Location	SI	pp'-DDE		HEOD		PCB	
Northern Isles									
E7941	2001	Shetland	1.39	0.912	(12.1)	ND	(ND)	6.18	(81.8)
E7945	2001	Shetland	1.25	2.31	(32.6)	0.034	(0.479)	3.76	(53.0)
E7946	2001	Shetland	1.33	1.81	(25.5)	ND	(ND)	3.74	(52.9)
E7961	2001	Orkney	1.46	1.31	(57.5)	0.021	(0.919)	2.02	(88.8)
E7972	2001	Orkney	*	4.28	(42.5)	0.046	(0.456)	2.44	(24.2)
Western Isles									
E7900	2001	Rum	*	2.13	(27.0)	0.171	(2.17)	2.26	(28.8)
E7901	2001	Rum	1.33	1.80	(24.5)	0.169	(2.30)	2.16	(29.3)

ND is not detected

4 Organochlorines and mercury in golden eagle *Aquila chrysaetos* eggs

4.1 Introduction

The findings from the long-term monitoring of contaminants in golden eagle eggs carried out as part of the PBMS have been reported by Newton & Galbraith (1991) and were recently summarised as part of the present series of reports (Shore *et al.* 2005). Eggs from five clutches were received in 2001, of which four were from coastal areas (Western Isles). The results of the chemical analyses are given in Table 4.1.

4.2 Results

The DDE and PCB concentrations in the eagle eggs from Rum and Barra were relatively high compared with those in the other eggs that were analysed and also compared with average concentrations in eagle eggs from west coast eyries in previous years (Shore *et al*. 2005). However, the contaminant levels were below concentrations thought to impair reproduction (Blus 1996; Hoffman *et al.* 1996; Peakall 1996) and the eggshell indices were within the range of variation observed in other eagle eggs in recent years.

Table 4.1: Residue levels of organochlorine insecticides, PCBs and shell indices (SI) for golden eagle eggs received in 2001. Organochlorine insecticide and PCB concentrations are expressed as µg/g ww (µg/g lipid weight in parentheses).

Number	Year	Location	SI	pp'-DDE		HEOD		PCB	
Western Isles									
E7902	2001	Rum	4.78	0.706	(12.7)	0.102	(1.83)	6.94	(125)
E7903	2001	Rum	3.45	0.544	(10.7)	0.083	(1.63)	4.97	(98.0)
E7907	2001	Barra	3.06	1.30	(34.6)	ND	(ND)	6.75	(180)
E7940	2001	North Uist	2.63	0.195	(3.64)	ND	(ND)	1.59	(29.6)
Central & Eastern Highlands									
E7931	2001	Highland	3.10	0.053	(1.16)	ND	(ND)	0.032	(0.715)

ND is not detected

5 Organochlorines and mercury in northern gannet *Morus bassanus* eggs

5.1 Introduction

The findings from all gannet eggs examined up to 1988 were published by Newton *et al.* (1990a) and long-term trends in contaminant levels were summarised as part of the series of reports for the PBMS by Shore *et al.* (2005). Gannet eggs are usually included in this study every 1-2 years. No gannet eggs were received in 2001.

6 Organochlorines and mercury in white-tailed eagle *Haliaeetus albicilla* eggs

6.1 Introduction

White-tailed eagles were reintroduced to western Scotland between 1976 and 1985 but have had lower breeding success than individuals in some populations in continental Europe, although productivity has been similar to that of birds in Iceland. The relatively poor breeding success of the Scottish population is due to the number of total nest failures, and a few pairs persistently fail to rear young. One potential cause of breeding failure might be exposure to organochlorines and mercury, which the birds could acquire particularly from the marine component of their diet, various fish and seabirds.

Some of the Scottish white-tailed eagles nest on inaccessible sea cliffs. This makes collection of samples difficult. One failed egg was collected in 2001 and a total of nine eggs has been obtained and analysed during the course of this monitoring scheme.

The lipid pp’-DDE and PCB and HEOD concentrations in this egg were amongst the lowest recorded in any of the white-tailed eagle eggs analysed as part of the Predatory Bird Monitoring Scheme. The concentrations were well below those thought to be associated with adverse effects on shell thickness or productivity (Helander *et al.* 2002; Hoffman *et al.* 1996).

Table 6.1: Residue levels (µg/g lipid weight) and shell index (SI) for white-tailed eagle egg received in 2001

Number	Year	Location	SI	pp’-DDE		HEOD		PCB	
Western Isles									
E7867	2001	Mull	2.45	0.361	(4.74)	ND	(ND)	2.72	(35.7)

ND is not detected

7 Second-generation anticoagulant rodenticides (SGARs) in barn owls *Tyto alba*, common kestrels *Falco tinnunculus*, and red kites *Milvus milvus*

7.1 Introduction

The aim of this work is to monitor the exposure of certain predatory bird species to second-generation anticoagulant rodenticides (SGARs). The compounds of interest are difenacoum, bromadiolone, brodifacoum and flocoumafen and the species monitored are the barn owl *Tyto alba* and common kestrel *Falco tinnunculus*. The carcasses were supplied by members of the public and included birds that had died from various causes, mainly accidents. The PBMS has monitored SGAR residues in barn owls since 1983 and the findings from barn owls analysed in previous years have been reported by Newton *et al.* (1990b, 1999b) and in previous reports in the present series. This is the first year in which the PBMS has routinely monitored kestrels for SGARs. Kestrels have been incorporated into the scheme because a study of birds that died between 1997 and 2000 indicated that a very high proportion of the sample (24/36 individuals = 66%) had detectable concentrations of one or more SGAR in the liver (Shore *et al.* 2001). Red kites that have not been submitted for analysis through Defra's Wildlife Incident Investigation Scheme (Barnett *et al.* 2003) are also analysed for SGARs as part of the PBMS.

The results of the analysis of the livers of 53 barn owls that were sent in to CEH in 2001 are reported in Table 7.1. The analysis of the owls was supported by the annual PBMS funding but included additional support made available for the investigation of the potential exposure of barn owls to SGARs arising from large-scale rodent control operations on farms infected with foot and mouth disease. The findings from the analysis of the data with respect to rodenticide use on infected farms are reported elsewhere (Shore *et al*. in press) and only the overall picture for exposure in barn owls in 2001 is reported here. The results of the analysis of the livers of 23 common kestrels and the one red kite received at CEH in 2001 are given in Table 7.2.

The long-term trends in rodenticide exposure of predatory birds monitored by the PBMS are reviewed every three years and are reported in Section 7.4

7.2 Methods

Analysis of rodenticides in liver tissue was carried out using the technique outlined by Hunter (1985), and described in previous reports and by Newton *et al*. (1990), but using new HPLC and detection equipment (Hewlett-Packard LC-MS Series 1100) first employed to analyse birds collected in 1998 (Newton *et al.* 2000). Quantification was carried out on the basis of peak height. A detailed description of the methods is given in Shore *et al*. (in press). Liver tissue samples from barn owls, kites and kestrels were individually extracted and analysed at the same time but in random order.

7.3 Results of analyses of birds received in 2001

Of the 53 barn owls received in 2001, 22 (41.5%) contained detectable levels of one or more SGAR. This proportion was almost identical to that for owls that died in 2000 (19/45 = 42%) and were analysed at CEH. Overall, the data for the 2001 birds was consistent with the trend reported for earlier years that suggested the increase since 1983 (when monitoring began) in the proportion of birds exposed was levelling off at about 40% (Newton *et al.* 1999b).

Difenacoum, bromadiolone, brodifacoum and flocoumafen occurred in 16 (30.2% of the sample), 15 (28.3%), 3 (5.7 %) and 0 (0%) barn owls, respectively. The predominance of difenacoum and bromadiolone and lack of flocoumafen is consistent with findings in barn owls in previous years. Brodifacoum, like flocoumafen, is restricted to use indoors in Britain but has been detected in barn owls in previous years.

The potentially lethal range for liver residue levels in barn owls has previously been described as >0.1 µg/g ww (Newton *et al.* 1998) and >0.2 µg/g ww (Newton *et al.* 1999b) based on two sets of observations. Firstly, almost all owls diagnosed at post-mortem as having died from rodenticide poisoning (because they had characteristic signs of haemorrhaging from such organs as the heart, lungs, liver, brain and/or subcutaneous areas) were found to have liver residues >0.1 µg/g ww. Secondly, owls that had been experimentally poisoned had liver residues in the range 0.2-1.72 µg/g ww (see Newton *et al*. 1999b for review). Of the barn owls in the 2001 sample, 12 (22.6% of the sample) had liver residues greater than 0.1 µg/g ww (summed values for all four SGARS that were monitored) and seven of these (13.2% of the whole sample) had a liver residue >0.2 µg/g ww. The maximum residue was for difenacoum and was 0.335 µg/g ww. The proportion of birds with residues that were greater than 0.2 µg/g ww was broadly consistent with findings for previous years (see Section 7.4). Post-mortem examination did not reveal signs of haemorrhaging consistent with rodenticide poisoning in any of the birds in the 2001 sample. The causes of death attributed to the 12 birds with SGAR residues of >0.1 µg/g ww were: starvation (5 birds), road traffic accidents (4 birds), predation (1 bird) and accident/collision (2 birds, one of which had been euthanased).

In total, 14 of the 23 common kestrels (60.9%) that were received in 2001 contained detectable concentrations of one or more SGAR. This was the same proportion as detected in 15 birds that died in 1997-98 and a little lower than the proportion (71%) in a sample of 21 birds that died in 1999–2000 (Shore *et al.* 2001).

The difference between the proportions of barn owls and kestrels received in 2001 that contained detectable liver residues of one or more SGAR (41.5% vs 60.9%) did not achieve statistical significance (Fisher's Exact test, P=0.14). As in barn owls, difenacoum and bromadiolone were the SGARs that were detected most frequently in kestrels and they occurred in 11 (47.8% of the sample) and 8 (34.8%) birds, respectively; brodifacoum and flocoumafen were detected in 1 (4.3%) and 0 birds. Four kestrels contained detectable concentrations of difenacoum and bromadiolone, and one other bird contained residues of both these compounds and brodifacoum. The single red kite received and analysed by the PBMS in 2001 also contained liver residues of these three compounds.

A high proportion of the kestrels (7 out of 23; 30.4%) had liver SGAR residues that were greater than >0.2 µg/g ww and some birds had extremely high concentrations of individual compounds, particularly bromadiolone (maximum concentration was 1.51 µg/g ww). When the magnitude of liver SGAR concentrations in barn owls and kestrels with detectable residues (birds with non-detected residues excluded from the analysis) were compared, there was no difference in difenacoum residues between the species (geometric mean concentration of 0.05 µg/g ww in both species) but kestrels had significantly higher liver bromadiolone concentrations than barn owls (geometric means of 0.275 vs 0.062 µg/g ww; student t-test on log transformed data; $t_{(11)} = 3.68$, $P<0.01$).

Although liver SGAR residues in some individual kestrels were high, post-mortem examination did not reveal signs of haemorrhaging consistent with rodenticide poisoning in any individual. This was also found to be the case in kestrels examined previously (Shore *et al.* 2001). Of the seven kestrels and one red kite with residues between 0.2 and 0.8 µg/g ww, two were diagnosed as having starved, three (including the kite) were road traffic victims, two died as a result of collisions and the remaining animal was euthanased at a wildlife hospital after being found with both wings broken. One other kestrel had an extremely high liver residue (summed SGAR concentration of 1.73 µg/g ww) but this too did not have any characteristic signs of haemorrhage and was diagnosed as having starved. It is not known if exposure to SGARs contributed to this bird (and possibly others) dying from starvation, whether exposure to SGARS may predispose birds to other agents of mortality, or whether some birds with high residues would have died from rodenticide poisoning if they not first died from other causes.

Table 7.1: Difenacoum (difen), bromadiolone (brom), flocoumafen (floc) and brodifacoum (brodif) concentrations (µg/g ww) in the livers of 53 male (M) and female (F) barn owls received in 2001. Juveniles are birds in first year, adults are birds older than first year.

Bird no.	Date		Location	age	sex	difen	brom	floc	brodif
13436	Jan	2001	Buckinghamshire	*	M	ND	ND	ND	ND
13440	Jan	2001	Oxfordshire	J	F	0.018	0.159	ND	ND
13442	Jun	2000	Oxfordshire	J	F	ND	ND	ND	ND
13448	Feb	2001	Suffolk	J	M	ND	0.049	ND	ND
13452	Feb	2001	Dorset	A	F	0.335	ND	ND	ND
13455	Feb	2001	Oxfordshire	A	M	ND	ND	ND	ND
13456	Feb	2001	Shropshire	J	F	0.032	ND	ND	ND
13457	Feb	2001	Worcestershire	J	F	ND	ND	ND	ND
13458	Feb	2001	Shropshire	J	M	ND	ND	ND	ND
13463	Feb	2001	Norfolk	J	M	ND	ND	ND	ND
13467	Mar	2001	Lincolnshire	A	M	0.048	0.073	ND	ND
13476	Mar	2001	Lincolnshire	A	M	0.167	0.04	ND	ND
13482	Mar	2001	Norfolk	J	F	0.083	0.132	ND	0.032
13488	Mar	2001	Norfolk	J	M	0.128	0.12	ND	ND
13492	Apr	2001	Lincolnshire	J	M	ND	ND	ND	ND
13494	Mar	2001	Wiltshire	A	F	ND	ND	ND	ND
13495	Mar	2001	Suffolk	J	F	ND	ND	ND	ND
13499	Apr	2001	Lancashire	J	F	ND	ND	ND	ND
13503	Jan	2001	Devon	J	F	ND	ND	ND	ND
13508	May	2001	Somerset	J	M	ND	ND	ND	0.028
13514	May	2001	Lincolnshire	A	M	ND	ND	ND	ND
13520	Mar	2001	Somerset	J	*	ND	ND	ND	ND
13537	Jul	2001	Dorset	J	M	ND	ND	ND	ND
13545	Jul	2001	Lincolnshire	A	M	0.09	ND	ND	0.03
13546	Jun	2001	Anglesey	J	*	ND	ND	ND	ND
13547	Jul	2001	Lincolnshire	J	M	0.017	0.029	ND	ND
13553	Apr	2001	Sussex	A	F	0.114	0.075	ND	ND
13554	Apr	2001	Sussex	A	F	ND	ND	ND	ND

Bird no.	Date		Location	age	sex	difen	brom	floc	brodif
13559	Aug	2001	Lincolnshire	J	M	0.204	ND	ND	ND
13566	Aug	2001	Anglesey	J	F	0.004	ND	ND	ND
13569	Aug	2001	SW Yorkshire	J	*	0.02	0.224	ND	ND
13575	Jul	2001	Cornwall	J	*	ND	0.019	ND	ND
13576	Jul	2001	Cornwall	J	M	ND	0.051	ND	ND
13579	Aug	2001	Cornwall	*	*	ND	ND	ND	ND
13580	Aug	2001	Cornwall	J	M	ND	ND	ND	ND
13581	Sept	2001	Oxfordshire	A	F	ND	ND	ND	ND
13585	Sept	2001	Norfolk	A	M	0.006	0.014	ND	ND
13591	Sept	2001	Anglesey	J	M	ND	0.043	ND	ND
13597	Sept	2001	Lancashire	J	F	ND	ND	ND	ND
13599	Oct	2001	Anglesey	J	M	ND	ND	ND	ND
13615	Oct	2001	Leicestershire	J	F	ND	ND	ND	ND
13617	Oct	2001	Essex	A	F	ND	ND	ND	ND
13626	*	2001	Huntingdonshire	A	F	ND	ND	ND	ND
13627	Aug	2001	Huntingdonshire	*	*	ND	ND	ND	ND
13633	Oct	2001	Huntingdonshire	A	M	ND	ND	ND	ND
13634	Oct	2001	Anglesey	J	F	ND	ND	ND	ND
13635	Oct	2001	Dorset	J	F	ND	ND	ND	ND
13642	Nov	2001	Essex	*	*	0.054	0.095	ND	ND
13645	Nov	2001	Norfolk	*	M	0.27	ND	ND	ND
13648	Sept	2001	Caernarvonshire	J	F	ND	ND	ND	ND
13660	Sept	2001	Cumberland	J	*	ND	ND	ND	ND
13665	Dec	2001	Anglesey	*	F	ND	0.08	ND	ND
13777	Sept	2001	Cornwall	*	*	ND	ND	ND	ND

ND is not detected

Table 7.2: Difenacoum (difen), bromadiolone (brom), flocoumafen (floc) and brodifacoum (brodif) concentrations (µg/g ww) in the livers of 23 male (M) and female (F) common kestrels and one red kite received in 2001. Juveniles are birds in first year, adults are birds older than first year.

Bird no.	Date		Location	age	sex	difen	brom	floc	brodif
Common kestrel *Falco tinnunculus*									
13427	Jan	2001	South Somerset	J	M	0.081	ND	ND	ND
13428	*	*	South Somerset	J	F	ND	0.043	ND	ND
13429	Dec	2001	South Lincolnshire	A	M	0.402	0.418	ND	ND
13430	Jan	2001	East Perthshire	J	M	ND	ND	ND	ND
13438	*	*	North Essex	A	M	ND	0.285	ND	ND
13453	Feb	2001	*	A	M	ND	ND	ND	ND
13466	Mar	2001	Huntingdonshire	J	*	ND	ND	ND	ND
13472	Mar	2001	South Somerset	J	F	0.122	ND	ND	ND
13486	Mar	2001	West Sussex	J	M	ND	ND	ND	ND
13489	Mar	2001	West Norfolk	J	F	0.079	ND	ND	ND
13511	May	2001	East Kent	A	M	0.027	ND	ND	ND
13512	May	2001	South Somerset	A	M	0.041	0.161	ND	ND
13535	Jul	2001	Northamptonshire	J	*	ND	ND	ND	ND
13539	Jul	2001	North-East Yorkshire	J	M	ND	ND	ND	ND
13560	Aug	2001	South Lincolnshire	A	M	0.013	0.251	ND	ND
13572	Aug	2001	North Somerset	*	*	ND	ND	ND	ND
13592	Sept	2001	Surrey	J	F	0.009	ND	ND	ND

Bird no.	Date		Location	age	sex	difen	brom	floc	brodif
13621	Oct	2001	West Kent	J	F	0.142	1.514	ND	0.070
13624	Oct	2001	Huntingdonshire	J	M	ND	ND	ND	ND
13625	Oct	2001	Huntingdonshire	J	M	0.014	ND	ND	ND
13641	*	*	Berkshire	J	F	ND	0.363	ND	ND
13653	Nov	2001	North Hampshire	J	M	ND	ND	ND	ND
13656	Dec	2001	West Norfolk	J	M	0.071	0.288	ND	ND
Red kite *Milvus milvus*									
13538	Jul	2001	Berkshire	A	M	0.052	0.063	0.184	ND

ND is not detected

7.4 Long-term trends in SGAR residue in barn owls *Tyto alba*

The PBMS has monitored liver SGAR concentrations in barn owls since 1983. In total, data are available for some 993 owls that are known to have died between 1983 and 2001. Difenacoum and bromadiolone, the two SGARS licensed for outdoor and indoor use in Britain, have been found most frequently in the livers of the owls and have been detected in 189 (19% of the sample) and 114 (11.5%) birds, respectively. Residues of brodifacoum and flocoumafen, the two SGARs restricted to indoor use only in Britain, have been detected in 64 (6.4%) and 10 (1.0%) of birds, respectively. Overall, one or more SGAR has been detected in 295 owls (29.7%) during the monitoring period. The predominance of difenacoum and bromadiolone as the SGARs that are detected most frequently in owls reflects their greater usage in arable systems compared with brodifacoum and flocoumafen (Dawson *et al.* 2003; Garthwaite *et al.* 1999) and is consistent with the patterns of exposure detected in mammalian predators in the UK (McDonald *et al.* 1998; Shore *et al.* 2003a; Shore *et al.* 2003b).

The frequency with which SGARs have been detected in barn owl livers has changed during the monitoring period. This is thought to indicate a general increase in the proportion of the population that is exposed but may also in part be the result of changes in detection efficiency associated with upgrading of analytical equipment. The HPLC equipment and associated detectors used for determining liver rodenticide concentrations were upgraded in 1990 and 1998 at CEH, although the actual method of analysis for rodenticides was not changed. Repeated analysis of 19 livers with the analytical equipment that was used during the period 1990-97 and post-1997 suggested that the detection rate for difenacoum may have increased with the introduction of the new equipment (Newton *et al.* 2000). Statistical examination of the rodenticide data for the whole of the period during which monitoring has been carried out suggested that there may have been a similar improvement in the detection limit for difenacoum when the analytical equipment was upgraded in 1990. Typical lowest detected values for difenacoum in birds analysed in the period 1983-89 were in the range 0.012–0.016 whereas they were 0.002–0.005 µg/g wet weight in later years. Therefore, to prevent variation in detection limit causing significant bias, a detection limit for difenacoum of 0.012 µg/g wet weight was applied to the data for the whole monitoring period when changes in exposure over time were examined; concentrations below this value were scored as non-detected. The frequency with which bromadiolone was detected in birds may also have been influenced by the upgrading of analytical equipment in 1990. Only one of the 201 birds analysed between 1983 and 1989 using the detection system in place at that time had a detectable liver concentration of bromadiolone, whereas four out of 29 birds that died over the same time period, but which were analysed later using newer analytical equipment, had detectable residues; the difference in these proportions is statistically significant (Fisher's Exact Test, $P<0.001$). Thus, the occurrence of bromadiolone in owls between 1983 and 1989 may have been under-estimated, although bromadiolone was not detected in any owls that died between 1983 and 1987, irrespective of the detection system by which the analyses were carried out.

Over the whole time period during which monitoring of liver SGAR residues in barn owls has been carried out, the proportion of owls with detectable concentrations of one or more SGAR has increased from approximately 5% in 1983 to currently about 40% (Figure 7.1), although the overall detection rate in the 1980s may have been somewhat underestimated due to under-reporting of bromadiolone. The overall increase over time in the detection of SGARs in owls has been due to the rise in exposure to difenacoum and bromadiolone (Figure 7.2). Bromadiolone and flocoumafen have been detected in owls during the course of the monitoring period but there is no evidence of any significant progressive change in the extent of exposure over time (Figure 7.2).

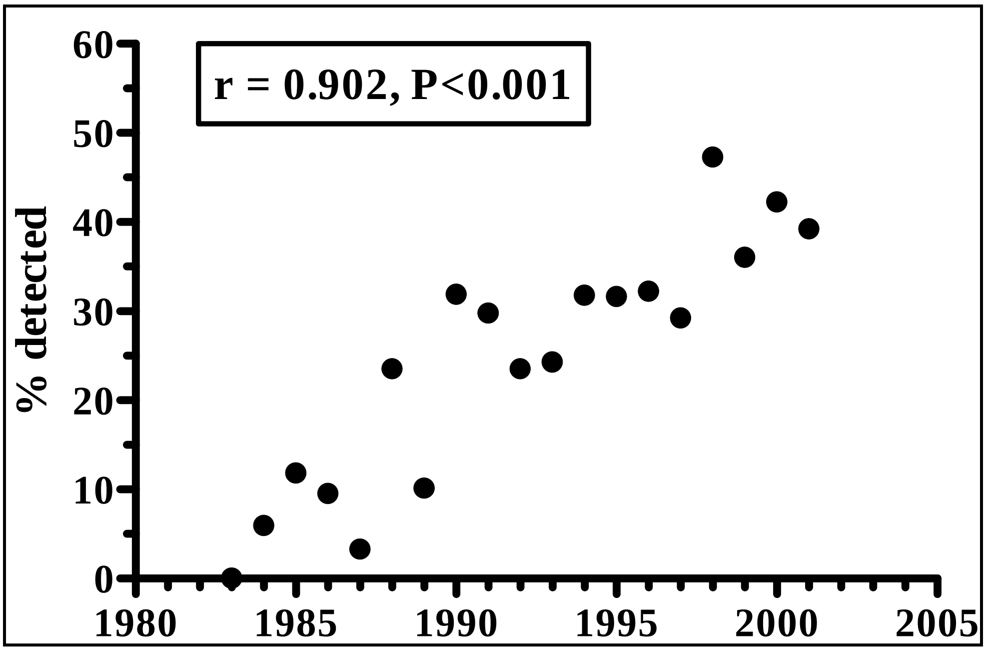

Figure 7.1: Percentage of barn owls in each year with detectable concentrations of one or more second-generation anticoagulant rodenticide (SGAR). The four compounds that are determined are difenacoum, bromadiolone, brodifacoum and flocoumafen. The mean (±SE) number of birds in the sample per year over the 19 years of monitoring is 52.3 ± 5.0.

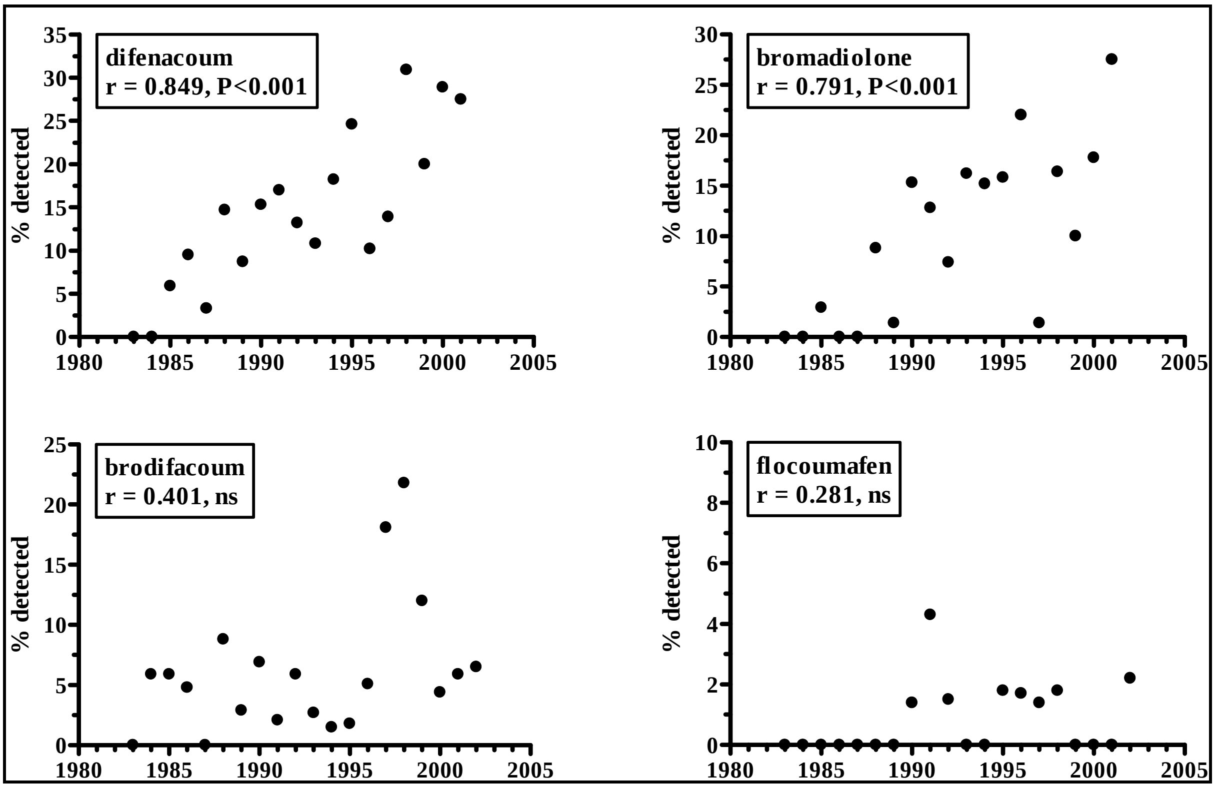

Figure 7.2: Percentage of barn owls in each year with detectable concentrations of difenacoum, bromadiolone, brodifacoum and flocoumafen. Detection limit for difenacoum was set at 0.012 µg/g wet weight for the whole monitoring period.

The concentrations of SGAR residues detected in barn owls range mostly over two orders of magnitude (Figure 7.3). The proportion of all birds analysed that had residues that were in the potentially lethal range of greater >0.1 or >0.2 µg/g wet weight was 10.6% and 4.7% respectively. However, only 12 birds (1.2% of the total examined to date) were diagnosed, on the basis of post-mortem examination and chemical determination of residues, as having died directly as a result of haemorrhaging associated with exposure to SGARs. This figure is not necessarily representative of the true mortality levels associated with exposure to SGARs in barn owls. Direct mortality may be underestimated as poisoned birds may die out of sight (and so not be submitted to the PBMS), and sub-lethal exposure may indirectly increase mortality either by impairing recovery from what would normally be non-fatal collisions and accidents, or by altering behaviour such that hunting ability is impaired and susceptibility to starvation increased. These possibilities are conjectural, however, and there is no evidence as yet that this occurs.

Assessment of the changes in barn owl numbers over time is problematic because the varying surveys that have been carried out are not strictly comparable in either methodology or the areas they have covered (Toms *et al.* 2001). However, comparison of the results from the various surveys (Table 7.3) suggests that barn owl numbers in Britain declined in the 20th century, but that this decline probably occurred before the 1980s. The use of difenacoum and bromadiolone in Britain began in 1975 and 1980 respectively (Newton *et al.* 1999b) and so substantial use of these compounds occurred after the decline in the barn owl population. Thus, there is no evidence to link SGAR exposure of barn owls during the 1980s and 1990s to declines in populations.

Changes in exposure pattern, particularly in terms of the magnitude of exposure of individuals, could potentially cause an increase in the numbers of owls that are killed by rodenticides. Concerns about whether the occurrence and spread of rodenticide resistance in rodents may increase the exposure of polecats *Mustela putorius* to SGARs has been expressed elsewhere (Shore *et al.* 2003a), and the same concerns apply to barn owls and other predators of small mammals. There is no evidence to date, however, of any national scale increase in difenacoum or bromadiolone liver concentrations in those barn owls that were analysed and contained detectable concentrations. Weighted regression analysis (using the number of birds with detectable residues in each year as the weighting factor) of the median difenacoum liver concentration against year did not reveal any significant trend over time ($F_{1,15}$ = 1.25, P>0.05). There was likewise no significant change in median liver bromadiolone concentrations over time (post-1990) in barn owls ($F_{1,15}$ = 1.03, P>0.05).

In summary, therefore, there is evidence of widespread exposure of barn owls and common kestrels in Britain to SGARs, predominantly difenacoum and bromadiolone. In barn owls, the proportion of birds exposed to both difenacoum and bromadiolone has increased over time and currently, approximately 40% of barn owls are exposed to one or more SGAR. Between 5% and 10% of barn owls that have been examined have liver SGAR concentrations in the "potentially lethal range" but approximately only 1% of the birds examined were diagnosed as having been directly poisoned by SGARs. There is no evidence to date of the magnitude of liver residues of difenacoum and bromadiolone increasing over time and there is no evidence that the exposure of barn owls to SGARs is currently causing any population decline.

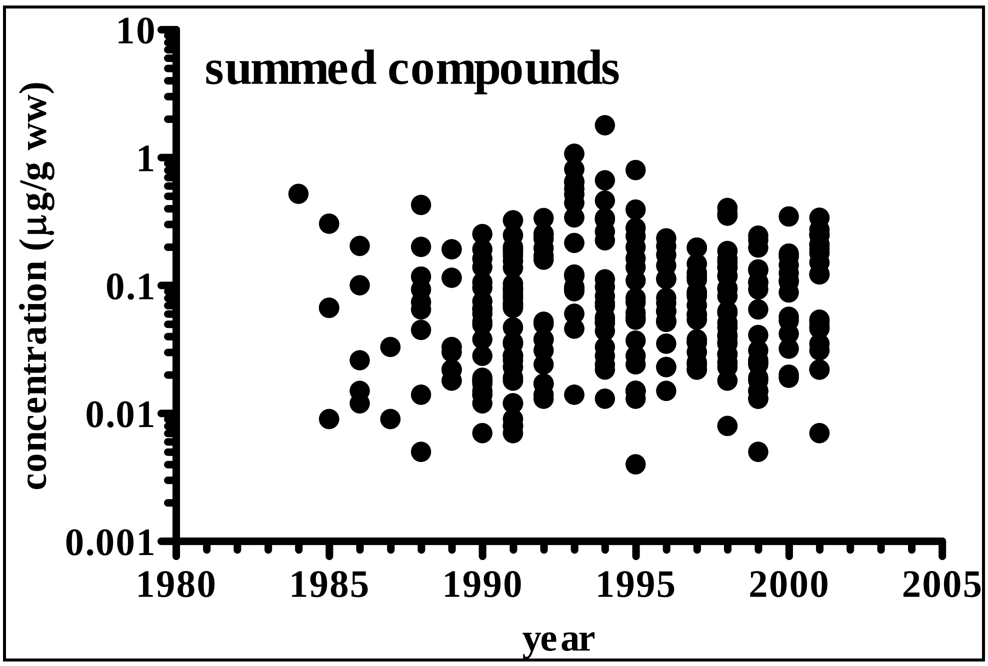

Figure 7.3: Summed detected concentration (concentrations for multiple SGARs found in the same bird were added together) for SGARs in the livers of barn owls plotted against year in which the dead bird was found. Non-detected concentrations are not shown.

Table 7.3: Population estimates for barn owls in the British Isles (Toms *et al.* 2001)

Year	Breeding pairs	Region
1930s	12,000	England and Wales
1968–1972	4500–9000	Britain and Ireland
1982–1985	3778	England and Wales
	4457	Britain (incl. Channel Islands)
1995–1997	4000	UK

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9 Appendix

Abbreviations used in the text:

b	linear regression coefficient
CEH	Centre for Ecology & Hydrology
pp’-DDE	*para para*-dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
g-HCH	gamma-hexachlorocyclohexane
GSE	Geometric Standard Error
HEOD	hexachloro-epoxy-octahydro-dimethanonaphthalene
Hg	mercury
JNCC	Joint Nature Conservation Committee
N	number of samples analysed
ND	not detected
ns	not significant
PCB	polychlorinated biphenyl
PBMS	Predatory Bird Monitoring Scheme
SGARs	second generation anticoagulant rodenticides
SI	shell index
ww	wet weight