British Trust for Ornithology

BTO Research Report No. 106

BARN OWL PRODUCTIVITY AND SURVIVAL IN RELATION TO THE USE OF SECOND-GENERATION RODENTICIDES IN 1988 - 1990

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October 1993

I.G. Henderson, M.N. McCulloch and H.Q.P. Crick, 1993.
Barn Owl productivity and survival in relation to the
use of second-generation rodenticides in 1988-1990.
BTO Research Report No. 106.
Thetford (BTO).

Published in August 1993 by the BTO, National Centre for Ornithology,
The Nunnery, Thetford, Norfolk, UK

ISBN 0-903793-30-X

CONTENTS

1. EXECUTIVE SUMMARY

1. An examination was made of temporal and regional variation in Barn Owl first-year productivity and survival rates in relation to second-generation rodenticide usage across England and Wales. The analyses compared BTO nest records and ringing data to Ministry of Agriculture, Fisheries and Food (MAFF) rodenticide data for the years 1988, 1989 and 1990.

2. No statistical relationships between total second-generation rodenticide usage and Barn Owl survival or breeding success were detected. Likewise, no relationships were found with difenacoum, one of the second-generation rodenticides used most frequently and detected in Barn Owl carcasses. All analyses suffered from small sample sizes and low statistical power. The analyses were not powerful enough to determine whether or not second-generation rodenticides might have been implicated in the decline of first year Barn Owl survival or associated with changes in aspects of breeding performance.

3. Recommendations for further study are discussed and include:

   a. To instigate a baseline survey of Barn Owl population densities throughout the UK.

   b. To encourage the formation of local Barn Owl study groups that will undertake the long-term monitoring of site-occupancy, productivity and survival of Barn Owls in their study areas.

   c. MAFF should be encouraged to continue long-term monitoring of rodenticide use in Britain, particularly on arable land.

   d. Monitoring of rodenticide residues in Barn Owl carcasses by the ITE should continue.

2. INTRODUCTION

Since the 1930s the Barn Owl (*Tyto alba*) population in Britain is estimated to have declined by as much as 65% and is currently thought to comprise around 4,500 pairs (Shawyer 1987). Several factors have been identified as being likely causes of this decline, most notably loss of feeding habitat, loss of nest sites, possible climatic changes and pesticide use (Percival 1991). Of the latter, organochlorines are the single most important group of compounds to have affected raptor populations in the past. The insecticide DDT was shown to limit breeding success in several birds of prey (Ratcliffe 1970, Newton 1979), whilst cyclodiene products, such as dieldrin and aldrin, have proved to be toxic to both adults and embryos particularly in bird-eating predators (Newton 1979). In Barn Owls too there is evidence that dieldrin was responsible for reducing adult survival rates (Newton *et al.* 1991) and, encouragingly, since the mid 1970s, reduced use of dieldrin has coincided with a recovery in Barn Owl survival and productivity in most of England and Wales (Percival 1990, 1992).

This apparent improvement in the general outlook for owls has coincided with the possible emergence of a problem posed by the use of rodenticides, which are targeted directly at some potential prey species of the predators of small mammals. Resistance by pest species to "first-generation" anticoagulant rodenticides, such as warfarin, has led to the development of more potent "second-generation" anticoagulant rodenticides as a means to control both farm Brown Rat (*Rattus norvegicus*) and House Mouse (*Mus mus*) populations (Newton & Wyllie 1992). Second-generation anticoagulant rodenticides are more persistent in rodent prey than first-generation rodenticides and remain in an animal's body for several days (Newton *et al.* 1990). These conditions increase the chance of contamination of owls, although such contamination is limited:

(a) by recommendations that restrict the use of some rodenticide products to within or near the vicinity of buildings (Ministry of Agriculture, Fisheries and Food (MAFF) Pesticide Safety Division, P. Davis *pers. comm.*), and

(b) because Field Voles (*Microtus agrestis*) rather than rats and mice, form the staple diet of British Barn Owls (Cramp & Simmons 1985).

Nevertheless, Glue (1974) points out that, on arable farmland, rats can be a nutritionally important component of the diet of Barn Owls and owls which nest or roost in buildings may also find food there, particularly during periods of bad weather and food shortage (Cayford 1992). In addition, some rodenticides of lower potency can also be used legally away from buildings (Olney *et al.* 1989, Newton *et al.* 1990) where the chemicals are possibly more likely to enter the Barn Owl's food chain.

Sales of second-generation rodenticides have increased steadily since the late 1970s, yet Percival (1990) found no negative association with either of several breeding variables (eg clutch size, hatching success, fledging success) and rodenticide sales for either Barn Owls or Tawny owls, although the rodenticide data were inadequate to investigate this. Likewise, first-year survival rates did not change greatly from 1976-87 in most regions except the south and east of England (covering counties to the east of a line approximately from West Sussex to North Yorkshire and including Hampshire, Wiltshire and Berkshire), where an unexplained apparent long-term decline occurred (Percival 1990). Although the south and east of England is intensively farmed, loss of feeding habitat, competition with released Barn Owls and higher survival rates amongst adult owls (and hence increased competition for prime feeding sites) could all have contributed to reduced first-year survival rates (Percival 1991). The possibility that rodenticides may contribute to lower survival rates in Barn Owls was raised by a recent analysis conducted by the Institute of Terrestrial Ecology where residues of second-generation rodenticides were discovered in the livers of 10% of 145 Barn Owl corpses sent to them, by members of the public, from across Britain between 1983 and 1989 (Newton *et al.* 1990). Only three individual owls were contaminated by potentially lethal doses of rodenticide. The sub-lethal effects of rodenticides are poorly understood. These findings have stimulated the further investigation of the potential hazard posed by second-generation rodenticides.

The present study was recommended by Percival's (1990) report because no regional rodenticide data were available to allow his examination of their possible effects on owl breeding performance and survival. Furthermore, there was no explanation for the low first year survival in south and east England. Thus, we used BTO databases to compare regional and temporal differences in first-year Barn Owl survival rates (from ringing recoveries), and productivity (from BTO Nest Record Cards) with regional, temporal and spatial use of rodenticides within Britain (Olney *et al.* 1988 and 1989, Olney & Garthwaite 1990). We discuss:

(a) the quality of available data;
(b) conclusions, and reservations, drawn from the analysis;
(c) future areas of research.

3. METHODS

3.1 Rodenticide data

Two sources of rodenticide data were to be used in this project:

(a) sales data, supplied by agrochemical companies and converted to indices by MAFF;
(b) usage data, based on surveys undertaken by the Pesticide Usage Survey Group, MAFF.

Unfortunately the former were considered unsuitable for analysis because:

(a) the sales areas were different between companies;
(b) rodenticides need not be used within the sales areas in which they were sold; and
(c) differing formulations and concentrations of active ingredients made meaningful indices difficult to calculate.

Rodenticide usage data was collected by MAFF in the years 1988, 1989 and 1990 (Olney *et al.* 1988, 1989; Olney & Garthwaite 1990). The three years were not directly comparable since the 1989 report refers to information gathered from grassland and fodder farms across England and Wales. The 1988 and 1990 reports, however, refer to surveys of arable farms across England only. The surveys comprised personal interviews with farm personnel or contractors on a stratified sample of farms in each agricultural region (Table 3.1). These sampled data were adjusted according to the crop size of each farm and their frequency of occurrence within each region, so that the data presented give an estimate of the total rodenticide usage in each region (active ingredient, kg ai). The total number of farms surveyed was 565, 459 and 706 for 1988, 1989 and 1990 respectively.

In Newton *et al.*'s (1990) analysis, two specific rodenticide products, brodifacoum and difenacoum, were identified in Barn Owl corpses. In the present analysis, brodifacoum was used in only small quantities across the country (Table 3.2) and is registered for professional application only (Olney *et al.* 1988, 1989). Difenacoum, on the other hand, was widely used and was investigated here in more detail. Thus, within each year we compared regional variation in:

(a) total second-generation rodenticide usage (kg ai) which included brodifacoum, bromadiolone, chlorophacinone, coumatetralyl, difenacoum and flocoumafen; and
(b) difenacoum usage (kg ai),

with aspects of Barn Owl breeding productivity and survival.

We also investigated a measure of the total second-generation rodenticide usage rate per area of land (kg ai/km^2), where area = total land area of each region. Rodenticide usage data was the sum of usage inside, around and away from farm buildings; this gross figure was analysed because Barn Owls are known to feed within and around farm buildings in addition to foraging away from them (Shawyer 1987, Newton & Wyllie 1992).

Table 3.1 The constituent counties for each of the six agricultural regions (in bold) identified by MAFF across England and Wales (Olney *et al.* 1988 & 1989, Olney & Garthwaite 1990).

North	**Midland & West**	**East**
Cleveland	Cheshire	Bedfordshire
Cumbria	Derbyshire	Cambridgeshire
Durham	Manchester	Essex
Humberside	Hereford & Worcester	Hertfordshire
Northumberland	Lancashire	Lincolnshire
North Yorkshire	Leicestershire	Norfolk
South Yorkshire	Merseyside	Suffolk
Tyne & Wear	Nottinghamshire	Northamptonshire
West Yorkshire	Shropshire	
	Staffordshire	
	Warwickshire	
	West Midlands	
South-east	**South-west**	**Wales**
Berkshire	Avon	Clwyd
Buckinghamshire	Cornwall	Dyfed
East Sussex	Devon	Gwent
West Sussex	Dorset	Gwynedd
Greater London	Gloucestershire	Mid Glamorgan
Hampshire	Somerset	South Glamorgan
Kent	Wiltshire	West Glamorgan
Oxfordshire		Powys
Surrey		

3.2 Barn Owl data

Measures of clutch size, brood size, fledging success and an estimate of first-year survival, were calculated for Barn Owls in each agricultural region. Regional mean values for clutch size and maximum number of young hatched per nest (a measure of hatching success) were calculated directly from the BTO nest records database for each year. Nest Record Cards are completed by volunteer contributors, who record details of location, date of inspection and contents at each visit to a nest. Clutch size records were discarded if a nest had been visited only once, if laying could still have been in progress on the last recorded visit, or if observations began after the eggs had hatched. The maximum brood size in a nest may be a slight under-estimate of the true post-hatching brood size, if small young died and were removed by parents before the nest was visited.

Because fledging success is difficult to record empirically, particularly for species where nestling age is not synchronised, fledging success was estimated using the method of Mayfield (1961 & 1975, Johnson 1979) which calculates daily rates of whole nest losses. The technique assumes constant rates of nest loss throughout incubation and nestling periods.

Analyses were carried out using data for individual years, but the number of regional data points were often too low to have adequate statistical power. Further analyses combined data from 1988 and 1990 because the rodenticide usage data came from similar types of arable farms. However, it should be noted that these analyses are relatively weak because the two values from each region are not statistically independent.

First-year survival of Barn Owls was estimated for the period 1988-89 from recoveries of birds ringed as nestlings using the program SURVIV (White 1983). Reporting rates were assumed to be constant in both years. Goodness-of-fit tests indicated that these models provided an adequate description of the data from each region. Estimates of survival were only calculated for 1988-89 because subsequent data were not available. Other statistical analyses were performed using the SAS package (SAS Institute Inc. 1985).

Table 3.2 Total second-generation rodenticide usage (kg active ingredient) in England in 1988 and 1990, and in England and Wales in 1989 (Olney *et al.* 1988 & 1989, Olney & Garthwaite 1990).

	1988	1989	1990
Brodifacoum	0.13	0.07	0.19
Bromodiolone	11.32	6.32	9.31
Chlorophacinone	22.92	5.04	17.91
Coumaetralyl	48.53	11.62	47.57
Difenacoum	35.03	5.75	18.44
Flocoumafen	0.03	0.00	0.03
Total	117.96	28.80	93.45

4. RESULTS

There were sufficient data to allow the calculation of mean clutch size for four regions only, brood sizes for all regions and Mayfield estimates of fledging success for only three regions (Table 4.1).

4.1 Clutch size and nest loss rates

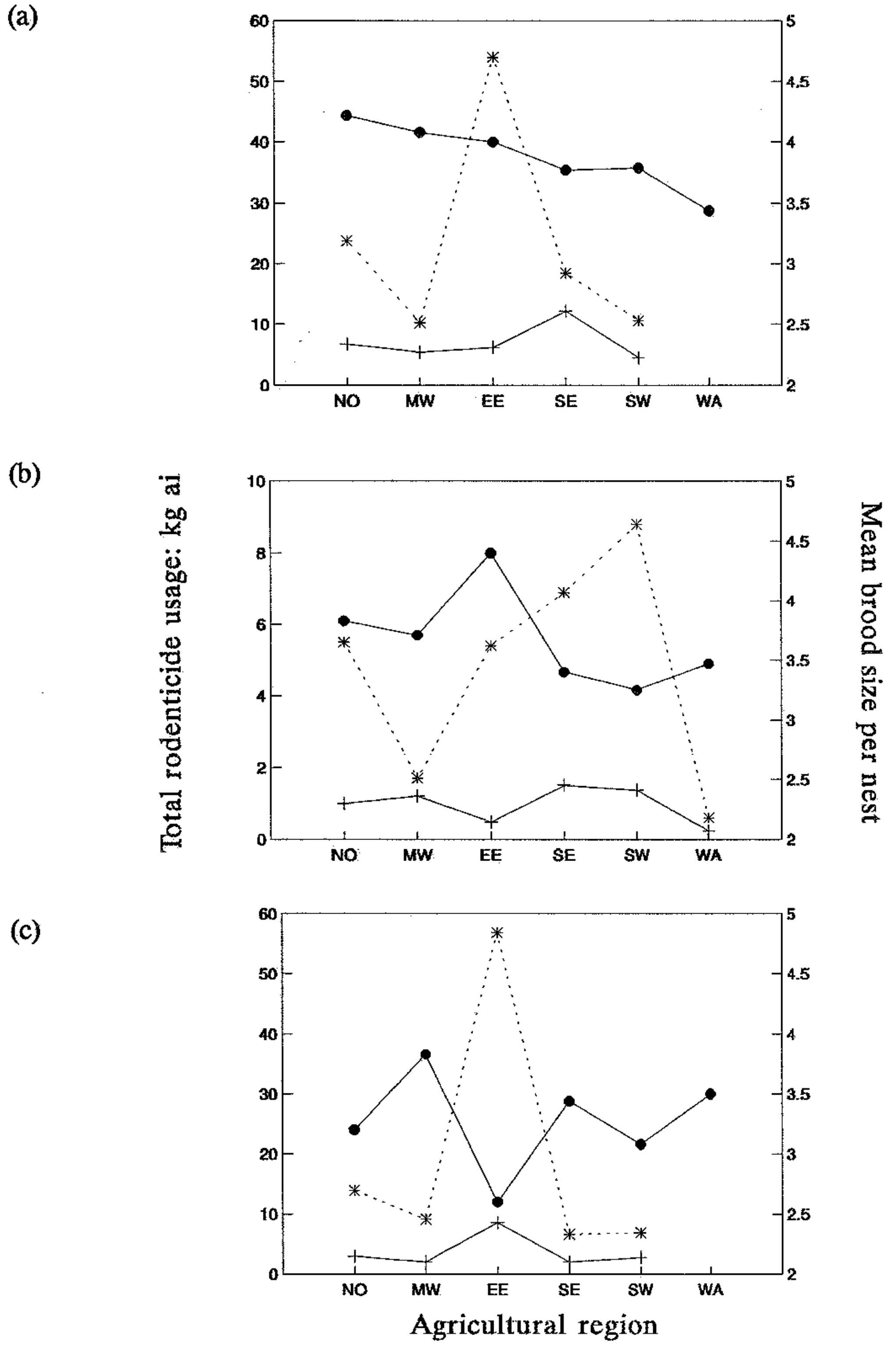
There were no correlations between regional variation in either total second-generation usage or difenacoum usage and either clutch size or nest loss rates. The number of regions available for comparison were less than five in each year and even when 1988 and 1990 were combined, the results were still not significant ($P > 0.1$).

Table 4.1 Regional and temporal variation in Barn Owl survival and productivity across England and Wales (large standard errors are associated with each value and are omitted here for the sake of clarity).

	Year	North	Mid/ West	East	South-east	South-west	Wales	Total n
Total area (km^2)		31087	27689	27397	20301	23834	20765	
Clutch size (Mean eggs per nest)	1988	6.0		6.0	5.0	5.9	5.4	18
	1989			5.5	5.0	5.5	6.0	10
	1990	3.0		6.5	6.5	4.8	5.0	13
Brood sizes	1988	4.2	4.1	4.0	3.8	3.8	3.4	101
	1989	3.8	3.7	4.4	3.4	3.2	3.5	87
	1990	3.2	3.8	2.6	3.4	3.1	3.5	58
Whole nest losses per day	1988	0.0101			0.0022	0.0032		62
	1989	0.0027	0.0036		0.0101	0.0007		51
	1990			0.0047	0.0058	0.0135		55
First-year survival* (per annum)	1988-89	0.60			0.89	0.71		
Second-generation rodenticide usage per region (kg ai)	1988	23.8	10.2	54.9	18.5	10.6		
	1989	5.5	1.7	5.4	6.9	8.8	0.5	
	1990	13.9	9.2	56.9	6.6	6.9		
Second-generation rodenticide usage per regional area (kg ai/km^{2}x10^{-4})	1988	7.7	3.7	20.0	9.1	4.4		
	1989	1.8	0.6	2.0	3.4	3.7	0.2	
	1990	4.5	3.3	20.8	3.3	2.9		
Difenacoum usage per region (kg ai)	1988	6.7	5.4	6.2	12.2	4.5		
	1989	1.0	1.2	0.5	1.5	1.4	0.2	
	1990	3.0	2.0	8.6	2.1	2.8		

Footnote: * Total number ringed = 204; 5% were recovered dead.

Figure 4.1 **Regional Barn Owl productivity and total second-generation rodenticide usage in England and Wales on (a) arable farms in 1988, (b) grassland and fodder farms in 1989, and (c) arable farms in 1990.**



Symbol key: ✳ Total kg ai
+ Difenacoum kg ai
● Mean hatch success

Region:

NO	North	MW	Midlands & West
EE	East	SE	Southeast
SW	Southwest	WA	Wales

4.2 Brood size

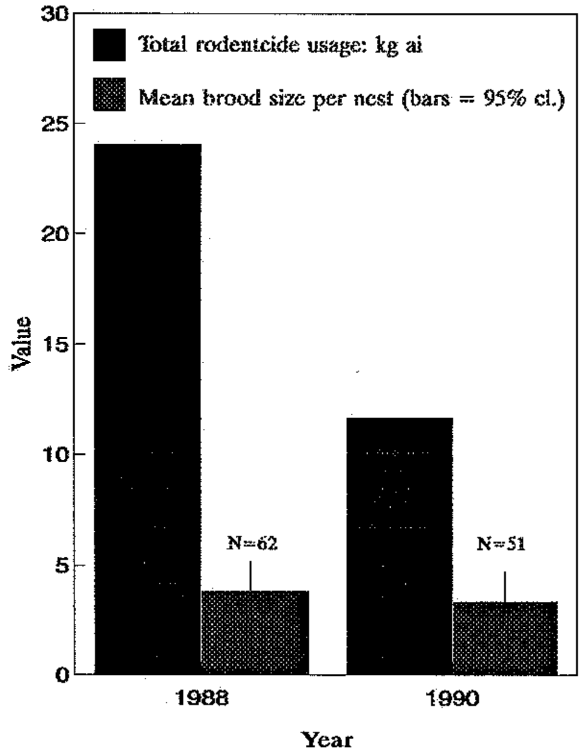
There was no significant relationship between total second-generation rodenticide usage and brood size in individual years (Figure 4.1) or even when data from 1988 and 1990 were combined (Spearman rank: $r_s = 0.14$, $P = 0.67$, $n = 10$). Similarly there was no relationship with usage adjusted to account for the total regional land area (kg ai/km^2) ($r_s = 0.11$, $P=0.75$, $n = 10$).

Difenacoum formed 20-30% of the total usage of second-generation rodenticides on farms over the three years (Table 4.2). There were non-significant negative associations between regional difenacoum usage and brood size of Barn Owls for two of the three years when analysed independently (Spearman rank correlations: 1988: $r_s = 0.10$, $P<0.84$, $n = 5$; 1989: $r_s = -0.6$, $P = 0.18$, $n = 6$; 1990: $r_s = -0.9$, $P = 0.07$, $n = 5$). But when 1988 and 1990 were combined the overall relationship was positive because both difenacoum usage and brood size were high in 1988 but low in 1990 ($r_s = 0.23$, $P = 0.50$, $n = 10$).

Table 4.2 The percentage use of total second-generation rodenticides (%kg active ingredient, see Table 3.2) on farms in England in 1988 and 1990, and Wales in 1989 (Olney *et al.* 1988 & 1989, Olney & Garthwaite 1990).

	1988	1989	1990
Brodifacoum	0.11	0.24	0.20
Bromodiolone	9.60	21.94	9.96
Chlorophacinone	19.43	17.50	19.17
Coumaetralyl	41.14	40.34	50.90
Difenacoum	29.70	19.97	19.73
Flocoumafen	0.03	0.00	0.03

Figure 4.2 Total annual second-generation rodenticide usage away from buildings on arable land, and Barn Owl brood size in England in 1988 and 1990.



4.3 First-year survival

Survival estimates of birds in their first year of life were only calculable for 1988 and for three regions (Table 4.1). In all cases, sample sizes were small because only 5% of Barn Owls ringed were recovered dead, and standard errors were large and no consistent patterns of trend with rodenticide usage were apparent.

4.4 Spatial use of rodenticides on farms

Twenty percent (1988), 14% (1989) and 12% (1990) of total annual second-generation rodenticide usage was away from buildings, farm yards and silage clamps, that is, in drainage ditches, headlands and hedgerows. There were large differences between 1988 and 1990 in the quantity of rodenticide used away from buildings (controlling for the number of farms sampled in each year) but the difference was not matched by corresponding changes in Barn Owl productivity (Figure 4.2).

5. DISCUSSION AND RECOMMENDATIONS FOR FURTHER WORK

5.1 Present study

The analyses reported above were severely limited by small sample sizes and large variances within the datasets. The low statistical power meant that no conclusions could be drawn from the data. Thus, although there was no evidence for or against an effect of second-generation rodenticide use on either Barn Owl productivity or first year survival, such an effect would have had to have been very large to be detected.

Of the breeding variables measured, brood size provided the most complete dataset, but it formed no significant relationships with either total second-generation rodenticide usage or difenacoum usage alone, even when data for 1988 and 1990 were combined.

The estimated first-year survival rates for the south-east were higher than those calculated by Percival (1990) but these data were not directly comparable since Percival included both the south and east in one region. However, it is unclear why first-year survival rates in this study were higher than those reported by Percival, although the precision of the estimates for 1988-89 was so low, due to unexpectedly small samples, that these estimates were not significantly different from Percival's. Ringing recoveries for 1988 from eastern England were too few to enable us to calculate first-year survival rates for that region alone and only longer-term, regional data would have helped us interpret the survival rates more fully.

5.2 Previous studies

Percival (1990) analysed breeding success between 1944 and 1988, and found long-term increases in the average brood size of Barn Owls, and in the number of chicks fledged in recent years in the north of England and Scotland and to some extent in the south and east of England too. These changes were consistent with a possible effect of organochlorine pesticides in the 1950s and 1960s (Percival 1990, Newton *et al.* 1991) and their subsequent decline in usage. Clutch size, by comparison, did not show such trends, although Percival (1990) found that periods of snow, rain and low temperatures coincided with reduced clutch sizes in Barn Owls. Hatching success in birds of prey has been affected by organochlorine pesticides through effects on parental condition prior to or during incubation (eg Hirons 1976; Newton 1979). The recent improvements in Barn Owl productivity suggest that rodenticides have not affected the condition of parents or young during the breeding cycle. This is consistent with our understanding of anticoagulant toxicology which is very different from that of the organochlorine insecticides. The persistence of anticoagulant residues at relatively low levels in Barn Owls is a concern which requires further monitoring until we have a more complete understanding of the risks involved.

Improvements in average brood size and fledging success of Barn Owls in Scotland, north England and in south and east England correspond to increases in adult survival rates in recent years (Percival 1990). In the south and east regions, however, first-year survival rates have apparently decreased progressively since 1977. The first-year survival rate in 1988/89 appears now to be relatively high in the south-east, although this result must be treated with caution because of poor precision. Over the same time period, the use of organochlorine pesticides on farmland has declined nationally (O'Connor & Shrubb 1986), whilst second-generation rodenticide use has increased (Percival 1990) and rodenticide usage is high in east and moderately high in south-east regions of England (Table 4.1). Unfortunately, information on the regional use of second-generation rodenticides prior to 1988 is not available, thus preventing regional comparison of trends between rodenticide usage and first-year Barn Owl survival rates. However, several other factors could be involved, including: changes in climate, loss of roost or nest sites, changes in agricultural practices and possibly the release of captive-bred Barn Owls (Percival 1991, Cayford & Percival 1992). Whether high first-year mortality influences population size in Barn Owls will also depend on the recruitment of immatures into the breeding population and the survival rate of adults. However, the key-factor analysis of Percival (1990) showed that post-fledging survival is the most important determinant of changes in national population level. The importance of regional differences in first-year survival should therefore be investigated by key-factor analysis at the regional level.

5.3 Recommendations for future study

In general, the monitoring of Barn Owl populations is hampered by the lack of a replicable baseline survey of population density in the UK. This information is essential to determine the relationships between habitat and Barn Owl demography and to assess the long-term effects on the UK population of changes in rodenticide use in relation to other environmental factors. Periodic national surveys need to be paralleled with long-term studies of site-occupancy rates, productivity and survival on study plots by teams of experienced Barn Owl observers. Such Barn Owl study groups would provide the long-term, in-depth data required to monitor the effects of changes in rodenticide usage in the UK. The results of such surveys could be extrapolated for the whole country by reference to the full national survey. The present analysis suffered from the presence of only three years of information on rodenticide usage. Further biennial rodenticide usage surveys by MAFF and continued carcass analysis by ITE are necessary to monitor any possible impacts of rodenticide on Barn Owls in the future.

Nest record data often contain too few visits or too great a gap between visits to allow Mayfield estimates to be calculated over small sections of the nesting period. More complete nest observations of Barn Owls using Percival's (1990) methodology should be encouraged to provide more precise data, accompanied by good ageing of nest contents using egg mass change curves and nestling growth curves. Exact values for fledging success, however, would require observations of nest activities around the predicted time of fledging in order to confirm the fate of the nestlings. However, nests checked late in the nestling stage may provide a good approximation to fledging success (Percival 1990). Ideally, more visits to nests are required to provide "mortality" estimates for the first and second halves of the egg and nestling phases respectively. Nest recorders should therefore be encouraged to collect information at pre-determined points through the nesting cycle. Again a particularly useful development to further this aim would be the organisation of an extensive network of Barn Owl study groups, which would provide detailed information from intensive study areas on an annual basis, and which could be linked together by information provided in a regular newsletter.

ACKNOWLEDGEMENTS

This project was sponsored jointly by Ciba-Geigy, ICI, Shell and Sorex, using databases collected at the BTO. The data on which this report is based have been collected by the many contributors to the BTO's Nest Record and Ringing Schemes, whose efforts make the analysis possible. The Nest Record and Ringing Schemes form part of the BTO's Integrated Population Monitoring Programme carried out under a contract from the Joint Nature Conservation Committee, on behalf of English Nature, Scottish Natural Heritage and the Countryside Council for Wales, and also under contract from the Department of Environment for Norther Ireland. The BTO is also grateful to MAFF/ADAS for supplying the rodenticide data and we thank Mr P Edwards, Dr A J Hardy, Dr R Davis and Dr M R Thomas for advice. We would also like to thank Dr W J Peach for help with the survival rate analyses, Dr R Langston for comments on the manuscript and Mrs S Waghorn for typing and formatting the report.

REFERENCES

Cayford, J. 1992. Barn Owl ecology on East Anglian farmland. *RSPB Conserv. Rev.* 6: 45-50.

Cayford, J. & Percival, S. 1992. Born captive, die free. *New Scientist* 8: 29-33

Cramp, S. & Simmons, K.E.L. (eds.) 1985. *The Birds of the Western Palaearctic.* Vol. IV. Oxford University Press, Oxford.

Glue, D.E. 1974. Food of the Barn Owl in Britain and Ireland. *Bird Study* 21: 200-210.

Hirons. G. 1976. *A population study of the Tawny Owl and its main prey species in woodland.* D. Phil thesis, Oxford University.

Johnson, D.H. 1979. Estimating nest success: the Mayfield method and an alternative. *Auk* 96: 651-661.

Mayfield, H.F. 1961. Nesting success calculated from exposure. *Wil. Bull.* 73: 255-261.

Mayfield, H.F. 1975. Suggestions for calculating nesting success. *Wil. Bull.* 87: 456-466

Newton, I. 1979. *Population Ecology of Raptors.* Poyser, Berkhamstead.

Newton, I. & Wyllie, I. 1992. Effects of new rodenticides on owls. In (ed.) Galbraith, C.A., Taylor, I. & Percival, S.M. *The Ecology and Conservation of European owls*: 49-54. JNCC, Peterborough.

Newton, I., Wyllie, I. & Freestone, P. 1990. Rodenticides in Barn Owls. *Environ. Pollut.* 68: 101-117.

Newton, I., Wyllie, I. & Asher, A. 1991. Mortality causes in British Barn owls *Tyto alba*, with a discussion of aldrin-dieldrin poisoning. *Ibis* 133: 162-169.

O'Connor, R.J. & Shrubb, M. 1986. *Farming and Birds.* Cambridge University Press, Cambridge.

Olney, N.J., Davis, R.P., Thomas, M.R. and Garthwaite, D.G. 1988. *Pesticide Usage Survey Report 89.* Ministry of Agriculture Fisheries and Food, Harpenden.

Olney, N.J., Davis, R.P., Thomas, M.R. and Garthwaite, D.G. 1989. *Pesticide Usage Survey Report 90.* Ministry of Agriculture Fisheries and Food, Harpenden.

Olney, N.J. and Garthwaite, D.G. 1990. *Pesticide Usage Survey Report 95.* Ministry of Agriculture Fisheries and Food, Harpenden.

Percival, S.M. 1990. *Population trends in British Barn Owls, Tyto alba and Tawny Owls, Strix aluco, in relation to environmental change.* British Trust for Ornithology Research Report No. 56. BTO, Thetford.

Percival, S.M. 1991. Population Trends in British Barn Owls. *British Wildlife* 2: 131-140.

Percival, S.M. 1992. Methods of studying the long-term dynamics of owl populations in Britain. In (ed.) C.A. Galbraith, I.R. Taylor & S.M. Percival *The ecology and conservation of European owls*: 39-48. JNCC, Peterborough.

Ratcliffe, D.A. 1970. Changes attributable to pesticides in egg-breakage frequency and eggshell thickness in some British birds. *J. Appl. Ecol.* 7: 67-107.

SAS Institute inc. 1985. *SAS User's Guide*. Version 5. SAS Institute Inc. Cary.

Shawyer, C.R. 1987. *The Barn Owl in the British Isles; its past, present and future.* Hawk Trust, London.

White, G.C. 1983. Numerical estimation of survival rates from band recovery and biotelemetry data. *J. Wildl. Mgmt.* 47: 293-305.