Epidem. Inf. (1989), **103**, 113–125
Printed in Great Britain

Tuberculosis: the disease and its epidemiology in the badger, a review

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(*Accepted 14 March 1989*)

SUMMARY

The data accumulated from 1972 to 1987 on the distribution and prevalence of tuberculosis in the badger population in Great Britain is reviewed. The current information on the influence of *Mycobacterium bovis* infection on badger population dynamics and its clinical effect on badgers is also summarized.

The results of these reviews indicate that *M. bovis* is endemic in the British badger population and that the badger is an ideal maintenance host for *M. bovis*. The studies in progress to obtain a fuller understanding of the epidemiology of tuberculosis in badgers are also described.

INTRODUCTION

The disease bovine tuberculosis (*Mycobacterium bovis*) in the European badger (*Meles meles*) came to light in Britain in 1971 following investigations by the Ministry of Agriculture, Fisheries and Food into the reasons for unexplained outbreaks of bovine tuberculosis in cattle (1). Prior to that time the only recorded occurrence of *M. bovis* in badgers was from Switzerland (2).

The presence of relatively high prevalences of *M. bovis* infection in badgers in south-west England in areas of high incidence of tuberculosis in cattle, resulted in the Ministry introducing a control policy in areas where badgers were thought to be responsible for outbreaks of the disease in cattle (1, 3). Since 1971, a large number of badger carcases have been examined, both from MAFF control operations following outbreaks of tuberculosis in cattle, and from carcases submitted for examination by members of the public as part of a national survey (4). In 1976, the Ministry initiated a long-term research programme at a study area in Gloucestershire to investigate the population biology of badgers and the epidemiology of tuberculosis in the badger population.

In this paper, we review the data accumulated on the distribution and prevalence of tuberculosis in the badger population in Britain. We also summarize information on the influence of *M. bovis* infection on badger population dynamics and its clinical effects on badgers.

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METHODS

Geographical distribution and prevalence

Data from the national survey (4) were collated to show the number of badgers examined per county and the number infected with *M. bovis*. These data exclude badgers examined as part of official investigations in connection with outbreaks of tuberculosis in cattle. An overall prevalence of infection for the period of the survey was calculated for each of the counties where infected badgers were identified.

In order to make approximate comparisons of badger density between counties where infected badgers were found, data were included on the mean badger social group density per county from the Nature Conservancy Council badger survey (P. Cresswell, S. Harris, and D. Jefferies, personal communication).

In certain areas where badger control operations were carried out, removal operations were conducted to give precise information on badger territory size, density and prevalence of tuberculosis. Seven such operations were undertaken, three in Gloucestershire and one each in Avon, Cornwall, Staffordshire and Sussex. For detailed accounts see (5), Gloucestershire 1 and 2, Avon and Cornwall; (6), Staffordshire; (7), Sussex.

Badger population density and disease dynamics

Ecological and epidemiological aspects of tuberculosis in badgers have been studied as part of the long term research programme in Gloucestershire. The study area lies in the Cotswold escarpment region where there has been a high incidence of tuberculosis in cattle. The countryside is hilly with woodland, permanent pasture and arable land. Habitat details are as described previously (5, 8).

A programme of regular capture, marking and sampling of individual social groups of badgers has provided data on population density, natality, mortality and the presence of *M. bovis* infection. Methods of social group delineation, badger capture, handling, population estimation, sample collection and laboratory screening are as described previously (8, 9) as are the methods of marking badgers (10). Badgers found dead in the study area were examined *post-mortem* for the presence of *M. bovis* (8).

Pathological and clinical findings

Regular clinical sampling (6, 8) of individual badgers enabled detailed case histories to be compiled of those infected with *M. bovis*.

RESULTS

Geographical distribution and prevalence

A total of 15064 badgers were examined in mainland Britain from 1972 to 1987 inclusive; 588 (3·9%) of these were positive for *M. bovis*. Figure 1 is a map of the estimated density of badger setts in Britain (11). This is included in order to see approximately how the distribution of infected counties corresponds with the national distribution of badgers. Figure 2 shows the 16 counties where infected

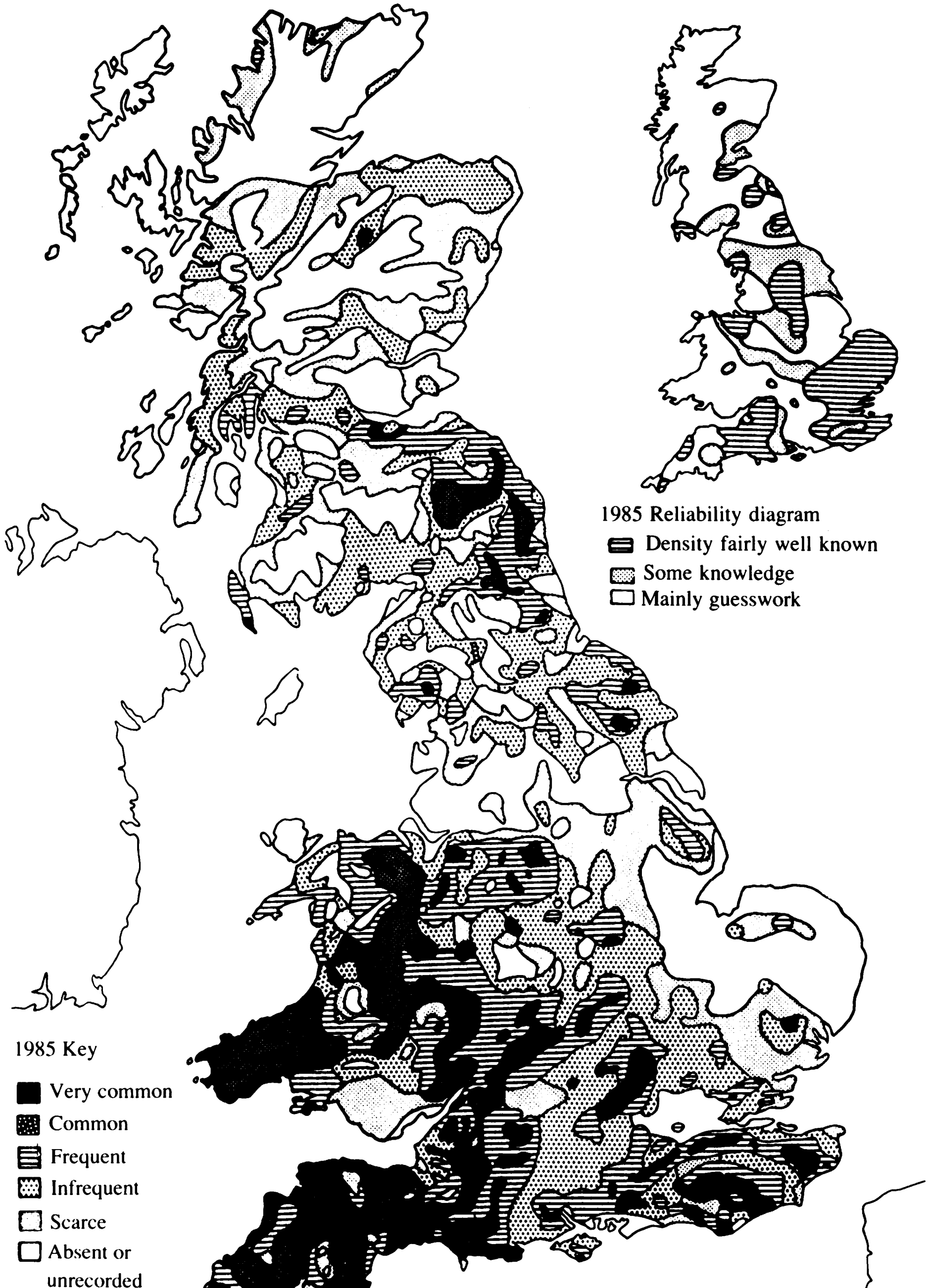

Fig. 1. Estimated density of badger setts in Great Britain (11).

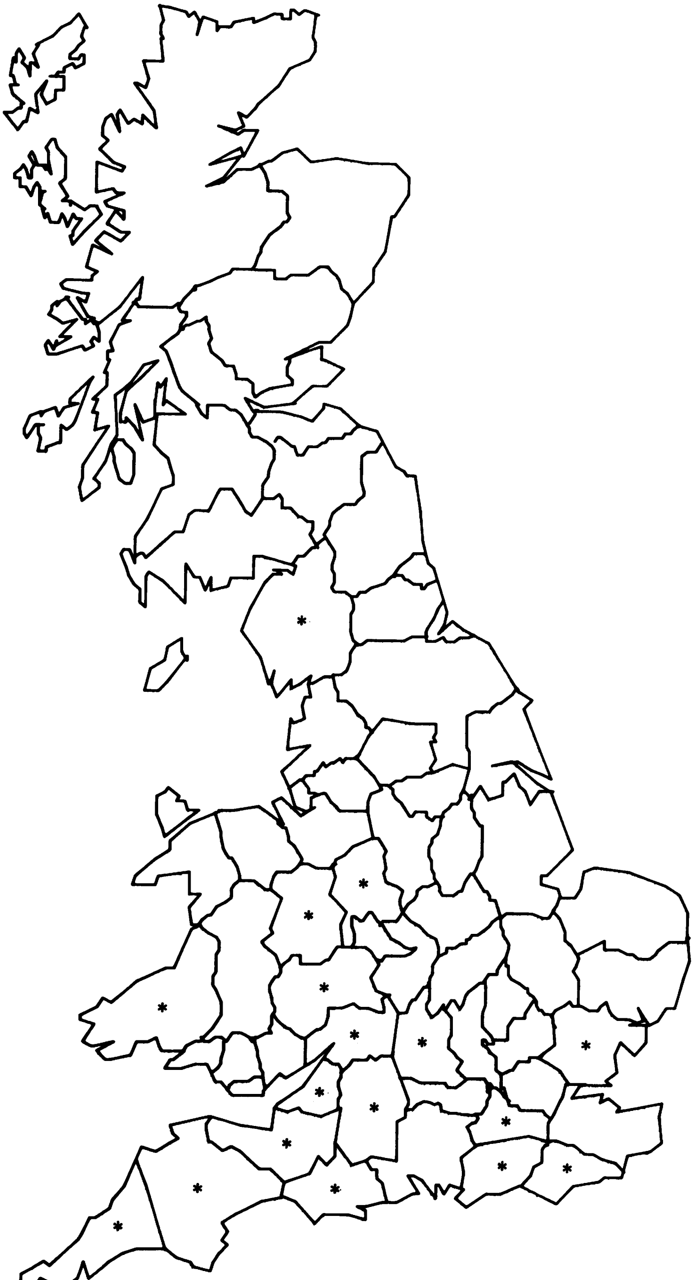

Fig. 2. Geographical distribution of *M. bovis* infection in badgers 1972–87.
* = $\geqslant$ 1 infected badger.

badgers have been identified. It can be seen that the disease is fairly widespread but the observed prevalence of infection is high in the counties in the south and west of Britain.

Figure 3 presents ranked histograms of the accumulated prevalence in the affected counties. These are grouped into counties in the south-west region and

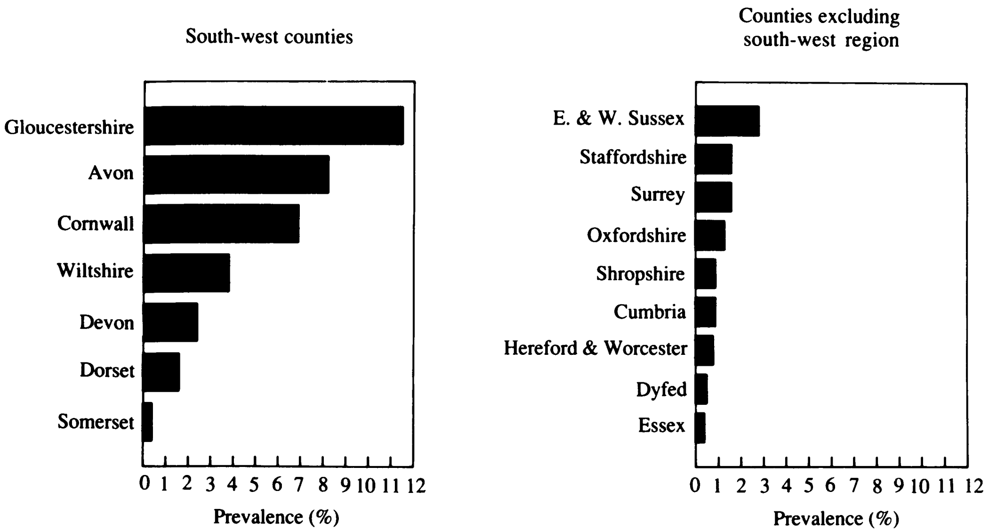

Fig. 3. Prevalence of *M. bovis* in badgers submitted by the public 1972–87.

Table 1. *Prevalence of* M. bovis *infection (1972–87) and badger population estimates in counties in which* M. bovis *has been confirmed in badgers*

County	Number of badgers examined	Number infected with *M. bovis*	Prevalence (%)	Mean number of social groups/km²*
Gloucestershire	2037	234	11·5	0·42
Avon	820	67	8·2	0·38
Cornwall	2377	165	6·9	0·46
Wiltshire	1061	40	3·8	0·46
Devon	1049	25	2·4	0·42
Dorset	855	14	1·6	0·43
Somerset	832	3	0·4	0·36
E. & W. Sussex	780	22	2·8	0·33
Staffordshire	256	4	1·6	0·18
Surrey	191	3	1·6	0·39
Oxfordshire	73	1	1·3	0·38
Shropshire	111	1	0·9	0·23
Cumbria	111	1	0·9	0·13
Hereford & Worcester	493	4	0·8	0·40
Dyfed	585	3	0·5	0·37
Essex	229	1	0·4	0·18

* Provisional data derived from Nature Conservancy Council Badger Survey 1988.

counties outside the south-west region. Table 1 shows the number of badgers examined and the number of infected badgers for each of the 16 infected counties. Also included in this table is an estimate of the mean number of badger social groups per km² for each county. All the counties in the south-west had relatively high mean badger densities of between 0·36 and 0·46 social groups per km². The prevalence of *M. bovis* infection in these counties ranged widely from 0·4% in Somerset to 11·5% in Gloucestershire. In the infected counties outside the south-west, the mean number of social groups per km² varied widely between 0·13 in

Table 2. *Badger territory size, population density and TB prevalence in different areas*

Study area	Number of social groups	Number of badgers removed	Average territory size (ha)	Population density (badgers km^{-1})	Prevalence of TB (%)
Gloucestershire 1	6	29	22	22·0 (19·7)	6·9
Gloucestershire 2	5	38	25	30·7 (19·4)	32·6
Gloucestershire 3	5	24	45	10·6 (6·2)	0
Avon	7	40	74	5·8 (4·9)	20·0
Cornwall	6	29	75	6·5 (4·7)	34·5
Staffordshire	5	45	104	8·7 (6·2)	17·8
Sussex	8	47	43	> 13·7* (> 9·0)*	21·3

* Not all badgers were trapped in this study. The estimates are therefore minimum densities.

Cumbria and 0·40 in Hereford and Worcester. The highest prevalence was in Sussex where 2·8% badgers were infected. The prevalence in some counties was comparatively low and in each of four counties: Cumbria, Essex, Oxfordshire and Shropshire, only one infected badger was found.

A similarly wide variation in badger density and prevalence of tuberculosis may be seen in the data from badger removal operations (Table 2). The highest prevalence of 34·5% was recorded in Cornwall where adult badger density was the lowest of the seven areas sampled (4·7/km^2). In contrast, Gloucestershire 2 had a very high adult badger density (19·4 km^2) but a relatively low prevalence of infection (6·9%).

Population density and disease prevalence

For the purpose of comparing fluctuations in population density with disease prevalence, data were examined from ten contiguous social groups in the Gloucestershire study area which were regularly trapped and sampled from 1981 and 1987 inclusive. Population and prevalence estimates were calculated at 3-monthly intervals from June 1981 to December 1987. The data are presented graphically in Figure 4. The number of badgers present showed a seasonal fluctuation due to the recruitment of cubs. Thus maximum numbers usually occurred around February at the time of the birth of cubs and numbers declined to a minimum towards the end of each calender year. [NB. The methods of direct enumeration used to calculate badger numbers allows only retrospective estimates to be made (9)].

The annual figures showed a gradual increase in the population over the 7-year period. With badger territory size remaining constant during this time (9), this represents an increase in population density. The prevalence of tuberculous badgers identified by clinical sampling reached a peak of 8·2% in February 1982, declined to a low level during 1984, and showed an increase up to the end of 1987. Thus, while badger population density increased over the 7-year period, the prevalence of tuberculous badgers varied considerably with an apparent cyclic pattern beginning to emerge. There is no correlation between the estimates of badger density and prevalence of tuberculous badgers.

Figure 5 indicates the incidence of new cases of infected badgers, detected by

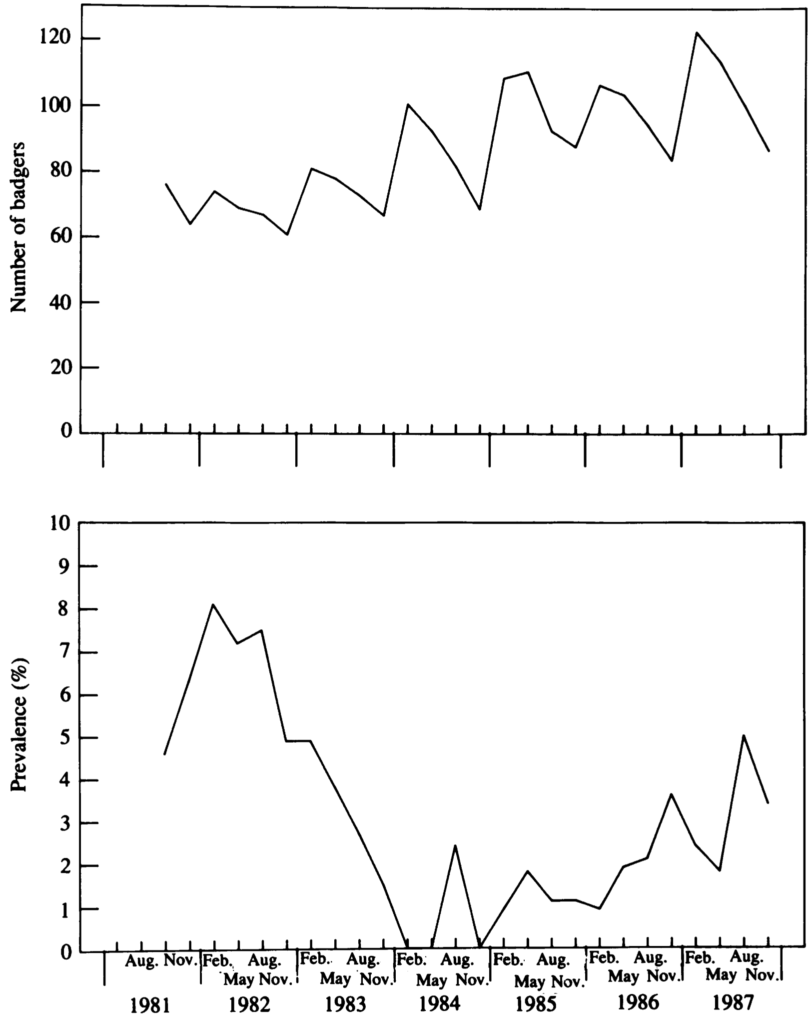

Fig. 4. Comparison of population density and prevalence of tuberculous badgers in the Gloucestershire study area (1981–87).

clinical sampling in each year from June 1981 to August 1988. This further highlights the cyclic change in the risk of infection for badgers. One hundred and ninety-seven badgers were found dead in the whole study area from 1977 to 1987 inclusive. The main causes of death are given in Figure 6. *M. bovis* infection was believed to be the primary cause of death in 20 (10·1 %) cases. Four badgers with advanced tuberculosis were found *in extremis* and put down as tuberculosis would ultimately have caused the death of these animals. This gives a total of (12·2 %) deaths due to tuberculosis. Road accidents accounted for by far the largest number of badgers 114 (57·9 %). The causes of death of the 11 (5·6 %) listed under 'other' causes were: severe pyelothorax and/or pleurisy [5], enteropathy [2], chronic nephritis [1], anaesthesia [1], and cardiopathy [2].

The sample of 197 badgers found dead was also used to examine the sex-specific prevalence of infection (Table 3). The accumulated prevalence in males

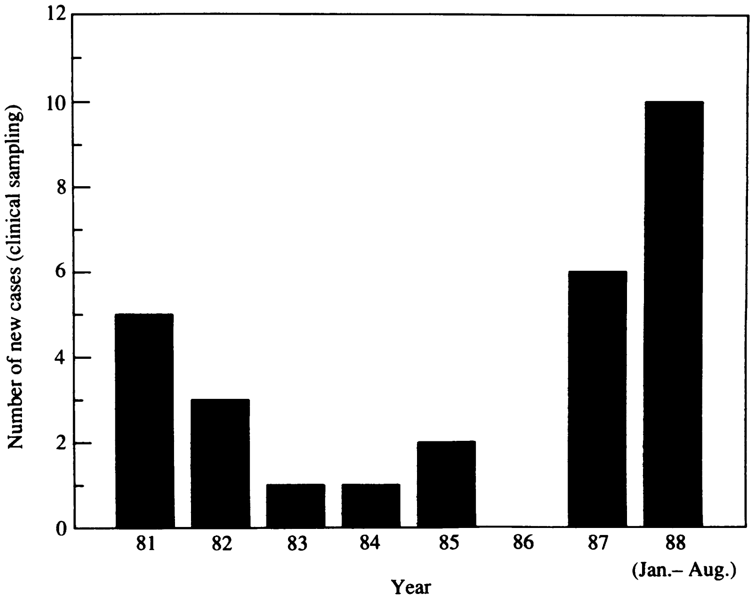

Fig. 5. Number of new cases of TB detected by clinical sampling in the Gloucestershire study area (June 1981–August 1988).

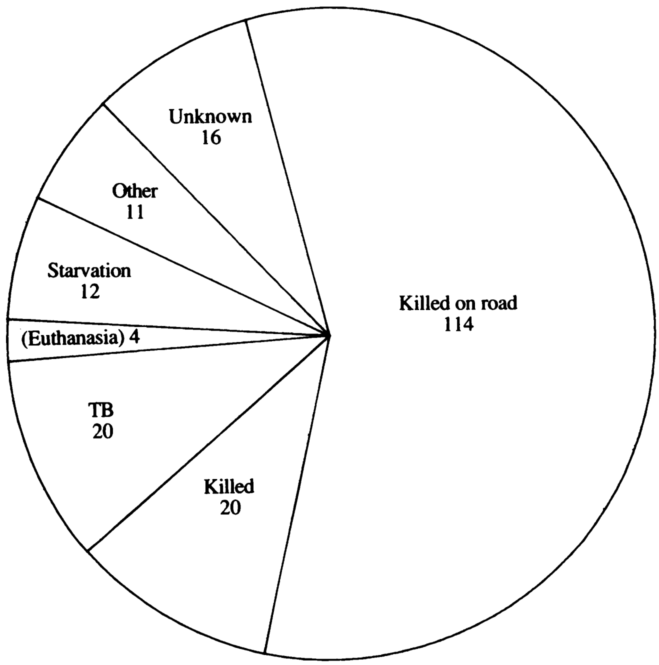

Fig. 6. Causes of death in all badgers autopsied in the Gloucestershire study area (1977–87).

Table 3. *Summary case histories in infected badgers detected by clinical sampling June 1981–August 1988*

Badger	Sex	Age at first diagnosis (years)	Observed period of excretion (months)	Suspected route of infection*
B16	F	1	—	R
B7	M	1	14	BW
G31	F	> 5	20	R
B25	M	1	—	R
B22	F	1	18	R
B33	F	> 3	3	R
G20	F	> 6	22	R
025	F	cub	—	BW
04	M	> 2	7	R
R16	F	6	—	R
01	M	> 4	—	R
P12	F	2	24	R
L55	M	1	—	R
P11	F	4	3	BW
K13	F	cub	5	R
F2	M	2	3+	R
L5	M	> 2	6	R
K17	F	cub	9+	R
F30	M	3	1	BW
K70	M	1	—	BW
E14	F	cub	2+	R
024	F	6	2+	R
G17	F	> 13	—	R
Y26	F	8	—	R
P13	M	5	—	R
N60	F	4	—	R
N59	F	4	—	R
F20	M	3	—	R

* R, respiratory route; BW, bite wound.

was 29·3% and in females 20·0%. The greater prevalence in males was not statistically significant at the 5% level ($\chi^2 = 2{\cdot}33$, D.F. = 1).

Pathological and clinical findings

During the period June 1981 to August 1988, 28 infected badgers were detected in the Gloucestershire study area by clinical sampling. Table 4 summarizes the case histories of these badgers. The observed period of excretion of *M. bovis* by four badgers was at least 18 months, the maximum was 24 months. There was evidence from the clinical and bacteriological examinations that infection could have been acquired through biting in only five (17·8%) badgers, the remaining 23 badgers having acquired infection via the respiratory route. Two adult females, (G31 and P12) produced cubs whilst tuberculous and badger 025 was believed to be one of the cubs, born to G31.

Table 4. *Sex-specific prevalences of* M. bovis *infection in all badgers autopsied 1977–87*

Year	Males	Females
1977	57·1 (4/7)	44·4 (4/9)
1978	66·7 (6/9)	50·0 (1/2)
1979	57·1 (4/7)	20·0 (2/10)
1980	16·7 (1/6)	18·2 (2/11)
1981	11·1 (1/9)	0·0 (0/13)
1982	33·3 (2/6)	20·0 (1/5)
1983	30·8 (4/13)	37·5 (3/8)
1984	11·1 (1/9)	14·3 ((1/7)
1985	0·0 (0/7)	8·3 (1/12)
1986	27·3 (3/11)	18·2 (2/11)
1987	12·5 (1/8)	23·5 (4/17)
Total	29·3 (27/92)	20·0 (21/105)

DISCUSSION

Infected badgers have now been recovered from 16 of the 61 counties in Britain. If the badger population of mainland Britain is considered as one (i.e. there are no geographical barriers which might separate different populations), it is apparent from the geographical distribution and prevalence that tuberculosis is endemic in the British badger population. The lack of evidence of infection from Scotland, for example, and certain counties in southern England such as Hampshire and Kent, may simply be due to the fact that insufficient badger carcases have been examined from these areas. Only 31 badgers were examined from the whole of Scotland during the 16-yr period, while over 15000 were examined from the rest of Britain. It is anticipated that as the survey proceeds infection will prove to be more widespread than has been revealed to date.

The national survey has depended upon badger carcases (mostly road casualties) submitted by members of the public. It therefore follows that regional variations in public awareness of the Ministry's appeal for badger carcases will influence the number received in different regions. Greater awareness probably exists in south-west England where the problem of tuberculosis in badgers has been given considerable publicity over the years.

County boundaries are, of course, arbitrary divisions and counties are unequal in area. Data has been collated by county in this paper merely for convenience. Thus factors such as the area of each county, regional variations in badger population density and road density are all further sources of bias which will influence the sample size in different counties. There is an obvious requirement for a critical analysis of the relationship between badger density and the prevalence of tuberculosis in badgers. Now that reliable data are becoming available on the density and distribution of badgers in Britain through the Nature Conservancy Council's national survey, this will be the basis of a future investigation.

The total of 15064 badgers submitted by the public from 1972 to 1987 inclusive represents an average of nearly 1000 badgers per year for the whole of Britain. Most of these badgers were killed on the roads. Provisional data from the Nature

Conservancy Council badger survey has put the number of badger social groups in mainland Britain at 43000 (P. Cresswell, S. Harris and D. Jefferies, personal communication). Neal gives the average number of badgers per social group as five or six adult individuals (11). This gives a total population for Britain of between 210000 and 252000 badgers. This is in agreement with a previous estimate of 216000 (12).

Previous population studies have estimated the annual adult mortality to be approximately 30% (9, 12). This means that approximately 63000 to 76000 adult badgers die each year in Britain. Studies in Bristol (S. Harris personal communication) and in the Gloucestershire study area (8) estimate that road deaths account for at least one third of the annual adult mortality. If this figure is representative nationwide then some 21000 to 25000 adult badgers are killed each year on the roads. Although these figures are approximations, they are nevertheless based on reliable sources of data and demonstrate that only a small proportion of badgers killed on the roads have in fact been recovered by the Ministry. Indeed, in the Gloucestershire study area it has been observed that badgers die of injuries, as a result of road traffic accidents, out of public view either in fields or in their setts.

Information obtained from the removal operations demonstrates that the relationship between badger density and the prevalence of tuberculosis cannot be explained by simple linear density-dependence. High prevalence was found in areas of low density and vice versa. However, these data are not considered adequate to confirm or deny the density-dependence hypothesis. A further difficulty which arises with samples taken at one point in time, as is the case in removal operations, is that any cyclic patterns in badger density or disease prevalence may not be revealed. It is the objective of the long-term study in Gloucestershire to investigate epidemiological trends.

The Gloucestershire study area comprises a highly suitable habitat for badgers and consequently has a high carrying capacity, probably in excess of 20 adults/km^2 (5, 9). In the ten social groups regularly sampled badger density increased over the period of study, although this overall trend has been shown to mask wide fluctuations in individual group size (9). As this study proceeds a picture is beginning to emerge of density-dependent fertility in conjunction with density-dependent mortality (9). Through these regulatory mechanisms the population has been maintained at a stable level, albeit with a gradual increase in density over a 7-year period, with no apparent cyclic pattern. The prevalence of tuberculosis, on the other hand, has shown a cyclic trend, providing further evidence that the prevalence of tuberculosis in badgers is not necessarily related to their overall population density. The explanation for this apparent systematic temporal variation is unclear and at present cannot yet be attributed to demographic features of the population. This explanation should however be revealed as the study progresses. Interestingly, this temporal variation is mirrored by the cattle population in the study area and in other areas of Gloucestershire (14).

It is notable that *M. bovis* infection does not appear to have had any effect on badger numbers. Mathematical modelling studies resulted in the hypothesis that *M. bovis* infection acts to depress badger population density to significantly below disease free levels (15). Such an effect may still become apparent in the course of a future epidemic in the study area.

The data on the causes of death of badgers found dead in the study area are inherently biased. Badgers killed on the road are more likely to be found than those which die underground in their setts. Similarly, known infected badgers are monitored by radio tracking and thus more likely to be found when they die than individuals not monitored in this way. We would however, conclude that road accidents were an important cause of death and that mortality due to *M. bovis* infection was low.

The higher prevalence of infection in male badgers than in females, although not statistically significant in our sample, has been recorded in other studies (16). It is possible that male badgers may be immunologically more susceptible to infection than females, as has been recorded in other species and diseases (17). However, it is felt that a behavioural explanation is more likely. Studies on movement of badgers have indicated a greater frequency of movement in male badgers and it has been established that males play a greater role in territorial defence (18). A greater frequency of bite wounding has been recorded in male badgers (16). It is therefore likely that the probability of cross infection between males is increased during agonistic territorial encounters.

The investigation of the epidemiology of *M. bovis* infection in badgers in the Gloucestershire study area is obviously made difficult by the lack of a valid non-destructive diagnostic test, such as a serological assay. However, repeated clinical sampling has been found to be a valid means of detecting tuberculous (excreting) badgers (19). The results of the epidemiological study can therefore be considered with confidence. The latter, together with the results of other studies (7) indicate that the badger is an ideal maintenance host for *M. bovis*. The evidence for this is that badgers survive relatively long periods whilst suffering from frank disease; tuberculous females have produced cubs; the size and structure of both the population and individual social groups are not significantly perturbed by the presence of infection or disease, and badger populations remain infected in the absence of exposure of *M. bovis* from other sources. There is also some evidence, albeit limited, that this maintenance of infection is the result of a high component of post-natal maternal transmission and that females may be more important than males in maintaining infection because of their greater lifespan (8). Further evidence on this and other aspects of the epidemiology will become available with the advent of suitably valid serological test for the detection of *M. bovis* infection. Such a test, for which there is some optimism, will allow the examination of the sera collected, and banked, from all badgers caught here since June 1981 resulting in a unique description of the epidemiology of an infectious disease in a wild animal population.

Despite the incomplete understanding of the epidemiology of tuberculosis in badgers, two important points are apparent from this review of studies to date. First, *M. bovis* is endemic in the British badger population and secondly, the badger is an ideal maintenance host for *M. bovis*. It is unfortunate that infection in badgers poses a relatively low, but real, risk of infection for cattle. However, the studies which are planned and already in progress are designed to improve our understanding of this complex problem with the ultimate objective of minimising the spread of *M. bovis* infection from badgers to cattle.

ACKNOWLEDGEMENTS

We gratefully acknowledge Dr S. Harris and Mrs P. Cresswell for access to unpublished data from the NCC Badger Survey. We would also like to express our thanks to those people who took the trouble to inform their local MAFF office about badger carcases. Our thanks are also obviously extended to the other members of the Gloucestershire study research team.

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