The Yellow-necked Mouse *Apodemus flavicollis* in Britain: status and analysis of factors affecting distribution

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ABSTRACT

A national survey of the Yellow-necked Mouse (*Apodemus flavicollis*) in Britain was undertaken by The Mammal Society. The live-trapping study sampled small mammal populations from 168 deciduous woodlands in autumn 1998. Within their range, Yellow-necked Mice were widespread in deciduous woodland and were more abundant than Wood Mice in 15% of the woodlands sampled. These trapping records, as well as records solicited from local recorders, record centres and individuals, supplemented the existing distribution map, confirming the general pattern, but with minor extensions to some range borders.

Yellow-necked Mice were found in woodland of all ages, but were more common in woods of ancient origin than in younger woodland. Woodland size was not important in determining the presence or abundance of Yellow-necked Mice, but they were more often absent from woods more than 2 km from neighbouring substantial woodland.

The presence of Yellow-necked Mice did not affect the relative abundance of Wood Mice (*Apodemus sylvaticus*). However, the decline in the proportion of breeding male Wood Mice at the end of the main breeding season was more marked in those woods that also contained Yellow-necked Mice. Where their ranges overlapped, Bank Voles (*Clethrionomys glareolus*) were less abundant where Yellow-necked Mice were also present.

The distribution of the Yellow-necked Mouse was explored with respect to a number of climatic, soil and habitat variables. Maximum summer temperature was the most significant variable explaining distribution, although woodland cover variables also contributed. Soil moisture and pH, mean rainfall and winter temperature parameters did not predict Yellow-necked Mouse distribution. Low summer temperature may limit Yellow-necked Mouse distribution through its impact on tree seed production and diversity. Climatic change leading to a rise in summer temperature might encourage range expansion by Yellow-necked Mice, if their other habitat requirements are met.

Keywords: habitat requirements, fragmentation, climate change, national survey, wood mouse

INTRODUCTION

In Europe, the Yellow-necked Mouse (*Apodemus flavicollis*) is both abundant and wide-ranging; its distribution extends east into Russia, north into Scandinavia and south into Greece (Macdonald & Barrett, 1993; Mitchell-Jones *et al.*, 1999). In central Europe the Yellow-necked Mouse tends to be restricted to montane areas (Müller, 1972; Saint Girons, 1973) and it is absent from much of the lowland in the west of the continent. Comprehen-

sive studies of the Yellow-necked Mouse in Europe have examined allopatric populations (Pucek *et al.*, 1993; Mazurkiewicz & Rajska-Jurgiel, 1998), as well as populations living in sympatry with the Wood Mouse (*Apodemus sylvaticus*) (Bergstedt, 1965; Hoffmeyer & Hansson, 1974; Gosálbez & Castién, 1995).

Despite extensive data from Europe, there have been relatively few studies of Yellow-necked Mice in Britain, and these have been confined to limited areas (Hedges, 1966; Yalden, 1971; Corke, 1974; Montgomery, 1977, 1985; Yalden & Shore, 1991). As a consequence, the status and distribution of this species remains unclear. The most recent distribution map for the Yellow-necked Mouse (Arnold, 1993) largely relies on casual records and this makes its accuracy difficult to assess, particularly since Yellow-necked Mice are so similar in appearance to Wood Mice. The Yellow-necked Mouse has a distinctive range in Britain, being restricted to the south-east, south and west of England, and central and eastern Wales (Arnold, 1993).

The Yellow-necked Mouse probably became established in Britain in Mesolithic or early Neolithic times (Yalden, 1982). At this time, it may have been the most abundant woodland mouse, possibly excluding the Wood Mouse from this habitat (Yalden, 1999). Certainly, in these former times the range of the Yellow-necked Mouse appears to have been wider, as suggested by archaeological remains from Roman Manchester (Yalden, 1984), Dowel Cave, Derbyshire and elsewhere (Yalden, 1999). Older records from the late nineteenth and early twentieth centuries, where sightings have not been repeated in recent decades, have led some authors to conclude that numbers and/or range of the Yellow-necked Mouse may have declined (Morris, 1993; Harris *et al.*, 1995; Macdonald, Mace & Rushton, 1998).

In Britain, the Yellow-necked Mouse is associated with mature deciduous woodland (Montgomery, 1977, 1985); it is rarely found in other habitats. Woodland with a wide diversity of seed-bearing tree species, particularly certain key species, may be important (Yalden & Shore, 1991; Marsh & Harris, 2000a). The southerly distribution of the Domesday woodland and nineteenth century coppice (Rackham, 1986) show some correlation with the present range of the Yellow-necked Mouse (Montgomery, 1978), leading to its description as an ancient woodland species, much as for the Dormouse (*Muscardinus avellanarius*) (Bright & Morris, 1990). In coppice woodland, the Yellow-necked Mouse is the only rodent to prefer older, more established compartments, seldom being recorded in recent coppice (Gurnell, Hicks & Whitbread, 1992; Capizzi & Luiselli, 1996), but little is known about how other woodland management practices may affect Yellow-necked Mice. However, populations may decline when woodland is disturbed by extensive felling or replanting (Montgomery, 1978; Yalden & Shore, 1991). As well as tree and shrub diversity, other habitat features within woodland are likely to be important to Yellow-necked Mice. One theory is that Yellow-necked Mice are more arboreal than Wood Mice, thereby providing a means of spatial niche separation (Corbet, 1966; Hedges, 1966; Corke, 1974). Hence, the degree of habitat complexity, the vertical component of woodland habitat (August, 1983), may be important to their coexistence, although this is not confirmed (Montgomery, 1980a).

The surrounding landscape, including land use, the distance to neighbouring woodlands, and connectivity between woodlands, may also affect movement and abundance in *Apodemus* (Ylönen, Altner & Stubbe, 1991; Fitzgibbon, 1997; Tischendorf & Wissel, 1997). Bright (1993) suggested that its presumed habitat specificity might make the Yellow-necked Mouse vulnerable to habitat fragmentation. However, is not yet clear that woodland fragmentation does affect Yellow-necked Mice or, if it does, what degree of woodland isolation is important. Mader (1984) found that movements of Yellow-necked Mice were inhibited by the presence of roads dividing forest fragments, but Kozakiewicz (1993) concluded the opposite. In

Poland, Yellow-necked Mice were found to move across crop fields to neighbouring woods (30–100 m away) and to disperse up to 300 m over winter (Rajska-Jurgiel, 1992); they also use crop fields in south-east Britain (D. Corke, pers. comm.). Since both species of *Apodemus* can travel more than 1 km in short periods (Bovet, 1962; Montgomery, 1977; Wolton & Flowerdew, 1985), it seems unlikely that small distances between woodland fragments would affect populations.

Variations in climate or soil conditions may also influence the distribution of the Yellow-necked Mouse in Britain. Corke (1977) suggested its range was limited to warm, dry areas, while Montgomery (1978) explored the distribution of wet and dry soil types, concluding that Yellow-necked Mice preferred drier soils. However, both studies suffered from limited data and analyses, and a more rigorous examination of these and other possible explanatory variables is required.

In this paper, we present the results from our review of the status and distribution of the Yellow-necked Mouse in Britain. The first part of this work involved a national survey of the Yellow-necked Mouse undertaken by The Mammal Society, the aims of which were: (1) to review and improve the current distribution map for the Yellow-necked Mouse through the collation of records from trapping studies and casual recording; (2) to conduct a national trapping study using skilled volunteers to survey for Yellow-necked Mice in deciduous woodland across Britain; and (3) to evaluate specific woodland habitat and landscape variables that may affect the relative abundance of Yellow-necked Mice. In particular, the following hypotheses were tested: (i) the range and abundance of the Yellow-necked Mouse is declining in Britain; (ii) Yellow-necked Mice are more abundant in ancient than in recent woodland; (iii) Yellow-necked Mice are less likely to be present in more isolated woodlands; (iv) Yellow-necked Mice are less likely to be found, or are likely to be less abundant, in woodlands subject to high levels of human disturbance or management; (v) the abundance of woody climbers and fallen timber aid vertical movement and are positively correlated with the abundance of Yellow-necked Mice; and (vi) the structure and abundance of Wood Mouse populations are not affected by the presence of Yellow-necked Mice.

In the second part of the investigation we analysed the distribution of the Yellow-necked Mouse with the following aims: (4) to review, investigate and interpret the factors that may influence the distribution of the Yellow-necked Mouse in Britain, including climate, soil and woodland area; (5) to explore the potential impact of climate change on the distribution of this species; and (6) to use these data to assess the current conservation status of the Yellow-necked Mouse in Britain. In particular, the following hypotheses were tested: (vii) Yellow-necked Mice are confined to areas experiencing drier soils and lower rainfall; (viii) Yellow-necked Mice are limited to areas subject to warmer summers, but are not restricted by cold winters; and (ix) Yellow-necked Mice are associated with higher levels of broad-leaved woodland cover.

NATIONAL TRAPPING STUDY
Methods

A small mammal trapping study by experienced volunteers was undertaken between 1 September 1998 and 30 November 1998, a 3-month window chosen to cover the period when small mammals are most abundant. Two sites surveyed just outside these dates were included. Volunteer surveyors were drawn from wildlife professionals and skilled naturalists, and this enabled a large number of woods to be surveyed simultaneously across the country.

Study woodlands were chosen by volunteers, but had to be predominantly deciduous and > 2 ha in size. Very small woods, pure coniferous woodland and other types of habitat were

excluded as these were considered, *a priori*, to be marginal habitats. Sites were not preselected, as this would have reduced involvement, sample size and geographical coverage.

Trapping protocol

All surveyors used 40 Longworth live-capture traps, left in place for two consecutive nights, to survey each site. Two trap lines were laid in each woodland, each consisting of 10 pairs of traps placed at approximately 15-m intervals. Trap lines were laid at least 50 m from the edge of the woodland and at least 100 m from each other. The two traps were laid within 1 m of each other in promising capture positions. Hay was provided as bedding and food in the form of rolled oats (or similar). All traps also contained blowfly pupae (or similar) to minimize trap deaths amongst shrews (*Sorex araneus*, *S. minutus*, *Neomys fodiens*).

Traps were laid down on the afternoon of day 1 and checked as early as possible on the morning of day 2. They were then reset and checked on the morning of day 3 before being removed. All animals caught were identified, weighed, sexed and their reproductive condition assessed. In order to minimize any distress to shrews, they were usually identified to species and then released. Animals captured on day 2 were fur-clipped to identify them as recaptures if caught again on day 3.

One variation in methodology should be noted. An evening trap round on day 2 was an accepted deviation from the main protocol, provided certain procedures were followed. Animals caught were recorded as day 3 captures (or recaptures), as they would still have been there the following morning, and their traps were left closed overnight to avoid increasing the overall trap effort. The implications of this methodological variation are addressed in the discussion.

Landscape and habitat variables: selection and scoring

Seven habitat and three main landscape variables were assessed for each woodland site (see Table 1). Habitat variables were assessed at every other trap point in an area of 3 m radius around the traps and then averaged to give an overall score for that wood (*sensu* Marsh & Harris, 2000a). Canopy cover was assessed by looking upwards through a short tube (40 mm

Table 1. Variables measured for each woodland site

Abbreviation	Variable description	Data type
Woodland descriptives		
NVC	NVC woodland classification	Categorical (1–5)
PLANTING	Woodland planting date	Categorical (1–5)
AGE	Woodland age category (RW, ARW, ASNW)	Categorical (1–3)
Landscape variables		
AREA	Woodland area (ha)	Continuous
ISO2	Distance to nearest woodland >2 ha	Categorical (1–5)
ISO20	Distance to nearest woodland >20 ha	Categorical (1–5)
Habitat variables		
CANOPY	Canopy cover	Categorical (1–5)
HERB	Herb layer cover	Categorical (1–5)
HUMAN	Human impact level	Categorical (1–5)
LOGS	Fallen timber on ground	Categorical (1–5)
MANAGE	Management level	Categorical (1–5)
LIANAS	Free-hanging climbers in trees	Categorical (1–5)
IVY	Ivy coverage on trees	Categorical (1–5)

diameter) and assessing the percentage of canopy cover seen. The abundance of trees with free-hanging and attached climbers, e.g. Clematis (*Clematis vitalba*), Honeysuckle (*Lonicera periclymenum*) and Ivy (*Hedera helix*), was recorded. Fallen logs were assessed as the total length of fallen branches/trunks > 10 cm diameter within the 3-m wide habitat plot. All final woodland habitat scores were assigned a value of 1–5, based on ordinal scales according to specific guidelines.

In addition, data were collected on planting dates, National Vegetation Classification (NVC) (Rodwell, 1991) and age category. Planting dates were obtained from landowners' records where possible. The age category of each woodland was assessed as Recent Woodland (RW), Ancient Replanted Woodland (ARW) or Ancient Semi-Natural Woodland (ASNW). ASNW is woodland existing before 1600, ARW is woodland existing before 1600, but since replanted and RW is woodland planted post-1600.

Data analysis

All data were entered directly from the Microsoft Access-generated recording forms into the electronic Access form linked to data tables. These data were then imported into SPSS for Windows (Norušis, 1994) for analysis. Woodland area (ha), distance to the nearest small woodland (> 2 ha) and distance to the nearest large woodland (> 20 ha) were all recalculated using Pathfinder 1:25 000 Ordnance Survey maps in order to standardize the measurement of these values.

Missing data were frequent. Dichotomous coding variables were created to identify unreliable data and allow them to be excluded from relevant parts of the analysis. For example, where two or more escapees were recorded on the first trap round, before the animals were fur-clipped, the 'escapes' variable was marked. Such escapes could have affected the abundance index and this coding allowed these sites to be excluded from the appropriate parts of the analysis. The sex of Bank Voles is more difficult to determine than for mice, so for the purposes of this investigation its sex ratio and breeding status were not considered.

Classifying rodents as adults, sub-adults and juveniles was subjective, and with so many recorders considerable variation was to be expected. Records of animal age class were carefully examined; no true difference was found between sub-adult and juvenile age classes, and so these two categories were merged into one pre-adult class. To control for inaccurate age classifications in the resulting two age classes, a reclassification of outliers was implemented based on weight. All animals that were over two standard deviations outside the mean weight for their selected age class were reclassified. Reclassifications were only made once and this led to the reassignment of 39 (1.5%) Wood Mice, seven (1.6%) Yellow-necked Mice and eight (1.6%) Bank Voles into new age classes.

All continuous variables were checked for normality and homogeneity of variance. Wood Mouse abundance was normally distributed after a $\log_{10} (x + 1)$ transformation. Yellow-necked Mouse and Bank Vole abundance were not normally distributed and could not be transformed, so non-parametric tests were used on these data (Siegel & Castellan, 1988). In cases where multiple Chi-squared or Kruskal–Wallis tests were conducted on these same data, the significant *P*-values were Bonferroni-corrected; *P* was divided by the number of tests conducted to give *P*′ (Altman, 1991).

All woodland and landscape variables (Table 1) were checked for inter-correlation using Spearman correlation coefficients. LIANA was highly correlated with IVY, ISO2 with ISO20 and HUMAN with MANAGE. Where variables were highly correlated ($r > 0.7$) the variable that contributed least when individually entered into a logistic regression model was automatically discarded. Logistic regression was used to produce a model that best explained the

differences observed between woods where Yellow-necked Mice were present and those where they were absent. Initially, the variables were entered individually into the model and only variables where the Wald statistic had a probability value of $P < 0.25$ were included in the main logistic regression (Hosmer & Lemeshow, 1989). In the analysis LIANA, ISO2 and HUMAN were omitted. The remaining variables were entered simultaneously to produce a predictive model for Yellow-necked Mouse presence.

The trapping date for each wood was recorded and considered in the analysis. Woods were placed in six shorter trapping windows, which represented consecutive fortnights through the survey period. The two woods that were surveyed just before and just after the main survey period were included in the first and last time periods, respectively.

Results

Small mammal captures

A total of 4326 small mammal captures and eight species were recorded during the survey (Table 2). Wood Mice were by far the most abundant, representing 71.8% of all captures, followed by Bank Voles (13.4%) and Yellow-necked Mice (11.3%). Only these three species are considered in the analysis. Rodent captures increased on the second night of trapping (57.6% of total), with the overall capture of new animals (44.9%) slightly greater than that on night one (42.4%).

Wood Mice were recorded in 164 woods, while Yellow-necked Mice were found in 80 (Fig. 1) and Bank Voles in 124. The mean abundance of all three species for all woods, woods where Yellow-necked Mice were present and woods where Yellow-necked Mice were absent is shown in Table 3. There was no significant difference in the abundance of either Wood Mice (*t*-test; $t = 0.40$, $n = 145$, NS) or Bank Voles (Mann–Whitney; $U = 2232.0$, $n = 144$, NS) between sites with or without Yellow-necked Mice. More Yellow-necked Mice than Wood Mice were caught in 12 woods (15% of sites, $n = 80$) and they were equally abundant at a further three sites.

Geographical variation

Based on the known distribution of the Yellow-necked Mouse prior to the survey, sites were categorized as 'within range', 'outside range' or on the 'range border' (sites estimated to

Table 2. Survey capture totals. Traps were set on day 1 and checked on days 2 and 3

Species	Day 2	Day 3 (New)	Day 3 (Recaptures)	Total
Apodemus sylvaticus	1334 (42.9%)	1338 (43.1%)	435 (14.0%)	3107
Clethrionomys glareolus	231 (39.8%)	300 (51.7%)	49 (8.4%)	580
Apodemus flavicollis	206 (42.1%)	232 (47.4%)	51 (10.4%)	489
Sorex araneus	52 (43.7%)	54 (45.4%)	13 (10.9%)	119
Sorex minutus	11 (44.0%)	14 (56.0%)	0	25
Neomys fodiens	1	2	0	3
Mus musculus	0	2	0	2
Rattus norvegicus	0	1	0	1
Total				4326

● sites where *A. flavicollis* were caught
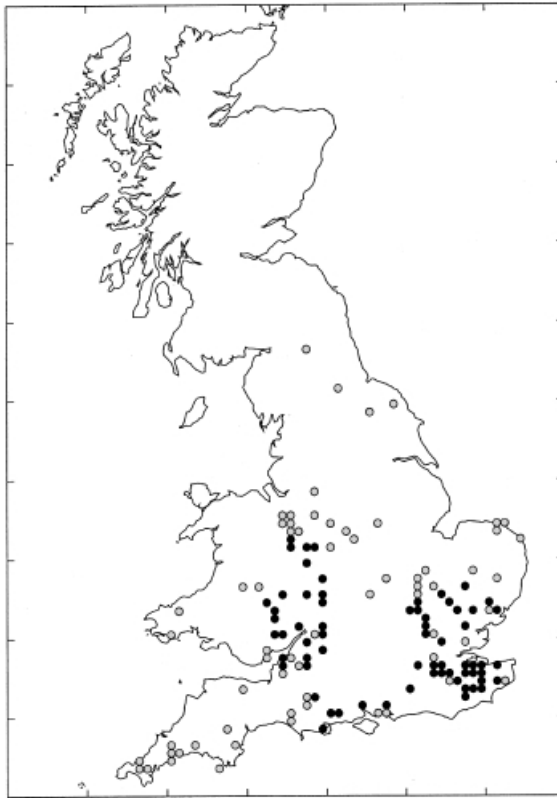○ sites where *A. flavicollis* were not caught

Fig. 1. Survey distribution map showing sites where *A. flavicollis* were caught and sites where they were not.

Table 3. Mean abundance of small mammals per 100 trap nights for all woods considered together and woods where *A. flavicollis* was present or absent. Woods with potentially inaccurate abundance estimates were excluded. Figures in brackets show the relative abundance; these only include woods in which the given species was found

	A. sylvaticus			*A. flavicollis*			*C. glareolus*		
	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*
All woods	16.03	10.45	142	2.45	3.89	142	3.28	4.10	139
	(16.26)	*(10.35)*	*(140)*	*(5.04)*	*(4.26)*	*(69)*	*(4.34)*	*(4.20)*	*(105)*
A. flavicollis present	15.62	10.16	69	5.04	4.26	69	4.12	5.12	67
	(15.62)	*(10.16)*	*(69)*	*(5.04)*	*(4.26)*	*(69)*	*(5.11)*	*(5.25)*	*(54)*
A. flavicollis absent	16.41	10.78	73		n/a		2.50	2.64	72
	(16.87)	*(10.56)*	*(71)*				*(2.52)*	*(2.49)*	*(51)*

be ± 20 km from the inland range border). In total, 92 sites were categorized as within range and Yellow-necked Mice were trapped in 71% of these sites. There were 54 sites on the range border, of which 28% contained Yellow-necked Mice. No Yellow-necked Mice were caught in any of the 22 sites categorized as outside the range.

Different variables may influence population density and structure in small mammal populations beyond the range of Yellow-necked Mice, where climatic and landscape differ-

ences may be significant. For this reason, sites classed as within or on the border of the Yellow-necked Mouse distribution (henceforth referred to as sites within the range of the Yellow-necked Mouse) were examined separately from those sites outside this range. For sites within the Yellow-necked Mouse range there was a significantly lower abundance of Bank Voles in those woods where Yellow-necked Mice were present than in those where they were not found (Mann–Whitney; $U = 1704.5$, $n = 131$, $P' < 0.05$). Abundance of Wood Mice did not differ between these woods ($U = 2108.0$, $n = 134$, NS).

Differences between Yellow-necked and Wood Mouse population structure

To avoid the possibility of additional confounding variables affecting the results, explorations of inter-specific differences in population structure between Yellow-necked and Wood Mice were confined to those woods where the two species were found in sympatry. There was no significant difference in the overall sex ratio in Yellow-necked and Wood Mice; males represented 58.6 and 61.7% of captures, respectively. However, there were significant differences in the ratio of adult to pre-adult captures between Yellow-necked and Wood Mice ($\chi^2 = 30.67$, d.f. = 1, $P' < 0.001$). Proportionately fewer pre-adult Yellow-necked Mice were recorded (18.2%) than pre-adult Wood Mice (32.5%).

The mean weights of all captures, adults and pre-adults, for the three dominant species are shown in Table 4. The ratio of breeding to non-breeding adult animals was significantly different between the two species of *Apodemus* ($\chi^2 = 17.88$, d.f. = 1, $P' < 0.001$); there was a lower proportion of breeding Wood Mice. However, trapping date had a significant effect on the proportion of breeding animals caught for both Wood Mice ($\chi^2 = 185.8$, d.f. = 5, $P' < 0.001$) and, to a much lesser extent, Yellow-necked Mice ($\chi^2 = 14.30$, d.f. = 5, $P' < 0.05$). The proportion of breeding Wood Mice appeared to decline rapidly from the second half of October, while Yellow-necked Mice showed a similar decline approximately 2 weeks later at the beginning of November.

Differences in Wood Mouse population structure in the presence and absence of Yellow-necked Mice

There was no significant difference in the overall sex ratio or age structure for Wood Mice between woods where Yellow-necked Mice were present compared to sites where they were absent. However, there was a significant difference in the proportion of breeding to non-breeding adult Wood Mice between these woods ($\chi^2 = 7.26$, d.f. = 1, $P' < 0.05$). This was attributable to a lower proportion of breeding male Wood Mice within woods containing

Table 4. Mean weights of small mammals from trapping study

	Mean weight (g)	SD	Min.	Max.	n
A. sylvaticus					
All	18.75	3.95	6.00	33.00	2301
Adults	20.42	3.51	14.00	33.00	1469
Pre-adults	15.46	2.56	6.00	21.00	754
A. flavicollis					
All	28.02	5.98	13.00	50.00	402
Adults	29.93	5.09	20.00	50.00	302
Pre-adults	21.26	3.84	13.00	29.00	85
C. glareolus					
All	17.38	3.81	7.00	35.00	472
Adults	19.02	3.55	12.00	35.00	286
Pre-adults	14.52	2.35	7.00	20.00	170

Yellow-necked Mice (χ^2 = 10.46, d.f. = 1, P' < 0.01). However, taking trapping date into consideration, prior to the mid-October fall in the proportion of breeding adult Wood Mice, there was no difference in this variable between woods with and without Yellow-necked Mice, whereas after mid-October there was a significant difference (χ^2 = 15.94, d.f. = 1, P' < 0.001). It appeared that although the proportion of adult Wood Mice in breeding condition declined in the woodlands as a whole, woods containing Yellow-necked Mice were subject to a greater decline than those where Yellow-necked Mice were absent.

There was no significant difference in the mean weight of Wood Mice in woods where Yellow-necked Mice were or were not recorded.

Effects of landscape and habitat variables
The National Vegetation Class (NVC) of the woodland was described for 150 of the 168 sites. Of these, 118 of the sites were equally distributed between W8 (*Fraxinus excelsior – Acer campestre – Mercurialis perennis* woodland) and W10 (*Quercus robur – Pteridium aquilinum – Rubus fruticosus*) classes. The presence and absence of Yellow-necked Mice was also equally distributed between these sites; they were trapped in 51% of both W8 and W10 sites. All nine of the sites classified as W12 (*Fagus sylvatica–Mercurialis perennis* woodland) contained Yellow-necked Mice. A further 15 sites were variously described including W14, W15 and W16 woodlands.

The classification of sites as Recent Woodland (RW), Ancient Replanted Woodland (ARW) or Ancient Semi-Natural Woodland (ASNW) was provided for 151 of the sites. Yellow-necked Mice were found in 33% of RW sites, 52% of ARW sites and 53% of ASNW sites. ARW and ASNW sites can be difficult to distinguish and so they were combined as 'ancient woodland'. Yellow-necked Mice were more likely to be present in ancient woodland than in recent woodland (χ^2 = 4.34, d.f. = 1, P < 0.05). The planting date was provided for 38 sites; four of the seven woods planted between 1900 and 1950 contained Yellow-necked Mice compared to only one of the seven sites planted since 1950.

Woodlands were categorized as small, 2–10 ha (35%); medium, 11–30 ha (24%); large, 31–100 ha (25%); or very large, > 100 ha (16%). There was no significant effect of woodland size and Yellow-necked Mice were recorded in 46–57% of woods from all four size categories.

The vast majority of woodlands (92%) were within 500 m of the nearest woodland larger than 2 ha in size. The distance to the nearest 20+ ha woodland (ISO20) showed a greater variation between sites. Although not stratified for their degree of isolation, all five classes of isolation (< 100 m, 101–500 m, 501–1000 m, 1001–2000 m and 2000+ m) were represented by between 25 and 33 sites. Overall, the effect of isolation (ISO20) on Yellow-necked Mouse abundance was not significant (Kruskal–Wallis ANOVA, H = 5.026, d.f. = 4, NS). However, a trend was apparent; a comparison of woodlands > 2 km and < 2 km from their nearest neighbouring substantial woodland (> 20 ha) indicated that Yellow-necked Mice were less likely to be present in the more isolated sites (χ^2 = 4.88, d.f. = 1, P < 0.05).

Correlation and regression analysis
The abundance indices for Yellow-necked Mice were heavily weighted towards lower numbers (see Fig. 2) and could not be transformed to fit a normal distribution. Abundance for this species was individually correlated with all woodland and landscape variables using Spearman correlation coefficients. Individually, none of the habitat variables measured showed a significant variation with the date of surveying. Two variables were significantly correlated with Yellow-necked Mouse abundance: Ivy cover on trees (IVY) (r = –0.221, n = 165, P < 0.01) and the level of management activity (MANAGE) (r = 0.188, n = 164, P < 0.05).
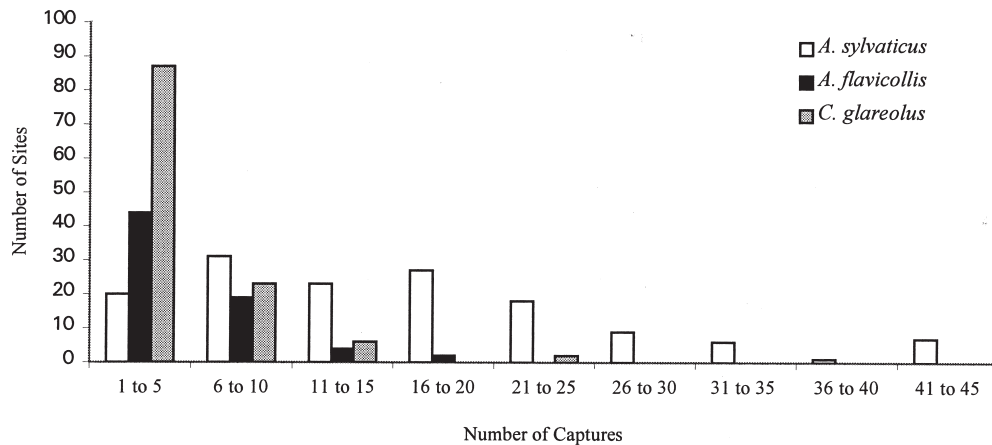
Fig. 2. Capture frequency.

Variable	Coefficient B	SE	Wald	d.f.	P
Constant	2.961				
MANAGE	0.619	0.206	9.020	1	0.003
IVY	0.546	0.257	4.501	1	0.034

Table 5. Results of logistic regression analysis comparing habitat and landscape variables in woods where *A. flavicollis* was present or absent ($n = 131$)

The variables ISO20, MANAGE, IVY, HERB, CANOPY, AGE and NVC were selected for the logistic regression analysis and entered simultaneously into the model. The model ($-2LL = 134.374$, model $\chi^2 = 47.040$, d.f. $= 11$, $P < 0.001$) correctly classified 73% of sites for the presence or absence of Yellow-necked Mice using these variables. The two variables that were found to be significant in this model were MANAGE and IVY (Table 5). The presence of Yellow-necked Mice was positively correlated with the amount of management and inversely correlated with the amount of tree-based Ivy.

DISTRIBUTION ANALYSIS
Methods
Record collection and reliability
Records of Yellow-necked Mice were collected from May 1997 until June 1999, building upon the records of Arnold (1993). Individual sightings, multiple records and small databases were collected from local mammal recorders, biological record centres, academic institutions and individuals. There was some duplication of records already shown in Arnold (1993). All records from Arnold (1993), county mammal recorders and environmental record centres were already checked, and were automatically accepted into our database. Outlying records that appeared on earlier distribution maps (Arnold, 1993) were included in these analyses, with the exception of those that represented mapping errors (H. Arnold, pers. comm.). All the 1998 trapping study results were accepted. A few records were accepted from expert naturalists and academics from a questionnaire survey by The Mammal Society in 1989 (T. Healing, unpublished data), along with a small number of carefully screened records from a 1998–99 questionnaire survey of mice in houses (Marsh & Harris, 2000b). Other records and sightings were individually assessed and included on merit.

Handling the records

The database of records was used to create a distribution map showing the presence and absence of Yellow-necked Mice in all land-based 10-km squares lying to the south of national grid 50 north (Windermere). No attempt was made to create any index of abundance for 10-km squares based on number of records, since records collected in this way reflect an uneven and unstructured recording effort. Instead, a smoothed distribution map was produced, where all 10-km squares were categorized as core, peripheral or absent. For this an index value of 0–4 was created, where < = 1 is 'absent', 1.25–2.75 is 'peripheral' and > = 3 is 'core'. Each square scored 1 point for an actual record in that square, 0.5 for a record in each adjacent square (those north, east, south and west) and 0.25 for a record in each diagonal square, thereby weighting surrounding squares according to their spatial proximity. Using these cut-off points, this smoothing index effectively removed singletons (both isolated presences and isolated absences) and treated any adjacent pairs as peripheral. Coastal squares were slightly disadvantaged by this method, but correcting for the presence of adjacent sea squares had the undesirable result that coastal squares without records could potentially achieve higher scores than squares in which Yellow-necked Mice had been recorded, so this approach was abandoned.

Derivation of variables

Temperature and rainfall data were purchased from the Meteorological Office in the form of 36 variables representing maximum and minimum temperature and mean rainfall for each of the 12 months. The original temperature and rainfall data were formed by taking the mean of the monthly values, as extrapolated from recording stations between 1961 and 1990, with temperature values given for every 5-km square (which were not adjusted to sea level) and rainfall values for every 1-km square. From these values it was possible to create a mean value for each 10-km square, for each of the 36 variables. In addition, the mean altitude of each 1-km square was also transformed into a mean value for each 10-km square.

Data on soil types in each 1-km square were purchased from the Soil Survey and Land Research Centre at Cranfield University. These data took the form of a habitat potential map derived from the national soil mapping programme 1979–84. The habitat potential map was formed by studying the relationship between natural and semi-natural habitats, and their underlying soils and amalgamating the associated soil types on the basis of soil wetness, pH and organic matter. Each 1-km square was assigned to one of 12 categories, with a few remaining squares uncategorized as 'other'. We calculated the total summed value for each of these 12 soil categories for each 10-km square and these 12 variables were used as independent variables in the analysis. In addition, the categories were regrouped to create new indices for soil pH and moisture for each 10-km square.

Two further variables describing woodland cover were also used. The areas of both broadleaved and coniferous woodland within each 1-km square were obtained from the Countryside Information System (CIS) (Department of the Environment, Version 5.23) and were originally derived from satellite imaging. The mean of the areas of each woodland type from every 1-km square was used to provide an index of relative woodland cover in each 10-km square.

Exploring the independent variables

Each of the three weather variables showed a high degree of cross-correlation between months. To reduce redundancy, 12 variables were derived representing seasonal values for mean rainfall, and maximum and minimum temperatures in each of four seasons, where

spring comprised March, April and May, etc. Principal components analysis confirmed that there was still considerable redundancy in these variables, with two factors explaining 89% of the overall variation. However, as our main analytical approach accommodated this cross-correlation, the original 12 weather variables, rather than the two principal components, were used since this facilitated subsequent interpretation.

Before undertaking complex analyses, the 29 variables finally selected (Table 6) were examined conventionally to look for linear relationships between the Yellow-necked Mouse index and the independent variables. Significant relationships were evident for nearly all the independent variables, although most only explained a fairly small part of the variation seen. Summer maximum temperature (23.0%), followed by spring maximum temperature (21.2%) and autumn maximum temperature (16.0%) were responsible for explaining the greatest part of the variation in the index. Matrix plots showed that some weather variables displayed more complex quadratic relationships with the Yellow-necked Mouse index. This indicated that conventional linear statistics would be inadequate to explain these data.

Table 6. The climate, soil and woodland variables considered in the analysis of *A. flavicollis* distribution

Abbreviation	Variable	Description
WINMAX	Winter maximum temperature	Maximum seasonal 10-km square values derived from
SPRMAX	Spring maximum temperature	the monthly 1-km square maximum temperature
SUMMAX	Summer maximum temperature	values taken from the mean monthly maximum
AUTMAX	Autumn maximum temperature	temperatures between 1961 and 1990.
WINMIN	Winter minimum temperature	Minimum seasonal 10-km square values derived from
SPRMIN	Spring minimum temperature	the monthly 1-km square minimum temperature
SUMMIN	Summer minimum temperature	values taken from the mean monthly minimum
AUTMIN	Autumn minimum temperature	temperatures between 1961 and 1990.
WINRAIN	Mean winter rainfall	Mean seasonal 10-km square values derived from the
SPRRAIN	Mean spring rainfall	monthly 5-km square mean rainfall values taken from
SUMRAIN	Mean summer rainfall	the mean monthly rainfall between 1961 and 1990.
AUTRAIN	Mean autumn rainfall	
DRYCAL	Dry calcareous soil	10-km square values were the total summed value of
DRYNEUT	Dry neutral soil	each category from all 1-km squares. Habitat
DRYACID	Dry acidic soil	potential types were derived by amalgamating
MSTCAL	Moist calcareous soil	associated soil types from the national soil survey on
MSTNEUT	Moist neutral soil	the basis of soil wetness, pH and organic matter to
MSTACID	Moist acid soil	form 12 categories to which each 1-km square was
WETCAL	Wet calcareous soil	assigned.
WETNEUT	Wet neutral soil	
WETACID	Wet acid soil	
FEN	Fen	
ACIDPT	Acid peat	
PTBOG	Peat bog	
MOIST	Soil moisture	10-km square values were derived from the habitat
PH	Soil pH	potential types according to weighted averages based
		on our own weightings that we gave to the soil
		descriptions provided.
DECID	Deciduous woodland	10-km square values were the mean of the total area of
CONIF	Coniferous woodland	each woodland type in all 1-km square , as derived
		from satellite imagery.
ALT	Altitude	10-km square values were the mean altitudes of all
		1-km squares

Discriminant Function Analysis (DFA)

The Yellow-necked Mouse index defined absent, peripheral and core areas, so a preliminary approach using stepwise DFA was used to explore which suite of independent variables might best discriminate between these areas. In stepwise DFA, variables are added to the discriminant function one at a time, until the addition of extra variables does not give significantly better discrimination.

Analysis using BEAGLE

BEAGLE (Forsyth, 1987) is a data-mining computer program utilizing a genetic algorithm to uncover hidden relationships between variables. It is similar to DFA in that it uses a set of independent variables to classify a data set according to a target expression. For example, we were interested in discriminating between the 10-km squares that were defined as peripheral or core from those defined as absent. In other words, the target expression was 'Index > 1'. BEAGLE randomly generates a population of expressions (or rules) based on the independent variables and then tests each one of these in turn against the target expression. The worst rules, i.e. those which predict least well are dropped and a new rule set is created from those remaining by mutation of the values and recombination of fragments of the rules. These are tested, in turn, on the target and the whole process repeated through a large number of generations. In this way, BEAGLE evolves a population of rules that are extremely powerful at predicting the target expression.

BEAGLE has numerous advantages over traditional DFA. First, and probably most importantly for ecological data, it can uncover non-linear relationships. In particular, it uses threshold values; for example, 'if temperature is greater than 20°C, then the target is true'. Secondly, BEAGLE can use combinations of categorical, ordinal and ratio scale data in its rules. Thirdly, it can produce conditional rules using Boolean logic; thus 'temperature > 20°C OR woodland is absent'. Finally, because it is a non-parametric technique it is not adversely influenced by problems such as cross-correlation in its independent variables. If a rule is bred that utilizes two correlated variables, it is because, at certain values, they are more powerful predictors in combination than either is alone.

We used BEAGLE to test a number of target expressions, setting each run for 1000 generations. All 29 independent variables were incorporated, based on all 1529 10-km squares in the area examined. It should be noted that the 1529 squares represented the whole statistical population, not just a sample. However, we also used the expression $((34 - \text{easting})*1.55) + (\text{northing} - 7) > 0$ to split the country into two zones, representing the eastern and the western regions of Yellow-necked Mouse distribution. The northern boundary of this area was set to the 40-north national grid line in order to equilibrate the number of squares in each zone. Separate BEAGLE runs were then made to see if different variables accounted for Yellow-necked Mouse distribution in each zone. In each case, the smoothed distribution (Fig. 4) was used in these analyses.

Climate change analysis

Data on predicted climate change were obtained from the UK Climate Impacts Programme (Hulme & Jenkins, 1998). Among the predictions available was mean summer temperature in 2020, 2050 and 2080, based on different temperature change scenarios. The low and high predictions for each of these periods were entered into the best overall rule set found by BEAGLE, which included maximum summer temperature, in order to assess the possible effect of rising temperatures on the distribution of this species. The implications of using mean rather than maximum temperature in our model is considered in the Discussion.

Results

Current distribution map

Figure 3 shows the 10-km square distribution map for the Yellow-necked Mouse in Britain, produced from the enhanced record database. One verified record from Northumberland dating back to 1911 was excluded by the northerly cut-off line. Figure 4 shows the smoothed distribution map that classified each 10-km square as core, peripheral or absent for Yellow-necked Mice.

Factors explaining distribution

Stepwise DFA allowed eight variables into the final model (Wilks' λ = 0.557, $F_{16,3038}$ = 64.6, $P < 0.001$) (Table 7), correctly classifying 94% of squares without Yellow-necked Mice and 62% of core Yellow-necked Mouse squares. Broadleaved woodland came into the model as the second variable, but was finally removed by the entrance of soil pH; winter temperatures and soil categories were absent from the model. With fewer than six variables in the model, its predictive success was poor. The high number of variables used in this discriminant function suggests that its significance must be assessed with caution.

BEAGLE produced rule sets that predicted presence and absence of Yellow-necked Mice in 10-km squares for: (a) all 10-km squares in the area considered; (b) 10-km squares in the eastern zone; and (c) 10-km squares in the western zone. The exact rules produced and their predictive powers are shown in Table 8.

The best rule set for the overall range correctly predicted Yellow-necked Mouse presence and absence with 64.3 and 88.4% accuracy, respectively, using just two variables–maximum summer temperature and broadleaved woodland area. The relationship between these variables is shown in Fig. 5. Squares containing Yellow-necked Mice predominantly experience maximum summer temperatures above 20°C and, where this temperature level starts to fall, higher levels of broadleaved woodland cover appear to be required if Yellow-necked Mice are still to be present. The predictive accuracy of the model is shown in Fig. 6.

The overall rule convincingly predicted the distribution in the east, but under-predicted the range in the west of the country. Separate models were generated for the eastern and western zones to investigate possible regional differences, and the two rules created predicted distributions in each zone with greater accuracy than the overall rule set (Table 8). In the eastern zone, the model included the area of coniferous woodland and fen type soils, as well as mean summer temperature; in particular, it showed that squares containing significant amounts of wet fen-type soil are seldom found to support Yellow-necked Mice. In the western zone the regional rule still struggled to predict distribution accurately, especially the spur into Carmarthenshire. Maximum summer temperature remained the key variable in both regions; the predicted distribution in each region is shown in Fig. 7(a,b).

	Wilks' λ	Partial λ	F-remove	P
SUMMAX	0.7182	0.7749	220.6	< 0.001
ALT	0.6571	0.8469	137.3	< 0.001
CONIF	0.5723	0.8925	21.5	< 0.001
SUMRAIN	0.6336	0.8784	105.2	< 0.001
AUTRAIN	0.6314	0.8814	102.2	< 0.001
WINRAIN	0.6025	0.9237	62.7	< 0.001
MOIST	0.5671	0.9814	14.4	< 0.001
PH	0.5631	0.9884	9.9	< 0.001

Table 7. Dicriminant function model to predict absent, peripheral and core 10-km squares for *A. flavicollis*
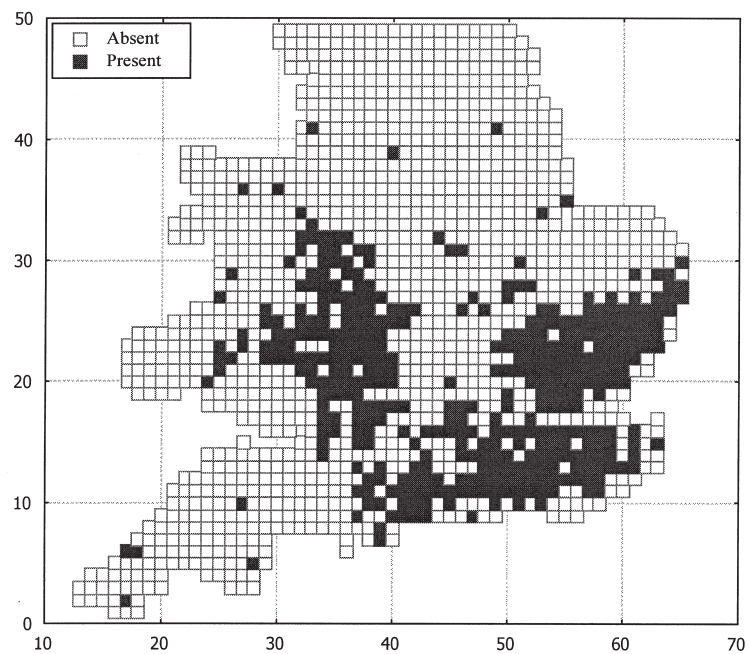
Fig. 3. Distribution of Yellow-necked Mouse records by 10-km squares combining records from Arnold (1993) and additional data from this survey.
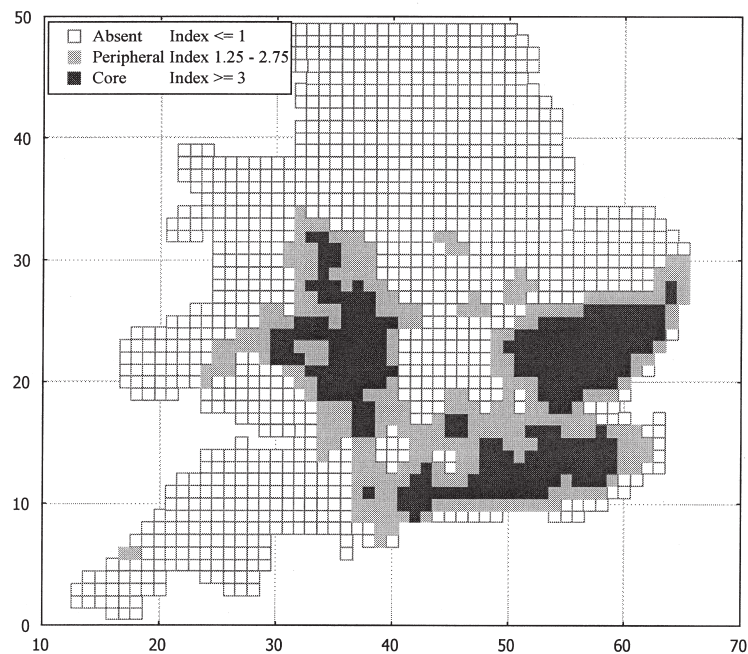

Fig. 4. Smoothed distribution map for *A. flavicollis* coding 10-km squares as core, peripheral or absent; see text for details.

Table 8. The rules produced by BEAGLE to predict the presence or absence of *A. flavicollis*, and the percentage of 10-km squares correctly or incorrectly predicted by these rules

(a) Best overall rule

(SUMMAX – 20.275) > (BROAD < 6.136)

Index > 1	Recorded absent	Recorded present
Predicted absent	907	119
Row percent	*88.40%*	*11.60%*
Predicted present	179	322
Row percent	*35.73%*	*64.27%*

(b) Eastern zone

((CONIF – FEN) > = 0.642) – (SUMMAX < = 20. 050)

Index > 1	Recorded absent	Recorded present
Predicted absent	168	59
Row percent	*74.01%*	*25.99%*
Predicted present	48	271
Row percent	*15.05%*	*84.95%*

(c) Western zone

(SUMMAX – AUTMAX) > 2.95

Index > 1	Recorded absent	Recorded present
Predicted absent	507	78
Row percent	*86.67%*	*13.33%*
Predicted present	52	130
Row percent	*28.57%*	*71.43%*

Effect of climate change

Figure 8(a,b) shows how the predicted rises in summer temperatures may affect the distribution of the Yellow-necked Mouse by 2020, 2050 and 2080, as described by our overall rule set. They represent high and low temperature change scenarios, respectively, and show that a potential range expansion to the north and west could occur, particularly if the temperature rises are at the higher end of predictions for climate change. This assumes that other controlling factors remain unchanged.

DISCUSSION

The national trapping study

This study was designed to provide an instantaneous view of the distribution and relative abundance of Yellow-necked Mice. The trapping protocol, therefore, would not be appropriate for monitoring long-term changes at the individual site level, as inter-annual effects may be marked. Experienced volunteers conducted the trapping studies and, although this enabled a large, broadly distributed number of sites to be surveyed, these data may incorporate differences between recorders in terms of their skills, accuracy and compliance with the methodology. For instance, the inclusion of an evening round trap by some surveyors is likely to have introduced a small variation in trap effort as animals released that evening could potentially have been recaptured in other traps the following morning. In practice, this variation was thought to be negligible and no greater than other sources of variation, such as the occasional animal that escaped before marking. Despite its potential problems, we believe that using experienced volunteers provided robust and reliable data.

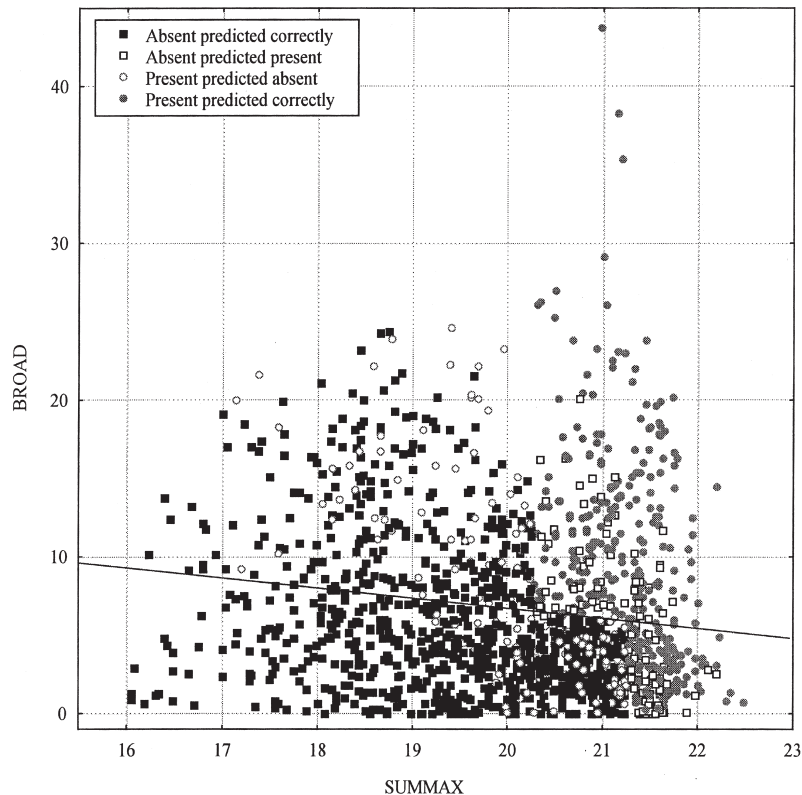The trapping study marginally extended the known range of the Yellow-necked Mouse into

Fig. 5. Scatter plot of 10-km square values showing the relationship between broadleaf woodland cover (BROAD) and summer maximum temperature (SUMMAX). The line represents the rule (SUMMAX − 20.275) > (BROAD < 6.136).

Staffordshire and Bedfordshire, and records from parts of Cambridgeshire, north-east Kent and Shropshire clarified more speculative parts of the distribution map. There were also many new records within the known range and the high number of such sites indicates that the Yellow-necked Mouse is still widespread within suitable woodland inside its existing range.

Previous studies have shown that Yellow-necked Mice may exist in greater numbers than Wood Mice (Yalden, 1971; Montgomery, 1980b; Marsh & Harris, 2000a), and it has generally been assumed that these woodlands represented exceptional sites or events. In this survey Yellow-necked Mice had a higher relative abundance than Wood Mice at 15% of sympatric sites, suggesting that within suitable woodland, at least during the autumn, Yellow-necked Mice are the dominant species more often than was previously thought.

Montgomery (1980b) showed that loss of breeding status in sympatric Yellow-necked and Wood Mice occurred much as suggested by this study, with males retaining breeding status for longer than females. However, it is the structure of Wood Mouse populations in woods with and without Yellow-necked Mice that is of particular importance to understanding possible consequences of sympatric living. Competitive interactions may occur between these two species (Montgomery, 1981, 1985), although how these manifest remains uncertain. One suggestion has been that Yellow-necked Mice may be more arboreal than Wood Mice, although efforts to investigate this have been largely inconclusive (Montgomery, 1980a;
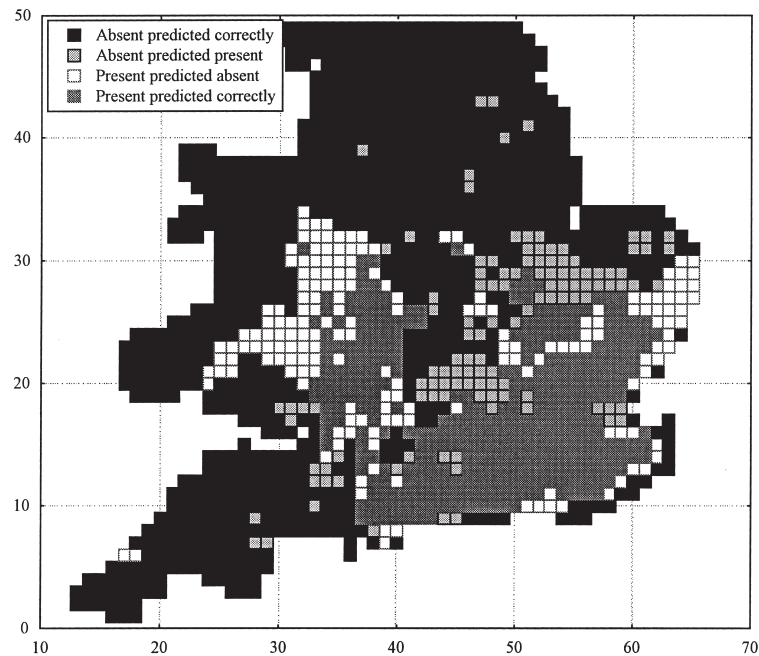
Fig. 6. The predicted distribution of *A. flavicollis* across southern Britain using the model: (SUMMAX – 20.275) > (BROAD < 6.136).

Marsh, 1999). Based on removal experiments, Montgomery (1981) concluded that competitive interactions between Yellow-necked and Wood Mice are weak and probably ameliorated by differences in their biology. The results from this study imply that the presence of Yellow-necked Mice within a wood somehow accelerates the loss of breeding condition of breeding male Wood Mice, although reasons for this are not clear.

Woodland age may be important to Yellow-necked Mice, with mature deciduous woodland the favoured habitat of this species (Montgomery, 1977, 1985). These data provided one of the first opportunities to explore these ideas on a wider scale. Although ancient woodland was significantly more likely to contain Yellow-necked Mice, even woodland planted in the last 100 years could support Yellow-necked Mice in autumn, although whether mice would be present at periods of lower abundance is not known. Woodland less than 50 years old appeared to be less suitable for Yellow-necked Mice. Overall, these results and those of other studies (Marsh *et al.*, 1999; Marsh & Harris, 2000a), suggest that, while ancient woodland may offer the best habitat for Yellow-necked Mice, mature diverse woodland that does not date back to pre-1600 may be just as suitable for this species.

Woodland size (> 2 ha) was not important in predicting the presence or absence of Yellow-necked Mice. However, woodlands isolated by more than 2 km from the next substantial woodland block (> 20 ha) were significantly less likely to contain populations of Yellow-necked Mice. Other studies have shown that lower isolation distances between woodlands do not appear to have any discernible effect on the relative abundance of Yellow-necked Mice (Marsh *et al.*, 1999; Marsh & Harris, 2000a). This supports the hypothesis that woods need to be well isolated before fragmentation affects the distribution of this species. However, the age and composition of neighbouring woodlands might also be important, as might differences in the intervening habitat type and the connectivity of fragments. We still know rela-

tively little about dispersal by Yellow-necked Mice and how these variables may affect such movements.

Yellow-necked Mice were more likely to be present in woods with less Ivy cover on the trees and higher levels of management activity. These results were at odds with initial hypotheses that Yellow-necked Mice would prefer sites showing least disturbance and greater Ivy cover to promote arboreal movement. However, Ivy is the only British member of the tropical family Araliaceae and its growth is strongly temperature dependent, displaying late flowering and great sensitivity to frost (Godwin, 1975). As a result, stems do not grow up into trees as frequently in the north and east of the country, where winters are cold and dry, as in the west, where winters are warmer and wetter. The regional variation in tree-based Ivy scores from this study reflected this pattern. The European range of the Yellow-necked Mouse (Mitchell-Jones *et al.*, 1999) correlates with areas that experience drier, colder winters, and we suggest that the relationship between this species and woods with lower levels of Ivy cover indicates a climatic effect.

We suggest two possible explanations for the ability of higher management scores to help predict the presence of Yellow-necked Mice. First, many of the woods surveyed were nature reserves; these are likely to be high quality woodlands that are often actively managed. Therefore, management activity may have been subtly linked to woodland quality, something that might explain its relevance to the presence of Yellow-necked Mice. Secondly, a high woodland management score did not necessarily indicate the type of disturbance that would be detrimental to Yellow-necked Mice or other rodents; recent evidence of thinning, ride-widening or coppicing would have resulted in a high score. When carried out sensitively, these practices may improve the variety of microhabitats within the wood, enhancing the range of potential food sources for rodents.

Distribution analysis

The distribution map created by the compilation of new and existing records confirmed the known range of the Yellow-necked Mouse, and made minor additions within and at the edge of its range. However, information on local populations is still very patchy, and in Devon and Cheshire, for example, despite the absence of records during the trapping survey, there are several recent, but unsubstantiated records. Furthermore, counties in central England are poorly represented and the existence of outlying populations in this and other areas should not be discounted.

The smoothed distribution (Fig. 4) of the Yellow-necked Mouse highlights core and peripheral areas. The analysis using BEAGLE generated rules that were good at determining the range of the species in the eastern zone, but notably less successful for the west of the country. Since the western part of their range displays more mountainous and varied topography than the east, one possibility is that the 10-km scale used here was too broad to detect the microclimatic differences in these areas, particularly across into Carmarthenshire. Alternatively, some other variable that we have not included may also be of particular importance in determining their range in this area. For example, these analyses were unable to take account of the age of woodland and only differentiated broadleaved and coniferous woodland. A computerized ancient woodland inventory was not available, but this would undoubtedly have been beneficial to these analyses.

Nonetheless, the predictive capabilities of the rules produced by BEAGLE were impressive. The repeated selection of summer maximum temperature in these rules and in the DFA suggests that this is an important variable. Both analyses suggest that winter temperature is unimportant in defining Yellow-necked Mouse range. The failure of rainfall, soil moisture, soil pH
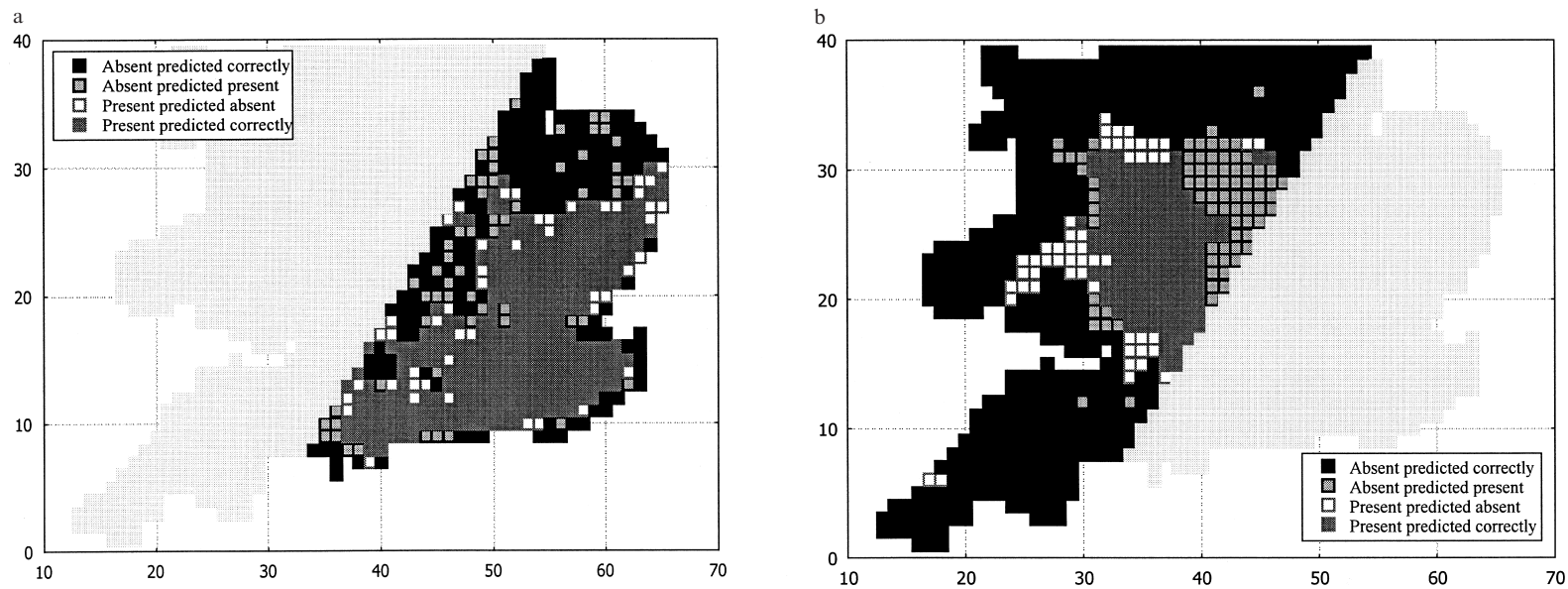
Fig. 7. (a) The predicted distribution of *A. flavicollis* in the eastern zone based on the model: ((CONIF–FEN) >= 0.642) – (SUMMAX <= 20.050). (b) The predicted distribution of *A. flavicollis* in the western zone based on the model: (SUMMAX – AUTMAX) > 2.95.
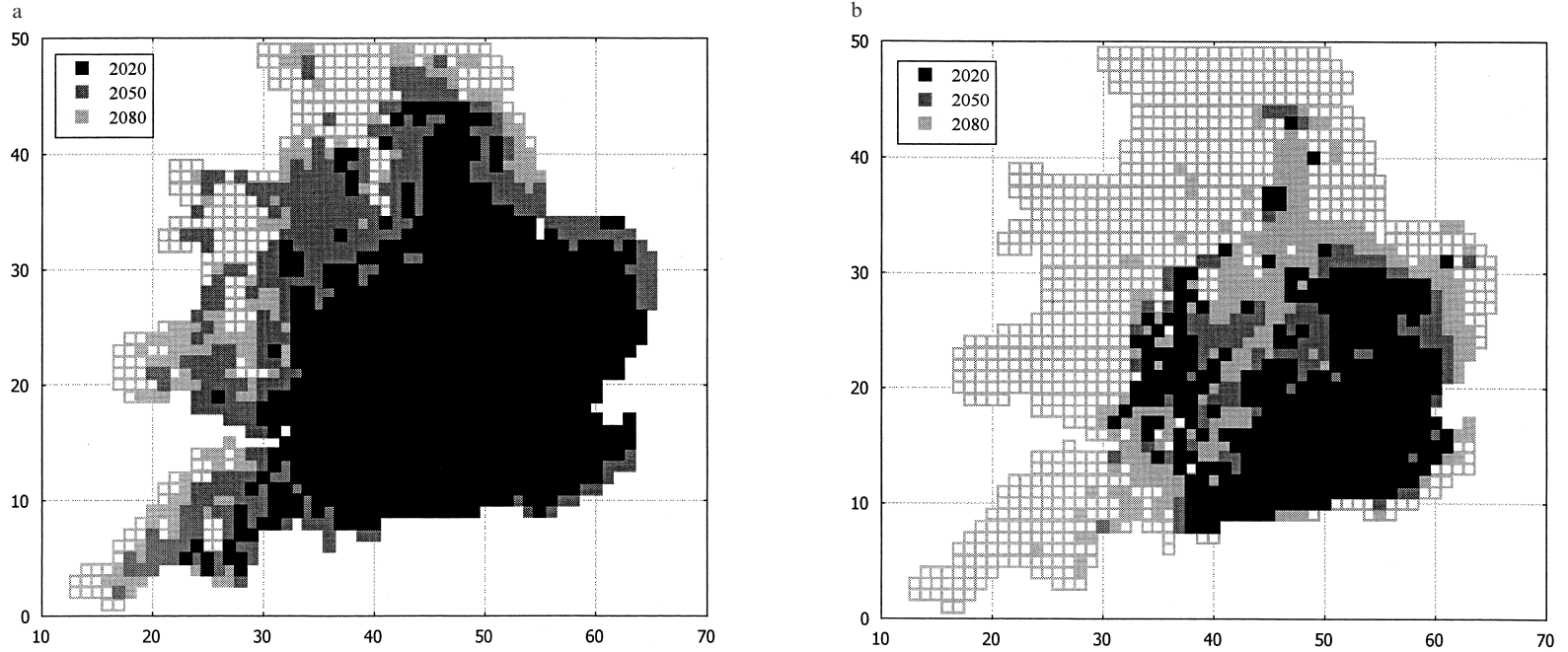
a

b

Fig. 8. (a) 10-km squares with suitable climatic conditions for *A. flavicollis* in 2020, 2050 and 2080, based on values for (a) high climatic change scenarios and (b) low climatic change scenarios entered into the overall model.

and most soil variables to help predict the range of the Yellow-necked Mouse indicates that these factors may not be important either. However, maximum summer temperature may be closely related to summer soil moisture deficit and so the conclusions of Montgomery (1978), who suggested that Yellow-necked Mice were limited to areas with drier soils, cannot be entirely discounted. Nonetheless, high summer temperature was found to be of overriding importance and we suggest that the most likely explanation may relate to botanical associations. High summer temperatures are known to affect tree seed production. If the Yellow-necked Mouse specializes on tree seed (Corbet & Harris, 1991), then the availability and reliability of seed production is likely to be particularly important. The laying down of flower buds in Beech and Oak, as well as other tree species, is favoured by high summer temperatures (see Matthews, 1955; Jones, 1959), and summer temperature can also influence tree seed fertility and thereby species distribution (see Pigott & Huntley, 1978).

We know that Beech mast, acorns and hazelnuts are regularly stored and utilized by Yellow-necked Mice, so the distributions of these tree species may be particularly important. Natural Beech woods are restricted to parts of southern Britain, and native Beech does not reach the far south-western counties of Somerset, Devon and Cornwall (Watt & Tansley, 1932). In addition, *Quercus robur* is the usual cover over Hazel in coppice-with-standard woodland, but it is rarer than *Q. petraea* in Wales, Devon and Cornwall (Jones, 1959). Where Yellow-necked Mice are found in areas not predicted by our models, such as across South Wales into Carmarthenshire, *Quercus* woodland is present against expectations based on climate. These observations are speculative and there is no evidence to show that any specific association exists with any tree species. However, it is known that all tree species show an irregular pattern of annual seed production. Thus, a seed specialist could be restricted to areas where sufficient species diversity occurs to ensure an adequate food supply each year from one source or another. Jones (1959) points out that even in years when a region suffers from almost complete seed failure, there will be abundant seed over a limited area, a single wood or a part thereof. This would seem to fit with the tentative conclusions of Montgomery (1985) and Marsh & Harris (2000a), who suggested that Yellow-necked Mice might retreat to key woodland areas over the winter, where tree seed availability remained good.

Since the rules produced by BEAGLE found that Yellow-necked Mouse distribution was most heavily influenced by maximum summer temperature, we used this to explore the way in which distribution may be affected by climate change. However, the predicted temperatures used in the model, based on climate change scenarios, were for *mean* summer temperature, while the model itself was based on *maximum* summer temperature. These two variables are closely correlated and since the analysis of distribution in relation to predicted climate change was for illustrative purposes only, this discrepancy was not considered crucial. The overall trend will not be affected by this anomaly; the predicted distributions will simply under-estimate range expansion, as can been seen in the 2020 low scenario, where predicted range is actually more restricted than the model predicts for the present. The predictions do show that as climate warms Yellow-necked Mice may benefit by expanding their range to the west and the north. Whether such range expansion actually occurs will inevitably depend upon a number of other local factors not highlighted in this broad model. These include the availability of suitable woodland, and the accessibility and connectivity of woodland fragments.

SUMMARY

This study provided no evidence to support the hypothesis that the Yellow-necked Mouse is declining, either in terms of distribution or abundance. In agreement with hypotheses (ii) and

(iii), the Yellow-necked Mouse was more likely to be present in woodland of ancient origin and less likely to be present in more isolated woodlands. Hypothesis (iv), that Yellow-necked Mice are less abundant in more managed/disturbed woodland is rejected. There was no evidence to suggest that moderate levels of woodland management or human disturbance had any impact on populations of Yellow-necked Mice. The presence of Ivy on trees was inversely correlated with the presence of Yellow-necked Mice, so hypothesis (v), that the opposite was the case, is rejected. This may correspond to the fact that the cold and dry winter conditions that limit the growth of Ivy's fruiting stems are those preferred by Yellow-necked Mice. Hypothesis (vi), that the structure and abundance of Wood Mouse populations is not affected by the presence of Yellow-necked Mice, cannot be accepted or rejected. While the presence of Yellow-necked Mice had limited specific effects on Wood Mouse population structure, the overall abundance of Wood Mice was not shown to be affected. Contrary to hypothesis (vii), the distribution of the Yellow-necked Mouse was not seen to be determined by soil moisture or rainfall. Yellow-necked Mouse range was strongly linked to high summer temperatures and, at least in part, to deciduous woodland cover, so supporting hypotheses (viii) and (ix).

The work presented here provides a review of the current status and distribution of the Yellow-necked Mouse in Britain. However, there are still a number of areas of Yellow-necked Mouse ecology that would benefit from further study, not least the comparative diet and arboreality of Yellow-necked and Wood Mice, details of Yellow-necked Mouse social structure and dispersal, and the impact of tree seed production on their abundance and distribution.

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