

Bat activity and species richness on organic and conventional farms: impact of agricultural intensification

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Summary

1. Agricultural intensification is perceived to be a major cause of the decline in many European bat populations. Because organic farming prohibits the use of agrochemicals, we compared organic vs. conventional farm types to test the hypothesis that agricultural intensification based on high levels of agrochemical use has been a factor in bat population declines. Bat activity and species richness were compared on matched pairs of organic and conventional farms.

2. Bat activity was quantified using acoustic surveys within specific habitats on farms in southern England and Wales. Eighty-nine per cent of bat passes were identified to species level using artificial neural networks (ANN). A further 9% were identified to genus.

3. Total bat activity was significantly higher on organic farms than on conventional farms. Significantly more bat passes were recorded over water on organic farms than on conventional farms. Foraging activity (quantified in two ways: total feedings buzzes and feeding buzzes per pass) was significantly higher on organic farms than on conventional farms.

4. The dominant species on both farm types were *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*. Significantly more passes of *Myotis* species were recorded on organic farms than on conventional farms. This difference was also significant when water habitats were considered alone.

5. The activity of both *Myotis daubentonii* and *Myotis brandtii* was significantly higher on organic farms than on conventional farms. The activity of *Myotis bechsteinii* and *Myotis brandtii* was significantly higher over organic water habitats than over conventional water habitats. *Rhinolophus hipposideros* and *Rhinolophus ferrumequinum* were only recorded on organic farms in wooded, arable and pasture habitats.

6. *Synthesis and applications.* This study highlights the position of bats as bioindicators and victims of agricultural change. The differences in bat activity between farm types may reflect features such as taller hedgerows and better water quality on organic farms. Higher foraging activity also suggests that habitat quality in terms of prey availability is greater on organic farms. Less intensive farming benefits bats, and as the number of organic enterprises increases it may help to reverse declines in bat populations.

Key-words: agrochemicals, artificial neural networks, foraging, habitat fragmentation, organic farming.

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Introduction

Growing evidence suggests that many bat species are declining across Britain and Europe (Stebbing 1988; Harris *et al.* 1995; Mitchell-Jones 1995; Walsh & Harris

1996a,b; Hutson, Mickleburgh & Racey 2001). The status of bats has received increasing attention at an international level, reflecting the importance of their role in biodiversity and ecosystems (Hutson, Mickleburgh & Racey 2001). Of the 16 species found in Britain, the International Union for the Conservation of Nature Red List published in 2000 identified *Rhinolophus hipposideros*, *Myotis bechsteinii* and *Barbastella barbastellus* as Vulnerable. The Bern and Bonn Conventions on

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biological diversity have focused on the plight of bats, resulting in an Agreement on the Conservation of Bats in Europe and the European Community (EC) Habitats and Species Directives (Annexes II and IV). All bat species found in Britain are protected by law in the European Union (EU) as well as by national legislation.

Six of the 16 species of bat in Britain [*Pipistrellus* species, since identified as two species, *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus* (Jones & Barrat 1999), *Myotis bechsteini*, *Rhinolophus hipposideros*, *Rhinolophus ferrumequinum* and *Barbastella barbastellus*] have UK Biodiversity Action Plans (BAP) assigned to them (Anon. 1995). The BAP identify habitat loss and agricultural intensification as reasons for the decline of all six. However, there are few data to show the impact of agricultural intensification on bat numbers. Nevertheless, the Department for Environment, Food and Rural Affairs (Defra) emphasized the need to incorporate the requirements of bats into agri-environment schemes (<http://www.defra.gov.uk>).

More than 76% of the land in Britain is used for agriculture (Robinson & Sutherland 2002) and all of the bat species found in Britain forage in agricultural landscapes. The intensification of agriculture, defined as increased production of agricultural commodities per unit area (Donald, Green & Heath 2001), has been possible through increased mechanization and use of synthetic chemical fertilizers and pesticides (agrochemicals). However, this increased production of commodities per unit area has been accomplished at the expense of farmland habitat diversity and farmland biodiversity (O'Connor & Shrub 1986; Altieri 1999; Mickleburgh, Hutson & Racey 2002). The loss of traditional rotations in farm management has led to a decrease in non-crop habitats such as hedgerows, field margins, ponds and copses (small areas of woodland) (Robinson & Sutherland 2002), which may be used as shelter, feeding sites and breeding sites for birds, insects and other wildlife. Species known to be affected by agricultural intensification include birds (Chamberlain, Wilson & Fuller 1999; Ormerod & Watkinson 2000; Ambrosini *et al.* 2002; Benton *et al.* 2002), spiders and several insect groups such as ground beetles (Aebischer 1991; Feber *et al.* 1997; di Giulio, Edwards & Meister 2001). Of the 28 farmland bird species studied in Britain, 24 have shown a contraction in range during the period between 1970 and 1990 that has been linked to intensification of British agriculture (Fuller *et al.* 1995). Bats in Britain are insectivorous, so declines in insect abundance as a result of agricultural intensification are likely to have serious implications for bat foraging.

Organic farming is a production system in which the use of synthetic fertilizers, pesticides, growth regulators and livestock feed additives are largely excluded (Lampkin 1998). The organic certifying bodies in the UK (The Soil Association Certification Limited, Bristol, UK; Organic Farmers and Growers Ltd, Shrewsbury, UK) have rigid criteria that restrict any chemical input, and provide

mandatory rules for the management of livestock and crops. The organic standards prohibit the use of agrochemicals and include recommendations for the management of non-crop areas such as woodland and riparian habitats. Therefore, the comparison between organic and conventional farms is an ideal model system with which to investigate the impact of agricultural intensification on biodiversity.

In this study we evaluated the extent to which agricultural intensification is implicated in bat population declines by investigating the effects of intensification on bat activity, species richness and habitat use on matched pairs of organic and conventional farms.

Methods

STUDY SITES

The study was conducted in 2000 and 2002 on 24 pairs of farms in seven counties across southern England and Wales, UK. To reduce the likelihood that confounding variables would obscure any real differences due to farm type, sites were paired to standardize for various characteristics as much as possible, with the exception of farm management. The organic farms used were those certified by the two official national certifying bodies. Certified farms are defined according to Soil Association and UK Register of Organic Food Standards after the completion of a 'conversion' period of 2–3 years of organic management. All the organic farms used had been established for 1 or 2 years post-conversion. As there is no national list of conventional farms, these were selected by asking the organic farmer about the nearest farm with a similar business that would be suitable for study. Each organic farm was paired with a conventional farm no more than 5 km away to standardize for geographical variation. The sizes of the farms within a pair were similar, and the pair had to contain one or more of four previously selected habitats: pasture, arable land, water and woodland, habitats known to be important for bats (Vaughan, Jones & Harris 1997).

HABITAT SURVEYS

Phase I habitat surveys (Anonymous 1990) were carried out on all farms. Geo-referenced tiles of all the study areas derived from digitized Ordnance Survey maps (<http://digimap.edina.ac.uk>) were put into a geographical information systems (GIS) application (ArcView version 3.2 and ArcView Spatial Analyst, Environmental Systems Research Institute, California, USA) so that the habitat information could be merged with the base map tiles. Using this GIS application, habitat variables such as farm area, habitat area and length of hedgerow were calculated. If any of the selected habitats were present in both farms within a pair, they were sampled. The order of habitats surveyed within a pair was kept the same, but visits were randomized between pairs. On the night of sampling, habitat and environmental variables were measured at

randomly selected sampling points within each habitat. These included temperature, wind speed, barometric pressure (Windwatch, Silva Alba, London, UK) and hedgerow height (1 m ruler, accuracy ± 1 cm). Means of these measurements were calculated for each habitat for further analysis.

SAMPLING PROTOCOL

To avoid temporal differences in bat activity, the two farms of each pair were sampled within the period June–September on consecutive nights. This was not likely to introduce errors because variation in bat activity was thought to be greater within a night than between nights (Hayes 2000). Because sampling took place on consecutive nights, variation in weather had to be controlled for between nights and thus a strict sampling protocol was followed to standardize between-pair comparisons. The temperature measured at dusk had to be within 4 °C of the previous night for sampling to take place. Insects become less active below 10 °C (Rydell, Entwistle & Racey 1996) and prolonged heavy rain would have damaged the sensitive equipment used to detect the bats, so sampling was abandoned if the temperature dropped below 10 °C or heavy rain set in. If sampling was abandoned half way through the pair, the second farm was sampled on the next night following the same sampling protocol. If this second night was also unsuitable according to the protocol, then the pair of sites was resampled. This meant there was a gap of no more than one night between sampling farms in a pair.

BAT ACTIVITY RECORDING

Within each habitat, three points were chosen randomly for the acoustic survey of bat activity, points being more than 15 m apart. Sample points were often in different fields of the same habitat and in close proximity to a hedgerow, unless the habitat sampled was water or woodland. Because individual bats cannot be counted with an acoustic method, bat activity was quantified by counting the number of bat passes per 10 min at each point (Fenton 1970). We used this method to estimate intensity of use at survey points rather than abundance, although the two are almost certainly correlated. Foraging activity was quantified by counting the number of feeding buzzes recorded (Griffin, Webster & Michael 1960). Bat sampling commenced 1 h after sunset to avoid peak emergence times for different bat species, and ended, on average, 1.5 h later. The length of sampling time varied between pairs depending on the number of habitat types present. The timing of sampling ensured that it coincided with the peak foraging activity for aerial foraging bats, and ended before insect abundance dropped (Racey & Swift 1985).

Bat activity was recorded sequentially for 10 min at each point, digitizing ultrasound using a laptop computer (Toshiba, Satellite Pro, 4080 XCOT, Toshiba of Europe, London, UK) with a PCMCIA III card (DAQCard AI-

16E-4; National Instruments, Austin, TX, USA; sampling frequency = 500 kHz) connected to an S25 bat detector (Ultra Sound Advice, London, UK). The detector was housed on a tripod 1 m above the ground angled up at 45°. If the habitat was bordered by a hedgerow, the detector was also angled approximately 20° from this feature towards the field. Recording was triggered manually for 5 seconds whenever a bat call was heard on frequency division (a setting that scans through a wide frequency range), and the bat passes sampled using BatSound software (BatSound v1.0; Pettersson Elektronik AB, Uppsala, Sweden). Such direct sampling enables high-quality recordings of ultrasound, similar to that achieved by time expansion, a system that involves the digital time expansion of a call to a lower frequency (Jones, Vaughan & Parsons 2000). The recordings can be made over long periods without losing recording time while a signal is being expanded, a problem inherent in time expansion systems. The recordings from the direct sampling method were used for quantification of activity and species identification.

A second method of recording bat activity was used simultaneously to obtain real-time recordings of feeding buzzes. A Pettersson D980 detector (Pettersson Elektronik AB) or S25 detector (Ultra Sound Advice) was linked to a professional Walkman cassette recorder (Sony WM D6C; Sony, Tokyo, Japan) or a digital audio tape (DAT, TCD-D8; Sony) and the frequency-divided output recorded continuously. The same combination of equipment was used within each pair so that changes did not affect the analysis.

BAT SPECIES IDENTIFICATION AND STATISTICAL METHODS

The first call with a good signal to noise ratio was selected from each pass and entered into an artificial neural network program (ANN; Parsons & Jones 2000). ANN are relatively new techniques that have been applied to the identification of individuals and species (Burnett & Masters 1999; Parsons & Jones 2000). The ANN used for this study had already been developed at the University of Bristol (Bristol, UK), where it was 'trained' using data sets of calls produced by known species and programmed to classify calls down to genus and then species level with a reported degree of confidence associated with each identification (Parsons & Jones 2000). ANN rarely give absolute confidence on species identification; the overall level of confidence used here was 85% and if the confidence fell below this value the result was considered unreliable and not used in the species-specific analysis.

The differences between farm types were analysed using the paired *t*-test, if the differences were normally distributed. Data were $\log(\log_{10}(x + 1))$ transformed if necessary to achieve normality in the differences (Zar 1999). Analyses were carried out using Minitab version 13 (Ryan & Joiner 1994). Organic data minus the conventional data were used to generate the differences; the direction was the same in all of the paired tests.

Table 1. Total sampling time in each habitat type and the corresponding total number of bat passes for farm type

Habitat	Total sampling time (h)	Total bat passes recorded	
		Organic	Conventional
Pasture	21	335	246
Arable	8	74	58
Woodland	10	267	176
Water	8	447	144
Totals	47	1123	624

Results

A total of 1747 passes was recorded in 47 h (Table 1); 89% were identified to species using the ANN. The 9% that could only be identified to genus consisted of *Pipistrellus*, *Myotis* and *Nyctalus* species, which comprised 44%, 48% and 8% of this value, respectively. The remaining 2% could not be identified to genus or species.

No statistical difference was found between organic and conventional farms for mean temperature, mean wind speed, total number of habitats (i.e. including those not sampled), farm area and areas of habitats sampled, confirming that the pairs used were comparable with respect to these characteristics. Hedgerow height was significantly greater on organic farms compared with conventional farms (Table 2).

BAT ACTIVITY

Total bat activity (all species) was significantly higher (by 61%) over organic farms than over conventional farms ($t = 2.38$, d.f. = 23, $P = 0.026$; Fig. 1a). When habitat types were analysed separately, significantly higher numbers of passes were found over water habitats only (Table 3). It should be noted that the directionality of the t -values was consistent in all non-significant results (Table 3). Foraging activity, derived from feeding buzz counts from the real-time recordings, was significantly higher (by 84%) on organic farms ($t = 3.15$, d.f. = 23,

Table 3. Statistical significance of differences in bat activity between organic and conventional farms. Buzz ratio = number of feeding buzzes per bat pass

	n	t	P
Passes: pasture	21	0.85	0.406
Passes: arable	8	0.68	0.516
Passes: woodland	10	0.48	0.642
Passes: water	8	2.51	0.040
Feeding buzzes: pasture	21	1.76	0.094
Feeding buzzes: arable	8	1.44	0.192
Feeding buzzes: woodland	10	1.67	0.139
Feeding buzzes: water	8	1.61	0.141
Buzz ratio: pasture	21	1.69	0.106
Buzz ratio: arable	8	0.54	0.603
Buzz ratio: wood	10	1.15	0.281
Buzz ratio: water	8	0.12	0.909

$P = 0.004$; Fig. 1b). The numbers of feeding buzzes per pass (buzz ratio) were also significantly higher on organic farms, indicating a higher foraging effort on this farm type ($t = 2.61$, d.f. = 23, $P = 0.016$; Fig. 1c). There was a significant correlation between the number of feeding buzzes and hedgerow height (Spearman's coefficient correlation $r_s = 0.354$, $n = 48$, $P = 0.016$). No significant differences in foraging activity within individual habitats were found between farm types (Table 3).

BAT SPECIES COMPOSITION

Species richness was not statistically significantly different between farm type. Fourteen of the 16 British bat species were detected on organic farms compared to 11 on conventional farms (Fig. 2a,b). In both farm types *Pipistrellus pipistrellus* had the highest activity levels, with *Pipistrellus pygmaeus* being the second most frequently detected species. Both species represented more than 70% of all passes for both farm types. Species composition differed between organic and conventional farms. *Rhinolophus* species were only detected on organic farms, with 11 *Rhinolophus hipposideros* passes and one

Table 2. Statistical comparison of habitat and environmental variables between organic and conventional farms. Not all farm pairs contained all habitat types, hence sample size differs. Mean \pm SD (minimum–maximum). P -values derived from paired t -tests

Variable	Farm type		d.f.	t	P
	Organic	Conventional			
Wind speed (m s^{-1})	0.2 \pm 0.3 (0–1.1)	0.4 \pm 0.5 (0–2.5)	23	–1.87	0.074
Temperature ($^{\circ}\text{C}$)	14.7 \pm 2.2 (11–18)	13.7 \pm 2.3 (10–18)	23	1.98	0.059
Hedge height (m)	2.5 \pm 0.5 (1.4–3.6)	1.9 \pm 0.6 (1.2–3.4)	22	5.77	< 0.001
Hedge length (km)	4.4 \pm 1.9 (1.4–8.9)	3.6 \pm 2.2 (1.3–10.9)	23	1.87	0.074
Farm area (ha)	47.2 \pm 29.0 (11.8–133.8)	55.3 \pm 28.0 (18.5–117.2)	23	–1.59	0.124
Pasture area (ha)	32.8 \pm 15.9 (9.0–75.2)	28.8 \pm 12.8 (13.0–53.4)	20	0.79	0.437
Arable area (ha)	33.0 \pm 17.1 (5.3–62.8)	35.8 \pm 18.5 (9.3–72.7)	7	–0.25	0.809
Woodland area (ha)	4.6 \pm 4.9 (0.3–14.9)	6.9 \pm 9.1 (0.5–29.5)	9	–0.44	0.672
Water area (ha)	1.6 \pm 1.6 (0.005–5.0)	0.7 \pm 1.1 (0.05–3.5)	7	–1.20	0.351
Total no. of habitats	3.6 \pm 1.2 (1–6)	3.4 \pm 0.9 (2–6)	23	0.92	0.366

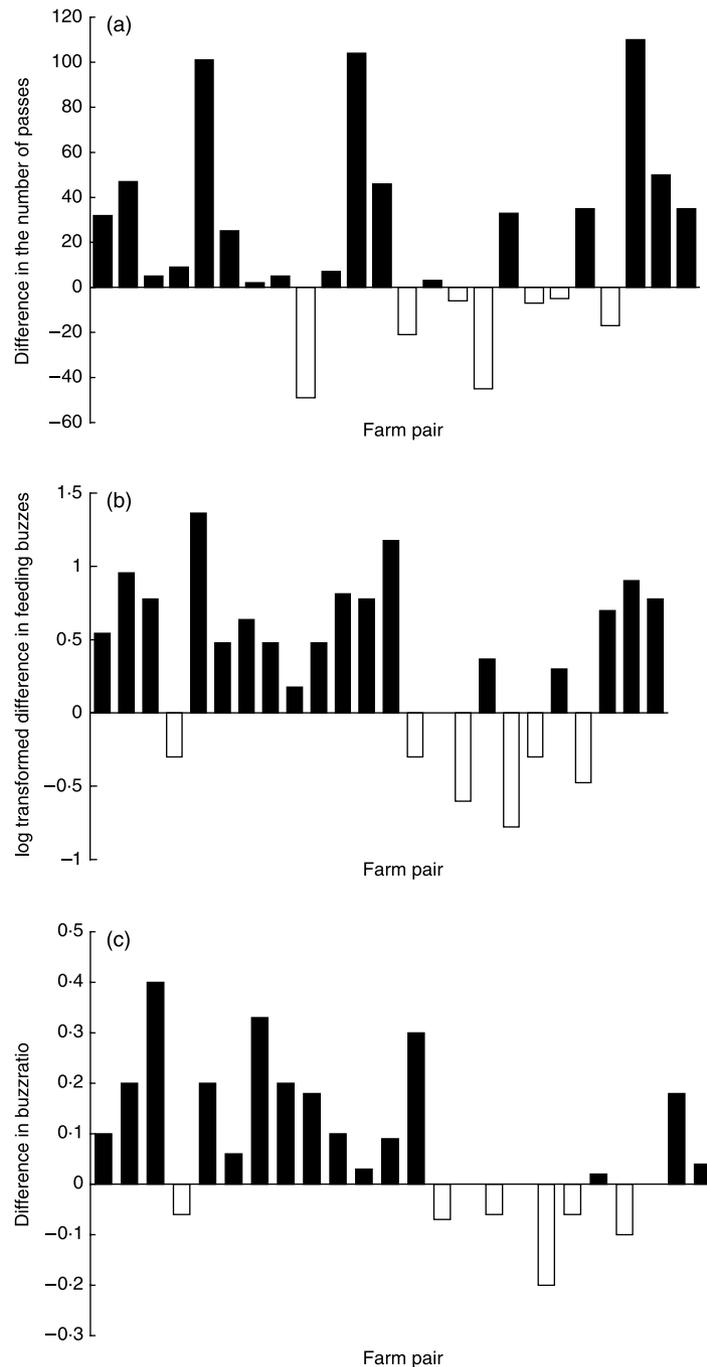


Fig. 1. (a) The differences in total numbers of bat passes per pair of organic and conventional farms. Black bars indicate more passes over organic farms; white bars indicate more passes over conventional farms. (b) Difference in total feeding buzzes per pair of organic and conventional farms. Black bars indicate more buzzes over organic farms; white bars indicate more buzzes over conventional farms. (c) Difference in buzz ratio per pair of organic and conventional farms. Black bars indicate a higher buzz ratio over organic farms; white bars indicate a higher buzz ratio over conventional farms.

Rhinolophus ferrumequinum pass. Significantly higher *Myotis* activity was recorded on organic farms than on conventional farms ($t = 2.62$, d.f. = 23, $P = 0.015$). When all the species data were considered in all habitats, the activity of both *Myotis daubentonii* ($t = 2.09$, d.f. = 23, $P = 0.048$) and *Myotis brandtii* ($t = 2.27$, d.f. = 23, $P = 0.033$) were significantly higher on organic farms than on conventional farms. More than 50% of the passes by both of these species were recorded over water habitats.

HABITAT USE

Rhinolophus hipposideros was only recorded on organic farms in pasture, arable and woodland habitats, with the majority being in woodland habitats (Table 4). The only recorded pass of *Rhinolophus ferrumequinum* was over an organic arable habitat. *Nyctalus noctula* was recorded in all habitats on both farm types, with the exception of organic arable, but was predominantly

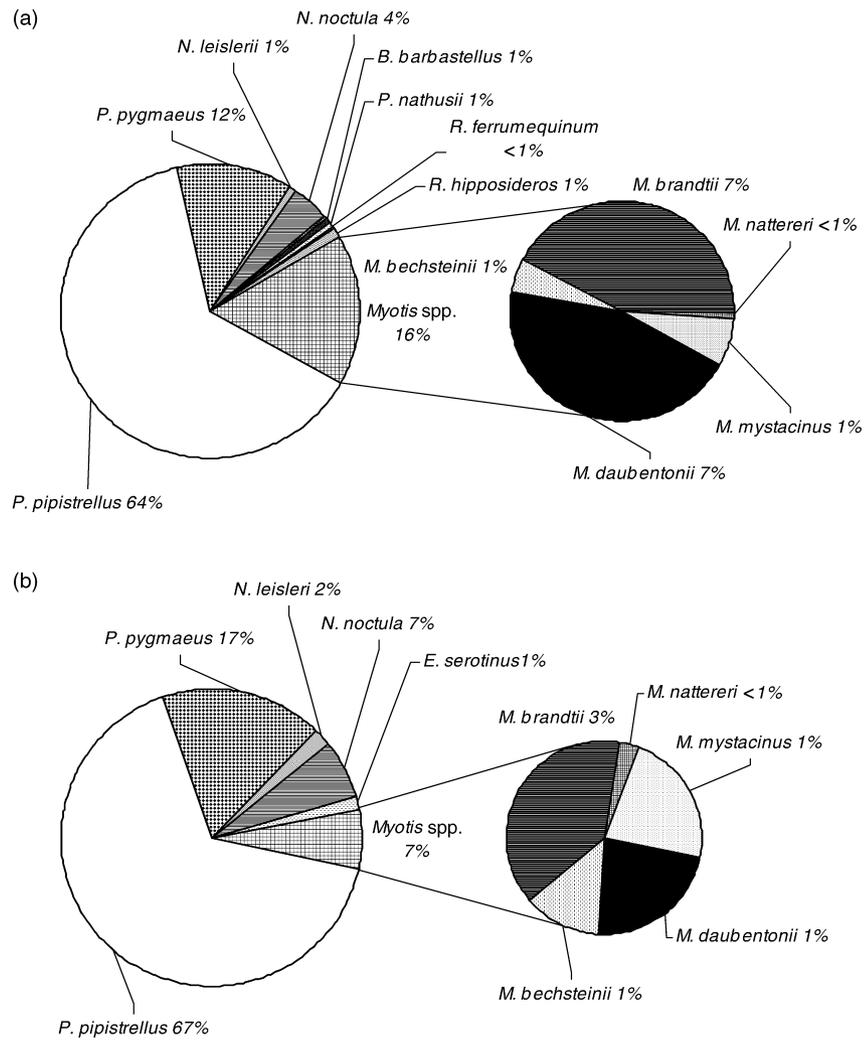


Fig. 2. (a) Species composition for bats recorded on organic farms, classified by the ANN (n = 976). (b) Species composition for bats recorded on conventional farms, classified by the ANN (n = 574).

Table 4. Habitat use by bat species on organic and conventional farms. Total hours of sampling shown in parentheses. See Table 5 for water habitats. Figures represent total passes recorded that could be classified by the ANN

Species	Pasture (21 h)		Arable (8 h)		Woodland (10 h)	
	Organic	Conventional	Organic	Conventional	Organic	Conventional
<i>Pipistrellus pipistrellus</i>	207	146	61	48	152	89
<i>Pipistrellus pygmaeus</i>	61	77	7	7	54	55
<i>Pipistrellus nathusii</i>	6	0	0	0	0	0
<i>Nyctalus noctula</i>	23	14	0	2	1	8
<i>Nyctalus leisleri</i>	5	7	0	2	4	2
<i>Eptesicus serotinus</i>	1	3	0	2	0	0
<i>Barbastella barbastellus</i>	2	0	1	0	0	0
<i>Rhinolophus ferrumequinum</i>	0	0	1	0	0	0
<i>Rhinolophus hipposideros</i>	2	0	2	0	7	0
<i>Myotis daubentonii</i>	17	5	3	0	3	4
<i>Myotis bechsteinii</i>	0	3	0	0	0	1
<i>Myotis brandtii</i>	24	8	3	2	2	2
<i>Myotis nattereri</i>	0	0	0	1	0	0
<i>Myotis mystacinus</i>	0	3	1	0	3	2

found over pasture and water habitats. Activity of *Myotis* species over water habitats was significantly higher ($t = 3.47$, d.f. = 7, $P = 0.01$) on organic farms than in the same habitat on conventional farms. All species of *Myotis*

were recorded over organic water habitats, although the numbers of passes of *Myotis bechsteinii* and *Myotis brandtii* were significantly higher on organic water habitats than on conventional water habitats (Table 5).

Table 5. Differences in the use of water habitat by bat species between conventional and organic farms. Figures represent total bat passes recorded that could be classified by the ANN

Bat species	Organic passes	Conventional passes	d.f.	<i>t</i>	<i>P</i>
<i>Pipistrellus pipistrellus</i>	179	78	7	2.10	0.074
<i>Pipistrellus pygmaeus</i>	122	4	7	1.57	0.160
<i>Nyctalus leisleri</i>	9	14	7	1.00	0.351
<i>Nyctalus noctula</i>	43	0	7	0.37	0.725
<i>Eptesicus serotinus</i>	1	1	7	-1.00	0.351
<i>Barbastella barbastellus</i>	5	0	7	1.00	0.351
<i>Myotis daubentonii</i>	67	0	7	2.07	0.077
<i>Myotis bechsteinii</i>	7	0	7	2.57	0.037
<i>Myotis brandtii</i>	66	2	7	2.54	0.039
<i>Myotis mystacinus</i>	12	2	7	1.08	0.316

The only *Myotis* species recorded over conventional water habitats was *Myotis brandtii* ($n = 2$).

Discussion

PAIRED DESIGN

Two important factors to consider when dealing with a paired design are sample size and sampling protocol. The number of paired sites needed and how often they are sampled depends not only on the sample size required for statistical power but also on the nature of the organism being sampled.

Bats are highly mobile animals covering several kilometres in a single night. They follow flight paths along landscape features, such as hedgerows and edge habitats (Racey & Swift 1985; Walsh & Harris 1996a,b; Verboom & Huitema 1997; Grindal & Brigham 1998; Verboom & Spoelstra 1999). A large number of farm pairs was studied, sampling each farm once. Within each habitat type in a farm, three points were chosen randomly from the habitat maps for bat activity sampling, each point often being in different fields of the same habitat and near different linear features. Points were 'blindly' marked on the maps and the nearest hedgerow within a suitable habitat was chosen as a sampling point. Our experimental design minimized any bias due to sampling in favoured flight paths by including a large number of farms (24 pairs) and by having multiple sample points within habitats. Also, the farms studied covered a large geographical area to represent regional differences in farm management.

This type of paired experimental design has been used widely in comparing aspects of organic and conventional farms (Feber *et al.* 1997; Chamberlain, Wilson & Fuller 1999; Letourneau & Goldstein 2001). Chamberlain, Wilson & Fuller (1999) found that when geographical location and observer differences were not standardized between farm pairs, such differences accounted for as much as 60–80% of variation in the species data. In this study, geographical location was standardized because farms within a pair were no more than 5 km apart. The same person sampled all the pairs. The 'mixed' nature of organic cropping systems and their

habitat management guidelines means that organic farms are more diverse in terms of habitat types. They are often smaller and have a greater species richness of livestock and non-crop flora compared with conventional farms (van Mansvelt, Stobbelaar & Hendriks 1998). Benton, Viceroy & Wilson (2003) recently argued that a reduction in habitat heterogeneity due to agricultural intensification is a major factor in farmland biodiversity declines. However, we found no difference in farm area, total number of habitats or area of habitats sampled between the two farm types studied here. These results reflect the effectiveness of the paired experimental design used for this study.

Nightly bat activity is variable, and many studies have shown that the highest activity peaks occur early in the night (Park, Jones & Ransome 1999; O'Donnell 2000; Kuenzi & Morrison 2003). Our study mainly considered those aerial hawking species producing detectable echolocation calls. Their prey, aerial insects, are known to peak in abundance early in the night, decreasing rapidly and reaching lowest numbers in the middle of the night (Racey & Swift 1985). Although there are biases associated with only sampling within a specific time period each night, and some authors recommend monitoring throughout the night (Kuenzi & Morrison 2003), the timing of our sampling coincided with the highest activity, especially for the aerial insectivores that were the main focus of the study. Sampling also started after the main emergence times, reducing any bat species bias or proximity to roosts that should be independent of farm type.

Until recently it has been difficult to quantify accurately the differences between bat species from their echolocation calls (Walsh & Harris 1996a,b), and previous methods could usually only identify bats to genus. We used the most recent advances in echolocation recording technology, which resulted in 89% of the calls being identified to species. This was important for discriminating species differences in habitat use, a crucial aspect of this study. However, there is an inherent problem with all acoustic methods in that not all species are detected equally. Those species with very low amplitude calls, such as *Plecotus* species, may not be detected adequately (Vaughan, Jones & Harris 1997).

This may explain why this genus was underrepresented in our data. However, the 9% of calls that could only be identified to genus by the ANN were not biased towards any one genus, with more than 40% from each of *Myotis* and *Pipistrellus* species.

IMPACT OF AGRICULTURAL INTENSIFICATION ON BAT SPECIES

The most important and large-scale cause of habitat fragmentation is the expansion and intensification of land use (Burgess & Sharpe 1981). Conventional farming systems fragment the wider landscape into a matrix or mosaic. Within this mosaic, organic farms have more characteristics in common with semi-natural habitats compared with the surrounding intensively farmed landscape, and may therefore be more attractive to a number of species. Fragmenting a large area of habitat into a mosaic may be beneficial to certain bat species by increasing edge habitat, although it will be detrimental to others by decreasing linear features connecting foraging areas (Russ & Montgomery 2002). This will isolate populations and remove access to suitable foraging sites.

Bright (1993) used life-history traits of British mammals to arrange species according to their potential response to habitat fragmentation. He proposed that generalist species use a wide range of habitats and are therefore less likely to be dramatically affected by habitat fragmentation compared with specialist species, which would be more vulnerable to the adverse effects of habitat fragmentation. Bright (1993) found that specialist species of bat, with those most affected by habitat fragmentation listed first, included *Myotis myotis*, both *Rhinolophus* species, *Myotis daubentonii*, *Myotis nattereri* and *Myotis mystacinus*. The generalists were identified as *Nyctalus noctula*, *Eptesicus serotinus*, *Pipistrellus pipistrellus* and *Plecotus auritus*. We only recorded *Rhinolophus* activity on organic farms, and *Myotis* activity was significantly higher on organic farms compared with conventional farms. In Britain the numbers of *Rhinolophus hipposideros* seem to be increasing, although there is particular concern about this species in Europe where it is threatened with extinction in Germany and is in severe decline over the rest of Europe (Hutson, Mickleburgh & Racey 2001). The more generalist species *Nyctalus noctula* and *Pipistrellus pipistrellus* were found on both farm types. Thus, our results support Bright's (1993) predictions and suggest that species adversely affected by habitat fragmentation are also adversely affected by agricultural intensification.

CHANGES IN BAT POPULATIONS AND AGRICULTURAL INTENSIFICATION

Bat activity overall was 61% higher on organic farms, and foraging activity was 84% higher on organic farms, suggesting that bats preferred the organic farms over

conventional farms for both foraging and general movements. The importance of linear features within a landscape has been well documented for bats (Verboom & Spoelstra 1999). Whether the features are walls, woodland edges or hedgerows, bats use them as flight paths and foraging sites if the feature provides enough shelter for insects to aggregate. With the main focus on aerial hawking bats, hedgerow height was thought to be more important in terms of shelter belts for insects and bats than hedgerow width. Insect densities are generally higher nearer vertical landscape elements (Lewis & Stephenson 1966; Lewis & Dibley 1970; Verboom & Spoelstra 1999). We found a significant correlation between the number of feeding buzzes and hedgerow height, supporting the hypothesis that the significantly higher hedgerow height recorded on organic farms contributed to the higher bat foraging activity on organic farms.

Habitat quality may well be important in explaining the differences seen between farm types. Riparian habitats are critical habitats for many bat species (Brigham & Fenton 1991; Rydell *et al.* 1994; Racey 1998; Grindal, Morissette & Brigham 1999). In conjunction with higher total bat activity over water habitats on organic farms, the activity of *Myotis* species was significantly higher. Water habitats are important foraging areas for *Myotis* species. Water quality is affected by agrochemicals (Racey *et al.* 1998) and a direct link between agricultural intensification and water quality has been reported in Canada (Berka, Schreier & Hall 2001). Eutrophication of water habitats from sewage outlets can increase abundance of some insect species and may benefit some species of bat (Vaughan, Jones & Harris 1996), whereas some agricultural pollutants might have a detrimental effect on the insect species found in and around water habitats, thus affecting food availability for bats. Increasing the nutrient content of water bodies may result in seasonal changes in invertebrates with consequences for organisms higher in the food web (Mason 2002). Agrochemicals applied to fields, particularly nutrients (nitrogen and phosphorous) and pesticides, are a major form of aquatic pollution (Angier *et al.* 2002; Hapeman *et al.* 2002). Organic pollution from silage liquor or slurry results in a reduction in the oxygen content of the water, adversely affecting some sensitive invertebrates, although the actual impact depends on the severity of oxygen depletion (Mason 2002). Thus, the use of agrochemicals may explain the differences in bat activity over water habitats between farm types, and implies that localized changes in water quality may account for differences in bat activity.

This study was designed to test the hypothesis that agricultural intensification had been a factor in British bat population declines, and we cannot reject it. The results presented suggest that, compared with similar areas on conventional farms, the habitats found on organic farms are of higher quality in terms of habitat structure and condition (due to the lack of agrochemicals), making them favourable foraging sites for bats.

Their high quality is also supported by evidence that organic farms have higher overall insect abundance, and that key insect families important to bats as food are more common on organic farms than on conventional farms (L.P. Wickramasinghe, S. Harris, G. Jones & N. Vaughan unpublished data).

CONSERVATION IMPLICATIONS

The results presented in this study add to the growing evidence from published data on the wildlife benefits of organic farming (Feber *et al.* 1997; Chamberlain, Wilson & Fuller 1999; Beecher *et al.* 2002). Moreover, the particular species of bat that benefit from organic farming are those covered by the UK BAP. The higher overall bat activity on organic farms suggests that as organic farm numbers increase, a general increase in bat populations may follow, including the populations of some of the rarer species found in Britain.

We highlight the importance of habitat management in farmland for bat conservation. In terms of restoring bat numbers, a less intensive system of farming will benefit bats by improving the quality of flight paths and foraging habitat.

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