

A small scale study into the foraging habitat selection of *Myotis* and *Pipistrellus* spp. along the Forth & Clyde Canal, Scotland

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Abstract

During the period September to October 2005, the distribution of foraging *Myotis* and *Pipistrellus* spp. present along the Forth & Clyde Canal was investigated in relation to the variation in overall water quality status and the extent of tree cover. The aim was to identify potentially important foraging sites, which will facilitate informed advice on habitat protection and conservation. The main findings were, that although it was not possible to determine the exact influence that water quality had on bat activity, it was unlikely to be the main factor influencing distribution. Land use, tree cover and the potential influence of roosting opportunities was more likely to account for differences in habitat use exhibited by the two species groups.

The re-opening of the canal as a navigation route has the potential to impact on the canals biodiversity through land development and increased boat traffic. Development plans should include considerations for the foraging habitat requirements of bats and maintain habitat continuity for all forms of wildlife that reside along the canal.

Key words: Bats, Conservation

Introduction

Growing evidence suggests that many bat species are declining across Britain and Europe (Harris *et al.*, 1995), with declines in Britain being largely attributed to pressures on landscape changes (Walsh & Harris, 1996b). It is therefore important to accurately identify the habitat factors likely to influence bat populations, in order to define appropriate conservation guidelines and apply effective protective measures (Russo & Jones, 2003).

UK status of bats and their foraging habitats

A UK-wide bat survey carried out from 1990 to 1992 established that habitats favoured by foraging bats have undergone rapid rates of loss and are believed to be a contributing factor to the decline of some bat species in Britain (Walsh *et al.*, 1995). The UK Biodiversity Action Plan (BAP) has identified six species that have declined as a result of habitat loss through development and agricultural intensification (Anon, 1995). Included in the plan are *Pipistrellus pipistrellus*, which has since been classified as two separate species that are genetically distinct (Barratt *et al.*, 1997). These are now known as *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*. Both species are common and widespread throughout the UK with a population estimated at two million, of which 550,000 are believed to be in Scotland (Harris *et al.*, 1995). However, estimates from the Annual Bat Colony Survey suggest that numbers of *Pipistrellus* spp. have declined by 70% between 1978 and

1993. This is believed to be the result of reductions in insect population density (through insecticide use and destruction of habitats) owing to high intensity farming, and inappropriate riparian management (Anon, 1995).

Both *Pipistrellus* species are now listed as priority species for conservation concern under the UK BAP (Racey *et al.*, 2004). Although all species of British bats and their roosts are protected by law within the European Union as well as under UK legislation, foraging habitats are not afforded the same protection.

Land use in Britain and pressures on habitats

In Britain, increasing anthropogenic pressure and changes within agricultural practices during the past century has led to a vast reduction in our diversity of landscapes. Approximately 75% of the land is being used for agriculture, with arable land under 5 years old representing 35% (Robinson & Sutherland, 2002). Within farmland, habitat diversity has been reduced by the decline in the numbers of hedgerows, field margins, ponds and woodland strips, all of which provide natural shelter, feeding sites and breeding grounds for birds, insects and other wildlife (Wickramasinghe, 2003).

A study carried out on the population changes in the wildlife of arable land in Great Britain between the 1940's and 1990's has revealed a widespread decline in farmland taxa. Around half of plants, one third of insects, and four fifths of birds have experienced a population decline, with biodiversity

loss being linked to intense field management, habitat quality degradation, and increasing habitat simplification (Robinson & Sutherland, 2002).

In Scotland, declines in insect diversity and abundance have been linked to the intensification of agriculture, which may have contributed to farmland bird declines (Benton *et al.*, 2002). All bats in Britain are insectivorous, so declines in insect abundance as a result of agricultural intensification are likely to have serious implications on bat foraging (Wickramasinghe *et al.*, 2003).

Land use in Scotland is dominated by agriculture. The use of fertilisers and crop protection chemicals in efforts to improve land productivity have impacted upon the overall environmental quality; particularly through the seepage of nitrates, pesticides, soil particles and bacteria into the surrounding water environment. This is known as diffuse agricultural pollution (Anon, 2004). Synthetic chemicals and nutrients such as nitrogen and phosphorous and increased ammonia leaking into waterways can result in eutrophication, causing deoxygenation of the water (Maitland *et al.*, 1994). Depending on the severity of oxygen depletion, this can affect sensitive invertebrate organisms such as Trichopteran larvae and Plecoptera. These are key insect families important in bats diets in Britain (Wickramasinghe *et al.*, 2004). Until fairly recently, under the New Water Framework Directive developed in 2000, there had been no single approach to tackling diffuse agricultural pollution and this continues to be a threat to the quality of water in Scotland (Anon, 2006).

Implications of water quality for bat foraging

Ecosystems are complex entities and dependent on many interactions among animal species. A minor problem, low down in the food chain, can have major repercussions for top predators. Adverse impacts on the quality of water that does not directly affect top predators, but does affect its habitat or metabolism, may alter survival, population density, species diversity and reproduction (Anon, 2000). The air above bodies of water is usually rich in flying insect diversity owing to many insects having specialised aquatic larval stages (Walsh & Harris, 1996a). This is an important feeding habitat for many bat species (Rydell *et al.*, 1999).

A bat species, occurring in the UK, highly dependent on aquatic insects, is *Myotis daubentonii*. This species of bat often feeds over water, gaffing insects floating on or just above the water surface (Rydell *et al.*, 1999). This habitat preference exhibited by *M. daubentonii*, makes it especially vulnerable to changes in this habitat type, since changes in water quality can seriously

impact upon availability of food. *M. daubentonii* is considered to be of conservation importance (Anon, 1995).

In the UK-wide bat survey of foraging habitat preferences in Britain (1990-1992), emphasis was placed on the importance of water bodies for bats in all land classes. However, there was a weak selection for rivers/canals observed in some intensive agricultural land classes. This suggested the quality of those river sites as foraging habitats may have been reduced due to decreased insect availability as a result of agricultural run-off.

Both *P. pipistrellus* and *P. pygmaeus* are not restricted to riparian habitats, but this habitat is exploited where it occurs (Vaughan *et al.*, 1997). *P. pipistrellus* feed mostly on insects that occur in a wide range of habitats, whereas *P. pygmaeus* feed mainly on insects that are almost exclusively found in aquatic habitats (Barlow, 1997).

M. daubentonii is widely reported to be increasing in numbers throughout mainland Europe. One possible explanation being due to the eutrophication of fresh waters (Racey *et al.*, 1998). A study carried out on the effects of sewage effluent on bat activity found that *M. daubentonii* concentrated their feeding downstream of sewage works, and may have actually benefited from the increasing availability of pollution-tolerant insects (Vaughan *et al.*, 1996). This however may only create short-term benefits as changes in water quality over a longer period of time could potentially have a negative impact on insect population density and subsequently affect the number of *M. daubentonii* (Harris *et al.*, 1995). It is also noteworthy that there were significantly more feeding buzzes produced by *P. pipistrellus* upstream of sewage works. *P. pygmaeus* produced similar numbers both upstream and downstream. For *Pipistrellus* spp. water pollution may be a contributing factor to differences in their foraging habitat selection and may reflect differences in their diet. *P. pygmaeus* has been shown to eat more insects from the families Chironomidae and Ceratopogonidae (in which many pollution tolerant insect species are found) than *P. pipistrellus* (Barlow, 1997). Therefore the foraging habitat selection of bats may vary, with different species having very different requirements. This is important to consider when devising BAPs.

Other factors relating to foraging habitat selection by bats

Many studies have investigated and compared the variation in habitat selection between different land classes on a large scale. However, small-scale characteristics of habitats (e.g. along a canal corridor) at a local level ought also to be taken into

consideration when predicting the impacts of management practices.

Small-scale variations of land use along a canal corridor may offer confounding variance with respect to the influence land use may have on foraging habitat selection along its length. The function of linear landscapes, such as watercourses, can include many elements, including; orientation cues, foraging habitats and commuting routes between favourable sites (Verboom & Huitema, 1997).

Watercourses sheltered by tree cover or woodland edge can also serve as protection against wind and possibly predators. Bats foraging over exposed open stretches of land or water are likely to be more visible and hence more prone to predation. Some studies have found that *P. pipistrellus*, *P. pygmaeus*, and *M. daubentonii* select for sections of a river that are bordered by trees on both sides, which may reflect a higher insect population density as a consequence of natural shelter from the wind (Kusch *et al.*, 2004). For *M. daubentonii* in particular, shelter from wind is considered important. In part because wind can increase ripples on water surfaces, thus effecting echolocation and making bat foraging less efficient (Rydell *et al.*, 1999).

Urbanisation, or the development of rural habitats, transforms landscapes and the composition of flora and fauna resulting in natural areas becoming fragmented (Gehrt *et al.*, 2003). Landscape elements such as tree lines, hedgerows and woodland edges may enhance long-term survival of local bat populations by linking fragmented landscapes (Walsh and Harris, 1996a) and possibly reduce the search time for prey by using vegetation elements as structural cues to facilitate orientation. In Scotland, the lowlands are at the greatest risk of habitat loss or fragmentation in comparison to upland areas, as they are situated in the most agriculturally productive areas where human population and consequently commercial pressure is also high.

Although the closure of the Forth & Clyde Canal as a navigation route in the 1960's allowed the aquatic ecosystem to develop undisturbed for many years, recent development to re-establish navigation is likely to impact upon the canal's biodiversity in the future. Increased water traffic may impact on the available foraging area for *M. daubentonii* in particular. Although the water quality at present is not seriously polluted, increased pollution from boats and adjacent land development may have significant adverse effects on water quality in the future. This may impact on the aquatic ecosystem, upon which this bat species depends. If poor water

quality sites are identified as poor foraging habitats for bats, then declining water quality may impact on local bat populations.

Considerable road developments lie close to the Forth & Clyde Canal (Quadrat Scotland, 2002), as such, where bankside vegetation, tree cover and earth is stripped for land development, recreation or agriculture, this may reduce the available foraging area and consequently impact negatively on current and future bat populations.

Due to flight, manoeuvrability does not limit bats in ways that other small mammals are limited to find food resources. However, site management that incorporates habitat features preferable to bat foraging will enhance the value of the canal.

In accordance with optimal foraging theory, bats are more likely to select areas where foraging efficiency is highest (Stephens & Krebs, 1986), and some studies have found that high feeding rates are likely to be associated with high insect densities (Vaughan, 1996; Park & Cristinacce, 2006). This suggests at those sites where the level of foraging activity is high, it is an indication of good quality foraging sources, which are worthy of note for conservation.

Knowledge of potentially good quality sites can be incorporated into effective riparian management to enhance the canals biodiversity value, and in addition, be implemented into action plans for the maintenance of other rivers and canals.

Aims & Objectives

The study was conducted along 19.2km of the Forth & Clyde Canal located in Central Scotland. Built in 1768, the total length of the canal covers 56km. It is up to 18m wide and 3m deep, lying at 48m above sea level and consisting of 39 locks along its length. The canal was the first of its kind to be built in Scotland and links the two largest river systems in the Scottish Lowlands (the River Forth in the east, and the River Clyde in the west).

The central lowland's landscape generally comprises of meandering watercourses, broad floodplains, rough grassland and mire, as well as scattered woodland strips. Intensive agriculture and urban development covers much of the available land (Quadrat Scotland, 2002).

The aims of this study were to quantify the foraging habitat use by *Myotis* and *Pipistrellus* spp. present along the Forth & Clyde Canal in order to investigate whether differences in habitat use could be explained by differences in the overall water

quality status and/or small-scale differences in land use within the study area.

The following questions are considered:

1. Is the distribution of *Myotis* and *Pipistrellus* spp. present along the canal the same, or does distribution between the species groups vary?
2. If habitat use varies, which sites are being selected for and which are being avoided?
3. If habitat use differs, what are the factors that may explain the variation in foraging habitat selection?

Materials & Methodology

Sampling procedure

The 19.2km was divided into eight 2.4km transects, each of which was surveyed in one night. Each 2.4km transect had 16 sampling stations, 150m apart, giving a total of 128 sampling stations. A GPS was used to record the precise grid co-ordinates of each station. An odometer was used and reset at each station to ensure each transect fell within its designated water quality grade.

The survey was carried out from late September through to October 2005 (post breeding and pre-hibernation) and the order in which the eight sites were surveyed was selected at random. At the start, midway and end of an evening's survey, the air temperature (°C) was measured to the nearest 0.1°C and wind speed estimated according to the Beaufort Scale. The percentage cloud cover was also noted. The survey was abandoned on nights where strong winds exceeded a Beaufort Scale reading of 4, when moderate/heavy rain conditions prevailed or if the air temperature at sunset fell below 10°C. The survey was also abandoned if the temperature midway through the survey fell below 7°C. Bat and invertebrate activity has been found to begin to reduce at temperatures below 10°C, and especially below 5°C (O'Donnell, 2000).

Water quality classification scheme

The 19.2km study area was divided on the basis of water quality grades issued by a digitised river classification scheme produced by the Scottish Environmental Protection Agency (SEPA, 2005), which was developed in 1974 to monitor the quality of all rivers in Scotland. Water quality is classified in km stretches as Excellent (A1), Good (A2), Fair (B), Poor (C) and Seriously Polluted (D). These classifications vary according to measures of biological, chemical nutrients (toxicity) and aesthetic parameters (Scottish Progress Report, 2005). There is no stretch along the Forth & Clyde Canal that is classified as seriously polluted (D) so only grades A1, A2, B and C were used. Each grade covered 4.8km of the study area. For details

of each transect and their associated water quality, please refer to Appendix 1, Table 5.

Land use classification

The Institute of Terrestrial Ecology (ITE) has allocated every 1km square in Great Britain to one of 32 land classes. These are defined on the basis of environmental characteristics such as topography, geology, land use, human geography, and climate (Bunce *et al.*, 1996). These land classes fall into seven major land class groups, namely: Arable I, Arable II, Arable III, Pastural IV, Pastural V, Marginal Upland VI, and Upland VII. Within the study area, 77.3% of the land use is classified to the land class group Arable III. The land class sub-group accounting for 18.5% of the study area was Urban. Only 4.2% of stations were allocated to Pastural V.

When identifying any potential confounding variables (e.g. all good water quality sites correlating with urban land use), only the land class groups Arable III and Urban were included. The category Pastural V was omitted from this analysis, due to the sample size being too small. For land use allocation to each 1km square in the study area please refer to Appendix 1, Table 5.

Table 1: Description of the land class groups. (Based on Bunce *et al.*, 1981)

Land Class Group	No of Stations	Description of Land Use
Arable III	92 (77.3%)	Gently sloping, medium to low altitude. Intensively farmed lowland with many fences & some moorland vegetation.
Urban	22 (18.5%)	Over 75% built up (not categorised further).
Pastural V	5 (4.2%)	Medium/low altitude. Varied lowland landscape with many natural features. Grassland types predominate with some moorland.

Tree cover survey for each transect

From the start point, using the GPS to measure distance covered, the amount of tree cover on either side of the canal was recorded whilst walking in one direction. Only tree cover adjacent to the banks of the canal was recorded, categorised as: trees both sides, trees present on only one side, or no trees present either side.

Bat activity

At each station, three minute recordings of bat activity were made using a frequency division bat detector (BatBox Duet, Stag Electronics, Steyning, UK; frequency response 17-120 kHz) connected to a recordable MiniDisc (Sony MZ-R909). Frequency

division is a broad-band system that records all frequencies continuously, and is sufficient for distinguishing between the genera *Myotis* and *Pipistrellus*, and between UK *Pipistrellus* species (Vaughan *et al.*, 1996). From beginning to end, the average surveying time was 95 minutes. The bat detector was directed towards the canal and any light source, which may have influenced the level of bat activity recorded (i.e. a torch) was switched off.

Bat sampling commenced one hour after sunset. This was in order to coincide with the appearance of *Myotis* spp., specifically *M. daubentonii*. During bat activity surveys (N=36) conducted by BaTML along the Forth & Clyde Canal between 2001 and 2005, the time of first appearance of *M. daubentonii* was recorded. Based on these surveys, the average time of appearance on the canal for *M. daubentonii* was 52.7 minutes after sunset (BaTML: personal correspondence - N Middleton). In addition, the highest abundance of small aerial insects, mainly dipterans, usually occurs around dusk (Rydell *et al.*, 1996) and this coincides with the time at which bats are actively foraging.

Sound analysis

The number of bat passes recorded provides an index of bat activity, as it is not possible to count individual bats from the recordings of their echolocation calls (Vaughan *et al.*, 1996). Sound analysis was done using Batsound v3.31 (Petersson Elektronik AB, Uppsala, Sweden) and analyses carried out blind for each transect to eliminate any possible bias. One bat pass was defined as a sequence of at least 3 echolocation calls of a passing bat. When there was a break in the sequence (i.e. a distance in milliseconds greater than that of the last 3 calls in the sequence), this was indicative of a new pass. The separation of *Myotis* spp. from *Pipistrellus* spp. can be distinguished by differences in their call structure. The two species of *Myotis* found in the study area, *M. daubentonii* and *M. nattereri* have considerable overlap in their call structure and so due to the possibility of misidentification, calls were not classified beyond *Myotis* spp. The two *Pipistrellus* spp., *P. pipistrellus* and *P. pygmaeus* can be distinguished by the peak frequency of their echolocation calls (FmaxE). Bat passes with calls that had a peak frequency of 40-49kHz were classified as *P. pipistrellus*, and peak frequencies above 52kHz were classed as *P. pygmaeus*. Those with an FmaxE of between 49-52kHz were classified as unallocated *Pipistrellus* spp. (Vaughan *et al.*, 1996).

Foraging activity can be quantified by counting the number of feeding buzzes recorded (Wickramasinghe *et al.*, 2003). These high pulse repetition sounds are produced by aerial-hunting

and trawling Vespertilionidae when they attempt prey capture (Griffin, Webster & Michael, 1960). The total number of feeding buzzes attributed to each species at each station was recorded. The buzz ratio (i.e. the ratio of feeding buzzes to bat passes) was also recorded. This provides a measure of foraging effort per unit of flight activity (Vaughan *et al.*, 1996, 1997; Wickramasinghe *et al.*, 2003).

Data Analysis

Bat activity was quantified as the total number of *Myotis* spp. and *Pipistrellus* spp. passes at each station. The proportion of *Pipistrellus* spp. passes classified as *P. pipistrellus* was very low. Therefore it was assumed all unknown *Pipistrellus* spp. passes were from *P. pygmaeus* and so for analysis purposes, all passes classified as *Pipistrellus* spp. were included (see Park & Cristinacce, 2006). The survey carried out on 29/09/05 at Wyndloch was abandoned owing to persistent rain. Therefore only 7 stations for this transect were included in the analysis, giving a new total of 119 stations.

Habitat selection was quantified by performing a series of χ^2 analyses on the counts of bats. Habitat categories based on water quality, tree cover and land use were assigned to each station and the number of bat passes within each habitat category was determined. The chi square test establishes whether the bats were randomly distributed, or not, between the different habitat types by comparing the actual and expected use of habitats. The expected use is quantified based on the assumption that each habitat category is being utilised by bats in exact proportion to its occurrence within the study area (Neu *et al.*, 1974). Habitats that were selected for or avoided, were determined using the z statistic with Bonferroni adjustment and a confidence level of 95% (see Appendix II, Tables 7 and 8). Individual confidence intervals were constructed around each proportion observed in each area (p_i). Where the available habitat proportion lies below the lower limit of the confidence interval, the habitat was deemed to be significantly selected for ($p < 0.05$); where the available proportion lies higher than the upper limit of the confidence interval, the habitat was significantly avoided (Glendell & Vaughan, 2002).

Results

Association between land use and other habitat categories

There was a significant association between water quality and land use in the study area ($\chi^2_3 = 35.75$, $p < 0.01$). The number of stations classified as A1 (Excellent), which were allocated to urban areas, was higher than expected. All the stations

classified as A2 (Good) or B (Fair), were allocated to Arable III land, with none found in Urban areas (Table 2). There was no association between land use and tree cover, ($\chi^2_6 = 11.5$, $p = 0.074$).

The term association with respect to this study refers to the number of stations observed in an area, in comparison to what would be expected from a random distribution (i.e. were there more stations in a particular area than expected?) If so, there is the potential element of bias in that land use may be a confounding variable influencing bat foraging.

Table 2: Observed number of stations in both land use and water quality categories, against their expected values

Water Quality	A1	A2	B	C
	Observed (Expected) no. of stations			
Arable III	15 (25.8)	23 (18.6)	27 (21.8)	27 (25.8)
Urban	17 (6.2)	0 (4.4)	0 (5.2)	5 (6.2)
Total	32	23	27	32

Table 3: Observed number of stations that lie in both tree cover and water quality categories, against their expected values

Water Quality	A1	A2	B	C
	Observed (Expected) no. of stations			
No trees present	15 (9.14)	4 (6.57)	10 (9.14)	5 (9.14)
Trees one side	16 (13.18)	12 (9.47)	10 (13.18)	11 (13.18)
Trees both sides	1 (9.68)	7 (6.96)	12 (9.68)	16 (9.68)
Total	32	23	32	32

Referring to Table 3 (above), there was a significant association between tree cover and water quality ($\chi^2_6 = 21.59$, $p < 0.01$). Of the 32 stations classified as A1, only 1 station (3%) was allocated as having trees present on both sides. Nearly half (47%) had no trees present.

Bat activity

Bat activity was recorded at 119 stations across the 19.2km study area. A total of 937 bat passes were recorded over eight nights during the period 20th September to 7th October 2005, involving 357 minutes of recording time. Table 4 provides a summary of the totals. For a summary of the results per transect please refer to Appendix I, Table 6.

Table 4: Total number of bat passes and feeding buzzes recorded for each species

Species	Number of passes	Number of feeding buzzes
<i>M. daubentonii</i>	183 (19.5%)	25 (25.5%)
<i>P. pygmaeus</i>	668 (71.3%)	68 (69.4%)
<i>P. pipistrellus</i>	20 (2.1%)	3 (3.1%)
Unallocated <i>Pipistrellus</i> spp.	35 (3.7%)	2 (2.0%)
Unknown	31 (3.4%)	0 (0%)
Total	937 (100%)	98 (100%)

For analysis, the total number of *Myotis* spp. and the total number of *Pipistrellus* spp. (including unknown bat passes) were compared. A total of 98 feeding buzzes were recorded, 74.5% of these were produced by *Pipistrellus* spp.

The number of feeding buzzes constituted 10.46% of the total passes. However the number of feeding buzzes at most of stations was too low for statistical analysis, possibly due to the limited data set.

Ongoing survey work carried out by BaTML (from 15 August 2001 to 23 August 2005) at specific sites along the Forth & Clyde Canal provided supportive data showing that bat activity can be assumed to accurately reflect the levels of foraging. In 2005, the total number of feeding buzzes produced by *M. daubentonii* was positively correlated to the total number of bat passes (Spearman rank: $r = 0.883$, $p = 0.02$). This correlation was consistent over the 5 year period. (BaTML: personal correspondence – N Middleton).

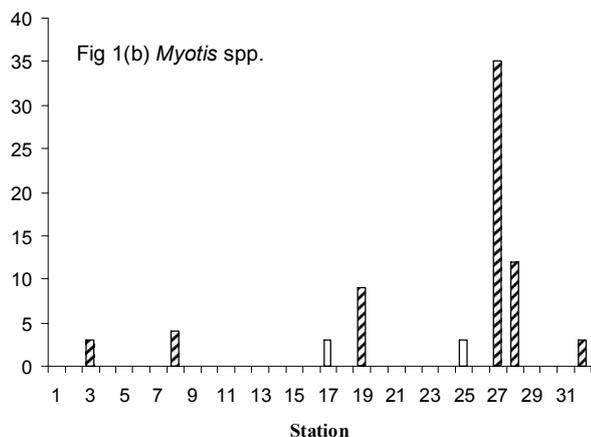
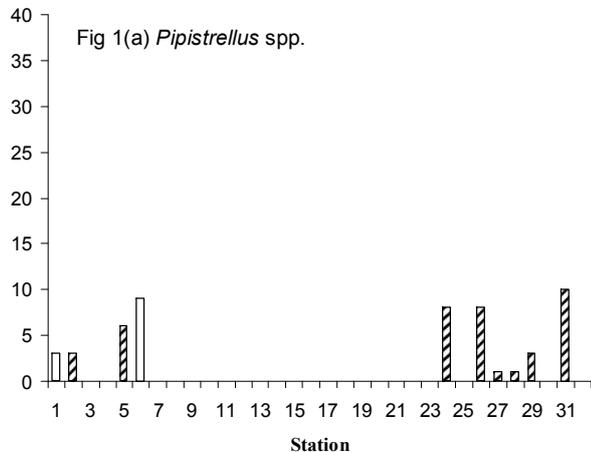
Variation in bat activity between stations

Water Quality A1 (Transect 1 and 2)

In general bat activity by both species groups was fairly low. There were a few exceptions. At stations 24 to 32, bat activity was generally higher with a distinctive peak in activity from *Myotis* spp. (Figure 1b). It is worthy of note that these stations

were located near mixed woodland in comparison to the majority of the other stations, which were situated in largely industrial or commercial areas with little to no trees present.

Figures 1(a) and 1(b): The distribution of *Pipistrellus* spp. and *Myotis* spp. at stations classified as A1 for water quality. The bars indicate the total number of bat passes. Clear bars: no trees present. Striped bars: trees present on one side only.



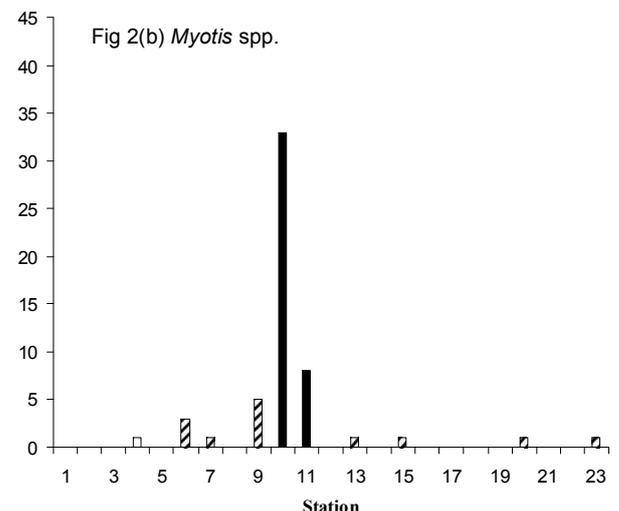
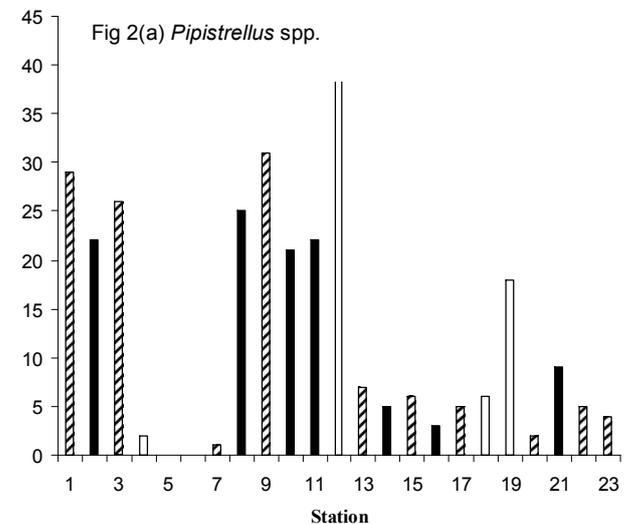
Water Quality A2 (Transect 3 and 4)

The amount of activity recorded by *Myotis* and *Pipistrellus* spp. varied considerably. *Myotis* spp. activity was generally low with a single peak in activity at stations 9 to 11. The peak coincides with stations that had trees on both sides (Figure 2b). For *Pipistrellus* spp. the distribution across the stations was fairly wide spread, with the majority of stations recording some activity. Only a couple of stations recorded no activity. No distinction can be made between bat activity and tree cover for *Pipistrellus* spp. as the stations categorised differently on the basis of tree cover, all recorded fairly high activity.

Only 23 stations were included in the A2 category. Stations 1 to 7 represent site 3 at Wyndford Lock. This survey, which was abandoned partway owing

to persistent rain, may explain why stations 4 to 7 recorded virtually no activity. Stations 8 to 23 represent site 4, which based on observations in the field, had tall dense tree cover bordering the canal along most of this transect.

Figures 2(a) and 2(b): The distribution of *Pipistrellus* spp. and *Myotis* spp. at stations classified as A2 for water quality. The bars indicate the total number of bat passes. Clear bars: no trees present. Striped bars: trees present on one side only. Solid bars: trees on both sides

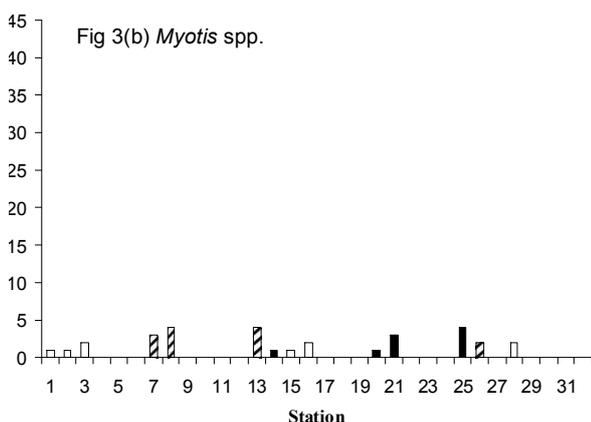
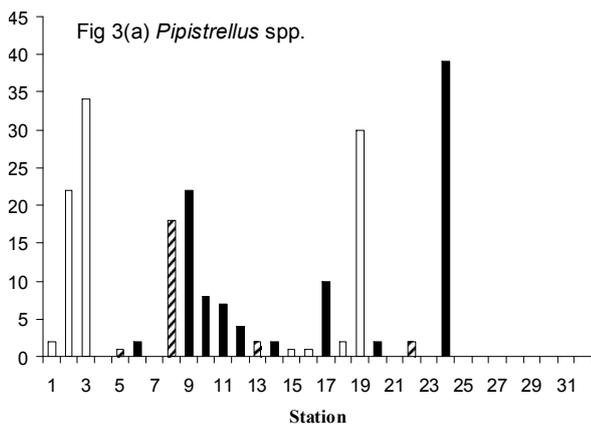


Water Quality B (Transect 5 and 6)

The amount of activity varied between the two species groups considered. For *Pipistrellus* spp. there were a few peaks in activity. Many coincided with stations that had trees present on both sides. However some stations where no trees were present also recorded high *Pipistrellus* spp. activity. Although stations 2 and 3 for example were not categorised as having tall tree cover, they did have bushes bordering both banks and so not completely open or lacking in vegetation. In contrast to this, where no activity was recorded by *Pipistrellus* spp., the land occupied open fields either side with no shrub layer on either bank (Figure 3a).

At stations which had no trees present, *Myotis* spp. activity was little to none. One would expect that at stations 9 to 12 where trees were present on both sides of the canal, *Myotis* spp. activity would be recorded. This assumption is based on previous studies (see Kusch *et al.*, 2004) that *Myotis* spp. would prefer sections of a river bordered by trees on both sides. There was however no *Myotis* spp. activity at these stations (Figure 3b).

Figures 3(a) and 3(b): The distribution of *Pipistrellus* spp. and *Myotis* spp. at stations classified as B for water quality. The bars indicate the total number of bat passes. Clear bars: no trees present. Striped bars: trees present on one side only. Solid bars: trees on both sides

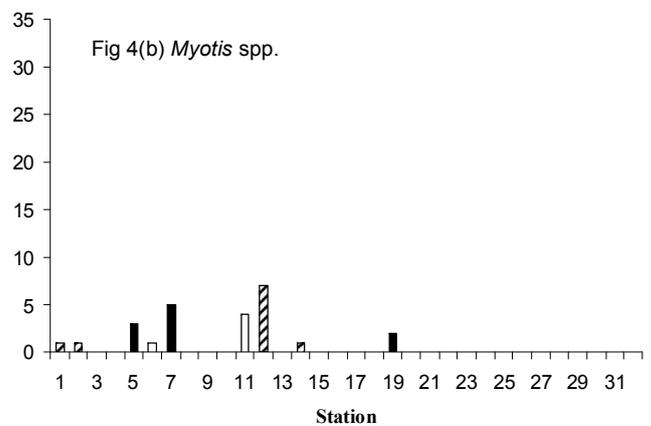
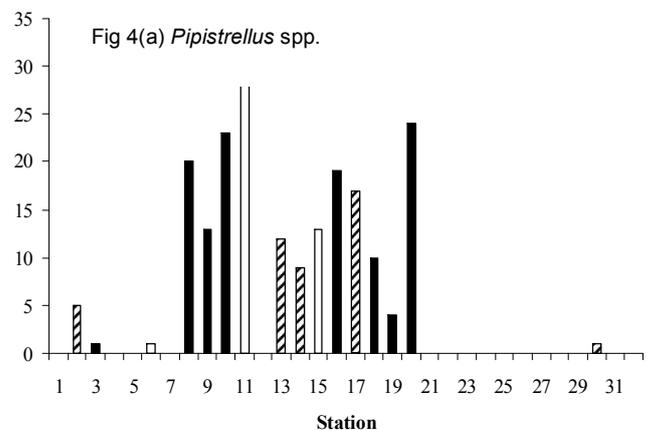


Water Quality C (Transect 7 and 8)

Bat activity was generally low by both species at stations 1 to 7, although *Myotis* spp. activity was generally higher than *Pipistrellus* spp. These stations are within the outskirts of Kirkintilloch occupying residential and commercial buildings. At stations 1 and 2 the canal becomes narrow with boats mooring on the water. From station 8 onwards the land changes to a more rural setting. There is a clear peak in *Pipistrellus* spp. activity at stations 8 to 20. This largely coincides with tree cover. However, there is an exception at station 11; high activity was recorded where no trees were present. This station did however occupy a dense shrub layer and was also within 40m of sections that had tall trees present on both sides. At stations 21 to 32 virtually no activity was recorded

by either species group (Figure 4a and 4b). A majority of these stations had tall tree cover present on one side of the canal and so one would expect some activity. There is a sewage treatment works located near Glasgow Bridge in this area and large agricultural fields on either side.

Figures 4(a) and 4(b): The distribution of *Pipistrellus* spp. and *Myotis* spp. at stations classified as C for water quality. The bars indicate the total number of bat passes. Clear bars: no trees present. Striped bars: trees present on one side only. Solid bars: trees on both sides



Factors Affecting Bat Activity

Relationship between bat activity, water quality and tree cover

The study area was divided into water quality categories according to a grade issued by the SEPA river classification scheme. Neither *Pipistrellus* spp. nor *Myotis* spp. were randomly distributed among the different habitat categories; ($\chi^2_3 = 534.79$, $p < 0.01$) and ($\chi^2_3 = 22.39$, $p < 0.01$).

Pipistrellus spp. in total showed significant selection for stretches of the canal classified as A2. Sites classified as B and C were used in proportion to their availability, whilst A1 sites were significantly avoided (Appendix II, Figure 5a). *Myotis* spp. showed significant selection for both A1 and A2 sites. Sites classified as B and C were significantly avoided (Appendix II, Figure 5b).

The study area was separated into discrete categories based on tree cover bordering the banks of the canal. Neither *Pipistrellus* spp. nor *Myotis* spp. were randomly distributed among the different tree cover habitats ($\chi^2_2 = 59.31$, $p < 0.01$) and ($\chi^2_2 = 28.54$, $p < 0.01$) respectively.

Pipistrellus spp. showed a significant selection for stretches of the canal which had trees on both banks. Stretches of the canal which only had trees on one side were significantly avoided. Where no trees were present on either side, this habitat type was used in proportion to its availability (Appendix II, Figure 6a). *Myotis* spp. significantly avoided stretches of the canal which had no trees present. Where there were trees on both sides, this habitat type was used in proportion to its availability. A significant selection was shown for sites consisting of trees on only one side (Appendix II, Figure 6b).

Pipistrellus spp. significantly avoided A1 stretches in comparison to *Myotis* spp., which significantly selected for A1 stretches (Appendix II, Figures 5a and 5b). It should be noted that 53.1% of stations classified as A1 were allocated to Urban land use, more so than expected. Thus land use could be a confounding variable that may explain some of this variation. The mean bat activity at these stations was fairly low by both species groups (Appendix III, Figures 7a and 7b). There was large variation from the mean for *Myotis* spp. activity at A1 stations which had trees on one side (4.13 ± 2.25), which may account for the selection of A1 stretches by this species group. A2 stations were the only stretches significantly selected for by both species (Figures 5a and 5b). The variation in bat activity at these stations however revealed that *Myotis* spp. activity was only high at one particular station where there were trees present on both sides. Bat activity at the remaining stations was generally low by this species group. The mean bat activity for *Myotis* spp. at sites A2 with trees on both sides had considerable variation from the mean (5.86 ± 12.33) (Figure 7b). *Myotis* spp. significantly avoided stretches classified as B or C, in comparison to *Pipistrellus* spp., which used these water quality sites in proportion to their availability. *Myotis* spp. in this study have been found to avoid stations where no trees were present (Figure 6b). At stations classified as C for water quality, 50% of stations had trees present on both sides, compared to an expected 30.25%, and 34.4% had trees present on one side. Therefore tree cover in this instance does not appear to explain why *Myotis* spp. avoided these class C stretches. The mean bat activity for this species group was fairly low at these stations in all tree cover categories.

For *Pipistrellus* spp. bat activity at C stretches was high where there were trees present on both sides

with little variation around the mean. Mean bat activity at these stations was nearly twice that of stations which had trees present on only one side. The bias in this example is that sites classified as C had more stations with trees on both sides than expected, which may account for the higher bat activity recorded at those sites compared to sites classified as A1 which had only 3% of stations with trees on both sides. At sites C, where there were no trees present, there was sizeable variation from the mean (8.4 ± 5.48).

Discussion

Water quality

In terms of this study, the association identified between water quality and land use, coupled with a limited set of data employed in the analysis of the study area make it difficult to determine with a specific degree of clarity the exact influences of such conditions on foraging habitat selection. Reference to previous studies has been made to minimise any bias the data may conclude.

Information provided from SEPA on the water chemistry data at designated points along the canal has revealed that the variation in water quality along the canal corridor is not likely to be at the level at which bat activity would be seriously affected. For example: the biochemical oxygen demand (BOD) of the canals water (along C classified stretches in the study area) over the last 5 years has been more characteristic of A1 (Excellent) classification. BOD is the most commonly used indicator of the potential pollution from organic matter and is a measure of the amount of oxygen required by micro-organisms to break down the organic material present (Maitland *et al.*, 1994). Unpolluted water has a BOD of less than 3mg/l (Maitland *et al.*, 1994). The BOD recorded in October months between 1990 and 2004 along C classified water in the study area has not exceeded 2.8mg/l (SEPA: unpublished data).

Information on the nitrate levels along this stretch of water showed that although the nitrate levels indicated some seasonal variation, the range in 2005 was still likely to be below the level at which invertebrate diversity would be seriously affected (0.26 - 4.31mg/l). This assumption is based on a study by Racey *et al.*, (1998) who found that the River Ythan in Scotland, (designated as a nitrate vulnerable zone with nitrate levels exceeding 10mg/l), supported as many bats as the oligotrophic River Dee, suggesting that the River Ythan level may not have reached the eutrophic stage at which sensitive invertebrate abundance declines. The water chemistry recorded along this C stretch of canal appears to have only been classified an

overall grade C on the basis that the percentage O₂ saturation in 2003 was only 37.5%, which is characteristic of a C classification. Between 1990 and 2005, the percentage O₂ saturation recorded has generally exceeded 60%, which is characteristic of a B classification (SEPA: unpublished data). The overall grade allocated therefore does not reflect the average figures occurring over a longer period.

It is likely that the differences in habitat use by bats between the sites studied here could be explained by habitat factors other than water quality. However, the re-opening of the canal as a navigation route and important recreational amenity, increased boat traffic and land development is likely to have adverse effects on the future water quality status of the canal. These influences may impact on future bat populations that frequent the canal corridor for commuting and foraging.

Factors affecting foraging habitat selection

Optimal habitats for bats are rare within all landscapes, and highly patchy in their distribution, emphasising the specialist nature of the habitat requirement of bats (Walsh & Harris 1996a).

Myotis and *Pipistrellus* spp. differed in their habitat selection. The first result noting a differentiation was that *Myotis* spp. showed a significant selection for A1 stretches whilst *Pipistrellus* spp. significantly avoided the A1 stations. High *Myotis* spp. activity was recorded near the Falkirk Wheel at Carmuir. There was however large variation in activity between stations as only one station in particular recorded high foraging activity in comparison to the majority of stations, where no activity was recorded. This stretch of canal actually falls under Arable III land use as it is situated on the outskirts of Falkirk and has a patch of mixed woodland on the south side of the canal. This indicated that although the majority of A1 stations were allocated to Urban land use, selection for A1 stretches by *Myotis* spp. in this study did not necessarily indicate a positive selection for Urban land use, and it is more likely that woodland edge or tree cover could explain their distribution. There may have been a possible preference for woodland edge, which has been shown to positively correlate with bat activity (Gehrt *et al.*, 2003). The actual number of recorded feeding buzzes made by *Myotis* spp. along this stretch of canal was considerably higher in comparison to the rest of the study area emphasising the importance of this area as a foraging site for *Myotis* spp.

Roosting opportunities may influence foraging habitat use by bats (Geggie & Fenton, 1985). *Myotis* spp. tends to roost in trees, bridges or

natural rock crevices (Altringham, 1996), which is an indication of how difficult roost sites can be to locate. The distance of a *Myotis* roost from a study area is another reason for explaining the selection for a foraging site.

In a bat roost survey carried out between January 1998 and September 2005 by Scottish Natural Heritage (SNH), all known roosts were recorded within the Forth and Borders area, covering 100km². Although numbers recorded are likely to be a vast under estimate of the actual numbers of roosts within the area, it may potentially explain some of the variation in bat activity between different transects within the study area.

Within Falkirk, there are four known *P. pygmaeus* roosts within 400m of the canal at transect 2, classified as A1 (SNH: personal correspondence - K Marshall). There is furthermore an unknown roost site identified at Carmuir, 500m from the canal (BaTML: personal correspondence - N Middleton). Considering the close proximity of recorded *P. pygmaeus* roosts to stations classified as A1 for water quality, one might expect that the level of foraging activity would have been higher at these stations, since *P. pygmaeus* are strongly associated with riparian habitats (Barlow, 1997). It was in reality low in comparison to other water quality sites with 68.75% of stations recording no *Pipistrellus* spp. activity at all. As the majority of stations classified as A1 were largely allocated to Urban land use, with only 3% of stations having trees on both sides, this does appear to suggest that the Urban area of Falkirk provides suitable roosting opportunities for *P. pygmaeus*, and possibly *P. pipistrellus*, but that the suitability as a foraging site may be limited. This is supported by the fact that *Pipistrellus* spp. activity recorded near the patch of woodland where *Myotis* spp. activity was high, recorded no feeding buzzes by this species group at all, and may have therefore not been using the area for foraging.

In Kirkintilloch, at C classified stations, bat activity was low by *Pipistrellus* spp. at stations that were allocated to Urban land use, but activity peaked as land use changed to a more rural setting. The interface between urban and rural areas may therefore be of marked value to *Pipistrellus* spp. under study, since Kirkintilloch may provide ideal roosting opportunities within buildings, bridges, schools etc, but still be at the interface of a rural setting where prey availability is likely to be less diminished by adverse developments (Geggie & Fenton, 1985). Bats may also feed where large concentrations of insects cluster, and so light sources in urban areas may create a dilution effect where insects are more dispersed, or that insect abundance is lower nearer to the town centre. Bats

may therefore aggregate on the outskirts where insect biomass is likely to be higher (Geggie & Fenton, 1985).

The influence of tree cover was demonstrated by both groups of species in both land class groups. *Myotis* spp. were found to avoid stretches where no trees were present, which may explain why hardly any activity was recorded at the majority of A1 stretches. *Myotis* spp. have been shown to disfavour sections of a river where no trees are present, and to favour stretches of river that have trees bordering both sides, which is likely to reflect the distribution of insect prey in relation to shelter from the wind, and increased availability of food plants for insects. *M. daubentonii*, which are strongly associated with water, are further influenced by turbulent or cluttered water, where exposed windy stretches are likely to increase the number and size of ripples on the water surface, which may interfere with echolocation (Rydell *et al.*, 1999). In this study, *Myotis* spp. selected for stretches of the canal which had trees on one side and only used areas with trees on both sides in proportion to availability. *Pipistrellus* spp. significantly selected for areas where trees were present on both sides and avoided stations which had trees on one side. This may imply that possible competition by *Pipistrellus* spp. could be limiting *Myotis* spp. in their choice of a foraging patch. *Myotis* spp. were found to avoid C stretches, which was largely categorised by trees on both sides. It was expected that more *Myotis* spp. activity would be found here. Limitations of sampling procedure may account for the variation in bat activity between C classified stretches in that there was a two and a half week gap between sampling. This may account for the much lower activity recorded in Cadder compared to Kirkintilloch. However as C classified stretches were utilised less than expected, the possibility of this area being a poor quality foraging site for *Myotis* spp. cannot be eliminated. Further investigation is required to monitor bat activity in this area, in comparison to adjacent stretches, to determine if *Myotis* spp. are consistently avoiding this area.

Both *Myotis* and *Pipistrellus* spp. significantly favoured A2 stretches, located near the Craigmarloch Aqueduct. This stretch recorded the highest number of *Pipistrellus* spp. where bat activity was considerably higher than other recorded stretches. *Myotis* spp. also particularly favoured a small stretch in this area where the amount of recorded activity was near to that of the A1 site at Carmuir. Based on observations in the field, this site was by far the most secluded in terms of distance to roads, and very sheltered, particularly near the aqueduct where non-coniferous woodland

occupied moderate slopes that further sheltered the canal. There are two known *P. pygmaeus* roosts in the vicinity, approximately 600m away from the canal. The first has been identified at the disused quarry to the south of this stretch of canal, opposite Kelvinhead Jetty (SNH: personal correspondence - K Marshall). The second has been identified at Auchincloch, to the north side of this area near Wyndford Lock. This roost supports a large colony of *P. pygmaeus* bats (BaTML: personal correspondence – N Middleton).

Unfortunately the stretch near Wyndford Lock had to be abandoned owing to persistent rain conditions. This stretch was largely exposed with very little tall tree cover to shelter its banks. It would have been useful to see if bats, which generally favoured the area, were avoiding this particular patch. There may be a general trend for reduced activity as tree density decreases. If so, the value of tree cover will be emphasised as an important component of habitat continuity for foraging bats, which will require greater protection.

In view of the information provided on roost sightings, it is interesting to note that in Falkirk where known roosts have been located close to the canal, very little activity was recorded near the stretch which had woodland edge. However, Craigmarloch Aqueduct where known roosts have also been identified, activity was considerably higher. This land surrounding the canal was largely arable with some unimproved grassland. In a paper by Walsh & Harris (1996a) bats were shown to avoid arable land. This however was largely in upland areas, where prey availability may have been lower (Walsh & Harris 1996a). The majority of the study area falls under arable land but this study did not look at bat activity across the lowland landscape, only along the canal. The importance of water bodies for foraging bats has been confirmed in numerous studies (Walsh & Harris 1996a), and it may be that bats avoid foraging over land in arable areas where fields are more open and intensively managed, but that the canal provides a habitat within the agricultural landscape that can be exploited. It has been shown that general bat activity along water sites is more heavy in agricultural landscapes, and less so in urban landscapes (Gehrt & Chelsvig, 2004).

Conclusion

In a predominantly agricultural landscape, the Forth & Clyde Canal provides an important habitat for both commuting and foraging bats. The analyses in this study have identified potentially good foraging sites along the canal that are worthy of note for conservation. Carmuir in Falkirk is an important

foraging habitat for *Myotis* spp. in this study. Potentially good foraging sites for mainly *Pipistrellus* spp. are near Craigmarnock Aqueduct, and the outskirts of Kirkintilloch West. Factors affecting habitat use were likely to be largely attributed to tree cover, proximity to roosts and land use. There were some inconsistencies in the data, which made reasoning more challenging and further study will be required to support these findings. Monitoring changes in bat activity at these sites will be of value in the future to determine if the levels of habitat use along the canal are being affected by the re-opening of the canal corridor to navigation etc. Bankside vegetation, tree cover, and water quality in particular, if not maintained, may have a profound effect on the available foraging area to bats, reducing the value of an important habitat for not only bats but also other wildlife that inhabit the canal corridor.

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Appendix I: Detailed results for each transect

Table 5: Summary of transects

Site no.	Date	Site name	NS start grid	NS end grid	Transect length	Land use	Water quality	Description
1	03/10/05	Bankside	89699 81409	87750 80422	2.4	Largely Urban	A1	Excellent
2	25/09/05	Falkirk Wheel	87555 80270	85341 80235	2.4	Largely Urban	A1	Excellent
3	29/09/05	Wyndford Lock	75456 78094	76320 78376	2.4	Arable	A2	Good
4	04/10/05	Aqueduct	73502 77304	75591 78155	2.4	Arable	A2	Good
5	05/10/05	Auchinstarry	70189 76258	72090 76889	2.4	Largely Arable	B	Fair
6	06/10/05	Twechar	68197 74759	69982 75985	2.4	Largely Arable	B	Fair
7	20/09/05	Kirkintilloch	65527 73828	63514 73010	2.4	Arable/Urban	C	Poor
8	07/10/05	Cadder	61637 72333	63356 73054	2.4	Arable	C	Poor

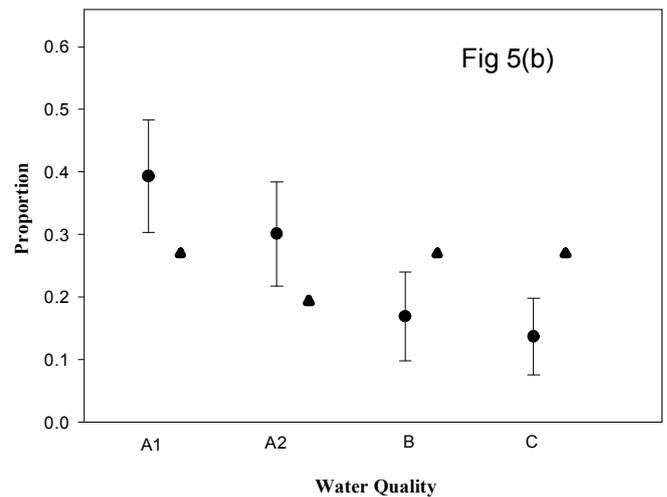
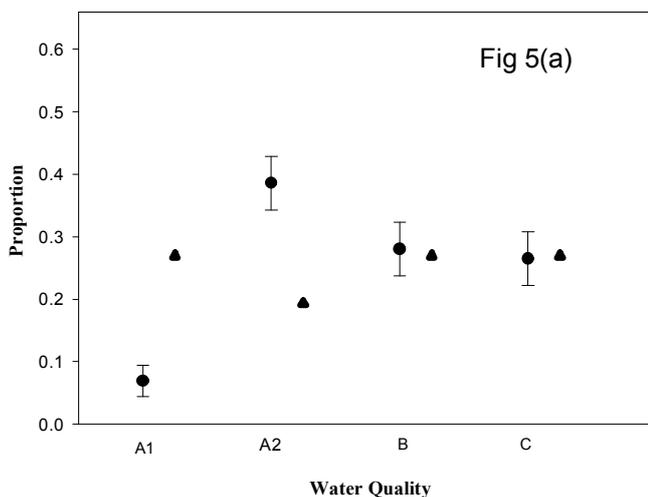
Table 6: Results from Bat sampling survey including details of bat activity (BP) and feeding buzzes (FB) at each transect for each species.

Site No.	Date	Start Time	End Time	Total number		<i>Myotis</i> spp.		<i>P. pygmaeus</i>		<i>P. pipistrellus</i>		Unallocated		Unknown	
				BP	FB	BP	FB	BP	FB	BP	FB	BP	FB	BP	FB
1	03/10/2005	19:50	21:22	28	2	7	1	13	1	4		3		1	
2	25/09/2005	20:05	21:45	96	17	65	17	21		0		0		10	
3	29/09/2005	20:00	20:47	85	3	5		78	3	0		2		0	
4	04/10/2005	19:45	21:20	261	17	50	1	200	16	0		9		2	
5	05/10/2005	19:40	21:15	145	7	19		90	4	13	3	7		16	
6	06/10/2005	19:30	21:04	97	4	12	1	79	3	0		5		1	
7	20/09/2005	20:20	21:58	167	40	23	5	131	33	3		9	2	1	
8	07/10/2005	19:10	20:50	58	8	2	8	56		0		0		0	

Appendix II: Statistical Analysis

Table 7: Bonferroni Confidence Intervals: observed proportion of bat passes in relation to water quality

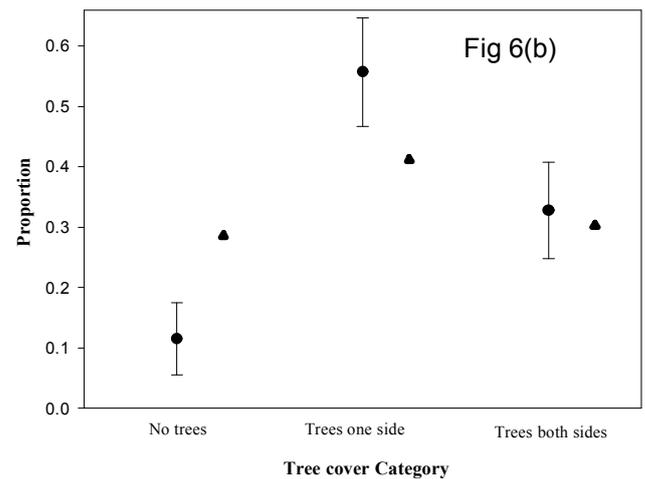
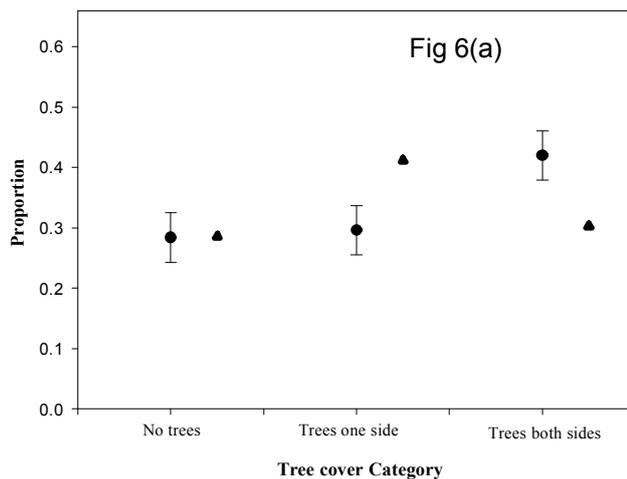
For <i>Pipistrellus</i> species						
Water quality category	Number of stations for each cat	obs no. of passes	Obs. propor. (p_i)	exp no. of passes	Exp propor.	95% CI Intervals
A1 - Excellent	32	52	0.069	202.76	0.269	$0.044 \leq p_1 \leq 0.094$
A2 - Good	23	291	0.386	145.73	0.193	$0.343 \leq p_2 \leq 0.429$
B - Fair	32	211	0.280	202.76	0.269	$0.237 \leq p_3 \leq 0.323$
C - Poor	32	200	0.265	202.76	0.269	$0.222 \leq p_4 \leq 0.308$
Total	119	754	1	754	1	
For <i>Myotis</i> species						
Water quality category	Number of stations for each cat	obs no. of passes	Obs. propor. (p_i)	exp no. of passes	Exp propor.	95% CI Intervals
A1 - Excellent	32	72	0.393	49.2	0.269	$0.303 \leq p_1 \leq 0.483$
A2 - Good	23	55	0.301	35.4	0.193	$0.218 \leq p_2 \leq 0.384$
B - Fair	32	31	0.169	49.2	0.269	$0.098 \leq p_3 \leq 0.24$
C - Poor	32	25	0.137	49.2	0.269	$0.076 \leq p_4 \leq 0.198$
Total	119	183	1	183	1	



Figures 5(a) and 5(b): Habitat use by *Pipistrellus* spp. (a) and *Myotis* spp. (b). The proportion of available habitat, and hence expected use, is shown by triangles; the actual use of each habitat is shown by circles (●). The upper and lower confidence intervals (CI) are represented by error bars. Where the expected proportion lies below the lowest CI, the habitat is significantly selected for. Where the expected proportion lies above the upper CI, the habitat was significantly avoided

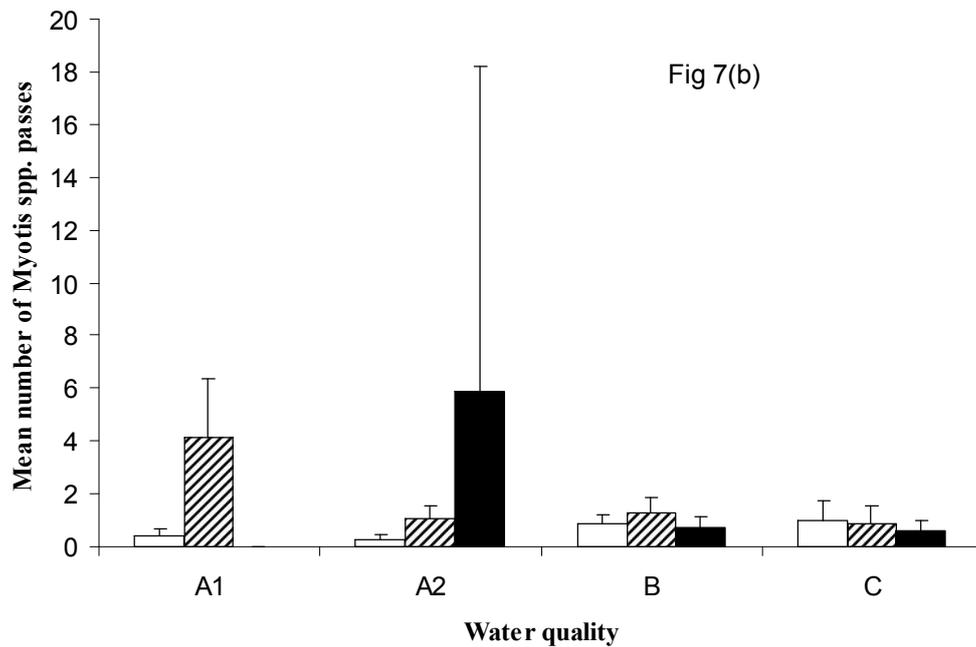
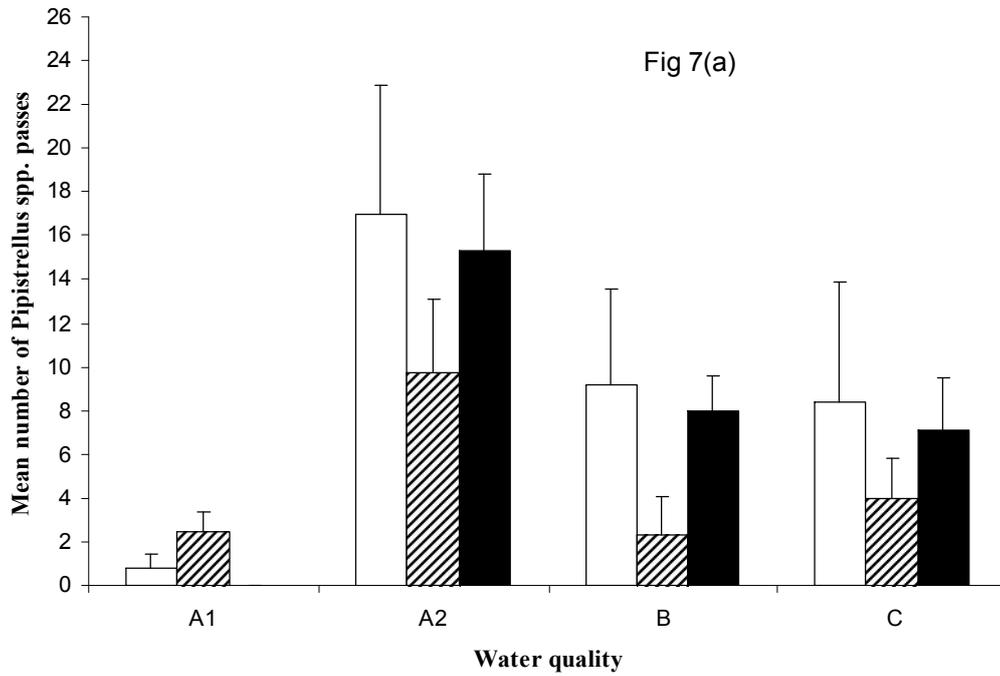
Table 8: Bonferroni Confidence Intervals: observed proportion of bat passes in relation to tree cover

For <i>Pipistrellus</i> species						
Habitat category	Number of stations for each cat	obs no. of passes	Obs. propor. (p_i)	exp no. of passes	Exp propor.	CI Int. of propor. of occur (95% CI Coef)
No trees	34	214	0.284	215.4	0.286	$0.243 < p_1 < 0.325$
Trees one side	49	223	0.296	310.5	0.412	$0.255 < p_2 < 0.337$
Trees both sides	36	317	0.42	228.1	0.303	$0.379 < p_3 < 0.461$
Total	119	754	1	754	1	
For <i>Myotis</i> species						
Habitat category	Number of stations for each cat	obs no. of passes	Obs. propor. (p_i)	exp no. of passes	Exp propor.	CI Int. of propor. of occur (95% CI Coef)
No trees	34	21	0.115	52.3	0.286	$0.055 < p_1 < 0.175$
Trees one side	49	102	0.557	75.35	0.412	$0.467 < p_2 < 0.647$
Trees both sides	36	60	0.328	55.36	0.303	$0.248 < p_3 < 0.408$
Total	119	183	1	183	1	



Figures 6(a) and 6(b): Habitat use by *Pipistrellus* spp. (a) and *Myotis* spp. (b). The proportion of available habitat, and hence expected use, is shown by triangles; the actual use of each habitat is shown by circles (●). The upper and lower confidence intervals (CI) are represented as error bars. Where the expected proportion lies below the lowest CI, the habitat is significantly selected for. Where the expected proportion lies above the upper CI, the habitat was significantly avoided

Appendix III: Mean Number Of Bat Passes



Figures 7(a) and 7(b): The mean number (+ standard error) of *Pipistrellus* spp. (a) and *Myotis* spp. (b) passes observed in relation to tree cover and water quality status. The bars represent the total number of passes in three distinct categories. Clear bars represent no trees present, striped bars indicate trees present on one side, and the solid bars represent mean passes in the category of trees on both sides.