South Yorkshire Magnesian Limestone Autumn Swarming Survey

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Introduction

Autumn bat swarming is characterised by intense bat flight activity in and around the entrances of underground sites, often by multi-species groups of bats. Bats captured at swarming sites often display a strong male bias and autumn swarming has been shown to function as a promiscuous mating behaviour (van Schaik *et al*., 2015). The species present are usually limited to those that make use of the underground site for hibernation during the winter. Swarming is the major source of gene flow in many bat species (Rivers *et al.*, 2005; Furmankiewicz and Altringham, 2007) and is also likely to allow bats the chance to assess hibernation sites ahead of roosting (van Schaik *et al*., 2015). Autumn swarming is potentially also a means of passing on knowledge of hibernacula locations from adults to young bats (Glover and Altringham, 2008).

The peak period for autumn swarming varies between sites and bat species (Glover and Altringham, 2008; van Schaik et al., 2015; Rivers *et al.*, 2006), with this period extending from August to October, inclusive. Nightly peaks in bat swarming activity have been shown to vary with site, and period of the swarming season. Peak activity is most often recorded 4-6 hours after sunset (Parsons *et al*., 2003b; Rivers *et al*., 2006).

Previous trapping studies at autumn swarming sites have shown that caves in other parts of northern England are used by large numbers of bats throughout the course of the swarming period (Glover and Altringham, 2008; Rivers *et al.*, 2006). Some of these swarming sites are considered to be of national importance to the bat species utilising them (Rivers *et al*., 2006). Individual bats have been shown to commute distances of up to 60km between summer roosts and major swarming sites (Rivers *et al*., 2006), with bats most often returning to their day roosts after a night's swarming activity (Furmankiewicz, 2008). Studies have shown that bats may return to the swarming site of capture (Parsons & Jones, 2003) but mainly appear to visit only a single swarming site within one swarming season (Furmankiewicz, 2008).

Notable amongst known swarming sites in northern England are the 'windy pits', a series of mass-movement caves located close to Helmsley in North Yorkshire (Murphy and Cordingley, 2010), which were estimated to support a population of 2000–6000 Natterer's bats *Myotis nattereri* across the three best-studied caves (Rivers *et al.*, 2006). A study undertaken on mainland Europe also showed that bat species composition and abundance during swarming can correlate with composition and abundance during hibernation at the same site (van Schaik *et al*., 2015).

Caves are rare in South Yorkshire and largely restricted to areas along the Magnesian Limestone belt that runs approximately north to south through sections of Doncaster and Rotherham, however, many of the bat species that engage in autumn swarming are known to be numerous in the county. Given there is a significant energetic cost involved in bats commuting from South Yorkshire summer roosts to swarming sites in other counties, it follows that there would be a strong driver for bats to swarm locally, where conditions allow. During 2014 and 2015, preliminary surveys of several potential bat swarming sites on the Magnesian Limestone were undertaken by South Yorkshire Bat Group members. These surveys showed that several caves were used by autumn swarming bats. Survey techniques adopted at that time included static monitoring, the use of infra-red enabled video cameras and lighting to record bat activity around cave portals and the recording of swarming bats using thermal imaging cameras. These survey techniques confirmed the presence of autumn swarming bats and recorded several bat species as using one or more sites. However, these techniques were limited in their ability to determine the species, sex, age and breeding status of bats using the site. Therefore it was considered that a systematic programme of trapping and static monitoring survey should be undertaken in two areas of South Yorkshire during autumn 2016.

Two locations were chosen in the Magnesian Limestone belt: Anston Stones Wood in Rotherham and Nearcliff Wood in Doncaster (Figure 1).

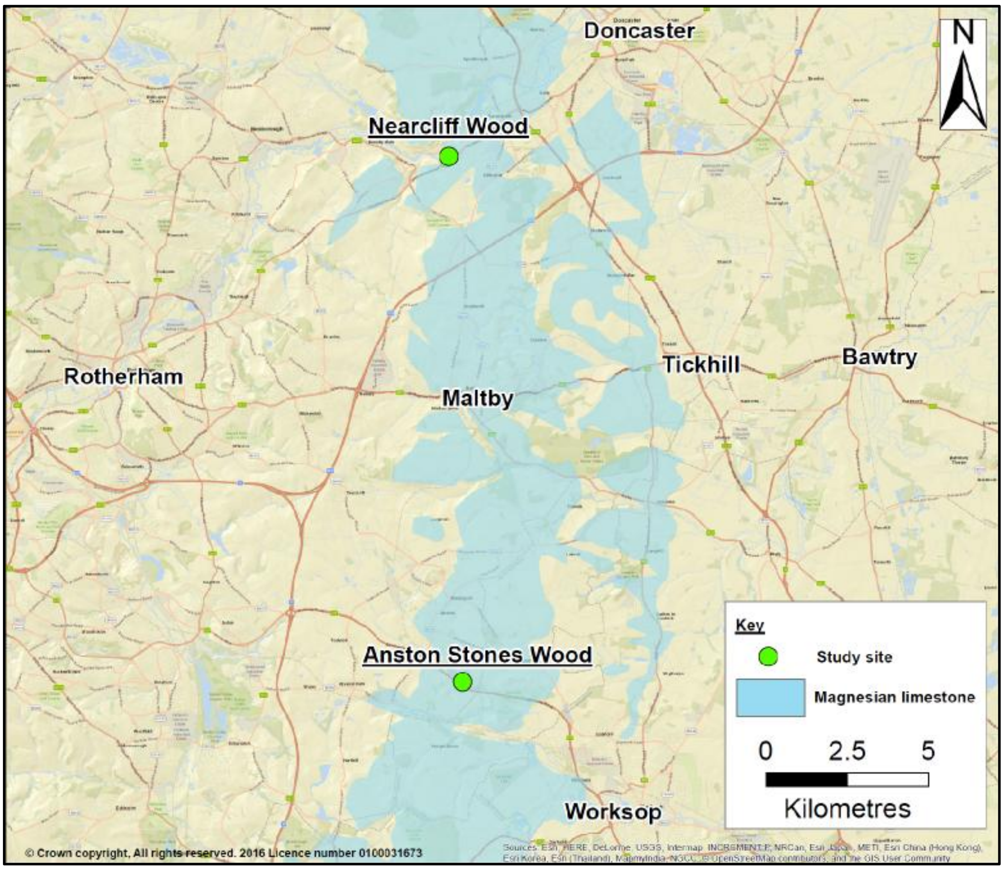

Figure 1: Map showing study site locations. Map prepared by Daniel Best with Ecus Ltd software.

Background information on the study sites and the cave/s surveyed is presented below.

Anston Stones Wood SSSI, South Anston, Rotherham

Anston Stones Wood is a 33ha area of mainly limestone woodland, comprising the second best example of this woodland type in South Yorkshire. The site is designated as a Site of Special Scientific Interest (SSSI) for its botanical communities. The Magnesian Limestone outcrops as natural crags on the Anston Brook valley slopes and also within a railway cutting. A study of the caves of this wood notes the presence of two caves and one large fissure together with a number of smaller fissures (Brown, 1968).

The principal cave at this site is known as Dead Man's Cave, named after the finding there of a human body in the winter of 1966/67. This small cave, which is a Scheduled Ancient Monument, consists of an entrance fissure 2.5m wide and 1.5m high. This leads, via a narrow passage, to a chamber 4.5m long by 3m wide. It appears to have been formed through historic water erosion which enlarged a natural fissure in the limestone. The sediment deposition in the cave has been shown to have covered Roman artefacts and also material dating from the Later Upper Palaeolithic period, including reindeer bone radiocarbon dated to c.9850 years ago (Historic England, 2017).

The 2016 trapping surveys also sampled a mass movement created limestone fissure known as Large Fissure. The entrance to this fissure is approximately 3m tall by 45cm wide and can be accessed for approximately 6m before continuing for an unknown distance.

A second cave known as Fissure Cave comprises an 8m tall by 3m high chamber accessed via a squeeze from above. Bat access is also possible via two additional entrance points. This cave was not covered during the 2016 survey work. Dead Man's Cave, Large Fissure and Fissure Cave are separated by a distance of only c.190m. Given the close proximity of these features the two caves and single fissure could be considered as one large swarming site, with the same bats likely to swarm at more than one of the three features during the same visit.

Nearcliff Wood, Conisbrough, Doncaster

Nearcliff Wood is a 21ha area of limestone woodland on the southern side of a gorge cut by the River Don. Part of the wood is included within the Sprotbrough Gorge SSSI, designated for its botanical and invertebrate communities. Sections of Nearcliff Wood have been subject to extensive former quarrying, resulting in changes to the ground levels. In addition, the wood is bisected by a gorge cut in the early 1900s for the former Dearne Valley Railway.

A group of mass movement caves are known from this section of the River Don valley (Murphy & Cordingley, 2010; Engering & Barron, 2007). Within Nearcliff Wood this grouping includes Nearcliff Wood Rift Cave and a number of smaller caves, associated with the former railway gorge.

Nearcliff Wood Rift Cave was the only cave at this site covered during the 2016 swarming survey. This cave is 88m long by 12m deep. It can be accessed by either of the two entrances. The upper and lower entrances both comprise of squeezes separated by a vertical distance of 10m on the steep slope of a quarry face.

It is likely that all caves within Nearcliff Wood could be considered as one large swarming site, with the same bats likely to swarm at more than one feature.

Aims

The study aims are given below:

- Confirm the range of bat species swarming at each of the two sites.
- Compare relative levels of bat swarming at the two sites.
- Compare the sex ratio, age distribution and reproductive status of bats captured at the two sites.
- Compare the results of trapping and static monitoring survey conducted in parallel.

Methodology

The two study sites were surveyed on four occasions each; with a single survey visit during each of the below survey periods:

- Mid-late August.
- Early-mid September.
- Mid-late September.
- Early-mid October.

Trapping protocol

Trapping surveys were carried out using a pair of $4.2m^2$ Austbat triple-bank harp traps. Single traps were used to cover the openings of Dead Man's Cave and Large Fissure at Anston Stones Wood (Figure 2). Two individual traps were required to cover both the upper and lower entrances to Nearcliff Wood Rift Cave in Nearcliff Wood. Harp traps were erected directly across cave openings in order to intercept bats entering/exiting these features, with additional sections of camouflage netting used to cover the larger spaces between trap sides and the edges of the cave opening.

Figure 2: Surveyed caves with Nearcliff Wood Rift Cave (Nearcliff Wood) on left, Dead Man's Cave (Anston Stones Wood) in centre and Large Fissure (Anston Stones Wood) on right.

Trapping nights were selected based on recent weather forecasts for the survey night. Dry survey nights, with little or no wind and temperatures above 8°C at sunset were targeted. Weather data including temperature, wind speed and rainfall at the beginning and end of the survey were taken from local weather station records. The survey team was formed of an even mix of surveyors drawn from South and West Yorkshire Bat Groups, including at least two surveyors experienced in bat trapping surveys.

Harp traps were installed from sunset until six hours after this time, with traps checked every 15 minutes during the survey period. The time of each bat retrieval was recorded with captured bats transferred to cotton drawstring bags for transfer to a bat processing area. In the bat processing area bat species, sex, forearm length, age and where possible, breeding status was recorded. Bats were processed in order of capture. Bats were aged as either adults or juveniles based on the degree of ossification of the joints within the finger bones (Mitchell-Jones & McLeish, 2004). A fur clipping (Natural England, 2013) was taken from all bats prior to release in order to allow re-captured bats to be identified. Bats were identified to species level with reference to their morphological characteristics, as presented in Bats of Britain and Europe (Dietz & Kiefer, 2016). In order to confirm species identification of suspected whiskered bat *M. mystacinus*/Brandt's bat *M. brandtii*/Alcathoe bat *M. alcathoe*, clipped fur was retained in a numbered vial for future DNA analysis. To date, seven fur samples have been subject to DNA analysis with a further ten probable whiskered bat samples awaiting identification. DNA analysis was undertaken by the Waterford Institute using a targeted qPCR analysis technique.

Static monitoring protocol

A single Pettersson d500x full spectrum static monitoring bat detector was installed adjacent to one of the two harp traps used on each survey occasion. The location of the static monitoring device was alternated between cave entrances with each survey occasion. Consequently, all surveyed cave entrances were covered by the static detector on two separate occasions. Sound files recorded by the static detector were downloaded and analysed to species level using BatClassify analysis software (Scott & Altringham, 2014). Any species identifications performed by the software which generated a probability of occurrence of 0.7 or more were accepted. Within the BatClassify software the calls of whiskered and Brandt's bat are grouped. The only sound files considered in this report, are those which relate to a bat species caught during the trapping surveys, which is also known to exhibit autumn swarming behaviour at cave sites. Species fitting these two criteria comprise Daubenton's bat *M. daubentonii*, whiskered/Brandt's bat, Natterer's bat and brown long-eared bat *Plecotus auritus*.

Hibernation survey

A single hibernation survey was undertaken on each surveyed cave in January 2017. Hibernation survey comprised a single daytime visual inspection undertaken with a high power torch. The survey of Nearcliff Wood Rift Cave was carried out on 21/01/2017 with the surveys of Dead Man's Cave and Large Fissure taking place on 29/01/2017.

It should be noted that it was not possible to survey all sections of any of three caves and consequently additional bats may have been present. Whilst most sections of Dead Man's Cave could be viewed, Large Fissure could only be accessed for the first 1-2m, whilst Nearcliff Wood Rift Cave supports extensive internal fissures which could not be fully inspected.

Evaluation of results

The findings of this study were compared with those of other documented swarming surveys, with an emphasis on those studies undertaken within the same region.

In particular, comparison of capture rates was made with studies of the North Yorkshire Windy Pits (Rivers *et al*., 2016) and a number of caves and mines in Derbyshire (Roe, 2016). Relevant background information on the methodologies adopted by these studies is detailed below.

Between 2001 and 2003, Dr. Nicky Rivers trapped at three mass movement caves close to Helmsley in the North Yorkshire Moors. Dr. Rivers kindly supplied her survey data from which we calculated the median number of bats trapped at each of three caves (Slip Gill, Antofts and Bucklands) between mid-August and mid-October 2001-2003. Whist the number of traps used and the start and end time of surveys varied, it appears that trapping typically continued from sunset until approximately six hours afterwards (Rivers *et al*., 2006).

Over recent years Derbyshire Bat Conservation Group have carried out swarming surveys on a number caves and mines within their county. The 2015 survey data presented in Figure 12 of the group's 'Summary Report 2015: Derbyshire Underground Sites Project Phase II' (Roe, 2016) was used to calculate the median number of bats trapped at each of three caves or mines (Owl Hole Cave, Jacobs Dream Mine and Jug Holes Cave and Mine). Again only survey data collected between mid-August and mid-October was used in the calculations. A maximum of three harp traps and two mist nets was used during surveys at each site; however the typical duration of survey works is not stated.

Given the number of sampling visits varied between studies, it was considered that use of a median value would offset the occasional very high or low capture rates, which are more likely to be encountered with an increased number of survey visits. Consequently the median was adopted as the measure of average used in comparisons.

Statistical analysis

Statistical analysis was completed by Dr Rebecca Slack to identify whether the results were statistically significant. The four null hypothesis tested, along with the type of statistical test used are shown in Table 1 below.

Table 1: Statistical tests performed.

Hypothesis	Statistical Test Used
There is no significant relationship between number of male and female bats captured and the species of bats present.	Chi Squared
There is no significant difference in the number of each species of bat captured at each site.	Chi Squared
There is no significant relationship between the age and species of the bat and the month of capture.	Chi Squared
There is no relationship between the age, sex, or location of the site of capture and the time of capture (relative to sunset).	Univariate ANOVA

Results

Trapping rate

A total of 129 bats were caught across all swarming sessions at both sites, totalling a catch rate of 2.69 bats caught per hour, per site. A higher catch rate was recorded at Anston Stones Wood, overall and during each catching session except October, when catching rates were even. Table 2 details total catches and catch per hour, broken down by site and catching period.

Table 2: Number of bats caught, broken down by recording session and site.

Sessions	Anston Stones Wood		Nearcliff Wood		Both Sites	
	Totals	Catch Per Hour	Totals	Catch Per Hour	Grand Total	Catch Per Hour
August	27	4.50	20	3.33	47	3.92
Early Sept	25	4.17	12	2.00	37	3.08
Late Sept	20	3.33	5	0.83	25	2.08
Oct	10	1.67	10	1.67	20	1.67

Sex ratio

The number of males caught far outnumbered females, resulting in a breakdown of 100 males, 28 females and 1 unknown[1] (77.52%, 21.71% and 0.78%, respectively). The breakdowns for Anston Stones Wood (76.83%, 21.95% and 1.22%) and Nearcliff Wood (78.72%, 21.28% and 0%) were similar to the overall male/female catch rate. Table 3, below, details the catch broken down by sex. There was no significant difference ($p>0.05$) in the sex ratios recorded between the species captured ($\chi(8) = 2.189$, $p = 0.975$, Pearson's Chi-Square).

Table 3: Sex breakdown across both sites.

Sex	Count	Catch Per Hour	%
Female	28	0.29	21.71
Male	100	1.04	77.52
N/A	1	0.01	0.78

Species composition

Across all sites in combination, Natterer's bats were the most common species caught. Daubenton's bats were the second most abundant species, followed by whiskered bats. Brown long-eared bats were the least common swarming species caught[2] (Chart 1).

[1] A single bat escaped prior to being processed.
[2] A single common pipistrelle *Pipistrellus pipistrellus* was also caught but this was considered likely to have been a foraging bat, rather than a swarming individual.

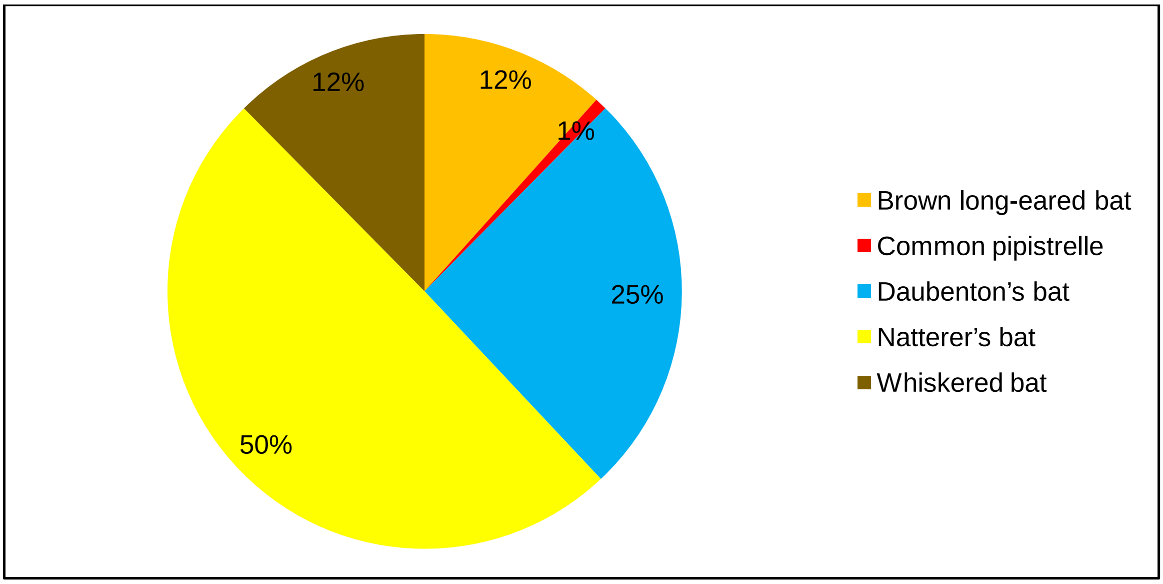

Chart 1: Species caught at both Anston Stones Wood and Nearcliff Wood.

The relative level of species abundance was not consistent across both sites. While only three species were caught at Anston Stones Wood, five species were caught at Nearcliff Wood Rift Cave; although one species caught at Nearcliff Wood, the common pipistrelle, was considered likely to have been foraging rather than swarming.

Whiskered bats were the most abundant species caught at Nearcliff Wood however this species was not caught at all at Anston Stones Wood. Natterer's bats were the next most frequently caught species at Nearcliff Wood and the most commonly caught species at Anston Stones Wood. At both sites this was followed by Daubenton's bat, and finally brown long-eared bat. The difference in the number of bats of each species caught at each site was highly statistically significant ($\chi(8) = 37.061$, $p = 0.000$, Pearson's Chi-Square); this is likely to be primarily due to the lack of whiskered bats caught at Anston Stones Wood. The relative proportion of each species caught at the two sites is shown in Charts 2 and 3.

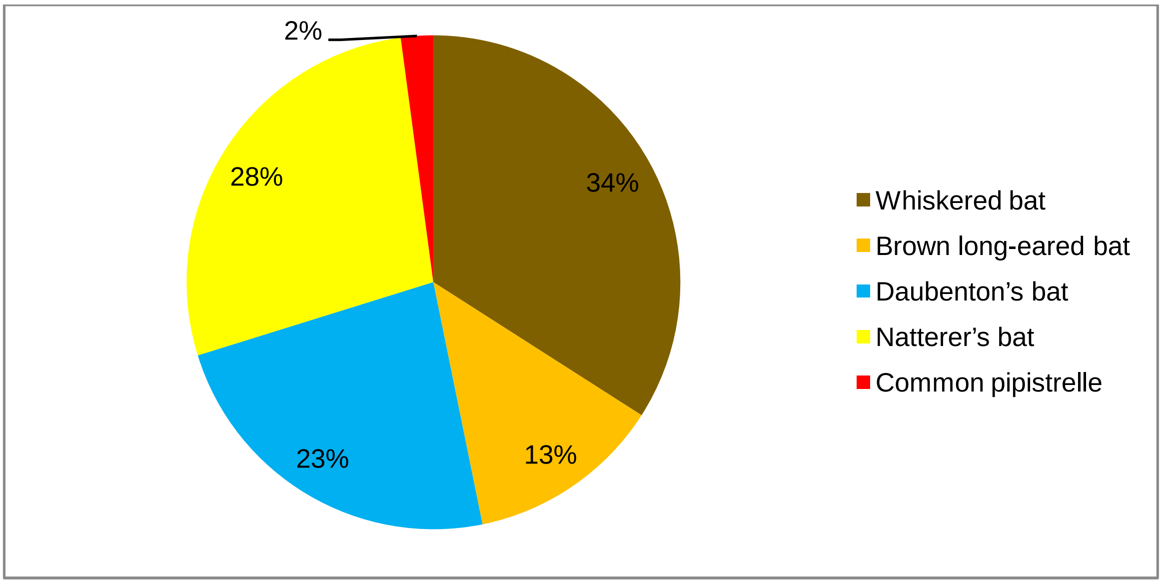

Chart 2: Species caught at the Nearcliff Wood site.

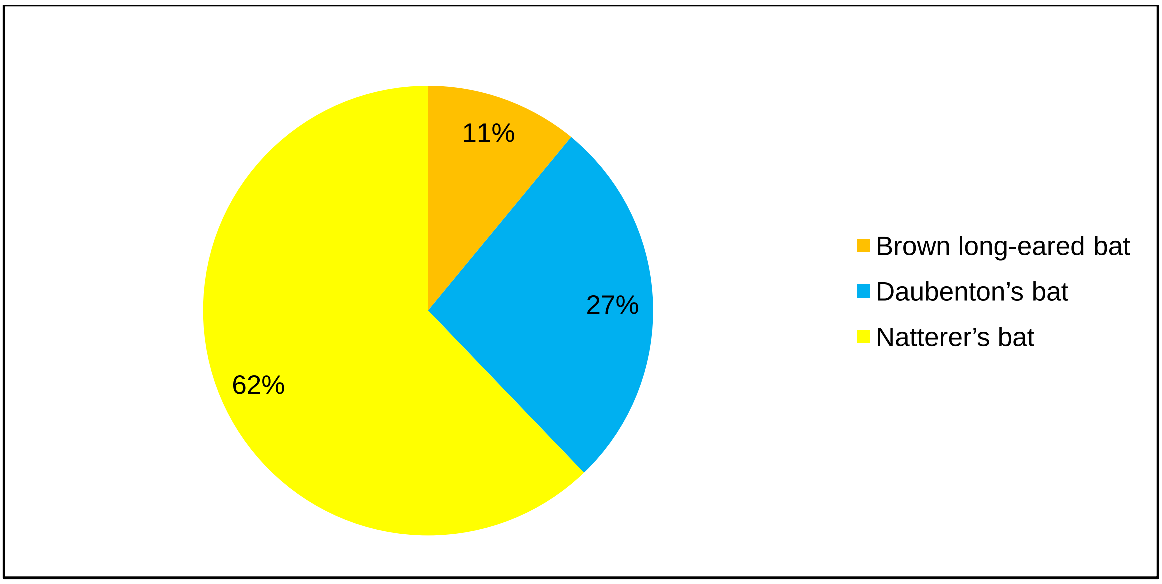

Chart 3: Species caught at the Anston Stones Wood site.

Adult / juvenile capture ratio

Adult bats made up 65% of all captures with juveniles comprising 35% with one bat (1%) unidentified. The proportion of juveniles was slightly higher at Anston Stones Wood (38% of all captures) than at Nearcliff Wood (28% of all captures).

The proportion of adult bats captured differed substantially between species, as shown in Table 4 below. The proportion of adult Natterer's bats and Daubenton's bats caught was broadly similar, slightly more adults than juveniles of both species were captured. However the proportion of juvenile whiskered bats and brown long-eared bats caught was much lower than the proportion of adults captured. Although the overall capture rate for whiskered bats and brown long-eared bats was lower than for the other two swarming species, very few juveniles of these species were captured (at just two and one bat respectively).

Table 4: Proportion of adults and juveniles captured for each species.

Species	Proportion of Captures Identified as Adults (%)	Proportion of Captures Identified as Juveniles (%)
Natterer's bat	59	41
Daubenton's bat	55	45
Whiskered bat	88	13
Brown long-eared bat	93	7

Seasonal differences in capture rate

The adult capture rate was highest early in the season; August recorded 47.6% of all adults captured with the rate decreasing each month until October, when only 9.5% of all adult bats captured during the study were recorded. Conversely, the juvenile capture rate increased initially (15.9% of all juveniles caught were captured in August, with this figure rising to 29.5% in late September) before dropping off slightly (to 27.3%) in October. Further investigation showed that both adults ($\chi(8) = 33.975$, $p = 0.000$, Pearson's Chi-Square) and juveniles ($\chi(8)$ = 19.948, p = 0.003, Pearson's Chi-Square) showed a highly significant relationship with season and species (Chart 4).

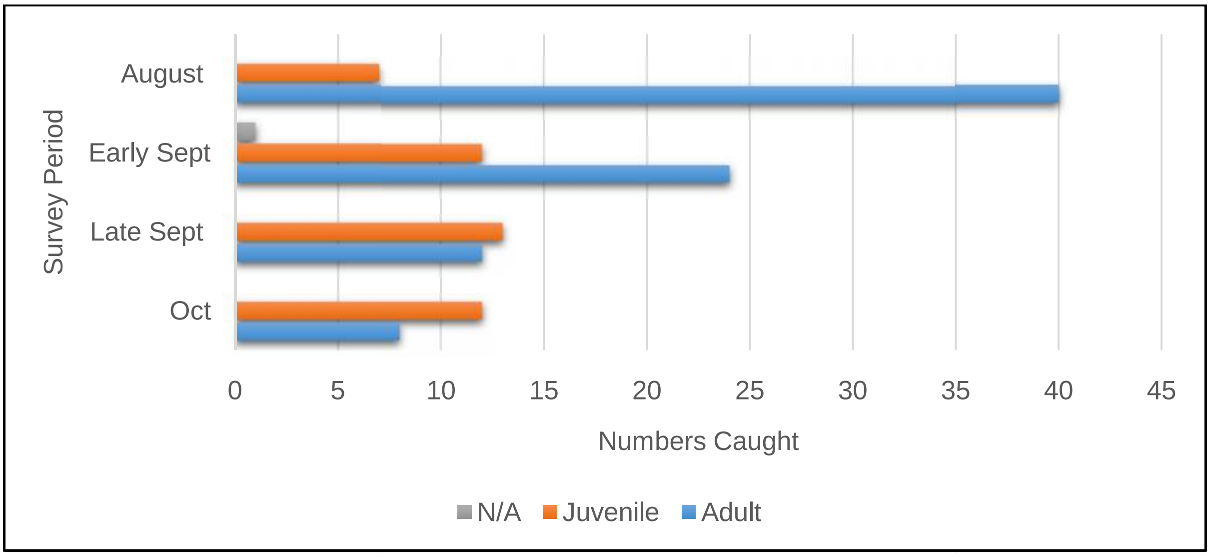

Chart 4: Number of adults and juveniles captured in each trapping session (combined across all species and for both sites).

The timing of the peak adult and juvenile capture rates was not constant for each species. The adult bat capture rate for Daubenton's bats, whiskered bats, and brown long-eared bats peaked early in the season (Charts 5-7). The adult Natterer's bat capture rate peaked later, in early September (Chart 8).

Adult Daubenton's bats only outnumbered juveniles in August, although as Chart 5 below shows, the difference in activity levels in that month was substantial. The lag in peak juvenile capture rate, relative to adult capture rate also appears to be present for Natterer's bats, with the number of juvenile bats caught continuing to build in late September and October, well after the peak in adult captures in early September. The numbers of juvenile brown long-eared bats and whiskered bats caught were too low to draw any meaningful conclusions from.

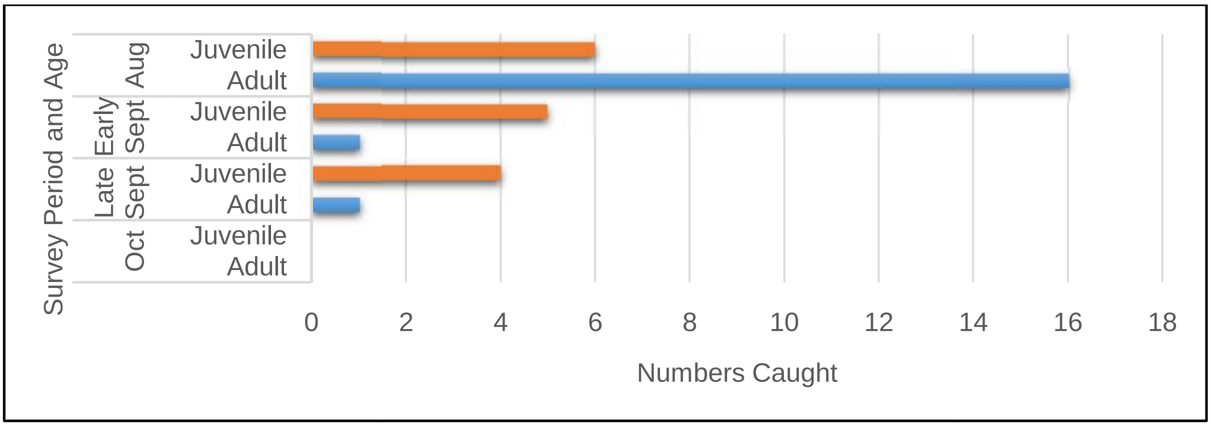

Chart 5: Number of adult and juvenile Daubenton's bats caught (combined for both sites) in each trapping session.

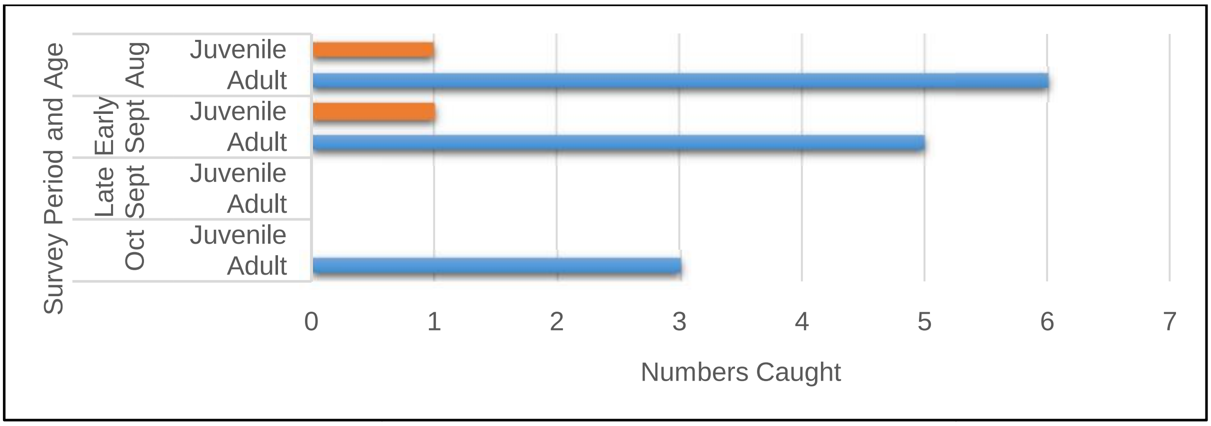

Chart 6: Number of adult and juvenile whiskered bats caught (combined for both sites) in each trapping session.

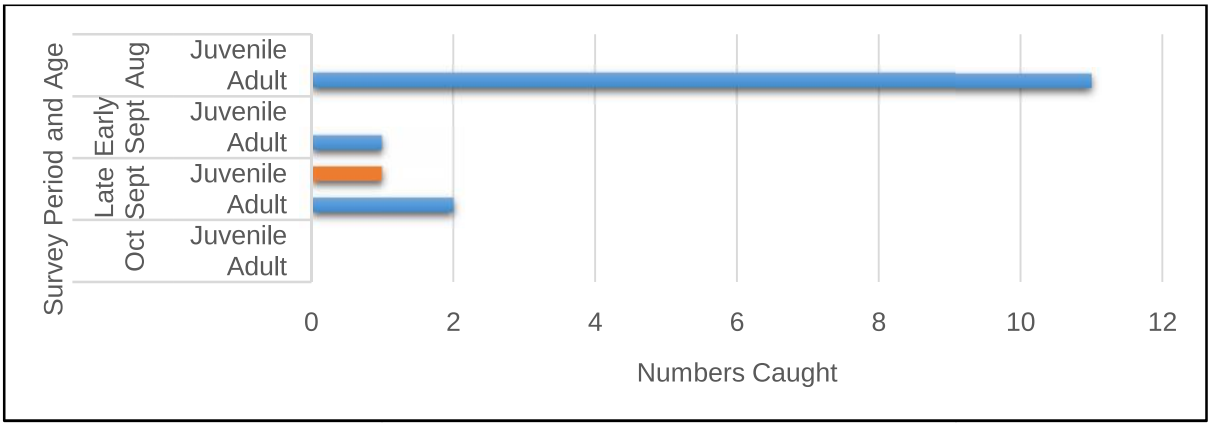

Chart 7: Number of adult and juvenile brown long-eared bats caught (combined for both sites) in each trapping session.

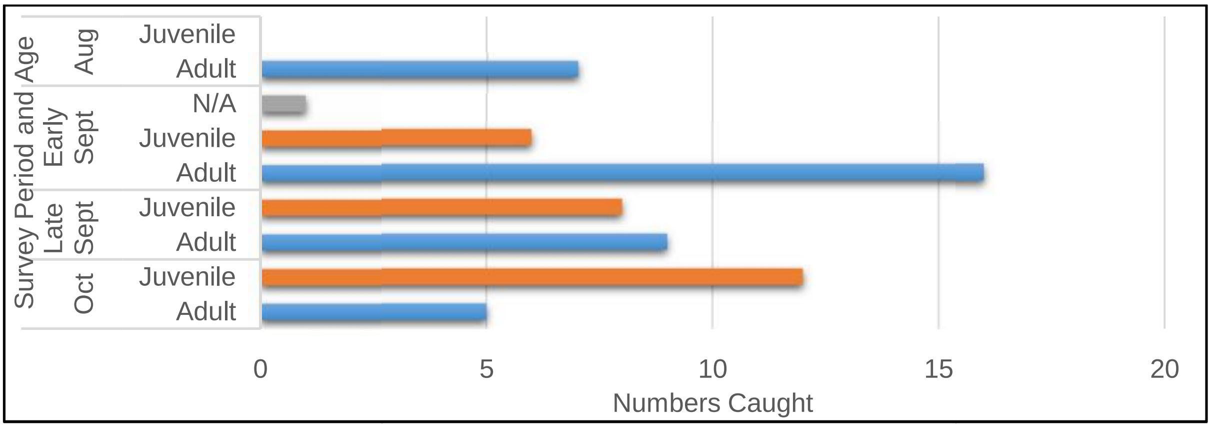

Chart 8: Number of adult and juvenile Natterer's bats caught (combined for both sites) in each trapping session.

Capture time

The peak capture rate, across all sessions, and all species, was recorded between 3 to 5 hours after sunset at Anston Stones Wood and 5 to 6 hours after sunset at Nearcliff Wood. The site of capture significantly influenced capture time at the $p<0.05$ level ($F(1,103) = 5.35$, p = 0.023, univariate ANOVA). There were no significant effects caused by the other variables considered (see table in appendix), apart from an interaction effect between age, species and location. However, it is considered possible that the single common pipistrelle caught may have skewed the result. Chart 9 summarises levels of activity per hour following sunset for each site.

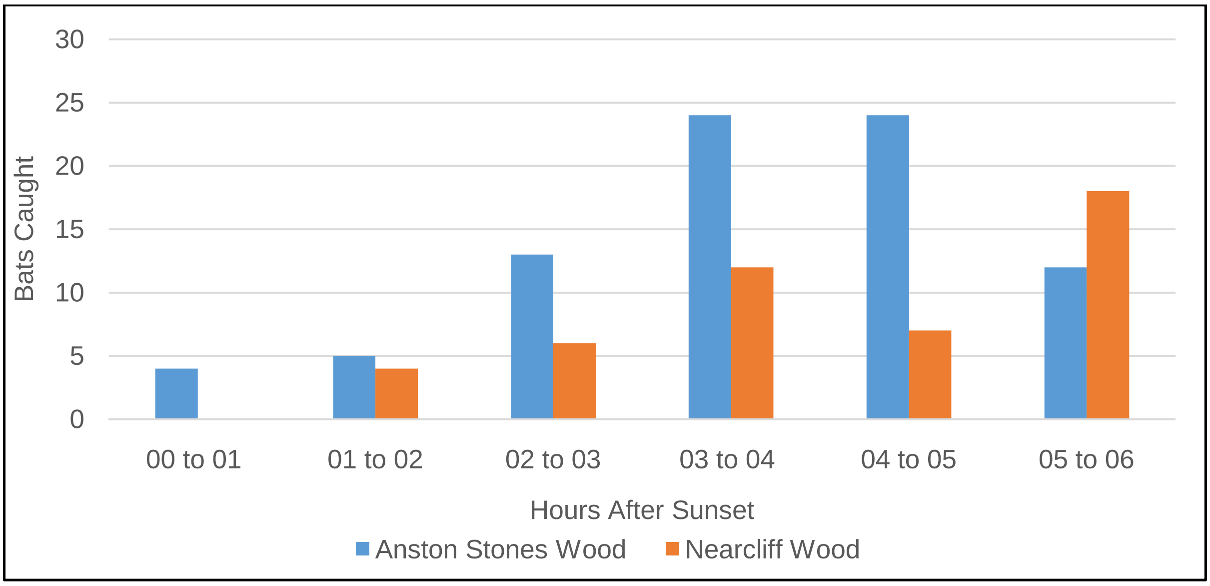

Chart 9: Bat captures broken down by hours after sunset.

Recaptures

The overall recapture rate was approximately 3.91%, across both sites and all species. This differed between sites, with Anston Stones Wood lowering the average recapture rate. The recapture rate at Anston Stones Wood was approximately 2.74% but 6.38% at Nearcliff Wood. Across both sites, all recaptures were male.

Static Monitoring

A total of 2,898 sound files were recorded from those bat species, which fitted the selection criteria outlined in the methods. A far higher number of sound files relating to autumn swarming bats species were recorded from Anston Stones Wood (2,717 sound files/94% of sound files), in comparison with Nearcliff Wood (181 sound files/6% of sound files) as shown in Table 5. This contrasted with the results of the trapping survey, which showed 64 % of all bats trapped were caught at Anston Stones Wood in comparison with 36% of bats trapped in Nearcliff Wood.

Table 5: Sound files breakdown by site and trapping session.

Sessions	Anston Stones Wood		Nearcliff Wood		Both Sites	
	Total Sound Files	Sound Files/Hour	Total	Sound Files/Hour	Total	Sound Files/Hour
August	335	56	25	4	360	60

Sessions	Anston Stones Wood		Nearcliff Wood		Both Sites	
	Total Sound Files	Sound Files/Hour	Total	Sound Files/Hour	Total	Sound Files/Hour
Early Sept	1186	198	92	15	1278	213
Late Sept	893	149	17	3	910	152
Oct	303	51	47	8	350	58

The static monitoring species breakdown at the two sites is detailed in Table 6 below. This shows that the majority of sound files recorded at both sites were identified as Natterer's bat, although the percentage of Natterer's bat calls was higher at Anston Stones Wood. A higher percentage of whiskered/Brandt's bat sound files was recorded from Nearcliff Wood (24% of sound files recorded at site), in comparison with Anston Stones (3% of sound files). This fits with the expectations from trapping survey which did not record any Brandt's bat from either site, with whiskered bat only recorded from Anston Stones Wood. The percentage of Daubenton's bat and brown long-eared bat calls recorded at both sites was similar.

Table 6: Species breakdown across both sites.

Species	Anston Stones		Nearcliff Wood		Both Sites	
	Totals Sound Files	% Total Sound Files	Totals Sound Files	% Total Sound Files	Totals Sound Files	% Total Sound Files
Whiskered/Brant's bat	93	3	43	24	136	5
Daubenton's bat	206	8	10	6	216	7
Natterer's bat	2364	87	126	70	2490	86
Brown long-eared bat	54	2	2	1	56	2

In order to explore the correlation between the results of the trapping and static monitoring surveys, the number of bats captured has been plotted against the number of sound files recorded in Chart 9. Only trapping data obtained from cave or cave entrances surveyed using both the trapping and static monitoring survey method has been plotted. Each survey occasion generated four data points, comprising one for each autumn swarming bat species recorded during the trapping surveys (Daubenton's bat, whiskered/Brandt's bat, Natterer's bat and brown long-eared bat). Chart 10 shows that static monitoring data correlated quite weakly with the trapping results, with the data having a Pearson's correlation co-efficient of 0.55.

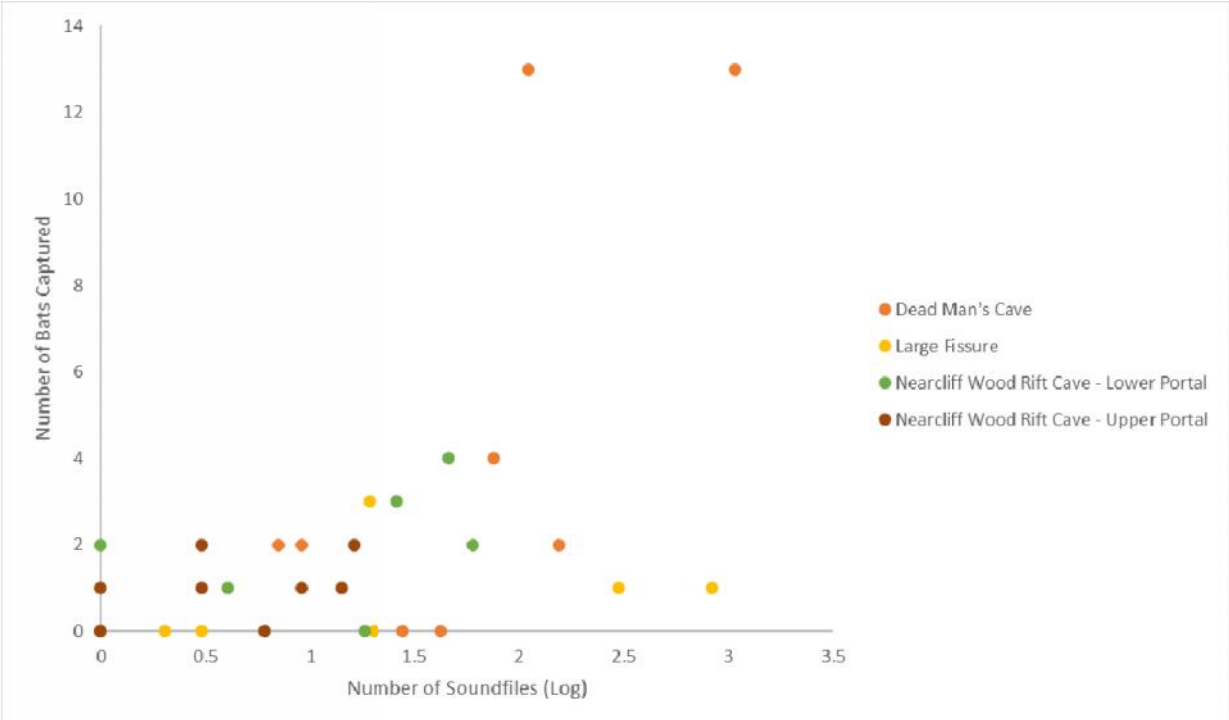

Chart 10: Comparison of trapping and static monitoring by cave or cave portal.

Hibernation survey findings

During hibernation survey undertaken at each cave in January 2017, a single hibernating brown long-eared bat was recorded from Nearcliff Wood Rift Cave, with no bats recorded during surveys of Dead Man's Cave and Large Fissure.

Discussion

Comparisons with other local studies

In comparison with other known swarming sites in northern England, these South Yorkshire sites display a number of similarities. This study captured a range of bat species commonly recorded at other swarming sites within the region including Daubenton's bat, whiskered bat Natterer's bat and brown long-eared bat.

Although the level of variation in species composition is notable, the overall species breakdown recorded during this South Yorkshire Bat Group (SYBG) study was broadly comparable to most other swarming capture projects (Glover & Altringham 2006, Rivers *et. al.*, 2006, Roe 2015), even those located in southern England (Parsons *et. al.*, 2003a). Although this is not true of the 2015 Derbyshire Bat Conservation Group work (DBCG) (Roe, 2016), it is interesting that the DBCG trapping study findings from 2014 do broadly match the breakdown in this study (Roe 2015) (Table 7).

Table 7: The percentage of captures recorded at Anston Stones (AS) and Nearcliff Wood (NW) as well as the percentage captured during the study overall (Tot). The table also shows the percentage of captures recorded for other nearby, or notable, projects.[3]

Species Recorded	Study							
	SYBG			Glover and Altringham (2006)	Rivers *et. al.* (2006)	DBCG		Parsons *et. al.* (2003a)
	AS	NW	Total			2014	2015	
Natterer's bat	62	28	50	54	79	40	11	37
Daubenton's bat	27	23	25	24	6	14	33	32
Brown long-eared bat	11	13	12	9	12	22	13	5
Whiskered bat	0	34	12	6	2	19	11	8
Brandt's bat	0	0	0	8	1	3	32	7
Other	0	1	1	0	0	0	0	12

Species composition is known to differ between swarming sites. A key difference between the results of this study and work conducted in North Yorkshire (Rivers *et al*., 2006; Glover & Altringham, 2006) and Derbyshire (Roe, 2016) is the lack of any Brandt's bat captures. Additionally, the high proportion of whiskered bats recorded at Nearcliff Wood was substantially higher than average. It is noted that this is possibly due, in part, to the relatively low sample size of bats caught (just 47 bats in total) at Nearcliff Wood. Glover and Altringham (2008) identified that Natterer's bats dominated major swarming sites but that at minor swarming sites the species mix tended to be more evenly distributed. This fits with the findings of this study as both the capture rate, and proportion of Natterer's bats caught were substantially higher at the Anston Stones site than at Nearcliff Wood.

The sex ratio recorded at swarming sites varies across each research project and between species. Although the sex ratios recorded consistently have a highly male bias (Glover & Altringham, 2006; Rivers *et al.*, 2006; Roe, 2016), as with these other projects the sex ratio recorded at the South Yorkshire sites was also highly male biased.

The sex ratio for Anston Stones (78.72% males) and Nearcliff Wood (76.83% males), were both similar, with the percentage of males caught within the 70-80% range, resulting in an overall value of 77.52% (both sites combined). Rivers *et al.* (2006) recorded a similar sex composition. The sex ratio can be even more skewed, for example 84% of the 2015 Derbyshire Bat Group study captures were male (Roe, 2016), with Glover & Altringham (2008) suggesting differences in behaviour between the two sexes may be more pronounced in upland areas.

The peak period for autumn swarming varies between sites and bat species (Glover and Altringham, 2008; van Schaik *et al*., 2015; Rivers, *et al.* 2006), with this period generally extending from August to October. The seasonality of use recorded in this study fitted with this pattern, but was dependent on species recorded.

[3] The percentages in the table have been rounded up or down to the nearest whole number.

The earlier peak in whiskered bat and Daubenton's bat swarming activity when compared to Natterer's bat swarming is in line with other studies (Parsons *et al.*, 2003a; Glover & Altringham 2006; Roe 2016). Parsons *et al.* (2003a) propose that this could be primarily due to differences in hunting strategies as gleaning species such as Natterer's bat may be able to continue hunting in conditions that are unsuitable for aerial hawking species. However, if this were the only cause, it does not explain why brown long-eared bats also appeared to swarm earlier in the season in this study.

The lag in the start, and end, of swarming by juvenile Daubenton's bats and Natterer's bats could be the result of inexperienced juveniles taking time to learn where the swarming sites are and when to stop swarming. Although it is known that juveniles are more likely than expected to be caught with other juveniles than adults (given their respective overall capture rates) (Burns & Broders, 2015), such a lag in the timing of juvenile capture at swarming sites is not widely reported.

The nightly peak in swarming activity is most often recorded 4 to 6 hours after sunset (Parsons *et al.*, 2003b; Rivers *et al.*, 2006). A similar pattern was recorded at the South Yorkshire sites with the overall peak recorded between 3 to 6 hours following sunset. However, if study sites are assessed independently then the peak switches to 3 to 5 hours after sunset for Anston Stones Wood with a more complex pattern at Nearcliff Wood Rift Cave. At Nearcliff Wood Rift Cave a spike in the number of captures was recorded between 3 and 4 hours of sunset, followed by a lull from 4 to 5 hours, with the peak recorded between 5 and 6 hours of sunset. Although this could be the result of capturing foraging bats at Nearcliff Wood Rift Cave, it is noted that this could also be a facet of the low number of survey occasions (4 repeats) and effects of weather on one or more nights.

As documented by almost all previous swarming studies (Parson *et al.*, 2003b; Roe, 2016) weather on the survey night appeared to have a large influence on bat activity, however weather recorded during each of the 2016 catching sessions was considered to fall within the acceptable range for swarming surveys. As a some what anecdotal example of the likely impact of weather, intermittent light rain was experienced during the 21/09/2016 Nearcliff Wood trapping session and the number of bats caught was 58% lower than the early September trapping session at the site. This result suggests that inclement weather (at site or further afield) on the survey night is likely to have negatively affected trapping results.

Comparison of trapping and static monitoring methods

The survey results showed a positive but weak relationship between the number of bats trapped at a cave and the number of sound files recorded by a paired static monitoring device. Whilst both survey methods suggested that Anston Stones Wood experiences a higher level of bat swarming activity than Nearcliff Wood, static monitoring results showed the magnitude of difference between the two sites to be greater.

This study recorded a slightly weaker relationship between static monitoring and trapping data than a comparable study undertaken on a chalk mine in south-east England, which contrasted bat passes recorded by a custom bat activity logger with the number of bats caught in a single harp trap (Parsons *et al*., 2003b). This might be in part due to our study encompassing two sites and four cave portals, in comparison with the single cave studied by

Parsons *et al.* (2003b). Our study would appear to suggest that the number of bats entering/exiting a cave and the level of echolocation activity close to the cave portal is likely to vary, depending upon site specific factors. It is likely that the distance between a cave portal and the main external bat flight areas utilised during swarming will vary with the site.

Within this study, trapping and static monitoring survey also recorded differences in the proportion of each bat species present at the study site. Both trapping and static monitoring survey recorded a greater level of whiskered bat activity at Nearcliff Wood and a higher proportion of Natterer's bats at Anston Stones. It was, however, noted that static monitoring recorded a higher proportion of Natterer's bats at both swarming sites when compared to trapping surveys. In comparison, static monitoring recorded a lower proportion of Daubenton's bats and brown long-eared bats.

Differences in the relative species abundance recorded during trapping and static monitoring are likely to result from an interplay of the following variables: ability of a species to evade the trap; variability in the volume and frequency of a species' echolocation call; and bias in species identification ability of any auto-analysis software used.

Overall our study demonstrates that in some instances static monitoring survey will give a different impression of the overall level of bat activity and bat species richness when compared with trapping survey data.

Importance of surveyed caves as hibernacula

A recent study in the Netherlands showed that bat species composition and abundance during swarming can correlate with composition and abundance during hibernation at the same site (van Schaik *et al*., 2015). This relationship can, however, be difficult to demonstrate in practice as *Myotis* and *Plecotus* bat species often hibernate out of sight (Stebbings, 1988) and consequently visual surveys may be poor methods of assessing hibernacula (Glover and Altringham, 2008).

Whilst limited hibernation survey was undertaken as part of this study, the survey findings do appear to suggest that a far larger number of bats swarm at the surveyed cave than subsequently hibernate there. In particular, Dead Man's Cave is small, relatively easily surveyed and experiences high levels of human disturbance. Of the three caves studied, this cave appears to experience the highest level of use by autumn swarming bats, however no bats were recorded there during the hibernation survey. It appears unlikely that a high number of bats could use this cave during the hibernation period.

The findings of this study suggest that in some instances the autumn swarming importance of caves might far outweigh their importance as bat hibernacula. It is likely that in areas with few caves, small caves with limited chamber development and low suitability as hibernacula may nevertheless be of conservation importance as a location for autumn swarming.

Comparison of capture rates against other regional studies and contextualising results

Comparison of the level of autumn swarming behaviour recorded at different sites is biased by the trapping effort used during surveys. Additional sources or error and bias result from variation in annual and nightly survey timing, trapping efficiency, weather and identification protocols. Despite these considerations, in order to determine the level of importance of our sites, a contrast of our findings with those of two other studies undertaken within our region has been provided in Table 8.

Table 8: Comparison between studies.

Study	County	Cave	Median Number of Bats Caught/ Night
Rivers, Butlin and Altringham, 2006	North Yorkshire	Antofts	37
Rivers, Butlin and Altringham, 2006	North Yorkshire	Bucklands	35
Rivers, Butlin and Altringham, 2006	North Yorkshire	Slip Gill	32
Roe, 2016	Derbyshire	Owl Hole Cave	27
South Yorkshire Magnesian Limestone Study	South Yorkshire	Dead Man's Cave	19
Roe, 2016	Derbyshire	Jacobs Dream Mine	14
Roe, 2016	Derbyshire	Jug Holes Cave and Mine	12
South Yorkshire Magnesian Limestone Study	South Yorkshire	Nearcliff Wood Rift Cave	11
South Yorkshire Magnesian Limestone Study	South Yorkshire	Large Fissure	2.5

Table 8 shows that whilst trapping at the South Yorkshire caves typically records fewer bats than trapping at the North Yorkshire windy pits, median catch rates at Dead Man's Cave and Nearcliff Wood Rift Cave are comparable with the three sites studied in Derbyshire. The median nightly catch rate at Dead Man's cave is between 0.51-0.59 of the catch rate at the three windy pits. The windy pits are considered to be of up to national importance to nature conservation (Rivers *et al*., 2006). On this basis, it appears reasonable to suggest the South Yorkshire study sites are likely to be of at least regional importance to nature conservation.

Importance of DNA testing

The importance of the DNA testing undertaken for this study cannot be underestimated due to the potential for misidentification of *Myotis* species, especially when confronted with an aberrant individual. It became apparent that one can prematurely misidentify an individual by not following a systematic procedure using an identification key. For an example of the potential pitfalls in identification; a DNA test result for a positive Daubenton's bat was surprisingly mistakenly identified as a Brandt's/whiskered bat. The individual was small and dark in appearance and in hindsight, obviously a juvenile. Another example was when an aberrant *Myotis* species bat was identified as a Daubenton's bat using the key but the individual in question superficially appeared more like a Natterer's bat because of its red arms (a characteristic of Natterer's bat). The two thirds length of the calcar together with its large feet determined its identification as a Daubenton's bat. The bat had all the appearance of a hybrid but unfortunately a DNA test was not undertaken in this instance.

Importance of co-operation

The Magnesian Limestone Swarming Study was an inter-bat group working project between both South Yorkshire and West Yorkshire Bat Groups. Whilst it was a South Yorkshire Bat Group project, it would not have been achieved without the co-operation of the West Yorkshire Bat Group who loaned out a harp trap and contributed significantly to the field work. In our opinion this is a good example of inter-bat group working in the UK and it has resulted in numerous positive experiences and outcomes for members of both groups. The trapping sessions were attended by 22 South Yorkshire members and 12 West Yorkshire members in total, all of which were involved to some degree in the erection of harp traps and handling, processing and release of captured bats.

Figure 3: The trapping team in action and a Natterer's bat captured during the project.

Opportunities for further study

Repeat surveys at the 2016 study sites should in future years help to smooth any anomalies recorded and strengthen any assessment of the typical activity levels experienced at each site. In addition, alternative caves located within or close to the existing survey sites, such as Fissure Cave at Anston Stones Wood or Cadeby Pot located within the Don Gorge, could be surveyed either independently or in combination with the 2016 caves. Such an approach could provide further information on movements of bats between swarming sites located in close proximity to each other.

An alternative proposal being considered is to repeat the survey protocol across a number of new sites potentially reducing the number of survey occasions in order to increase the number of sites studied. New sites would be selected to maximise spread across the county and to take in alternative types of potential swarming sites, such as man-made tunnels. Given the relatively early stage of swarming survey works in South Yorkshire, inclusion of new sites would increase knowledge of swarming site abundance and diversity in the region and contribute to existing information on bat species distributions in the county. This approach would also benefit the group when assessing the relative conservation value of county swarming sites.

Brandt's bat is a species regularly recorded at swarming sites. However, to date in-hand identification, and DNA analysis, has not recorded this species at either of the two South Yorkshire 2016 survey sites. This species has only been confirmed as resident at the western end of South Yorkshire (Jon Moore, pers. comm.) and its status within the wider county is poorly defined. This species is known to swarm early in the swarming season with activity recorded as peaking between the first and third week of August (Glover & Altringham, 2008; Roe, 2016). The first survey visits undertaken as part of this study were carried out in late August. It might be that early August trapping surveys undertaken at the 2016 study sites in future years would increase the likelihood of catching Brandt's bat.

The fur clipping method used in this study was considered to minimise risk/stress to the bats captured. However, this approach provided limited information regarding the recapture of individuals, as individual bats could not be identified and there was a risk of fur clip marks growing out during the survey period. Ringing of individual bats can provide extensive further information, including the location and date of first and repeat captures. This method would also allow identification of swarming bats in their summer and hibernation roosts. Joint effort to ring swarming bats across the region over the long term, could also provide information on cross county movements of individual bats. The ability to gather additional information does, however, need to be balanced against the risk to the bats welfare, with ringing only to be undertaken if future trapping effort can be committed to, and there is a clear use for the data collected.

Promoting site conservation

It is the aim of the project team to promote to Natural England a case for inclusion of autumn swarming bats as a feature of interest on the SSSI citation for Anston Stones Wood. It is considered that inclusion on the citation will help ensure that the importance to bats of the site's caves and fissures to bats is not forgotten or overlooked within future management plans or site assessments.

It is noted that Nearcliff Wood Rift Cave is located less than 100m from a SSSI boundary (Sprotbrough Gorge). A number of nearby caves and man-made underground features (Murphy & Cordingley, 2010; Engering & Barron, 2007), located both within and outside the SSSI have yet to be subject to autumn swarming survey. It might subsequently be possible to make a case for extension of Sprotbrough Gorge SSSI to cover a proportion of these underground features, due wholly, or in part, to their importance as sites for bat autumn swarming.

In addition to promotion of the study findings through this Northern Bats article, findings will be presented to audiences at South Yorkshire Natural History Day and the North of England Bat Conference. It is hoped that this study will inspire others to undertake bat conservation works in South Yorkshire and will promote study of the counties bats.

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Appendix

Results from a Univariate ANOVA considering the difference in time of capture when considering age, species, location and sex

Tests of Between-Subjects Effects

Dependent Variable: Hours after sunset

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	840021158.008[a]	25	33600846.320	1.658	.041
Intercept	3636749606.926	1	3636749606.926	179.481	.000
Sex	12109356.859	1	12109356.859	.598	.441
Age	50673195.924	1	50673195.924	2.501	.117
Species	88624053.167	4	22156013.292	1.093	.364
Location	108434554.812	1	108434554.812	5.351	.023
Sex * Age	14184279.452	1	14184279.452	.700	.405
Sex * Species	70630963.622	3	23543654.541	1.162	.328
Sex * Location	3033685.165	1	3033685.165	.150	.700
Age * Species	99994317.791	3	33331439.264	1.645	.184
Age * Location	80965681.834	1	80965681.834	3.996	.048
Species * Location	29284571.778	2	14642285.889	.723	.488
Sex * Age * Species	81595300.068	2	40797650.034	2.013	.139
Sex * Age * Location	49481385.239	1	49481385.239	2.442	.121
Sex * Species * Location	13709598.472	2	6854799.236	.338	.714
Age * Species * Location	141535273.475	1	141535273.475	6.985	.010
Sex * Age * Species * Location	.000	0	.	.	.
Error	2087050767.57	103	20262628.811		
Total	27241117200.0	129			
Corrected Total	2927071925.58	128			