

FORESTRY ENGLAND

BAT SURVEY

SUMMARY OF 2019 PILOT PROJECT



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Executive summary

Recent developments in the design of acoustic sensors and the identification of sounds using artificial intelligence have revolutionised bat monitoring. They offer the opportunity to undertake large-scale acoustic monitoring of bats in woodlands for the first time.

In 2019 Forestry England and the Bat Conservation Trust undertook a study in South-West GB to explore the ability of passive acoustic bat surveys to inform natural capital accounting and woodland condition monitoring.

We developed the *Forestry England Bat Survey*, which uses AudioMoth sensors to record bat echolocation calls in the field. These bat calls are then automatically classified to species or species-group using the AI algorithms BatDetect and BatIdentify.

Over summer 2019 400 surveys were undertaken by Forestry England staff on 36 nights, across 16 woodlands and 60 monitoring locations. This generated 9.5TB of data, from which 1,732,059 bat calls were identified. Eight species and two species groups were detected across the study area. The most commonly detected species were common pipistrelle, soprano pipistrelle, noctule and *Myotis sp.* The least frequently detected species were Leisler's bat and *Plecotus sp.* Using data from this survey we were able to provide a measure of species richness, species evenness and an index of species activity for each monitored site.

The Forestry England Bat Survey was shown to be cost-effective, scalable and an appropriate option for long-term monitoring of bat populations on the Public Forest Estate, capable of informing Forestry England's natural capital accounting and woodland condition monitoring. The data collected in 2019 are the largest, most comprehensive and attribute-rich dataset of woodland bat records ever compiled by the Bat Conservation Trust. In the long term, data from this survey has a wide range of potential applications, including in research, change management, and monitoring progress towards commitments in the UK Government's 25 Year Environment Plan. We provide recommendations for further development of the survey.

1 Introduction

Forestry England are England's largest land managers, and are custodians of the nation's forests. They manage the Public Forest Estate, over 1,500 woodlands and forests covering more than 250,000 hectares. This estate is sustainably managed for timber according to the UK Woodland Assurance Standard. It is also open to the public, and has a long history of providing access to outdoor recreational activities. On average, the Public Forest Estate has a footfall of 230 million visits per year (Forestry England, 2019).

Over the years, Forestry England's role has evolved to ensure their forests provide a wealth of benefits. These benefits reach further than timber production and include a number of ecosystem services, the value of which they aim to capture in their Natural Capital Accounts (Forest Enterprise England, 2018). Some benefits, for example the amount of carbon sequestered or the number of visits per year, are more tangible and easier to quantify than others. The social, economic and intrinsic benefits of biodiversity are more challenging to measure. It is recognised that certain groups of species can be used to indicate the status of woodland health and biodiversity as a whole (Forest Enterprise England, 2018), and to date indices for butterflies and birds have been developed for inclusion in the accounts.

All 17 UK breeding bat species make use of woodland, whether for foraging, roosting or commuting between roost and foraging sites. UK bats are insectivorous, and the invertebrate community associated with woodlands are a key food source (Walsh and Harris, 1996). Trees also provide roosting opportunities in the form of woodpecker holes, rot holes, loose bark, cavities and splits (Key, 2018). These features are used by bats for rearing their young, mating, feeding and hibernating, often with different features used for different life stages. Deciduous woodland containing mature and veteran trees provide the greatest source of roosting opportunities, however young trees, non-native and coniferous species can also provide roosts (Key, 2018). Trees and woodlands provide connectivity to the wider landscape via hedgerows, tree-lines, shelterbelts and river corridors. These linear features provide safe cover, allowing bats to avoid flying in the open, thus reducing the risk of predation (Downs and Racey, 2006; Walsh and Harris, 1996).

UK bats can be classified as either woodland specialists or woodland generalists. Woodland specialist bat species prefer to forage in woodland habitats and/or primarily roost in trees. These species typically favour interior woodland with dense understorey and a closed canopy (e.g. brown long-eared bat *Plecotus auritus*, Murphy et al., 2012). Woodland generalist bat species make reduced use of tree roosts, having adapted to roost in built structures, and forage in a wider range of habitats. Woodland generalist species often favour woodland edge or more open areas (Table 1).

Table 1. The woodland associations and call characteristics of UK breeding bat species

Species	Woodland generalist/specialist	Use of tree roosts	Foraging preferences	Acoustically distinct
Common pipistrelle (<i>Pipistrellus pipistrellus</i>)	Generalist	Occasional use of tree roosts, mainly roosts in buildings	Woodland edge, and a wide variety of other habitats	Reasonably
Soprano pipistrelle (<i>Pipistrellus pygmaeus</i>)	Generalist	Occasional use of tree roosts, mainly roosts in buildings.	Woodland edge, and other habitats, particularly riparian habitats and waterbodies.	Reasonably
Nathusius pipistrelle (<i>Pipistrellus nathusii</i>)	Generalist	Occasional use of trees	Edge habitat – along woodland edges, rides and water bodies	Reasonably
Barbastelle (<i>Barbastella barbastellus</i>)	Specialist	Roosts almost exclusively in trees. Uses flaking/loose bark, splits and cracks, tree hollows and crevices.	Edge and open habitats – prefers rides and woodland edges. Forages in woodland interiors at dusk.	Yes
Bechstein's bat (<i>Myotis bechsteinii</i>)	Specialist	Roosts in trees all year. Prefers woodpecker holes and cavities. Associated with broadleaved woodland containing veteran trees like oak.	Woodland interior – prefers closed canopy woodland with cluttered understorey layer, close to water.	No
Natterer's bat (<i>Myotis nattereri</i>)	Specialist	Some use of tree roosts, mainly in the summer.	Woodland interior and edge habitats – tree canopies and along woodland rides, tree-lined rivers and ponds	No
Daubenton's bat (<i>Myotis daubentonii</i>)	Generalist	Some use of tree roosts, mainly in the summer	Woodland edge, and other habitats, particularly over open water bodies and slow flowing rivers.	No
Whiskered bat (<i>Myotis mystacinus</i>)	Generalist (regarded as a specialist in Europe)	Some use of tree roosts in the summer	Utilises both woodland interior and edge, and also forages over water.	No
Brandt's bat (<i>Myotis brandtii</i>)	Generalist (regarded as a specialist in Europe)	Occasional use of tree roosts	Utilises both woodland interior and edge, and also forages over water.	No

Species	Woodland generalist/specialist	Use of tree roosts	Foraging preferences	Acoustically distinct
Alcathoe bat (<i>Myotis alcathoe</i>)	Specialist	Limited information available. Utilises tree roosts, preferring fissures or small cavities.	Woodland interior – relies on woodlands like ancient and semi natural for foraging.	No
Noctule (<i>Nyctalus noctula</i>)	Specialist	Primarily roosts in trees. Has a strong preference for woodpecker holes, but also utilises rot holes and cavities.	Forages in open habitat and over woodland.	Reasonably
Leisler's bat (<i>Nyctalus leisleri</i>)	Generalist	Will roost in trees. Prefers cavities and rot holes.	Open habitats – woodland edges, hedgerows, near water, over pasture land.	Reasonably
Serotine bat (<i>Eptesicus serotinus</i>)	Generalist	Rarely roosts in trees	Open habitat – over woodlands, hedgerows, open pasture land, hay meadows	Reasonably
Greater horseshoe bat (<i>Rhinolophus ferrumequinum</i>)	Generalist	Tree roosts not used.	Open and edge habitat including pasture, ancient or semi natural woodland, often by water	Yes
Lesser horseshoe bat (<i>Rhinolophus hipposideros</i>)	Specialist	Generally roosts near woodland, but tree roosts only occasionally used, typically as transitory roosts.	Interior of woodlands and along well connected tree lines and hedgerows.	Yes
Brown long-eared bat (<i>Plecotus auritus</i>)	Specialist	Some use of tree roosts. Will also roost in old buildings (barns, churches) and bat boxes. Prefers cavities, sometime low down (basal cavities) on the tree.	Woodland interior – strongly associated with tree cover and cluttered understorey. Will also forage in mixed woodland edge and among native conifer.	Only where it does not co-occur with <i>P. austriacus</i>
Grey long-eared bat (<i>Plecotus austriacus</i>)	Generalist	Tree roosts not used.	Open and edge habitat - Forages over grassland close to the roost.	No

UK bats are long-lived animals which function as top predators of nocturnal insects, and interact with their environment at both local and landscape scales (Jones *et al.*, 2013). They account for almost a third of mammal species in the UK, are sensitive to pressures that affect a wide range of taxa (including landscape change, agricultural practices, habitat management and infrastructure development), and are all reliant on woodlands to a greater or lesser degree. These characteristics make bats an important indicator of woodland biodiversity and condition.

Despite their potential as woodland indicator species, monitoring bats in woodland is challenging. Three monitoring approaches are commonly used: trapping, active acoustic surveys and passive acoustic surveys. Many woodland bat specialists are acoustically cryptic; they cannot be reliably identified to species using their echolocation call. To confirm the presence of such species requires that they be trapped and identified in the hand, or via DNA analysis. This can only take place under licence from Natural England, requires experience and specialist equipment, involves a large investment of surveyor time and is untested as a method of monitoring changes in abundance. These factors make it difficult to using trapping for large-scale monitoring (Scott and Altringham, 2014).

Active acoustic surveys, in which a surveyor conducts a point count, transect walk or area search using an acoustic sensor ('bat detector'), are much more cost-effective, can be undertaken using equipment costing around £100, and can be carried out by surveyors with only moderate experience of bat monitoring. However there are challenges to conducting active acoustic surveys in woodland. Woodland specialist bat species are typically rare or uncommon, and echolocate quietly. As a result high surveyor effort is needed to provide sufficient encounters to calculate population trends. It is also difficult to navigate woodland habitats in the dark safely, particularly in the woodland interior.

Passive acoustic surveys offer advantages over both active surveys and trapping. Passive acoustic monitoring (PAM) uses acoustic sensors that can be deployed in the field and left unattended to record bat activity for long periods of time. This greatly increases the survey effort that it is possible to achieve, while at the same time minimising surveyor effort. As sensors are deployed during daylight they are easier to locate in difficult-to-survey habitats such as woodland interior. It is also a technique that can be used by surveyors with little or no previous experience of bat monitoring. Until recently there were two barriers to the use of PAM for large-scale projects; the costs of the sensors and the vast quantity of recordings generated by this approach. 'Full-spectrum' passive acoustic sensors, of the kind required for effective monitoring, previously retailed at around £1,000/unit but in recent years, following a proliferation of open-source designs, more affordable sensors have become available (e.g. the AudioMoth which costs around £50/unit, Hill *et al.*, 2019).

Passive acoustic sensors generate huge numbers of recordings which would be impossible to classify manually. However rapid developments in the field of artificial intelligence mean there are now algorithms that can identify a recording to species without any manual input. These algorithms can process recordings quickly and efficiently, and when provided with sufficient training data are showing promise at distinguishing species that were previously considered to be indistinguishable.

Taken together, the advances in sensor design and audio classification have revolutionised bat monitoring, and offer the opportunity to employ PAM for large-scale monitoring of woodland bats for the first time.

In 2019 Forestry England and the Bat Conservation Trust (BCT) undertook a ‘proof-of-concept’ study in South-West GB, designed to explore the ability of passive acoustic bat surveys to inform natural capital accounting and woodland condition monitoring. Here we summarise the aims, methods and results of this study. Among our objectives were to:

1. Develop a passive acoustic survey protocol that can be implemented by novice surveyors with minimal support.
2. Facilitate passive acoustic monitoring surveys at a sample of Public Forest Estate (PFE) woodlands (the ‘Forestry England Bat Survey’).
3. Quantify monitoring effort, bat activity, species richness and species evenness at each monitored woodland.
4. Assess the viability of passive acoustic surveys for long-term bat monitoring on the PFE.
5. Generate data that can be used to estimate the survey effort required to produce robust long-term bat population trends for the PFE.

In the long term, data from passive acoustic monitoring of bats in woodland has a wide range of applications, including in research, change management, and monitoring progress towards commitments in the UK Government’s 25 Year Environment Plan (DEFRA, 2018).

2 Methods

2.1 Study area

All UK bat species make use of woodland for roosting, foraging or commuting, and so could be considered candidate species for a woodland bat monitoring programme. However, UK species differ in the degree to which they can be distinguished from their echolocation calls. As this proof-of-concept study employs passive acoustic monitoring it was targeted at species that are acoustically distinct. Of the 17 breeding species in the UK, nine can be identified from their echolocation calls with a good or reasonable degree of confidence and so were identified as target species for this study (Table 1).

An objective of this study was to collect data that could be used to estimate species detection probabilities, which requires repeat surveys at sites where the species is present. The nine target species all co-occur in South-West Britain, so to maximise the chances of detecting these species we focused our study in this region. To identify the precise extent of the study area, we intersected the GB ranges of the widespread target species (Figure 1). The two remaining target species, Leisler’s bat *Nyctalus leisleri* and Nathusius’ pipistrelle *Pipistrellus nathusii*, have a highly localised distribution within South-West Britain. Their ranges were not included in this calculation as to do so would have resulted in too small an area from which to select study sites.

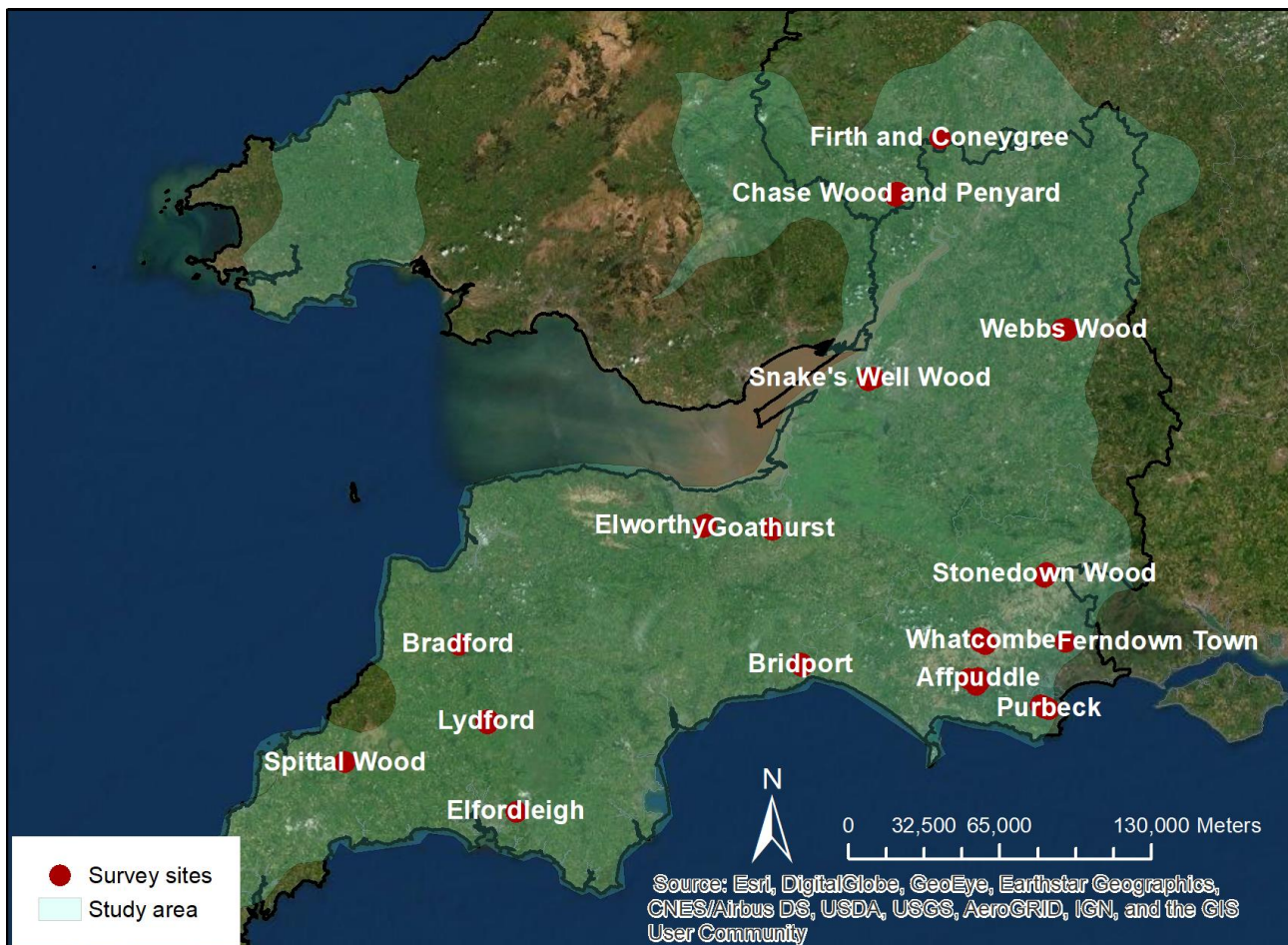


Figure 1. Extent of study area and survey sites for the 2019 Forestry England Bat Survey

2.2 Selection of study sites and monitoring locations

Woodlands were selected from within the study area using a random-stratified approach, accounting for woodland type, size and location. Information about the location and characteristics of PFE woodlands were taken from the National Forest Estate Subcompartments database, England (Forestry Commission, 2018). Bats travel between subcompartments when foraging, so to identify functionally connected woodlands, all subcompartments within 30m were dissolved into a single site. Each site was allocated one AudioMoth per 5ha, with a minimum of one and a maximum of five AudioMoths per site, to achieve a total of 60 AudioMoths across all sites. In total sixteen woodlands were selected for this study (Figure 1).

Within each site a number of provisional monitoring locations were randomly selected, equivalent to the number of sensors allocated to the site. Local Forestry England staff visited each site and selected monitoring locations as close as possible to the provisionally selected locations, while also ensuring that the location was at least 200m from other monitoring locations, safe to access, secure enough to leave a sensor overnight, not lit by artificial light, and at least 1.5m away from vegetation, hard surfaces or water.

2.3 Survey equipment

This proof-of-concept study uses AudioMoth sensors (version 1.1.0, Hill *et al.*, 2019) to record bat echolocation calls in the field. These sensors ran a bespoke firmware developed for the British Bat Survey

by Open Acoustic Devices as part of an earlier NERC-funded collaboration (Fairbrass *et al.*, 2019). This firmware allows the sensors to be configured using a 'chime' sound, played by pressing a button on the BCT website. The recording settings for the Forestry England Bat Survey were embedded within the chime, so that when the sensor detected the chime it automatically applied the correct settings.

The AudioMoth is not waterproof and therefore needs to be deployed inside a protective casing to protect the microphone and circuitry from moisture damage. A bespoke injection-moulded case has been developed for this purpose by Open Acoustic Devices. This bespoke case was unavailable for the 2019 field season, so alternative solutions were investigated. BCT has previously trialed the use of small push-close plastic bags and an acrylic laser-cut case (Figure 2) however neither solution performed well. Push-close plastic bags are insufficiently water-tight, and the acrylic case was difficult for volunteers to use in the field. In addition both solutions affect the sensitivity and directionality of the sensor, reducing its detection space.



Figure 2. Options for weatherproofing AudioMoths, trialed by BCT prior to the current study. A push-close plastic bag (*left*) and an acrylic laser-cut case (*right*).

For the 2019 Forestry England Bat Survey we employed a solution designed and produced by Adrian Bicker (www.livingrecord.net). This design is based on a modified waterproof push-fit junction box (OBO Bettermann A8), fitted with a foam insert to hold the AudioMoth in place (Figure 3). The microphone is protected by a double layer of wax-coated metal gauze, which in tests demonstrates a marked improvement in acoustic transparency over commercially available acoustic vents, particularly in the ultrasonic spectrum. It is also water resistant, although not waterproof (Bicker 2019, unpublished data).



Figure 3. AudioMoth case used in this study, produced to a design by Adrian Bicker.

2.4 Survey protocol

For the Forestry England Bat Survey we developed an automated passive acoustic bat monitoring protocol based closely on the British Bat Survey, adapted to deliver the objectives of this study (Figure 4, see <https://www.bats.org.uk/our-work/national-bat-monitoring-programme/british-bat-survey> for more information on the British Bat Survey).

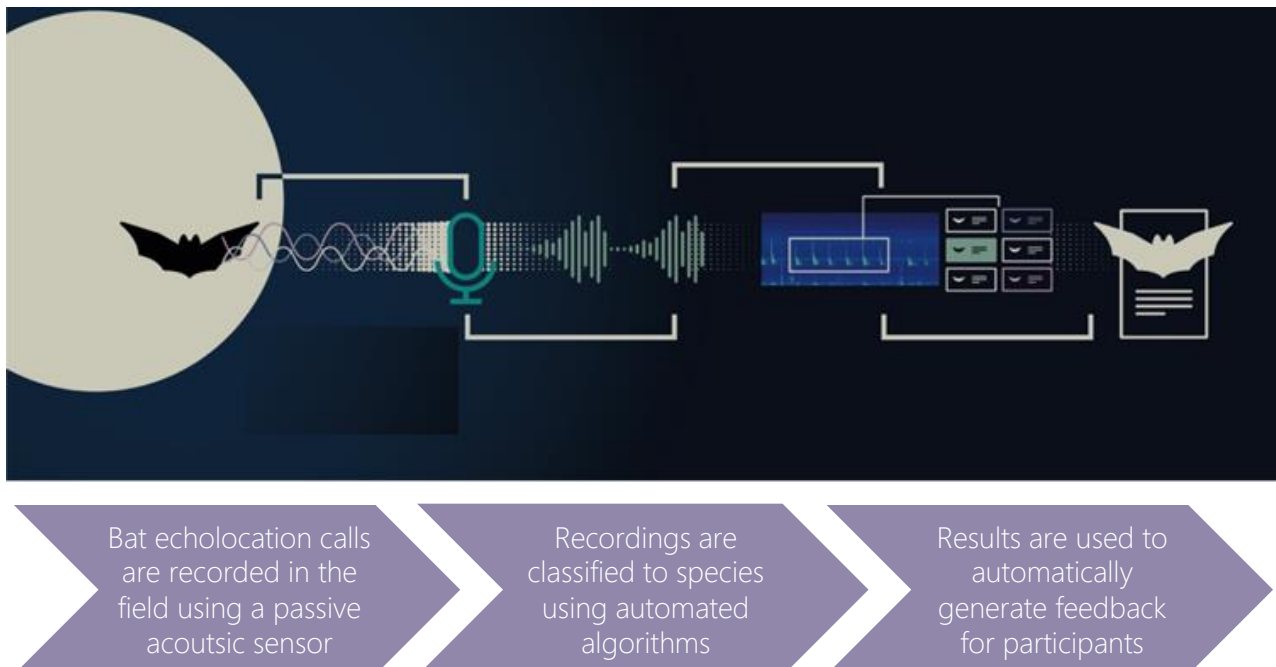


Figure 4. Schematic of an automated passive acoustic bat monitoring protocol (adapted from Fairbrass *et al.*, 2019).

The 2019 survey was conducted by Forestry England staff with support from BCT. Surveyors were provided with written survey instructions and a survey kit containing an AudioMoth(s), weatherproof case, SD cards and prepaid envelopes. Batteries and a means of elevating and fixing the sensor were purchased locally, with guidance from BCT.

Sensors were deployed at monitoring locations during the day. They were fixed 2m above the ground, as elevating the sensor has been found to provide higher quality recordings. Sensors were deployed vertically to protect them from rain. They were programmed to record from 20:00 until 06:30 the following morning, using a 384kHz sampling rate and a quasi-continuous recording schedule (297 seconds recording, 3 seconds sleeping; this was the closest to continuous recording as it was possible to achieve). Surveyors were asked to avoid surveying in rain, cold temperatures and strong wind. Surveyors collected the sensors the following day, removed the memory cards, and returned them to BCT in the prepaid envelope provided. A supply of blank SD cards was provided for subsequent surveys. Surveyors were asked to repeat the survey on as many non-consecutive nights as possible between the 1st July and 11th August 2019 inclusive.

An objective of this proof-of-concept study was to collect data that could be used to estimate the survey effort required to produce robust trends in species occupancy and relative abundance (see *Power analysis*, section 2.6). This requires 'oversampling', multiple repeat visits to the same sites. We asked surveyors to repeat the survey on as many non-consecutive nights as possible over the survey period. We recognised that each surveyor's capacity would vary so did not set a minimum or maximum number of surveys, but provided guidance that the most valuable data would come from sites surveyed on between four and ten nights. We achieved sufficient repeat visits during the 2019 survey that in future years oversampling will not be required. In future surveys we anticipate that sensors will be deployed and collected once only per year.

2.5 Classification of audio recordings

Once received by BCT, audio files were uploaded to a cloud storage space on Amazon Web Services. Within the cloud each file was passed to two AI algorithms, BatDetect and BatIdentify (Mac Aodha et al., 2018). These algorithms have been developed by researchers at UCL and the University of Edinburgh, and use a convolutional neural network approach to detect bat echolocation calls within the audio recordings (BatDetect), and then use the characteristics of the calls to classify them to species (BatIdentify) with a measure of classification confidence at each stage. Confidence thresholds for each species were set with respect to the fitted false positive rate, calculated using the methods described in Barré *et al.* (2019). The presence of each species within each 1 minute time interval was determined; a species was considered to be present if the interval contained three or more pulses exceeding the species-specific confidence threshold (or in the case of *R. hipposideros* and *N. leisleri*, one and two pulses respectively). An index of bat activity was calculated by summing the number of minute intervals within which the species was present, divided by the number of hours of survey conducted. These metrics were used to generate a summary report for each site (A1-A16).

2.6 Power analysis

Power analysis is a technique that can be used to estimate the sample size required to detect an effect of a given size with a given degree of confidence. Here, we can use power analysis to estimate the survey effort required (in terms of number of woods surveyed and number of hours/nights of survey at each wood) to produce robust trends in species occupancy and relative abundance. A common approach to power analysis is to use data collected during the first year of a survey to estimate the survey effort required in future years. This requires ‘oversampling’, or repeated surveys of the same site on non-consecutive nights (MacKenzie *et al.* 2017, p. 439). At sites where the species is detected, we can use the results of repeated surveys to calculate the probability of detecting the species on any one survey, which can in turn can inform a power analysis.

A power analysis is an important step in assessing the viability of the Forestry England Bat Survey protocol for long-term bat monitoring on the PFE. This analysis will be undertaken in 2020. When the results of the power analysis are known we will revise the survey protocol accordingly. Survey effort in 2020 will be considerably reduced as oversampling will no longer be required. In future the level of repeat surveys will be set at no more than the level required to produce robust species population trends and species richness estimates. We do not anticipate requiring surveyors to deploy sensors more than once each year. Whether this deployment will be for a single night or multiple nights will be informed by the power analysis.

3 Results

3.1 Species metrics

Here we present a brief summary of results from the 2019 Forestry England Bat Survey. Survey data were successfully recorded on 400 surveys that took place on 36 nights, across 16 sites and 60 monitoring locations. The number of repeat surveys carried out at each monitoring location varied from 3 to 10 (mean 6.7, SD 1.5).

The 2019 Forestry England Bat Survey generated 9.5TB of data. 45,683 audio files were recorded which, after classification and post-classification procedures were applied, contained 1,732,059 bat calls. Eight species and two species groups were detected across the study area. The most commonly detected species were common pipistrelle *P. pipistrellus*, soprano pipistrelle *P. pygmaeus*, noctule *N. noctula* and *Myotis sp.*, which were detected at every study woodland. The least frequently detected species were Leisler’s bat and *Plecotus sp.*, detected at two woodlands each (Table 2).

Table 2. Species and species groups detected during 2019 Forestry England Bat Survey, after classification and post-classification procedures were applied to audio recordings.

Species	No. woodlands
Common pipistrelle (<i>Pipistrellus pipistrellus</i>)	16
Soprano pipistrelle (<i>Pipistrellus pygmaeus</i>)	16
Noctule (<i>Nyctalus noctula</i>)	16
<i>Myotis</i> sp.	16
Barbastelle (<i>Barbastella barbastellus</i>)	13
Greater horseshoe bat (<i>Rhinolophus ferrumequinum</i>)	10
Serotine (<i>Eptesicus serotinus</i>)	4
Lesser horseshoe bat (<i>Rhinolophus hipposideros</i>)	3
Leisler's bat (<i>Nyctalus leisleri</i>)	2
<i>Plecotus</i> sp.	2

Site-level results, including monitoring effort, bat species richness, evenness, and activity are presented in appendices A1-A16.

3.2 Performance of passive acoustic monitoring equipment

To evaluate the performance of the survey equipment, we recorded all issues observed or reported to us during the survey. We recorded 50 surveys where at least some data was lost due to equipment failure, representing 12.5% of surveys undertaken.

The primary cause of equipment failure was loss of power to the AudioMoths, this being the case on 40 surveys. In response improved guidelines on battery usage were developed. No power issues were experienced by surveyors following these revised guidelines.

Other causes of equipment failure included problems configuring the AudioMoths (4 surveys) and faulty SD cards (6 surveys).

Eleven of the 60 AudioMoths deployed during the 2019 survey developed a loose fixing between the circuit board and the battery holder by end of the survey period. This does not affect the performance of the sensor. No damage to switches, or any other instances of damage to AudioMoths were recorded.

Only one instance of damage to the case was recorded, in which the protective microphone cover came loose from the case. There were no other instances of damage to the cases. No significant water ingress was reported during the survey period and no water damage to sensors was observed when sensors were inspected following the conclusion of the survey.

3.3 Performance of passive acoustic monitoring protocol

Surveyors reported that the survey protocol was straightforward for a novice surveyor to follow. Guidance was provided in the form of written instructions and support via email. A very low rate of ‘user error’ was experienced; on only 7 surveys were data lost due to the survey protocol being incorrectly followed, representing 1.8% of surveys.

Surveyors reported that the part of the protocol requiring the greatest time investment was travelling to and from the site. In comparison to travel time, the time taken to set up the sensors, deploy them and collect them was minimal.

In most cases the system of returning used memory cards to BCT, with blank cards being sent out to replace them, worked smoothly. However in some cases replacement cards arrived on the morning that a deployment was planned, or just after.

Data upload to the cloud, classification and post-classification were straightforward but time intensive, primarily due to the large volume of data collected. We are developing several bespoke management programs to improve this process.

Detection probabilities achieved by this survey protocol will be calculated during a subsequent power analysis (section 2.6).

4 Discussion and recommendations

The 2019 Forestry England Bat Survey was designed to contribute towards Forestry England’s Natural Capital Accounts. Using data from this survey we were able to provide a measure of species richness, species evenness and an index of species activity for each monitored site (objective 3). It is not currently possible to estimate the absolute abundance of bat species from acoustic data as individuals cannot be distinguished, however bat activity is a commonly used alternative which provides a measure of relative abundance. If repeated annually, this survey will also provide trends in species occupancy and activity. These outputs meet the needs of Forestry England’s Natural Capital Accounts (objective 4).

The 2019 survey was also designed to provide data for a power analysis to estimate the survey effort required to produce robust long-term species population trends (objective 5). This required multiple repeat visits. Such ‘oversampling’ will not be required in future years.

Data were successfully recorded on 400 surveys across 60 monitoring locations and 16 sites (objective 2). To put this effort into context, it exceeds the number of surveys carried out annually for BCT’s National Bat Monitoring Programme Field Survey (378 surveys were carried out for the Field Survey in 2019, a national citizen science survey which produces population trends for four species, see <https://www.bats.org.uk/our-work/national-bat-monitoring-programme/surveys/field-survey>).

A precise estimate of the number of sites required to generate robust trends in species occupancy and activity will be provided by a forthcoming power analysis. However, previous studies have shown that monitoring approximately thirty sites each year can be sufficient to produce robust population trends (Border et al., 2019). In future we anticipate that only one sensor will be required at each site, and it will be deployed no more than once each year (whether this deployment will be for a single night or for multiple nights will be determined by the power analysis). Under these assumptions, the survey effort achieved

during the 2019 Forestry England Bat Survey is equivalent to monitoring 400 sites, more than ten times the likely number of independent sites that will be required to produce a robust trend.

To produce unbiased trends, long-term monitoring sites should be selected using a random-stratified approach based on woodland type, and the siting of sensors should be random within the woodland. It is highly likely that over the course of monitoring a proportion of monitoring locations will change woodland type due to activities such as felling and replanting. In these cases, from the year in which the change occurred such locations will be treated as new sites for the purposes of analysis. To produce trends within a reasonable timescale monitoring locations should be surveyed annually.

Recommendation 1. Select long term monitoring locations using a stratified random approach based on woodland type, and survey locations annually.

The results and feedback from the 2019 Forestry England Bat Survey indicate that it is a cost-effective, scalable and an appropriate option for long-term monitoring of bat populations on the Public Forest Estate (objective 1 and 4). The AudioMoth sensor and weatherproof case performed well, however there were instance where at least some data was lost due to power failure. Guidelines on battery replacement were revised during the survey and no loss of data was experienced by surveyors following the revised guidelines. It will therefore be important to provide surveyors with clear guidance on battery usage in future surveys.

Recommendation 2. Provide clear guidance on battery usage to surveyors.

Approximately a sixth of the AudioMoths developed a loose fixing between circuit board and battery holder during the survey. This does not affect the performance of the AudioMoth and is simple to repair, however it highlights the importance of checking and repairing all AudioMoths at the end of the survey. This can be done locally if necessary.

Recommendation 3. Check for and repair loose circuit boards at the end of each survey season.

One innovation used in the Forestry England Bat Survey (and BCT's British Bat Survey) is bespoke firmware that allows the AudioMoths to be configured by playing a 'chime' from a website. This method replaces the usual method of configuring AudioMoths, which involves connecting the sensor to a PC via a USB cable, and using a configuration app to select and apply recording settings. The use of a chime was found to quick and easy, and had the benefits that no cables were required, it removed the likelihood that incorrect settings would be used, and allowed the AudioMoths to be reconfigured in the field if necessary, by playing the chime from a smartphone (e.g. if the batteries had been dislodged and configuration setting lost). We recommend that the use of chime is retained in future surveys.

Recommendation 4. Retain the use firmware that allows the AudioMoth to be configured using a 'chime'.

The Forestry England Bat Survey protocol also performed well. There were very few instances of data loss due to the protocol being incorrectly followed, demonstrating that it could be successfully followed by novice surveyors using only written instructions with minimal remote support (objective 1).

The time commitment required to undertake surveys is one of the most important factors when considering the viability of a protocol in the long term. Surveyors reported that the most time-consuming

step of the Forestry England Bat Survey was travelling to and from the site to deploy and collect the sensors. Excluding travel time, the time required to set up and deploy the sensors was minimal.

Recommendation 5. Minimise travel time by deploying sensors at each site only once per year.

Staff time commitment could be further reduced by utilising volunteers, or by the use of an autonomous sensor.

Recommendation 6. Consider utilising volunteers in future surveys.

Recommendation 7. Investigate the use of autonomous passive acoustic sensors.

The aspect of the survey which required the greatest investment of administrative support was receiving and processing memory cards from surveyors. This step could be circumvented entirely using an app to allow surveyors to upload their recordings directly to the cloud storage space, alongside any survey metadata required (e.g. site location). This would have the additional benefits of reducing the potential for administrative errors, removing the risk of data being lost in the post, and removing the need for surveyors to wait to receive further blank SD cards before undertaking subsequent surveys.

Recommendation 8. Develop an app to allow surveyors to upload their recordings directly to cloud storage.

A more thorough understanding of the performance of the Forestry England Bat Survey could be obtained retrospectively by collecting systematic feedback from Forestry England staff who participated in the 2019 survey.

Recommendation 9. Collect systematic feedback from Forestry England staff who participated in the 2019 survey.

The cloud-based classification pipeline successfully processed 45,683 files, representing 9.5TB of data. This data volume is exceptional and resulted in classification proceeding slower than anticipated. In future data volumes are expected to be lower (as oversampling will not be required), however data volumes could be reduced further if recordings are only triggered when a bat call is detected. An upcoming release of the AudioMoth firmware will include a trigger option. This should be tested to understand its impact on species detection probabilities.

Recommendation 10. Investigate the use of a recording trigger to reduce data volumes.

At 9.5TB of data from 400 surveys, the 2019 Forestry England Bat Survey is the largest, most comprehensive and attribute-rich dataset of woodland bat records ever compiled by BCT. Here we have explored the potential of the data to inform Forestry England's natural capital accounting and woodland condition monitoring, however the data has many other potential uses. In the long term this dataset could provide district-level indicators, and comparisons of trends between different woodland types, between woodland specialist and woodland generalist bat species, and between the PFE and the wider countryside (via a comparison with data from the British Bat Survey). At a site level these techniques could be used to assess the impact of management interventions. At a national scale these data could be used in change modelling and strategic planning, to address critical evidence gaps in our understanding of how bats use woodland, and to inform sustainable forestry practices and policy.

5 Acknowledgements

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Site-level results (A1-A16)

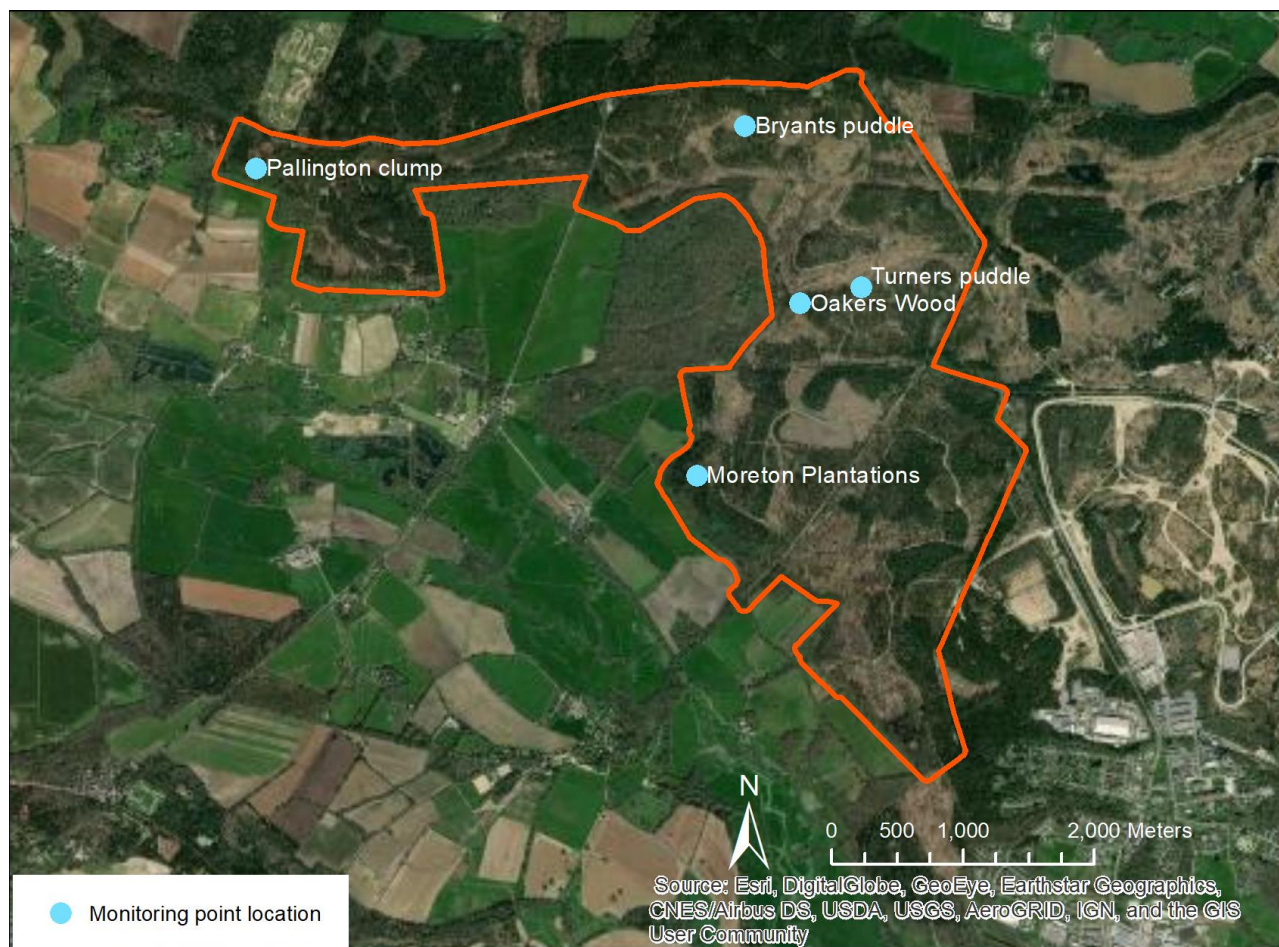
STUDY SITE CHARACTERISTICS

District: South

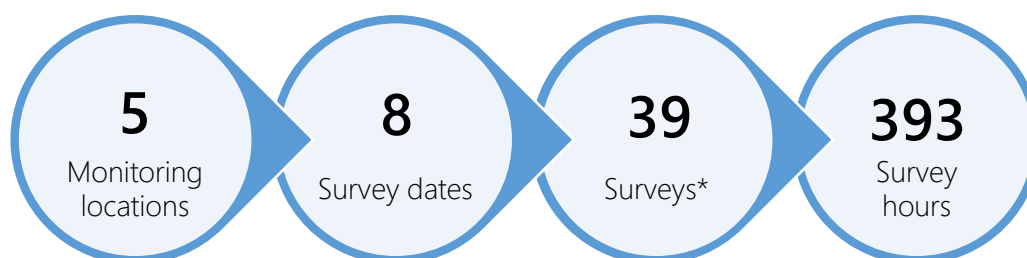
Habitat class: Coniferous dominated

Area: 411 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Affpuddle (and average hourly activity index):

Pipistrellus pipistrellus (7.36)

Pipistrellus pygmaeus (3.54)

Nyctalus noctula (1.7)

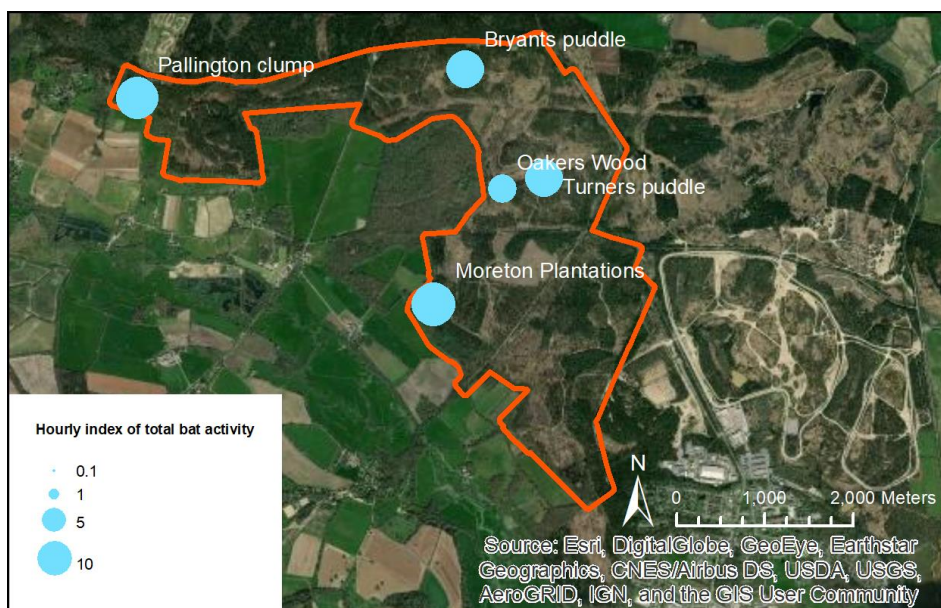
Myotis sp. (0.75)

Barbastella barbastellus (0.06)

Rhinolophus ferrumequinum (0.02)

Eptesicus serotinus (0.01)

Plecotus sp. (0.01)



11.21

Hourly bat activity

5/16 sites

8

Species richness**

2/16 sites

0.55

Species evenness

8/16 sites

Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

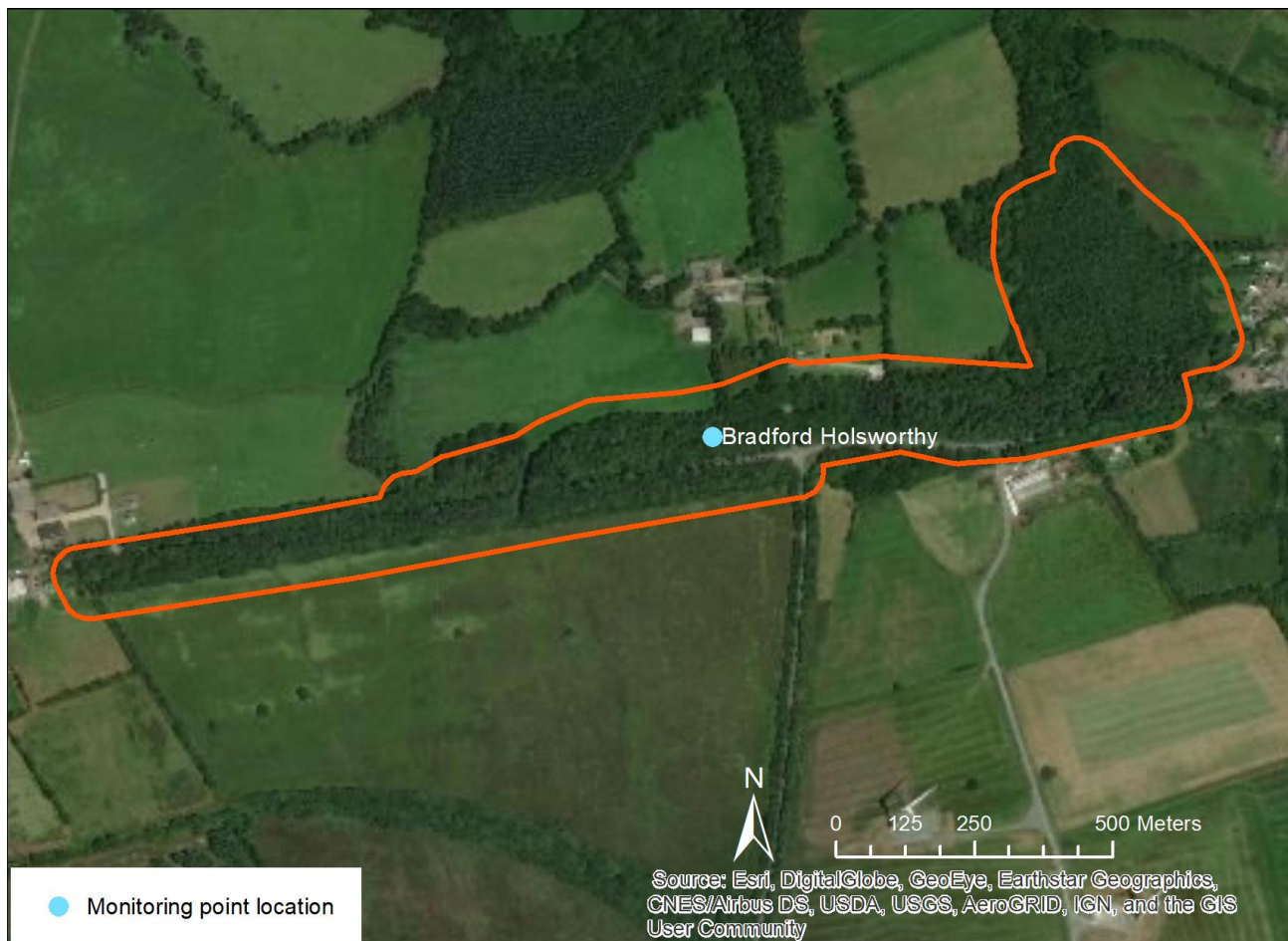
STUDY SITE CHARACTERISTICS

District: West

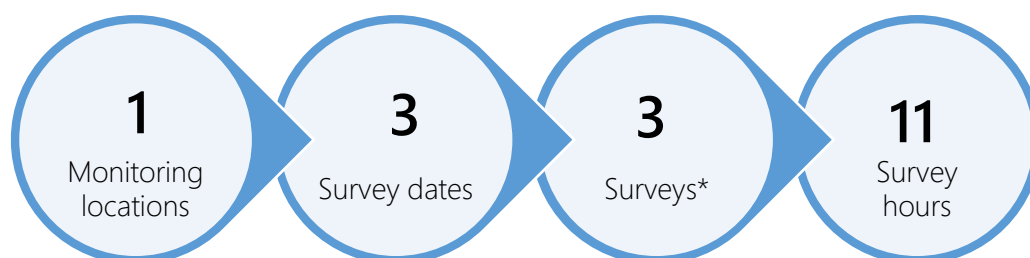
Habitat class: Broadleaved dominated

Area: 9 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

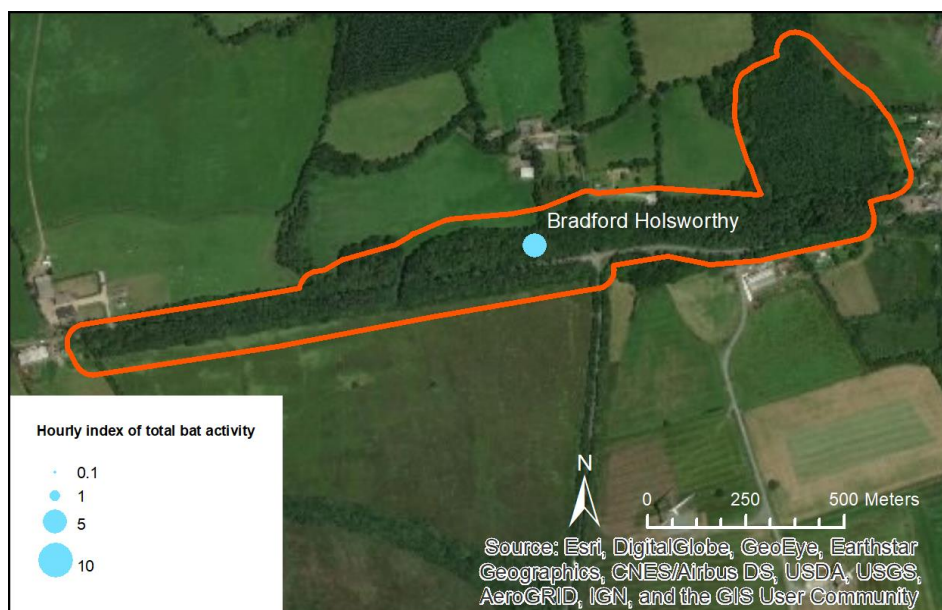
Species detected at Bradford (and average hourly activity index):

Pipistrellus pipistrellus (3.64)

Pipistrellus pygmaeus (1.09)

Nyctalus noctula (0.45)

Myotis sp. (0.09)



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

4.36

Hourly bat activity

13/16 sites

4

Species richness**

14/16 sites

0.62

Species evenness

6/16 sites

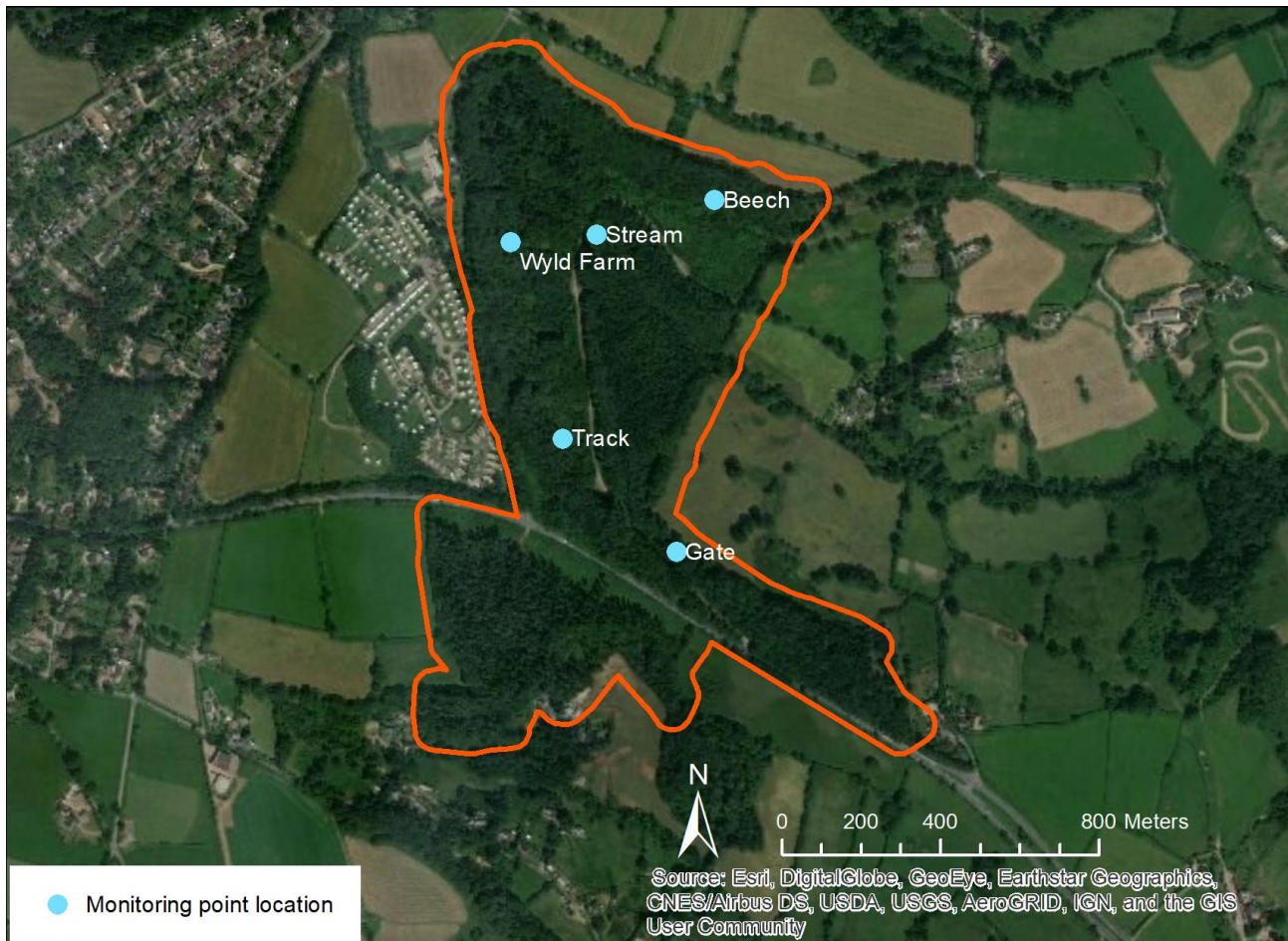
STUDY SITE CHARACTERISTICS

District: West

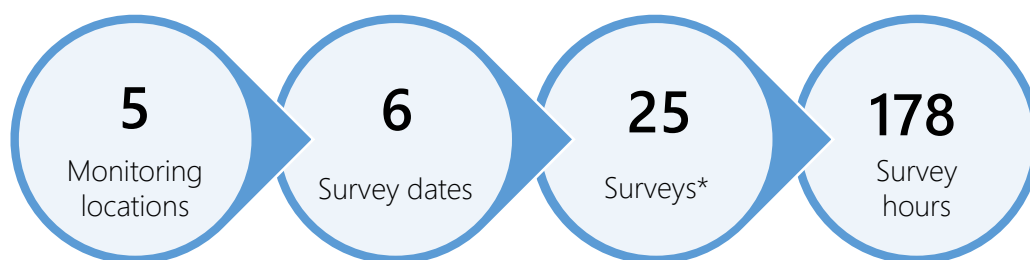
Habitat class: Broadleaved dominated

Area: 37 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Bridport (and average hourly activity index):

Pipistrellus pipistrellus (6.79)

Barbastella barbastellus (1.54)

Pipistrellus pygmaeus (0.57)

Nyctalus noctula (0.33)

Myotis sp. (0.1)

Rhinolophus ferrumequinum (0.01)

8.76

Hourly bat activity

8/16 sites

6

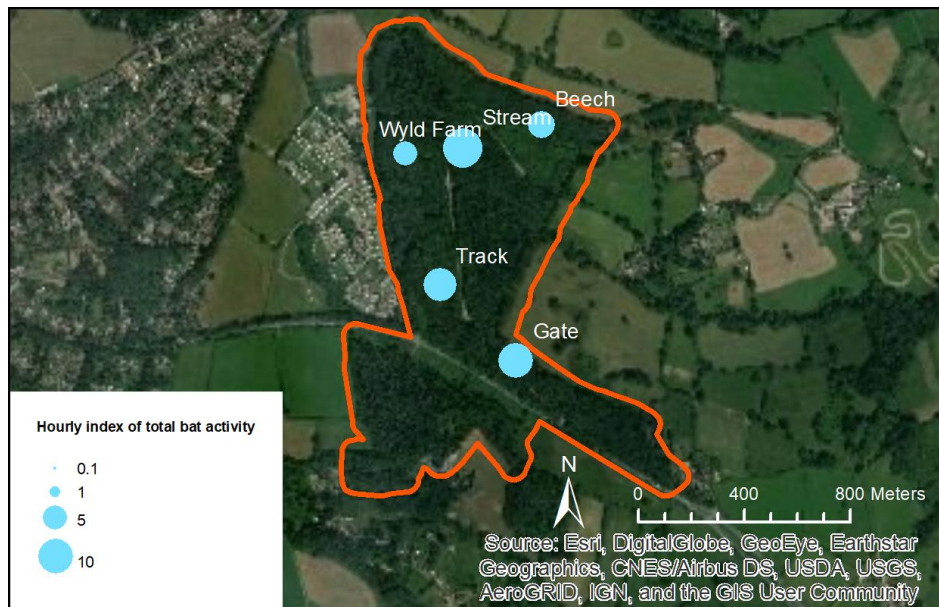
Species richness**

8/16 sites

0.49

Species evenness

10/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

FORESTY ENGLAND BAT SURVEY

Chase Wood and Penyard

A4

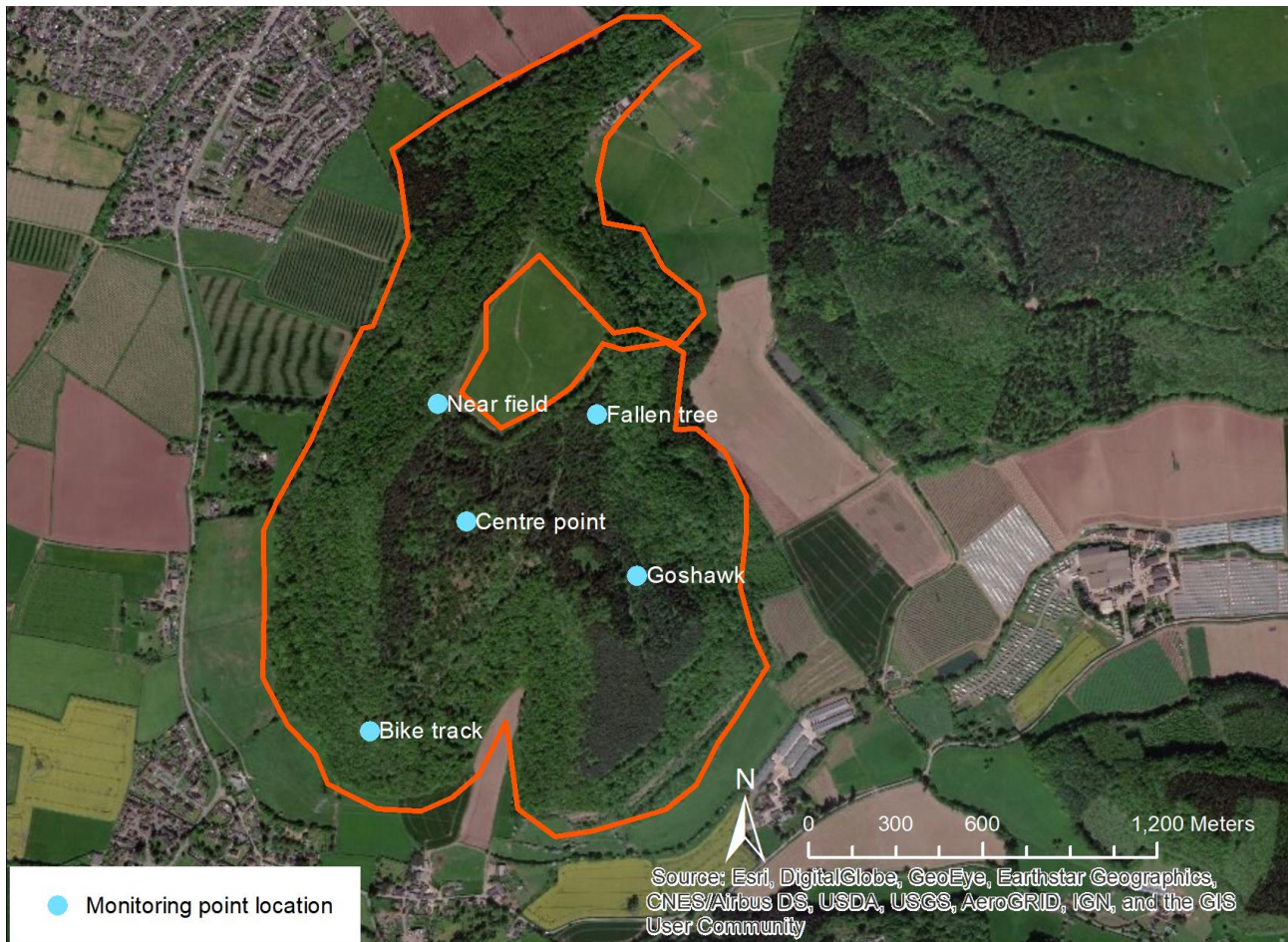
STUDY SITE CHARACTERISTICS

District: West

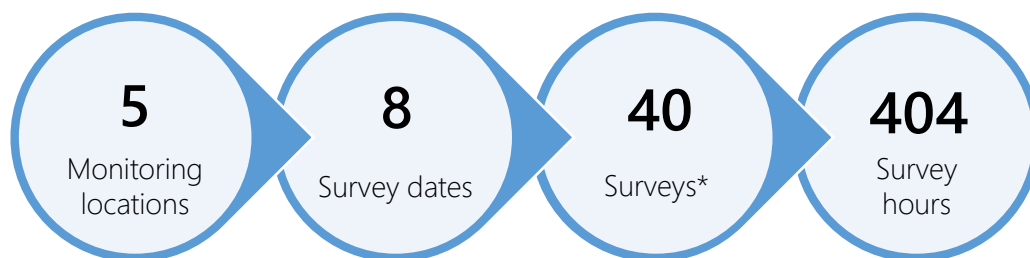
Habitat class: Broadleaved dominated

Area: 87 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

FORESTRY ENGLAND BAT SURVEY

Chase Wood and Penyard

A4

SPECIES AND ACTIVITY

Species detected at Chase Wood and Penyard (and average hourly activity index):

Pipistrellus pipistrellus (2.62)

Pipistrellus pygmaeus (1.21)

Barbastella barbastellus (0.23)

Myotis sp. (0.22)

Nyctalus noctula (0.18)

Rhinolophus hipposideros (0.01)

Rhinolophus ferrumequinum (<0.01)

4.27

Hourly bat activity

14/16 sites

7

Species richness**

4/16 sites

0.59

Species evenness

7/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

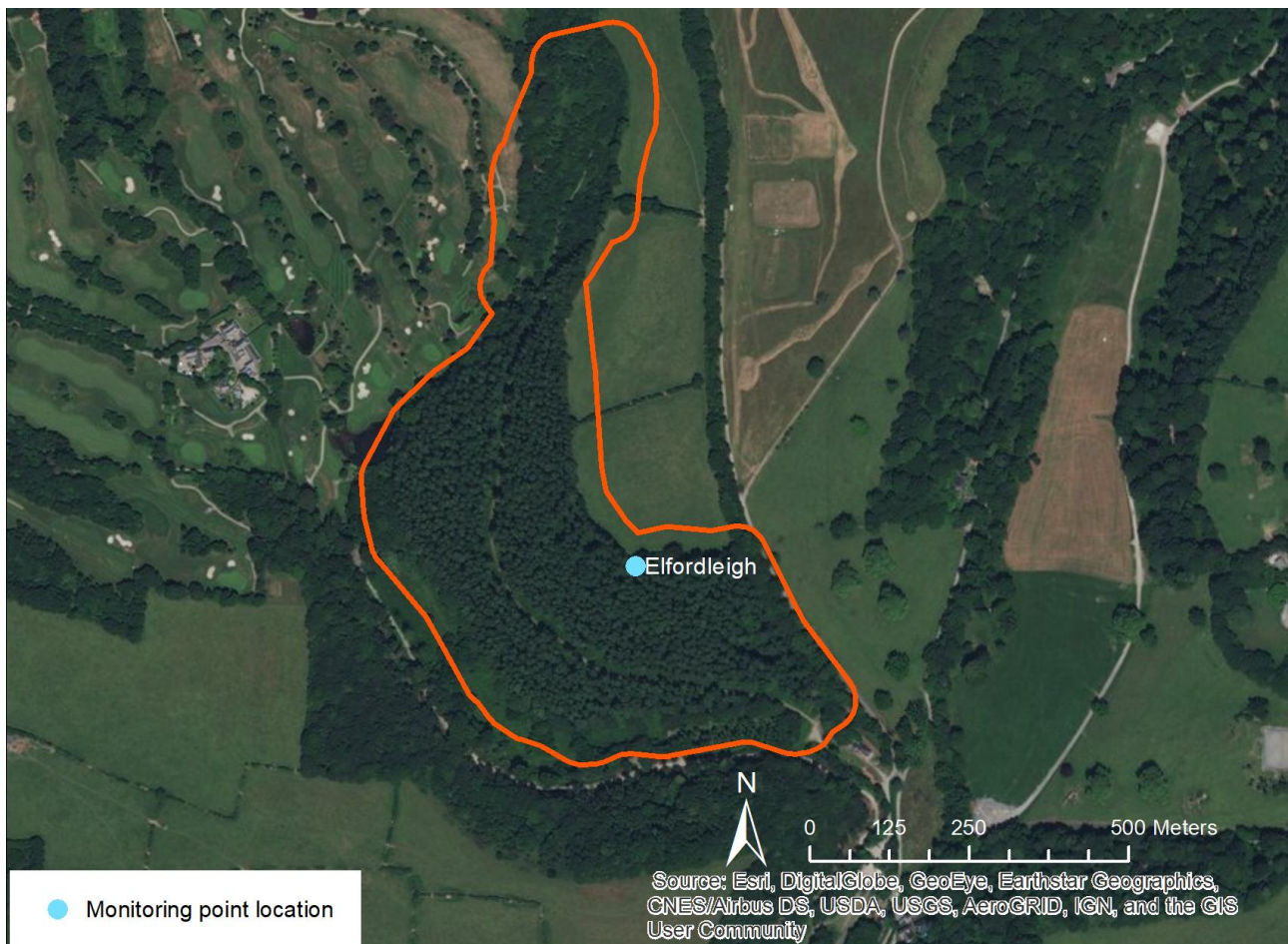
STUDY SITE CHARACTERISTICS

District: West

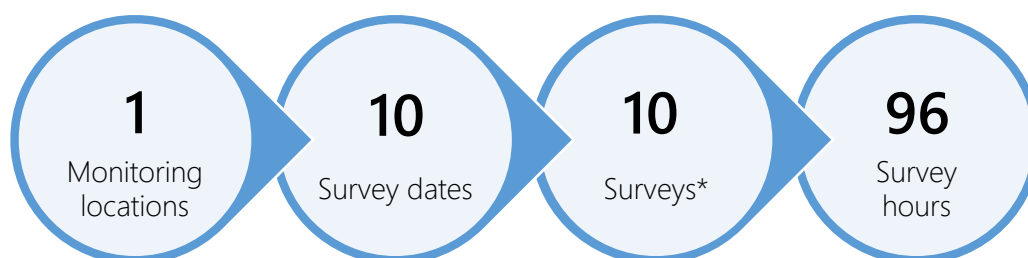
Habitat class: Coniferous dominated

Area: 10 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Elfordleigh Wood (and average hourly activity index):

Pipistrellus pygmaeus (4.53)

Pipistrellus pipistrellus (2.08)

Myotis sp. (0.11)

Nyctalus noctula (0.07)

Rhinolophus ferrumequinum (0.01)

5.65

Hourly bat activity

11/16 sites

5

Species richness**

10/16 sites

0.47

Species evenness

11/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

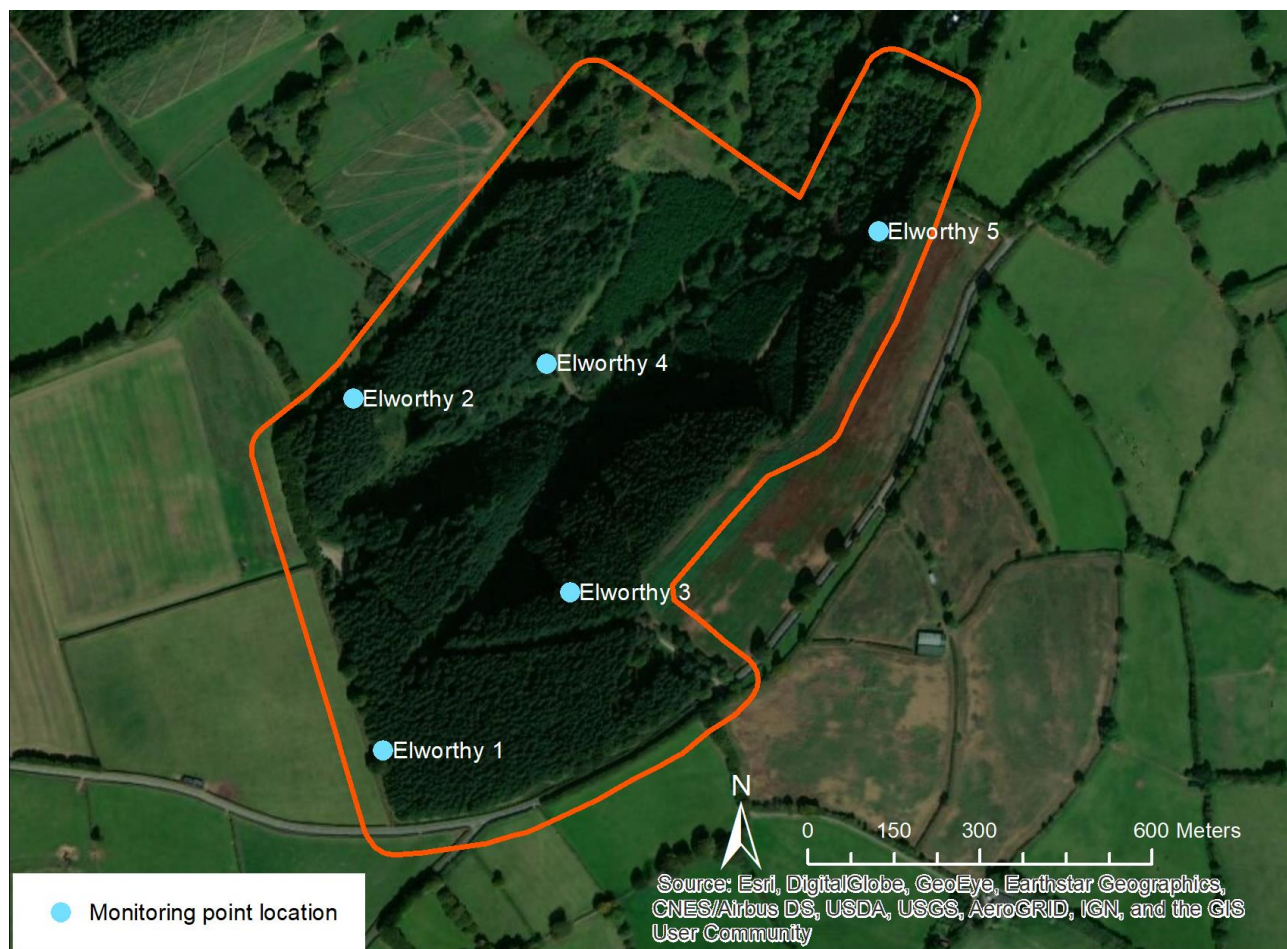
STUDY SITE CHARACTERISTICS

District: West

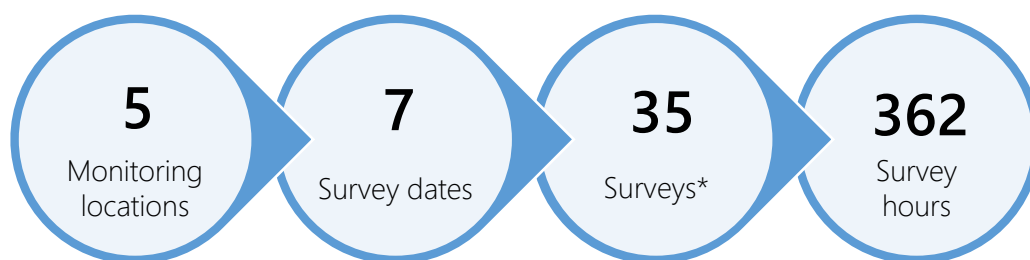
Habitat class: Coniferous dominated

Area: 31 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Elworthy Wood (and average hourly activity index):

Pipistrellus pipistrellus (13.62)

Nyctalus noctula (0.86)

Pipistrellus pygmaeus (0.81)

Myotis sp. (0.31)

Barbastella barbastellus (0.25)

Rhinolophus ferrumequinum (0.17)

Nyctalus leisleri (0.01)

Rhinolophus hipposideros (0.01)

Eptesicus serotinus (<0.01)

14.6

Hourly bat activity

3/16 sites

9

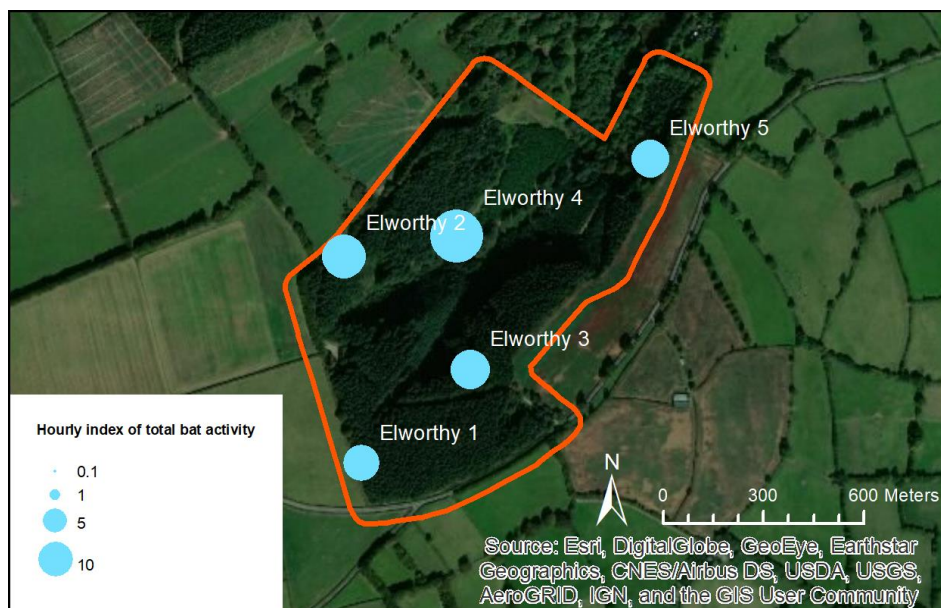
Species richness**

1/16 sites

0.29

Species evenness

14/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

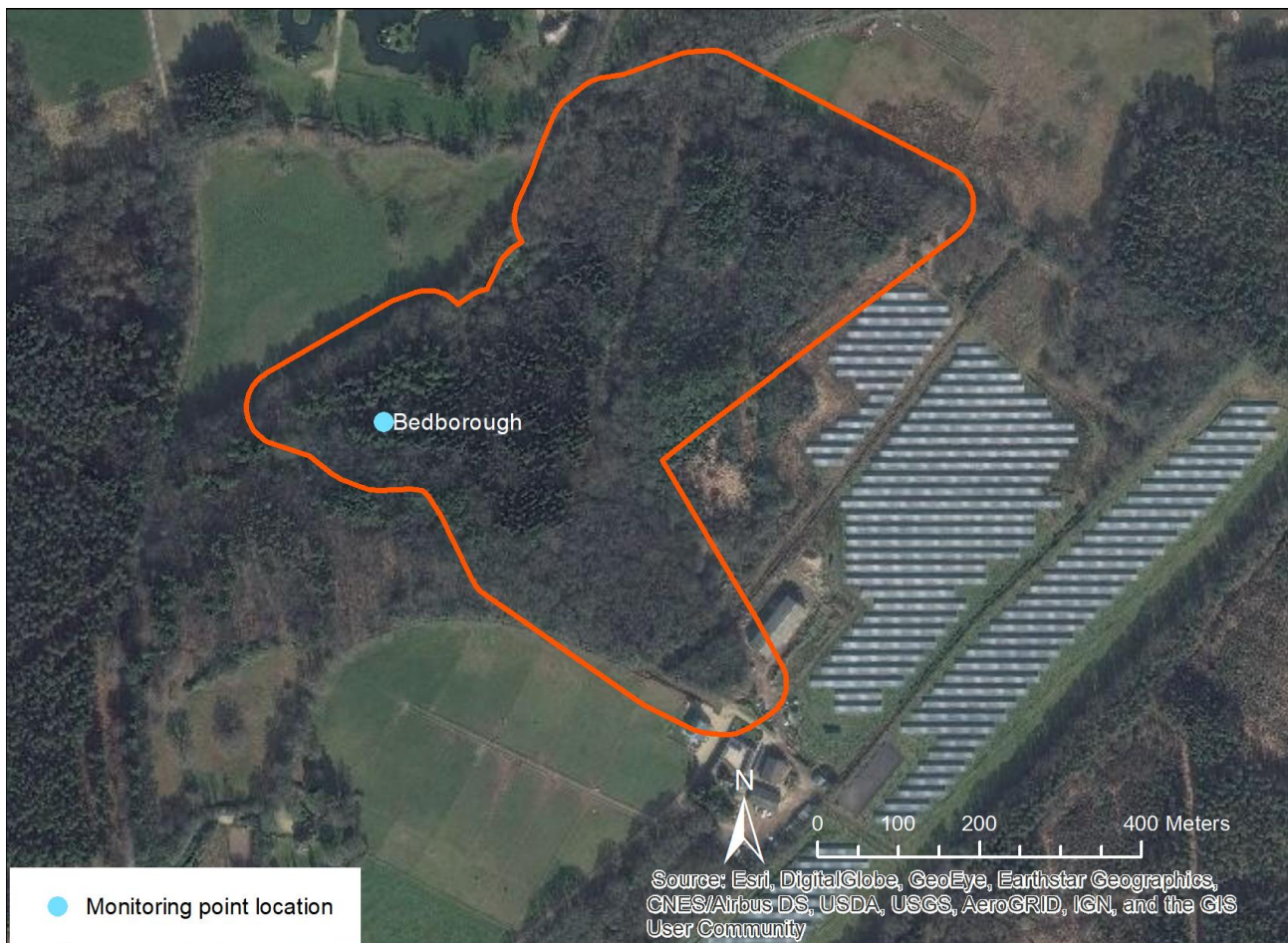
STUDY SITE CHARACTERISTICS

District: South

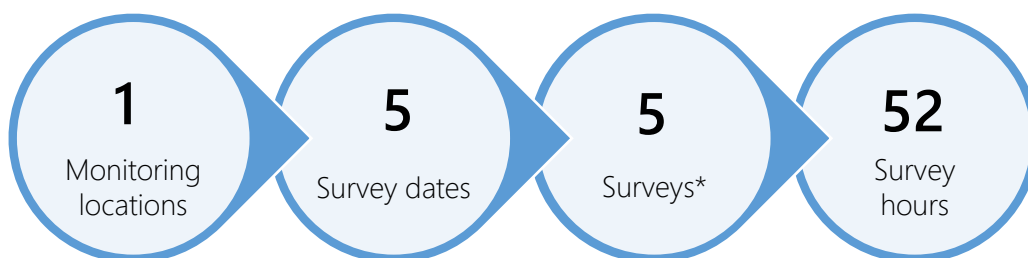
Habitat class: Broadleaved dominated

Area: 9 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Ferndown Town (and average hourly activity index):

Nyctalus noctula (0.65)

Myotis sp. (0.25)

Pipistrellus pipistrellus (0.23)

Pipistrellus pygmaeus (0.17)



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

1.23

Hourly bat activity

16/16 sites**4**

Species richness**

15/16 sites**0.89**

Species evenness

1/16 sites

FORESTY ENGLAND BAT SURVEY

Frith and Coneygree Wood

A8

STUDY SITE CHARACTERISTICS

District: West

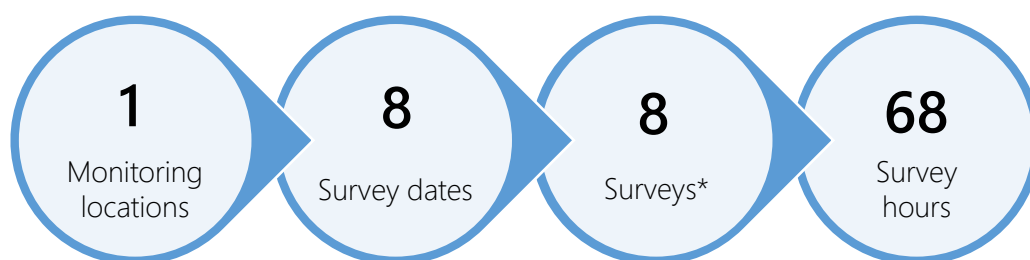
Habitat class: Broadleaved dominated

Area: 2 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

FORESTY ENGLAND BAT SURVEY

Frith and Coneygree Wood

A8

SPECIES AND ACTIVITY

Species detected at Frith and Coneygree Wood (and average hourly activity index):

Pipistrellus pipistrellus (19.44)

Pipistrellus pygmaeus (0.65)

Myotis sp. (0.1)

Nyctalus noctula (0.09)

Barbastella barbastellus (0.04)

19.8

Hourly bat activity

1/16 sites

5

Species richness**

10/16 sites

0.13

Species evenness

16/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

FORESTY ENGLAND BAT SURVEY

Goathurst Wood

A9

STUDY SITE CHARACTERISTICS

District: West

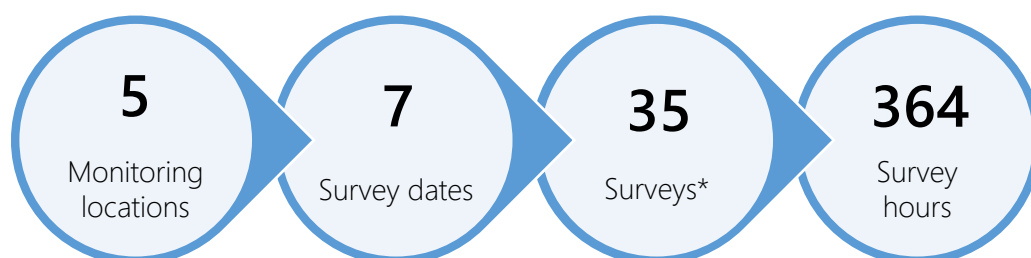
Habitat class: Broadleaved dominated

Area: 42 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Goathurst Wood (and average hourly activity index):

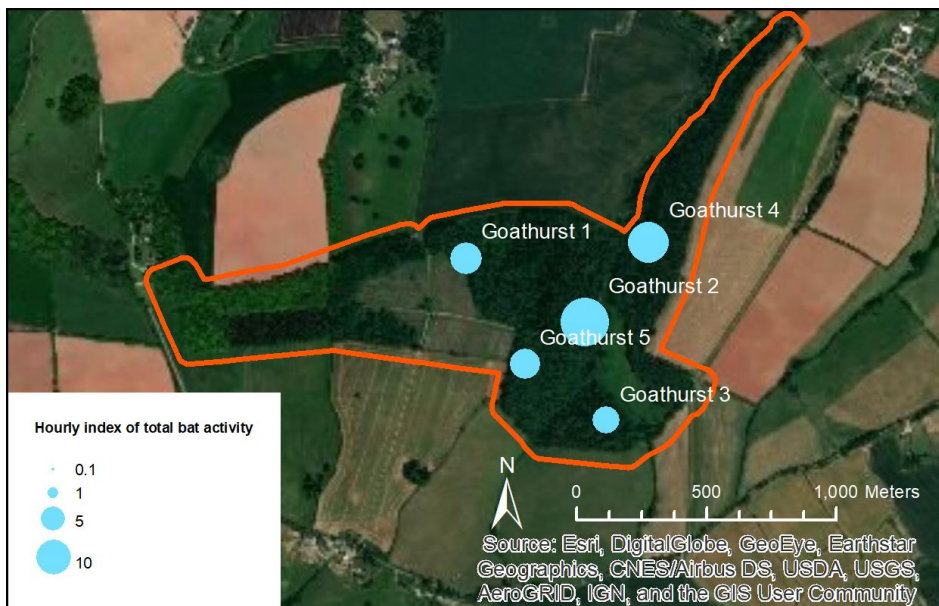
Pipistrellus pipistrellus (7.04)

Pipistrellus pygmaeus (2.57)

Barbastella barbastellus (1.32)

Myotis sp. (1.17)

Nyctalus noctula (0.41)



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

11.15

Hourly bat activity

6/16 sites

5

Species richness**

10/16 sites

0.76

Species evenness

2/16 sites

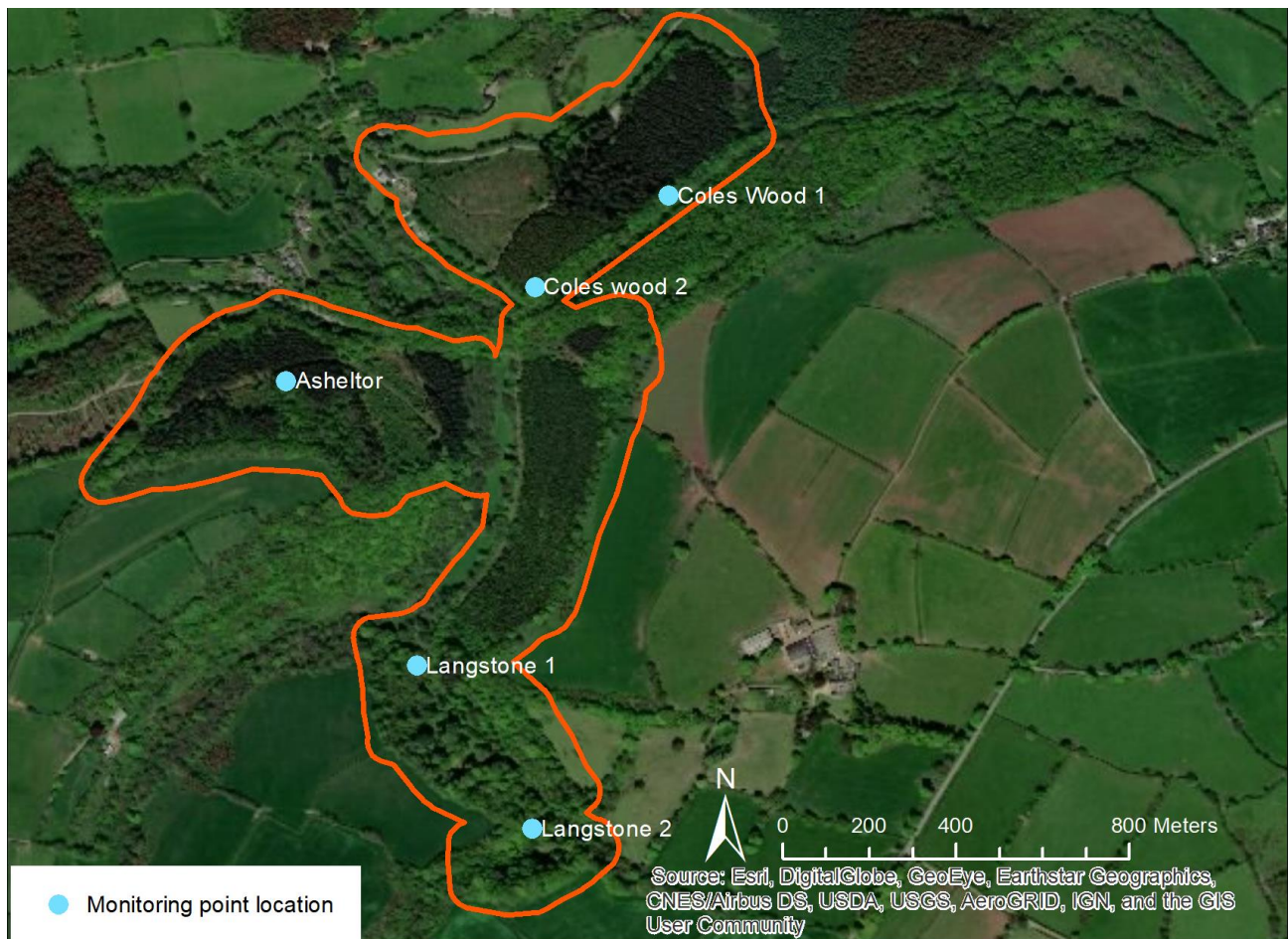
STUDY SITE CHARACTERISTICS

District: West

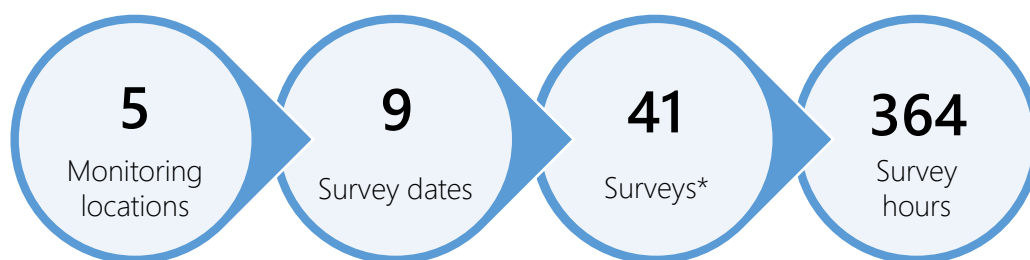
Habitat class: Coniferous dominated

Area: 31 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Lydford (and average hourly activity index):

Pipistrellus pipistrellus (3.61)

Pipistrellus pygmaeus (1.19)

Nyctalus noctula (0.65)

Myotis sp. (0.23)

Barbastella barbastellus (0.21)

Rhinolophus ferrumequinum (0.01)

5.59

Hourly bat activity

12/16 sites

6

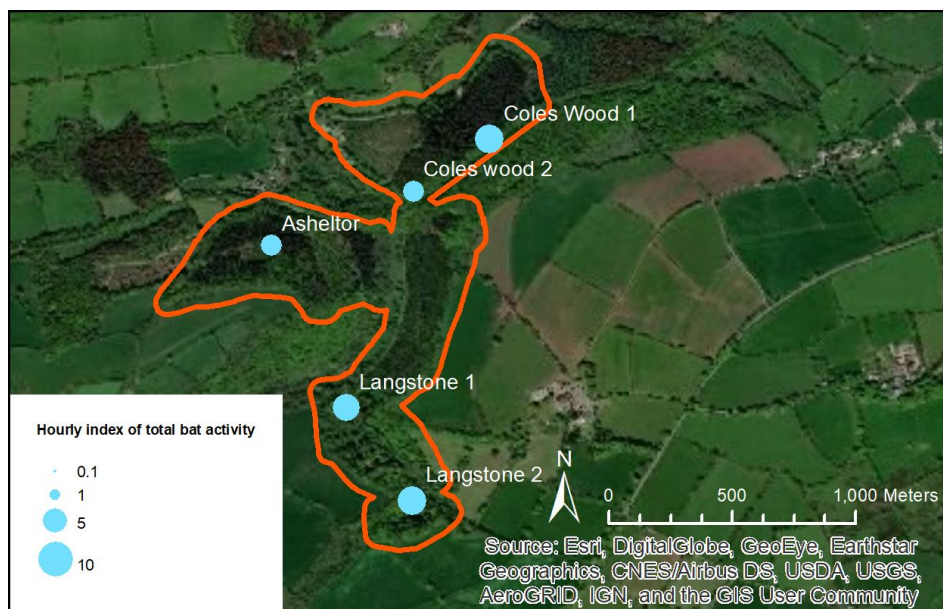
Species richness**

8/16 sites

0.63

Species evenness

5/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

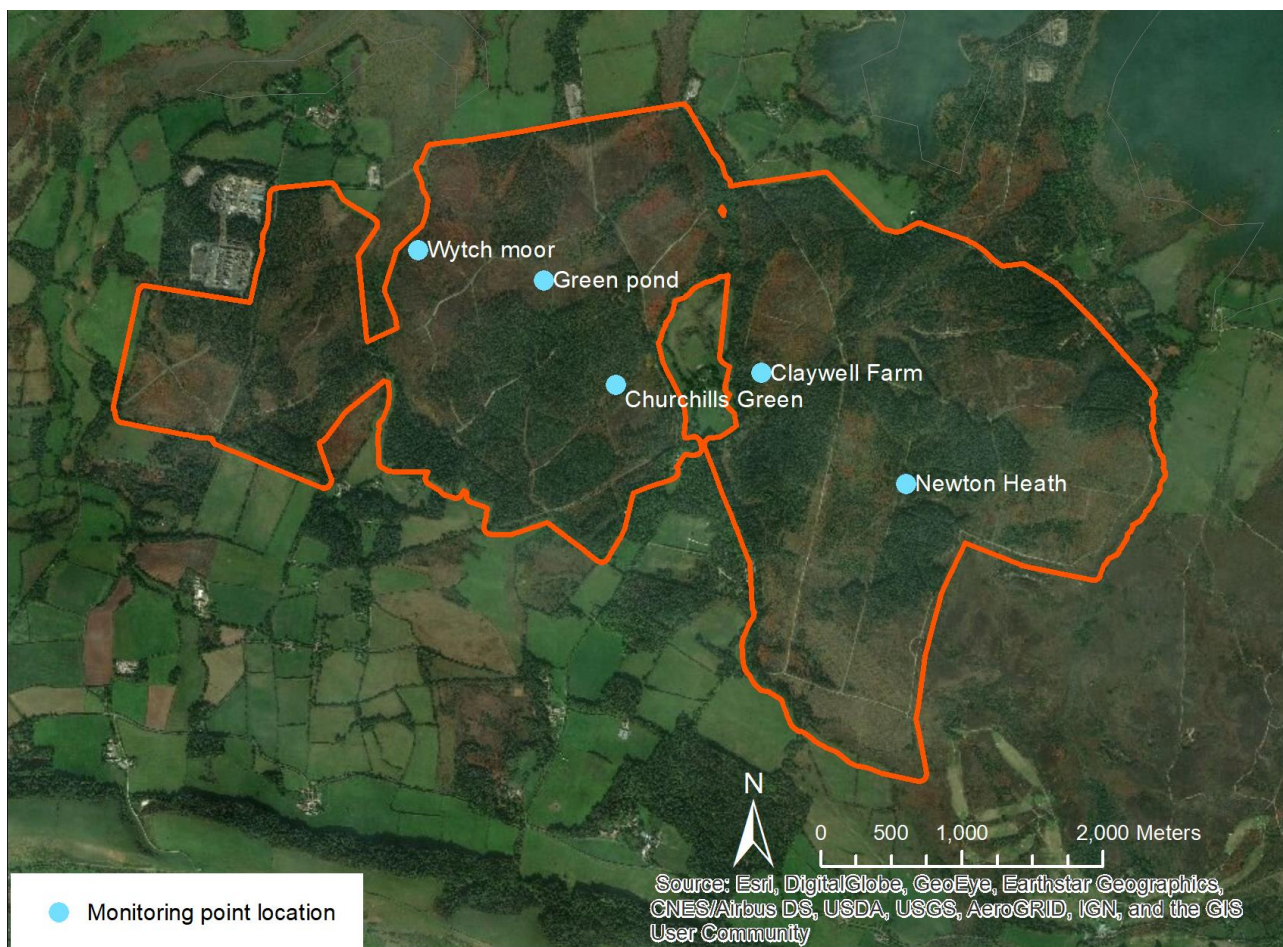
STUDY SITE CHARACTERISTICS

District: South

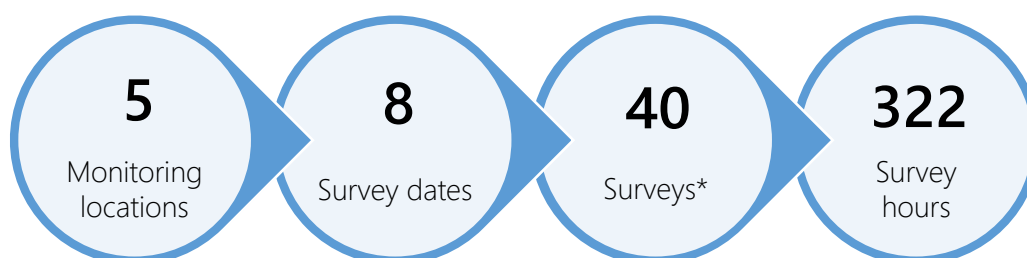
Habitat class: Coniferous dominated

Area: 612 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Purbeck (and average hourly activity index):

Pipistrellus pipistrellus (12.61)

Pipistrellus pygmaeus (1.39)

Nyctalus noctula (0.89)

Myotis sp. (0.19)

Barbastella barbastellus (0.09)

Eptesicus serotinus (0.08)

Rhinolophus ferrumequinum (0.02)

13.8

Hourly bat activity

4/16 sites

7

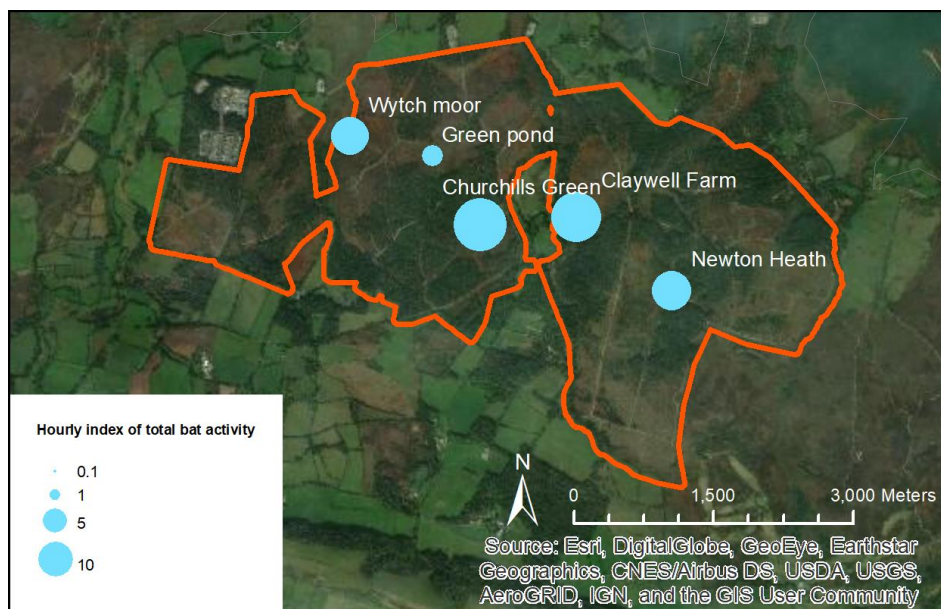
Species richness**

4/16 sites

0.34

Species evenness

13/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

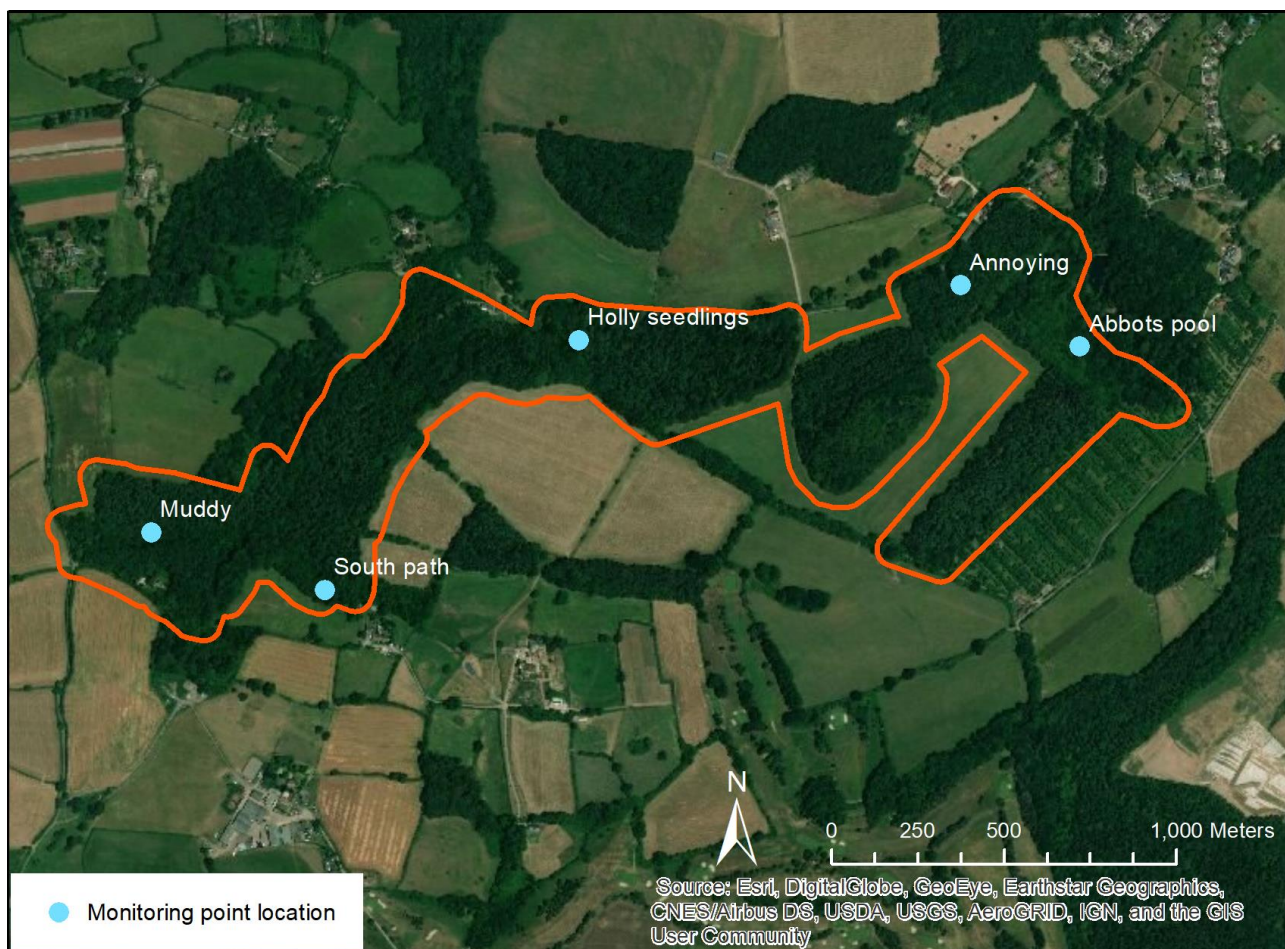
STUDY SITE CHARACTERISTICS

District: West

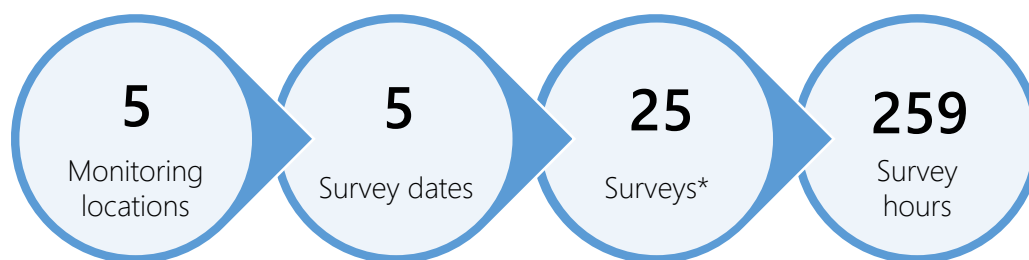
Habitat class: Broadleaved dominated

Area: 37 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Snake's Well Wood (and average hourly activity index):

Pipistrellus pipistrellus (6.32)

Pipistrellus pygmaeus (2.93)

Nyctalus noctula (0.36)

Myotis sp. (0.19)

Rhinolophus hipposideros (0.01)

Barbastella barbastellus (<0.01)

Rhinolophus ferrumequinum (<0.01)

Nyctalus leisleri (<0.01)

9.33

Hourly bat activity

7/16 sites

8

Species richness**

2/16 sites

0.41

Species evenness

12/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

STUDY SITE CHARACTERISTICS

District: West

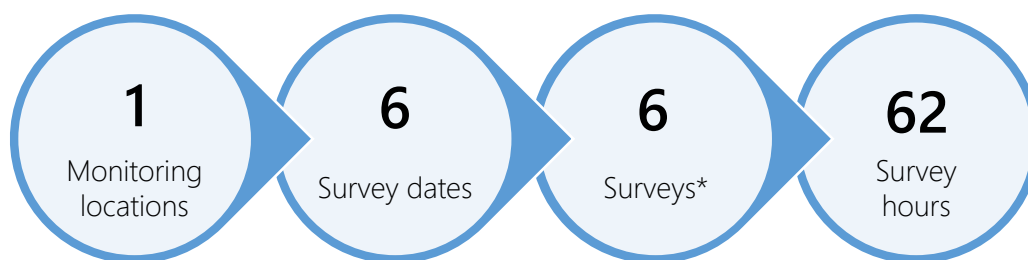
Habitat class: Broadleaved dominated

Area: 7 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Spittal Wood (and average hourly activity index):

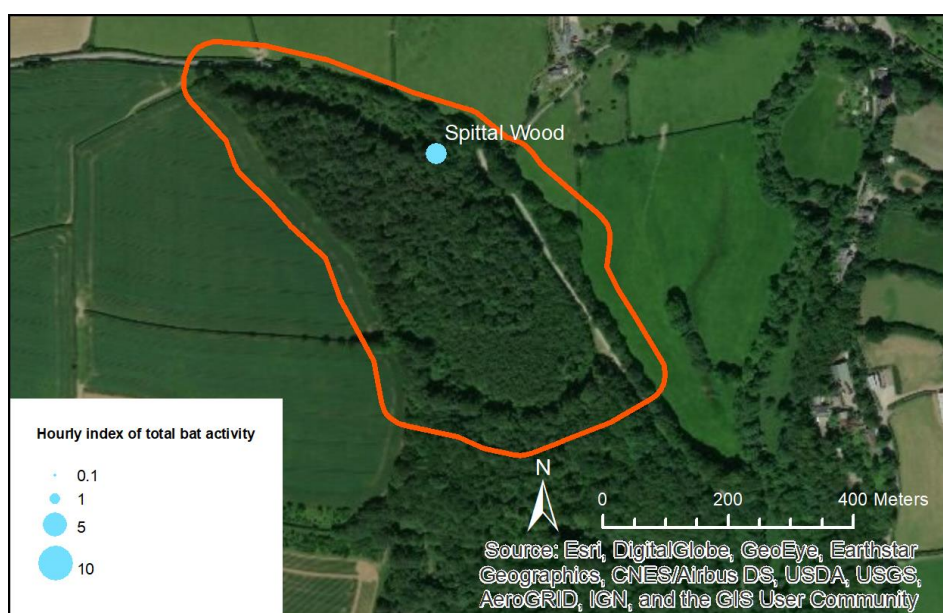
Pipistrellus pipistrellus (1.58)

Pipistrellus pygmaeus (0.61)

Nyctalus noctula (0.37)

Barbastella barbastellus (0.11)

Myotis sp. (0.08)



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

2.63

Hourly bat activity

15/16 sites

5

Species richness**

10/16 sites

0.72

Species evenness

3/16 sites

STUDY SITE CHARACTERISTICS

District: South

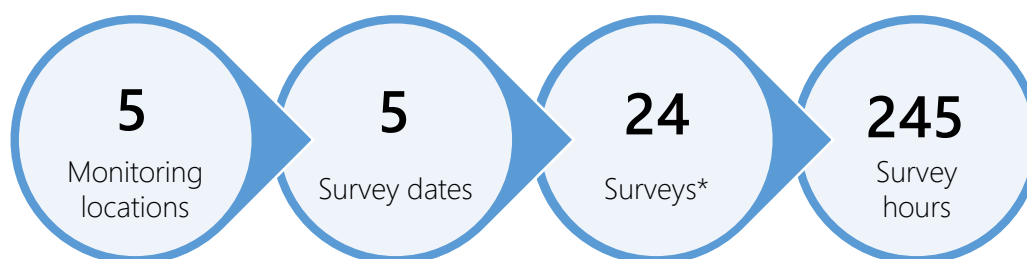
Habitat class: Broadleaved dominated

Area: 108 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Stonedown Wood (and average hourly activity index):

Pipistrellus pipistrellus (6.13)

Barbastella barbastellus (0.39)

Pipistrellus pygmaeus (0.17)

Myotis sp. (0.12)

Nyctalus noctula (0.04)

Rhinolophus ferrumequinum (0.01)

Eptesicus serotinus (<0.01)

6.62

Hourly bat activity

10/16 sites

7

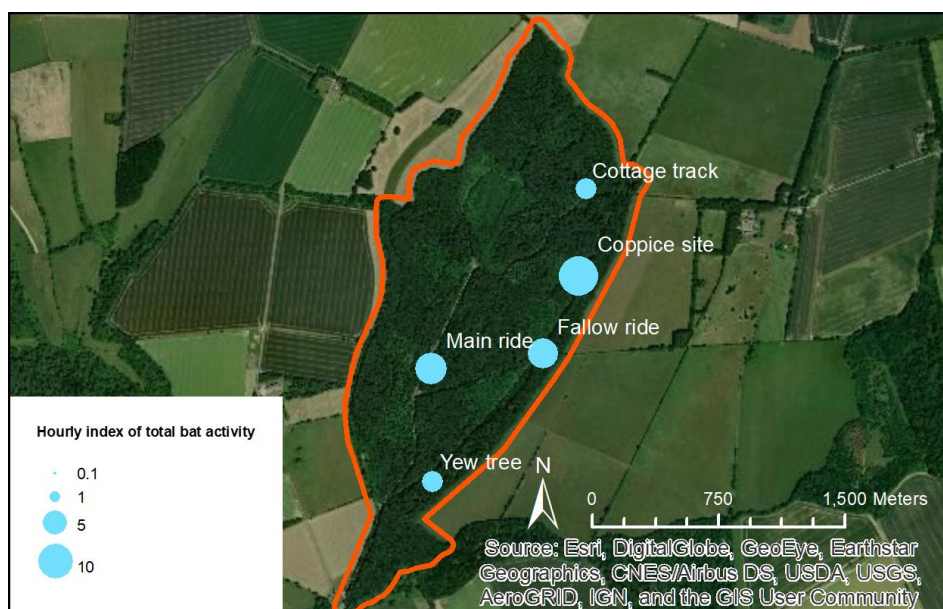
Species richness**

4/16 sites

0.24

Species evenness

15/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

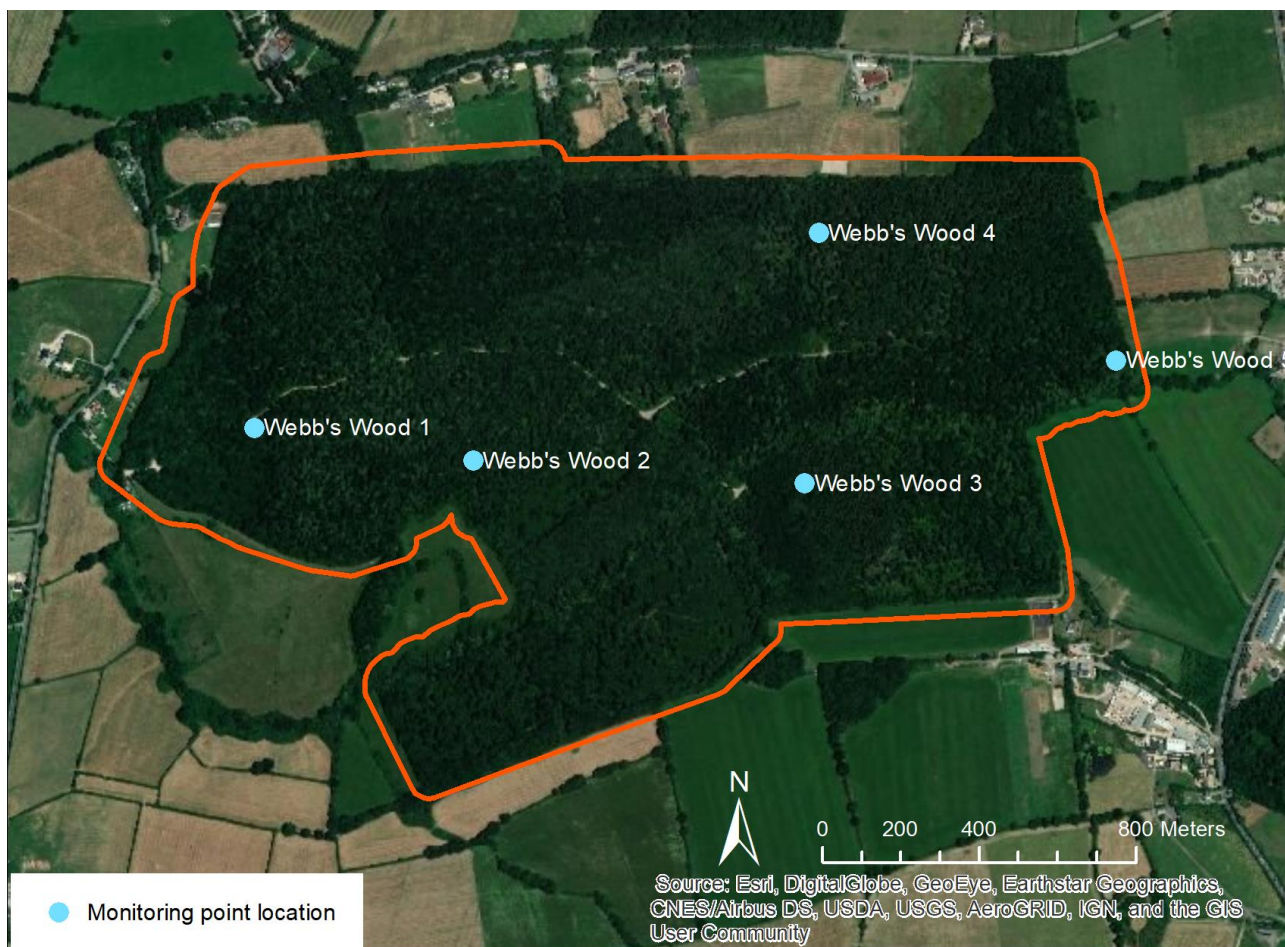
STUDY SITE CHARACTERISTICS

District: West

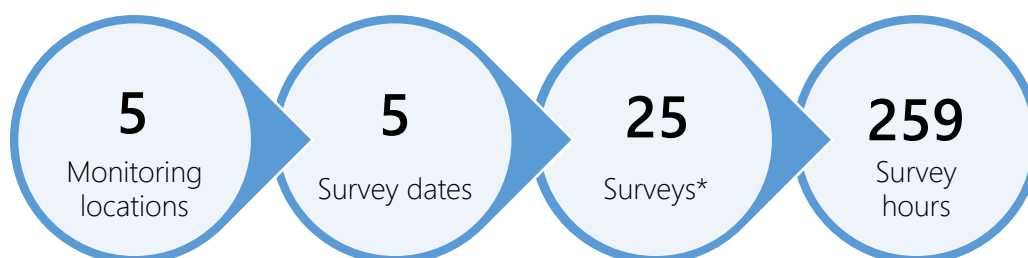
Habitat class: Broadleaved dominated

Area: 100 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Webbs Wood (and average hourly activity index):

Pipistrellus pipistrellus (11.64)

Myotis sp. (3.01)

Nyctalus noctula (2.77)

Pipistrellus pygmaeus (1.53)

Barbastella barbastellus (0.05)

17.0

Hourly bat activity

2/16 sites

5

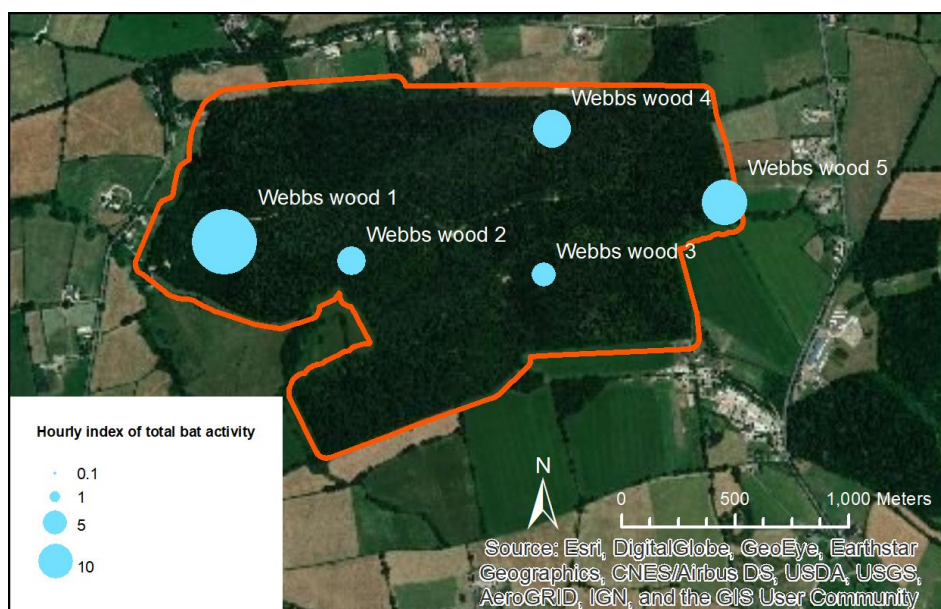
Species richness**

10/16 sites

0.68

Species evenness

4/16 sites



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

FORESTY ENGLAND BAT SURVEY

Whatcombe Wood

A16

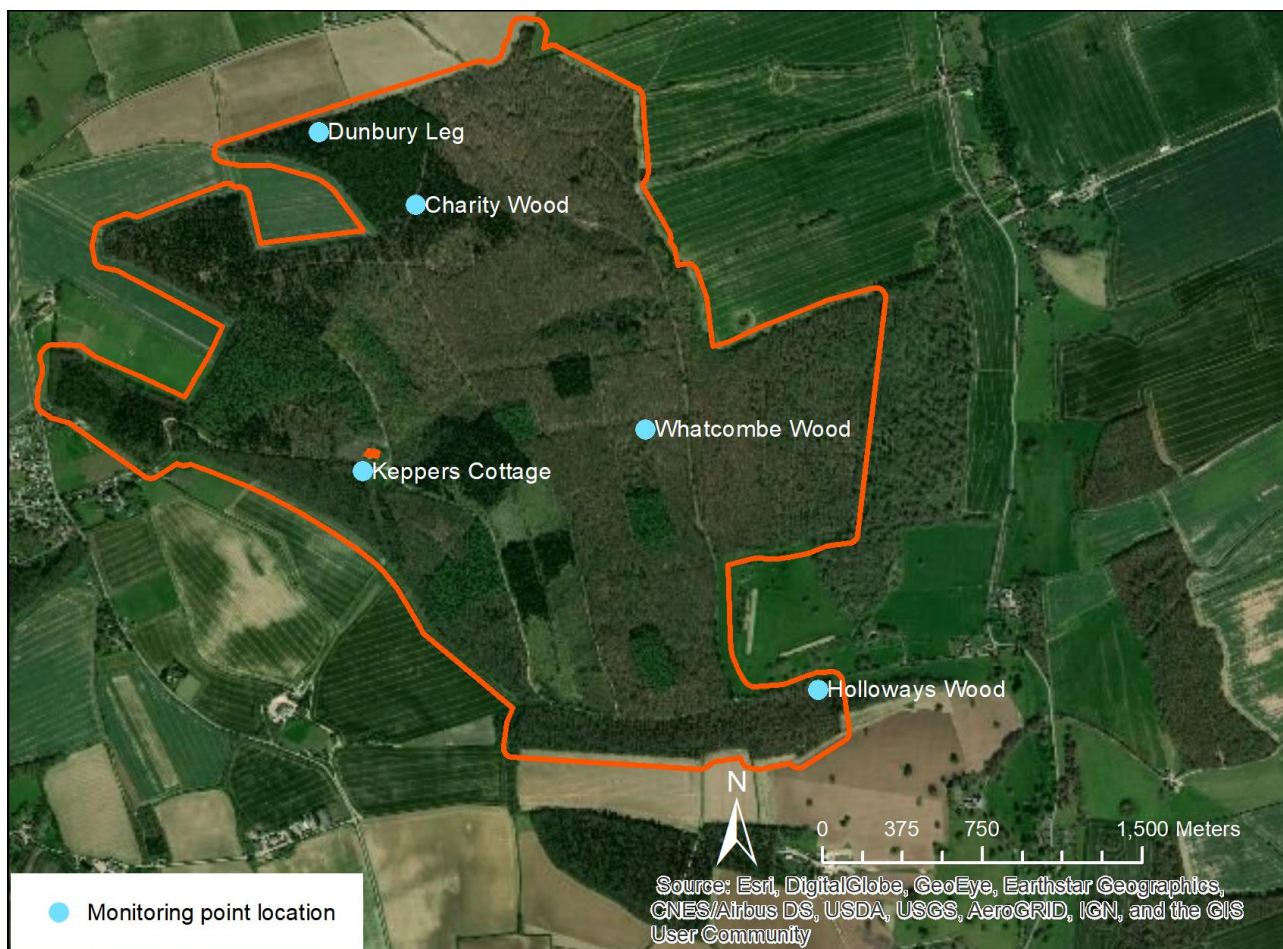
STUDY SITE CHARACTERISTICS

District: South

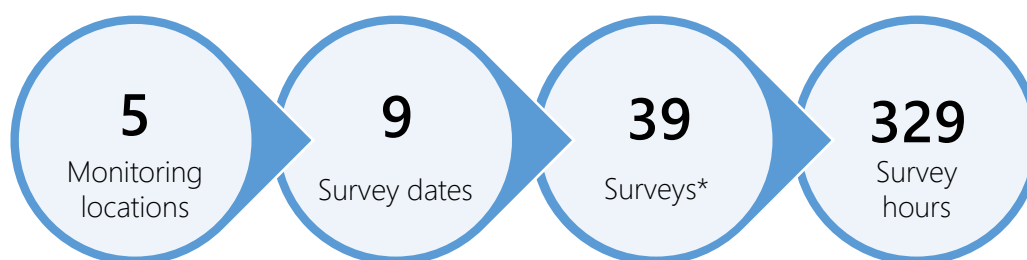
Habitat class: Broadleaved dominated

Area: 267 ha

MONITORING LOCATIONS



MONITORING EFFORT



* Surveys with at least some successfully recorded data.

SPECIES AND ACTIVITY

Species detected at Whatcombe Wood (and average hourly activity index):

Pipistrellus pipistrellus (5.58)

Pipistrellus pygmaeus (1.3)

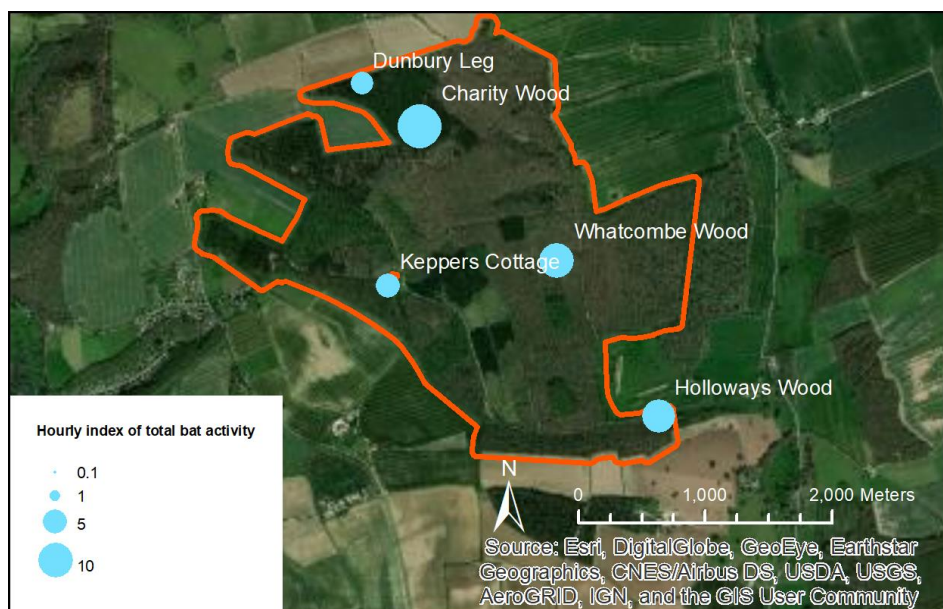
Barbastella barbastellus (0.58)

Nyctalus noctula (0.32)

Myotis sp. (0.18)

Rhinolophus ferrumequinum (0.02)

Plecotus sp. (<0.01)



Note a lower ranking does not indicate a poor quality site

** Species/species groups detected.

7.47

Hourly bat activity

9/16 sites

7

Species richness**

4/16 sites

0.5

Species evenness

9/16 sites