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Bat Conservation Trust

SCOPING AND METHOD DEVELOPMENT REPORT

Determining the potential ecological impact of wind turbines on bat populations in Britain

Phase 1 Report

Final

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Executive Summary

Most world leaders agree that climate change poses a long-term threat to the planet. Many industrialised countries, including the UK, have pledged to reduce their emissions of carbon dioxide, considered to be the largest contributor to climate change, along with other pollutants.

The exploitation of renewable energy will undoubtedly contribute towards reducing carbon dioxide emissions, and wind-generated energy will play a significant role in this in the UK. The UK Government has set a target of obtaining 20% of its energy requirement from renewable sources by 2020, but currently wind energy contributes less than 2.2% of the UK's electricity supply. The UK is the windiest country in Europe, which presents a great opportunity for the development of wind power. Consequently the production of wind energy from construction of onshore wind turbines is expected to rise exponentially over the next 10 years to help meet the Government's target.

Despite the clear benefits of wind energy, there are growing concerns about the potential impact of wind farms on bat populations due to high numbers of bat fatalities recorded in North America and Europe, particularly Germany and to a lesser extent France. No research has been undertaken to date to determine if bats are being killed by wind turbines in Britain. The University of Bristol and the Bat Conservation Trust have been commissioned by Defra to compile this scoping and method development report. This document reports on Phase 1 of a project to determine the potential ecological impacts of onshore wind turbines on UK bat populations. The overall aim of Phase 1 is to review existing information on bats and wind farms and to develop a research protocol suitable for investigating this issue in the UK. Phase 2 of this project is urgently needed to understand what, if any, ecological impacts wind farms have on bats. Understanding the extent of these impacts would help to promote positive planning decisions to ensure that future wind farm development occurs in suitable locations, and would inform the implementation of appropriate mitigation strategies where necessary. The aims of Phase 1 of the project are to:

1) critically review the extensive literature, available from North America and Europe on bats and wind farms;

2) identify appropriate survey protocols for use in the UK;

3) identify suitable sites for surveys and selection criteria; and

4) detail the resources needed to undertake the proposed surveys to successfully complete this project.

In this report we propose a 3 year research project for Phase 2. We propose that fatality searches should be carried out at operational wind farm sites across Britain, on five days a week throughout August and September, as peak fatalities have been found at this time of year in other countries. We suggest that 10 wind farm sites are monitored each year of the project. A team of surveyors will be required to complete this intensive monitoring work, and will all undertake a three-day training course prior to the commencement of the surveys to ensure standardised protocols are followed.

In addition to the fatality searches in August and September, three core sites will be selected for fatality searches on a fortnightly basis throughout the bat active season (April to October) in 2010 and 2011. The core sites will be selected after the initial fatality searches in 2009. Acoustic surveys are also proposed at the three core sites throughout the bat active season, starting in April 2010. The most effective approach, as indicated from the literature review, would be to install remote recording bat detectors on turbines at nacelle[1] height, to record bat echolocation calls continuously from sunset to sunrise each day. These data can then be used to determine bat activity levels close to turbines and within the rotor-swept area.

Sampling bias in fatality searches has been well documented both in North America and Europe. Variation in searcher efficiency and carcass removal by scavengers both lead to bat fatality rates being underestimated. Searcher efficiency and carcass removal trials should therefore be conducted during the intensive fatality survey period to account for this sampling bias and to allow fatality rates to be adjusted accordingly.

In this report we review the available literature on impacts of wind turbines on bats and assess the various methods used in different studies completed to date (section 2). From this information we recommend detailed survey methods for fatality studies and acoustic surveys (section 3), and we propose a short-list of potential study sites with information on selection criteria (section 4). Details of the training requirements for surveyors undertaking fatality surveys are set out in section 5 of the report. Finally, in section 6, a detailed list of the resources required to undertake the proposed surveys for Phase 2 are given for each of the 3 years of the study. 1

[1] The nacelle is the casing covering the key components of the wind turbine, including gearbox, generator and blade hub located at the top of the turbine tower.

1. General Introduction

1.1 Background

Wind-generated electricity is a source of renewable energy that has the potential to contribute significantly towards reducing the UK's carbon dioxide emissions. Anthropogenic greenhouse gases are widely accepted as a major contributing factor of climate change, which few people would deny presents us with a serious long-term threat. As such there is a strong drive towards reducing greenhouse gas emissions by using renewable energies. A legally binding international environmental agreement, the 'Kyoto Protocol', was produced at the United Nation's Earth Summit in Rio de Janeiro in 1992. Within this agreement, industrialised countries were set the target of reducing six greenhouse gases, with varying national limitations. The UK, along with many other countries (including 14 other EU countries), ratified this agreement in 2002 thereby pledging to stabilise and subsequently reduce carbon dioxide emissions, among other pollutants. The Kyoto Agreement has been the catalyst for national policies on renewable energy to be produced for England (Planning Policy Statement 22: Renewable Energy (PPS22)), Scotland (Scottish Planning Policy 6: Renewable Energy (SPP6)) and Wales (Technical Advice Note 8: Planning for Renewable Energy (TAN8)), which are summarised in Appendix 1. To set out how renewable energy developments will be encouraged, these policies have set targets for the amount of national energy that should be produced from renewable energy sources; for example Scotland have set a target of 40% of their energy to come from renewable sources by 2020.

To facilitate delivery of their commitment to climate change and renewable energy, the Government has produced an Energy White Paper (2007). This policy aims for a 60% reduction in carbon dioxide emissions by 2050, with some significant progress to be made by 2020 (as detailed in PPS22, SPP6 and TAN8). As part of this goal the Government has committed to generating 10% of UK energy from renewable sources by 2010, and 20% by 2020 (Energy White Paper 2007). In order to meet this target the British Wind Energy Association (BWEA – the trade and professional body for the UK wind and marine renewables industries) estimate that 35-45% of the UK's electricity will have to come from green resources, including an estimated 33GW from wind energy. It is considered that renewable energy has the potential to achieve in excess of 30% of the UK's electricity by 2020 (Committee on Climate Change 2008). The UK is the windiest country in Europe, with an estimated 40% of the wind resource in Europe (Drewitt & Langston 2006). Therefore, wind is arguably the most appropriate source of electricity to meet climate change and renewable energy commitments in the UK as it is clean, sustainable and low cost. In 2007 the UK only produced 5% of electricity from renewable sources (http://www.berr.gov.uk/energy/sources/renewables/index.html). If the UK targets are to be reached, there will be a need for a sharp rise in the number of wind farms (both offshore and onshore) as currently the UK only produces 2.2% of its electricity from wind energy that is largely produced from onshore wind farms (http://www.bwea.com/onshore/index.html). With this large wind resource in the UK, the BWEA state that: "…we could power our country several times over using this free fuel…in January 2009; wind turbines in the UK had the capacity to prevent the emission of 3,682,563 tonnes of carbon dioxide per annum" (http://www.bwea.com/onshore/index.html).

Despite the clear environmental benefits of wind energy, there are concerns about the potential ecological impact of wind turbines, initially triggered by large numbers of bird fatalities recorded at some wind farm sites in North America and some countries in mainland Europe. Bat fatalities at wind farms received relatively little attention until 2003, when 1,400 – 4,000 bats were estimated to have been killed at a wind farm in West Virginia, USA. (Kerns & Kerlinger 2004). Subsequently, several other studies undertaken at large-scale wind farms in North America have also reported bat fatalities (e.g. Johnson 2005; Piorkowski 2006; Kunz *et al*. 2007a; Arnett *et al*. 2008). Bat fatalities have also been recorded in 14 European countries, most notably in Germany, France, Portugal, and also the UK. A total of 1,502 European bat fatalities were reported as of 30 April 2009 (Dürr & Dubourg-Savage 2009; cited by Rodrigues *et al*. 2009). At many of the study sites in North America and some in mainland Europe the number of bat fatalities has been so high that these figures have sparked serious concern for the conservation status of the species concerned (e.g. Arnett 2005; Johnson 2005; Piorkowski 2006; Arnett *et al*. 2008; Rodrigues *et al*. 2008).

It is now thought that bats may be at greater risk of death from wind turbines than birds because they may be affected by barotrauma as well as injuries caused by direct collision as has been shown in Canada (Baerwald *et al*. 2008). Barotrauma is described by Baerwald *et al*. (2008) as "*tissue damage to air-containing structures caused by rapid or excessive pressure change; pulmonary barotrauma is lung damage due to expansion of air in the lungs that is not accommodated by exhalation"*. The prevalence of barotrauma in bat fatalities but not bird fatalities from wind turbines could result as a consequence of differences in mammalian and avian biology as birds have a unique respiratory system. The relatively large numbers of bat fatalities at wind farms could also be related to differences in flight height of these groups during migration in relation to turbine height. In Canada, bat fatalities increased exponentially with turbine tower height; whereas bird fatalities were lower at taller turbine towers (Barclay *et al*. 2007).

The majority of bat fatalities have been recorded in late summer and autumn (e.g. Brinkman 2004; Dürr & Bach 2004; Johnson *et al*. 2004; Johnson 2005; Cryan & Brown 2007; Arnett *et al*. 2008) and the vast majority of species recovered have been migratory (e.g. Cryan & Brown 2007; Arnett *et al*. 2008). However, bats are not exclusively killed during the migration period and fatalities have not been solely migratory species: in Germany significant numbers of bat collisions have also occurred earlier in the summer (Behr & von Helversen 2006; cited by Rodrigues *et al*. 2008). In Portugal (data presented by Dubourg-Savage *et al*. 2009 at the First International Symposium on Bat Migration held in Berlin in January 2009) and Germany resident bats have also been affected (Behr & von Helversen 2006 - cited by Rodrigues *et al*. 2008; Brinkmann *et al*. 2006) and migratory and non-migratory species were killed in similar proportions at wind farm sites in Sweden (Ahlén 2003).

Studies undertaken in Europe have shown that noctule (*Nyctalus noctula*), Leisler's bat (*N. leisleri*), Nathusius' pipistrelle (*Pipistrellus nathusii*) and soprano pipistrelle (*P. pygmaeus*) migrate considerable distances (Schober & Grimmberger 1993; cited by Hutterer *et al*. 2005; Ahlén 2002; Brinkman 2004; Hutterer *et al*. 2005). There is currently a lack of information available on the migratory behaviour of British bats, but these four species occur in Britain and could potentially migrate from summer roosts to winter hibernacula even if over shorter distances than currently recorded in mainland Europe. Consequently, bats may be at increased risk of collision if turbines are installed along these flight paths and it is not currently known whether British bats migrate or commute at altitudes that would expose them to an increased risk of colliding with a wind turbine.

At present, due to a lack of systematic research, it is unclear whether wind turbines pose a real threat to bat populations in the UK. Without this information it will not be possible to determine whether bat populations will be affected significantly by the predicted high development rate of wind farms likely to occur across the UK in the near future. Consequently, adverse impacts on bat populations from future wind farm developments cannot be properly assessed. Data need to be collected on which species are affected and in what numbers, when fatalities peak in the year, how weather conditions affect fatality rates (i.e. high/low wind speeds) and on the relationship between fatality rates, turbine locations and surrounding habitat. This information is particularly important in the siting of future wind farms as further information may inform the implementation of national guidelines and fulfil the UK Government's international obligations to protect bat populations and its national obligations to safeguard biodiversity.

Sections 1.2 - 1.5 briefly describe the legal protection afforded to bats in the UK, the UK Biodiversity Action Plan (BAP) for certain bat species and relevant planning policies, where biodiversity is a consideration. Finally, the generic European guidance and Natural England's interim guidance is also discussed briefly.

1.2 Relevant International, European and UK Legislation

In the UK all bat species and their roosts are legally protected, by both domestic and international legislation: under the Wildlife and Countryside Act (1981) (as amended by the Countryside and Rights of Way Act, 2000 for England and Wales), which implements the Bern Convention; the Natural Environment and Rural Communities Act (NERC, 2006); and by the Conservation (Natural Habitats &c.) Regulations (1994) (as amended 2007, 2008, 2009), which implements the EC Habitats Directive. In summary, together these pieces of legislation make it an offence to damage or destroy any bat roost; intentionally or recklessly obstruct a bat roost; deliberately, intentionally or recklessly disturb a bat; or intentionally kill, injure or take any bat. The NERC Act (2006) also provides protection for bats and their roosts by requiring that local authorities take into account impacts on biodiversity when assessing planning applications. Further details of these relevant pieces of legislation have been set out in Appendix 1.

1.3 Biodiversity Action Plans

The UK Biodiversity Action Plan (BAP) is a direct result of the signing of the Convention on Biological Diversity at the Earth Summit in 1992 ("Rio Convention"). The Convention sought to provide a legal framework for biodiversity conservation to protect, conserve and enhance biodiversity under threat (as described in Appendix 1). It has provided the tool required for the creation and enforcement of national strategies and action plans to conserve, protect and enhance biodiversity. At the UK level a national strategy was developed, which provided the catalyst for BAPs to be drawn up.

The UK Government launched *Biodiversity: the UK Action Plan* (UK Biodiversity Partnership 2006); a national strategy to conserve threatened native species and habitats that replaced the UK Biodiversity Action Group. These action plans set out Species Action Plans (SAPs) and Habitat Action Plans (HAPs). In order to target conservation action, SAPs were initially developed for six priority bat species: barbastelle (*Barbastella barbastellus*), Bechstein's bat (*Myotis bechsteinii*), greater horseshoe bat (*Rhinolophus ferrumequinum*), lesser horseshoe bat (*R. hipposideros*), common pipistrelle (*P. pipistrellus*) and the greater mouse-eared bat (*M. myotis*). The SAP for common pipistrelle was written prior to the soprano pipistrelle being distinguished as a separate species. Following this the SAP was amended to cover both species.

A revised list was published in August 2007, following a review of species, which added a further two bat species to the priority list: brown long-eared bat (*Plecotus auritus*) and noctule, and whilst the common pipistrelle was removed, the soprano pipistrelle remained on the list (http://www.ukbap.org.uk/ NewPriorityList.aspx). Although the existing UK SAPs will be retained for the species, actions and targets are being devolved to the country level and delivery will be co-ordinated by Biodiversity Integration Groups (BIGS) in England and Ecosystem Groups in Wales. The common pipistrelle was retained on the Wales Biodiversity List (Section 42 list) because of a lack of evidence to justify its removal: (http://www.biodiversitywales.org.uk/ wales_biodiversity_partnership_documents-134.aspx). All nine species found in Scotland appear on the Scottish Biodiversity List, namely: Brandt's bat (*M. brandtii*), Daubenton's bat (*M. daubentonii*), whiskered bat (*M. mystacinus*), Natterer's bat (*M. nattereri*), noctule, Nathusius' pipistrelle, common pipistrelle, soprano pipistrelle and brown long-eared bat.

1.4 Relevant Planning Policies

There are a number of national, regional and local policies that relate to nature conservation and ecology within the planning process. Relevant national policies have been described in Appendix 1 to provide a summary and indication of the likely requirements and expectations of statutory authorities in relation to planning applications and the nature conservation and ecology within application sites and the surrounding area. All new wind farm applications will need to refer to these policies as wildlife is considered a material consideration in the planning process and these policies provide an indication of the likely requirements and expectations of statutory authorities in relation to planning applications and nature conservation and ecology within a given area.

1.5 Guidelines

1.5.1 EUROBATS Guidance

The Advisory Committee of the 'Agreement of the Conservation of Populations of European Bats' (known as EUROBATS), has provided generic guidance for European countries on assessing the impact of wind turbines on bats (Rodrigues *et al*. 2008 - EUROBATS Guidelines for consideration of bats in wind farm projects). The guidance states that, although most species have been killed in the migratory period, resident bats have also been killed; therefore pre-construction surveys should be undertaken throughout the bat-active season. The guidance also states that the pre-construction assessment should identify bat species and any features used by bats within the landscape and the following information should be obtained to help inform the assessment:

- Obtain biological records to ascertain habitat survey maps, species distribution within the area, known roosts, foraging and commuting areas, bird migratory routes that may give us a hint on bat migration and European bat migration data.

- Assess bat activity on site, looking at features that could be used by bats to determine any roosting sites, foraging areas, and commuting and migration routes.

- Identify any potential impacts in relation to what the desk study and site surveys have found.

- Identify the scale of the assessment and what future survey effort is required to inform the potential effects of the proposed wind energy development relating to the local findings.

1.5.2 Natural England Interim Guidance

All Parties to the EUROBATS Agreement are urged to develop their own national guidelines (Rodrigues *et al*. 2008). However, as Britain currently does not have an evidence-base to inform national guidelines, interim guidance has been drawn up by Natural England (Natural England 2009)). This interim guidance recommends a less rigorous survey protocol than the EUROBATS guidance. In addition, a key difference between the national interim guidelines and the EUROBATS guidelines is the distance recommended between features used by bats and wind turbines. Natural England's interim guidance recommends a much lower separation distance (50m) than EUROBATS (200m). Natural England's guidance states that: "*To minimise risk to bat populations our advice is to maintain a 50m buffer around any feature (tree, hedges) into which no part of the turbine intrudes. This means the edge of the rotor-swept area needs to be at least 50m from the nearest part of the habitat feature*." More detail of this guidance is given in Section 2.1.5.

1.6 Aims and Objectives

To date there has been a significant body of research completed in North America, and some work carried out in mainland Europe at existing wind farm sites. However, in Britain there has been no organised monitoring or research on bat activity or fatalities at wind farm sites post-construction.

In this report, we aim to provide a summary of the extensive literature, and informed by this to develop robust, scientifically valid monitoring methods to assess bat activity and bat mortality at wind energy facilities in Britain. All information in this report relates to bats and onshore wind farms Impacts of offshore wind farms on bat populations are not considered in this report. The report is set out as follows:

- **Section 2** (Literature Review) summarises evidence of bat fatalities in North America and Europe, 'Grey literature' reports from pre- and post-construction ecological monitoring, and relevant data on bat migration in Europe relating to British bat species;
- **Section 3** (Survey Methods and Protocols) details our recommended standardised protocols to undertake bat fatality searches and bat activity acoustic surveys to monitor trends at core sites throughout the bat active season;
- **Section 4** (Study Sites) summarises the selection criteria for wind farm sites and the geographical distribution of sites across Britain;
- **Section 5** (Training Programme) lists the recommended training programme for surveyors and details how this training will be carried out to ensure standardised, high quality surveys.
- **Section 6** (Resources) details a comprehensive list of resources needed to carry out the surveys recommended;
- **Section 7** (References); and
- **Section 8** (Appendices).

In Phase 2 of the project, the recommended survey protocols will be followed to answer the main underlying question:

- Are British bats being killed from collision with wind turbines?

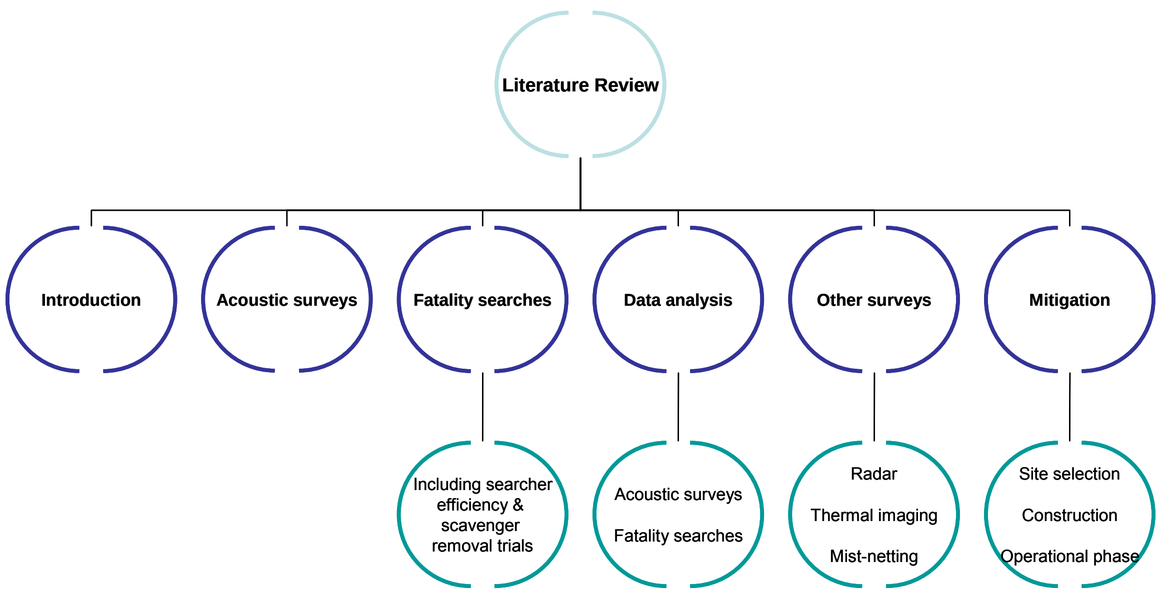
If this is found to be the case, data collected will help to inform any factors that may be contributing to these fatalities.

Phase 2 of the project will be funded by Defra, the British Wind Energy Association, Natural England and the Countryside Council for Wales.

2. Literature review

2.1 Introduction

This review focuses on survey methods and protocols for assessing bat activity and fatalities at wind farm sites in North America, mainland Europe and from the limited information available in Britain. Bat fatalities have also been reported in Australia, where 22 white-tailed mastiff bats (*Tadarida australis*) were found at the base of a wind turbine (Hall and Richards 1972; cited by Betts 2006), and to date 16 bat species have been killed in Mexico (Ed Arnett, *pers*. *comm*.). These findings have been included here for completeness but will not be discussed further in this report due to the lack of information available. This section is set out as shown in the block diagram below. We provide a summary of relevant data from pre- and post-construction surveys, where the main focus was on acoustic surveys, although radar, thermal imaging and mist-netting studies have also been summarised. However, the review concentrates mainly on fatality searches because identifying whether bats are at risk from being killed by wind turbines in Britain is the primary aim of the project. Due to potential sampling biases associated with fatality searches, we also include a review of searcher efficiency and carcass removal trials.



The information presented in this review has been taken from published literature, 'grey literature' (which has largely comprised of reports on individual sites), and previous reviews (e.g. Arnett *et al*. 2008 and Rodrigues *et al*. 2008). It is important to note that there are difficulties in making direct comparisons between many of the studies due to a number of factors, for example differences in survey methods, varying levels of survey effort (e.g. daily vs. fortnightly fatality searches), the time of the year that surveys were undertaken, and variation in habitat types and the extent of training/experience of personnel. Additionally some studies did not account for sampling bias, and where sampling bias has been accounted for there is often no consistency in the methods used or in the level of survey effort. Sampling bias needs to be accounted for in each study due to the variation in searcher efficiency (i.e. when using different searchers at the same site) and carcass removal surveys (to determine the predation or scavenger rate at each site) as these may change depending on the area, habitat and visibility conditions (e.g. in relation to vegetation height). Although limited information is currently available, mitigation actions that attempt to reduce bat fatalities at operating wind farms have been included.

The results of these fatality studies, particularly in Europe, and existing knowledge about the different British bat species ecology are discussed, along with their estimated ‘risk’ from fatality caused by the presence collision with wind turbines. Species composition for fatalities in North America and mainland Europe has largely comprised of migratory species, therefore where information is available on European bat migration it has been summarised for the species found in the UK.

2.1.1 Potential impacts of wind turbines on bats

It is still unclear why bats are killed by wind turbines, although a number of hypotheses have been proposed by researchers (Table 2-1). The likelihood of bats colliding with a wind turbine by chance is considered to be low because bat densities would generally be low (Ahlén 2003). Therefore, it was proposed that bats must concentrate in particular areas, for example to forage or migrate, and where these areas are in close proximity to wind turbines, bats may subsequently be attracted to wind turbines (Ahlén 2003). On the other hand, bats may be unaware of the presence of turbines and may be drawn into its vortex while flying past rather than being visually attracted to turbines. These ‘passive risks’ are considered unlikely given the high number of fatalities recorded in some areas. Whatever the reason bats are attracted to wind turbines, the fact that their behaviour may change after the turbine has been installed presents a mitigation problem, in that during pre-construction surveys bats may not be present within the swept are of the rotor blades until the turbines are installed (Cryan 2008). Currently, survey effort post-construction is either not carried out at all, or not done at an appropriate level to inform post-construction mitigation actions at many sites.

Table 2-1: Hypotheses for bat injuries and fatalities at wind turbines

Hypothesis	Reasoning behind hypothesis
Random collision	Flying bats, both migratory and resident, may come into contact with wind turbines while foraging or commuting (Horn *et al*. 2008). This is likely to mean that turbines near features that bats would use to forage or commute along would pose a higher risk. Because echolocation calls attenuate quickly in air, it has been suggested that bats may not have enough warning to fly out of the way before they collide with the blades (Horn *et al*. 2008). An experiment to determine whether moving microturbine blades affect acoustic pulses by simulating an echolocating bat approaching an operational microturbine at rotor height was conducted by Long *et al*. (2009). The further away a signal source (synthesised bat echolocation call) was from the turbine the more the signal was scattered / dissipated. The implication of this research is that a bat would need to be very close to a turbine in order to detect an echo that only contains an estimated 3-10% of the energy of an outgoing echolocation pulse. The dissipation is likely to be greater near the blade tip edges, and even when stationary the bat may only detect the blades within less than half a metre (Long *et al*. 2009). However, at the Bats and Wind Energy Workshop held in Austin, Texas in April 2009, Arnett reported that no fatalities were found during curtailment experiments (when turbines that were randomly 'turned off'). Long *et al.'s* (2009) experiment was conducted on a microturbine, and therefore it is difficult to extrapolate findings to industrial wind turbines. The flight behaviour of bats after detection of the blades may put them at greater risk of collision than birds (Millikin 2009). Observations were made by Millikin (2009), using radar and acoustic monitoring, showed that bats were not 'flying blind' and were using echolocation calls around turbine blades. However their response to the presence of the blades happened close to the blades, giving them little time to react, and they tried to avoid the blades by attempting to fly 'up and over' (i.e. climbing to blade height and vary their direction). This large change in the bat flight behaviour to try and avoid the turbine blades with little prior warning may result in bats colliding with the blades rather than

Hypothesis	Reasoning behind hypothesis
	avoiding them (Millikin 2009).
Acoustic attraction	Sound produced by operating turbine blades or turbulence created by moving turbine blades may attract or disorientate bats making them more likely to collide with turbines (Ahlén 2003; Kunz *et al*. 2007a; Horn *et al*. 2008). Wind turbines are '*known to produce complex electromagnetic fields in the vicinity of nacelles*' (Kunz *et al*. 2007a) and acoustic studies of turbine blades have showed that low frequency amplitude modulated (AM)-sounds were emitted and could be heard in favourable conditions more than 2km from the turbine (Ahlén 2003). One study tested the behavioural response of bats to turbine noise emitted by powerful speakers in foraging areas close to open habitat and along migratory flyways (Ahlén 2003). The observations did not support the hypothesis of acoustic attraction. Another study also tested whether ultrasonic emissions from turbines could be attracting bats, this was done by randomly selecting ultrasonic resonance anemometers on turbines and turning them off but this seemed to have no effect as fatalities continued to occur at turbines with both operating and non-operating ultrasonic anemometers (Arnett *et al*. 2004). A preliminary investigation to measure the ultrasound emissions of operating turbines as a potential contributing factor for attracting bats towards wind turbines was carried out by Szewczak and Arnett (2006). Full spectrum ultrasound emissions were measured using a Petterson D240x ultrasound detector from seven different turbine models, with a particular focus on 1.5MW NEG Micon turbines that were installed on a site where high bat fatalities had been recorded. Recordings could only be made at ground level (34m directly below the Micon turbine rotors); however the authors considered that in order to attract bats ultrasound emissions would need to have sufficient amplitude to be audible to bats at a distance greater than the length of the rotors. Although a limited number of turbine models were sampled, the study recorded only minor levels of ultrasound above ambient levels (approximately 5, 3 and 2dB above ambient at 20, 30 and 40kHz above; 50kHz there was no significant difference from the ambient sound levels). The

Hypothesis	Reasoning behind hypothesis
	ultrasound emissions recorded were considered to be highly unlikely to attract bats from a distance, given that ultrasound attenuates rapidly in air.
Tree attraction	Bats may investigate turbines believing them to be trees with potential for roosting (Horn *et al*. 2008). Migratory bats may be attracted to these structures as potential temporary roosts (Cryan & Diehl 2008; cited in Horn *et al*. 2008) or they may fly towards the nearest 'tree' when the sun begins to rise, as is known for some migratory species (Cryan & Brown 2007). This hypothesis fits in with results showing that migratory tree-roosting bats killed during the autumn migration period present the highest proportion of fatalities overall (Cryan & Brown 2007). Baerwald (*pers. comm.*) suggests that if this is the case, lone turbines could pose a significant impact too, as they stand out in the landscape. An exponential increase in bat fatalities as wind turbine towers increase in height has been was reported by Barclay *et al*. (2007). If bats are attracted to turbines believing them to be trees, there may be an exponential increase in future bat fatalities as the number of taller turbines installed increases. However, Ahlén (2003) suggests the tree attraction hypothesis is less important for onshore wind farms due to the large number of potential roost trees available for bats to choose from, but may be more relevant for offshore wind farms.
Prey concentration	Some studies have reported bats foraging around turbines (e.g. Ahlén 2003; Horn *et al*. 2008). Some flying insects are believed to be attracted to the heat of the nacelle, and insects also swarm above prominent landscape features in behaviours such as 'treetopping' (Thornhill & Alcock 1983); bats may subsequently be attracted to the turbines for foraging. Observations were made using a thermal imaging camera that found turbine blades and generator were warmer than the surrounding environment (Ahlén 2003). Forested edges, created through the clearance of vegetation to create access roads needed to operate wind energy facilities, may create suitable edge habitat that attract large numbers of insects in this sheltered habitat (Hein & Todd 2009). Consequently if bats

Hypothesis	Reasoning behind hypothesis
	are attracted to these foraging areas, they may be at increased risk of collision (Kunz *et al*. 2007a; Horn *et al*. 2008). If prey abundance can be predicted by seasonal weather patterns, it is highly likely that bat activity levels can be too, which may have implications for mitigation (Horn *et al*. 2008). If wind energy facilities increase near or within woodland habitat it becomes more critical to determine if insects are attracted to these areas when they are cleared (Hein & Todd 2009).
Mate attraction / concentration	Some researchers believe that the pattern of bat fatalities (i.e. tree roosting, migratory species largely killed in late summer and autumn) give some clue as to why bats are attracted to wind turbines (e.g. Cryan 2008). One hypothesis put forward is that bats may be attracted to the 'tallest tree' for mating and turbines could provide a visual stimulus that attracts bats towards them for lekking or resource defence polygyny (Cryan 2008). Leks are formed when female groups are unstable (i.e. with highly dispersed migratory species) and densities increase, resulting in male territories becoming less dispersed (Altringham 1996). Consistent fatality patterns among tree-roosting bats across North America and Europe, may indicate that they share common behaviours during late-summer and autumn (Cryan 2008). During this time sex differences in fatalities were not as prevalent when mating activity was observed, yet during spring and early autumn males and females tend to differ in geographic distribution (Strelkov 1969; Baker 1978 and Cryan 2003; all cited in Cryan 2009). The species of tree bats most frequently killed in Europe (Leisler's, noctule, Nathusius' pipistrelle, common pipistrelle, soprano pipistrelle and the parti-coloured bat *Vespertilio murinus*) are species where the males establish and defend mating territories (Sachteleben & von Helversen; cited in Cryan 2008). Songflight and social calling by males during peak mating activity have been recorded and could be used to advertise as well as defend a territory (Pfalzer & Kusch 2003). While this could increase the risk from wind turbines to bats most songflight displays and territorial defence by European tree bats were generally observed within a few metres from the ground (Cryan 2008). However, behaviour around wind turbines may be different

Hypothesis	Reasoning behind hypothesis
	and there may also be a limitation to the observations made, or bats may still be hit by wind turbine blades while flying around the wind turbine between songflight displays. This hypothesis needs to be tested. If evidence is found that bats are attracted to wind turbines to mate, urgent work is required to determine how to prevent this attraction. The implications could be quite serious because bats could not only be attracted from large distances, but the bats being killed would be in prime breeding condition and could be killed in large numbers (Cryan 2008). Over time the cumulative effects could potentially have significant impacts on populations (Cryan 2008).
Strobe lighting	Preliminary evidence suggests bats are not attracted to strobe lights on turbines (Arnett 2005; Arnett *et al*. 2008). Arnett *et al*. (2008) found that none of the studies they reviewed showed a significant statistical difference between fatalities at lit and unlit turbines. However, the lights studied were flashing strobe lights and further investigations on different lighting types used at other wind energy facilities would be useful.
Bats do not echolocate during migration	There has been some speculation that bats do not echolocate or at least echolocate less frequently whilst migrating and therefore do not detect wind turbines (e.g. Ahlén 2003 and Erickson *et al*. 2000). However, this hypothesis may be due to migrating bats flying too high for Anabat bat detectors to record (and hence be detected), although the bats may still fly within the zone of collision risk (Erickson *et al*. 2000). Bats flying too high to be detected from ground level surveys seems much more likely given that bats have been recorded echolocating at high altitude (feeding buzzes recorded for at least seven species at 600m in Africa – Fenton & Griffin 1997; foraging up to 300-800m for Brazilian free-tailed bats in the U.S.A. – D.R. Griffin & G.F. McCracken; cited in Fenton & Griffin 1997) and post-construction acoustic monitoring studies have reported detecting bat echolocation calls. Bats have been observed flying close to stationary wind turbine blades when there was no wind and apparently the bats did not echolocate (Ahlén 2003 – although perhaps faint calls were not detected from distant bats). Ahlén (2003) also noted a slower rhythm of echolocation calls in migratory species. Given that bats are known to echolocate at altitudes of 100-300m above ground level (Griffin &

Hypothesis	Reasoning behind hypothesis
	Thompson 1982), and it seems unlikely that they would cease to echolocate during migration.
Vortices	Although avoiding direct collision with turbine blades, bats may become trapped in vortices created by the moving turbine blades and experience rapid decompression (barotrauma) (Baerwald *et al*. 2008). This is a particular issue for bats, as birds have a different respiratory system.

In addition to the direct impact on bats killed by wind turbines, indirect effects of wind turbines have also been noted that include displacement or exclusion from foraging areas and the barrier effect – "*the loss or shifting of flight paths*" that could interfere with migration or commuting routes or access to roosts (Bach & Rahmel 2004, Harbusch & Bach 2005; Hotker *et al*. 2006). It has been suggested that ultrasound (high frequency sound inaudible to humans) emissions from turbines may disturb bats as some turbines can emit ultrasound up to 32kHz (Schröder 1997; cited in Bach & Rahmel 2004). Bach and Rahmel (2004) reviewed data from a five year post-construction study undertaken by Bach (2002), which found serotine foraging activity decreased around turbines compared to a test zone, whereas foraging activity of common pipistrelle bats increased. However, although serotines changed their foraging behaviour they did not alter their flight path through the wind energy facility (Bach 2002; cited in Bach & Rahmel 2004). This research illustrates the importance of assessing species-specific collision risks by taking into account foraging and flight behaviour.

Evidence of a barrier effect has been found in 81 bird species, particularly geese, common cranes (*Grus grus*), waders and small passerines, but has not been documented for bats.

Although it is not yet fully understood why bats collide with wind turbines, the large numbers of fatalities reported in North America and mainland Europe are of particular concern. Bats are long-lived mammals with low reproductive rates; this means that populations can take taking a long time to recover from losses. Bats are very sensitive to disturbance, for example at their roosting sites, and further anthropogenic pressures (such as from collision with wind turbines) could result in negative impacts on the conservation status of species. Therefore, it is important to understand what potential effects wind farm developments could have on bat populations (in a local, county, or national context) in order that further future development can be managed accordingly.

2.1.2 Species killed by wind turbines

North America

Eleven of the 45 species of bat found in Canada and the U.S.A. have been killed by wind turbines (Kunz *et al*. 2007a; Arnett *et al*. 2008), either directly from collision with turbine towers or blades, or from barotrauma (e.g. Brown & Hamilton 2006; Arnett *et al*. 2008; Baerwald *et al*. 2008). Of the 2,846 fatalities found in the papers reviewed by Kunz *et al*. (2007a), nearly 75% were foliage-roosting eastern red bats (*Lasiurus borealis*), hoary bats (*L. cinereus*), and tree cavity-dwelling silver-haired bats (*Lasionycteris noctivagans*); all of which are long distance migratory species. The other bat species that have been reported as fatalities at wind farms include western red (*Lasiurus blossivilli*), Seminole bat (*Lasiurus seminolus*), eastern pipistrelle (*Perimyotis* [=*Pipistrellus*] *subflavus*), little brown myotis (*Myotis lucifugus*), northern long-eared myotis (*M. septentrionalis*), long-eared myotis (*M. evotis*), big brown bat (*Eptesicus fuscus*), and Brazilian free-tailed bat (*Tadarida brasiliensis*). In a study by Johnson *et al*. (2003), 83.2% of bat fatalities recorded were migratory tree-roosting bats. Erickson *et al*. (2002) also noted the majority of fatalities were migratory bat species that were tree- and/or foliage-roosting bats (such as hoary and silver-haired bats in the western U.S.A., and hoary and eastern red bats in the Midwest and eastern U.S.A.).

Studies in North America have recorded very few bat fatalities in the breeding season even though relatively large populations of some bat species were recorded close to wind turbines (e.g. Erickson *et al*. 2002; Johnson *et al*. 2003). Erickson *et al*. (2002) suggest that wind energy facilities do not currently have a significant impact on resident breeding bat populations in the U.S.A. and that the evidence indicates the impact is mainly on migrant and/or dispersing bats in the late summer and autumn.

Europe

Bat fatalities were first discovered in Germany in 1999 (Bach & Ramel 2004). To date in Europe 20 species are known to have suffered fatalities (Table 2-2) including both sedentary and migratory species. Additionally, lesser mouse-eared (*Myotis blythii*) and whiskered bats were considered to be at risk of collision by the EUROBATS' Intersessional Working Group (IWG) (Rodrigues *et al*. 2008). Fatalities of six species, all of which were aerial hunters that forage in open habitat rather than gleaners that forage close to the ground or vegetation, were reported by Ahlén (2003). The only confirmed species with recorded fatalities in Britain is soprano pipistrelle.

Table 2-2: Summary of bat fatalities in Europe. Species are listed in order of most to least fatalities recorded (species resident in Britain are highlighted). (Sourced from Dürr & Dubourg-Savage 2009 (as of 30 April 2009) in the EUROBATS 14th Meeting of the Advisory Committee Report) – Rodrigues *et al*. 2009.

Common name	Species name	*No. fatalities recorded
Noctule	*Nyctalus noctula*	366
Common pipistrelle	*Pipistrellus pipistrellus*	362
Nathusius' pipistrelle	*Pipistrellus nathusii*	334
Chiroptera species	-	83
Pipistrelle species	*Pipistrellus* spp.	81
Leisler's bat	*Nyctalus leisleri*	78
Parti-coloured bat	*Vespertilio murinus*	47
Serotine	*Eptesicus serotinus*	40
Soprano pipistrelle	*Pipistrellus pygmaeus*	35
Kuhl's pipistrelle	*Pipistrellus kuhlii*	23
Savi's pipistrelle	*Hypsugo savii*	16
Northern bat	*Eptesicus nilssonii*	10
Grey long-eared	*Plecotus austriacus*	7
Daubenton's bat	*Myotis daubentonii*	5
Brown long-eared	*Plecotus auritus*	3
Greater mouse-eared bat	*Myotis myotis*	3
Eastern bentwing	*Miniopterus schreibersii*	3
European free-tail	*Tadarida teniotis*	2
Brandt's bat	*Myotis brandtii*	1
Pond bat	*Myotis dasycneme*	1
Whiskered	*Myotis mystacinus*	1
Greater noctule	*Nyctalus lasiopterus*	1
Total		**1502**

2.1.3 Migration data relevant to British species

There is currently very limited information available on bat migration in the UK. Altringham (2003) states that: "*In Europe, migration is invariably to hibernation sites and is typically south-west in autumn and north-east in spring, although short 'migration' flights can go in all directions.*" Altringham (2003) also noted that migration distances can exceed 2,000km; for both large species such as noctules (*Nyctalus noctula*) and small species such as Nathusius' pipistrelle.

Below we summarise European migration studies that relate to bat species occurring in the UK (although the greater mouse-eared bat has been included due to the low numbers currently found in the UK they are not considered to be at risk from wind turbines) (Table 2-3). Whilst there will invariably be some differences in migratory behaviour of UK species compared to other European countries and findings from mainland Europe cannot be extrapolated directly to the UK, this section aims to provide background information on migratory species to better understand which species may be more likely to be affected by wind farm developments in Britain.

Each species, apart from soprano pipistrelle (for which the migratory status is currently unknown), has been assigned a general description to reflect their migratory behaviours, as described by Hutterer *et al*. (2005):

Long distance migrant
Regularly flies 3,000-4,000km one-way from summer breeding area to winter habitat and back.

Regional migrant
Seasonal migration a few hundred km but also disperse or facultatively migrate over distances up to 800km.

Sedentary species
Travel short ranges between roosts (tens of km) barely disperse or migrate <100km.

Table 2-3: Summary of bat movements for European species found in the UK

Species	Results of bat banding data in Europe
Leisler's bat	**Long distance migrant** Regular seasonal migrant between summer and winter roosts but has been recorded as vagrant or sedentary in NW and SE Europe (Bogdanowicz & Ruprecht 2004; cited in Hutterer *et al*. 2005). From the low recovery data recorded most bats migrated in NE to SW direction. The longest migration was 1,567km (Ohlendorf *et al*. 2000; cited in Hutterer *et al*. 2005).
Noctule	**Long distance migrant** Principally migratory but some populations are sedentary staying close to summer roosts. Noctule bats are also believed to be less migratory in Western Europe but some long-distance migration has been recorded up to 900km SW from Holland to Bordeaux (Sluiter & Heerdt 1966; cited in Harris & Yalden 2008). Noctule bats migrate SW-SE to hibernate, most distances <1,000km (Roer 1995; Gebhard & Bogdanowicz 2004; both cited in Hutterer *et al*. 2005). Northernmost populations in UK are

Species	Results of bat banding data in Europe
	considered to be sedentary (Racey 1991; cited in Hutterer *et al*. 2005) but there have been records of noctule bats on Orkney Island and from drilling platforms in North Sea (Racey 1990; cited in Hutterer *et al*. 2005) indicating movement within and/or into the UK. Studies have shown that nuclear DNA from males was genetically homogenous throughout Europe, but mtDNA from females formed four distinct populations in Europe (Mayer *et al*. 2002; Petit & Mayer 1999, 2000; Petit *et al*. 2001; all cited in Hutterer *et al*. 2005). Adult males disperse randomly to occupy male territories (Petit & Mayer 1999; cited in Harris & Yalden 2008). These data imply that males are migratory whereas females are more sedentary, which could put males at higher risk of collisions with wind turbines in areas where these migratory routes are near wind energy facilities.
Nathusius' pipistrelle	**Long distance migrant** Typically long and regular autumn movements from NE to SW, but some migrations have also been recorded in an E-W direction (Schmidt 2004; cited in Hutterer *et al*. 2005). Longest movement is 1,905km (Petersons 1990; cited in Hutterer *et al*. 2005). However, further recovery data from southern and central France suggests that Nathusius' pipistrelle may migrate even further south than currently recorded. Although limited data on migration in the UK exists, Russ *et al*. (2001) suggest this species migrates from Scandinavia to the UK in the autumn (with numbers peaking in September) and returns in the spring. Apart from roost records, most of the records presented by Russ *et al*. (2001) were incidental records from oilrigs, with the highest number of records reported in September but also with high numbers in May and October. The species breeds in Ireland and populations may be more sedentary there. At present only two (www.nathusius.org.uk) to four (Harris & Yalden 2008) nursery colonies are known in Britain, and the species probably mainly occurs as a migrant (www.nathusius.org.uk).
Barbastelle	**Regional migrant** Generally sedentary but may occasionally migrate or disperse. In Central Europe summer and winter roosts up to 20km apart (Dolch *et al*. 1997; cited in Hutterer *et al*. 2005). Banding data reflects that this species has a small home range. Longest distances recorded were both in Germany 127km by Felten & Klemmer (1960) and 145km by Hoehl (1960) (both cited in Hutterer *et al*. 2005).

Species	Results of bat banding data in Europe
Serotine	**Regional migrant** Sedentary but occasionally performs dispersal flights. Distances between roosts have been recorded as being shorter than 50km (Baagøe 2001b; cited in Hutterer *et al*. 2005). Banding data have shown distances are generally below 100km but can reach 330km (Havekost 1960; cited in Hutterer *et al*. 2005), with other examples between 144 to 201km (Schmidt & Mainer 1999; Steffens *et al*. 2005; Topál 1956; all cited in Hutterer *et al*. 2005).
Brandt's bat	**Regional migrant** Occasional migrant (Tupinier 2001; cited in Hutterer *et al*. 2005) but migration behaviour is currently poorly understood. Records have shown short movements up to 40km, with only a few movements that are longer distance of 74km and 230km in Bavaria (Kraus & Gauckler 1972; Kraus 2004; both cited in Hutterer *et al*. 2005) and between 10 and 308km in Germany (Heise 1999a; Ohlendorf 1990; Zöphel & Wilhelm 1999; Steffens *et al*. 2005; all cited in Hutterer *et al*. 2005).
Daubenton's bat	**Regional migrant** Middle range (or facultative) migrant (Roer & Schober 2001b; cited in Hutterer *et al*. 2005). Seasonal movements between summer and winter roosts range within 100km to 150km, with longest distances being 257km (Tress *et al*. 2004; cited in Hutterer *et al*. 2005) and 304km (Steffens *et al*. 2005; cited in Hutterer *et al*. 2005). However, distances of 27km movement was recorded from a swarming site (Parsons & Jones 2003) and 19km have been recorded in the UK (Speakman 1991; cited in Hutterer *et al*. 2005). Distances and direction of seasonal movements seems to depend on resource availability.
Whiskered bat	**Regional migrant** Considered sedentary with occasional migration (Tupinier & Aellen 2001; cited in Hutterer *et al*. 2005) but migration is poorly understood. Due to difficulty in segregation of whiskered and Brandt's data may be unreliable. Very few long distance migration records. Distances mostly recorded between 10km and 70km and one record being 112km, but a maximum distance of 625km has been reported (Heymer 1964; cited in Hutterer *et al*. 2005). This individual was later confirmed to be a whiskered bat.
Common pipistrelle	**Regional migrant** Most populations in Central Europe are considered sedentary, although occasional migration over larger distances has been reported (Taake & Vierhaus 2004; cited in Hutterer *et al*. 2005). Distances around 10km and

Species	Results of bat banding data in Europe
	20 km have been reported between summer and winter roosts. The longest migration is 1,123km. Most of the banding data were obtained prior to taxonomic distinction between common pipistrelle and soprano pipistrelle and Nathusius' pipistrelle has also been mistaken as common pipistrelle. Homing experiments performed by Roer (1989b) documented returning journeys of common pipistrelle up to 295km (cited in Hutterer *et al*. 2005). Genetic analyses suggest gene flow between Britain and continental Europe, with no evidence that the North Sea serves as a barrier to gene flow (Racey *et al.* 2007).
Greater mouse-eared bat	**Regional migrant** The movement behaviour of this species has been one of the best studied bat species in Europe, with more than 100,000 individuals banded in Europe (Hutterer *et al*. 2005). Regular movements between summer and winter roosts have been recorded but distance depends on availability and distance to suitable hibernating sites (Gaisler & Hanák 1969b, c, d; cited by Hutterer *et al*. 2005). Not all individuals migrate, some remain close to winter roosts (Hutterer *et al*. 2005) and roost fidelity has been found to be very strong in large hibernation sites but weak in smaller roosts (Roer 1971; cited by Hutterer *et al*. 2005). The longest known movement in Europe is 436km (Simon *et al*. 2004; cited by Hutterer *et al*. 2005).
Greater horseshoe bat	**Sedentary species** Occasionally travels more than 100km (Gaisler 2001a; cited in Hutterer *et al*. 2005). Movements between summer and winter roost range between 10-60km (e.g. Aellen 1983; cited in Hutterer *et al*. 2005). However, movement from one hibernaculum to another during the hibernation season would rarely be over 15km.
Lesser horseshoe bat	**Sedentary species** Seasonal movements 5–20km (Roer & Schober 2001a; cited in Hutterer *et al*. 2005) but have been recorded up to 153km (Heymer 1964; cited in Hutterer *et al*. 2005). There have been records of very short movements in southern UK of only 7.7-14km (Hooper & Hooper 1956; cited in Hutterer *et al*. 2005).
Bechstein's bat	**Sedentary species** Regularly change roosts locally (Baagøe 2001b; cited in Hutterer *et al*. 2005), with distances of few km between summer and winter roosts (Kerth 1998; Rudolph *et al*. 2004a; both cited in Hutterer *et al*. 2005). Maximum distance recorded was 73km (Steffens *et al*. 2005; cited in Hutterer *et al*. 2005).

Species	Results of bat banding data in Europe
Natterer's bat	**Sedentary species** Recovery data indicates that this species is at least a facultative migrant. Roost changes and seasonal movement are usually short, between 0.5km-54km (Ohlendorf 2002; Haensel 2005; both cited in Hutterer *et al*. 2005). Long distances of 266km flown by a male and 327km flown by a female have recently been recorded (Steffens *et al*. 2005; cited in Hutterer *et al*. 2005).
Brown long-eared bat	**Sedentary species** Seasonal movements range only a few km (Schober & Grimmberger 1998; cited in Hutterer *et al*. 2005), the longest distance currently recorded is 90km. Approximately 1,000 individuals were banded in the UK and reported only short movements up to 1.5km (Stebbings 1996; Boyd & Stebbings 1989; Swift & Racey 1983; all cited in Hutterer *et al*. 2005). This species has also been recorded on lightships in the North Sea indicating that it may occasionally migrate, with flights of up to 60km being documented (Corbet 1970; cited in Harris & Yalden 2008; Hutterer *et al*. 2005).
Grey long-eared bat	**Sedentary species** Seasonal movements range only a few km (Schober & Grimmberger 1998; cited in Hutterer *et al*. 2005), the longest distance currently recorded is 61km (Gaisler & Hanák 1969; cited in Hutterer *et al*. 2005). Distances between summer and winter roosts are usually <30km (Gaisler *et al*. 2003; cited in Hutterer *et al*. 2005).
Soprano pipistelle	**Not currently known** Seasonal migrations or habitat changes not yet studied but individuals have recently been banded in Germany and Sweden. Genetic analyses suggest gene flow between Britain and continental Europe, with no evidence that the North Sea serves as a barrier to gene flow (Racey *et al.* 2007). Soprano pipistrelles were not known to migrate until Ahlén *et al*. (2007) recorded them as the most common species observed from observations made out at sea and 13 coastal take-off sites.

2.1.4 Behaviour and ecology of British bat species

The behaviour and ecology of British bat species killed at wind farms in Europe is summarised below. Additionally, barbastelle has also been included as it is considered to be medium risk species according to the Natural England Interim Guidance (2009). A summary of the behaviour of British bat species in relation to turbines is also given in Appendix 2. This information is taken from the EUROBATS' Publication Series No. 3 and is based on the knowledge and experience of the Intersessional Working Group (IWG) members and findings in literature reviewed by the IWG members (for information of all European species considered to be at risk refer to the EUROBATS' Publication Series No. 3).

Nyctalus / Eptesicus group (Noctule, Leisler's, and serotine bats)

These big bats generally favour open habitats but are also found in woodland, wetland and pasture habitats (Altringham 2003). Species in this group fly fast (typically 6-9 m/sec (Jones 1993; Holderied 2001; Holderied & Jones 2009).

Noctule bats have two distinct flight patterns; at or just before sunset they fly fast and very high, up to 200m above the ground; while at other times they fly fast, approximately 30m above the ground and dive and occasionally glide (Stebbings *et al*. 2007). Noctules are tree-roosting species and forage over pasture near woodland, over water and near lit areas (Harris & Yalden 2008); for example around street lights.

Leisler's bats also fly high when commuting and lower when foraging (Harris & Yalden 2008). In Europe, Leisler's bat predominantly roosts in trees, but in Ireland and Great Britain it roosts mainly in buildings with occasional roosts (other than maternity roosts) in trees and bat boxes. This species mainly forages over open areas (particularly pasture), parkland and woodland edge or hedgerows (Harris & Yalden 2008).

Serotines are described by Harris and Yalden (2008) as having a "*leisurely flapping flight*" up to 30m. Serotines are mainly found in lowland open flat pasture, parkland and woodland edge or hedgerow and roost mainly in buildings (Harris & Yalden 2008).

Common, soprano, and Nathusius' pipistrelle bats

The flight behaviour of pipistrelle bats is characterised as being medium to high (generally 5-25m above ground level), with rapid, jerky and twisting flight patterns along areas that are clear of vegetation (Stebbings *et al*. 2007). Pipistrelles typically fly between 3-7 m/sec (Jones 1993; Holderied 2001; Holderied & Jones 2009), and fly faster when commuting than while foraging (Jones & Rayner 1989).

Common pipistrelles are associated with a range of different habitats, such as unimproved grassland, improved cattle pasture, coniferous and mixed plantations and water bodies (Harris & Yalden 2008), but have been recorded as having a minor preference for foraging in deciduous woodland (Davidson-Watts & Jones 2006).

Soprano pipistrelles have a strong preference for foraging habitat associated with waterbodies and riparian woodland (Harris & Yalden 2008). Davidson-Watts and Jones (2006) found that while common pipistrelles spent a longer time flying and utilised more foraging areas, soprano pipistrelles spent less time flying but flew greater distances which may be because this species is selecting specific foraging habitats.

Nathusius' pipistrelle has also been reported in Northern Ireland to forage around water and is associated with riparian, broadleaved and mixed woodland and parkland habitats, and to a lesser extent in farmland (Harris & Yalden 2008).

Common and soprano pipistrelles roost preferentially in churches and chapels with maternity roosts found in old and new residential properties, amenity buildings and churches but are rarely found roosting in trees or caves (Harris & Yalden 2008). There are at most only four known maternity roosts for Nathusius' pipistrelle in the British Isles, which are all in buildings; whereas males have been recorded roosting singularly in trees as well as in buildings (Harris & Yalden 2008). However, in mainland Europe summer roosts are usually located in trees and rarely in buildings (Harris & Yalden 2008).

Barbastelle

Barbastelles are associated largely with wooded riverine habitats that have connecting features but have also been found crossing extensive open habitats to search for suitable foraging sites (Harris & Yalden 2008). However, this species has a strong preference towards ancient woodland (Greenaway 2001; Matt Zeale, *pers*. *comm*.). Barbastelles are limited to the southern part of England and Wales and within their range roost preferentially in trees where there is suitable woodland habitat available (Harris & Yalden 2008).

Myotis species (Daubenton's, Brandt's, and greater mouse-eared bats)

Although there are five species of *Myotis* bat resident in the UK, only the three listed above have been recorded as fatalities at wind energy facilities in Europe, all at relatively low levels (Daubenton's bat accounted for only five fatalities and Brandt's bat only one). All *Myotis* species fly at either slow or medium speeds (typically about 3.9 m/sec (range 2-6 m/sec) for Daubenton's bat – Jones & Rayner 1988) and are generally low-flying species ranging between 2–20m from ground level. Therefore, they are unlikely to fly at the same height as the rotating blades of a wind turbine. All *Myotis* species are either associated with woodland or riparian habitats and are not thought to frequently fly over open habitat. In the summer Daubenton's bats roost in trees, bat boxes, bridges and buildings close to water (Bat Conservation Trust 2008; Harris & Yalden 2008), Brandt's bat roosts mainly in buildings and occasionally in bridges and bat boxes in the summer (Harris & Yalden 2008). The greater mouse-eared bat was declared extinct in the UK in 1990. Since then, a single record of a juvenile male was recorded in 2002 and in subsequent years, and a female recorded in 2003 subsequently died. Both records were from the south coast of England. The species' current status is unconfirmed (Bat Conservation Trust 2006).

Long-eared bats

Both grey- and brown-long eared bats habitually fly close to vegetation and often hawk or glean insects from the surfaces of leaves. They are highly manoeuvrable and tend to avoid open habitats such as grassland and pasture, instead favouring woodland and parkland where there is a complex vegetation structure and a variety of foraging and navigational routes (Altringham 2003).

Brown-long eared bats are strongly associated with tree cover and prefer light deciduous woodland. They also forage in mixed woodland edge and native conifer (Harris & Yalden 2008), as well as parkland and orchards (Bat Conservation Trust 2008). Brown long-eared bats have been reported as flying around 6m/sec (Howard 1995; cited in Harris & Yalden 2008). Brown-long eared bats roost in older buildings, barns, churches and sometimes in trees (Bat Conservation Trust 2008; Harris & Yalden 2008).

Grey long-eared bats have not yet been studied in detail in the UK but from studies in Europe they are considered to have a slow, hovering flight in cluttered environments such as among tree branches and faster flight in more open situations (Harris & Yalden 2008). Grey-long eared bats are extremely rare and are confined to areas along the south coast and are known to roost in houses and churches (Harris & Yalden 2008).

2.1.5 British species most at risk from collision with wind turbines

To date, there is insufficient information on the migratory behaviour and flight behaviour of bats at height and around turbines to make a full assessment of which British species may be most at risk from wind turbines.

Betts (2006) made an initial estimate of collision risk, not considering migratory behaviour, based on information available from Europe and an assessment of the foraging strategies of British species (aerial hawkers were considered to be most at risk.) Six species were estimated to be at high risk of collision: noctule, Leisler's bat, serotine, common pipistrelle, soprano pipistrelle and Nathusius' pipistrelle.

In its interim guidance on the potential impacts of onshore wind turbines on bats, Natural England considered a number of factors including flight patterns and foraging strategies in relation to how they might contribute to risk of collision, and each species was placed in a low, medium or high risk category. Each bat species has been assessed to determine their risk of collision with operational wind turbines (Table 2-4).

The level of risk for each species is classified as high, medium or low based on what is known of the species' habitat preference, echolocation characteristics, weight, wing-shape, flight speed and height, hunting techniques, flight behaviour and use of landscape. In addition, the guidance assesses the likely level of risk (high, medium or low) posed to the UK populations of species from mortality caused by collision with wind turbines (Table 2-5). This assessment is based on current UK population estimates for each species (published by the Joint Nature Conservation Committee (JNCC/Tracking Mammals Partnership (Battersby 2005)) in combination with the collision risk assessment for each species. Full details of how the risk was assessed in relation to bat species are given in Appendix 1 and 2 of Natural England's Interim Guidance (2009).

Table 2-4: Assessment of the likely level of risk to bat species from collisions with wind turbines (reproduced from Natural England Interim Guidance (2009)).

Low risk	Medium risk	High risk
Myotis species	Common pipistrelle (*Pipistrellus pipistrellus*)	Noctule
Long-eared bats	Serotine	Leisler's bat
Horseshoe bats	Soprano pipistrelle	Nathusius' pipistrelle
	Barbastelle	

Table 2-5: Assessment of the likely level of risk to the UK populations of bat species from collisions with wind turbines (reproduced from Natural England Interim Guidance (2009)).

Low risk	Medium risk	High risk
Long-eared bats	Serotine	Nathusius' pipistrelle
Myotis species	Barbastelle	Leisler's bat
Horseshoe bats		Noctule
Soprano pipistrelle		
Common pipistrelle		

2.1.6 Population estimates of British bat species

All the information from this section is taken from Harris *et al*. 1995 (A review of British mammals), which attempted to estimate population size and trends for all British mammals other than cetaceans. For most species these assessments are based on subjective rather than objective criteria due to limit of long-term population datasets. The authors note that providing populations for bats proved difficult because there were few density estimates and little quantified data on bat numbers in relation to habitat associations and patterns of land use. Therefore, the majority of the estimates provided were based on subjective estimates of relative abundance.

The uncertainty of bat population estimates make it impossible to determine potential ecological impacts, but do provide enough information to be able to monitor fluctuations in populations over time. For each bat species, the conservation status, distribution and estimated population (pre-breeding) are presented (Table 2-6). Information for Nathusius' pipistrelle was not included as it was classed as vagrant at the time and soprano and common pipistrelle had not been split and therefore the data for both species were presented for both species combined. Because of the difficulties estimating population sizes each species has been assigned a number which gives an indication of the '**reliability of the population estimate**' **-** these are presented in Table 2-6 derivation of this number system is described as follows:

[1] A widely distributed species for which there had been a recent census or for which there were regular counts that were believed to have a high degree of accuracy, or a rare species for which most of the populations were thought to be known and regularly monitored. For these species it was believed that any improvements in census techniques were unlikely to alter the population estimate by more than 10% either way.

[2] A widely distributed species for which the population estimate was based on good data on population densities in different habitat types, or a rare or local species for which the estimate was based on a good understanding of the factors that were limiting its distribution or numbers, and good information on population densities in a reasonable range of habitat types. For these species, there was scope for improving the population estimate, but any improvements were unlikely to be substantial, and any resulting change in the population estimate would probably be less than 25%.

[3] A widely distributed species for which the population estimate was based on a limited amount of data on population densities in different habitat types, or for which the population estimate was obtained by scaling abundance relative to a species for which there was a reasonable population estimate. For rare species, the estimate was based on only a limited knowledge of the factors limiting its distribution or numbers, or only a few density estimates from a limited range of habitats. Any improvement in the population estimate could result in a change of up to 50%, but on current knowledge it was considered unlikely that the estimate would be wrong by a greater margin.

[4] An estimate based on a very limited amount of information on the species, for which there was a need for much more information on either its distribution in Britain, or population densities in a variety of habitat types, or relative abundance. Any improvement in knowledge would greatly improve the basis on which the estimate was achieved, but may not necessarily have made a substantial difference to the estimate presented here, since all species have been ranked in order of relative abundance and its position in the rankings was through to be correct.

[5] A species for which there was so little information on its distribution and/or abundance in different habitat types, and for which the data were so inadequate or biased, that it was not possible to scale its abundance relative to other species reliably. For these species the estimate was believed on subjective criteria to be within the right order of magnitude, but no greater degree of accuracy was through to have been achieved.

Table 2-6: Estimated pre-breeding population size, conservation status and known distribution of British bat species (excluding Nathusius' pipistrelle and data for common and soprano pipistrelles are combined).

Status	Distribution	Population Estimates
Greater horseshoe Very rare and endangered	Confined to south-west England and south Wales, south of the line Cardigan-Cheltenham-Southampton, including the Isle of Wight.	A total pre-breeding population of at least 4,000, and possibly nearer 6,600 (3,650 in England, none in Scotland and 350 in Wales).[2]
Lesser horseshoe Rare and endangered	Widely distributed in south-west England and Wales, south and west of a line from Chester to Southampton.	A total pre-breeding population of about 14,000 (7,000 in England, none in Scotland and 7,000 in Wales).[2]
Whiskered bat Locally distributed	Probably found throughout England and Wales. There are a few records from southern Scotland as far north as the Firth of Forth (Ayrshire, Borders, Dumfriesshire and Midlothian); it is probably absent from the highlands. Its status in Scotland is uncertain, although it is probably rare (Haddow *et al*. 1989 and J. Herman, *pers. comm*.; both cited by Harris *et al*. 1995).	A total pre-breeding population of about 40,000 (30,500 in England, 1,500 in Scotland and 8,000 in Wales).[4]

Status	Distribution	Population Estimates
Brandt's bat Common in west and north England, rare or absent elsewhere.	This is unclear because of confusion with whiskered bats, but Brandt's bats are believed to be widespread in England and Wales. The status of the species in Scotland is less clear.	A total pre-breeding population of about 30,000 (22,500 in England, 500 in Scotland and 7,000 in Wales).[5]
Natterer's bat Fairly common throughout much of Britain.	Found throughout England and Wales; recent records have extended the known range of Natterer's bats in Scotland to all areas except the extreme north-west (Haddow 1992; cited by Harris *et al*. 1995).	A total pre-breeding population of about 100,000 (70,000 in England, 17,500 in Scotland and 12,500 in Wales).[4]
Bechstein's bat Very rare in central southern England.	Most records are from the south-west England and the Isle of Wight; there are some records from the south-west midlands (R.E. Stebbings *pers. comm*.; cited by Harris *et al*. 1995), and one was found in Brecon in Wales in 1993 (J. Messenger, *pers. comm*.; cited by Harris *et al*. 1995).	A total pre-breeding population of about 1,500 (all in England).[4]
Greater mouse-eared bat Colonies reported this century were probably never well established and are now extinct.	All recent records are confined to south coast countries in England.	Extinct.[1]
Daubenton's bat Common throughout much of Britain.	Widespread north at least to Inverness, and probably occurs throughout all of mainland Scotland.	A total pre-breeding population of about 150,000 (95,000 in England, 40,000 in Scotland and 15,000 in Wales).[4]

Status	Distribution	Population Estimates
Serotine Widespread in southern Britain.	Well established south-east of a line from Bristol to Great Yarmouth (including the Isle of Wight), with a few records from the south-west England, central and south Wales.	A total pre-breeding population of about 15,000 (14,750 in England, none in Scotland and 250 in Wales). However, this species was believed to have been under recorded in Wales and the estimate for Wales in particular was thought to be too low.[4]
Noctule Generally uncommon, but more numerous in well-wooded areas.	Widespread over most of England and Wales.	A total pre-breeding population of about 50,000 (45,000 in England, 250in Scotland and 4,750 in Wales.[3]
Leisler's bat Widespread but scarce in Britain.	There are few records from Britain, and these are mostly from eastern and central England and the Welsh borders.	A total pre-breeding population of about 10,000 (9,750 in England, 250 in Scotland and none were known to occur in Wales at the time.[4]
***Pipistrellus* species** *(Referred to as common pipistrelle but the estimate was made before these species were divided).* Common in most areas.	Found thought the British Isles and on many islands but probably not resident in Orkney or Shetland.	A total pre-breeding population of about 2,000,000 (1,250,000 in England, 550,000 in Scotland and 200,000 in Wales).[3]
Barbastelle Widespread but rare.	Widely distributed throughout England and Wales, south of a line from Mersey to the Tees (Arnold 1993; cited by Harris *et al*. 1995).	A total pre-breeding population of about 5,000 (4,500 in England, none in Scotland and 500 in Wales).[5]
Brown long-eared Common.	Occurs everywhere except in open uplands and perhaps in exposed regions of north-west Scotland and off-shore islands.	A total pre-breeding population of about 200,000 (155,000 in England, 27,500 in Scotland and 17,500 in Wales).[4]

Status	Distribution	Population Estimates
Grey long-eared Very rare, and only a few small colonies are known.	Found only in Devon, Dorset, Hampshire (including the Isle of Wight) and Somerset.	A total pre-breeding population of about 1,000 (all in England).

2.2 Acoustic surveys

All UK bats use echolocation for orientation and prey detection. Most echolocation calls are of high frequency (>20kHz) and are therefore out of the range of the human ear. However, bat detector devices can be used to convert echolocation calls into sound within the human audible range or into digital data which can then be recorded and stored for later analysis. Acoustic surveys can be carried out to monitor bat activity either along a transect route or by setting up automated bat detector systems at specific locations to allow multiple sites to be monitored simultaneously (e.g. Kunz 1988). By completing acoustic surveys at wind farm sites, it is therefore possible to determine the presence and activity levels of different bat species around turbine locations.

Bat detectors have a limited detection range (Fenton 2000; Fenton *et al.* 2001) and different bat species produce echolocation calls of varying intensity (Holderied & von Helversen 2003). These two factors mean that the detection rates of different species by different bat detectors will vary and bat detector studies are likely to be biased towards bats that produce high intensity (loud) calls. Different bat detector systems also generate highly variable amounts of data that can be analysed at a later date; for example to determine levels of bat activity and species present.

Anabat frequency division bat detectors are recommended as a practical choice for acoustic monitoring at wind farm sites (Kunz *et al.* 2007a). The zero-crossing operating procedure used by Anabat bat detectors means that the amount of data collected per night (in megabytes) is of a quantity that makes it viable to record *in situ* for one or two weeks, although there are some compromises in resolution of call data collected which may restrict the level of species identification possible. Due to the limitations of species identification some researchers (e.g. Kunz *et al.* 2007a) note that additional acoustic surveys may be required to provide full species identification, for example full-spectrum acoustic surveys. However, due to the limited number of species in the UK and because acoustic surveys will be carried out at height it is highly likely that only a small number of the species in the UK will be recorded.

In this section, methods and results of acoustic surveys carried out at wind farm sites in North America and Europe are discussed, and some of the key findings are summarised. Further details on individual studies can be found in Appendix 3.

2.2.1 Pre-construction acoustic surveys at height

Pre-construction surveys to determine bat activity can help to identify the presence of bats and patterns of bat activity at proposed wind farm sites. Survey information can also identify periods and locations of high bat activity to inform impact assessments on bats. Although acoustic surveys cannot determine numbers of bats present, they can provide population indices or indications of relative bat abundance (e.g. Hayes 2000). There are a number of advantages and disadvantages of acoustic monitoring in assessing potential impacts of turbines on bats, and these factors need to be considered in design of acoustic surveys.

Bat activity can vary significantly between nights at any single point, and one night of data collection does not generally provide sufficient information to determine trends in activity at that site (e.g. Gannon *et al.* 2003). The limited detection range of bat detectors (discussed in the introduction of this section), means that a single detector location will only monitor bat activity within a limited area. However, the limited detection range can also have advantages in that bat activity at ground level and at turbine height can be distinguished by monitoring at different heights above ground level (Arnett *et al.* 2006). There may also be seasonal variation in activity and variation between years. In order to account for all of these variables in bat activity and detection, pre-construction acoustic surveys should therefore ideally monitor bat activity at all turbine locations and should include use of bat detectors within the turbine blade swept area (Kunz *et al.* 2007a). In addition, it is important to monitor locations throughout the active bat period to assess variation in bat activity within seasons (defined as April to November in temperate North America), and over at least three years to assess inter-annual variation (Kunz *et al*. 2007a).

North America

There have been a variety of methods trialled for monitoring pre-construction bat activity in North America, all comprising arrays of Anabat bat detectors at ground level and within the turbine blade swept area across the proposed wind farm area (e.g. Reynolds 2006; Arnett *et al.* 2006, 2007; Redell *et al.* 2007). The exact locations of detector stations has varied between studies: for example random weekly cycling of Anabat stations around proposed turbine locations using portable towers (e.g. Arnett *et al.* 2006; Weller 2007; Figure 2-1); and use of meteorological towers at fixed locations within the wind farm site (Arnett *et al.* 2007) have both been trialled. The Alberta Bat Action Team recommend an array of five Anabats, one at each of the north, south, west and eastern extents of the wind farm boundary, with a fifth central Anabat station (Lausen *et al.* 2006). Kunz *et al.* (2007) recommend a much more rigorous approach, however, with a systematic three-dimensional array of detectors at ground, intermediate and turbine blade level at each proposed turbine location. This method would require very large numbers of bat detectors, particularly for large sites. In some cases therefore, detector stations have been placed only on static meteorological (MET) masts at fixed locations, and in other cases portable towers have been used which have been moved at regular intervals to cover all proposed turbine locations during the survey period at least once.

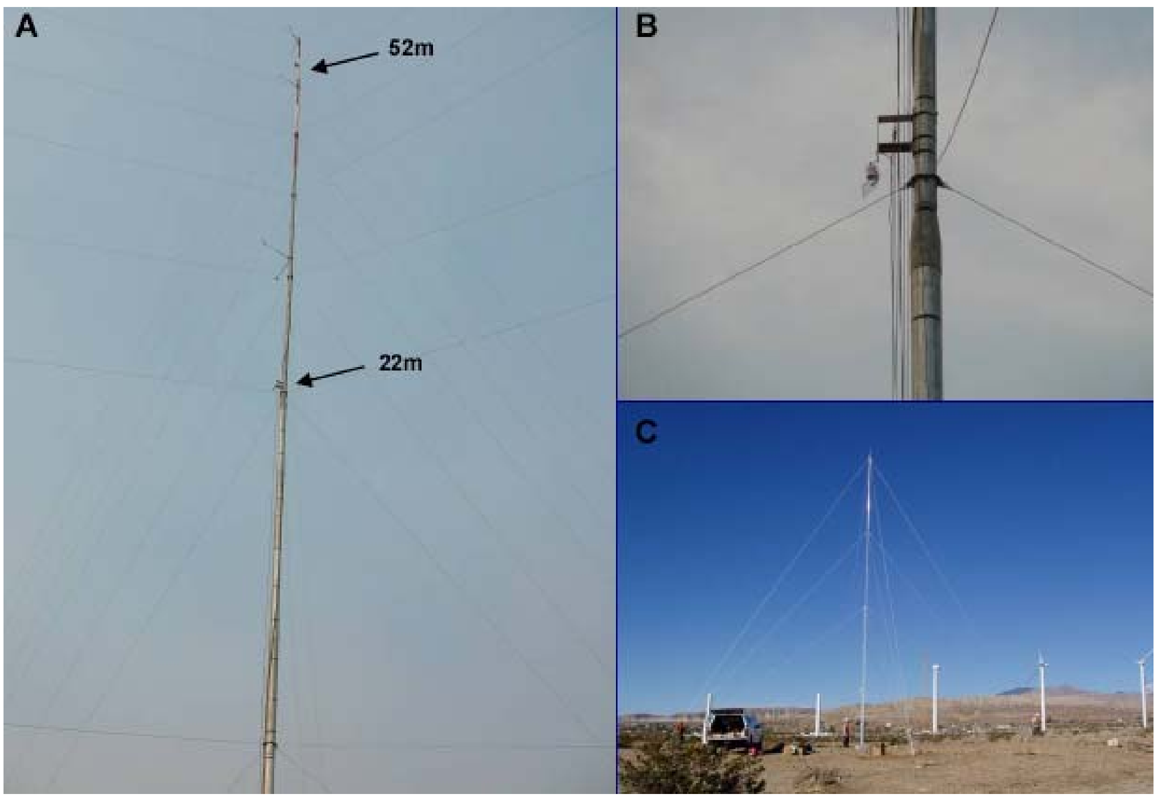


Figure 2-1: Examples of MET and portable towers used for acoustic surveys at height (taken from Weller 2007).

Illustrating:

A) detector microphones mounted on the MET tower at different heights (22m and 52m),

B) close up photo of the pulley system used to position microphones on MET towers, and

C) a portable bat monitoring tower.

One factor that may affect the area within which bats are detected, is the orientation of the Anabat bat detector microphone. There has been variation between studies in how the microphones are orientated with no consensus on the optimum microphone position: for example in one study microphones were oriented into the prevailing wind (Arnett *et al.* 2006); in another they were oriented subjectively in the direction most likely to record maximum bat activity (Arnett *et al.* 2007). In both these studies, the microphones from Anabat bat detectors are installed at height using a long cable, a 'bat hat' cover and a pulley system (Figure 2-2).

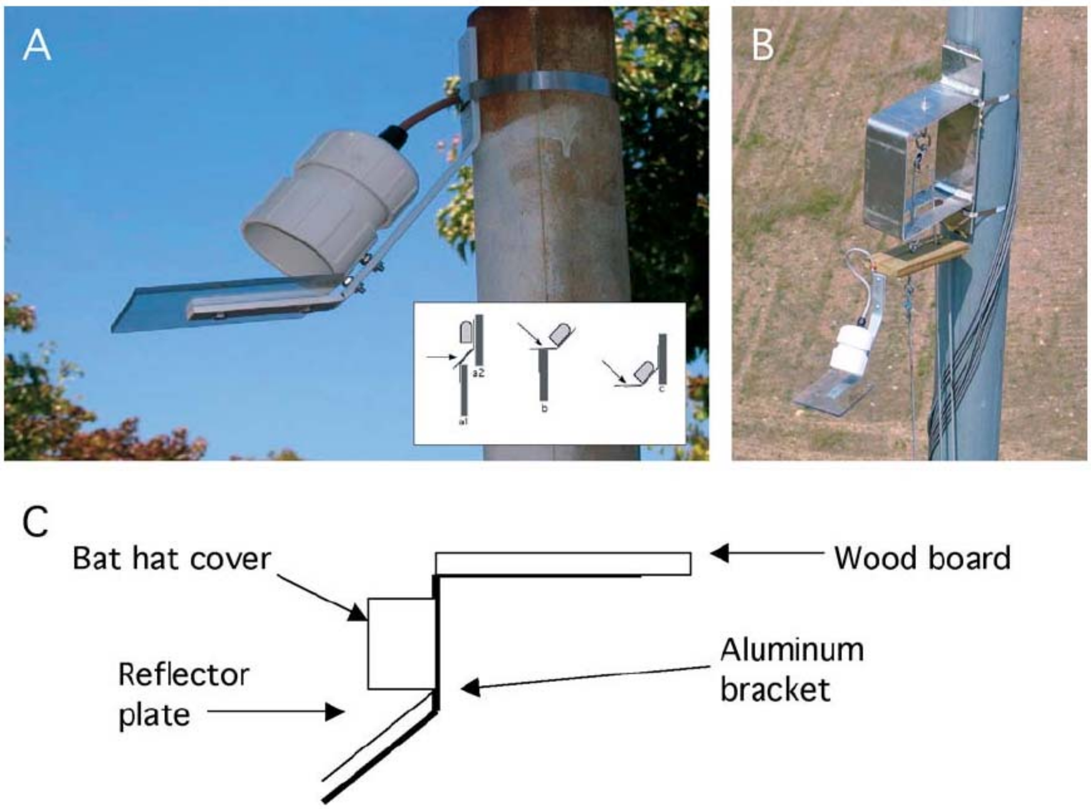


Figure 2-2: Example of installation of a bat detector microphone at height (taken from Kunz et al. 2007a).

A) Anabat microphones protected by a weather-proof bat hats can be deployed and linked by cables to ground-based data-logging units. When installed, the microphone points downward and receives signals from a clear Lucite or Plexiglas reflector. Three optional designs of brackets are shown for mounting bat hats (see inset).

B) Removable microphones protected by weather-proof bat hats are mounted on a carriage that is part of a pulley system. When attached to a tethered pole, this configuration enables retrieval and deployment of microphones (using a crane) from the ground following initial installation.

C) Schematic diagram of bracket used to mount a bat hat on a pulley system shown in A (E. B. Arnett, Bat Conservation International, unpublished data).

The most recent published guidance on methods for pre-construction acoustic monitoring (Lausen *et al.* 2006; Kunz *et al.* 2007a; New York State Department of Environmental Conservation 2009) includes the following recommendations:

- Use of Anabat bat detectors at least at ground level (2-3m above ground level (agl)) and turbine blade height (>30m agl), with an intermediate level if additional detectors are available;

- Sampling at height can be achieved using meteorological towers and/or additional portable towers;

- All night monitoring from April to October;

- At least 5 monitoring stations across the wind farm site (at each turbine location for sites up to 5 turbines, in a systematic array for larger sites);

- Minimum 1 year sampling, multi-year sampling preferable;

- Monitoring to continue to include post-construction period following identical methods.

There has been one attempt to determine the number of acoustic sampling stations required to provide sufficiently representative information on bat activity on any given wind farm site. Monitoring is often restricted to 2-3 meteorological masts for sites ranging from small sites of just a few turbines to large sites of anything up to over 100 turbines. However, preliminary analysis from a site in Pennsylvania (Arnett *et al.* 2006) suggests that this small number of monitoring sites may not provide enough information to adequately represent bat activity at the site (M. Huso, Oregon State University, unpublished data reported in Kunz *et al.* 2007). Much larger arrays of bat detector stations may therefore be required to fully assess the level and variation in bat activity at a particular proposed wind farm site.

Bat activity data from acoustic surveys is usually presented as the number of bat passes per unit time and generally in a graphical form. Guidance on pre-construction survey methods from Canada states that data from acoustic surveys should be presented as a minimum as the total number of bat passes and the mean number of bat passes per detector-night or detector-hour (Lausen *et al.* 2006). Kunz *et al.* (2007a) adds that this index should be normalised to number of hours after sunset to allow comparisons between studies. A standard definition of a bat pass, a sequence of two echolocation calls with each pass separated by >1sec (e.g. Fenton 1970), is generally used. Data from Anabat detectors require some level of processing before the number of bat passes can be determined: filters are applied in the Anabat analysis software Analook to separate likely bat echolocation calls from non-bat ultrasound. Files are then inspected visually to confirm the presence of bat passes which are counted and summed by date and sampling location (e.g. Arnett *et al.* 2006; Weller 2007).

Species identification from Anabat bat detector recordings for North American species is not possible in all cases. Some species with distinctive echolocation calls may be identified to species level. In other cases, calls have been put into species groups. For example bat passes have been separated into two groups: 'low' frequency calls (<35kHz) and 'high' frequency calls (>35kHz) (e.g. Arnett *et al.* 2007; Weller 2007) Species with 'low' frequency echolocation calls have been shown to be more active at turbine height (e.g. Arnett *et al.* 2007) than those with 'high' frequency calls.

For most of these studies, some analysis of bat activity data has been carried out, mainly using general linear models (e.g. Arnett *et al.* 2006) to investigate variation in activity in relation to the following factors (generalised linear models are used when there are many zero values in the data):

- species or species group;
- habitat (e.g. forest or open);
- height above ground; and
- meteorological variables (e.g. wind speed, air temperature and their interactions as recorded by meteorological stations at the wind farm site).

Results of each of the studies mentioned above are summarised in Appendix 3. Some general findings from pre-construction surveys include an overall high level of both temporal and spatial variation in bat activity, although several studies show activity peaks in late summer or early autumn. A general increase in bat activity with increasing temperature and a decrease in activity with increasing wind speed have also been found (e.g. Arnett *et al.* 2006; Redell *et al.* 2006; Weller 2007).

The increased level of bat activity at low wind speeds pre-construction is consistent with the findings of increased levels of fatality at low wind speeds post-construction, as discussed in the following sections. However, there are no definitive data yet available which link pre-construction bat activity levels to post-construction fatality levels, although data on post-construction fatality monitoring at sites where systematic acoustic monitoring at height pre-construction has been carried out are ongoing. For example, there are a number of studies being completed by the Bats and Wind Energy Cooperative (BWEC) on multi-year pre- and post-construction surveys at wind farms in North America (e.g. Arnett *et al.* 2007), including sites in Pennsylvania, Massachusetts and West Virginia. Analysis of the data from these studies is underway and further detailed recommendations for pre-construction surveys will be produced by BWEC following these analyses later in 2009. It may also be possible to further link pre-construction acoustic data with post-construction fatality levels as further results are published.

Europe

There is limited European literature available in English on bats and wind turbines, therefore the information summarised in this section has largely been obtained from Rodrigues *et al*. (2008).

As larger wind turbines have a blade rotation of between 25 and 180m, the EUROBATS' guidelines strongly recommend pre-construction surveys to be undertaken at height to ensure a full assessment can be made of all species that fly above canopy height, but with a focus on high flying species (Rodrigues *et al*. 2008). Rodrigues *et al*. (2008) consider that automatic surveys with bat detectors at height could be achieved by the use of balloons, kites, weather towers or other suitable structures. Behr *et al.* (2006; cited by Rodrigues *et al*. 2008) mounted their 'Batcorder' at a height of 34m on an observation tower at one of their study sites whereas Sattler and Bontadina (2007) used zeppelin balloons and Grunwald and Schäfer (2007) used helium balloons (both cited by Rodrigues *et al*. 2008).

In all three of these European studies, a subset of the species recorded on the ground were also recorded at height (i.e. there were no species recorded at height that were not also recorded on the ground). This is not a surprising finding, given what is known of bat flight habits and the distance covered by echolocation calls, but it should be noted that it may in part reflect the fact that different technology was used at height than on the ground in at least one of the studies; therefore detection rates were not directly comparable.

Rodrigues *et al*. (2008) also note that the effectiveness of radar (which could be used to study bat migration, foraging and flight at height) in combination with automatic recording of ultrasound at height and/or an infrared camera could provide valuable data but the effectiveness of these techniques has still to be proven. Also, given that radar may have a deterrent effect (section 2.5.3 under mitigation), its use in measuring bat activity is questionable. As both resident and migratory species have been killed at wind farm sites, Rodrigues *et al*. (2008) recommend undertaking surveys throughout the active bat season to get a clear picture of how the site is being utilised throughout the year.

Using ultrasound time expansion detectors that record echolocation calls for subsequent analysis have also been recommended for use in Europe (Harbusch & Bach 2005). Ground level monitoring (either by undertaking a walked or cycled transect at different times of night) is recommended but the additional use of automatic ultrasound detectors placed at each of the wind turbine locations per night are also suggested. However, the authors do not detail whether these stations should be at height. Given that bats recorded at ground level may be quite different from those recorded at turbine height, we advise against only using ground-level monitoring as a means of estimating fatality risk.

UK

There is very little published information on pre-construction surveys completed for proposed wind farm developments in the UK. Natural England (2009) recommend a risk-based approach to assessing survey effort according to factors such as site size, habitat types present and proximity to roosts.

The survey methods recommended by Natural England include: desk studies, roost searches, bat detector surveys at and around the site (manual and automated), and taking advantage of opportunities to survey at height. Bat detector survey effort at the level of at least one visit per month or use of automated bat detectors during the period when bat activity is likely to be highest (April to October) is recommended for most situations. Natural England also recommends that standard Bat Conservation Trust bat survey guidelines (Bat Conservation Trust 2007) should be applied appropriately.

The BCT survey guidelines provide guidance on survey effort and frequency for manual bat activity surveys (Bat Conservation Trust 2007). These guidelines suggest two or three bat detector transect surveys at ground level be carried out between March and September (optimal period June to August) to assess bat activity at a site, with at least one of these comprising dusk to dawn or dusk and dawn for sites considered to be of moderate to high value for bats. The guidelines also discuss automated bat activity surveys and refer readers to the EUROBATS guidelines on wind farm impact assessment for surveys at wind farm sites. Following the BCT guidelines in conjunction with the Natural England (2009) interim guidance may therefore lead to some difficulties in interpretation on requirements for survey effort, as the two documents do not provide identical advice.

A specific example of survey methods adopted by one ecological consultancy (Andrew McCarthy Associates as reported in Cook *et al*. 2008) proposes a three tiered approach to identify roosts, activity levels at each proposed turbine location and overall bat activity patterns at the site, focussing on the summer months of peak bat activity. Automated activity surveys are proposed at each turbine location for three consecutive nights on a minimum of three occasions between April and September. It is noted that in most cases, only ground-level sampling is likely to be undertaken. In addition, manual transect surveys across the entire turbine area plus a 200m buffer are proposed to provide additional information on overall patterns of bat activity, at a frequency between three visits per season up to two visits per month. Bat activity is calculated as the number of bat passes per unit time for each turbine location and across the site. Maps of bat activity can also be produced from the survey data to highlight areas of high bat activity.

The above approach is not likely to provide adequate information on levels and patterns of bat activity at most proposed wind farm sites in the UK, given the findings described in previous sections for North America. Recommendations for survey methods documented to date use inadequate sampling of the proposed sites, rarely include any sampling of bat activity at height, and do not provide for any changes in sampling level throughout the season, for example by increasing sampling during the bat migration period. There is a clear need for improved guidance in the UK on pre-construction acoustic survey methods.

A search of the Internet brought up a small number of examples of ecological consultants in the UK testing methods for surveying for bats at height. Very little information was available on methods used by most ecological consultants, although most responses to queries on the topic were that only ground level activity surveys were being carried out. Free-floating helium balloons or blimps have been used to monitor bat activity at height in North America with some success (e.g. Menzel *et al.* 2005; McCracken *et al.* 2008). We have received anecdotal evidence that they have been tested on a small number of occasions in the UK by ecological consultancies, with little success however. For example, White Young Green trialled a helium blimp for bat monitoring at canopy level (45m agl) in forestry at a proposed wind farm site in Wales (Carnedd Wen, npower Renewables) (Duncan Watson, *pers. comm*.). A number of problems were encountered including costs (e.g. high cost of re-filling the balloon), wind affecting position of the balloon and resources as the balloon needed constant monitoring to maintain its position. Automated bat detectors can be attached to the balloon with the aim of recording bat activity at height. In the example described, Anabat bat detectors were tested but sufficient data were not collected to compare levels of activity at height and at ground level (Duncan Watson, *pers. comm.*). Another consultant based in Scotland (Stuart Spray Wildlife) is trialling placing Anabat bat detectors on a 15m pole to survey above ground level, and a consultant in Norfolk (Wild Frontier Ecology) is trialling the use of helium weather balloons in 2009 carrying bat detectors to gather data at height. We suggest that using balloons for long-term bat monitoring at height is not a practical option. The balloons would require constant monitoring to ensure data is collected at the correct altitude and location, costs would be prohibitively expensive, and the risks from malfunctioning balloons are high.

A recent study in England (Collins & Jones, *in review*) investigated differences in bat activity in relation to the height of bat detectors in the south of England by comparing activity recorded by Anabat bat detectors placed at ground level and at 30m agl on existing structures (telecommunications and research masts). Significantly more bat activity, and in particular more pipistrelle activity was recorded at ground level than at 30m. A higher proportion of bat passes assigned to the *Nyctalus/Eptesicus* group (bats producing low frequency echolocation calls) were recorded at 30m although the difference in number of bat passes of this group at the two detector heights was not significant. However, many passes of *Nyctalus/Eptesicus* species were recorded only by the detectors at height (and presumably the same occurred for ground level detectors given the lack of a difference in the total number of passes between the two detectors), suggesting that high-flying bats were not adequately recorded by ground level detectors.

Anabat bat detectors appear to be the automated bat detector of choice in the UK, as in North America. The limited range of species in the UK means that no greater resolution in species identification is possible through the use of Anabat bat detectors compared with full spectrum recording methods. The following species can be identified unambiguously by using Anabat bat detectors: greater horseshoe, lesser horseshoe, most common pipistrelle (>90%), soprano pipistrelle, Nathusius' pipistrelle, and barbastelle. Identification of *Myotis* species is not feasible, and so bats can be identified to genus level only. Additionally, difficulties in identifying noctule, Leisler's bat and serotine can occur, leading some authors (e.g. Collins & Jones, *in review*) to lump these bats as *Nyctalus/Eptesicus* species. Some low-frequency (<20 kHz) noctule calls produced at high altitude are diagnostic however. Calls of *Plecotus* species are also characteristic at least to genus level, though the low-intensity calls emitted by these species means it is rarely detected. In the UK, therefore, most species identified to be at medium or high risk of collision with wind turbines (Natural England 2009) can be identified reliably with Anabat bat detectors, removing the need for additional full-spectrum acoustic or capture survey techniques at wind farm sites.

There are also full-spectrum bat detection systems available on the market (e.g. Batcorder and the Pettersson Elektronik D500X), but these systems have no remote download facility. Limitations of data storage capacity on memory cards has been reduced in the Pettersson D500X as it has the capacity for four CF-cards. The Batcorder has been used successfully installed in the nacelles of wind turbines in Germany and trials have just started in America to test the new Pettersson bat detector at height on portable towers (Ivo Niermann, *pers comm*. and Volker Runkel, *pers comm*.). These systems do produce high quality sonograms however, and software is being developed to quantitatively identify calls based on a large call library in America but can be programmed within a day for British species if a large call library is available to be installed to programme the system (Joe Szewczak, *pers comm*.).

2.2.2 Post-construction acoustic surveys at height

North America

Acoustic monitoring post-construction was listed within the top three tools required to better understand these interactions at the Bat Conservation International technical workshop in 2004 (Energetics Inc 2004), in addition to thermal imaging and radar (which are discussed later in this section). This was confirmed in a recent review of the ecological impacts of wind energy development (Kunz *et al*. 2007a), in which it was recommended that acoustic surveys should be included in pre- and post-construction monitoring to provide a better understanding of how bat activity around turbines varies with wind speeds. Similar methods should be continued into post-construction monitoring as discussed in the previous section.

Quantitative studies at existing wind farms should be used to evaluate how a range of factors affects bat activity around turbines such as:

- air temperature;
- wind speed and direction;
- cloud cover;
- moon phase;
- barometric pressure; and
- precipitation.

In Canada, acoustic monitoring studies at a number of operational wind farms in Alberta showed that migratory bat activity was generally higher at low wind speeds, higher temperatures and when a greater part of the moon was illuminated (Baerwald & Barclay 2009). Because moon phase and wind speed also affected bat mortality, some links between activity levels and fatality rates are likely.

Most post-construction acoustic surveys reported in the literature are based on ground level surveys (e.g. Johnson *et al.* 2004; Jain 2005). Of these, several studies showed no relationship between daily bat activity levels and bat fatality rates (e.g. Gruver 2002; Johnson *et al*. 2004; Jain 2005) although a study in Iowa (Jain 2005) found similar patterns in both activity and fatalities: both peaked in July / August. One study at a wind farm site in Tennessee (Fielder 2004) showed that ground level bat activity was higher on the nights when fresh fatalities were found on the following day.

There have been five studies in North America where post-construction acoustic monitoring has been completed alongside fatality surveys (Arnett, unpublished data; Fielder 2004; Jain 2005;

Johnson *et al* 2004; Gruver 2002 in Appendix 3 and reported in Kunz *et al.* 2007a). Across these sites Kunz *et al.* (2007a) showed that there is a positive correlation between estimated number of bat calls recorded per detector-night and number of bat fatalities. Comparison of the results across the five sites should be interpreted with caution, however, as different detector types and methods were used and monitoring was not always completed at turbine height. In addition, pre-construction survey data are not available for these sites, and it is therefore not possible to relate pre-construction activity to fatality rates. As described above, only one of these studies (Fielder 2004) found any relationship between bat activity and fatalities within the site.

As with pre-construction, in North America post-construction acoustic surveys have been undertaken at height by installing bat detectors on either MET masts or portable towers rather than within the turbine nacelle. The disadvantage to this method is that the area being surveyed will be away from the rotor-swept area. Therefore, if bats are attracted to turbines the level of activity surveyed outside these areas will not be representative of what happens at the turbines. A more accurate representation of bat activity within the rotor swept area would be determined from echolocation call monitoring using bat detectors placed on the turbine itself at nacelle height.

Europe

Germany is currently the only country that has completed automated acoustic surveys by installing bat detectors onto nacelles (Anabat and 'Batcorder' bat detectors have both been used). In this study Anabat bat detectors and 'Batcorder' detectors (that sample full spectrum recordings in real time) were installed into the nacelles of 70 wind turbines across Germany (Behr *et al.* 2007). The results of this study are currently being analysed to determine if there is any correlation between bat activity and bat fatality rates, however calls from noctule and pipistrelles were detected within the rotor swept area (Ivo Niermann, *pers*. *comm*.).

Potential difficulties to undertaking acoustic surveys at nacelle height include the requirement for permission to gain access into the nacelle, the need for holes to be drilled into the bottom of the nacelle for the Anabat microphone to be set up to record bat echolocation calls, and the potential problem of electrical interference with the Anabat bat detectors. Advantages are that the Anabat bat detector can be connected to the energy supply of the nacelle and therefore does not require batteries. Also, new hardware and software has recently been developed by Titley Electronics (who manufacture the Anabat bat detector) to enable data to be remotely downloaded and stored on their website. The Anabat GML1 Remote Download System will automatically download data recorded the previous night and data can then be collected from any computer using a unique login to Titley's website. The use of the system requires the GML1 remote download device, a GML1 diagnostic monitor and a GPRS connection to retrieve the data in addition to the Anabat bat detector and associated microphones and leads. Consequently, using this new system, access to the nacelle would only be required for the initial setup and any subsequent maintenance requirements.

To minimise the labour intensity of installing bat detectors and other equipment within nacelles at 70 wind turbines, a manual was produced that has detailed the full process (Reich *et al*. 2008. In summary, consultation with the wind turbine manufacturer needs to be undertaken in the early stages to ensure the warranty of the turbine is still valid and permission to drill holes to secure the battery and install the bat detector. In Germany the bat detectors have only been installed in Enercon wind turbines, working in partnership with Enercon staff. Four holes are drilled to secure the battery to the ground with cable ties (Figure 2-3).

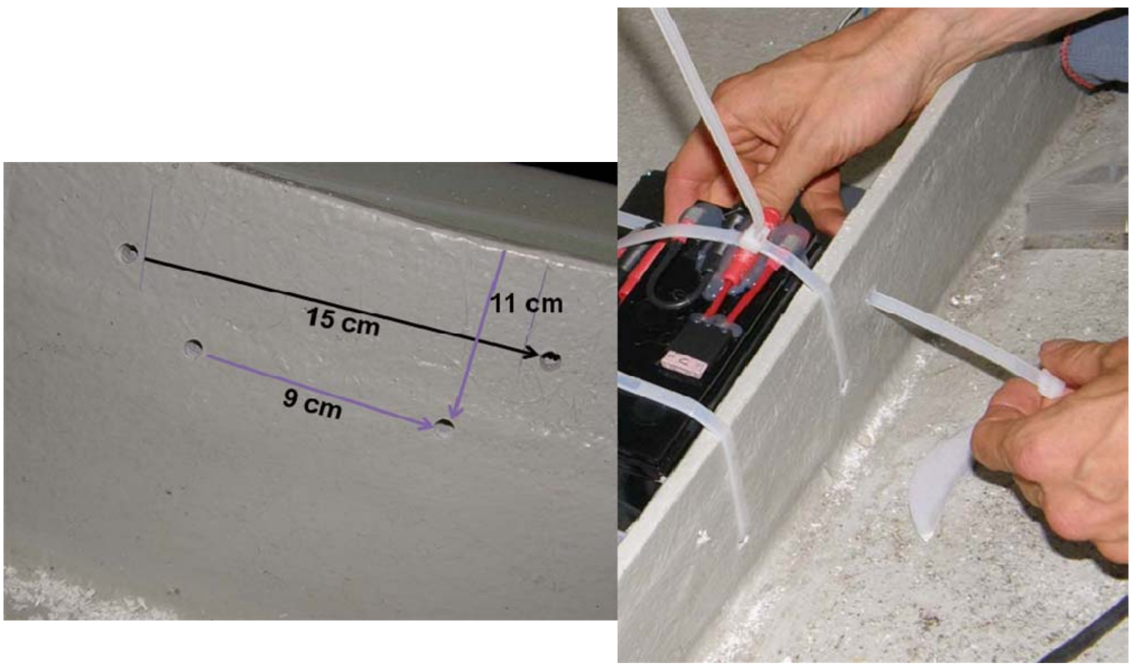


Figure 2-3: Setup of acoustic surveying equipment within the wind turbine nacelle (taken from German manual produced by Reich *et al*. 2008 – with thanks to Ivo Niermann).

A hole 102mm in diameter is drilled through the fibreglass floor of the nacelle for bat detector, in this case an Anabat, 70cm away from the deepest part of the floor using a template placed on the floor as a guide. The piece of fibreglass needs to be measured when removed because there is variation between the thicknesses of each nacelle floor. The Anabat microphone is protected by putting foam around the microphone before placing the Anabat in position and secured in place by an L-shaped angle and masking tape (Figure 2-4b). The equipment is connected up to the electricity mains within the nacelle to keep the equipment charged up, as shown in Figure 2-4 (a and b).

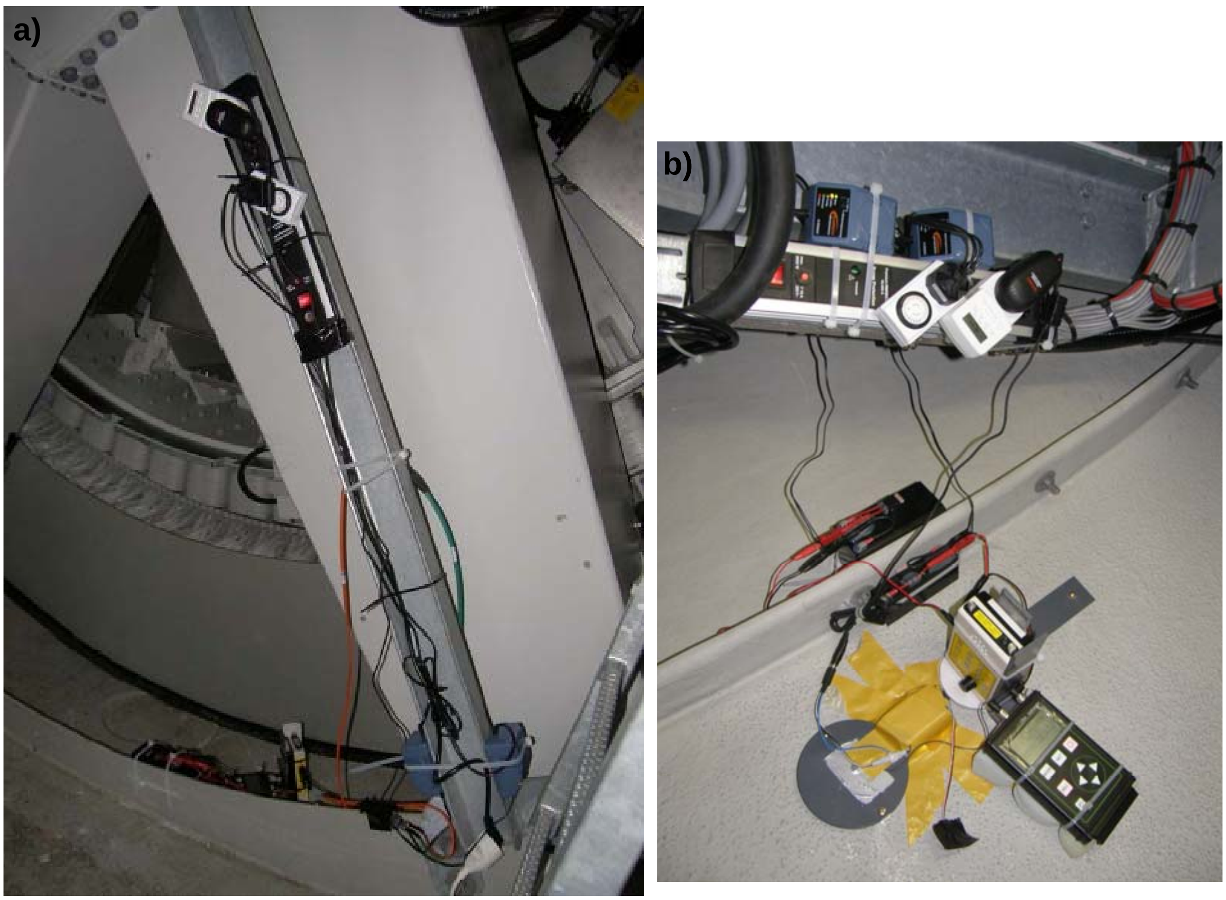


Figure 2-4: Final setup of Anabat bat detector with microphone facing out of nacelle through a drilled hole and connected up to an electrical supply in the nacelle (a) taken from German manual produced by Reich *et al*. 2008 and (b) presentation given by Niermann *et al*. 2009).

The Anabat detector then records bat calls within the rotor swept area and because it is facing downwards it is protected from rain (Figure 2-5). However, to ensure the equipment is calibrated the German researchers have devised a test using a Marderschreck (a device used to scare mustelids away from cars: it works by emitting an alarm call). The Marderschreck device is set off to test that the detectors are working correctly.

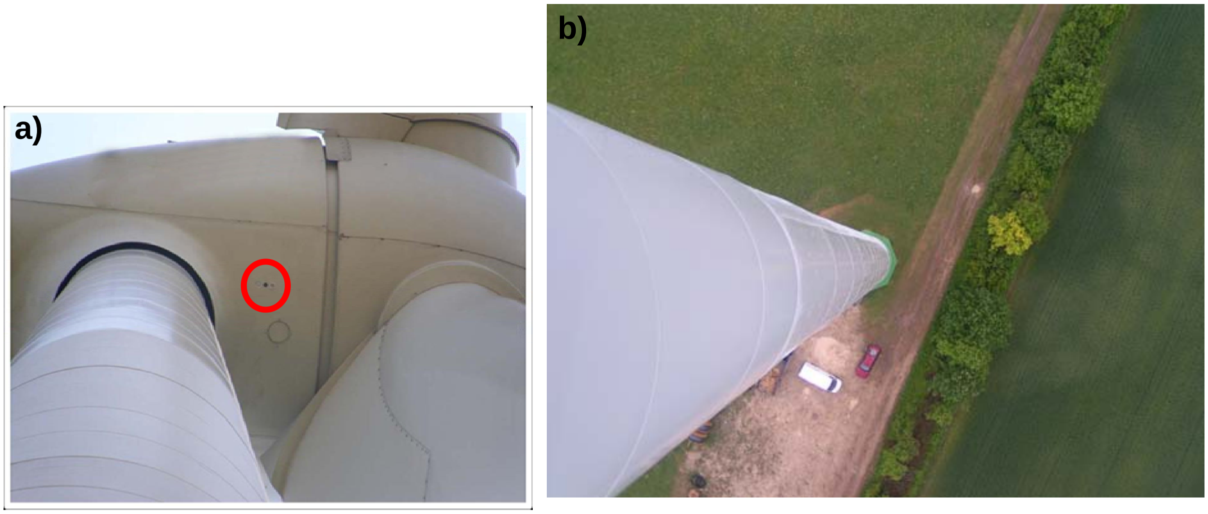


Figure 2-5: a) Position of the bat detector (indicated by the red circle)**, and b) scale of the height the bat detectors are placed within the rotor swept area (taken from Niermann *et al*. 2009).**

UK

Following a thorough search and discussion with a number of consultants and energy companies in the UK, we were unable to find any reports detailing post-construction acoustic surveys at height that have been carried out in the UK. There is a small amount of anecdotal evidence (e.g. from Braes of Doune, John Haddow, *pers comm*.) that bats are active in the vicinity of wind turbines, but no data have been recorded in any systematic way.

In summary, in order to determine levels of bat activity around turbines at operational wind farms in Britain, we recommend the following methodology based on the work completed to date in North America and mainland Europe as described in this section:

- acoustic surveys using Anabat detectors at turbine blade height;
- acoustic surveys to comprise all night data collection for the entire bat active season (April to October);
- a multi-year survey programme with minimum three but ideally five turbines surveyed at each of a minimum of three sites (to allow variation within and between years and within and between sites to be investigated);
- simultaneous collection of meteorological data for analysis to determine factors affecting bat activity; and

- acoustic surveys to be accompanied by fatality monitoring throughout active bat season to allow comparison between bat activity and bat fatality rates (see section 3 for proposed methods).

2.3 Fatality searches

Fatality searches using standardised methods are the only way to assess bat fatality rates at wind energy facilities. Fatality search methods have been developed to adjust 'actual' bat fatalities found in order to provide accurate estimates of fatality rates (Arnett *et al*. 2004). Determining fatality rates is an essential step towards determining whether wind turbines are having a significant impact (i.e. at a population level) on the bat species being affected. Appendix 4 summarises the methods and results of fatality searches completed to date at wind farm sites in North America and Europe.

Estimates of fatality rates are not reported in a consistent way in the literature. Some studies take into account factors such as search efficiency, carcass removal rate and search area which will all affect detection rate of fatalities, but others do not. In addition, some studies quote fatalities per turbine per night, while other authors have reported fatalities per turbine per year or over another time period. The use of different methods has made it difficult to compare studies directly, as many of the fatality searches also have varying survey effort, such as infrequent search intervals (e.g. 7-14 day intervals). Some authors do not provide sufficient information (or in some cases any information) on other factors that may help account for fatalities (e.g. wind speeds), and there are studies that do not provide accurate estimates of bat fatality rates (Arnett *et al*. 2004). These differences make it difficult to predict cumulative impacts (Arnett *et al*. 2008; Kunz *et al*. 2007). Studies should ideally take place across several years to account for seasonal and yearly variation in fatality rates. In a review conducted by Arnett *et al*. (2008), of 21 studies carried out in the United States and Canada 57% were conducted for less than 12 months.

The following sections summarise different methods, search area setup, and sampling bias studies that have been trialled at wind farm sites in North America and Europe.

2.3.1 Search area and turbine selection

The majority of North American fatality studies used a square plot, ranging in maximum dimensions from 100m by 100m (e.g. Johnson *et al*. 2003a) to 140m by 140m (e.g. Brown & Hamilton 2006; Johnson *et al*. 2003b). Rectangular plots have also been used, with maximum dimensions of 120m (north-south) by 130m (east-west) (e.g. Arnett *et al*. 2004); and occasionally circular plots have also been used (e.g. Brown & Hamilton 2006; Erin Baerwald *pers*. *comm*.). All search plots are centred on the wind turbine base. The search area dimensions have been selected to ensure a 50m radius from the turbine is included in the search area, because most fatalities have been recorded within this area. For example, in one study 54% of all bat carcasses were found less than or equal to 10m from the turbine tower, with 43% between 10m-20m, 3% from 20m-30m and only 0.5% located further than 30m (Johnson *et al*. 2003a).

Most of the European studies used a 50m radius from the turbines base as the fatality search area. Several used a larger area, for example 65m and 68m, or a search area with a radius equal to turbine height. Several studies gave an analysis of how far dead bats were recovered from the turbines, which might influence the definition of future search areas. For example, Ahlén (2003) found bats being found between 3 and 25m (mean 12m) from the turbine, whereas Brinkmann *et al*. (2006) found the furthest bat 37m away from the turbine. Rodrigues *et al*. (2006) cites Lekuona (2001) and Petri and Munilla (2002) papers, stating the average distance from the turbine was 25m. During one study a bat carcass was retrieved 95m away from the turbine, which was outside their search area (68m radius) (Behr & von Helversen 2005; cited by Brinkmann 2006). Recommendations for search area in Europe vary, for example one review recommends a search area the radius of the blades plus 50m (Dürr & Bach 2004), while another a radius equal to the total height of the wind turbine or an area not less than 50m (Rodrigues *et al*. 2008). The shape of the search area used was square rather than circular, marked with four corner poles and poles on opposing sides indicating 5 or 10m transects, as has been suggested by researchers in North America due to visibility limitations (Rodrigues *et al*. 2008).

Even where the search area was standardised throughout the survey season, the actual search area around the turbine locations varied with landscape and vegetation conditions due to visibility or inaccessibility (e.g. scrub or steep slopes / cliffs) and these areas were not included in the search area (e.g. Arnett *et al*. 2009).

It has not been possible to determine in all cases how many turbines were surveyed for fatalities, how turbines were selected, or how often changes were made to the turbines surveyed. Not all of the studies specify how many of the turbines were surveyed, and there is little information on the proportion of turbines that have been surveyed and no detail of how turbines were selected has been given. One study numbered turbines consecutively and daily searches were undertaken at all odd-numbered turbines and weekly searches at even-numbered turbines for the first three weeks. In the subsequent three weeks all even-numbered turbines were searched daily and odd-numbered turbines were searched weekly (Arnett *et al*. 2004).

Although not entirely clear from the European summaries reviewed, it seems that for most studies all turbines were surveyed, but many study sites had small numbers of turbines. There were some exceptions where large wind farms were studied, but it is not clear how the order in which the turbines were selected for survey was obtained. Dürr and Bach's (2004) protocol recommends that each study area should have a minimum of 10-15 turbines and that all should be checked once a week in the early morning. Rodrigues *et al*. (2008) recommend that every wind turbine be sampled. However, where a large wind farm is to be surveyed, surveys are recommended on all turbines close to landscape features that are likely to be used by bats and a random selection of the remaining wind turbines. Rodrigues *et al*. (2008) also state that the number of turbines that will be included in the fatality searches will depend on the size of the wind farm and its siting but give no further recommendation as to the proportion of turbines that should be surveyed in large farms. When only a selection of turbines was monitored, the selection was done randomly.

2.3.2 *Search protocol*

Brown and Hamilton (2006) walked seven parallel 120m long transects spaced at 20m intervals, although this would only be possible at high visibility sites because surveyors searched 20m-wide strips for carcasses and at the end of the transect scanned at least 10m beyond the endpoint (resulting in an area of 140m x 140m square plot). Although some studies still use circular transects (e.g. Piorkowski 2006, using methods set out in Kerns & Kerlinger 2004), most have moved away from circular search areas due to greater difficulties in delimiting search area boundaries. However, Brown and Hamilton (2006) changed the transect walk on their study site at Summerview Wind Farm (Alberta, Canada) to cover a 40m radius from the centre of the turbine. This was due to crop heights reaching 30-40cm in late summer (August), which affected searcher visibility. The objective of this approach was to increase search effort, thereby increasing the potential to locate bat carcasses obscured by the vegetation. Figure 2-6 shows the 'standard' search area and the modified search area and transects used by Brown & Hamilton 2006). Circular transects were also used in one study because the landowners asked the researchers not to leave items such as flags in the fields that cattle could eat (Erin Baerwald, *pers. comm.*). As a consequence, a method was designed whereby a searcher held the end of 45m piece of rope attached to the base of the wind turbine and the second searcher held the end of a 7m rope that was attached onto the first searcher. The surveyors can then focus solely on carrying out the fatality search without having to keep looking up to follow a transect line. The surveyor on the outside of the circular transect has a longer route to walk and therefore needs to set the pace to ensure that the search is not sped up. Once a circuit has been completed the rope wraps around the wind turbine tower and draws the surveyors closer. The surveyors carry on walking around the turbine until they reach the base of the tower.

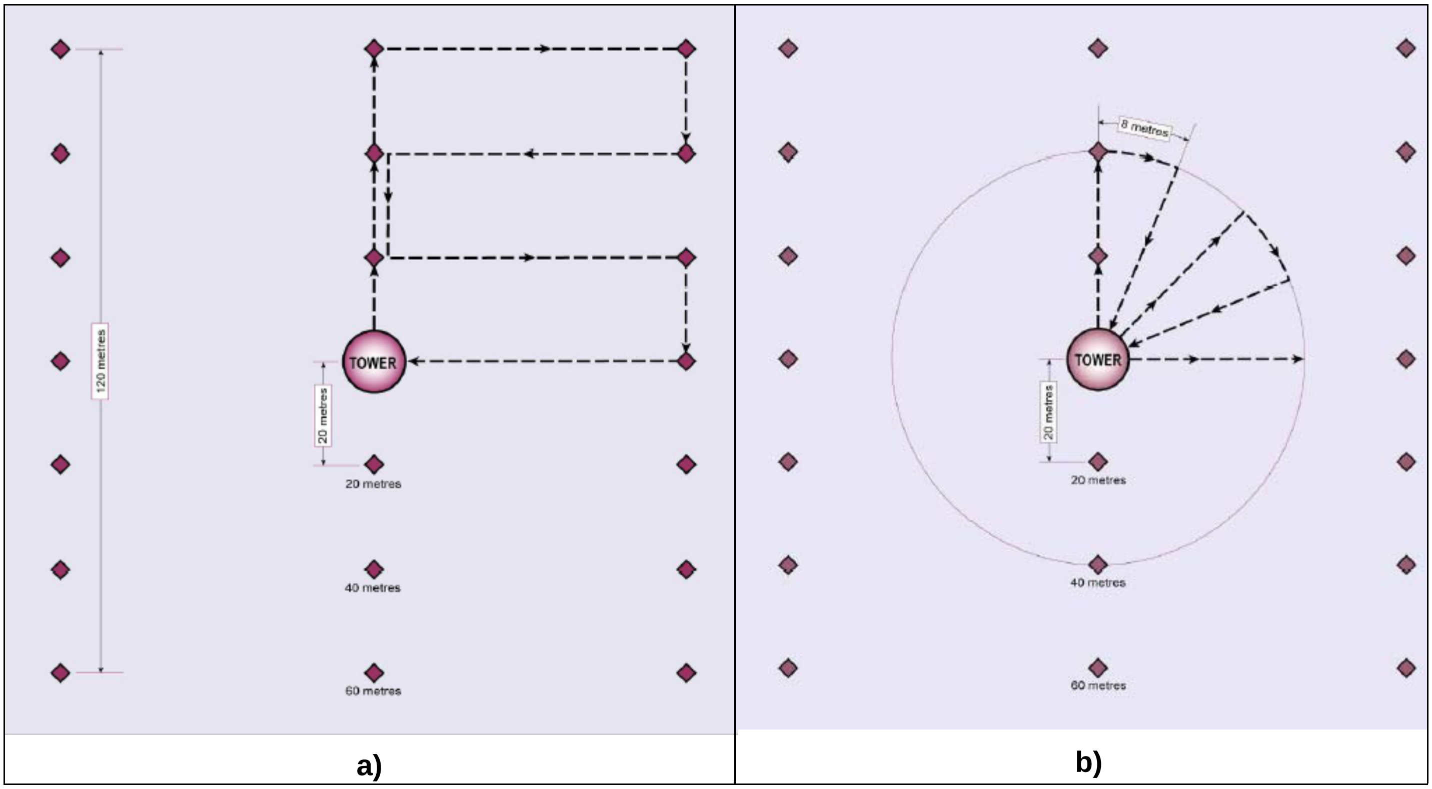


Figure 2-6: Illustrates two different carcass survey search patterns used at Summerview Wind Farm taken from Brown and Hamilton (2006): a) shows the standard search pattern that was used and b) shows a modified carcass survey pattern, to increase search effort when the vegetation was high.

Some studies recorded the proportion of vegetation cover within a particular radius of the wind turbines and the distance from each fatality to the nearest wetland and woodland (e.g. Johnson *et al*. 2004 recorded this information within 100m of the turbines). Because of access limitations, for instance difficult terrain (e.g. cliff edge) or vegetation (e.g. very dense scrub), it was not always possible to survey the entire search plot. In these cases the search area was made smaller or sections left out of the search area as is demonstrated in Figure 2-7 (taken from Arnett *et al*. 2004).

Standardised transects within the search area were established usually every 10m (Johnson *et al*. 2003a) or 6m (Erickson *et al*. 2000; Johnson *et al*. 2004), but vary between 5m to 11m (Osborn *et al*. 1996) depending on visibility, which is primarily influenced by vegetation height.

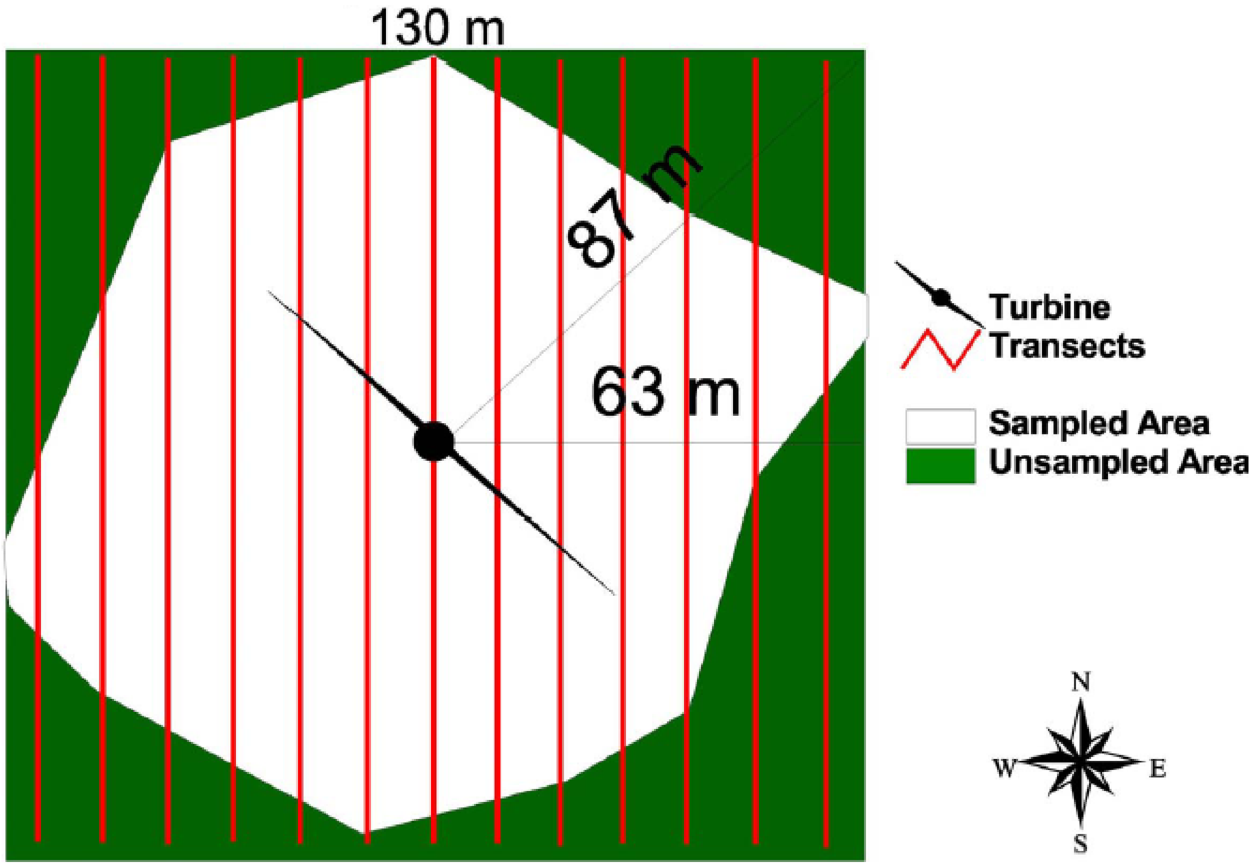


Figure 2-7: An example of fatality search plot, with inaccessible search areas - taken from Arnett *et al*. (2004).

Rodrigues *et al*. (2008) recommends that the searcher should walk each transect (5 or 10m apart) at a slow and regular pace looking for fatalities at both sides of the line. On finding a carcass the following should be noted: GPS (global positioning system) coordinates of the bat location, direction to the wind turbine the bat was found, distance to the tower the bat was found, state of the carcass, type of wounds and vegetation height where the bat was found.

Where mentioned, all studies have included bat fatalities found incidentally (i.e. by searchers driving around the site or other personnel on site) at turbines not selected to be sampled (e.g. Brown & Hamilton 2006; Johnson *et al*. 2003) if they were found close to a wind turbine. Erickson *et al*. (2004) note that where injured animals were found but could not be linked to a specific turbine number they were not recorded as casualties. If no further information was available the animal was recorded as having been 'on site'. The majority of studies photographed bat carcasses where they were found and either mapped the location on a detailed map or measured the distance to turbine.

Species, sex and age (if known) were recorded, along with the date and time, unique identification number, and condition (i.e. intact, scavenged, or dismembered). Injuries observed were recorded during a cursory field necropsy (post mortem). Some studies undertook field necropsies to record injuries, while others labelled, bagged and froze bats to be sent away for further investigation. However, due to the high volume of fatalities at some sites only a sample was taken of the carcasses to age and sex all bats. Some bat carcasses were not sampled due to the condition carcasses. For example if they were in advanced stages of decomposition or had been severely scavenged as this would prevents identification. However, caution should be taken as using a subset of fresh intact carcasses (as used for example by Johnson *et al*. 2003a) could cause sampling bias. Rodrigues *et al*. (2008) recommend also recording weather conditions between surveys including temperature, wind speed and direction, rain/thunderstorms and moon phases.

Although not described in the European literature, in North America turbine search plots have been searched in a random order to ensure that if predation/scavenging rates were high on any site, the carcasses from the same turbine were not removed each day before surveyors were on site.

2.3.3 Search interval between searches and time taken per search area

Search interval varied between daily (e.g. Arnett *et al*. 2004), weekly (e.g. Brown & Hamilton 2006), or fortnightly which occurred most frequently (e.g. Johnson *et al*. 2003; Piorkowski 2006). However, some studies used search intervals of between 28-30 days (Johnson *et al*. 2003b); in one study survey effort was increased to twice a week during the bird migration period (May-July and September) (Brown & Hamilton 2006). The areas within the plots are searched by walking parallel (or circular) transects. Each turbine plot is searched for approximately 30-90 min, depending on the searchable area and habitat conditions (Arnett *et al*. 2004). The average time spent searching plots at Buffalo Ridge (Minnesota, U.S.A.) was between 30 and 45 min (Johnson *et al*. 2003a). Transect width and search speed were adjusted after an initial trial depending on habitat type, topography and in some cases time of year as vegetation height made visibility more difficult. In some studies, prior to commencing any fatality searches all search plot area is cleared of any carcasses (e.g. Johnson *et al*. 2003b). Fatality searches commenced either at dawn or one hour after dawn and carried on up to approximately eight hours (e.g. Rodrigues *et al*. 2008; Ed Arnett, *pers. comm*.).

Similarly, in Europe various time intervals between fatality searches have also been used. Some studies used intervals of 2-5 days, some weekly or even fortnightly but surveys on consecutive days have not been recorded. A few studies conducted only one search per turbine. A short time interval (ideally 1 day) for small wind farms and a maximum of 5 day interval for larger wind farms is recommended in Europe (Rodrigues *et al*. 2008), although other recommendations have suggested fatality searches should be conducted twice a week starting early in the morning from mid-July until mid-October (Harbusch & Bach 2005). The general consensus in Europe is to start the searches one hour after sunrise when lighting conditions enable dead bats to be distinguished (Rodrigues *et a*l. 2008).

When the time between search intervals are longer, fatality rates are likely to underestimate the actual number of fatalities due to survey biases; namely searcher efficiency in different habitat types and removal of carcasses (which will be discussed later in this section). Therefore, some of the fatality rates presented in this summary will not represent the total estimated mortality because not all the rates can be adjusted.

Rodrigues *et al*. (2008) refer to Arnett (2005) for consideration of time interval in the analysis as the longer the time interval between fatality searches, the higher the probability of predation bias. In Europe it is recommended that fatality searches start as soon as bats leave hibernation, and that search effort should be greater during spring and autumn migration seasons than in mid-summer, however timings should be adjusted as and when to start and end these surveys depending on the geographical location of the site. For example, depending on the geographical location of a site the survey timescales may need to be adjusted to account for variation in the length of time bats hibernate at different geographical locations (for instance there may be delays in bats emerging or they may emerge earlier than the same species in other parts of Europe (Rodrigues *et al*. 2008)).

2.3.4 *Sampling bias/limitations*

Sources of bias influence the estimates of bat fatality rates, such as different removal/scavenging rates and searcher efficiency in different habitats at different sites or at the same site throughout the survey season, differences in searcher efficiency between searchers and other variables (such as weather conditions). To address underestimating fatality rates, searcher efficiency and scavenger removal trials can be undertaken to account for bias and subsequently adjust these fatality rates.

Visibility seems to be the most significant limitation to locating bat fatalities, where carcasses have not been removed. Overall bias corrections for the field season should take into account changes in the ability to detect bats because of the change in vegetation (across sites and throughout the survey season). These bias-correction trials can even compensate for corpse detection differences among vegetation types (Arnett *et al*. 2004). Fatality estimates become less accurate as the ratio of the interval between searches to mean removal time (in other words, the length of time the carcass is left *in situ* until scavenged) increases (Erickson *et al*. 2004).

In the following sections, methods that have been used for searcher efficiency trials and carcass removal trials in both North America and Europe are summarised.

Estimation of searcher efficiency through field trials

Searcher efficiency is defined by Brown and Hamilton (2006) as "*the proportion of carcasses present that were observed on a single survey*". In trials to quantify searcher efficiency, experimental carcasses were randomly distributed either within the same sample plots that the fatality searches are carried out in or outside the search plot to avoid confusing trial and 'actual' bats. Where there was a shortage of suitable bat carcasses for these trials, a combination of the following has been used: bats and birds (Brown & Hamilton 2006), only birds (Erickson *et al*. 2004; Johnson *et al*. 2003), plastic bats (Johnson *et al*. 2004), or fabric bats or mice (Dubourg-Savage, *pers. comm*.). In most of the European studies cited by Rodrigues *et al.* (2008), substitutes for bat bodies have been used, including bird or mice carcasses and dummy bats made of paper or brown fur. As well as using 'fresh' bat carcasses, frozen bat (and bird) carcasses have been used (e.g. Arnett *et al*. 2004). Where bird carcasses have been used, species were chosen as similar to bats in relation to size and colour, including: juvenile (<7-d old) mallards (*Anas platyrhynchos*), juvenile (7 to 14 d old) northern bobwhites (*Colinus virginianus*), adult house sparrows (*Passer domesticus*) and European starlings (*Sturnus vulgaris*) (Johnson *et al*. 2003a). A study at Klondike Wind Farm (Oregon, U.S.A.) used house sparrows to simulate bat carcasses (Johnson *et al*. 2003b). Where bird and bat fatality searchers are being undertaken two different sizes of birds have been used to account for biases associated with the likelihood of finding larger birds (Erickson *et al*. 2004).

Carcasses were placed in exposed, hidden or semi-hidden locations to simulate a range of conditions the searchers were likely to encounter during their fatality searches (Johnson *et al*. 2004). Brown and Hamilton (2006) randomly selected locations, distance and orientation using a random number generator and subsequently placed carcasses around turbines by dropping them from shoulder height. Searcher efficiency carcasses were discreetly marked to ensure they could be distinguished from carcasses found during the fatality searches (e.g. Brown & Hamilton 2006 used small individually numbered pieces of tape). More recently trial bats have had teeth removed so they are not distinguished from the 'fresh' bats (Ed Arnett, *pers. comm*.).

To account for differences in searcher efficiency with regard to visibility at and across sites and also differences in searcher detection generally, all searchers should take part in the trials. Where more than one surveyor is used for fatality searches, each searcher should complete the survey separately to account for individual differences in searcher efficiency. In one study three of the most frequently used surveyors undertook searcher efficiency trials for each of the major habitat types, to account for individual differences (Brown & Hamilton 2006). The surveyors located 72.3% of the bird carcasses and 75.4% bat carcasses. In these trials the three surveyors each conducted the same trial separately, without seeing the others complete their trial. During the searcher efficiency trials at Klondike Wind Farm, Johnson *et al*. (2003b) ensured that the surveyors did not know when trials were scheduled, placing trial carcasses at random locations on the plots used for fatality searches.

Of 21 studies reviewed by Arnett *et al*. (2008), only eight undertook searcher efficiency trials; the lowest searcher efficiency rates were recorded in forested areas (25% - 42%) and highest in open habitats (42% - 75%). Searcher efficiency averaged 77.3% on gravel pads but only 19.7% in other cover types, with a combined detection rate of 46.5% (Johnson *et al*. 2004). Arnett *et al*. (2004) found that searcher efficiency was generally high on bare ground and other high visibility habitats but very low in dense vegetation, boulder and rock piles, and other low-visibility habitats. Although final estimates of searcher efficiency have not been calculated, Arnett *et al*. (2004) predicted that Mountaineer (West Virginia, U.S.A.) would have higher searcher efficiency than at Meyersdale (Pennsylvania, U.S.A.) because the site had more dense tall grass on the majority of turbine plot areas.

When testing ‘different’ carcasses, there was no significant difference between the detection of bat carcasses and plastic bats. In one study 72 birds (divided equally between small & med/large) were used for searcher efficiency trials (Johnson *et al*. 2004). The results remained fairly consistent between seasons but varied by size class of bird. When all habitats were combined, 75% of small birds and 92% of large birds were detected, with an overall detection rate (all bird sizes and all habitats) of 83%. These detection rates are higher than most other studies because high-visibility habitat conditions surrounded turbines (ploughed agricultural fields or wheat stubble as wheat crops were not produced adjacent to turbines). In some studies both small and large birds were used in trials (e.g. Erickson *et al*. 2000 reported searcher efficiency rates of 50.0% for small birds and 87.5% for large birds). In another study the overall observer detection were recorded as 78% detection rate for medium/large carcasses and 42% of small carcasses (Erickson *et al*. 2004). However, detection rates for smaller birds were similar in cultivated agricultural land (39%) and grassland (43%).

Rodrigues *et al.* (2008) state that classification of ground cover (height of vegetation, type of vegetation, season) is required, as this influences detection of fatalities. They recommend searcher efficiency trials to be conducted four times a year (to take account of variable vegetation heights). Bat bodies should be randomly distributed, their locations noted and the searcher should conduct their search as usual.

In most trials personnel did not know when trials were scheduled until the first trial bat or bird (discretely marked) was found (e.g. Erickson *et al*. 2004; Ed Arnett, *pers. comm*.; Erin Baerwald, *pers. comm*.). However, personnel were not aware of the number or locations of carcasses used in each trial. The proportion of carcasses remaining for the searcher efficiency trial was determined immediately after the trial by the person responsible for distributing the carcasses, because scavengers may have removed trial birds before searches were conducted (Erickson *et al*. 2004).

Dogs have been used to search for bat carcasses. When the dog searcher efficiency was tested the dogs found 71% of bat carcasses at Mountaineer and 81% of those at Meyersdale (Arnett 2006). These results compared favourably against human searchers who found only 42% of carcasses at Mountaineer and 14% at Meyersdale. Both dogs and humans found a higher proportion (88% and 75%) of trial bats within 10m of the turbine, as this area usually has open ground and hence greater visibility of carcasses. In this study as vegetation got higher and denser humans found fewer carcasses during searcher efficiency trials, whereas dog search efficiency remained high. Therefore, if sites have low visibility it may be most appropriate if well trained dogs are used in fatality searches. Alternatively, where dogs cannot be used for fatality searches, site selection may need to take into account the type of vegetation surrounding the immediate area of each wind turbine because if this is high and dense fatalities might not be found at all; particularly if there are low collision rates occurring at the site.

Currently only one study has using dogs to detect bats has been reported in Europe, the study was carried out in the Czech Republic (presented on a poster at the 1st International Symposium on Bat Migration held in Berlin 2009). For the study Australian shepherd dogs were used, but the results were not available (Rehak *et al*. 2009). Rodrigues *et al*. (2008) note that a dog trained to point at bats may be used but its search efficiency should be tested in the same way as for human searchers. A pointer dog, which do not remove whatever they are trying to locate, is preferred to a retriever by Rodrigues *et al*. (2008), which allows the precise location of the carcass to be noted. However, Arnett (*pers*. *comm*.) explained that it can be difficult to engage pointers in fatality searches if birds are located on the site as they are distracted and chase the birds (this is less of a problem on sites with high and dense vegetation because the pointers remain more focused) and recommends using Labradors.

Because dogs will not be available for use at all sites, the use of dogs would increase biases in searcher efficiency across sites, and we do not recommend their use in searcher efficiency trials in the UK.

Estimation of carcass removal through field trials

Carcass removal trials estimates the proportion of carcasses that are likely to have been removed through scavenging or by other means (e.g. a field being ploughed as suggested by Erickson *et al*. 2000) between search intervals. In other words, these trials enable fatality rates to be corrected by calculating the length of time bat fatalities were likely to remain in the search area.

Carcass removal trials have been conducted within and outside of the search areas of turbines being used for fatality searches. Where carcass removal trials are conducted away from the search plots in some studies these locations were randomly-selected within the same wind farm (Johnson *et al*. 2003a); in others they were at turbines near the fatality search plots (Johnson *et al*. 2003b). In one study four trials, each with 10 fresh hoary bat carcasses, were carried out during routine fatality searches. Bat carcasses were placed completely exposed, hidden or partially hidden in different habitats to simulate positions of bats that were killed and wounded, and these were monitored daily for 14 days to determine scavenger removal rates (Johnson *et al*. 2003). In another study methods are described in which field crew periodically placed trial carcasses outside of the fatality search areas and monitored them over time, but no details are provided on the length of time for which monitoring was continued (Erickson *et al*. 2004).

In Europe, Rodrigues *et al*. (2008) recommend trials at least four times per year to take account of variable vegetation heights in the search area. Frozen but defrosted bat bodies are preferred, if available, but in most cases small passerines or one day old chicks (preferably dark in colour) should be used. Each trial should last for 10 consecutive days to see how long a carcass stays on the ground before being eaten, removed or buried by mammals, birds or insects.

It is recommended to conducting carcass removal trials under a range of conditions, to allow for differences in scavenging to be accounted for (Brown & Hamilton 2006). Erickson *et al*. (2000) carried out two carcass removal trials in each of the four seasons: winter (1 Jan – 31 Mar), spring (1 Apr – 30 Jun), summer (1 Jul – 30 Sep), and autumn (1 Oct – 31 Dec). Instead of using different turbine locations, carcasses were placed randomly between 5m to 25m away from fatality search areas to prevent confusion with other carcasses. During each season 10 carcasses of birds of two sizes – small and medium to large, resulting in a total of 80 trial carcasses being used (different bird sizes were also used by Johnson *et al*. 2003b). The small birds used were Brewer's blackbird (*Euphagus cyanocephalus*), or juvenile northern bobwhite.

However, they monitored carcasses over a 28 day period but not on consecutive days; carcasses were checked every day for the first 4 days, and on days 7, 10, 14, 20 and 28.

In contrast to some trials, Brown and Hamilton (2006) used the remaining carcasses that had been used in the searcher efficiency trial, after removing any carcasses that were decayed or highly desiccated. All remaining carcasses were monitored for 14 days and were marked out with a flag 2m due north of the carcass to aid relocation but not interfere with the trial. If any of the carcasses were not seen during a routine search, the surveyor searched a 10m radius around the area. The probability of the carcass not being removed and available to be sampled was calculated each week by dividing the number of carcasses remaining at the end of the trial by the number of carcasses at the beginning of the period. The overall disappearance rate used was the average weekly values.

Of the eight carcass removal trials that Arnett *et al*. (2008) reviewed, bat carcasses remained *in situ* between 1.9 and 12 days on average while bird carcasses lasted as long as 23 days. However, no reference was made to the size of bird carcasses used. Most studies have shown that carcasses are largely removed by insects, particularly maggots and carrion beetles (e.g. Johnson *et al*. 2004; Johnson *et al*. 2003b) with carcasses lasting on average 10.5 days on gravel turbine pads and 10.4 days in other habitat types at Buffalo Ridge wind farm (Johnson *et al*. 2004). Forty-eight percent of carcasses remained after 7 days and 30% remained after 14 days (Johnson *et al*. 2004) but other studies have shown carcasses remaining within the search area on average 25 days before being removed and report differences in removal rates in relation to the size of the carcasses (i.e. small birds were removed on average 16.7 days) (Erickson *et al*. 2000). In scavenger removal trials 64 carcasses were used and recorded the length of time the carcass remained to be 14.2 days on average for small carcasses and 19.9 days on average for large carcasses. After seven days in the field 81% of large and 59% of small carcasses remained *in situ*, by 28 days the carcass remains had reduced to 22% and 16% respectively.

From the literature reviewed, no trials have compared removal rates of bird and mice carcasses. However, Brinkmann *et al*. (2006) monitored frozen laboratory mice placed in open, overgrown and heavily overgrown areas for 10 consecutive days. The mice used were a similar colour to but slightly larger than a Leisler's bat (head and body length: up to 80mm compared to a Leisler's bat ranging between 50-65mm) and to minimise human odour on the carcasses gloves were worn during handling bat fatalities. In this study it was found that after only six days on average, more than 90% of the mouse carcasses could no longer be traced. However, there was a high variation in removal rates as all carcasses were removed on the second day of the trial at one location, but carcasses remained considerably longer at other turbines. To evaluate the overall carcass removal rate, the authors averaged the carcass removal rate over the first five days, which resulted in an average removal rate of 58.8%. At this rate it would mean that only 41.2% of bat fatalities would be available to be found during fatality searches if carried out every fifth day, which emphasises the importance of completing sampling bias trials to enable appropriate adjustments to be made of fatality search results. Leukona (2001) and Petri and Munilla (2002) (cited by Rodrigues *et al*. 2006) give 'disappearance' (removal) rates of 57% and 67% in July and November respectively over 24 hours and 70% and 80% in July and November respectively over 48 hours. Similar figures of 70% removed after 24 hours and 85% after 48 hours were stated by Kusenbach (2007; cited by Rodrigues *et al*. 2008).

Extremely high scavenging rates by crows and ravens have been reported, particularly first thing in the morning (Arnett *et al*. 2003b) and other predators have included: raptors, turkey vultures, common ravens, gulls coyotes and badgers (Johnson *et al*. 2003b). When carcasses were scavenged by insects (mostly burying beetles), the carcass continued to be monitored until it was no longer visible. Additionally Brinkmann *et al*. (2006) noted wasps, bottle flies, shrews, mice and small carnivores feeding on bat carcasses, and fox droppings were frequently found indicating that they could be responsible for a large number of carcasses being removed from the search areas. However, they also noted that no diurnal birds of prey or corvids were observed removing carcasses.

Carcass removal trials need to simulate fatalities and care should be taken not to 'over seed' the area with bat/bird/mice carcasses as this could result in an influx of predators or scavengers, or alternatively this may 'over saturate' the area and carcasses may be left for longer than they would normally (Manuela Huso, *pers. comm*.). It is therefore important to estimate a reasonable number of carcasses to be put out for these trials.

In summary, we recommend the following survey effort to determine whether bats are being killed at operational wind farms in Britain based on work completed to date in North America and mainland Europe as described in this section:

- intensive fatality searches in late summer and early autumn (August and September);
- fortnightly fatality searches at three core sites in April – July and October each year in addition to the intensive searches;
- multi-year fatality searches at the core sites to determine inter-year variation in fatality rates;
- geographical distribution of the other sites (seven each year) to determine whether bats are being killed at a national level;

- to carry out searcher efficiency and carcass removal trials to adjust any fatality rates if bat carcasses are found; and

- collate data on weather conditions and features that would be used by bats on site to allow data analysis to be undertaken to determine any correlation.

2.3.5 *Training*

The training provided to searchers prior to commencing fatality searches is not detailed in any of the literature; however the length of training provided in North America is between one to two weeks (Ed Arnett, *pers. comm*.; Erin Baerwald, *pers. comm*.). The training provided is largely field based and trainers on site determine when searchers have received enough training. As all British bat species are protected, and newly trained searchers will be independently we consider it appropriate to for searchers to be provided with high quality training in legislation, why the project is being run, survey methods, bat ecology and conservation, and health and safety (the training programme outline is detailed in section 5).

2.3.6 *Summary and discussion of bat fatality results*

Very high numbers of migratory bats are being killed in North America, with estimates of mean bat fatality per turbine ranged from 0.1 to 69.6, with the highest fatality estimates reported for forest ridges. For sites in the upper Midwestern United States this translates to estimates ranging from 0.2 to 8.7 bats/MW of turbine energy (Arnett *et al*. 2008). Brown and Hamilton (2006) state that the mean number of bats recovered (unadjusted) was 13.64 bats/turbine/year, which ranged between 4 and 29. This figure was then related to output as 7.58 bats/MW/year. However, the fatality rate increased to 18.48 bats/turbine/year after adjustments to account for searcher efficiency and carcass removal were made.

In Europe a total of 1,503 bat fatalities have been recorded in Europe since the first report in Germany in 1998. Nineteen different species are represented among the fatalities and they have been reported from 11 countries. Estimates of fatalities range from 1.34 – 27.2 per turbine per year (for full details of individual studies refer to Appendix 4).

To date, there have been no systematic surveys for bat fatalities in Britain. Bat fatalities have been recorded at three wind farm sites, two in Cambridgeshire and one in Scotland. In two cases, the principal aim of monitoring was to determine avian fatalities. In the third site in

Cambridgeshire, a single bat fatality was discovered during pre-construction surveys for a proposed extension.

In Cambridgeshire, avian mortality monitoring was completed at the Coldham wind farm site between October 2006 and October 2007 (Bioscan (UK) Ltd 2008). The site consists of eight 2MW Vestas turbines which comprise a 40m radius blade on top of a 60m tower, giving a total turbine height of 100m to blade tip. The site is located in flat arable land at around sea level surrounded by drainage ditches, and is adjacent to the River Nene.

Monitoring was completed on a weekly basis with a square area around each turbine searched for corpses to a minimum distance of 60m from the turbine base. Five bat corpses were found in the autumn of 2007; four on the 6th September 2007, and a further one on the 12th October 2007. DNA analysis completed by the Central Science Laboratory on three of these corpses suggested that they were soprano pipistrelles, and it is likely that all bats found were of this species. An additional bat (unidentified) was also recovered by a member of the public on 1st August 2007. Three of the six fatalities were recorded at a single turbine, which was located very close to the River Nene. Five of the six bats were located within 20m of the turbine.

A test of observer detection rates for bats was also completed at the site. The rate of detection of planted bat corpses was 66%. Adjusting for this detection rate, the collision rate is estimated to be 1.24 bats / turbine / year at the Coldham site (approximately 10 bats / year for the site).

A single common pipistrelle fatality was recorded at Ransonmoor wind farm in Cambridgeshire in autumn 2008. The bat, a juvenile with obvious injuries, was found around 40m from a turbine base during fatality surveys completed in September and October 2008. The site, which comprises three 2MW Gamesa G80 turbines, is located in open fenland.

Two bat fatalities, identified as adult soprano pipistrelle bats by John Haddow (Auritus Wildlife Consultancy Ltd), have been recorded at the Braes of Doune wind farm site during avian fatality searches (Duffy & Steward 2008). Monitoring was completed over a 130 x 130m square around each turbine on a weekly basis, sampling 3 of the 36 turbines each week, rotating around all turbines over 12 weeks. The first bat was found on 5th October 2007, the second at a different turbine on 28th July 2008. The first bat had a broken left forearm, but the second bat had no obvious external signs of trauma. The Braes of Doune site consists of 36 2MW Vestas turbines located on open moorland between around 350 and 500m agl.

An Anabat bat detector was set up to monitor bat activity at a location within 200m of the turbine at which the second bat fatality was recorded. The Anabat bat detector was left to record bat activity at approximately 2m agl for a week in September 2008 between dusk and dawn. No detailed analysis of the data has been completed, but regular activity of soprano pipistrelles was recorded (on 5 of the 8 nights of data gathering), with very low numbers of bat passes of common pipistrelle and *Myotis* species also recorded (John Haddow, *pers*. *comm*.).

A more detailed account of factors relating to bat fatality studies are listed below:

Species composition

As previously discussed 11 bat species have been killed at wind energy facilities to-date in North America; and the majority were tree or foliage roosting, long distance migratory species (e.g. 75% - Kunz *et al*. 2007a). Fatalities of summer resident species were usually recorded in relatively low numbers. Arnett *et al*. (2004) recorded 466 bat fatalities at Mountaineer Wind Farm, comprising six bat species (hoary bat, eastern red bat, eastern pipistrelle, little brown bat, silver-haired bat, and big brown bat, from highest to lowest number found). More males than females and more adults than juveniles were recorded amongst the fatalities. At Meyersdale Wind Farm 290 bat fatalities were recorded, comprising seven species (hoary bat, eastern red bat, eastern pipistrelle, silver-haired bat, big brown bat, little brown, and northern long-eared bat, from the highest to lowest numbers found). As with Mountaineer more adults and more male bats were recorded during the examination of carcasses. Yet unlike many of the other studies of the 111 bat fatalities recorded 86% were Brazilian free-tailed bats, other bat species recorded include the eastern pipistrelle, big brown bat, silver-haired bat, red eastern bat and hoary bat (Piorkowski 2006).

The highest numbers of bat fatalities in Europe have been reported for common pipistrelle, noctule, Nathusius' pipistrelle, and to a lesser extent Leisler's bat and serotine. Noctule, Nathusius' pipistrelle and serotine have been defined as long distance migrants in Europe, whereas Leisler's and common pipistrelle have been described as regional migrants (Hutterer *et al*. 2005). However, there is some debate over the migratory status of common pipistrelle and Dubourg-Salvage *et al*. (2009) reported that overall 55% of bat fatalities were potential migrants (see section 2.1.3).

Habitat type of search area

When working on sites with low visibility it may be appropriate to alter methods of searching or to undertake extensive searcher efficiency trials to make accurate adjustments to numbers of fatalities found. However, there are implications of changing survey methods for data analysis, and this would need to be considered before making changes within a survey season. During fatality searches bats are nearly twice as likely to be found on grassland habitat, than on agricultural areas (Kunz *et al*. 2007). However, it is unclear whether grassland is pasture or natural grassland.

Further evidence of the significance of habitat types was demonstrated by a study undertaken at a large wind farm in Minnesota; at this site, detection rates for searcher efficiency trials of humans were very high (75% for small birds) when compared to below 20% at other sites (Johnson *et al*. 2004). The authors explain this difference was due to the habitat in the turbine search area (which was ploughed agricultural field or wheat stubble, as wheat crops were not grown adjacent to wind turbines). In another study detection rates for small birds were similar in cultivated agricultural land (39%) and grassland (43%) (Erickson *et al*. 2004). Of the 21 studies reviewed by Arnett *et al*. (2008), 76% were located within agricultural cropland or landscapes with mixed habitats that included cropland, grazed and ungrazed grassland, pasture, woodlots, or habitats set aside by Conservation Reserve Programme. Ten percent were located in short grass prairie and 15% in completely forested habitat on ridges. However, bat fatalities were highest at wind turbines that were in close proximity to forested ridges even though searcher efficiency was lowest within forested sites (25-42%) and highest in open habitats (42-75%). Brinkmann *et al*. (2006) found more dead bats around wind turbines situated in forest than at the forest edge (Figure 2-8). No dead bats were found around wind turbines situated in open meadow, despite bat activity being recorded there also. Conclusions were drawn that, in forests, resident bat species that are more at risk from turbines than migratory bats.

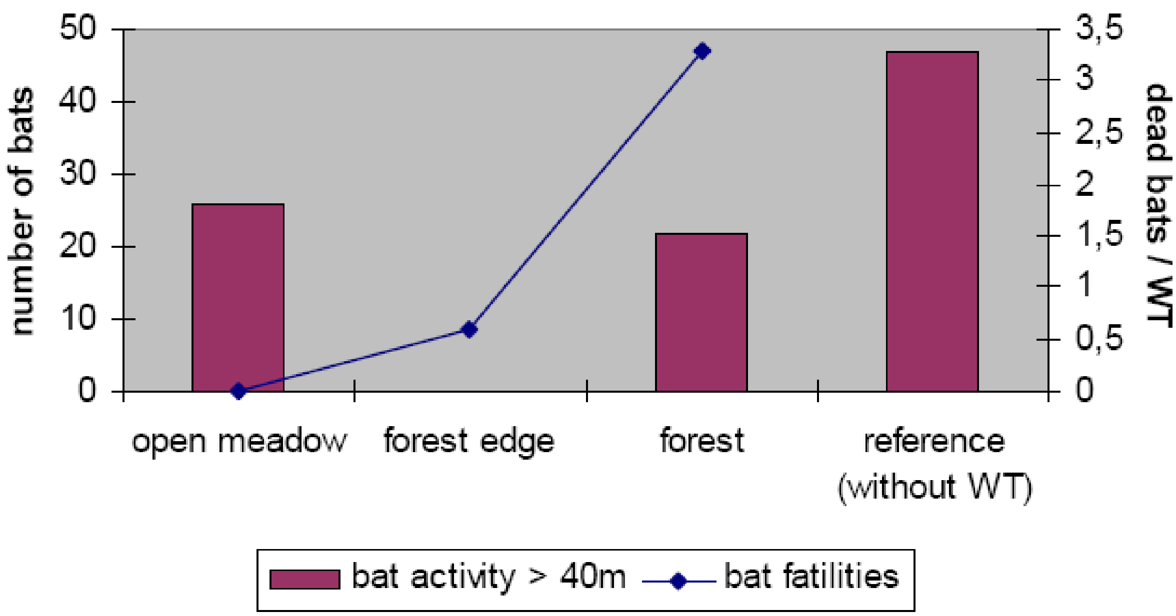


Figure 2-8: Influence of habitat type on bat fatality rates in Germany (Brinkmann *et al*. 2006; cited by Dubourg-Savage *et al*. 2009).

Dürr & Bach's (2004) review of the German data on bat fatalities showed that 77% of dead bats were found beneath turbines less than 50m from trees. Although the sample sizes were rather small, analysis by species showed that mortality of *Pipistrellus* species occurred mostly near trees, but for noctule mortality occurred at a mean distance of 200m and a maximum of 600m from woodlands. There is some evidence in Germany that bats are at greater risk of colliding with wind turbines when wind energy facilities are located close to woodland than open habitats (Bach 2002; cited by Hötker *et al*. 2006), with disproportionately high fatalities of Nathusius' pipistrelle, common pipistrelle and greater mouse-eared bats close to trees and hedgerows (Dürr 2003b; cited by Hötker *et al*. 2006). In another Germany study, based in Brandenburg (Bach & Harbusch 2005), 77% of the fatalities were found at turbines within 50m of hedgerows or treelines (Figure 2-9).

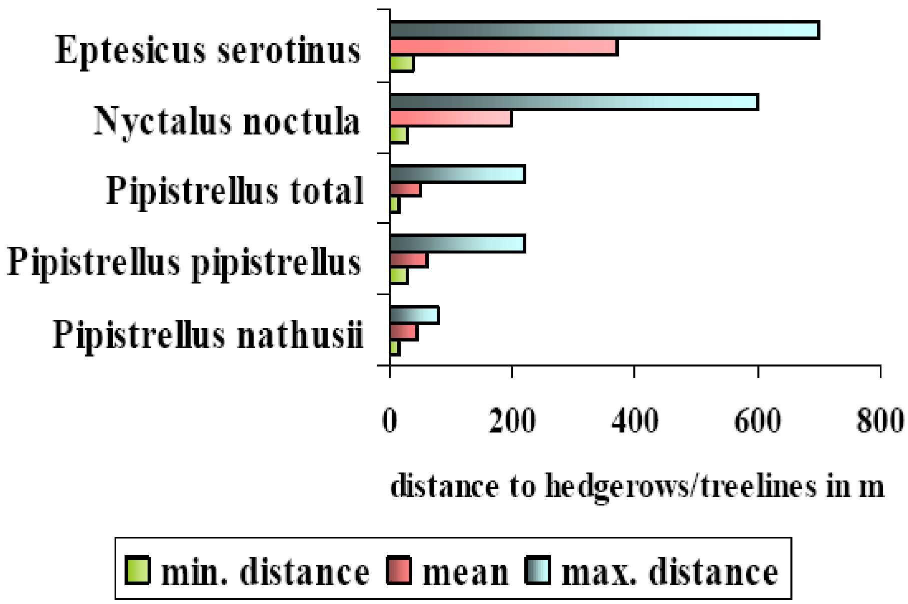


Figure 2-9: Distance to hedgerow or treeline bat fatalities were found (taken from a presentation prepared by Bach and Harbusch 2005).

Peaks in fatalities

Across North America and Europe the majority of fatalities have been reported in late summer and early autumn, with some studies reporting up to 97% of all fatalities during this time. Although highly variable and periodic, bat fatalities throughout the 21 studies reviewed by Arnett *et al*. (2008) in the United States and Canada consistently peaked in late summer and autumn, coinciding with migration of lasiurines and other species. Brown and Hamilton (2006) also found the majority of bats were being killed in August and September. However, at Buffalo Ridge (Minnesota) Osborn *et al.* (1996) recorded higher fatality rates in summer than in autumn. Notable exceptions to the general trend for an autumn peak were the documentation of pregnant Brazilian free-tailed bats being killed during May and June at a wind farm in Oklahoma, and female silver-haired bat fatalities recorded during spring in Tennessee and Alberta (Arnett *et al.* 2008). However, further details of these fatalities are not provided in the review.

Bats in Europe have also been killed predominantly in late summer and autumn and most species affected were fast-flying and migratory species (Dürr 2003b; cited in Hötker *et al*. 2006). Dubourg-Savage *et al.* (2009) presented a graph (after Dürr 2007) showing that mortality peaked in Germany between mid-July and the end of September (Figure 2-10). A similar graph attributed to Dulac (2008) showed peak fatalities varying between the late summer and early autumn on a migration route over four years (Figure 2-11). Brinkmann (2006) also showed a main peak at the beginning of August in Frieburg in Germany. In Portugal (a study cited in Dubourg-Savage *et al.* 2009 – source unknown), however, most fatalities were recorded in May and June, with a moderate level in July, August and September (as Figure 2-12). This last study presents a different pattern of results from others in Europe, but it is likely that the level of fatalities in different seasons will vary depending on latitude, and on whether the wind turbines are close to resident bat populations or are located on a migratory route.

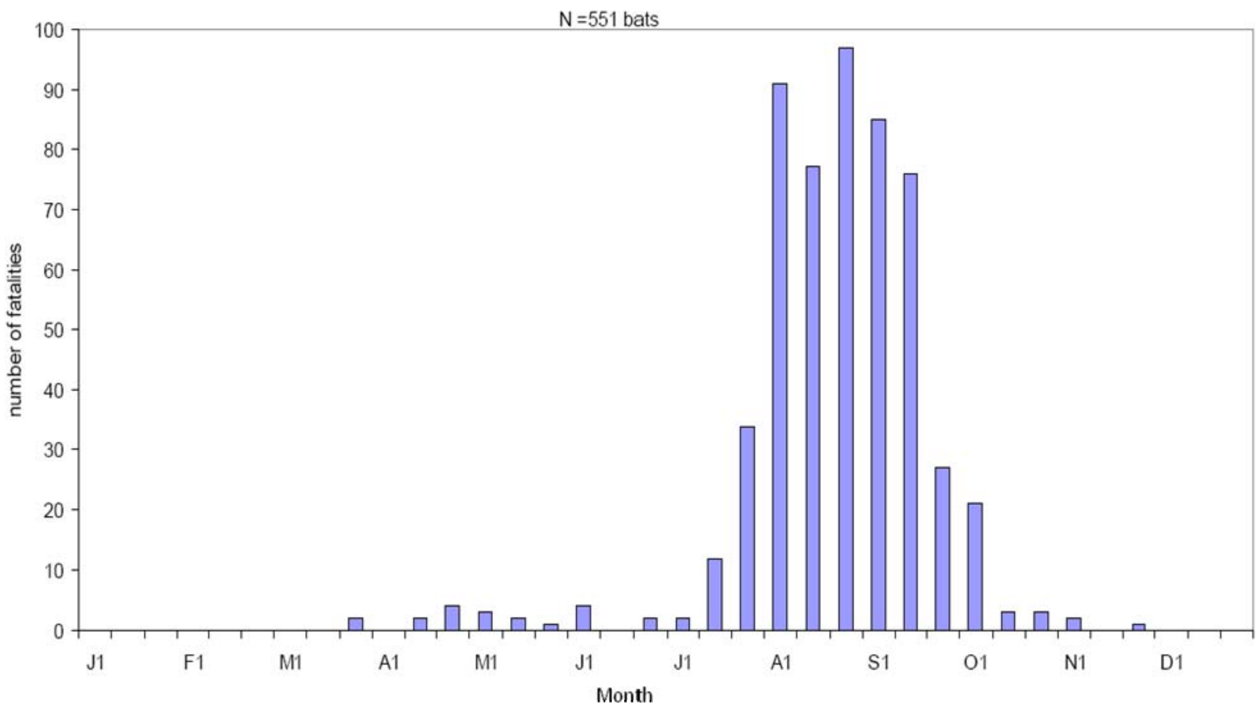


Figure 2-10: Seasonal variation in mortality in Germany over late summer and autumn (Dürr 2007; cited by Dubourg-Savage *et al*. 2009).

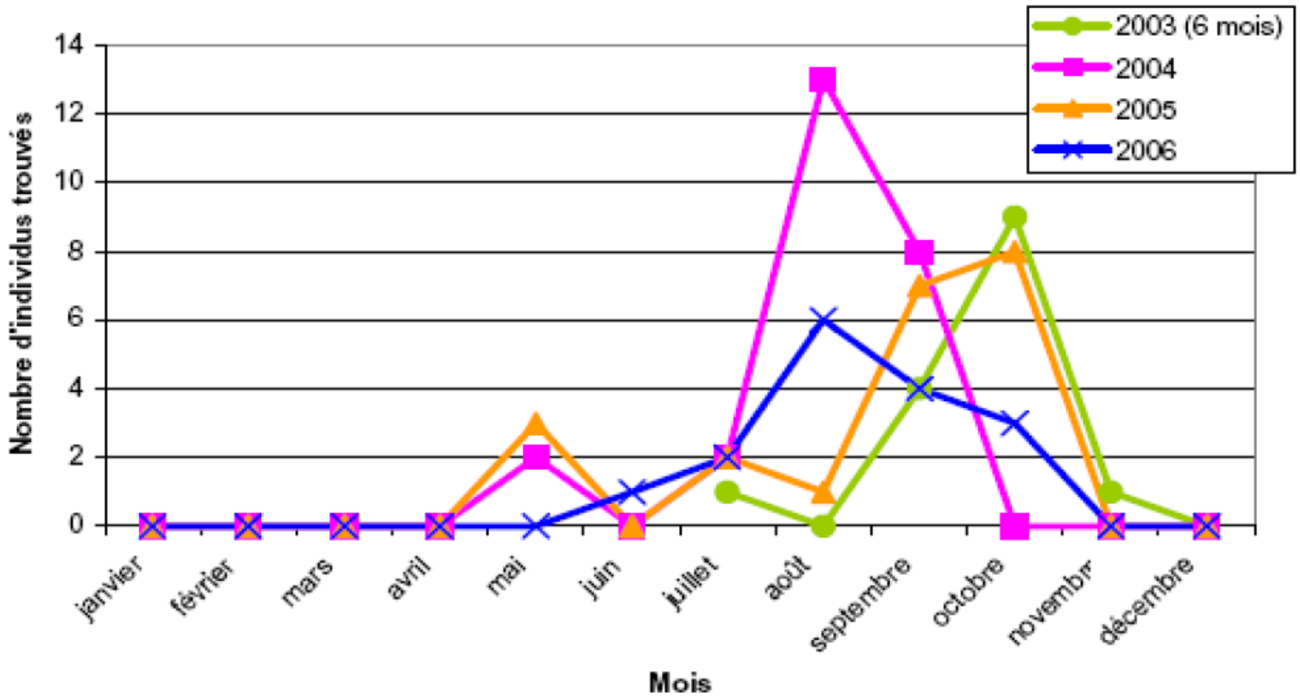


Figure 2-11: Seasonal variation in fatalities at a site located along a migration route in France (Dulac 2008; reproduced from Dubourg-Savage *et al*. 2009).

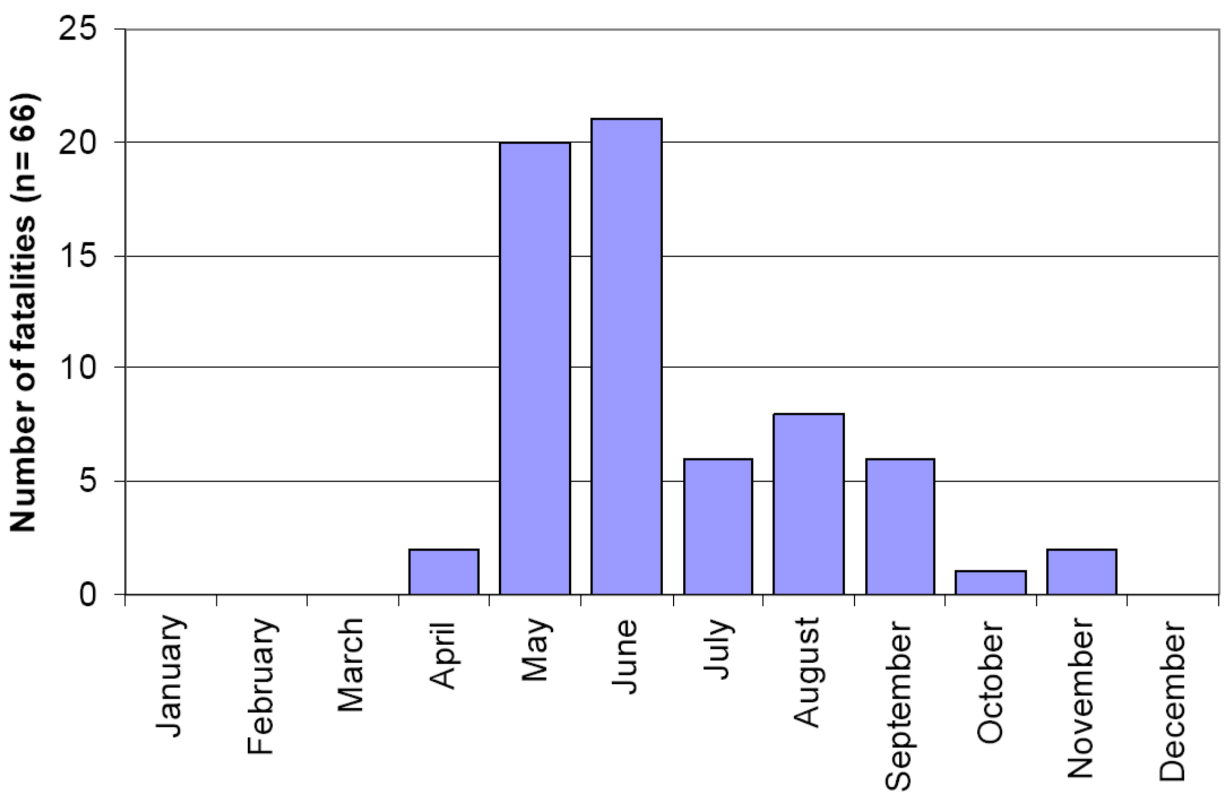


Figure 2-12: Seasonal variations in bat fatalities in May and June in Portugal (reproduced from Dubourg-Savage *et al*. 2009).

Factors influencing fatality rate

Tower height and rotor swept area

Barclay *et al*. (2007) found bat fatality rates increased with tower height but not with rotor-swept area in Alberta, Canada. In this study an example was given of Buffalo Mountain wind energy facility (Tennessee, U.S.A.) which has three tall towers (65m) with relatively small rotors (47m diameter) but had the second highest corrected bat fatality rate of the sites for which they had collected data.

Dubourg-Savage *et al*. (2009) also cited unpublished data from Dürr showing the relationship between rotor height and the number of dead bats of the five most common species. Rotor heights of 31-50m appear to result in most fatalities for noctules, 31-40 for Leisler's bat and 20-50m for Nathusius' pipistrelle but there were fatalities under all heights of turbine blade from 20m to 80m (Figure 2-13). Dürr and Bach (2004) presented data from Germany on the relationship between rotor axle (nacelle) height and bat fatalities. No fatalities occurred when the rotor axle was lower than 50m. Fatalities occurred at all heights between 51m and 100m. It would appear that more fatalities were found at turbine heights of 61-70m, 71-80m and 91-100m. However, no statistical analysis had been performed and there was no control for factors such as different numbers of surveys conducted at each site such as season and site characteristics.

The capacity of the turbine has also been shown to affect fatality rates; in Germany Hötker *et al*. (2006) cited by Dürr (*pers*. *comm*.) noted that no fatalities were found around turbines that have a capacity of less than 500kW. This could be related to tower and blade size, however, as smaller capacity turbines generally have smaller blades and shorter towers.

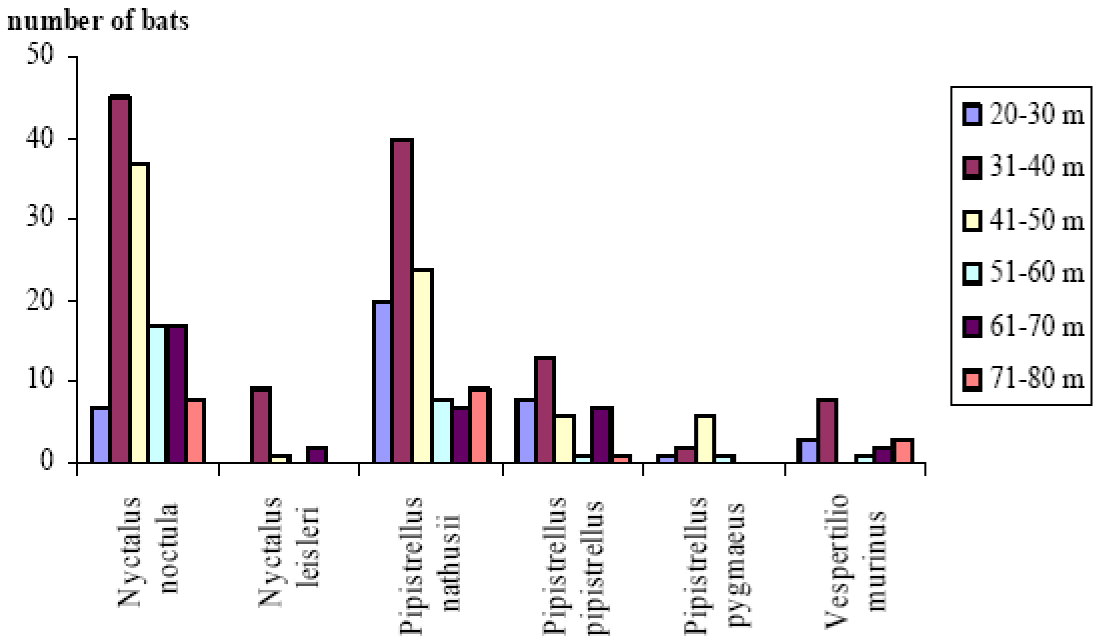


Figure 2-13: Relationship between bat fatalities of the five most common species killed at wind turbine sites against wind turbine height (unpublished data from Dürr; cited by Dubourg-Savage *et al*. 2009).

<u>Turbine operation</u>

At Mountaineer Wind Farm a non-operational turbine (blades feathered but allowed to free-wheel) was included in the fatality searches but no fatalities were found (Arnett *et al.* 2004). The first U.S-based curtailment experiment was conducted by changing turbine cut-in speeds on (Arnett *et al*. 2009). During the experiment bat fatalities were significantly reduced by changing turbine cut-in speed and reducing the hours the turbine was operational during low wind speeds. The curtailment of these turbines resulted in nightly reductions of between 53 and 87% in bat fatality, which indicates that bats have more difficulty detecting operational wind turbine blades.

<u>Lighting</u>

At both Mountaineer and Meyersdale wind farms, fatalities were distributed independently of Federal Aviation Administration (FAA) lighting (Arnett *et al*. 2004). Johnson *et al*. (2003a) also did a comparison between lit and unlit turbines, but found no significant difference in bat mortality in each group. However, these studies investigated strobe lighting and if lights used on turbines in Britain are different they will need to be investigated. The Civil Aviation Authority (CAA) is responsible for safety regulation of the civil aviation in the UK under the Civil Aviation Act (1981) and has produced a policy and guidance document on the impacts of wind turbines on aviation (Civil Aviation Authority 2006). As part of their requirements all 'obstacles' greater than 150m in height, located away from airfields (aerodromes), are required to be fitted with a medium intensity steady red light positioned on top of the structure. Currently in the UK no wind turbines exceed 150m, however five wind turbines in the UK have been fitted with lights because they are located in 'critical' areas (e.g. close to the M4 where police helicopters are in operation) (Jan Matthiesen, *pers*. *comm*.). Consequently, it is not considered necessary to consider impacts of lighting on turbines into this research project but there may be future implications as BWEA are currently in discussions with the Ministry of Defence (MoD) over lighting requirements for low altitude flights.

Artificial lighting from certain types of lamps, particularly lamps that produce ultra-violet (UV) light, is known to attract a range of insects and certain bat species (especially the fast-flying, open-space species most at risk from wind turbines) have been observed routinely feeding on insects attracted to artificial light sources, such as street lighting (Rydell 2006). Due to the increased density of insects certain bats are known to feed around these lights (such as noctules, Leisler's bats, serotines and pipistrelles), particularly white mercury vapour street lights and to a lesser extent high pressure sodium vapour lamps (Rydell 2006). The reason insects are attracted to these lights is because mercury lamps produce a bluish white light that includes ultraviolet light and high pressure sodium lamps produce mostly orange but some ultraviolet light (Rydell 2006). The other most commonly used street light is low pressure sodium vapour lamps, which emit monochromatic yellow light that does not include any ultraviolet and consequently does not attract flying insects (Rydell 2006). Slow-flying species such as horseshoe bats appear to be averse to flying in lit conditions (Stone *et al*. 2009).

If there is a sharp increase in lighting on wind turbines across the UK measures to mitigate against the potential effect of attracting insects and consequently bats to turbines should be taken to ensure that the lights installed do not produce any ultraviolet light.

Wind speed

In general more bats are active and more fatalities are recorded on nights when wind speed is low (<6m s^{-1}) (Kunz *et al*. 2007a). Rodrigues *et al*. (2008) cited studies showing that bats were significantly more active at low wind speeds (<5m s^{-1} taken from Behr *et al*. 2007; 6m s^{-1} taken from Grunwald & Schäfer 2007). Behr *et al*. (2007) found that the highest wind speed bats were active at was 6.5m s^{-1}; however noctules were recorded flying in wind speeds of 8m s^{-1} (Grunwald & Schäfer 2007; cited by Rodrigues *et al*. 2008). Dubourg-Savage *et al*. (2009) presented a graph (taken from Bach & Bach 2008 and Behr & von Helversen 2006) showing that 95% of noctule, serotine and Nathusius' pipistrelle bats stopped flying above 8m s^{-1} (Figure 2-14).

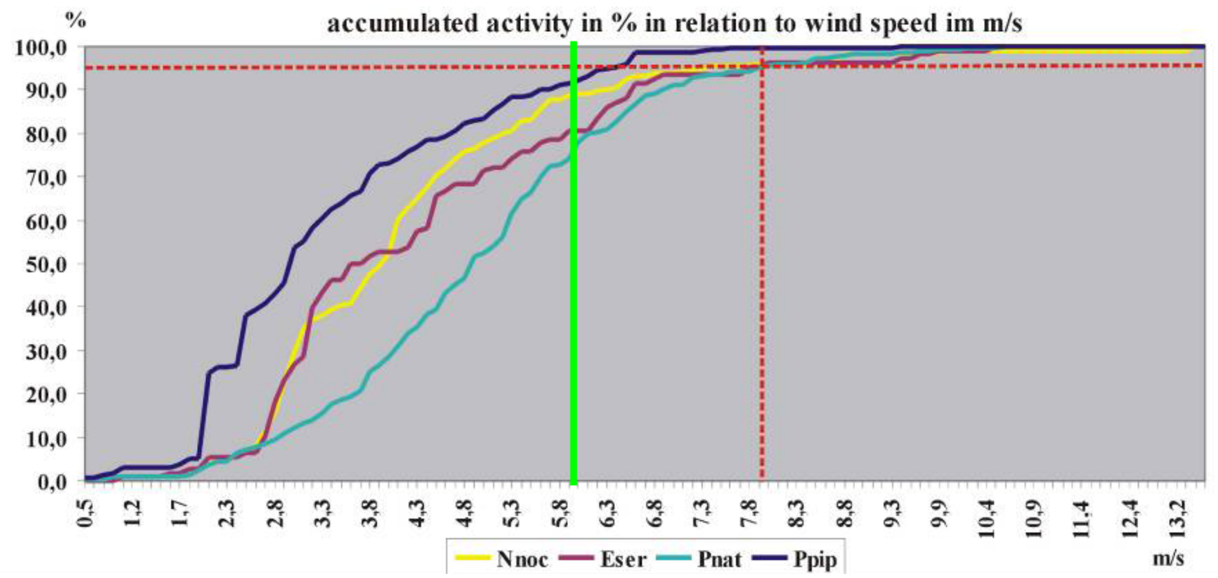


Figure 2-14: Accumulated activity in relation to wind speed (taken from Bach & Bach 2008 and Behr & von Helversen 2006; cited by Dubourg-Savage *et al*. 2009).

The highest bat fatalities have been recorded on nights when wind speed is relatively low (<6 m s^{-1}) (Kunz *et al*. 2007a). Arnett *et al*. (2008) estimated fatalities of 82% at Meyersdale and 85% at Mountaineer occurred on nights where median nightly wind speed was <6m s^{-1}. Conversely, Arnett *et al*. (2008) note that when median nightly wind speeds were >6m s^{-1} no bat fatalities were reported the next day on 81% of occasions.

2.4 Data analysis

Data analysis methods used for wind farm studies and other relevant papers have been reviewed to determine the best data analysis methods for both acoustic surveys and fatality searches and are detailed in sections 3.3.7 and 3.4.3 within the Recommended Methods section.

2.5 Other surveys

2.5.1 Radar

There is more than one way of applying radar to monitoring bats. Doppler weather stations, marine radar systems or more advanced radar systems can be used. All radar systems can detect bats at greater distances than other techniques and gives information on numbers, direction, velocity and altitude. However, all of these techniques are expensive and have the same major drawback of having difficulty in differentiating between bats, birds and insects, although work is currently being undertaken to help resolve this: even if ‘objects’ can be distinguished, radar cannot be used to distinguish species at present.

Weather station information is at a scale suitable for migratory movements; whereas marine radar has been used to look at nightly spatial movements of large colonies of bats. The system is the same as that used on boats for navigation and has a 6km range. Marine radar is less expensive and more readily available. The antenna is deployed on top of a van and can be positioned either horizontally or vertically. A video capture device is used to display the resultant information. The direction of movement of the bats shows as a trail on the images. The system has a number of limitations, most importantly the difficulty in distinguishing between birds, bats and insects. Another important consideration is the need for a clutter and shadow free location; proximity to buildings and ground vegetation is likely to cause a cluttered image that is difficult to interpret. Furthermore, detection is not equal across the screen, horizontal and vertical cannot be done together and dispersed bats are hard to see with tight groups being easier to detect. There is work ongoing to distinguish bats from birds.

New radar technologies are more expensive at about $250,000 (currently approximately £170,000). They include a computer program to remove a lot of the ground clutter by eliminating anything not moving, but this can result in some losses of slow moving bats perceived as stationary because of the direction of movement of the bat relative to the radar. Bat and bird differentiation remains difficult but data on wing beat frequency may allow isolation of bats although overlaps with both birds and insects appear large (Bruderer & Popa-Lisseanu 2005). The pattern of flapping may help to distinguish bats at close range. The UK has one of these systems with a scissor lift platform up to 36 feet (approximately 11m). The system is small enough to be pulled by and all-terrain vehicle (ATV).

Radar systems present the possibility of surveying the movements of large numbers of bats over a wide area and at great vertical height, rather than individuals or smaller numbers of dispersed bats making use of the landscape. Radar is expensive and does not appear fit for the purpose of researching the impacts of wind turbines on the bat population in Britain. It may however, have an application in furthering our knowledge of the movement of any migratory bats between the UK and the rest of Europe. Given that radar may deter bats (Nicholls & Racey 2007, 2009) its use as a monitoring tool is open to question. However, for the purposes of this study the priority is to determine whether bats are being killed we therefore do not consider the use of radar a priority.

2.5.2 Thermal (passive) infrared imaging

Thermal infrared (TIR) imaging is termed passive imaging as it relies on detection of the heat of an object which is emitted in the infrared part of the spectrum, to which the detection unit is sensitive. Active infrared imaging involves the use a source of infrared light being shone onto the target area to allow detection by the imaging unit.

Harbusch and Bach (2005) suggest the use of infrared cameras or night vision goggles could prove useful to survey bat activity at height, particularly for whispering bat species that are unlikely to be detected on automated bat detectors. Rahmel *et al*. (2004) suggest that high-quality thermal imaging is more reliable for recording bats flying at altitude than using detectors, especially if bats are not echolocating or echolocate with large gaps between the calls. Rodrigues *et al*. (2008) note that a downside of this technology is its cost. High quality thermal imaging cameras typically cost around £25,000. The use of two cameras potentially allows stereo techniques to reconstruct flight paths, and to determine flight heights of bats. TIR imaging can also be used as a non-invasive technique to estimate colony numbers by recording bats emerging from roosts (Ammerman *et al*. 2009). In one study recordings of the entire emergence of bats from the main exit point were used to determine when the greatest number of bats were present (June, July or August); the data suggest this method provides a more reliable and accurate estimate than estimating bat numbers from surface cover on a cave ceiling (Ammerman *et al*. 2009).

Arnett *et al*. (2004) used TIR technology to evaluate bat abundance and timing of activity, as well as the interaction of bat flight behaviour at operating wind turbines. The experiment was undertaken by placing three TIR video cameras (FLIR S60) at a single turbine each night from sunset to sunrise (9 hr dataset) between 2 and 27 August 2004. In order to observe bat-turbine interactions the three cameras were set up using 45° field-of view (FOV) lenses to simultaneously record data. Cameras were positioned beneath turbines at elevation angle of approximately 60°, giving a FOV measured 32m high, and 43m wide and recorded continuously. The recordings were examined and analysed in detail for flight activity and fatality searches were undertaken the next morning. ‘Targets’ were defined as bird, bat or insect based on a set of criteria consistent with the ecology and known flight behaviour of each (such as wing beat frequency, flight path and manoeuvrability). Arnett *et al*. (2004) described the activity as highly variable, and frequently observed bats flying through the rotor swept area in what appeared to be investigation of stationary and moving blades. Bat collisions were observed. Most activity observed by the research team was during the first few hours after sunset and Arnett *et al*. (2004) noted that: “*The ratio of avoidance behaviour to contact with blades is high*”.

Horn *et al*. (2008) used three TIR cameras recording to video to observe the behavioural responses of bats to operating wind turbines (as shown in Figure 2-15). It was possible to distinguish between bats, birds and insects but 40% of observations were not able to be categorised. This study showed bats flying around both rotating and motionless wind turbine blades and were observed feeding and foraging around and within the rotor-swept area of the turbine. Even where it is possible to determine bats from other flying objects, they cannot be identified to species. Thermal imaging appliances used in Horn *et al*.'s (2008) study cost $15,000 (currently approximately £10,000) for a small hand held device. The cost of more specialised arrangements required for use with wind turbines would be substantially more.

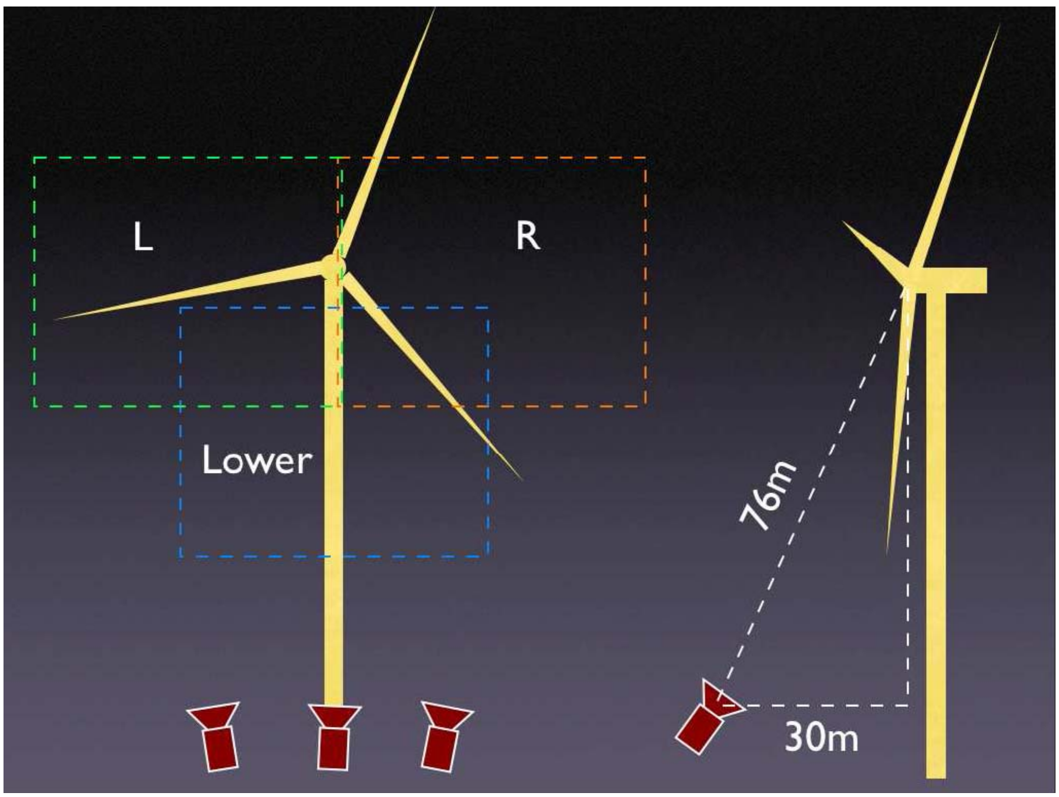


Figure 2-15: Illustrates a hypothetical example of three TIR cameras positioned 30m from the turbine base, pointed directly upwind and perpendicular to the plane of blade rotation (taken from Horn *et al*. 2008).

In Germany TIR imaging has been used in association with acoustic monitoring and fatality searches (Ivo Niermann, *pers*. *comm*.). The system was used to observe the rotor swept zone using two synchronised infrared cameras that were used in a standard stereo view set-up. This was done to test the range of the bat detectors being used by comparison of the visual and acoustic recording techniques. In this instance it has been used as a verification procedure and the conclusion was that the acoustic activity measured was a reliable indicator of fatalities.

Brinkmann *et al*. (2006) used thermal imaging to observe bats at three different locations (a wind turbine in woodland, a wind turbine in an open area and a reference site in a wind blown area but with no wind turbine). Each of these sites was observed four times for half a night (four hours from sunset). However, the researchers experienced difficulty in distinguishing bats from birds or large moths and in discerning how far an object was flying from the camera and consequently also from the turbine, or whether an object was in front of or behind the turbine. In addition, two bats were by chance found on the ground injured, but were not seen colliding with the turbine on the camera recordings, presumably because the image covered a relatively small area of the turbine. Bats were observed flying around the study areas and 25% showed evasive behaviour, moving away from the wind turbine blades, while the remaining 75% showed no change in direction.

In summary it would seem that TIR technology would not be the most appropriate or efficient method for determining the impact of turbines on the UK bat population. However, the use of TIR can be of value in assessing bat behaviour around turbines and may therefore be of use in further research on this subject in the UK if the initial findings warrant this.

2.5.3 Mist-netting

Due to the limitations of species identification using acoustic monitoring, Kunz *et al.* (2007a) recommend that where full species identification is required additional surveys may need to be undertaken. Mist-netting is the most commonly used method for capturing flying bats (Kunz 1988). Mist nets can be deployed successfully at most sites but recommends using acoustic surveys or visual observations to identify bat commuting or foraging routes prior to mist netting in order to locate areas to target that have the highest bat activity levels, as the location of mist nets has a major influence on capture success (Kunz 1988). This method is most effective at sites where mist nets can be put close to roosts, water bodies, trees and hedgerows and known flyways. The difficulty in mist netting around wind energy facilities is that bats are more difficult to capture in nets at feeding sites, where their sensory perception is the keenest and there may be limited suitable areas for undertaking mist netting. The principal disadvantage of using mist nets is that they require constant attention and they are invasive (the bats are captured and handled before release) and sampling bias is also an issue as bats of different species, sexes and ages may be biased by differences in their foraging habits, energy and water requirements, visual and acoustic resolution of the nets, and flight behaviour (altitude, speed, and manoeuvrability) (Kunz 1988).

Mist-netting may be more appropriate in assessing the impact of new wind energy facilities during the planning process where species identification is required and cannot be established through bat detector recordings. Harbusch and Bach (2005) recommend mist-netting for pre-construction surveys, particularly where wind energy facilities are planned at sites near woodland or highly structured areas. However, because most fatalities occur at the heights of turbine blades when bats are flying above 20 metres mist-netting alone is inappropriate for assessing bat activity at proposed wind-energy installations. Mist netting may also complement radar data (Kuenzi & Morrison 1999) by providing unequivocal identification of species.

In summary, mist-netting is considered a low priority for a survey to determine the impacts of wind turbines on British bat population.

2.6 Mitigation

Mitigation is defined by the Institute of Ecology and Environmental Management (IEEM 2006) as: "*Measures taken to avoid or reduce negative impacts. Measures may include: locating the development and its working areas and access routes away from areas of high ecological interest, fencing off sensitive areas during the construction period, or timing works to avoid sensitive periods*." Although compensation measures are considered to be in most cases unsuitable to redress the balance of the ecological impact of wind turbines in sensitive areas, IEEM define compensation as: "*Measures taken to make up for the loss of, or permanent damage to, biological resources through the provision of replacement areas. Any replacement area should be similar to or, with appropriate management, have the ability to reproduce the ecological functions and conditions of those biological resources that have been lost or damaged*."

As stated by Dubourg-Savage *et al*. (2009) there can be no compensation for killing bats as they are an European protected species, and therefore fatalities are unacceptable (refer to Appendix 1 for further details on the legislation afforded to bat species in the UK and throughout Europe). Consequently, where bat fatalities do occur as a result from wind turbines statutory authorities and industry will need to work together to find a sustainable solution. Although there is relatively limited information, particularly in Britain, the following section will discuss what is currently recommended to prevent bat fatalities through careful siting of wind turbines or reduce bat fatalities through mitigation actions.

2.6.1 Site selection

As part of the pre-construction surveys desk studies, consultations and site surveys should be undertaken to determine whether the proposed site is used by bats, and if so at what time of the year. Therefore, surveys should ensure that data are collected across and within the site and throughout bat active season to account for changes in bat activity (Natural England 2009). The Natural England interim guidance recommends that most effort should be focused when bats are found in significant concentrations, particularly in relation to those species identified as being at high risk. Natural England have produced simplistic categories to aid ecological consultants and developers to determine whether a development is likely to fall into low or high risk and to therefore adjust their survey effort accordingly (Table 2-7). As a rough guide the guidance stated in the Natural England interim guidance is that at least one visit should be conducted per month (which could include use of remote detectors) but for high risk sites the survey effort should be increased. For example, by increasing the number of visits during key times or increasing the use of remote detectors, which may be left *in situ* a longer period of time.

Table 2-7: Bat usage of site – criteria to set survey effort (taken from Natural England's interim guidance 2009).

Risk	Low	High
Site size	Small	Small or large
Site feature	Windy, higher altitudes	Less windy
Habitat	Open, at least 100m from suitable habitat (such as, but not restricted to, woodland, water bodies or linear features)	Suitable habitat features (such as, but not restricted to, woodland, water bodies or linear features) are on or adjacent to site
Roosts on or bounding site	Very few or none	Several. Risk will increase with significance of roost type or species, especially high risk species
Likely threat to bats	**Low – medium**	**High**

Natural England's interim guidance states that ecological consultants should "*take advantage of any opportunity to survey at height*" when carrying out bat surveys. Currently in the UK survey effort has focused on undertaking acoustic surveys at ground level.

As previously discussed Rodrigues *et al.* (2008) have produced generic guidance that recommend wind turbines should be located away from narrow bat migration routes and concentrated feeding, breeding and roosting areas and a minimum distance of 200m from forest edges. Features considered to be important for bats in each area should also be considered. For example Ahlén (2003) states that, in Sweden, the highest risk may be in coastal areas and habitats that attract and support high concentrations of insects such as wetlands, particularly in the autumn months. Ahlén (2003) recommends that wind farms should be avoided near coastal areas and larger lakes; and in agricultural areas near rows of trees and water bodies. Wetland areas also need to be safeguarded as bats congregate in habitats with high insect densities (Ahlén 2003).

The Natural England interim guidance recommends a buffer of only 50m between features used by bats and turbines. The guidance of distance for siting wind turbines in the UK has been based on some evidence that suggests the further away from linear/habitat features, the greater the decline in activity, up to approximately 50m. This has even been found for high flying bats like noctules that tend to fly in open areas (Natural England 2009). The Natural England interim guidance states that "*a 50m buffer around any feature (trees, hedges) into which no part of the turbine intrudes*". As illustrated in Figure 2.16 this means that the 50m is measured to the edge of the feature that is closest to the turbine, and not the base of the feature, which can be estimated by using the following formula:

$$b = \sqrt{(50 + bl)^2 - (hh - fh)^2}$$

Where: bl = blade length, hh = hub height, fh = feature height (all in meters). For the example given in Figure 2-16 (below) b = 69.3m.

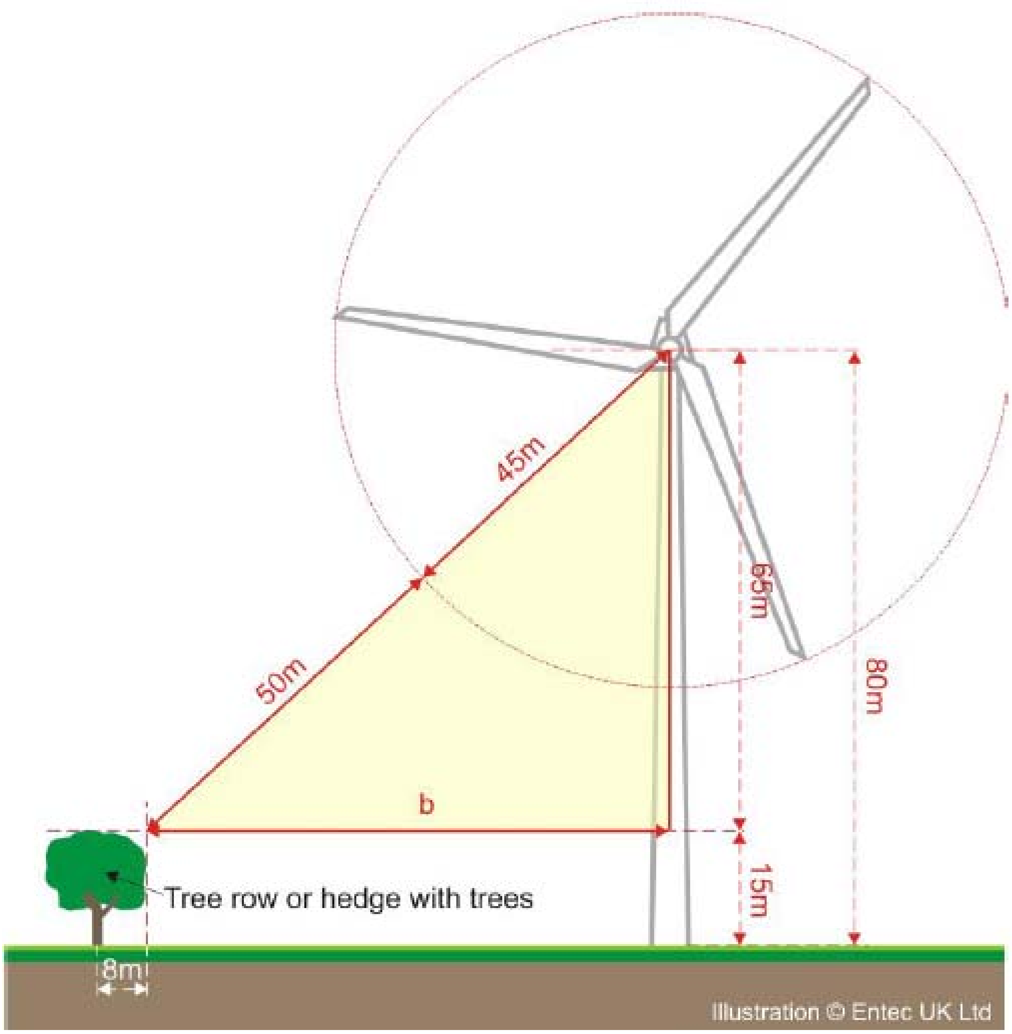


Figure 2-16: Illustration to show how to calculate the 50m buffer zone into which no part of the wind turbine should enter (taken from Natural England interim guidance 2009).

2.6.2 Construction

Rodrigues *et al*. (2008) recommend that construction activity should be undertaken at times of day and year when bats are not active. Infrastructure associated with wind turbines such as access roads are also potentially damaging to bat habitat. Table 2-7 lists the potential impacts to take into consideration during the construction phase (adapted from Bach & Ramel 2004; cited by Rodrigues *et al*. 2008).

Table 2-8: Potential impacts of constructing a wind energy development during the summer and migration periods

Impacts related to siting		
Impact	**Summer time**	**During migration**
Loss of hunting habitats during construction of access roads, foundations, etc.	Small to medium impact, depending on the site and species present at the site	Small impact
Loss of roost sites due to construction of access roads, foundations, etc.	Probably high or very high impact, depending on the site and species present at that site.	High or very high impact, e.g. loss of mating roosts.

2.6.3 Operational phase

Large numbers of bat being killed by wind turbines is still a relatively recent phenomenon, therefore studies investigating mitigating actions to avoid or minimise these impacts are still relatively limited and will be discussed in this section. Table 2-9 describes some of the potential impacts operational wind energy facilities may have on bats (adapted from Bach & Ramel 2004; cited by Rodrigues *et al*. 2008).

Table 2-9: Potential impacts of operating wind energy facilities during the summer and migration periods

Impacts related to operating the wind farm		
Impact	**Summer time**	**During migration**
Ultrasound emission	Probably a limited impact	Probably a limited impact
Loss of hunting areas because the bats avoid the area	Medium to high impact	Probably a minor impact in spring, a medium to high impact in autumn and hibernation period.
Loss or shifting of flight corridors	Medium impact	Small impact
Collision with rotors	Small to high impact, depending on the species	High to very high impact

Changing cut-in speeds

Experiments at large scale wind farm sites that previously recorded high numbers of bat fatalities have seen dramatic reductions in fatalities when the cut-in speed (wind speed at which turbines start turning) is increased. Bats do not appear to collide with stationary blades (Barclay *et al.* 2007). As a form of mitigation it has been suggested that changes to the cut-in speed when wind turbines become operational could reduce bat fatalities as bat activity drops with higher wind speeds. At Summerview Wind Farm (Alberta, Canada) bat collisions were significantly reduced by increasing the cut-in speed from 4m/sec to 7m/sec, in response to high mortality rates recorded in autumn 2005 (Brown & Hamilton 2006).

Baerwald *et al*. (2009) set out to test this hypothesis at a site with known high bat fatalities. Twenty-one turbines were used during the experiment, which altered by changing the wind speed trigger (to not be operational during low wind speeds) or by changing the blade angles when means that higher wind speeds are needed to start the wind turbine blades moving (from 4m/sec to 5.5 m/sec). Baerwald *et al*. (2009) reported significant reduction (by 60.0% or 57.5%) in bat fatalities. From these initial results and similar success from other experiments (Ed Arnett, *pers*. *comm*.) changes in cut-in speed may prove to be a very successful mitigation action. However, Baerwald *et al*. (2009) note that further work is still needed to assess costs and benefits at other sites as the experimental turbines did not produce electricity an average of 59% of the period at night rather than 29%. As not all turbines can be operated remotely, cost implications are higher because turbines will be turned off below the cut-in wind speed day and night rather than only at night when bats are active. However, with modern turbines many can be controlled centrally and changes in cut-in speeds as a form of mitigation is likely to be limited to sites with high bat fatalities at peak times in the year.

At Cassleman Wind Project in Somerset County (Pennsylvania) 12 turbines out of 23 were selected for an operational curtailment experiment, making up three turbine treatments with four replicates each (1 – fully operational, 2 – cut-in speed at 5.0m/s, and 3 – cut-in speed at 6.5m/s) (Arnett *et al*. 2009). The 12 turbines were searched daily between 26 July to 10 October 2008, additionally a further 10 different turbines were searched daily and were selected because they had acoustic data from 2005 until 2007. During the study at least one fresh fatality was found at each of the turbines. The proportion of fatalities recorded from the three treatments were:

- three fatalities when turbines were curtailed when wind speeds were below 5.0m/s the previous night;
- six fatalities when turbines were curtained when wind speeds were less than 6.5m/s; and
- 23 fatalities at fully operational turbines.

Over the study period 73% of fatalities were recorded at turbines that were fully operational and nightly reductions of bat fatalities were between 53% and 87% throughout the study. The power output lost was calculated by comparing operational and curtailed turbine output throughout the study; Iberdrola Renewables calculated a difference of approximately 2% of the total project output during the 76-day study. All three studies undertaken to date investigating the impact of turbine curtailment (which include this study, Baerwald *et al*. 2009 and O. Behr, University of Erlangen, unpublished data; cited by Arnett *et al*. 2009) have indicated that bat fatalities could be reduced by at least 50%, which clearly demonstrates that more emphasis needs to be put on mitigation actions that could reduce the fatality rates particularly for pre-existing wind energy facilities that have high rates of bat fatalities each year.

Acoustic deterrents

Due to the high numbers of bat fatalities and studies showing bats foraging for aerial insects around operational turbines, the BWEC in collaboration with other researchers have been looking for appropriate methods to deter bats acoustically as hearing is their primary sense. The theory behind acoustic deterrents is that they interfere with, or perhaps jam echolocation by bats, and consequently deter them from the area. With wind energy facilities growing exponentially around the world in order to prevent or minimise the number of bats being killed any mitigation action that may reduce the number of bats around wind turbines should be explored.

The first acoustic deterrent designed for commercial-scale use (Binary Acoustic Technology http://binaryacoustictech.com) which emit randomised (between 20 to 80kHz) and constant ultrasound was tested against two control wind turbines in similar habitat but with no deterrents installed (Horn *et al*. 2008). Bat activity was observed at the treatment and control turbines for 10 consecutive nights using thermal imaging cameras. The deterrents emitted ultrasound that created a 20m ‘keep out zone’ that was omni-directional, but the results were inconclusive as the first 10-night experiment showed a significant difference between bat activity around the treatment and control turbines but the second test did not observe reduced bat activity. Horn *et al*. (2008) suggest that these results may indicate that a number of other factors are affecting these results, while every effort was made to pair treatment and control turbines there may be differences in for example habitat types or insect abundance. The other difficulty is that due to limitations with acoustic deterrents the area covered may not be large enough to see a significant effect. Horn *et al*. (2008) also caution that as the ultrasound is emitted around the rotor swept area a bat would need to fly close to the blades to be deterred and if the bat became disorientated by the ultrasound emissions there may be an increased risk of collision with the blades. Bats may over time show avoidance behaviour to all turbines but there is also the possibility that acoustic deterrents lose their effectiveness over time if bats habituate to the ultrasound being emitted and alter their behaviour (Horn *et al*. 2008).

Szewczak and Arnett (2008) also tested the effectiveness of an acoustic deterrent (AT800 Binary Acoustic Technologies portable ultrasonic amplifier and transducer unit – shown in Figure 2-17) to reduce bat activities at sites with constant bat activity in close proximity to a roost or limited resource (such as a pond). The experiment was set up in such a way that bats had an alternative area to continue foraging within. Each site was monitored for five to seven nights with two nights being used to establish the baseline activity levels for the site and then the rest of the nights were used to monitor changes in activity levels when ultrasound was being emitted. To reduce additional factors the experiments were only carried out under particular weather conditions (e.g. no rain and low wind speeds) so were not always carried out on consecutive nights. Bat activity was recorded on video camera and bat passes were counted by visual observation using video playback in five minute intervals. The median activity rate/hour was significantly less when ultrasound was being emitted compared to the controls (estimated at being between 2.5% and 10.4% of the activity level when no ultrasound was emitted). The effect was immediate and reported bats scattering out of the treated airspace within one minute of activating the ultrasound deterrent but these bats were observed continuing to swarm over other areas of the pond; and that bats did not accommodate or habituate to the ultrasound as bat activity continued to decline within the treated airspace overtime (Szewczak and Arnett 2008). However, the authors do also caution that the effectiveness of acoustic deterrents as a mitigation measure is unknown and this may largely be due to the rapid attenuation of ultrasound in air which will limit the area this device can cover. Szewczak and Arnett (2008) recorded bats avoiding an area of approximately 12-15m from the ultrasound source; however they note that "*bats could detect the presence of such airspace from a greater range*."

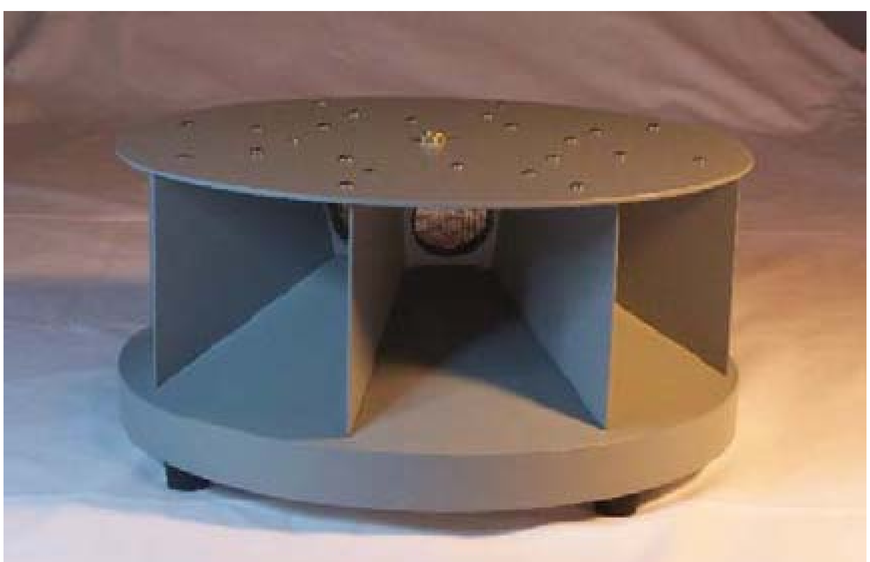


Figure 2-17: AT800 acoustic deterrent developed by Binary Acoustic Technology, picture taken from Szewczak and Arnett (2008).

A large-scale study of the effects of acoustic deterrents is currently underway in the U.S.A., and will determine differences in activity between control turbines and those with acoustic deterrents, as well as monitoring fatalities between the two turbine classes during the migration period.

Radar deterrent

Researchers at Aberdeen University observed reduced bat activity around Aberdeen Civil Air Traffic Control despite suitable habitat in the area, which they thought may be explained by radio frequency (RF) radiation associated with radar installations. Consequently, Nicholls and Racey (2007) tested a hypothesis that bat activity would be reduced around areas with RF radiation, which have an electromagnetic spectrum between 3kHz and 300GHz. Nicholls and Racey (2007) investigated bat activity around 10 radar stations located in areas with suitable foraging habitat (broadleaved woodland, linear vegetation and riparian habitats). Each radar station had three sampling points located at increasing distance from the radar station, where electromagnetic field strength was also recorded. Nicholls and Racey (2007) showed that bat activity was significantly reduced in areas exposed to electromagnetic radiation greater than 2V/m. However, the authors caution that further detailed studies would need to be required to determine the impact of radar on foraging bats before recommending its use as a form of mitigation to prevent bat fatalities at wind farm sites. A recent experimental study supports the hypothesis that radar deters bats, but not insects (Nicholls and Racey, 2009). The implications of the effect of radar on bats would need to be studied in detail and fully understood and costed before it could be used as a form of mitigation.

To summarise the extensive finding, based on the findings discussed in this section, we provide a summary of recommended methods to be employed in order to determine levels of bat fatalities around turbines at operational wind farms in Britain. These will be discussed in detail in section 3.

- fatality surveys that cover the entire active bat season with intensive surveying in the period of most risk (autumn migration in August and September);
- surveys to be carried out at as many sites as possible across Britain to allow for a range of locations and habitats to be considered and comparisons made between sites;
- surveys to include core sites used for both acoustic monitoring and fatality searches over 3 years;

- surveys to target wind farm sites with larger numbers of turbines (preferably > 10) to allow high number of turbines to be surveyed within sites;
- multi-year surveys to allow comparison between years and between sites; and
- additional surveys to be included that determine biases in search methods: searcher efficiency and carcass removal.

3. Recommended Survey Methods and Protocols

3.1 Introduction

In the previous section existing information on surveys carried out to assess the impacts of wind turbines on bats was reviewed and broad recommendations were made for the types of survey that should be completed. This section outlines in more detail the recommended survey protocols and methods for determining the impacts of wind turbines on bat populations in Britain. Due to resource limitations and potential site access restrictions there may be constraints on what can be achieved, and where currently known these have been taken into account.

Given that there has been no systematic research to determine impacts of wind turbines on British bat populations, apart from a small number of anecdotal reports of bat casualties, there is undeniably a need to build an evidence base to help inform national guidance on wind farm development. In addition, the UK has an obligation under the Habitats Regulations (as amended) to monitor incidental bat fatalities and report on these to the EU. Furthermore, a fuller understanding of impacts of wind turbines on bats will allow more targeted bat assessments to be completed for future proposed wind farms, where appropriate. The findings of this research will also provide much needed information for statutory authorities (Natural England, Countryside Council for Wales and Scottish Natural Heritage) to provide accurate and consistent advice across Britain when responding to wind farm planning applications.

The overriding aim of this project is to determine **whether bats are being killed by wind turbines in Britain**. This question will be addressed by undertaking fatality surveys across Britain. If fatalities are recorded the data collected will help to inform national guidance by understanding whether any and if so what factors are related to bat fatalities, such as:

1. **Is there any regional variation in bat fatalities?**
   Data will be collected at three core sites and an additional 21 (seven different sites for each of the three years) five days a week throughout August and September in 2009, 2010 and 2011 to determine any regional variation across the sites. Information collected across years is vital to understand between-year variation in fatality rates and activity.

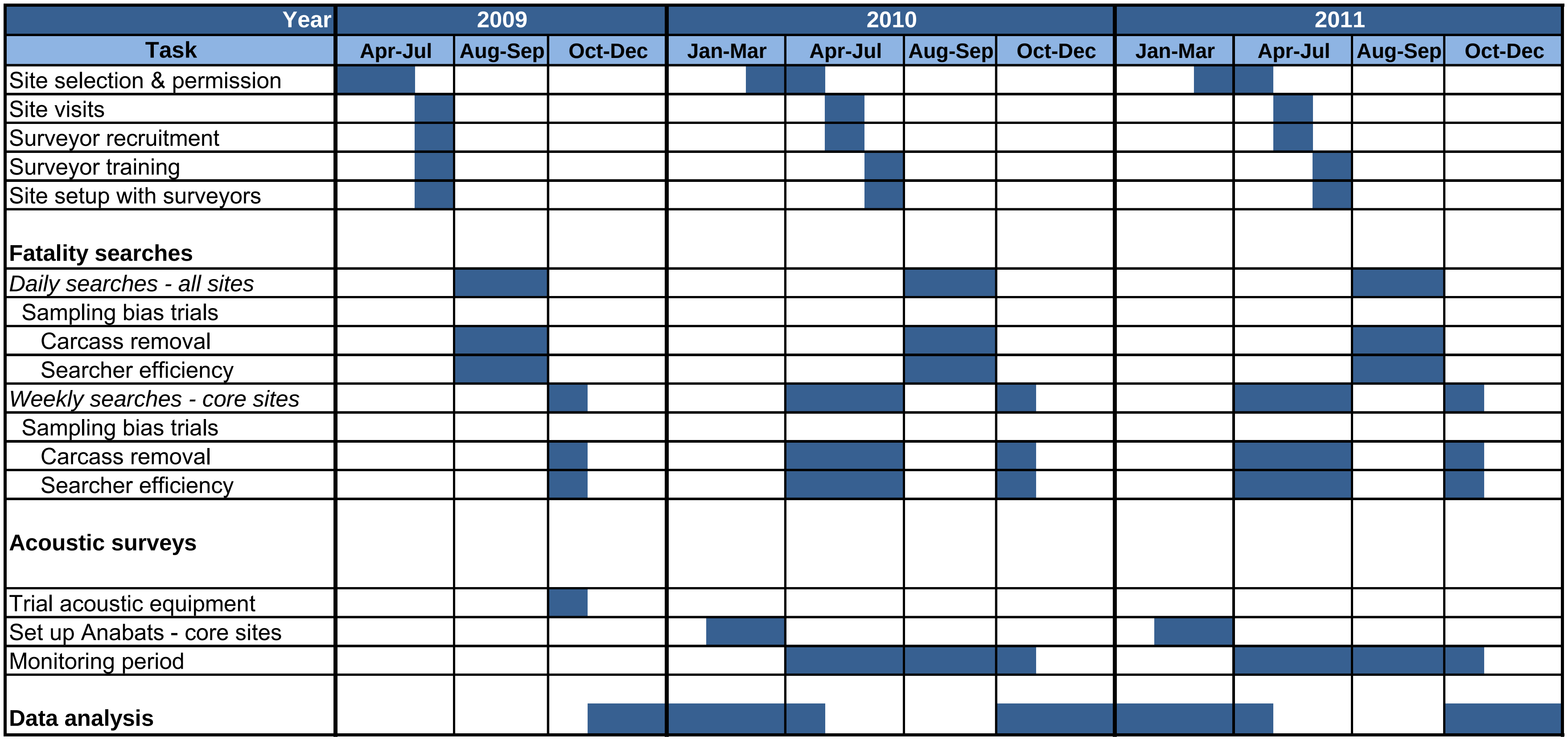
2. **Does bat fatality rate vary seasonally?**
   Data will be collected throughout the bat active season (April to October) at the three core sites during the study to allow for seasonal and potentially inter-year variation to be determined.

3. **How does bat activity vary throughout the season (and annually)?**
   Acoustic data will be collected from sunrise to sunset each night at the three core sites in England, Scotland and Wales throughout the bat active season each year. Bat activity will be analysed to seek correlations with bat fatalities and with other factors including site location, habitat type and meteorological variables.

4. **Are there any factors that contribute to bat fatality rates within and across sites?**
   Throughout the period of fatality searches both at core sites and intensive monitoring sites, meteorological data will be collected. Analysis will be completed to determine key factors affecting bat fatalities, such as wind speed. Habitat features at each turbine will also be measured so that fatality rates can be related to landscape features.

The various elements of the survey and its preparation and analysis are described in detail below and a Gantt chart has been provided in Table 3-1 to illustrate the timings of activities in each year.

Table 3-1: Gannt chart showing project plan for the three year project



3.2 Site selection

Ten sites across Britain will be surveyed intensively for bat carcasses each year. These will be distributed evenly across five geographical areas: south, mid and north England, Scotland and Wales. After completing the fatality searches in August and September 2009, three core sites (one each in England, Scotland and Wales) will be selected based on the results from the ten sites being surveyed intensely in 2009 and will also be dependent on whether access is granted by the wind energy operator to install remote recording bat detectors within the nacelle of three to five wind turbines per site or on MET masts and/or portable towers. From 2010 these three core sites will be surveyed once a fortnight throughout the bat active season (defined as April – October for this study) and will also be included in the intensive fatality searches each year for the entire duration of the project. The remaining seven sites to be surveyed intensively during August and September in 2010 and in 2011 will be different sites each year and would ideally include new wind energy developments as and when they become operational. With the three core sites monitored throughout and the additional seven sites monitored each year, the total sample size will be 24 sites for intensive fatality surveys.

Criteria for selection of study sites are as follows:

3.2.1 Habitat types

Three distinct habitat types (e.g. woodland, farmland and moorland) will be selected to ensure replicate sites will be sampled across the five geographical regions specified above. The final habitat selection will need to be completed as a priority when the Phase 2 contract commences.

Phase 1 habitat maps will be used as a base map for each wind farm site. An initial site walk over will be undertaken at the start of Phase 2 to ensure that the site is appropriate for the study and also that the map provided still relates to the habitat features on site. For each of the turbines selected the surrounding habitat, and any potential features that may be used by bats such as woodland, hedgerows or water bodies, will be detailed on a map with approximate distances from turbines documented to allow for these factors to be accounted for in the data analysis.

3.2.2 Site features

Wind turbines across Britain vary in design and height; for example turbine height to blade tip ranges from 42m to 193m. Although it is not currently known whether turbine height influences the risk of bat fatalities occurring in Britain, Barclay *et al*. (2007) found the highest bat fatality rates at turbine towers 65m or taller. For this reason, the majority of sites selected for this study will be those with taller wind turbines. However, sites in the south of England are largely restricted to turbines below 1MW which range in height from 42m to 53m, with one that is 67m. As six sites will need to be selected in the south of England over the three years the sites will of necessity include those with smaller wind turbines (less than 1MW). This may be useful to help determine whether turbine height is related to bat fatality rate in Britain.

Sites with 10 or more turbines will be preferentially selected to maximise the amount of data that can be collected by two surveyors on each site while ensuring they have enough time to undertake fatality searches thoroughly. Where this is not possible, sites with eight turbines will be selected but sites with fewer than eight turbines will not qualify.

The sites are described in detail in section 4 on page 4-101.

3.2.3 Turbine selection

Eight to 10 turbines will be randomly selected at each wind farm site prior to commencing fatality searches. These turbines will be searched each day in a random order using a random number generator in Microsoft Excel.

3.2.4 Site specific requirements

On the commencement of Phase 2 all site operators taking part in the study will be contacted to get site specific information on health and safety requirements (in addition to the PPE (personal protective equipment) being provided to surveyors) and also whether or not site inductions are required before access to the site is granted. Wind energy companies that have granted permission to sites have obtained permission from landowners but it will be necessary to speak to landowners directly prior to commencing any surveys to determine whether they have any site-specific requests. For example, where livestock are present on any of the sites surveyed, the landowner will be contacted to discuss what the work will entail and if there are any restrictions that need to be adhered to (e.g. not using flags or tape in fields where livestock are present). Advice on how to deal with livestock will be given in the training course provided for surveyors.

3.3 Fatality Searches

3.3.1 Search plot area

We recommend using a 120m x 120m square search area centred on the turbine tower. This area has been chosen to ensure that a 50m radius is covered with an additional 10m buffer. This area will be the maximum area searched and may be reduced if inaccessible areas and/or particularly dense or high vegetation (that limits the ability to search for carcasses) fall within it. If the maximum area is reduced, this will be accounted for by calculating the proportion of the search area searched per turbine and will be factored into the data analysis when producing fatality rate estimates.

Four flags or wooden stakes will be used to mark the search area boundaries and additional wooden stakes, marked with distance from turbine, will be used to mark out the transect lines to be walked at approximately 30m and 60m intervals in a north-south direction. Depending on visibility these stakes should be spaced every 6m or 10m in an east-west direction. However, it is most likely that, unless the vegetation is very low, transects should be every 6m to be able to search a 3m area either side. Figure 3-1 illustrates a hypothetical search plot with a 120m x 120m search area and transects at 6m intervals. Prior to commencing the fatality searches a ‘clean sweep’ of all turbine search areas should be undertaken, which involves removing all old carcasses or partial remains within the selected search plot areas. The ‘clean sweep’ should be carried out using the same search protocol as used for fatality searches.

3.3.2 Fatality search protocol

Fatality searches will be conducted at 10 randomly selected turbines from 1 August to 30 September for five consecutive days, with weekend breaks. Fortnightly searches will also be conducted at the three core sites between April to the end of July (when the intensive searches will commence) and again in October starting in 2010.

Two trained surveyors will be assigned to each site to carry out fatality searches on selected turbine plots. The surveys will commence approximately 30 minutes to one hour after sunrise (depending on light levels); walking opposing parallel transects (as shown in Figure 3-1). The order transects are walked should be alternated, for example if on day 1 the transect starts in a north-south direction then the following day the transect should be walked in a south-north direction. Baerwald (*pers. comm.*) noted that altering transect direction has enabled surveyors to locate a carcass that was previously not seen during a searcher efficiency trial and, where carcasses are not located on the first day, olfactory cues on subsequent days has helped to locate them. During searcher efficiency trials this has been up to four days after the carcass was placed within the search plot area.

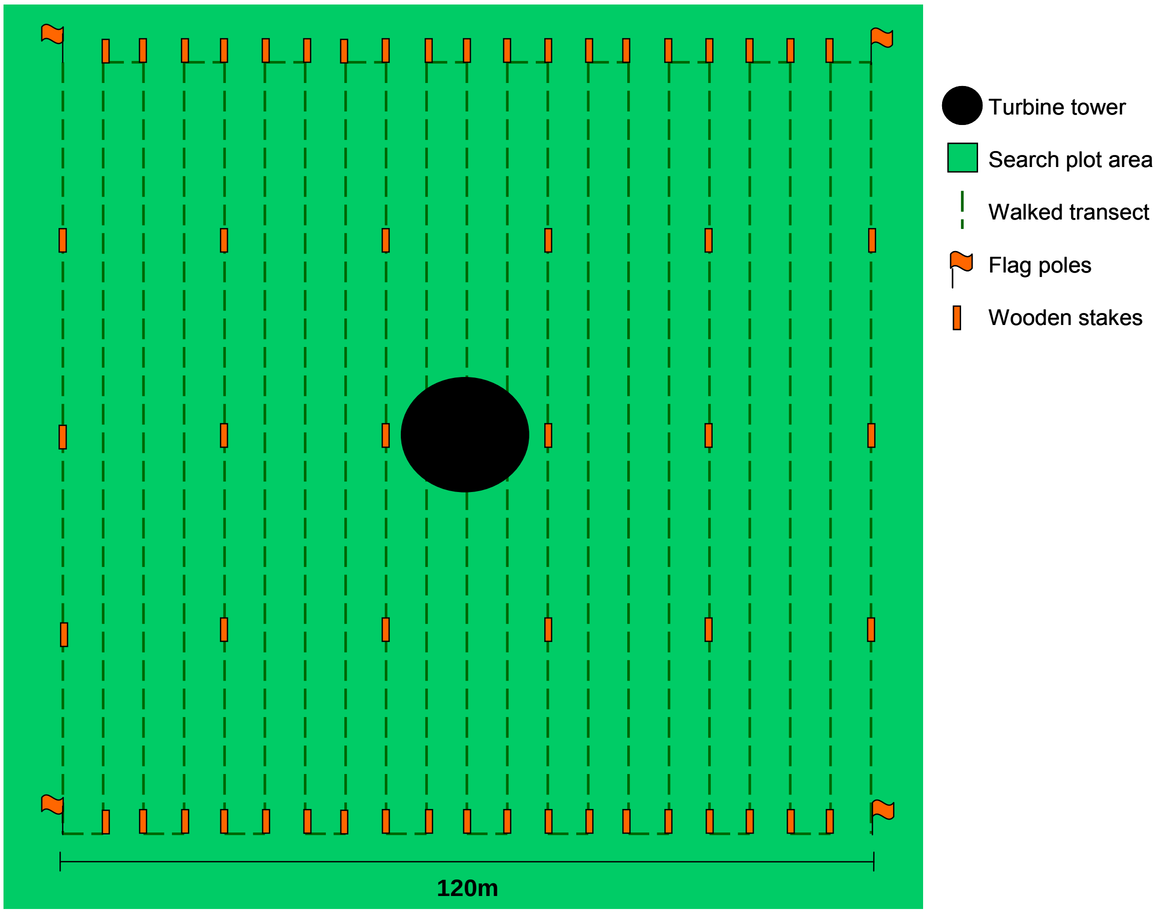


Figure 3-1: Hypothetical turbine search area set up.

All searches will commence soon after sunrise to reduce the chance of predation or scavenging of fresh carcasses. Studies from North America have reported search times per plot averaging between 30 to 90 minutes, depending on terrain, and habitat type / ground visibility. Surveyors should walk at a rate of approximately 10 – 20m/min along each transect searching either 3m or 5m each side for 6m or 10m transects respectively. Transect search speed may need to be adjusted after an initial trial of each search plot.

The order in which turbines are searched will be randomised each day to minimise the chance of predators removing carcasses from specific turbines prior to the surveyors arriving at the search area. Randomising the order of turbine searches will also take into account other variables that differ on a daily basis, such as lighting and alertness of surveyors.

If fatalities are found, the carcass will be bagged immediately to reduce the risk of scavenging and all relevant data will be recorded (as detailed in section 3.3.3). Incidental fatalities found outside the search plots used for the fatality searches, either by surveyors or other staff, will be included and the same information will be collected with the addition of a grid reference to illustrate where the carcass was found in relation to the nearest turbine.

3.3.3 Data collection

General detail

The following information should be recorded at the start of each survey:

- wind energy facility name and turbine number;
- surveyor name;
- time of sunrise;
- start and end time of each fatality search;
- weather conditions at sunrise and at the end of searches.

Details taken when fatality found

Photographs should be taken of any dead bats (or birds) found and the following information should be recorded:

- date and time of when the carcass was found;
- carcass location noted on detailed map of turbine search plot;
- distance from turbine;
- orientation (by taking a compass bearing) relative to the turbine;
- perpendicular distance from the transect line to the carcass;
- photograph number;
- species, age and sex if known ;
- condition (i.e. intact, scavenged, any obvious injuries, etc.);
- pre-defined criteria to describe search visibility (e.g. easy, moderate, or hard – or vegetation type and height); and
- any other comments/observations.

All carcasses found should be handled wearing gloves for protection against pathogens and in case they are later used for carcass removal trials (as described later on) and labelled with unique number, bagged, frozen and sent off for a necropsy to be carried out at an appropriate facility by a suitably qualified staff member.

Where resources allow GPS units should be used to plot the location of bat fatalities, or else the distance can be recorded using an industrial tape measure or using the stakes positioned as a guide.

Meteorological data

Ideally meteorological data will be obtained from the MET masts at each of the wind farm sites. Permission to gain access to these data will be subject to wind energy operators' consent as some of it may be commercially sensitive. Where this is not possible, data will be obtained from nearby weather recording stations. Data obtained will only be used for statistical analysis. The following weather conditions should be recorded for each fatality from the previous night:

- air temperature;
- wind speed and direction;
- cloud cover;
- moon phase;
- barometric pressure; and
- precipitation.

3.3.4 Equipment required

The following equipment will be required at all sites to carry out the fatality searches, which includes PPE required for working on an operational site:

- flag poles/wooden stakes;
- industrial tape measure;
- camera;
- watch;
- compass;
- data recording sheets;
- weather writer;
- labels; and
- freezer bags to place carcasses in.

PPE kit:

- gloves;
- high-visibility jacket;
- hard hat; and
- steel toe-capped boots.

3.3.5 Sampling bias trials

To take into account sampling bias, searcher efficiency and carcass removal trials will be undertaken. We propose that two trials should be undertaken at the beginning of August and the beginning of September each year using dark brown or black mouse carcasses to simulate dead bats. The mice will initially be used for estimation of searcher efficiency and then left *in situ* for carcass removal trials. Additional searcher efficiency trials will be conducted on a weekly basis using artificial carcasses (e.g. plastic bats). Sampling bias trials for the core sites will largely be undertaken in the same way but carcass removal trials will be conducted three times a year (in April, June and beginning of October) and searcher efficiency trials will be conducted on a monthly basis. If sufficient bat carcasses can be obtained then the final searcher efficiency/carcass removal trial (in August) will be done with dead bats at all 10 sites. However, it is considered to be unlikely to obtain enough bat carcasses because all dead bats are sent to the Veterinary Laboratory Agency (VLA) as part of a rabies screening programme. Once there, the bat carcasses are stored in formaldehyde and any bats stored in this way could not be used in the trial as it would be likely to influence the scavenging rate.

Estimation of searcher efficiency through field trials

Although there are currently no data on actual bat fatality rates in Britain, from studies in Germany surveyors found between zero and four fatalities per day (Ivo Niermann, *pers. comm.*). The figures are much higher in North America and therefore it is recommended that searcher efficiency trials be based on the expected level of carcass finds from the German data. For the weekly and monthly searcher efficiency trials being undertaken with artificial carcasses an Excel random number generator will be used to randomise the number of artificial carcasses put out per trial (ranging between zero and four replica bats). The day these artificial carcasses are placed on site will also be randomised to ensure that searchers are unaware of when the trial is being done until they find the first artificial carcass. Due to the restricted number of trials using dead mice, 10 mice will be used at each site for the two trials (200 mice per year for the two trials during the intensive surveys and an additional 90 mice per year for the three trials at the core sites – total of 200 mice in first year and 290 mice in subsequent years). To reduce the risk of the surveyor being able to locate the carcass by identifying trampled vegetation etc. the person putting out the searcher efficiency trial mice or artificial carcasses will need to walk around the area so it is not obvious.

As there are two surveyors per site the turbines will be divided evenly between them (i.e. four or five search plots each) and they will each place carcasses in the other surveyor's search area on the morning of the trial before the fatality searches begin and when all fatality searches have been completed the surveyor will return to where they placed the carcasses to ensure that those that have not been located have not been preyed upon or scavenged and they can therefore calculate the searcher efficiency rate for that day.

Data will be recorded for each trial carcass as described for fatality searches (above), including a category for visibility according to pre-defined criteria (e.g. easy/moderate/hard or a description of vegetation type and height to be defined at a later date). Carcasses will need to be evenly distributed across the selected turbine sites to ensure all vegetation types within the selected turbine search areas are sampled and to avoid 'saturation' (also known as overseeding) of these areas. Searcher efficiency will be determined on the day the trial is carried out. When mouse carcasses are used in the searcher efficiency trials and subsequently left *in situ* for carcass removal trials they will be marked by placing a flag 2m due-north of the location.

Estimation of carcass removal through field trials

A benefit of using mouse carcasses is that they avoid confusion with bat fatalities, because the carcass removal trials will be conducted within the fatality search plots. After the mouse carcasses have been found in the searcher efficiency trials, they will be marked as described above and left *in situ* and checked during the usual fatality searches until they are scavenged or decompose. If any carcasses remain at the end of the trial, details of their condition will be recorded. During the trial period, if a carcass is not found, a 10m radius should be searched to ensure the carcass is not still in the close vicinity (as described by Brown & Hamilton 2006). The same principles for carcass removal trials apply to the fortnightly searches at the core sites.

3.3.6 Obtaining further information from bat carcasses

A necropsy will be undertaken on all bat carcasses to determine the likely cause of death and document injuries (e.g. external or barotrauma). As part of the necropsy the brain will be removed and sent to VLA as part of an ongoing rabies surveillance scheme. Tissue samples will be taken from each carcass and stored in 80% ethanol at -80°C to preserve the sample for potential genetic analysis at a later stage. Such research could be useful to ascertain the geographical origin of specimens, or for calculating effective population size if sufficient samples are available (e.g. Beebee & Rowe 2008).

It should be noted that carcass and genetic analysis have not been included in the Gantt chart but where bat carcasses are recovered the necropsy will be undertaken without delay where possible, as there is a time limit to identify whether bats have died from barotrauma (usually around 8 to 12 hours). It is also recognised that it may be difficult to find the bats and transport them to be necropsied within this timescale but where possible this will provide valuable information and genetic samples can always be taken even when undertaking a necropsy is no longer viable.

If bird carcasses are found during the fatality searches the carcass will be bagged and information on distance to turbine will be collected. Carcasses will subsequently be sent to an appropriate laboratory / RSPB in order to determine the species found and to confirm the likely cause of death.

3.3.7 Data analysis

Searcher efficiency and carcass removal trials give estimates for the bat fatalities that are found, or available to be found, and allow for adjustments to be made to overall fatality rates. Authors have adjusted bat fatalities using different formulae, which have evolved over time, so details of all these formulae are not included in this section. The most recent and advanced statistical methods, which have been developed by the BWEC (Arnett *et al*., *in review*), estimate the probability that a bat carcass was removed in the interval between searches, and this has then been used to adjust carcass counts. The length of time a carcass remains on the study area before it is removed is typically modelled as an exponentially distributed random variable.

The probability that a carcass is not removed during an interval of length (I) can be roughly approximated as:

$$r = \exp(-0.5 \times I / t)$$

The multiplier of 0.5 is based on the assumption that fatality is approximately constant in the interval between searches and the probability of removal over the entire interval (when some animals died at the beginning of the interval, others near the end), can be approximated by the probability of removal half way through the search interval.

The fatality estimates were adjusted using the following equation:

$$\hat{f}_{ijk} = \frac{c_{ijk}}{\hat{a}_i * \hat{p}_{jk} * \hat{r}_{jk} * \hat{e}_{jk}}$$

Where:

$\hat{f}_{ijk}$ is the estimated fatality in the k^{th} visibility class that occurred at the i^{th} turbine during the j^{th} search;

c_{ijk} is the observed number of carcasses in the k^{th} visibility class at the i^{th} turbine during the j^{th} search;

a_i is the density-weighted proportion of the area of the i^{th} turbine that was searched;

$\hat{p}_{jk}$ is the estimated probability that a carcass in the k^{th} visibility class that is on the ground during the j^{th} search will actually be seen by the observer;

$\hat{r}_j$ is the probability than an individual bird or bat that died during the interval preceding the j^{th} search will not be removed by scavengers; and

$\hat{e}_j$ is the effective interval (i.e., the ratio of the length of time before 99% of carcasses can be expected to be removed to the search interval).

If bats are found during this study, bat fatalities statistical analysis to determine any correlation between different variables can then be undertaken. Although the analysis conducted will depend on the data collected, we currently propose that a generalised linear model (GLM) is used as it is highly likely in many cases no bat fatalities are found and therefore the data will be heavily skewed with zero values.

3.4 Acoustic monitoring

Automated acoustic monitoring using remote recording bat detectors is considered to be the most appropriate method to gain as large a data set as possible throughout the bat active season. Because of the expense of the equipment acoustic surveys will only be conducted at the three core sites to allow seasonal and inter-year variation in bat activity to be monitored.

In terms of the remote recording bat detectors that could be used there are currently three systems to choose from, all of which have pros and cons:

- Anabat bat detector (with or without the remote download system) - Anabat bat detectors have been tried and tested on both pre- and post-construction acoustic monitoring at height on MET masts, portable towers or helium balloons and have been installed within the nacelle of wind turbines in Germany where noctule and pipistrelle species were recorded. The Anabat remote download system relies on a mobile phone signal for data downloading and as such is not rolling out in the UK as well as the rest of Europe due to ongoing problems with mobile phone coverage. If this system is used it will need to be carefully trialled at each core site to ensure it works. Due to the difficulties with the mobile phone coverage suppliers in the UK are unable to give a quote of the full costs of this system and we are currently waiting on further information from Titley Electronics after our initial discussions with them. Without the remote download system the CF card will need to be changed every 1 – 2 weeks depending on number of calls recorded but this would potentially limit placing the Anabats into the nacelle due to access restrictions.

Anabat bat detectors are often used on wind farm sites because they can be used remotely and can record continuously over long time periods. Anabat detectors are broadband (cover a wide range of frequencies), and use a frequency division method of recording signals, which results in the dominant harmonic of the call being recorded. Anabat detectors start recording when the microphone 'hears' ultrasound, such as bat calls, in the vicinity of the detector, and any bat calls are stored as sound files on a Compact Flash (CF) Card. Detection is most efficient in a 60 degree sector in front of the microphone, but it is possible to detect bat calls over a wider range particularly for some of the louder species, such as noctules. The Anabat bat detector records up to 15 seconds of ultrasound on to a single sound file. If this time period is exceeded consecutive new sound files are created, which may also be up to 15 seconds in duration. Echolocation calls, recorded as sound files, can then be imported into Analook software for analysis. Bat calls are converted into data files that allow researchers to identify species and estimate number of bat passes recorded throughout the survey period.

- The Pettersson D500X system automatically records bat calls in full spectrum (with no delay from time expansion). It has the capability of using four CF cards, enabling it to be left out in the field for weeks. However, there is currently has no remote download system which is likely be to a limitation for setting this system up within the nacelle. Currently the new Pettersson D500X system is being trialled in the eastern U.S.A (Joe Szewczak, *pers*. *comm*.).

- The ecoObs Batcorder system has been installed in nacelles and has been proven to work with the set up used in Germany. It is claimed to be able to reject non-bat ultrasonic sounds, which would reduce the memory needed to record data. The system can record for between 30 to 60 nights (Volker Runkel, *pers*. *comm*.). This system does not have the capacity to remotely download data and another limitation is that it requires a Macintosh computer to run the Ecoobs software designed for the data analysis, which is an additional cost.

3.4.1 Survey protocol

Automated acoustic surveys will be undertaken at height (to be determined according to mounting method and bat detector used) at all three of the core sites to record bat activity. Ideally five remote recording bat detectors will be used at each of the core sites; these will be placed at a central location and at each compass point to provide representative data on bat activity levels throughout the site. If any of the core sites have turbines distributed in a linear formation, only three Anabat bat detectors will be used (one at each end and one in the centre).

There are two main options for mounting the remote bat detectors at height, as detailed below:

1. Mounting within the nacelle at the top of the turbine towers

This has been achieved in Germany. The set up would require drilling through the fibreglass which forms the floor of the nacelle (unless some other method of mounting can be devised). It would be necessary to work with wind turbine manufacturers to conclude a satisfactory method of attachment. The benefit is that recordings are made within the turbine rotor swept area at the height of the nacelle and hence are most representative of bat activity in the region of the rotor blades and thus more comparable with the results of fatality searches. The noise from the wind and blades moving will be recorded on the bat detector; however researchers in Germany have still recorded bat calls successfully despite the additional noise. There is not considered to be any electrical interference as long data cables are not used or run outside the nacelle. A further advantage of placing the detectors in the nacelles is that they can be permanently connected to an electrical supply. Also, if the new Titley Electronics system to download data remotely to a server where users can login to retrieve their data was chosen as a viable option for this project (bearing in mind cost and mobile phone coverage) then aside from installation and potential maintenance the Anabat bat detectors can be left in place to record all season.

2. Mounting on meteorological (MET) masts or portable towers

MET masts or portable towers are a possible alternative option for acoustic monitoring that have been used in North America, however they have limitations. The detector would not be located within the rotor-swept area of the turbine because the mast or tower would have to be located at a safe distance away from any wind turbine. Most portable towers are approximately 20m high (so significantly shorter than the larger turbines); however MET masts reaching heights of 75m have been installed in the UK (Simon Pickering, *pers. comm.*) but would require planning permission, which can be a lengthy process. The detectors would need to be powered by a 12-volt battery connected to a solar panel to keep the battery recharging and would require data cables to place the microphone at height to allow easy access to the detector to change batteries or CF cards. Another downside of portable towers is their cost.

Bearing in mind the benefits and limitations of the two alternatives, we consider the preferred method would be to attach remote recording bat detectors to the nacelle. We recommend carrying out a trial in October 2009 to test the chosen method in Britain before data collection begins in April 2010.

3.4.2 Data collection

Bat activity (echolocation calls) will be recorded from 30 minutes before sunset until 30 minutes after sunrise each night (the time of which will change throughout the season and will be different at each site due to their different geographical locations). Data will be collected throughout the bat active season (April to October) in 2010 and 2011 at the same locations each year to allow data to be compared across years.

Meteorological parameters will also be collected as described in section 3.3.3 above.

3.4.3 Data processing and analysis

Data files containing acoustic information will be generated from each night of data collection from each of the bat detectors. Analysis of acoustic data will continue into the winter months following each survey season because of the large quantity of data that is likely to be collected and the time it takes to analyse. A considerable amount of processing will be required of the data files as follows:

- processing of files to eliminate files containing non-bat acoustic data;
- determining numbers of bat passes within each bat data file;
- identifying social calls and peak frequencies of these calls;
- species identification of bat passes from bat data files; and
- summing and summarising results from each bat detector for each night.

The data have mainly been presented as the total number of bat passes and the mean number of bat passes per detector-night or detector-hour (Lausen *et al.* 2006). The best presented data have been normalised to number of hours after sunset, which allows comparisons between studies and throughout seasons. A standard definition of a bat pass, a sequence of 2 echolocation calls with each pass separated by >1s (e.g. Fenton 1970) has been used in some studies; in others where Anabat bat detectors have been used for acoustic surveys, a simpler count of the number of Anabat files recorded with bat data in them per unit time has been used.

During analysis only relative abundance (activity) can be determined, because it is often difficult to determine whether separate bat passes are from the same or different individuals (Kunz *et al*. 2007b). An additional limitation with acoustic surveys is there may be sampling biases because some species (especially those with high-intensity of low frequency echolocation calls) are detected more readily than species emitting low-intensity or high frequency signals (e.g. Kunz *et al*. 2007b).

As an alternative to analysis of variation in bat activity over time, activity data can be compartmentalised into habitat types that were sampled, and examined by using a two-factor (sampling period x habitat type) general linear model with post hoc Tukey's multiple comparisons procedure to examine where significant differences lie. Reynolds (2006) used this type of approach, with three sampling periods of equal length (10 April – 4 May, 5 May – 29 May, and 30 May – 22 June), and analysed activity data using a three-factor (night period x sampling period x sampling height) general linear model with post hoc Tukey's multiple comparisons procedures conducted subsequently. Bat activity data were categorised (post hoc to minimise group size variation) as none, low (1-2 bats/night), medium (3-6 bats/night), and high (>6 bats/night) because of the large number of nights when no bat activity was recorded. Meteorological variables were subsequently compared using Pearson correlation analyses although meteorological variables could be entered as covariates in general linear models.

We propose using Generalized Linear Models to analyse factors that affect both activity and fatalities (Nicholls 1989; Bolker *et al*. 2009). Given the large number of zero values likely for both activity levels and fatalities, Generalized, rather than General Linear Models will be necessary. By using this approach we can relate activity and fatalities to variables such as weather conditions, and distance to landscape features, which can be entered as covariates. In the analyses, individual turbines will be repeated measures, and will be nested within site. We can therefore investigate how meteorological and habitat features affect activity and fatality rates both within and across sites. Knowledge of whether high bat activity or fatality rates are associated with particular weather conditions may be useful for predicting periods of high risk to bats, and such information could eventually be valuable for implementation of mitigation measures (e.g. under which conditions might changes in cut-in speed be most effective).

We propose relating bat activity to fatalities within the 3 core sites by using regression approaches, with turbine nested within site. We will therefore have 3 replicates to investigate whether high fatality rates are associated with high levels of bat activity.

3.5 Training protocols

In order to carry out the field work successfully surveyors will be recruited each year and trained in fatality survey methods to ensure they are competent and that consistency in survey methods is maintained across sites and indeed years. All surveyors will be trained during both classroom- and field-based sessions and a visit to an operational wind farm site to be given experience in all techniques required prior to undertaking the field trials. A full description is given in Section 5 (Training Protocols).

3.6 Resources

A summary of the tasks needed to complete the surveys and resources need is shown in section 6.

4. Study sites

During the site selection turbine height (ideally above 65m) has been taken into consideration; as well as number of turbines per site (at least eight but 10 ideally), location (to ensure an even distribution across Britain), and habitat type. We currently propose choosing sites from three habitat types (farmland, open habitat and woodland) with replicates of these habitat types to enable comparisons to be made across sites.

To obtain inter-year variation we propose selecting three sites that will be used throughout the three year study (known as core sites). A core site will be selected in England, Scotland and Wales. A further seven annual sites will be selected each year, making up 21 annual sites. In total 24 sites will be used in the project, which will be distributed across Britain. There has been a very positive response from the wind energy industry and we currently have agreement for 37 sites to take part in the study that meet our initial criteria. The vast majority of site information has been received for these sites, however at the time of writing this report we were still waiting on some of the site information but we will ensure all of this information is available before the start of Phase 2. Therefore the final shortlist will be a priority action at the start of Phase 2, however as the site access and information gathering will all be completed we do not perceive this to be a lengthy process. The list of sites has not been presented in this report but will be made available to the Phase 2 contractor, with the site information and our recommendations for final site selection. As more sites become operational it is highly recommended that the list of site selected is reviewed at the start of each year in light of these changes and potentially more suitable sites becoming available.

4.1 Distribution of sites across Britain

4.1.1 England

To ensure sites are evenly distributed across Britain and particularly in England we propose dividing England into a south, middle and north section. Each section will have two sites in each. Wherever the core site is selected for England this will be the permanent site for the study and only one additional site will be selected in the section each year, whereas the other two sections will have two new sites selected yearly. Due to the low numbers of wind farms in the southeast of England we propose that the southern border is drawn slightly north of Northampton and the middle/north border is drawn just below Manchester. Wherever possible turbines taller than 65m should be selected but the site selection will also be constraint to sites available and/or habitat types. For example, in the southwest of England all turbines are currently below 1MW. These sites will need to be included in the study to obtain a geographical representation of the country. For this study, assuming no core site is selected in the south of England, six sites will be selected in the south and three of these will be in the southwest. More sites may be available in subsequent years due to sites being repowered or new sites being built but for 2009 all of the sites available are below 1MW. Further constraints on site selection are due to the number of small wind farms, for example in the southwest (excluding Cornwall) and Newcastle.

4.1.2 Scotland

In Scotland one site will be the core site and three others will be selected, one each year. Due to the reduced number of species found in the north of Scotland and bats found likely to in small numbers, the distribution of sites in Scotland will be concentrated in the southern half of Scotland (encompassing Central Scotland, the Lothians, Scottish Borders, Strathclyde and Dumfries and Galloway). Wind farm sites in Scotland are located on farmland, in woodland (particularly conifer plantations) and on open moorland, so sites from all habitat types will be selected in this region. Because of the large numbers of turbines found on many of the wind farms in Scotland, selection of sites with 10 or more turbines is not considered to be a constraint.

4.1.3 Wales

As with Scotland, Wales will also have one core site and three yearly sites in total (one each year). Therefore, four sites will be selected in total throughout Phase 2 of this project. Many of the wind farms in Wales have turbines that are below 65m, but there are enough sites in Wales to have sites in south, mid and north Wales. It is most likely that the site selection in Wales will be based on habitat suitability, with a priority to survey sites located near woodland.

5. Training programme

The development of the survey methods outlined in the previous sections has resulted in the identification of a number training requirements. The key requirement is to ensure that all surveyors participating in the fatality searches are trained to a set level to ensure continuity of searching across study sites. To achieve this we propose that a training course be held each year prior to the start of the fatality search period comprising desk based lectures and practical sessions to be held out in the field. An outline of this proposed course is set out Table 5.1.

5.1 Fatality search training

In each year of the project, high intensity fatality searches will be undertaken between 1 August and 30 September at 10 wind farm sites (including the three core sites in England, Scotland and Wales). This work will be carried out by 20 surveyors (2 per site) and training on survey methods is required to ensure that all surveyors follow the same protocols. A three day course is proposed, with one day spent in the classroom and the second and third day out in the field developing the practical skills required for fatality searches.

5.1.1 Learning objectives of the course

The learning objectives for the course are set out below. By the end of the course, participants should be able to:

1. Understand the background to the project
2. Understand basic bat biology
3. Complete a risk assessment for the survey work
4. Complete a fatality survey
5. Complete all data forms related to fatality surveys
6. Complete searcher efficiency trials

Objectives 1 to 3 would be covered by classroom lectures, and Objectives 4 to 6 requiring both a classroom and practical element.

5.1.2 Course timetable

The timetable outlined in Table 5-1 gives approximate timings and content of each section, although it may be subject to review once the course content is developed in more detail.

Table 5-1: Outline programme for fatality search training

Time	Session	Content	Length
DAY 1			
Classroom session			
09:30	Introduction	What will be covered and domestic arrangements	10mins
09:40	Background	Background to project Info on wind farms in Britain Info on bat fatalities from other countries Info on bat impacts in Britain – what we do and don't know Project aims and structure	30mins
10:10	Intro to British bats	Basic bat biology and ecology in Britain, including the bat year	30mins
10.40	Intro to bat species	All British species Risk level identified at wind farms	30mins
11:10	*Coffee break*		*20mins*
11:30	Focus on species at risk	More detail on high and medium risk species and flight behaviour and ecology	40mins
12:10	Reasons for collision	Background on some hypotheses Causes of death Photos of dead bats to illustrate what may be found	35mins
12:45	*Lunch*		*1hr*
13:45	Survey methods	Details of how fatality surveys will be done - Step by step Equipment list and recording forms	1hr
14:45	H&S and risk assessment	H&S issues working at wind farms (incl. PPE and working around livestock) Doing a risk assessment before starting work What to do if live bats found during surveys (bat care)	45mins
15:30	*Tea break*		*20mins*
15:50	Search efficiency and carcass removal trials	Why are these needed What do they entail Methods for trials	1hr
16:50	Questions and discussion		25mins
17:15	Planning for day 2		15mins
Fieldwork session			
After dinner	Setting up fatality search areas	Surveyors will be divided into groups to practice measuring and marking out a fatality search area.	1hr
	DAY 1 ENDS		

Time	Session	Content	Length
DAY 2			
Classroom session			
09:30	Collect PPE	All surveyors to collect their PPE, equipment and relevant forms	30mins
Fieldwork session			
10:00	Site induction	H&S issues, PPE etc. Complete risk assessment form Get risk assessment forms checked by tutors	30mins
10:30	Mapping habitat features	Marking features likely to be used by bats, including the distance these features are from the 'turbine'.	40mins
11:10	*Coffee break*		*20mins*
11:30	Fatality searches	All participants to do 'practice' trial search Complete forms Get forms checked by tutors	1.5hrs
13:00	*Lunch (packed)*		*1hr*
14:00	Fatality searches	All participants to do a trial search in different search area Complete forms Get forms checked by tutors	1.5hrs
15:30	*Coffee break*		*20mins*
15:50	Set up for searcher efficiency and carcass removal trials	All participants to set up searcher efficiency and carcass removal trials for other participants	1.5hrs
16:50	Questions and discussion about forms, equipment and field work		40mins
17:30	DAY 2 ENDS		
DAY 3			
Fieldwork session			
09:30	Fatality searches, searcher efficiency and carcass removal trials	All participants to do trial search, supervise other teams undertaking searcher efficiency trials and calculate searcher efficiency Complete forms as required Get forms checked by tutors	3hrs
12:30	*Lunch*		*1hr*
Classroom session			
13:30	Site specific information	Participants to be given packs with site specific information for their individual site and brief discussion over site, layout, contacts, etc.	1hr
14:30	Final question session and equipment check		45mins
15:00	COURSE ENDS		

5.1.3 Course development

It is recommended that the course is developed in full as part of Phase 2 of this project. Development of the course would require the following tasks to be completed:

1. Preparation of PowerPoint presentations and tutor notes for each classroom session
2. Preparation of handouts for classroom sessions summarizing key points
3. Determination of content of practical sessions and how these will be conducted
4. Preparation of survey sheets to be provided as handouts during practical sessions
5. Identification of a suitable venue for the practical sessions (at an operating wind farm) and a nearby classroom venue.

The course would then be run each year (2009, 2010 and 2011) during the second half of July just prior to the commencement of the intensive fatality searches. All surveyors taking part in fatality searches will be required to attend. Resources required for the course would be as follows:

1. Two tutors to run course (Project Officer for Phase 2 of project plus an experienced bat tutor).

2. Operating wind farm site allowing access on one day per year for 20 people for training purposes – site to be visited prior to first training course.

3. Venue for course close to above site providing classroom space and accommodation for 20 people.

4. Travel arrangements between the above two venues (options are minibus or sharing vehicles used to attend course).

5. Laptop and projector for classroom lectures.

6. Tutor presentations and notes.

7. Participant handouts.

8. Equipment required for fatality searches (for all participants, see section 3.3.4 above for equipment list).

9. Corpses for initial searcher efficiency trials will be required for training day.

6. Resources

In section 3, we set out the methods to be used and the equipment required to complete the work proposed in Phase 2 of this project. In this section, we provide a list of resources for all the fieldwork and data analysis, which includes a full-time Project Officer for the duration of the project and other personnel such as trainers, surveyors for the fatality searches (Table 6-1). We recommend that the project is run by a full-time Project Officer to ensure sufficient personnel time is available to co-ordinate all summer fieldwork, to carry out the acoustic surveys and fortnightly fieldwork on at least two of the three core sites (to keep costs low), and to complete the acoustic data processing and all data analysis over the winter months.

Table 6-1: Resources required for this project

Task / Resources	Personnel / Further details
Acoustic surveys	
Organisation, procurement and testing of bat detectors. Confirmation of method to be used for acoustic surveys (including type of installation for bat detectors). Trialling acoustic surveys in October 2009	Project Officer
Installation and setting up of bat detectors and downloading data throughout the bat active season at core sites in 2010 and 2011 (including any ongoing maintenance required on equipment).	Project Officer plus contractual staff as required for installation of bat detectors.
Acoustic data collection, processing and analysis	Project Officer to be responsible for acoustic data downloading and checking, plus processing and analysis (throughout the year).
Equipment	Remote recording bat detectors for core sites Additional equipment for setting up bat detectors and remote downloading (e.g. CF cards, Anabat GML1 Download system / batteries and data cables, hi-microphones, etc. depending on system used). Equipment needed for the installation of remote bat detectors on turbines or MET masts/portable towers. Sound analysis software. *If required*: Portable towers, with pulley system and protective casing for bat detector.
Fatality searches	
Finalising site selection and setting up of	Project Officer

Task / Resources	Personnel / Further details
survey sites, including liaison with wind farm operators over access and health and safety issues.	
Fortnightly fatality searches at core sites	Project Officer to complete surveys at English and Welsh core sites, 1 visit each site per fortnight in April to July and October (will require an assistant for each visit: assistants will be paid basic daily rate). Scottish site – will require 2 surveyors for 1 day per fortnight in April to July and October.
Intensive fatality searches and bias trials at 10 sites in August and September each year	20 surveyors required 2 per site for 2 months (to work 5 days per week). Project Officer to deal with recruitment of surveyors. Project Officer to visit all sites twice within this period, each year, to manage intensive surveys.
Fatality survey data analysis	Project Officer to be responsible for checking fatality data and analysis Nov-Mar each winter following surveys.
Equipment	Compass Weather writers Maps Recording sheets Maps Cameras Industrial tape measure PPE (gloves, hi-visibility jacket, hard hat and steel toe capped boots) Consumables and additional kit required for setting out survey areas, etc. *If budget allows*: GPS unit per site
Laboratory work	Necropsies to be undertaken and genetic samples to be taken from all bat fatalities.
Training course	
Personnel	Training course development – to be managed by a professional training provider in 2009, and subsequently managed by the Project Officer. The training course will be delivered by the Project Officer and an experienced trainer and bat worker each year. The course will run once per year (in July prior to the

Task / Resources	Personnel / Further details
	commencement of fieldwork). Trainer's fees and expenses
Training venue and materials	Training manuals and equipment needed for in-field training. Accommodation and subsistence at training venue. Travelling costs for trainees to and from the training centre and to visit a wind farm site.
Other	
Travel	Travel costs for site visits, ongoing fieldwork in each season and to attend meetings (Project Officer).
Admin fees	Report production
Training and PR	Conference attendance, wider publicity for project and findings

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8. Appendices

Appendix 1: Relevant Legislation and National Planning Policies

8.1 Legislation

All bat species and their roosts are legally protected in the UK. There is variation in legislation between different countries within the UK, and full details of each country's legislation are not given here in detail: an overall summary is provided instead. Information on the following pieces of legislation are largely taken from Harris & Yalden (2008) and the Joint Nature Conservation Committee (JNCC) website, but also from interpretation provided on the Bat Conservation Trust website and individual pieces of the legislation:

EC Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora, 1992 (Habitats Directive)

The main aim of this Directive is to promote maintenance of biodiversity in Europe. This Directive introduced the system of Natura 2000 sites (Special Areas of Conservation, SACs), requiring Member States to designate protected areas for listed habitats and species. It also required Member States to implement a system of strict protection for listed species (European Protected Species, including all bats) with the aim of maintaining them at favourable conservation status.

The Conservation (Natural Habitats, etc.) Regulations 1994 and amendments (Habitats Regulations)

The Habitats Directive is implemented in the UK by the Habitats Regulations. Significant amendments were made to the Regulations in 2007 meaning that for most purposes, this is the key piece of legislation protecting bats in the UK. Further amendments were also made in 2008/09. All bats and their roosts are protected in the UK under the Habitats Regulations. In summary it is an offence to capture, injure, kill or disturb bats (subject to exceptions). The most recent (2008/09) amendments to the Habitats Regulations include more detailed provisions for monitoring of the incidental capture and killing of European Protected Species, including bats. European guidance suggests that bat fatalities at wind farm sites should be included as incidental killing.

Conservation of the Conservation of European and Wildlife and Natural Habitats, 1979 (Bern Convention)

The Bern Convention was adopted in Bern, Switzerland in 1979 and came into force in 1982. The principal aims of the Convention are to ensure conservation and protection of listed species and their natural habitats. To implement the Bern Convention in Europe, the European Community adopted Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (as described above). The Bern Convention was implemented in UK law by the Wildlife and Countryside Act (1981 as amended).

Convention on Migratory Species, 1979 (Bonn Convention)

This convention was adopted in Bonn, Germany in 1979 and came into force in 1985 and operates as a framework for a range of regional agreements covering particular species groups. Contracting Parties work together to conserve migratory species and their habitats by providing strict protection for endangered migratory species (listed in Appendix 1 of the Convention). One of the current agreements on mammals is the Agreement on the conservation of populations of European bats (EUROBATS), of which the UK is a party to.

Convention on Biological Diversity, 1992 (Rio Convention)

The Convention on Biological Diversity was signed by the UK following the 1992 Earth Summit in Rio de Janeiro. This convention required Parties to develop national strategies to maintain biodiversity and undertake a range of actions aimed at maintaining or restoring biodiversity. In 1994, the government produced the UK Action Plan, a national strategy for the conservation of biodiversity, the UK Biodiversity Action Plan. BAP priority species were reviewed in 2007, so now the current list for bats is: the greater horseshoe, lesser horseshoe, soprano pipistrelle, Bechstein's bat, barbastelle, brown long-eared and noctule bat. There are also separate BAPs for each country within the UK, as well as local BAPs.

Wildlife & Countryside Act (1981) and the Countryside & Rights of Way Act, 2000 (England and Wales)

The Wildlife and Countryside Act prohibits any intentional disturbance, destruction, killing or injury of protected species. Bats are included in Schedule 5 of the Act. The Act has been amended a number of times, with the most recent amendment being the Rights of Way Act (2000) for England and Wales (CRoW Act). The CRoW Act adds "reckless" to a number of offences.

Natural Environment and Rural Communities Act (NERC), 2006

In England and Wales the Natural Environment and Rural Communities (NERC) Act 2006 built on the Countryside and Rights of Way Act 2000. The NERC Act imposes a duty on all public bodies in exercising their functions, '*every public authority, in exercising its functions, have* *regard, so far as is consistent with proper exercise of those functions, to purpose of conserving biodiversity*' (Section 10 duty to conserve biodiversity). It says also that '*conserving biodiversity includes restoring or enhancing a population or habitat*'.

Section 42 (biodiversity lists and action (Wales)): this sets out the duty of the National Assembly for Wales to publish a list of the species and habitat which are considered to be of principal importance for the purpose of conserving biodiversity. In practical terms Section 40 and 42 are likely to mean that a local planning authority must have regard to the conservation of any species that is present on the these lists.

The Nature Conservation (Scotland) Act 2004 has a similar requirement in Scotland. Lists of habitats and species of principal importance for the conservation of biological diversity have been published for the relevant countries, which identify the habitats and species considered to be of principal importance for the conservation of biological diversity

Planning Policies

England

PPS9 - Planning Policy Statement 9: Biodiversity and Geological Conservation (ODPM, 2005a)

PPS9 sets out planning policies on the protection of biodiversity and geological conservation through the planning system and replaces Policy Planning Guidance Note 9 (PPG9) on nature conservation (Defra 1994). One of the six Key Principles (Principal (vi)) of PPS9 that regional planning bodies and local planning authorities should adhere to, is to ensure that the potential effects of planning decisions on biodiversity and geological conservation are fully considered, it states:

"*The aim of planning decisions should be to prevent harm to biodiversity and geological conservation interests. Where granting planning permission would result in significant harm to those interests, local planning authorities will need to be satisfied that the development cannot reasonably be located on any alternative sites that would result in less or no harm. In the absence of any such alternatives, local planning authorities should ensure that, before planning permission is granted, adequate mitigation measures are put in place. Where a planning decision would result in significant harm to biodiversity and geological interests which cannot be prevented or adequately mitigated against, appropriate compensation measures should be sought. If that significant harm cannot be prevented, adequately mitigated against, or compensated for, then planning permission should be refused.*"

PPS9 is accompanied by Government Circular: Biodiversity and Geological Conservation – Statutory Obligations and their Effect within the Planning System (Defra Circular 01/2005 and ODPM Circular 06/2005) (ODPM 2005b). This aims to support PPS 9 by "providing guidance on the application of the law in relation to planning and nature conservation as it applies in England". In addition, the Government has also produced further guidance to complement these two documents: Planning for Biodiversity and Geological Conservation: A Guide to Good Practice (ODPM 2006). This document provides guidance, through case studies and examples, to achieve the key principles of PPS9 and comply with the legal requirements set out in the Circular.

PPS9, the Circular Defra 01/2005 and ODPM 06/2005 aim to ensure that "construction development and regeneration should have minimal effects on biodiversity and enhance it where possible". The guidance proposes to ensure that planning decisions are made based on up-to-date information and ensure the maintenance, enhancement, restoration or addition of biodiversity within scheme design and ensure planning decisions "prevent harm to biodiversity and geological conservation interests" (ODPM 2005a). The government circular makes reference to the UK Biodiversity Action Plan, England Biodiversity Strategy and Local Biodiversity Partnerships. These documents outline strategic action for biodiversity at both the national and local level and are considered further below.

PPS22 – Planning Policy Statement 22: Renewable Energy

PPS22 states the Government's aspirations to generate 20% of electricity from renewable sources, of which wind energy technologies will contribute a significant amount. However, it also states that this should be done alongside improvements to energy efficiency of which many local authorities have already introduced subsidies for loft and cavity wall installation. In order to facilitate the Government's intension towards sustainable energy and to contribute to the UK's commitment towards climate change there will need to be a steep development of renewable energy in the form of positive planning. To ensure the Government's aspirations are met PPS22 lists the following seven key principals, which regional planning bodies and local planning authorities need to adhere to:

i. "*Renewable energy developments should be capable of being accommodated throughout England in locations where the technology is viable and environmental, economic, and social impacts can be addressed satisfactorily*.

ii. *Regional spatial strategies and local development documents should contain policies designed to promote and encourage, rather than restrict, the development of renewable energy resources. Regional planning bodies and local planning authorities should* *recognise the full range of renewable energy sources, their differing characteristics, locational requirements and the potential for exploiting them subject to appropriate environmental safeguards*.

iii. *At the local level, planning authorities should set out the criteria that will be applied in assessing applications for planning permission for renewable energy projects. Planning policies that rule out or place constraints on the development of all, or specific types of, renewable energy technologies should not be included in regional spatial strategies or local development documents without sufficient reasoned justification. The Government may intervene in the plan making process where it considers that the constraints being proposed by local authorities are too great or have been poorly justified*.

iv. *The wider environmental and economic benefits of all proposals for renewable energy projects, whatever their scale, are material considerations that should be given significant weight in determining whether proposals should be granted planning permission. Small-scale projects can provide a limited but valuable contribution to overall outputs of renewable energy and to meeting energy needs both locally and nationally. Planning authorities should not therefore reject planning applications simply because the level of output is small*.

v. *Local planning authorities, regional stakeholders and Local Strategic Partnerships should foster community involvement in renewable energy projects*[3] *and seek to promote knowledge of and greater acceptance by the public of prospective renewable energy developments that are appropriately located. Developers of renewable energy projects should engage in active consultation and discussion with local communities at an early stage in the planning process, and before any planning application is formally submitted*.

vi. *Development proposals should demonstrate any environmental, economic and social benefits as well as how any environmental and social impacts have been minimized through careful consideration of location, scale, design and other measures*.

vii. *Regional planning bodies and local planning authorities should not make assumptions about the technical and commercial feasibility of renewable energy projects (e.g. identifying generalised locations for development based on mean wind speeds). Technological change can mean that sites currently excluded as locations for particular types of renewable energy development may in future be suitable*."

Scotland

NPPG14: National Planning Policy Guidance 14: Land use planning and the natural heritage

NPPG 14 sets out government policy on land use planning and the natural heritage in Scotland. It states specifically that, *"the development of local site systems, and the level of protection accorded to them, should be a matter for the planning authority"*, and encourages these authorities "to safeguard and enhance the natural heritage beyond the confines of nationally designated areas".

This legislation also gives guidance on the role non-statutory local sites can play as part of a strategic approach to natural heritage planning.

Scottish Planning Policy (SPP) 6: Renewable Energy

The Scottish Ministers have set an ambitious target to produce 40% of Scotland's electricity from renewable energy sources by 2020, which they state is not a capped figure. Therefore, renewable energy generation will need to be supported, to ensure the delivery of this target. SPP6 sets out the national planning policies for renewable energy developments for planning authorities to consider and states that while the target should be met by a range of renewable technologies, hydro and onshore wind power are currently making the most significant contribution.

SPP6 also sets out the expectation of Scottish Ministers that planning authorities should make positive provision for renewable energy by:

- "*supporting a diverse range of renewable energy technologies including encouraging the development of emerging and new technologies;*
- *recognising the importance of fully engaging with local communities and other stakeholders at all stages of the planning process;*
- *guiding development to appropriate locations and providing clarity on the issues that will be taken into account when assessing specific proposals; and*
- *maximising environmental, economic and social benefits*;

While at the same time:

- *meeting international and national statutory obligations to protect designated areas, species and habitats and protecting the historic environment from inappropriate forms of development; and*

- *ensuring impacts on local communities and other interests are satisfactorily addressed. Such interests will vary from technology to technology*."

Wales

Planning Guidance (Wales): March 2002 (PG(W))

Planning Guidance (Wales) sets out the broad principles for the operation of the planning system in Wales. The document contains general commitment to sustainable development, the protection of biodiversity and the protection of the environment as a whole.

PG(W) indicates that local authorities should determine planning applications strictly in accordance with the policies contained in the current development plan, and should only do otherwise when there are significant material considerations to consider. Development plans are required to have reasonably detailed policies with respect to nature conservation and the document goes on to give guidance as to what these should cover.

Paragraph 5.3.20 states: "…*the presence of a protected species is a material consideration*" when considering planning applications and notes that applicants must conform to any statutory species protection provisions affecting the site concerned.

Technical Advice Note (TAN) 5 – Nature Conservation and Planning (1996)

TAN 5 is still in force until it is replaced by the revised TAN (detailed below) is issued. The current TAN 5 gives advice on development control issues for Special Protected Areas (SPAs), Special Areas of Conservation (SACs) and Sites of Special Scientific Interest (SSSIs). It also covers the selection and designation of non-statutory nature conservation sites and the protection of species.

Draft revised Technical Advice Note 5 – Nature Conservation and Planning (2006)

The revision of TAN 5 should be treated as emerging guidance until it replaces the current TAN 5 (1996). The revision of TAN 5 aims to consolidate advice on legislation relevant to nature conservation topics, these national policies on the protection of biodiversity that can then be taken into account and used by regional and local planning bodies. It states:

Paragraph 6.2.1: Species protected by law

"*The presence of a protected species is a material consideration when a local planning authority is considering a development proposal that, if carried out, would be likely to result in disturbance or harm to the species or its habitat*".

Paragraph 6.2.2 states that:
"*It is essential that the presence or otherwise of protected species, and the extent that they may be affected by the proposed development, is established before the planning permission is granted, otherwise all relevant material considerations may not have been addressed in making the decision. Planning permissions should not be granted subject to a condition that protected species surveys are carried out and, in the event that protected species are found to be present, mitigation measures are submitted for approval*".

Paragraph 6.5.1: Habitats and species of principal importance in Wales:
"*The potential effects of a development on habitats or species listed as priorities in the UK Biodiversity Action Plan (BAP) and by Local Biodiversity Partnerships are capable of being a material consideration in the preparation of local development plans and in making planning decisions*".

Paragraph 6.5.2: Section 74 of the Countryside and Rights of Way (CRoW) Act 2000 [now replaced by Section 40 of the Natural Environment and Rural Communities (NERC) Act 2006] places a duty on the Welsh Assembly Government in respect of the conservation of biodiversity. It may exercise this duty by promoting the taking of steps by others, such as local authorities, to further the conservation of the habitat types and species of principal importance in Wales.

Section 74 of the CRoW Act was replaced by Section 40 of the NERC Act, which takes further the requirements of S.74 and places a duty on all public bodies to have regard to the purpose of conserving biodiversity:

Technical Advice Note (TAN) 8 – Planning for Renewable Energy

TAN8 was produced to provide to outline the Assembly Government's commitment to renewable energy in Wales, and can be used as a material consideration in planning decisions by local authorities that must take into account the Assembly Government's policy. As such the document states: "*The Assembly Government has a target of 4TWh of electricity per annum to be produced by renewable energy by 2010 and 7TWh by 2020*. *In order to meet these targets the Assembly Government has concluded that 800MW of additional installed (nameplate) capacity is required from onshore wind sources*…" particularly as wind energy is considered to have the greatest potential to increase renewable energy in the short to medium term. TAN8 does also state that while the Assembly Government is committed to developing new sources of renewable energy, energy efficiency and conservation will also be promoted.

To meet the commitments for renewable energy experts consulted have concluded that "*for efficiency and environmental reasons among others, large scale (over 25MW) onshore wind energy developments should be concentrated in particular areas defined as Strategic Search Areas (SSAs)*. These SSAs have been described in more detail in the policy. Additionally, a number of urban and industrial sites have also been highlighted to site new wind energy facilities up to 25MW which should be encouraged.

Appendix 2: European bat species' behaviour of species found killed at wind energy facilities in Europe, relevant to species found in Britain

Species	Hunting close to habitat structures	Migration or long distance movements	High flight (> 40 m)	Low flight	Max. Distance (m) of ultrasonic detection (D980) (data from Michel Barataud)	Max. Distance (m) of ultrasonic detection (D240) (data from Lothar Bach)	Possibly disturbed by turbine ultrasounds	Attracted by light	Roosting inside nacelle	Known loss of hunting habitat	Risk of loss of hunting habitat	Known collisions	Risk of collisions
Greater horseshoe	X			X	10								
Lesser horseshoe	X			X	5								
Mouse-eared		X	X	X	30	20						X	X
Daubenton's	X		X	X	30	20-30						X	X
Natterer's	X			X	20	15							
Whiskered	X			X	15	20							X
Brandt's	X		X	X		20						X	X
Bechstein's	X			X	25	15*							
Noctule		X	X		100	150	X	X	?		X	X	X
Leisler's		X	X		60-80		X	X	?		X	X	X
Serotine		?	X		50	50	X	X		(X)		X	X
Common pipistrelle	X		X	X	30	30	?	X				X	X
Soprano pipistrelle	X	X	X	X	?	30	?	X				X	X
Nathusius' pipistrelle	X	X	X	X	30-40	30-40	?	X				X	X
Brown long-eared	X		X	X	30	10 (during hunting)						X	X
Grey long-eared	X		X	X	30	10 (during hunting)						X	X
Barbastelle	X			X	30	20							

Appendix 3: **Summary of pre-construction and post-construction acoustic surveys**

Source	Study site/ Habitat type	Time of year	Survey height (m)	Survey effort / methods	Survey results
			North America		
Lausen *et al.* 2006	**Pre-construction** survey protocol Alberta Bat Action Team	Aug & Sep	30-60m agl	Recommend surveys for migratory species. 5 Anabat detectors set at between 30 & 60m agl. For sites 1-5 turbines at each turbine location. For larger sites at north, south, west & eastern extents of site & central location.	Data to be presented as a minimum as total number. bat passes & mean bat passes / detector-night or detector-hour (if recording not continuous through night)
Kunz *et al.* 2007	**Pre-construction** survey recommendations	Apr-Nov Multi-year studies (3 yrs)	Ground level (2-3m agl), turbine height (>30, agl) & intermediate height if enough detectors.	Nightly sampling with Anabat detectors using met masts &/or portable towers. Recommend additional detector stations to Lausen *et al.* (2006) if site is large or terrain varies, or recommend use of a systematic sampling regime across site. 2-3 locations not likely to be representative of overall bat activity.	Data on number bat passes / detector-night should be normalised to hours after sunset to allow comparison between studies.
New York State Department of Environmental Conservation 2009	**Pre-construction** survey recommendations	Apr to Oct for min. 1 yr	Ground level (2-3m agl) & at least 150ft agl plus intermediate level if possible	Sample with Anabat bat detectors nightly from half an hour before sunset to half an hour after sunrise from 15 Apr to 15 Oct. Include additional summer bat activity transect surveys at ground level. In 'high risk' locations, radar studies may be required as well. If sites are within 40 miles of Indiana bat hibernacula, additional surveys for this Federally-listed species required.	Number of bat calls / detector-night for spring, summer & autumn to be reported. Range of detectors to be reported.

Source	Study site/ Habitat type	Time of year	Survey height (m)	Survey effort / methods	Survey results
Johnson *et al*. 2004	**Post-construction** Buffalo Ridge, MN 409 turbines Arable (wetland / woodland nearby) Swept area approx 25-75m	15 Jun - 15 Sept 2001 & 2002	? ground level	Anabat bat detectors monitoring at turbines 3 turbines per survey night, detectors moved between turbines randomly each night, total 216 turbines surveyed (plus Anabat bat detectors monitoring & mist netting to 3.6km from wind farm)	Averages of 2.2 & 1.9 bat passes / turbine / night in 2001 & 202 respectively (no feeding buzzes recorded at turbines). Number of passes decreased as distance to woodland increased. Peak activity mid July to end Aug, corresponding to peak mortality period. No relationship between bat activity & bat mortality at turbines. Estimated 1 fatality / 70 bat passes. (Bat activity higher in woodland / wetland close to wind farm. Species present near wind farm during breeding with no or very low mortality).
Fielder 2004	**Post-construction** Tennesse	2001-2003	Ground level (compared with activity at 15m agl & 70m agl in 2002 & 2003)	Anabat bat detector monitoring	Calculated an activity index from no. Calls. Peak activity mid-Aug, bat activity lower at 70m agl than at ground level. Bat activity was higher on nights when (fresh) fatalities found but activity level very variable between nights.
Jain 2005	**Post-construction** Iowa 89 turbines in arable habitat	Apr - Dec 2003, Mar - Dec 2004	Ground level	Anabat bat detector monitoring at tower & non-tower locations (paired design)	Highest activity July & August Mostly *Myotis* sp.

Source	Study site/ Habitat type	Time of year	Survey height (m)	Survey effort / methods	Survey results
Gruver 2002 (in Erickson *et al.* 2002)	**Post-construction** Foote Creek Rim, Wyoming	Jun - Aug 2000 & 2001	Ground level (& 1 location at 15m agl	Anabat bat detector monitoring near turbines from dusk to dawn (plus mist netting near wind farm)	2.6 bat passes / turbine / night 80% *Myotis* sp. calls No correlation between bat activity & mortality (found no difference in activity at 15m agl)
Schmidt *et al* 2003	**Pre- & post-construction?** NWTC, Colorado	Jun '01 - Jun '02	Ground level	Batbox & Petterson D240x	Bat activity recorded in locations (*Myotis*, hoary & *Tadarida*) with no mortality
Arnett *et al.* 2006	**Pre-construction** Pennsylvania (as start of 5 yr study to cover pre- & post-construction) Western section in forest ridge habitat, eastern section in open ridge habitat	Aug - Oct 2005	Vertical array: 1.5, 22 & 44m agl (microphones placed at height in a 'bathat' using a pulley, with cable to detector at ground level)	Anabat recordings from half hr before sunset to half hr after sunrise. Microphones facing prevailing wind. Portable towers (1.5 & 22m): detectors at 2 levels, towers rotated between pairs of randomly selected turbine locations (40m away from turbine so post-construction monitoring could continue) on weekly basis. MET towers (1.5, 22 & 44m): detectors at all 3 levels. Monitored at 2 reference sites away from turbines. Detectors rotated between weeks.	Calls divided into 'high' & 'low' (> or < 35kHz Total dataset: 1,116 observations (2 species groups / 2 habitats [ridges] / 3 heights / 93 nights Activity highest mid-Aug to mid-Sept. Activity peaked after sunset & declined through night. 'High' frequency bats more active at low levels, & 'low' frequency bats more active at high level. Activity levels of both species groups similar at 44m height (within swept area). Bat activity increases with increased temp.
Redell *et al.* 2006	**Pre-construction** Wisconsin (as start of 3 yr study) Site close to large hibernaculum	19 Jul - Sep 2005	Vertical array: 2, 22 & 48m agl	Anabat recordings from half hr before sunset to half hr after sunrise Portable towers (2 & 22m): detectors at 2 levels, towers rotated around all 33 turbine sites. Met towers (2, 22 & 48m): detectors at all 3 levels. Detectors rotated between weeks.	26,495 bat passes recorded, 15% with feeding buzzes Activity highest in August Calls divided into 'high' (Myotis, red bat & eastern pipistrelle) & 'low' (big brown / silver haired / hoary bats) (> or < 35kHz. 'High' frequency bats more active at 2m than other heights, 'low' frequency bats showed no difference Bat activity increased with increased temperature. Bat activity increased with increased wind speed.

Source	Study site/ Habitat type	Time of year	Survey height (m)	Survey effort / methods	Survey results
Arnett *et al.* 2007	**Pre-construction** Massachusetts (as start of multi-yr study)	26 Jul – 20 Dec 2006	Vertical array: 10, 31 & 39m	Anabat bat detector recordings from 19H00 to 06H00 each night. Detectors placed on met towers at 10, 31 & 39m agl. Microphone direction decided subjectively.	Average of 8.9 calls / tower / night to 11 Nov, no activity recorded after 11 Nov. Bat activity variable during sampling period but generally high late July & mid-Aug. Activity peaked after sunset & declined through night. 'High' frequency bats (mostly hoary / big brown) more active at low level (10m), & 'low' frequency bats (mostly *Myotis* & red bats) more active at high levels. Bat activity increased with increased temperature, & increased initially with wind speed, then decreased at high wind speeds.
Reynolds 2006	**Pre-construction** New York Northern hardwood forest	10 Apr – 22 Jun 2005 23 Jun – 5 Jul 2005	7, 25 & 50m agl (using met masts) 1.5m agl	Anabat bat detectors recorded from 19H00 – 06H00 1 night at each of 35 locations	Median activity level 2.0 bat passes / hour. Big brown/silver-haired group & hoary bat most common bats recorded. 50% activity at 7m, 17% at 50m. Most activity when winds <5.4m/s Median activity 6.2 bat passes / hr Id of *Myotis* sp grouped (accounting for 95.7% calls) Decline in activity through night Activity concentrated around ponds

Source	Study site/ Habitat type	Time of year	Survey height (m)	Survey effort / methods	Survey results
Europe (excluding the UK)					
Behr *et al* (2007)[2]	**Post-construction** Black Forest, SW Germany. 3 sites with 2-4 turbines each. Forested area, partially shrubby re-growth following storms.	Aug - Oct 2004, Jul - Oct 2005	Ground & nacelle level (total height 121-133m, blade height 70-77m)	2-4 Batcorders at each site on 4 subsequent days each month. (Not mentioned how attached at height).	Regular activity of 3 species (common pipistrelle, Nathusius' pipistrelle & Leisler's bat) at both heights. Other species (Natterer's bat and whiskered/Brandt's bat, greater mouse-eared, Bechstein's bat, Daubenton's bat & *Plecotus* species) at ground level only. Significantly more bats active at low wind speeds (<5 m/sec). Highest wind speed with bat activity was 6.5 m/sec.
Grunwald & Schäfer (2007)[1]	**Post-construction** Germany. 4 sites with 5-11 turbines each.	Jul - Oct 2005 & 2006	Ground & nacelle level (total height 104-114m, blade diameter 70-90m)	Specially designed bat detectors suspended from helium balloons with radio transmission of signals.	Common pipistrelle, Nathusius' pipistrelle, noctule, & Leisler's bat were all present at both ground & nacelle level. Common pipistrelle. Soprano pipistrelle, Natterer's bat, whiskered/Brandt's bat, Bechstein's bat & greater mouse-eared were present only at ground level. Flight activity of common pipistrelle & Leisler's bat at nacelle level correlated with structure richness – more activity in forests. More bats were active at low wind speeds (<6 m/sec). Highest wind speed with bat activity was 8 m/sec (noctule).

[2] Summaries obtained from EUROBATS 'Guidelines for consideration of bats in wind farm projects' Rodrigues *et al*. (2008) rather than from original source.
[1] Summaries obtained from EUROBATS 'Guidelines for consideration of bats in wind farm projects' Rodrigues *et al*. (2008) rather than from original source.

Source	Study site/ Habitat type	Time of year	Survey height (m)	Survey effort / methods	Survey results
Sattler & Bontadina (2005)[2]	France, two planned wind farm sites. Study site 1 - 4 sites were surveyed. Study site 2 - 11 sites were surveyed. Paired controls were matched for habitat type as far as possible, with the exception of two of the controls which were in optimal bat habitat.	11-13 Sep 2005 at study site 1 & 14-19 Sep 2005 at study site 2.	Simultaneous recordings at ground & at lower & upper rotor blade heights (study site 1 – 30m & 90m respectively, study site 2 – 50 & 150m respectively)	Nightly surveys during the timeframe given. On the ground, a Petterson 980 detector was used, connected to a laptop via a converter. At height, a heterodyne Mini-3 bat detector set to 40kHz connected to a digital or analogue recorder was suspended from a zepplin balloon. From the ground detectors 20 call sequences were analysed from each 40 min block of recording. Sonograms were analysed to species. Call sequences from the detectors at height were considered unique if separated by a gap of at least 2 seconds from one another. Calls were identified to genus only.	Activity on the ground & at altitude did not always coincide. Because of the different methods & techniques used at ground & at height, bat activity at height was presumed to be underestimated. Common pipistrelle, Kuhl's pipistrelle, Nathusius' pipistrelle, barbastelle, serotine, noctule & greater horseshoe were recorded at ground level. *Eptesicus* & *Pipistrellus* groups were identified at the upper rotor blade heights of 90 & 150m. *Eptesicus*, *Myotis* & *Pipistrellus* groups were identified at the lower rotor blade heights of 30 & 50m. Feeding buzzes were recorded at 90m.

[2] Summarised from original source.

Appendix 4: Summary of mortality search methods and results

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
North America						
Anderson *et al*. (2004)	Tehachapi, California		20 x 30	637		0.002 bat fatalities / turbine annually. No corrected annual figure.
Arnett *et al*. (2004)	Mountaineer, mid-Atlantic highlands, West Virginia. Site located along a mountain ridge in Appalachian mixed forest.	31 Jul – 11 Sep 2004	1.5MW	44	Rectangular plots 120m (N-S) by 130m (E-W) centred on turbine. Area sampled varied with topography & vegetation. Habitats unsuitable for searching (e.g. shrub cover, steep) eliminated from search area. Transects every 10m in N-S direction. Daily searches at all odd turbines & weekly searches at even turbines during the first 3 weeks, & then switched turbine sets & search intervals during later 3 weeks. Each plot searched approx. 30-90 min, depending on area & habitat.	466 bat fatalities, 6 spp. (hoary, eastern red, eastern pipistrelle, little brown, silver-haired, & big brown bats from highest to lowest number found). More adult & more male bats than juvenile & female bats. Days of high bat fatalities appear to be correlated to nights of relatively low wind speed.
Arnett *et al*. (2004)	Meyersdale Wind Energy Facility	2 Aug – 13 Sep 2004				290 bat fatalities, 7 spp. (hoary, eastern red, eastern pipistrelle, silver-haired, big brown, little brown, & northern long-eared bats, from highest to lowest number found). More adult & more male bats than juvenile & female bats. Days of high bat fatalities appear to be correlated to nights of relatively low wind speed.
Baerwald *et al*. (2008)	Wind energy facility in south-western Alberta					188 bats killed in one night, 87 had no fatal external injury. Of 75 fresh bats necropsied, 32 had obvious external injuries, but 69 had haemorrhaging in the thoracic &/or abdominal cavities. 26 (34%) had internal haemorrhaging & external injuries, whereas 43 (57%) had internal haemorrhaging but no external injuries. Only 6 (8%) bats had an external injury but no internal haemorrhaging.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Brown & Hamilton (2006)	Summerview Wind Farm Alberta. Located either side of Highway on broad, level plateau within grassland (entirely agri – crop & seed pasture). 79% of turbines in crop, other 21% on seeded pasture.	Jan 2005 – Jan 2006	80 x 65 (hub height)	39	66 surveys weekly most of year & twice weekly during bird migration (May-Jul & Sep). Walked standardised transects at the base of each turbine to search for carcasses of birds & bats.	534 bat fatalities, 5 spp. (little brown (6), big brown (4), hoary (244), silver-haired (272), eastern red (1), & unidentified bats (5)). Of all dead bats found 46% hoary bats & 51% silver-haired bats. A few silver-haired fatalities in spring, but most occurred in fall, ↑ late Aug until mid-Sep. Hoary bat fatalities ↑ Aug & into Sep.
Brown (pers. Comm 2006)	Magrath		77 x 65	20		1.35 bat fatalities / turbine annually corrected to 1.76.
Brown (pers. Comm 2006)	McBride Lake		47 x 50	114		0.47 bat fatalities / turbine annually. No corrected annual figure.
Brown & Hamilton (2002)	Castle River, Alberta		47 x 50	41		0.93 bat fatalities / turbine annually. No corrected annual figure.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Curry & Kerlinger (2006)				Up to 90 turbines as they became operational	Prior to fatality searches a 'clear sweep' was conducted to remove carcasses and remains from survey area using fatality search protocols. Fatality searches were conducted twice monthly between 1 &15 of month and 16-end of month at every wind turbine. Each round of surveys started from 4 turbines down from where the previous survey began. Surveyors walked in concentric circles around tower's base at distances of 15, 30, 40, 50, 60 & 70m. Recorded data at start of each survey included meteorological data (cloud cover, temperature, wind velocity) & ground cover information (crop type & height). Start & finish times of each tower search recorded.	116 bat fatalities comprising of 4 species (hoary, Mexican free-tailed, western red and silver-haired bats). With 78% of bat fatalities found between Aug & Oct
Erickson *et al*. (2004)	Stateline Wind Farm, semi arid habitat in Columbia Basin Privince. Land use is dryland (not irrigated), wheat production and cattle grazing.		47 x 50	454 (140 – typically every 4th & end turbine is lit with obstruction lighting)	Detailed methods taken from FPL Energy *et al*. (2001), OEFSC (2001, 2002, & 2003), in Erickson et al. (2003a). Turbine search plots rectangular & typically contain 3 turbines but range from 1-4. Personnel trained in proper search techniques and conducted standardised carcass searches by walking 45-60m/min parallel transects set 6m apart. All area within min of 63m from turbine was searched.	150 bat fatalities recorded, 128 found on search plots of which 50% are silver-haired bat, 46.1% are hoary bat, with little and big brown bats each comprising less than 2%. For hoary bats 68% were adults, 28% were juveniles and 4% were unidentified to age. Of 32 hoary bats where sex could be determined 53% were male and 47% were female. Of 18 silver-haired bats where sex determined, 83% were males & 17% females.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Erickson *et al*. (2000)	Vansycle Ridge Wind Farm, Umatilla County, Oregon. Habitat largely comprises of cultivated wheat fields, but also has areas of grassland (primarily non-native).		660-kilowatt Bestas	38	Searched half turbines every 14d, all turbines 28d. Biologists were trained in proper search techniques prior to conducting searches. Square or rectangle plots used 126m width. Transects initially set 6m apart & walked approx. 45-60m/min searching 3m either side of transect (Johnson *et al*., 1993). Transect width & search speed adjusted on visibility. Ave approx. 30-60m/min depending hab. Recorded species, sex & age where possible, date & time, location, habitat, condition & any comments to indicate time & cause of death. All casualties photographed as found & mapped on detailed map of study area. Labelled with unique number, bagged and frozen for future necropsy.	10 bat fatalities found throughout study (also 12 bird fatalities likely nocturnal migrants). Adjusted to 28 bats (24 birds).

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Johnson *et al*. (2004)	Buffalo Ridge Wind Resource Area	15 Jun – 15 Sep 2001 & 2002		354	Conducted daily carcass searches at 3 turbines (Anabat detectors placed the previous night to determine any relationship between bat activity at turbines & collision mortality levels). Selected additional 80 turbines (2001) or 100 turbines (2002) using systematic design with a random start. Searched same turbines every 14 days throughout study. Recorded proportion of each cover type within 100m & distance from each carcass search turbine to the nearest wetland & woodland. Used square plot initially transects 6m apart & walked along each transect searching both sides out of 3m for casualties. Adjusted transect width & search speeds based on visibility. On average approximately 20-25 min searching each plot. Field methods followed Johnson et al. (2003). Used slightly different statistical approach for estimating total mortality. Aging & sexing followed criteria in Anthony (1988) & Racey (1988). Recorded weather conditions on estimated date the fatality occurred for each fatality estimated to be <1 week old.	151 bat fatalities (115 hoary bats, 21 eastern red, 8 big brown, 4 silver-haired & 3 little brown bats). Fatalities found 19 Jun – 12 Sep, but 82% from 16 Jul – 21 Aug. 56 (37%) were intact, 93 (62%) were scavenged & 2 (1%) was found alive but with injuries that prevented flying. Virtually all scavenging done by insects. Distance bat found from turbines ranged from <1-35m mean 11.1m. 90% of all bats <20m from turbine. Fatalities recorded during inclement as well as good weather. Did not examine potential effects of high winds on bat collision mortality. No significant relationship (P>0.10) between the number of bat fatalities & cover type within 100m or distances to nearest wetland (P=0.43) or woodland (P=0.67). No significant difference between bat fatalities at lit & unlit turbines (P=0.59). Bat mortality was 839 in 2001 & 364 in 2002.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Johnson *et al.* (2003a)	Buffalo Ridge, 100km long stretch of the Bemis Moraine, southwest Minnesota & northeast South Dakota. Terminal moraines & stream-dissected lands. Vegetation types consist of crops, pasture & Conservation Reserve Programme grassland, as well as to a lesser extent deciduous woodland ass with farmsteads, wooded ravines & wetlands.	15 Mar – 15 Nov throughout 1996 - 1999	33 x 36 46&47 x 50 46&47 x 50	Phases: 1 =21/73 2 =40/143 3 = 30/138	Each turbine searched every 14 d Mar – Nov using random start. 100m x 100m plot centred around turbine to ensure 50m searched, marked out search boundaries. Transects initially 6m apart, walked approx 30 – 45m/min along each transect searching both sides of 3m. Width & search speed adjusted based on visibility (habitat type). Ave approx. 30-45 min spent searching each plot. Recorded species, date & time, location, distance to nearest turbine & condition. Injuries observed were recorded during field necropsy. Subset of fresh intact bat carcasses aged & sexed. Mean number of fatalities per turbine & associated variance were calculated using standard formulas.	184 bats found during study, of 163 bats able to be identified 66% hoary & 23% eastern red bats. Rest comprised of small numbers of silver-haired, eastern pipistrelles, little brown & big brown bats. In 1999, 21 bats aged & sexed & found both hoary & eastern red bats comprised primarily of males with 2 of 8 hoary bats & 7 of 11 eastern red bats were juveniles. Fatalities from 20 May-19 Oct, 97% found 15 Jul-15 Sep. 54% of all bat carcasses were found ≤10m from a turbine, 43% found from 10m – 20m, 3% from 20m – 30m & 0.5% was found >30m 34.8m). Lit turbines comprised 22% of all turbines in wind plant & 18% of bat fatalities were found at lit turbines but the mean number of fatalities was not found to be significantly higher at unlit turbines (z=-1,3, P=0.9).

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Johnson *et al*. (2003b)	Klondike Sherman County, Oregon. Orig bluebunch wheatgrass-Idaho fescue, predominately grassland & shrub-steppe with deciduous riparian forest & scrub along drainages. Agri & livestock grazing converted hab to mosaic of grazed shrub-steppe, CPR fields & cultivated wheat fields. 13 turbines in wheat fields , 3 in narrow strip of CRP fields.	Spring migration (16 Mar – 15 May), summer / breeding (16 May – 15 Aug), Fall migration (16 Aug – 31 Oct), winter (1 Nov – 15 Mar)	24MW	16	Standardised carcass searches, personnel trained in search techniques (no details given in paper of training). 1st search within 1 week after all turbines became operational, cleared plots of carcasses. Subsequent searches conducted at intervals of approx. 28–30 d. Total of 13 searches at each turbine & 1 perm. met tower. Boundaries of square plots 140m centred on turbine were delineated. Areas within plots searched by walking parallel transects. Transects initially set 6m apart & walked at rate of approx. 45-60m/min along each transect searching both sides out to 5m for casualties (Johnson et al., 1993). Search area & speed adjusted by habitat after evaluation of 1st searcher efficiency trial. Approx 45-90 min to search each turbine. All carcasses found labelled with unique number, bagged & frozen. Data recorded included species, condition (e.g. badly decomposed, sex & age where possible, date & time collected, location, condition & any comments that may indicate cause of death. All casualties were photographed as found.	6 dead bats found (3 hoary found in September, 1 silver-haired found in May & 2 unidentified *Myotis* species found in June). 3 bats were intact but 3 were scavenged, mainly by insects. Distances bats were found from turbines ranged from 8m - 30m, with an average of 17.5m. Estimated total bat mortality over one-year study period was 19 (90% confidence interval = 7 – 34).
Kerlinger *et al*. (2006)	High Winds, California		80 x 60	90		0.644 bat fatalities / turbine annually corrected to 3.43.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Osborn et al. (1996)	Buffalo Ridge, southwestern Minessota. Primary habitats are agricultural (corn, soybeans, small grains, pasture & hay) or Conservation Reserve Programme (CRP) fields. Small patches of woodland exist near farmsteads & in ravines.	Apr 1994 – Dec 1995	33m x 37m	73	Ground within at least 46m radius of turbines searched for carcasses, search intensity varied by season. During spring & fall all 73 turbines were searched once a week, in summer & winter only 30 plots were searched once a week. Searched walking in parallel transects, distance between transects ranged from 5-11m, depending on visibility& was primarily influenced by vegetation height. Used search procedures & frequency provided in Higgins *et al*. (1996).	During 20 months of continuous monitoring found 13 bat carcasses from 5 species. 1 collision (8%) occurred during spring, 11 (85%) during summer, & 1 (8%) on first day of fall. 6 of 13 (46%) of bat were found within 15m of turbines & 69% within 20m.
McCrary *et al*. (1986) & Anderson *et al*. (2005)	San Gorgonio, California		19 x 24.4	2947		0.001 bat fatalities / turbine annually. No corrected annual figure.
Piorkowski (2006)	Oklahoma Wind Farm. Hab dom rangeland & small grain (wheat). Approx. 42 of 68 turbines occur along heads of seasonally dry riparian ravines that drain into the Cimarron River.	May – Jul 2004 & 2005		68 (surveyed all)	Conducted two searches (late May & late June) in 2004 & 4 rounds of searches (about every 14d between 15 May – 15 Jul 2005. Walked circular transects (Kerns & Kerlinger, 2004) around base at 5m, 10m & 15m. Pace approx 20-30m/min but speeds adjusted depending vegetation & terrain.	111 bat carcasses of 6 bat spp., Brazilian free-tailed bats made up 86%, also eastern pipistrelle, big brown, silver-haired, red eastern bat & hoary bats (also 11 carcasses of 6 bird species). Estimated bat turbine collisions ranged from 1.19 – 1.71 fatalities/turbine/summer. Spatial analysis show no significant diff between 3 habitats & 2 topography types.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Smallwood & Thelander (2005)	Altamont, California		18 x 24	1526		0.001 bat fatalities / turbine annually corrected to 0.01.
West Inc. (2006)	Diablo Winds, California		47 x 50	31		0.00 bat fatalities / turbine annually corrected to 1.19.
Europe (excluding the UK)						
Ahlén (2002[1], 2003[2])	Various, from open with shrubs underneath to farmland (with hedgerows)	Aug – Sep 2002	Unknown. Possibly various.	160 turbines, each surveyed once.	Search area 50m radius. (In addition bat detectors and thermal imaging were used to observe bat behaviour around the turbines)	17 bats of 6 species (in addition 33 birds of 17 species were found). 0.1 bats/turbine. Found 3-25m (mean 12m around turbine). Almost half of the bat species were resident., the remainder migrant. Species found dead are the ones observed hunting close to the blades.
Alcade (2003[1])	Close to hedgerows	1995-2003	40m (older) and 60-80m. Blade diameter 20 (older) and 34m.	Around 1000 turbines	Search area with radius equal to turbine height. (Possibly also did some observation as they made some conclusions about habitat use – not summarised in EUROBATS report)	50 bats of 8 species. Mainly found during August and September.

[1] Summaries obtained from EUROBATS 'Guidelines for consideration of bats in wind farm projects' Rodrigues *et al*. (2008) rather than from original source.
[2] Summarised from original source.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Behr *et al*. (2006)[1]	Forest	31 July to 30 Oct 2005	Nacelle height 85m Blade diameter 70m	Site with 2 turbines (presumably both searched).	Search area 65m (radius?). 31 Jul - 30 Sep surveyed every other day. 01 Oct-30 Oct surveyed every third day. Estimation of search efficiency Mouse experiment (assuming ts is carcass removal rate)	4 dead bats. 0.18 bats per wind turbine per night. 16.5 bat per wind turbine (over the entire study period).
Behr & von Heleversen (2005)[1]	Forest	Aug-Oct '04 & 26 Jul - 30 Oct '05	Nacelle height 90m Blade diameter 77m	Site with 3 turbines.	Search area 68m. Surveyed every third day.	3 dead bats. Brinkmann et al. (2006) refer to this study and stated that one of the bats found was located 95m away from the turbine tower.
Behr & von Helversen (2006)[1]	Forest in areas with trees blown down	End Apr – mid Oct 2005	Height 98m, Blade diameter 70m	Site with 4 turbines	Apr-Jun every three days, Jul-Oct every four days. The difference in the search interval makes it difficult to compare the results from these survey periods, however it does show that more bats were found in the latter period even those the surveys were conducted every four days rather than every three.	31 dead bats (Apr-mid Jul 11 bats, mid Jul-Oct 20 bats). 0.18 bats per turbine per night.

[1] Summaries obtained from EUROBATS 'Guidelines for consideration of bats in wind farm projects' Rodrigues *et al*. (2008) rather than from original source.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Brinkmann *et al* (2006)[2]	Mostly forest, some at forest edges and meadows. 470-1100masl.	Aug-Oct 2004 Apr-mid May and mid Jul-mid Oct 2005	Varying between 69 and 98m in height, 44-80m blade diameter	16 turbines (2004 all 16 surveyed, 2005 8 surveyed)	Search area 50m radius around turbines. Walked 6m transects searching 3m either side taking 30-50 minutes per turbine. When carcass found, photographed, precise location recorded by measuring distance to turbine and taking compass bearing, species identified and condition described, carcass frozen for later more detailed examination. In 2004 there were between 9 and 18 surveys per turbine (roughly every five days). In 2005 turbines were surveyed, 12 times during spring and 18 times during autumn. Estimation of search efficiency and carcass removal rate using dead mice. Formula for projecting fatality given.	2004 – 35, 2005 – 10 dead bats, 4 spp. Additional 9 bird carcasses of 5 species were found during the searches. Average search efficiency 85% in open areas, 77% in overgrown areas and 40% in heavily overgrown areas. Carcass removal rate average over 5 day interval 58.8%. Taking searcher efficiency and carcass removal into account projected fatalities were 335 (variation 269-446, average 20.9 per turbine) in 2004 and 94 (75-125, average 11.8 per turbine) in 2005. Peak fatalities end Jul-mid Aug and beginning Sep. No fatalities in Apr-mid May. Carcasses found at all altitudes and under smaller and larger turbines (no statistical difference). Difference according to habitat – more bats found in forests than pastures. Furthest carcass from base of turbine 37m.

[2] Summarised from original source.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Cosson (2004) & Cosson & Dulac (2005, 2006, 2007)[1]	Open cultivated polder on one side, oyster beds on the other. (coastal)	23 Jul – 16 Dec 2003, Jan 2004 – Dec 2006		Presumed 8 turbines (from the results). Survey for every turbine	Protocol from J E Winkelman. Adjusted fatality estimates (highest figures taking into account adjustments for searched area also)	77 dead bats of 5 species. Estimates of mortality: 2003 M = 4.74/week/8 wind turbines (6 month study) 2004 M = 3.1-3.6/week/8 wind turbines (20.3-23.5/year/WT) 2005 M = 3.3-4.2/week/8 wind turbines (21.5-27.2/year/WT) 2006 M =0.9-1.4/week/8 wind turbines (6-9.3/year/WT)
Dürr (pers comm)[1]	Various. Often close to hedgerows	2001-2003	Various	2001 – 38 turbines, 66 surveys 2002 – 79 turbines, 394 surveys 2003 – 147 turbines, 550 surveys	Unsystematically surveyed between Feb and Dec, but mainly in Aug and Sep. Search area mainly 50m around turbine.	36 dead bats. (0.04 bat per survey). Mainly of three species, Nathusius' pipistrelle, common pipistrelle and noctule. Found at all types of turbines. Mainly first half of August.
Endl *et al.* (2005)[1]	Open farmland but mostly very close to forest or hedges (0-150m)	Mar-Nov 2004	Height 65-80m. Blade diameter 47-80m.	16 wind farms, 92 turbines. 5-8 surveys per year, average 24 day cycle	Search area blade diameter around turbine. Chicken experiments for carcass removal Search efficiency experiments	Mean mortality = 1.5 bats/turbine/year (1.1-4.6). In two other wind farms, 1.34 and 4.56 bats/turbine/year. Common pipistrelles had higher collision rate close to forest. Noctules and Nathusius' pipistrelles collision not affected by proximity to forest.

[1] Summaries obtained from EUROBATS 'Guidelines for consideration of bats in wind farm projects' Rodrigues *et al*. (2008) rather than from original source.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Göttsche & Göbel (2007)[1]	3 turbines in open habitat, 1 near hedges	2003 Jul – mid Sep 2005 End Apr to beginning Jun 2006	Nacelle height 60m, blade diameter 80m		2003 non systematic search. Jul & Sep 2005 and Apr-Jun 2006 surveys once per week. Aug 2005 surveys once per fortnight.	22 dead bats of 5 or 6 species. Most found under the wind turbines situated in open agricultural areas (but there were three of those compared with one near hedgerow).
Grunkorn *et al* (2005)[1]	Farmland, open area with few trees/bushes	Sep – mid Nov 2004	24 turbines 00m height, 2 turbines 120m height	3 wind farms, 26 turbines	16 surveys conducted (every 5th day). Search area radius equal to turbine height. Search efficiency experiments with birds of different sizes. Bird fall experiments.	No dead bats found. Concluded need to search area of total turbine height. Recommended searching in transects 10m wide. Sparse vegetation cover (<10%) find rate 44%. Dense vegetation cover (>30%) find rate 8%. 5m transects find rate for dense vegetation was 10%.
Haase & Rose (2004)[1]	Farmland, 50-200m close to hedgerows.	Mar-Apr, Aug-Oct 2004	Height 60m, 70m, 89m Blade diameter 48m, 58.5m	? turbines 3 surveys per turbine per month	Bat activity also surveyed by detector 500-1000, around the turbines	2 dead bats (Leisler's bat and brown long-eared). 0.06 bats per survey. No observed activity (of Leisler's, noctule and common pipistrelle) close to the turbines.
Kusenbach (2004)[1]	20-100m from hedgerows. Sometimes close to forest.	25 Aug – 23 Sep 2004	Various, size mostly unknown. 18 wind farms with 94 turbines	110 surveys (1-3 per turbine)	Chicken experiment.	7 dead bats. (0.06 bats/survey) 6/7 dead bats found in suspected migration corridor. Found 3-15m from turbine. Chicken experiment – 30% recovered after 1 day, 15% recovered after 2 days.

[1] Summaries obtained from EUROBATS 'Guidelines for consideration of bats in wind farm projects' Rodrigues *et al*. (2008) rather than from original source.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Latorre & Zueco (1998)[1]		1998			No details of method given. Conducted over 1 year	6 dead bats. Estimated 274.05 bats/year, 10.15 bats/turbine/year.
Leukona (2001)[1] and Petri & Munilla (2002)[1]	Various	Mar 2000 – Mar 2001	10 wind farms, 400 turbines. Height 40m, blade diameter 40m.	4 wind farms – 1 study per week (Mar – Mar) 1 wind farm – 1 study per week (Jun – Mar)	Bird study but found bats. Search area 50m around turbine. Sometimes smaller due to vegetation. Carcass removal and search efficiency conducted.	3 bats. Average distance from turbine 25m (unclear whether this is just bats) Disappearance rate: July 57% in 24h, 70% in 48h. Nov – 67% in 24h, 80% in 48h. Find rate: Jul 13.2%, Nov 11.6% Estimate of death rate in 2 farms: 3.09 and 13.36 bats per turbine. Estimate of number of deaths 749 bats.
Seiche *et al* (2007)[1]	Lowland and mountainour region. Open agriculture and structured landscapes, no forests.	May-Sep 2006	26 sites with a total of 145 turbines		Standardised search for dead bats – 2-5 surveys per turbine per week. Also detector monitoring and night vision scope	144 dead bats of 9 species. Mortality low in May and Jun. 50% of deaths in late July. High mortality in late August also. Mortality different in different habitats.
Traxler *et al* (2004)[1]	Farmland, 50-200m to hedgerow/forests	Sep 2003-Sep 2004	3 wind farms, 4 turbines height 98m, blade diameter 70m. 2 turbines height 100m, blade diameter 80m	6 turbines, 1 survey per turbine per day.	Search area 100m around turbine. Search efficiency experiment was carried out using dead birds.	14 dead bats of three species. Collision rate (Winkelman) mean 5.33 bats/turbine/year. Highest collision in August. Mean collision at wind speed of 5-6m/sec.

Source	Study site / Habitat type	Time of year	Turbine height (m)	No. turbines	Survey effort / Search interval	Results
Zagmajster *et al* (2007)[1]		Apr – Jul 2007 and Nov 2007	Site 1: 7 turbines, nacelle height 49m, blade diameter 52m. Site 2: 14 turbines, 50m, blade diameter 48m.		Non systematic search for dead bats	7 bats found
UK						
Bioscan (UK) Ltd 2008	Cambridgeshire. Flat arable with drainage ditches. Adjacent to River Nene.	Oct 2006 - Mar 2007, April - Oct 2007	100m to blade tip (Vestas 2MW)	8 turbines, all searched	Weekly searches over a square to min 60m from turbine in each direction along transects 1-2m apart. All turbines searched in 1 day by 1-2 surveyors	6 bats between Aug & Oct 2007 3 identified to be soprano pipistrelle from DNA, likely all bat sop pip
Duffy & Steward 2008	Scotland. Open upland moorland	Since Jan 2007	105m to blade tip (Vestas 2MW)	36 turbines	Searches on a 130 x 130m plot centred on turbine. Weekly search along transects 10m apart, 3 turbines searched each week by 1 surveyor, rotating so all turbines searched over 12 weeks	Found 2 bats, both soprano pipistrelles. First in Oct 2007 (broken forearm), & the second Jul 2008 at a different turbines.