A method for actively surveying mass hibernation sites of the common pipistrelle (*Pipistrellus pipistrellus*) in the urban environment

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Abstract: Common pipistrelles (*Pipistrellus pipistrellus*) congregate in mass-hibernacula, sometimes with hundreds to thousands of individuals. In the urban environment, these hibernacula are often situated in crevices and other spaces in buildings with poor insulation. Efforts to reduce carbon emissions are a threat to these hibernation sites when roost entrances are sealed to reduce heat loss, which may even lead to the total loss of roosts in buildings. We describe a survey method, based on our experiences in cities in the Netherlands, for localizing mass-hibernation sites of common pipistrelles by locating autumnal swarming behaviour. To pre-select potential hibernation roosts we used freely accessible data on buildings and carried out visual daytime checks. This method combines information on bat behaviour in specific parts of the urban landscape, including the characteristics of buildings that contain these mass-hibernation roosts and their place in the landscape. The timing and performance of fieldwork targeting the autumnal swarming behaviour is also described. We assess the status of buildings as a mass-hibernation site for common pipistrelles with a three step filter-surveying approach: A. Daytime visual site inspections of pre-selected buildings. B. Night time checks on autumnal swarming of the selected buildings. C. Checks during cold winter spells at buildings with autumnal swarming, either visually or by combined visual and acoustic observations or by long-term acoustic recordings. We invite bat researchers and conservationists to build on our approach and adapt it to their local circumstances. We also challenge bat researchers to try this method for other pipistrelle species.

Keywords: mass hibernacula, autumn swarming behaviour, common pipistrelle, active surveying method, long term acoustic recording.

Introduction

European bats species are known to inhabit a network of roosts with different functions, such as maternity, summer, mating and hibernation roosts, as well as frequenting other habitats that support them, such as feeding grounds and connective landscape elements (e.g. Helmer & Limpens 1988, Limpens et al. 1989, 1997, Limpens & Kapteyn 1991, Simon et al. 2004). Local data on the presence or absence of these functions of a landscape for bats are needed for effective environmental impact assessments.

Available survey methods to confirm the presence/absence of these functions and

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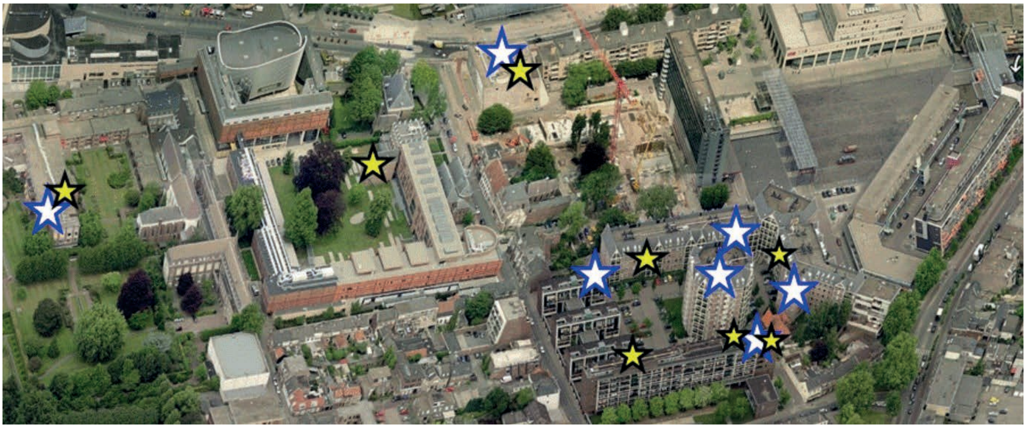

Figure 1. Overview of sites with repeated reports of bats (yellow stars: nuisance, invasions) and observed swarming sites (blue stars), an apartment block at Kloosterstraat (left), the former courthouse (upper-middle) and the Anna Paulownahof high rise buildings (lower right) in Tilburg. *Photo: Creative Commons Google Earth.*

species are often biased either towards certain species or certain functions (e.g. Helmer et al. 1987, Limpens 1993a, 2001, Hundt 2012). The effectiveness of different survey methods for confirming the presence or absence for example of a roost of a certain species is dependent on many factors. The factors most commonly described are the type, observability and intensity of use of the roost, indicating behaviour, its duration and predictability in time, and the number of individuals involved (e.g. Helmer et al. 1987, Brinkmann & Limpens 1999, Hundt 2012).

The presence of commuting routes, hunting sites and summer roosts of the common pipistrelle (*Pipistrellus pipistrellus*) can be surveyed relatively easy using bat detector techniques (e.g. Helmer et al 1987, Ahlén 1993, Limpens 1993a). These techniques can be applied in nearly all types of landscapes. However, a systematic method to survey mass hibernation sites for common pipistrelles was lacking until 2008.

The common pipistrelle is known to hibernate in, and swarm near entrances of, underground sites, such as caves (e.g. Kretzchmar & Heinz 1995, Nagy & Szántó 2002, Kaňuch et al. 2010), and crevices in rock faces (e.g. Hurst et al. 2016). In the Netherlands they are known to hibernate in the aboveground parts of fortresses (Limpens & Jansen 2007) and more sparsely in other "rock face type buildings" such as gatehouses, castles and churches (Jansen 2008a, 2012, 2017, Koelman 2010, Jansen et al. 2015). Although it is a very common species in the Netherlands, it is rarely found in large numbers in underground hibernation sites (e.g. caves, tunnels) that are more typical for the hibernation of, for example, *Myotis* species.

It has often been suggested, and more recently also well documented, that the common pipistrelle can form mass hibernacula in aboveground urban habitats (e.g. Bruijn 1986, Glas 1986, Degn 1989. In these mass-hibernation sites, the common pipistrelle congregate in hundreds to thousands of individuals (e.g. Koch 1865, Roer 1979, Simon et al. 2004).

In the urban environment these sites are often building types with poor insulation. The addition of insulation materials does not only make it harder for bats to access these buildings, but has also the potential to destroy the specific microclimate needed for hibernation. Furthermore there is a very high risk of bats being locked in and dying. European efforts to target the reduction of carbon emissions may pose a threat to the animals as well as the hibernation function of sites, especially

Table 1. Different types of nuisance behaviour as indicators for mass hibernation sites.

Type of nuisance	Remarks
Annual invasions of large groups of sub-adult common pipistrelles entering buildings in August.	
Recurring problems with bats setting off alarms in buildings.	If this happens outside of the maternity season then the chance of the site being a hibernation roost is greater.
Recurring findings of single or small groups of bats, throughout the year, in rooms within the buildings.	If this happens outside of the maternity season then the chance of the site being a hibernation roost is greater.
Recurring findings of bats found dead in buildings or on nearby terraces in September or end of February up to April.	If this happens the chance of the site being a hibernation roost is greater.
Reported nuisance from bat droppings on balconies during late autumn and winter.	

when the function of a building for bats is still unknown. Therefore, there is an urgent need to develop an effective survey method to find sites of mass hibernacula. An active approach to locating such mass hibernation sites in the urban environment was first deployed in 2008 (see Korsten et al. 2016a).

It is not financially feasible to check all the buildings in a city, hence a filtering method is needed to focus the research effort where it is most needed. We have developed guidelines to 'filter' and predict the possible presence of mass hibernation sites of the common pipistrelle in urban environments using observational data on known and recently discovered mass hibernation sites (e.g. van Noort & Jansen 1994, Sendor 2002, Jansen & Vreugdenhil 2009, Jansen et al. 2015b). For this filtering, we successfully used publicly accessible GIS data on building charateristiscs (retrieved from Basisregistraties Adressen en Gebouwen) (Schillemans & Jansen 2014, Boekhout et al. 2016).

We have further developed and tested this filtering method in several projects over a number of years in different cities across the Netherlands (Brekelmans & Korsten 2014). Tests were performed in the cities of Amersfoort (Boonman 2014), Ede (Hommersen et al. 2017), Utrecht (Jansen 2008b, 2010, Schillemans & Jansen 2014, Bouman 2015, Boekhout et al. 2016), Tilburg (Korsten et al. 2014, 2016b, Jansen & Hollander 2015) and Zwolle (Brekelmans et al. 2015, Limpens et al. 2017).

In this paper we present our approach as a method for actively surveying mass hibernacula of the common pipistrelle in an urban environment. This approach targets (mass) hibernation sites, and identifies the function of these sites while considering the differences between autumn and winter swarming. After being considered as an experimental approach for three years, our method has now been accepted and included in the Dutch Governmental Guidelines for Bat Surveys (Netwerk Groene Bureaus 2021).

A three step approach for surveying for mass hibernation sites

There are three steps in our approach for surveying (mass) hibernation sites of the common pipistrelle in an urban environment. In section A, we describe our approach for filtering potential mass hibernation sites. In section B, we describe how to undertake the active survey work in the field for autumnal swarming. In section C we present three methods to further verify whether a site with autumnal swarming bats is likely to be a mass-hibernaculum.

A. The pre-selection of areas and sites

Information and landscape analyses
This section examines the available information on bat occurrences and behaviour in the context of the urban landscape, focusing on the types of buildings and their position in the landscape to understand bat roost selection.

Bat behaviour around buildings
From our studies we learned that 'nuisance' behaviour can indicate potential areas of mass hibernation (figure 1). The first substantial clues regarding potential hibernation sites can be found by nuisance behaviour in the late summer, autumn or winter (table 1, figure 1). Other studies confirm the link between nuisance behaviour and mass hibernation sites of this species (Smit-Viergutz & Simon 2000, Nusová et al. 2021).

Such information may be reported to local bat workers or to animal rescue organisations. It may also be useful to actively consult building tenants, security firms and animal rescue organisations in this respect. Figure 1 gives an example of the information that can become available using the behavioural clues.

Our studies could not confirm the presence of higher concentrations of 'advertising' males, and of mating territories, around swarming sites or along landscape structures which connect mass hibernation sites with the surrounding areas. No concentration of calling males was found around the mass hibernation sites in the cities of Utrecht (Jansen 2008b, Boekhout et al. 2016) and Tilburg (Korsten et al. 2014, 2016b).

Higher concentrations of 'advertising' males, and/or of mating territories were not observed around more isolated rural hibernation sites such as Fort Honswijk (Jansen & Vreugdenhil 2009), Fort Rijnauwen (Jansen et al. 2005), Fort 't Hemeltje (Jansen & Limpens 2011), Kasteel de Haar (Jansen 2008a) or the ruin of the castle Brederode (Koelman 2010), although the wider areas around these sites were not studied for advertising males. The relationship between concentrations of calling males and mass hibernation sites was suggested and presented by Sachteleben & von Helversen (2006).

We conclude that information on locations of one-off invasion sites and other forms of bat nuisance can be useful in locating mass hibernation site(s). Further research should be done to evaluate the value of concentrations of advertising males as an indicator for the presence of mass hibernation sites.

Building characteristics
Our research resulted in us identifying a wide range of building types where midnight swarming and hibernation of common pipistrelles is observed. These buildings range from old monasteries and castles to recently built high rise buildings as well as motorway bridges and tunnels (table 2). Often, but not always, these buildings are relatively high compared to the surrounding buildings or landscape (e.g. Jansen 2007, Brekelmans et al. 2015, Boekhout et al. 2016). Although often not mentioned in the literature, the buildings are often among the most dominant buildings in the city (e.g. van Noort & Jansen 1994, Kaňuch et al. 2010, Sendor et al 2012).

In our studies we found that the buildings used for midnight swarming and hibernating are generally constructed with bricks (figure 2) and/or concrete, both of which have a high temperature buffering capacity and/or some form of latent heating.

High temperature buffering capacity is achieved by these thick solid walls, such as those found in castles and church towers from the Middle Ages. In these, often unheated, buildings the hibernation roosts are often situated inside the building. Latent heating is achieved by heat leaks or anti frost heating of adjacent rooms in buildings such as office buildings and retirement homes, large industrial buildings, hospitals, high rise buildings, stately homes, or have an outgoing, warmer air flow on cold days coming from out of the underground or inner part of the building (as in some forts and high rise buildings). These buildings may have cellars and/or cavity walls reaching below

Table 2. Types of building used by common pipistrelles as hibernation sites and autumn swarming sites.

Type of building	References in the Netherlands	References outside the Netherlands
Old castles	Glas 1986, Jansen 2008a, Koelman 2010	Sendor et al. 2000, Nusová et al. 2021
Monasteries	Bruijn 1986	
Follies (large)		Noort & Jansen 1994
Churches (pre 1800)	Koelman 2002, Jansen 2017	
Military barracks (soil covered)	Jansen et al. 2005, Jansen 2011, Jansen & Limpens 2011	
Poternes (short military tunnels soil covered)	Jansen 2011, Jansen & Limpens 2016	
Gate houses	Glas 1986, Jansen, personal observations	
Apartment blocks	Boekhout et al. 2016, Korsten et al. 2016, Hommersen et al. 2017	
Hospitals	Jansen 2010, Boonman 2014, Brekelmans et al. 2015	Vierhaus et al. 2013
Retirement homes	Jansen 2007	
Parking garages	Jansen, unpublished results	A. Wiermann pers comm.
Office buildings & flats	Glas 1986, Jansen 2008b, Bouman 2015, Boekhout et al. 2016	
Factory buildings	Glas 1986, Boekhout et al. 2016	Simon et al. 2004
Modern concrete bridges (>5m above ground level)		J. Koetnitz pers. comm. / personal observations
Traffic tunnels	Limpens pers. comm.	J. Koetnitz pers. comm. / personal observations

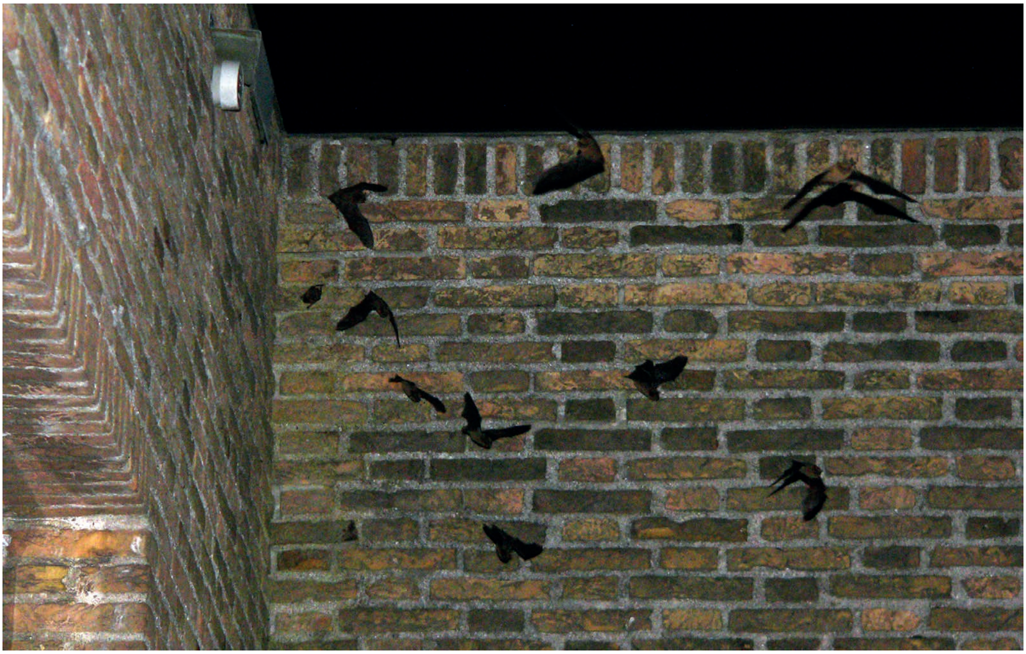

Figure 2. Common pipistrelles swarming at a mass hibernation site at the former courthouse in Tilburg. *Photo: Erik Korsten.*

Figure 3. Potential flight pathways via canals, groves and a river, as well as along railway tracks to the 'Inktpot', a mass-hibernaculum in the city of Utrecht. *Photo: Creative Commons Google Maps.*

ground level. Further studies should reveal the importance of such construction features for successful hibernation of the common pipistrelle. The combination of some of these features seems to result in bats favouring sites which offer more stable temperature conditions regardless of winter conditions.

We suggest that the warmer climate of inner cities may also be of importance for swarming and or hibernating bat species such as the common pipistrelle, which are regularly active, flying outside during winter (Avery 1985, Zahn & Kriner 2016). This warmer inner-city climate is also likely to result in more available suitable hibernation sites.

We conclude that a preliminary selection of potential mass hibernation sites can be made using aerial maps, GIS, analysis of building structures, and on-the-ground data collection using the list of potential building types and their heat characteristics (energy label).

Landscape characteristics

Our results suggest bat swarming sites are more often found near landscape features such as tree-lined rivers or canals, tree-lined railway tracks, interconnected parts of graveyards and parks (Jansen 2008c), roads and motorways lined with trees - all of which connect urban areas with their surroundings (figures 3 and 4). Mass hibernation sites have been found in central urban areas (e.g. Brekelmans et al 2015, Jansen et al 2015, Boekhout et al. 2016), other less central city areas (Korsten et al. 2016, Hommersen et al. 2017) suburban areas (e.g. Jansen 2008a, 2011, 2017) and rural areas (e.g. Jansen & Vreugdenhil 2009).

Theoretically it would be beneficial for common pipistrelles to hibernate in the warmer climate of inner cities, which would provide warmer roosts and more mild winter days on which foraging would be possible (Avery 1985). However, there may be no suitable buildings for hibernating in some city centres and, in addition common pipistrelles are known to prefer known hibernation sites (Sensor 2002).

Bat behaviour in the outskirts of urban areas

During nights when swarming activity occurs at potential mass hibernation sites, bats can be

Figure 4. Potential flight pathways to the Weezenlanden mass-hibernaculum in the city of Zwolle, following canals and a river. *Photo: Creative Commons Google Maps.*

observed using particular flight paths towards the mass hibernacula. We found that these flight paths are different when coming from the outskirts compared to the daily commuting routes because the common pipistrelles fly higher in the air when they cross open areas or blocks of housing. Commuting distances during these periods are often also longer than the daily commutes between summer roosts and hunting areas.

Incidental observations of this kind, which are already available, or using targeted field work to check for such flight paths, can help indicate where to start searching for the mass hibernation sites. This behaviour may however be difficult to observe in an inner city environment, where views of the sky may be blocked by buildings. Stationing observers in open areas on the outskirts of urban areas may provide better views. Non-foraging/passing common pipistrelles can be heard, but individuals will be difficult to observe, as a result of the bats flying high and due to a disturbance of the view by artificial light or higher buildings blocking sight lines. The higher acoustic activity of common pipistrelles in these migration zones can also be picked up with acoustic car transects (Nusová et al. 2021) or stationary detectors (Hurst et al 2016), but weather and the date are important cofactors in recorded total nightly activity.

B. The active survey work

Using these preliminary sites or area selection criteria an active survey can be carried out to determine any swarming behaviour at midnight.

Timing of survey periods

The mass hibernation sites in our studies in the Netherlands show nightly swarming behaviour all summer long, from June till

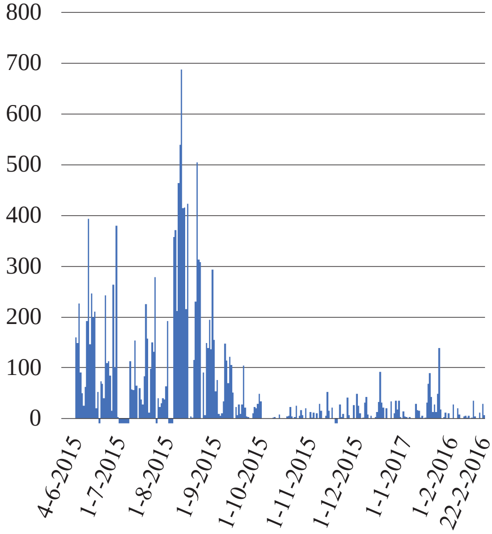

Figure 5. Number of recordings of common pipistrelles at a swarming site at the Tilburg Courthouse between 4 June 2015 and 22 February 2016. Negative values indicate occasions when the recording unit was not functioning.

October, with the main activity being between the end of July and the beginning of October. Our recordings show bat swarming behaviour to be highest in the first half of August (figure 5). Figure 6 shows high activity in the same period but with additional high acoustic activity in May and June. This later peak in activity was due to the presence of a summer roost at the same location. This summer roost was only present in this earlier study.

The peaks in numbers of autumnal swarming bats occur on calm, warm nights between approximately two hours after sunset and two hours before sunrise (figure 7). During less favourable weather conditions, swarming of some individuals can still be observed. Only during adverse weather, such as strong winds or rain, does the activity cease (van Noort & Jansen 1994). We used observations on autumnal swarming activity at a known larger hibernation sites as a reference to venture out on the right nights with a high autumnal swarming activity. For this we used the activity at the buildings such as the main office building of the Dutch Railway (HGB3), the Courthouse at Tilburg and the former Weezenlanden Hospital (figure 8).

We found that individuals come and leave during the night, sometimes coming and going in waves, sometimes more evenly spread over time. From October onwards, a winter population establishes itself with a cumulative increase in numbers of bats entering and using the site for hibernation and a decrease in numbers of bats arriving and swarming, resulting in total lower observable activity at the site (figure 5). The increase in numbers of bats hibernating is gradual in early winter, and notably stronger during cold spells (Simon et al. 2004). Temperatures in the Netherlands during the late autumn and winter fluctuate from -10 °C – +25 °C, with a winter daily average of 3.8 °C (KNMI, Klimaatnormalen 2010-2020). During cold spells in late autumn and winter (October/November – March), we found renewed arrivals of bats to hibernation sites and swarming peaks as a reaction to the colder weather conditions (figures 6 and 7). We therefore expected bats to arrive following a drop in night time temperatures, to prepare for hibernation.

Other studies show that the autumnal swarming behaviour of common pipistrelles can be observed from the end of July until the beginning of October, and that there is also some swarming in May (Sendor & Simon 2000, Sendor 2002).

We conclude that the best period for demonstrating the presence or absence of this swarming behaviour is from the start of August till mid-September, when adult females and juveniles of both sexes participate at the same time (Simon et al. 2004). Swarming activity is then observed from approximately one hour after sunset and activity ceases quickly shortly afterwards. We assume that this peak in swarming activity in this period is due to a combination of swarming activity of (some) already present bats and those that have newly arrived.

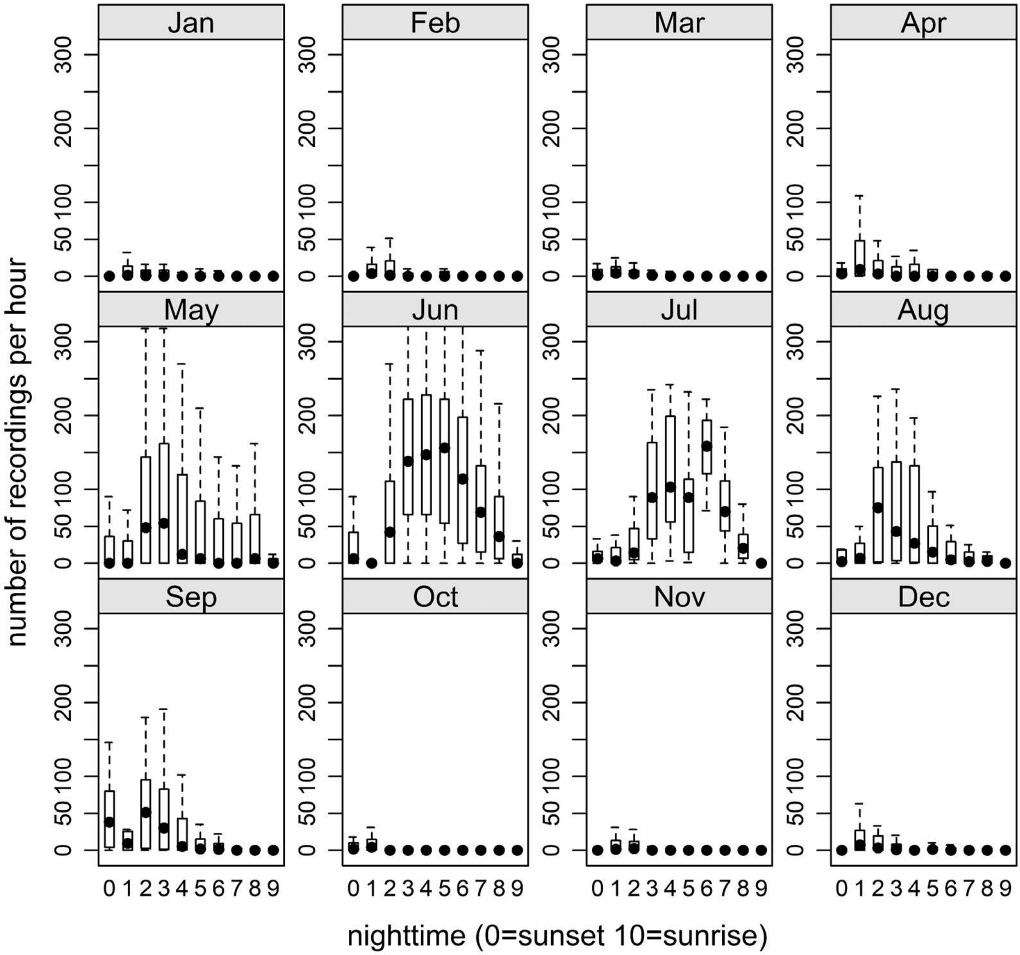

Figure 6. Seasonal differences in the acoustic activity patterns of common pipistrelles at the Tilburg Courthouse. The number of recordings per hour is given for standardized night time categories. The high numbers in May and June are the result of a summer roost of approx. 25 pipistrelles. Acoustic monitoring terminated at sunrise.

Nightly fieldwork in late summer and autumn
Our surveys were undertaken using the same method as used for the surveys of dawn swarming at summer and maternity roosts, using bat detectors (e.g. Limpens 1993). Midnight autumnal swarming behaviour is similar but not identical to the swarming behaviour observed in the morning hours adjacent to a common pipistrelle maternity roost (see text box).

Buildings potentially suitable as a mass hibernaculum or areas with such buildings were visited at the right period of the night and season. Surveys of buildings and structures were conducted on foot or bicycle to explore all sides of the building. An effective assessment of larger, more complex buildings (figures 1, 8, 9, 10) required a team of surveyors. In several studies, patrolling larger urban areas while focusing on buildings that may be hibernation roosts led to the discovery of other swarming sites (e.g. Bouman 2015, Boekhout et al. 2016). We surveyed buildings with a high potential to be hibernation roosts three to five times during the night and at least twice during the season. Existing known hibernation sites were monitored to

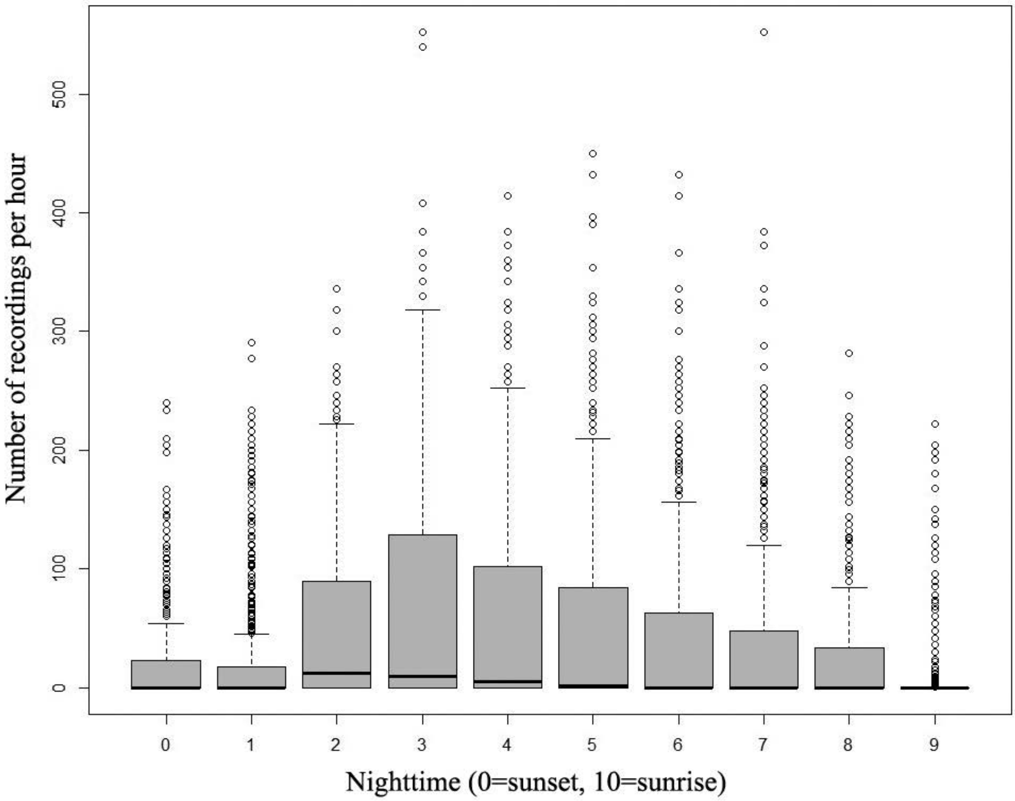

Figure 7. Acoustic activity of common pipistrelles, measured as the number of recordings per hour, in the course of the night. The boxplot with median presents the data, cumulated over August 2010, for the Tilburg Courthouse. 0 indicates sunset. Acoustic monitoring terminated at sunrise.

determine if swarming occurred regularly at a given time and date.

We conclude from our investigations that autumnal swarming behaviour of common pipistrelles at hibernation sites is a conspicuous phenomenon, which can be observed during a long period of the year and a long period during the night. This autumnal swarming behaviour can be confused with other types of bat behaviour in autumn (see also Textbox on p. 211). When unfamiliar with this phenomenon, it might prove useful to start by observing swarming at a known mass hibernacula, in order to get acquainted with this type of bat behaviour. This behaviour is harder to observe at greater heights (>8 m). The use of additional tools such as infrared or heat cameras or the moderate use of flashlights are advised in such situations. Strong flashlights need to be used with care, because lights on the swarming spots scare off bats and may strongly reduce swarming activity for a long period. When observations indicate a group of night swarming bats, it is useful to revisit the location a couple of times during the same night and the following nights, to confirm this behaviour.

C. The confirmation of a mass hibernation site

The results of our daytime surveys and our late summer night-time surveys revealed a list of several buildings with confirmed autumnal swarming. This list consists of a mix of buildings with either large (15-80 individuals), medium-

Different types of swarming behaviour

Maternity roost swarming

Swarming at maternity roosts has been best described by Helmer et al. (1987) and Limpens (1993). There is a pattern that every individual appears to follow, although at a given moment individual bats may be either at different stages of that pattern, or several of the behavioural elements described here may be happening at the same time. At the maternity site four or five stages of individual swarming behaviour occur. First, the bat flies around or over the building several times while progressively focusing on the front of the façade where the entrance might be. Secondly, while focusing more on this side of the building and the entrance, the bat makes a smaller circles in front of and just a little below or beside the entrance. Thirdly the individual bat approaches the entrance and wall flying up towards below the entrance and turning away again. Fourthly the bat lands on the wall just below the entrance, but then flies off again after a short while, repeated this behavior once or twice. Finally the bat approaches from below or just adjacent to the entrance, lands on the surface and quickly crawls through the entrance. More and more individuals reaching the last stage of swarming start landing and enter the roost straight away. Swarming also occurs at mating sites. Other males are chased away, but females are pursued. At the final stage small numbers of bats swarm near a roost.

Autumnal (roost) swarming behaviour

During autumnal swarming common pipistrelles are usually observed visiting the roost late at night but then leaving again. Swarming is mostly high up, and bats fly along and over the building, seemingly inspecting broad sections of the building. During these presumed inspections bats start circling and swarming at one of the locations near and in front of crevices that might serve as an entrance, as well as flights directed at the actual entrance, however bats are rarely seen entering the building. Sometimes they shift their interest towards another entry. After a couple of hours after midnight as morning approaches the numbers of bats swarming diminishes. The bats seem to have disappeared without entering the building. However for an observer, especially one unfamiliar with the site, it can be difficult to make out what is happening above his, or her, head. The spot(s) that the bats are choosing are not often very visible from below. Repeating the survey will be necessary to distinguish between swarming at potential hibernation sites and swarming at other roost types, such as a mating roosts. Note that this behaviour largely takes place inside a building, when the microsite for hibernation is inside the building and a large inside space is available.

Bats swarming at a mass hibernation site in the middle of autumn, towards the end of September, will be swarming as described above, but will also be found approaching, landing on and entering potential entrances. At this stage the bats – but probably not the complete population that might potentially use this site – start occupying the building structure and its different micro-sites.

Bats swarming at a mass hibernation site(s) later in winter after a cold period, can be used to confirm the hibernation status and the relative importance of the site (see section C), again through a swarming culminating with actual landing and entering

Behaviour at a mating site

At a mating roost swarming behaviour is often restricted to just a couple pipistrelles and is accompanied by obvious chasing behaviour and song flight behaviour (a repeated series of social calls).

Figure 8. A mass hibernaculum for common pipistrelles in a former hospital building. *Photo: Creative Commons Wikipedia.*

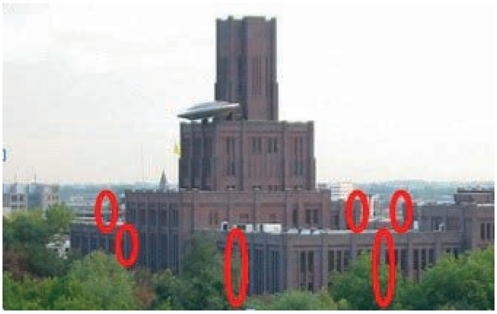

Figure 9. Autumnal swarm locations at a mass hibernaculum in an office building (HGB3 “Inktpot”) in the city of Utrecht. *Photo: Creative commons Google earth.*

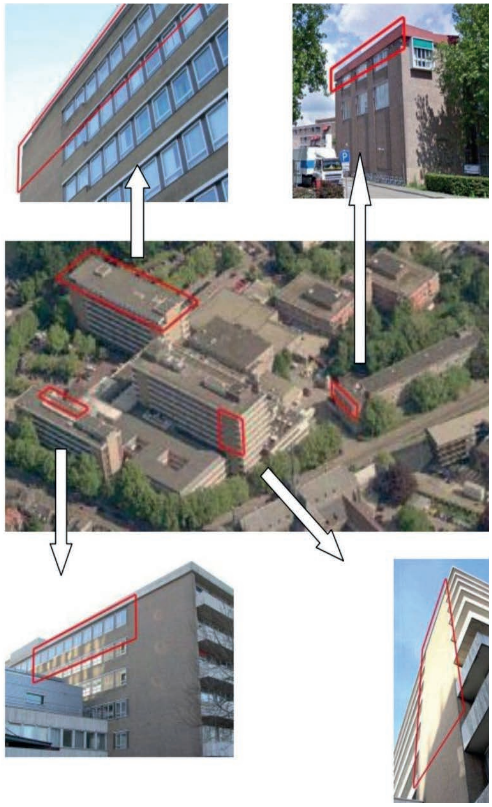

Figure 10. Micro-sites where autumnal midnight swarming was observed at a former hospital building in Weezenlanden.

sized (5-15 individuals) or small groups (1-5 individuals) of autumnal swarming common pipistrelles. Observing autumnal swarming at a particular site does not necessarily reveal whether it is an important or even suitable building for (mass) hibernation that fulfils the bats’ ecological requirements during the most severe periods of winter. In Dutch winters the temperature is mostly above freezing, with some colder spells. Therefore, we used three methods to confirm a building’s status as a (mass) hibernation site: a visual inspection of the roost; evidence of swarming and entering the roost during cold spells and, acoustic confirmation.

Visual winter inspection of micro-sites

One method we used to confirm the status of a building being a hibernation site for common pipistrelles is by a thorough close visual winter inspection, using strong lights, inspection mirrors, endoscopes, ladders and platforms. We carried out our visual inspections during, or shortly after, a spell of cold weather. These inspections also confirmed (some of) the micro-sites (figure 11), i.e. the actual sites in, or on, a building where the bats hibernate. Our inspections often led to observations of individual bats, or compact clusters of bats in the crevices (figure 12). Another method of inspection we used was to open the walls, or make use of accidental damage (due to poor management) to the building to look for droppings or actual bats. When cavity walls are large, complex in structure, largely internal and/or difficult to reach for a close-up inspec-

Figure 11. Example of micro-sites where hibernating individuals were observed at the former Weezelanden Hospital in Zwolle in the winter of 2014-2015.

tion, visual inspection of a building for hibernating bats is often not feasible. We piloted two other methods which can confirm the status of a (mass) hibernation site of common pipistrelles.

By moving more closer to, or further away from, a wall or by moving upwards or downwards in a cavity wall of a building, bats can stay in the optimum temperature zone for hibernation. This can be done by bats even whilst in a state of semi-lethargy (Bachorec et al. 2021). In winter the bats may roost more towards the surface, depending on the weather, the warmth radiating from the building and the stability of the temperature (warmth buffer) within the building (figure 12). When there is a relatively large heat loss from the buildings, the bats may be found on quite exposed sites even in colder weather. Surprisingly, in some cases we found bats in exposed situations almost on the outside of buildings (see Jansen 2008a, Brekelmans 2015).

Important sites for mass hibernation are indicated when up to several hundreds of bats are found swarming for prolonged periods during late summer and early autumn surveys. The next challenge is to confirm actual hibernation, as well as the status of the mass-hibernation site.

Checks on swarming and entering during cold spells

In our studies in Utrecht and Tilburg we checked whether some of the buildings were (mass) hibernation sites by checking for winter swarming and entering of bats in the first few nights during a cold spell (see Korsten et al. 2014, Brekelmans et al. 2015). We waited until the first night with a strong temperature drop and surveyed the site during the next two nights, using bat detectors, flash lights and thermal imaging cameras, starting one hour after sunset. We observed strong swarming activity on the first nights after a strong temperature drop (to below 0 °C). Winter swarming and bats entering buildings was observed at temperatures as low as -7 degrees Celsius. We also noticed a rapid drop in activity during these cold nights; swarming activity nearly ceased after 2- 2 1/2 hours after sunset, for two or three consecutive days and nights. When bats did arrive and swarm during nights after a temperature drop, we also observed them landing on the building's structure and enter crevices. This required a good view of the micro-sites. Observing bats leaving the hibernation site again when temperatures rise during a warm spell after a cold spell is another option (Jansen 2008b), but only when the micro-site of hibernation

Figure 12. The crevices on the balconies of a former hospital building with common pipistrelles using it for hibernation, February 2015. *Photo: Erik Korsten*.

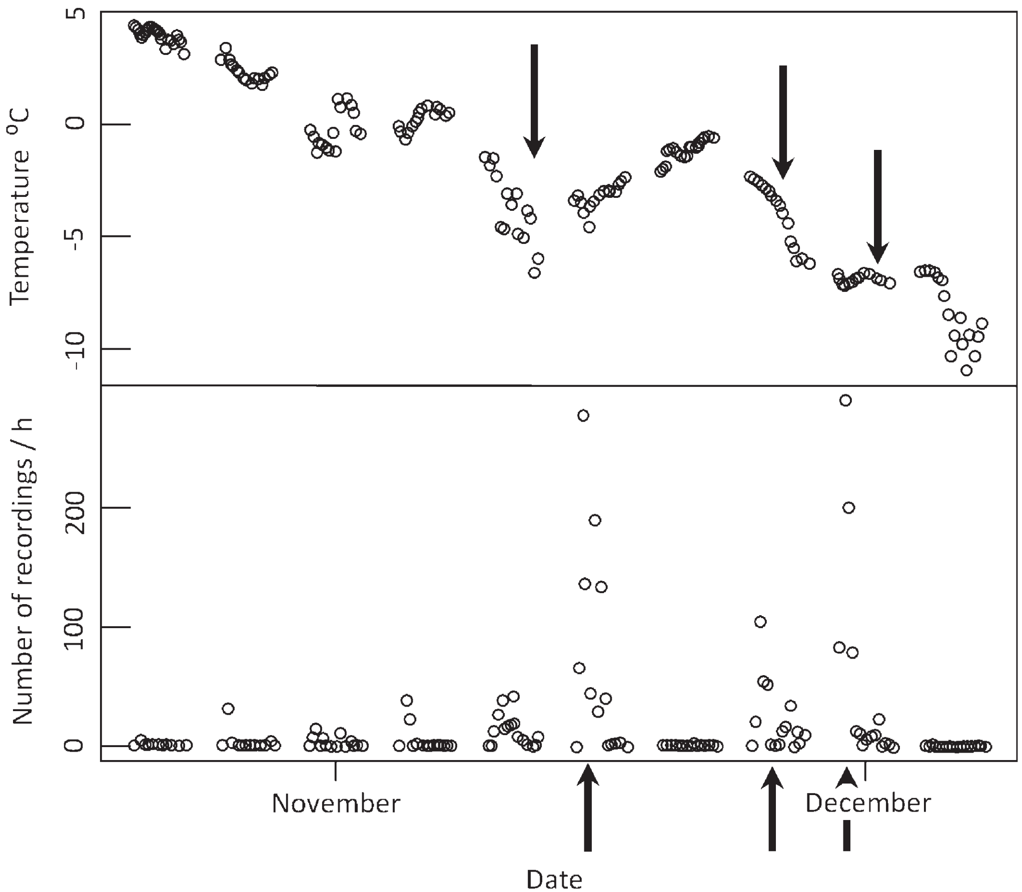

Figure 13. Number of recordings of common pipistrelles at the mass hibernaculum at the Courthouse in Tilburg (below), relative to outside temperature (data from the KNMI weather station at Gilze-Rijen) in the winter of 2010-2011. Arrows indicate the onset of cold spells, and peaks in activity.

is well known. This works when short warm spells occur in the middle of colder winters (Jansen 2008b).

Swarming behaviour during warm spells can be confused with pipistrelles foraging on insects that can also swarm around buildings in warm winter weather (e.g. *Operophtera brumata*) or insects resting on warm building surfaces.

Acoustic confirmation of a (mass) hibernation site

Some buildings or places with late summer/autumnal swarming are difficult to reach during the night. In those situations we deployed long time stand-alone equipment, such as automated ultrasound recorders (see. Kaňuch et al. 2010, Brekelmans et al. 2015, Jansen & Hollander 2015) or video cameras. We analysed the data and searched for patterns of high acoustic bat-activity in relation to cold spells confirming the use and function of a particular site in winter (figures 13 and 14). When late summer observations indicate a (mass) pipistrelle hibernation site, closer inspections sometimes revealed that it was not. We strongly advise field workers to do a second check. This second check can be a visual check during wintertime on hibernating pipistrelles in the building (in inside or outside wall crevices or holes) during prolonged

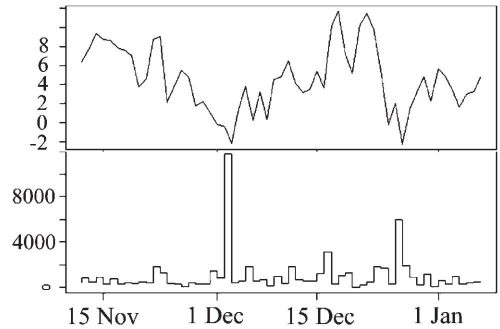

Figure 14. Temperature (KNMI weather station Heino / upper graph) and the number of recordings of common pipistrelles (lower graph) at the former Weezelanden Hospital in Zwolle in the winter of 2014-2015.

periods of frost. However, during very cold weather the animals may be roosting deeper in the crevices and will be less conspicuous. In late winter and early spring, individuals may be found closer to the entrances of the crevices.

When such a check is not feasible two alternative methods can be used: a check on swarming and entering bats during cold spells in winter or the running of long time stand-alone equipment such as automated ultrasound recorders or video cameras during the winter period.

Discussion

In this paper we present a three step approach to survey *P. pipistrellus* mass hibernacula in urban situations. The first step is selecting potential areas and buildings by specific bat nuisance data and the characteristics of buildings. The second step is surveying these buildings or areas for autumn swarming common pipistrelles. We describe the best timing in the year, the night and the influence of weather on this behaviour. The third step is the confirmation of a building as being a (mass) hibernation site using an additional method. We describe three methods which can be used, depending on the physical possibilities and limitations. In additional tables and a textbox we provide the types of buildings most commonly used found, the types of nuisance which can be linked to mass hibernation and a description of autumnal swarming behaviour at a mass hibernation site.

We have constructed filters using ecological interpretations of our observations. The focus of this paper lies in describing this filtering methodology as a way to focus our conservation efforts. Further research is required to validate the signs and the filters used as well as to test the ecological assumptions we use. Many of the signs we used are a practical interpretation of observed patterns and behaviour of bats, with the intention of finding mass hibernacula.

We propose that working a pre-screening approach can speed up the finding of mass hibernation sites in the urban environment. It is possible that some of the criteria are only specific to the Dutch urban landscape and climate and may not be generally applicable in other countries.

We suggest checking potential buildings repeatedly during the night, over several nights and preferably to use a known mass hibernation site as a reference of autumnal bat swarming activity in the late summer surveys. Note, however, that larger groups of bats may swarm longer and be more conspicuous and a site with seemingly smaller numbers of bats could still be a swarming/hibernation site. This method is sensitive enough in finding small groups of 3-15 hibernating common pipistrelles (see. Jansen et al 2005, Jansen & Limpens 2011).

In our experience it is possible to encounter unequivocal swarming behaviour at a certain site while not finding any further evidence of its use as a (mass) hibernaculum in subsequent surveys (compare Hommersen et al. 2019 with Hommersen et al 2016, 2017, Verboom et al. 2018). There are two explanations for this phenomenon: small numbers of bats may be using these sites temporarily, or bats were searching for, or trying out, new roosts. One-off swarming behaviour could be related to the functionality of a specific site as a roost site (in winter) during less adverse weather conditions. We are aware that identifying hibernation sites is not the same as fully understanding the behaviour and dynamics of this swarming phenomenon.

Finding mass hibernation sites is the first step to understanding and conserving these sites. Since they may hold aggregations of hundreds to thousands of individuals from large catchment areas, losing such sites may have a severe impact on the regional population of common pipistrelles. Understanding their swarming behaviour and hibernation roost preferences, the use of micro-sites, and the location of hibernacula in the landscape is necessary for effective conservation and for maintaining a favourable conservation status of the species. More research will be required to use the occurrence and concentration of territorial males and connective structures as a sign for the presence of swarming sites and potential hibernacula.

Common pipistrelles, like most other European bat species, are known to use a network of different roosts – connected to feeding grounds by preferred flight paths – with different functionalities (Limpens & Roschen 1996, 2002, Simon et al 2002). We assume that the activity of common pipistrelles at different sites during swarming and hibernation periods demonstrates the existence of a related network of hibernation sites. This network consists of a small number of more centrally located sites. These centrally located sites might provide better protection during severe weather conditions (Sendor et al. 2000). In other words, bats may use their roost network differently depending on the weather. Confirmation of these assumptions are, in the face of present push for energy efficient buildings, urgently needed.

Since the European Habitats Directive was translated into domestic legislation, much of the survey work related to bat ecology targets bat distributions and habitat use within the landscape, often in areas where a development is being planned. In such situations which relate to planning and development, missing or disregarding a species or hibernation roost can have serious consequences. The relationship between available survey methods and their effectiveness for revealing species or functional habitats should therefore be an important issue in which methods should be constantly developed and standardized (Limpens & Roschen 1996, 2002, Brinkmann & Limpens 1999, Haarsma & Tuitert 2009). With this paper we aim to contribute to this ongoing challenge. Bat researchers and conservationists are invited to build on our approach and adapt it to their local circumstances. We also challenge bat researchers to try this method for other pipistrelle species.

Acknowledgements: We would like to thank Clemency Fisher and Nick Parrot for their linguistic advice and valuable comments on the text. We also thank the referees for their helpful comments and assistance in preparing the paper.

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Received: 27 January 2022
Accepted: 13 July 2022