

Preface

The winter of 2021 was a special anniversary for bat counts in hibernacula in the Netherlands. It was 40 years after a first overview (in 1980) of the counts in the Netherlands and (almost) 25 years after the start of the National Ecological Monitoring Scheme (NEM) of bat hibernacula, but it was also the winter in which the counts were cancelled across the whole of the Netherlands and Flanders, due to the COVID-19 pandemic

This special issue starts off with a historical review of bat counts: *Eighty years of hibernation surveys: from banding to monitoring and protection* (Glas), which offers a clear view of the past. An introduction to the recent counting period is given by La Haye & van der Meij, who provide an overview of censuses in the Netherlands between 1986 and 2020, outlining how the counts of the various hibernating bat species have developed over the past 35 years. This Lutra special on hibernating bats in the Netherlands and Flanders continues with four regionally-focused articles about the marl quarries in Limburg and Flanders (Weinreich & Verheggen and Palmans, respectively), the New Dutch Waterline (Buys et al.) and the Dutch coast (Mostert et al.), all regions with their own specific characteristics, where counts have been carried out for decades. This results in impressive counting series and a clear view of the changes in species composition and the numbers of hibernating bats in these regions.

Bat hibernacula with a special story are explained separately in articles on the Voorberg and Jezuïtenberg (Beckers), Klein Heidekamp (Glas & Kaal), the Amsterdamse Waterleiding Duinen (Lange et al.) and Meijendel-Wassenaarse Slag (Lina et al.). Lefevre et al. compare visual counts with automatic counts, using an infrared light barrier system, at Fort Steendorp, near Antwerp, a foretaste of the technical developments in monitoring, and a useful additional tool when safety issues make some hibernacula inaccessible for counting. In addition, there are a number of more ecologically oriented contributions about the special phenomenon of the mass hibernacula of common pipistrelles (Jansen et al.) and about the relationship between brown long-eared bats and weather conditions (Bekker). Van Zuijlen & Groenendijk study the relationship between numbers of bats, outside temperatures and the nature of the hibernacula in a Noord-Holland dune area. Verhees et al. present a detailed study from northern Limburg, on the influence of climate change by looking at the relationship between the number of hibernating bats and outdoor temperatures. The final piece of these contributions on bat counts in hibernacula is the description of a rare sighting of a greater horseshoe bat in a bunker in the dunes (Mostert & Dijkhuizen).

The character of the counts of hibernating bats has changed over the years, and this is

described in several articles; the focus has shifted from research to monitoring, but the counts have also 'changed' in many other aspects. A clear example is the lighting used during the counts in the dark hibernacula. The technology has improved considerably over time and a number of contributions explicitly refer to this (e.g. Weinreich & Verheggen, Palmans). The time of carbide lanterns is now really history, gasoline lanterns (Petromax or Tilley) and mine lamps were only used in the 1990s, after which krypton lamps with three or four rod batteries made their appearance. Today practically every bat worker has a handy flashlight with a LED light source, sometimes supplemented with a headlamp. With such strong lamps, supplemented by mirrors, sometimes mounted on a telescopic handle, it is easier to detect and identify bats in cracks and crevices. The combination of binoculars with a LED lamp clamped underneath, and possibly a camera, has also increased the chance of identifying the species of bats hanging or crawled away at a higher altitude. The number of bats that cannot be identified with certainty, often referred to as 'indet' bats, has significantly decreased in recent years (aptly illustrated by Palmans). These developments in the method of counting, in addition to 'improving' hibernacula and ecological phenomena, such as changed hibernation preferences, make the interpretation of trends complicated. An observed trend is never 'just' a one-to-one representation of the population development of a species. The series of articles in this *Lutra* special shows that there is still an incredible amount to discover, especially with regard to the population-ecological dynamics of various bat species. At the same time, the articles show how important monitoring is and that the strict protection since the 1970s-1980s has indeed led to a recovery of populations. All in all, a wealth of information has been collected for many years by hundreds of volunteer counters

linking their hobby to science, a combination that will hopefully be sustained for many decades to come.

This publication could not have come about without the years, sometimes decades, of selfless efforts of counters. The same applies to the counting leaders and to the provincial and national coordinating bodies that also provide the necessary permissions for access. For many counters, an involuntary comparison with previous counts will often determine how the state of the bat population is perceived. The 38 different authors of the 17 contributions in this *Lutra* special have been able to present the bat counts of periods of up to 40 years for a large number of hibernacula in a concise manner, which provides a reliable picture of the ups and downs of the different populations of bat species. The editors of the *Lutra* special are grateful to all these authors for their dedication and creativity in describing their views on hibernating bats in the Netherlands and Flanders.

The regular edition for the subscribers of this *Lutra* special appears in English. To make the data and results of the years of counts more widely accessible, the editors of this *Lutra* special and the board of the Dutch Mammal Society, have decided to make an integral translated version available in Dutch for all counters, counting leaders, owners of hibernacula, those engaged in managing sites, or financing this issue of *Lutra*, and last but not least, the authors.

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Eighty years of hibernation surveys: from banding to monitoring and protection

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Forty years ago, a collective of authors described the population trends of a number of bat species in the Netherlands in a special issue of *Lutra*: 'The Dutch bats: population trends in winter and summer roosts' (Daan et al. 1980). The motivation for this special issue was the legal protection granted to bats in 1973 by the *Natuurbeschermingswet* (Nature Conservancy Act) combined with the more or less simultaneous decrease in government financing of bat research and consequently, available knowledge. There was a heightened awareness among those involved of the need for more cooperation and exchange of information. The 'bat world' at the time consisted of staff members of two university research groups (Utrecht University en University of Amsterdam), two government organisations in the field of nature management (Rijksinstituut voor Natuurbeheer / Research Institute for Nature Management and Staatsbosbeheer / State Forestry Service) and two natural history museums (Rijksmuseum van Natuurlijke Historie, now Naturalis Biodiversity Center, in Leiden and the Maastricht Natural History Museum). Furthermore, two volunteer groups were involved: the mammal study group of the NJN, (A)CJN (youth organisations for nature study) and the 'groevenlopers' ('quarry walkers') of the Studiegroep Onderaardse Kalksteengroeven (study group for

subterranean marl quarries), part of the *Natuurhistorisch Genootschap* (natural history society) in Limburg. Apart from these organisations, there were a number of people who were at the time or formerly interested in bats. Everyone included, the 'bat-world' summed up to about 40 people. The responses to a survey carried out among them showed wide support for the establishment of a coordinating council. Representatives from the groups mentioned above formed the Committee for the Study and Protection of Bats, which joined the Dutch Mammal Society and was expanded with participation from the responsible ministry (at the time, the Ministry for Culture, Recreation and Social Work). The committee advised on the execution of the bat counts and the granting of permits, which were required as of 1973. The committee also realised right away that more understanding of population trends was needed both to prove the need for and aid in the implementation of protective measures. It was decided that all available data from bat surveys would be brought together and published. The result was the aforementioned special issue of *Lutra* with contributions from 17 authors, including a chapter of conclusions.

Most of the available data were collected in the marl quarries of southern Limburg. A major part of it originated from banding studies that were started by the founder of bat research in the Netherlands, L. Bels (1952), and were continued by the zoology department of Utrecht University. After banding here stopped in

1957, the 'Utrecht' data were seen more as counts than as captures. Research by the Animal physiology department of the University of Amsterdam, carried out between 1950 and 1970 was aimed at the relationship between climatology and hibernation in the quarries and required surveys based on floor plans of the quarries. Many new floor plans were drawn up by staff members of the National Institute for Nature Management who participated. These 'Amsterdam' data were on the one hand based on more complete surveys, but on the other hand usually ran for only a few winters and each study involved different quarries which limited the number of quarries with long-running series of surveys. Only in part and only as of approximately 1965 were surveys by volunteers, particularly by the mammal study group of the NJN and (A)CJN and the "quarry walkers" able to provide additions. Out of approximately 35 quarries considered the most important for bats at that moment, 16 were found to have sufficient data available on them to calculate a trend for eight species, albeit on the base of a average numbers over periods of five winters. Due to gaps in survey series, data from fewer quarries were available for trend calculations. Among others, the quarries on the Dutch side of the St. Pieterberg, where originally the highest numbers of bats were found, had to be disregarded. Calculations based on total numbers made the significant decline from 'before' to 'now' evident immediately (Daan 1980). The log scale graph based on these calculations (figure 1) was much quoted as a source and thereby became iconic.

To answer the question whether this was a national or a regional trend, data from elsewhere in the country were taken into account. However, the number of hibernation sites outside the marl quarries proved to be very limited, both in number and in geographic spread. The Utrecht banding study was expanded as of 1950 to a number of brickwork forts in the Nieuwe Hollandse Waterlinie. The State Forestry Service and RIVON (predecessor to RIN, the Rijksinstituut

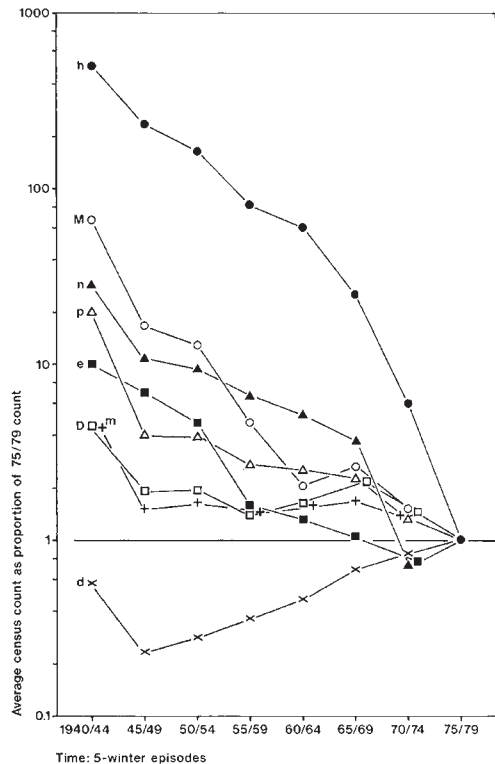


Figure 1. Relative numbers of bats in 16 marl quarries, compared to the corresponding survey average for the 1975-1979 winters. h = *Rhinolophus hipposideros*; M = *Myotis myotis*; n = *M. nattereri*; p = *Plecotus* sp.; e = *M. emarginatus*; m = *M. mystacinus*; D = *M. dasycneme*; d = *M. daubentonii* (taken from Daan 1980).

voor Natuurbeheer / Research Institute for Nature Management) performed studies of castle basements as hibernation sites around 1960 and of ice cellars around 1967. With the inclusion of a few 'accidental discoveries', no more than 55 objects outside the marl quarries were known to be hibernation sites, most of them located within a limited area in the centre of the Netherlands. They were 17 forts and other brick defense works, 7 castle basements, 21 ice cellars and 8 'other' constructions, plus 2 concrete bunker systems which had recently been visited for the first time. However, long-term surveys were only available from a number of forts. From castle basements and ice cellars, practically the only data available dated

from shortly after their discovery. To obtain recent data about 30 constructions were visited again in the winters of 1977 and 1979. The data from these three categories, though modest in numbers, supported the trends found in the marl quarries. The concluding chapter therefore stressed the need for protective measures to accompany legal protection. Furthermore, it posed that more study was needed to support the selection of effective measures.

At the time, the 17 authors of the special issue constituted about half of all people involved either professionally or as a volunteer in study or surveys of bats around 1980. This number gradually increased in the following years and several of them, using the experience gained in the marl quarries, discovered new hibernation sites, which in many cases were surveyed yearly. These surveys too were coordinated by the Committee, including the permits needed. In the winter of 1987 no less than 140 objects were surveyed outside the marl quarries by 25 'survey leaders', resulting in a sum total of more than 2000 bats counted. A new impulse was given by the start in 1987 of the 'Vleermuis-atlasproject' (VAP, 'bat atlas project') which attracted many new bat workers to bat distribution study with bat-detectors. Many of them too went along on winter surveys, became enthused and gained experience and made sure more hibernation sites were found. Among those sites were the first purpose-built new bat hibernation cellars, besides existing structures which had lost their function, like the ice cellars of before. From 1990 onwards, all hibernating bat surveys were coordinated by the board of the VLEN (Vleermuiswerkgroep Nederland, Dutch Bat Society) which, just like the by then no longer existing committee, is part of the Dutch Mammal Society.

Meanwhile, from the point of view of nature policy, the need for a better understanding of current developments in distribution and numbers of plant and animal species grew. For example, the population development of hibernating bats in the marl quarries of Zuid-

Limburg was studied once more (Weinreich & Oude Voshaar 1987).

Besides the National Databank Flora en Fauna (National Database Flora and Fauna) for distribution data, these developments led to agreements with the societies for the study and protection of species groups, such as the VZZ (Dutch Mammal Society), on monitoring projects for certain species and species groups. After a preliminary study, among other things into the suitability of hibernation surveys as an instrument for trend monitoring and possibly distribution monitoring (de Wijs 1995) this led to the Mammal monitoring project as a commission from various government authorities, such as the Ministry for Agriculture, Nature management and Fisheries, for the VZZ. From the entry and analysis of the data from hibernation counts up to 1995 it was determined that the data from the 1986 winter onwards were suitable as the starting year for the monitoring. As a consequence of this commission, the VZZ office took over the organisation of the hibernation surveys. This now well established system of staged coordination through the various provincial mammal and bat study groups that had arisen, was henceforth maintained. However, a somewhat stricter protocol for the execution of hibernation surveys was laid down, with a more clearly defined survey period among other things. Also, buildings situated near each other that were formerly considered a single system and object, but were not always all counted, were numbered as separate objects to allow comparison across surveys. Furthermore, since then photographic evidence is requested in cases where rare species are found for the first time in objects. In marl quarries, this concerns horseshoe bats, Bechstein's bat, grey long-eared bat and Western barbastelle. Outside the quarries, greater mouse-eared bat, Geoffroy's bat and pond bat are included.

Where bat winter surveys until the end of the 1960s were mostly in the context of scientific banding studies of migratory behaviour and the physiology of hibernation in the

marl quarries, in the following decades monitoring of population numbers, trends and protective measures gained more attention from the perspective of nature policy. Meanwhile the 'natuurtoets' (environmental impact assessment), in which the expected effects of a planned activity on protected flora and fauna occurring in the region are assessed in the light of the Wet Natuurbescherming (Dutch Nature Conservation Act), is obligatory for project developers. This is associated with more knowledge about and experience with bat at consulting agencies. With the devolution of state nature policies to the provinces, we also perceive an increased interest in bat monitoring. In the Natura 2000 European network of protected areas too, there is increased attention for the functions these areas provide for bats, such as swarming behaviour and hibernation, and for protecting and expanding them. Yearly surveys are and remain an essential tool in shaping this protection.

Now, forty years after the 1980 special issue, in the winter of 2019-2020 back then unimaginable numbers of survey leaders and assisting surveyors, in then unimaginable numbers of objects (including marl quarries) counted a then unimaginable total number of nearly 20,000 hibernating bats. The enthusiasm for this kind of bat research has remained, as

has the search for explanations for changes in survey results.

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Hibernating bats in the Netherlands in 1986-2020, based on the National Monitoring Scheme of Bat Hibernacula

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Abstract: Bats have been studied in their underground winter quarters in the Netherlands (and Flanders) since the 1930s. Over time, the focus has shifted from ecological and physiological research to monitoring. In the Netherlands these counts have been done as part of the National Monitoring Scheme of bat hibernacula (NEM Meetprogramma Wintertellingen Vleermuizen) since 1986. Statistics Netherlands (CBS) annually calculates national (winter) trends for seven bat species that hibernate in ‘traditional’ winter quarters. The importance of these counts has increased over the years: not only because of the length of the year-to-year counts but also because the data play an important role in nature policy, including providing data for the EU’s Habitat Directive reports. Almost all the bat species monitored in this national programme show a significant ‘strong or moderate increase’ with the number of counted bats generally increasing since 1986. However, there is always doubt about to what extent more and better counting or an actual increase in population drives these positive trends. Unfortunately, there is a lack of research looking into the population-ecological mechanisms underlying these trends. Nowadays some national trends are possibly stabilizing. It remains to be seen how the trends will develop in the coming years.

Keywords: hibernation, monitoring, counts, trends, population, hibernaculum, volunteers, provinces, Netherlands.

Introduction

Hibernating bats in the Netherlands and Flanders have been studied in, mostly underground, winter quarters since the 1930s, with a particular focus on marl quarries until the 1980s. This *Lutra special* contains a large number of more recent studies and results of research activities in recent decades. In this article we start off by giving some background information on how trends are calculated and give an overview of trends of hibernating bats in the Netherlands and their long-term population development. We do not discuss the

Flemish trend data, but in this special some interesting articles are presented on regional or local trends in Flemish hibernacula. This article shows how unique the national Dutch bat hibernacula counts are, and how much time and energy is spent annually by hundreds of volunteers in counting bats and how carefully site owners deal with bat hibernacula.

In 1930, when the first ‘counts’ of hibernating bats were conducted, the focus was almost entirely on research. Over the following decades, this focus shifted much more to monitoring various bat species (see Glas 2022, in this issue). Around 1980, bat counts became widely established and, since then, hundreds of hibernating roosts have been counted annually by volunteers. At around the same

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time the Dutch National Monitoring Scheme of Bat Hibernacula (NEM Meetprogramma Wintertellingen) was established.

This monitoring scheme is one of many monitoring programmes within the Dutch Ecological Monitoring Network (NEM), which is a collaboration of government bodies that collect data about species and habitat quality which is used as the basis for (inter)national nature policy. The partners in the NEM are the Ministry of Agriculture, Nature and Food Quality (LNV), the Ministry of Infrastructure and Water Management (Rijkswaterstaat), the Netherlands Environmental Assessment Agency (PBL), Statistics Netherlands (CBS) and the provinces. This monitoring scheme highly depends on volunteers under the supervision of a provincial coordinator. The Dutch Mammal Society (Zoogdiervereniging) collects all the national data, arranges access to hibernacula and permits and, checks the data in cooperation with Statistics Netherlands. Trends are calculated by Statistics Netherlands and published in collaboration with the Dutch Mammal Society.

All species of bat indigenous to the Netherlands hibernate. A large number of bat species hibernate in (underground) winter quarters which are accessible to humans, such as marl quarries, bunkers, (ice) cellars and fortresses. The NEM Monitoring Scheme of bat hibernacula focuses specifically on these species which hibernate in man-made structures. Those species that hibernate in tree cavities, the cavity walls of buildings or in other locations which are difficult or impossible to count are not monitored within this programme. These ‘non-countable’ bat species are monitored in alternative NEM monitoring programs such as the NEM Attic Bat Counts and NEM Bat Transects.

Materials and methods

In 2020 almost 1800 sites were registered as bat hibernacula in the Netherlands (figure 1

and figure 2). In practice many more (underground) sites will be used as winter quarters, but these are literally out of sight: they are either not (yet) recognized as winter quarters and/or not (yet) registered. Any site where bats hibernate can be registered as a hibernation site, although most sites are situated underground, have a size of at least a few m³, have a constant temperature and high humidity and must be accessible for counting bat numbers.

More than 80% of all registered hibernacula are checked annually for the presence of bats. In practice, it is not possible to count all hibernacula, because observers may be ill, the key to a site may not be available, hibernacula may no longer be accessible, or volunteers can’t get permission to visit the site. Some hibernacula are deliberately less frequently monitored because few or no bats are expected to be present. In addition, a hibernaculum can become unsafe due to the risk of collapsing, a phenomenon that occurs especially at the marl quarries in the south of Limburg (see Weinreich & Verheggen 2022, in this issue). The occasional inability to count in a few sites is not usually problematic, as so many other hibernacula are counted. However, the goal is to monitor as many sites as possible annually, as this minimizes the uncertainties in the trends.

Hibernacula are routinely monitored in the period of 16 December to 15 February, because during this period the largest numbers of hibernating bats are present in hibernacula and the numbers are relatively stable. Nevertheless, the numbers of bats in hibernacula does fluctuate throughout the winter for a variety of reasons, including seasonal and temperature effects, disturbance, or internal physiological stimuli (see, for example, Beckers 2022, in this issue). Monitoring hibernacula annually at more or less the same time (a fixed counting weekend or period) helps to reduce the ‘noise’ within the monitoring.

It is important to note that the official counting period overlaps two calendar years each winter. Because the monitoring period after

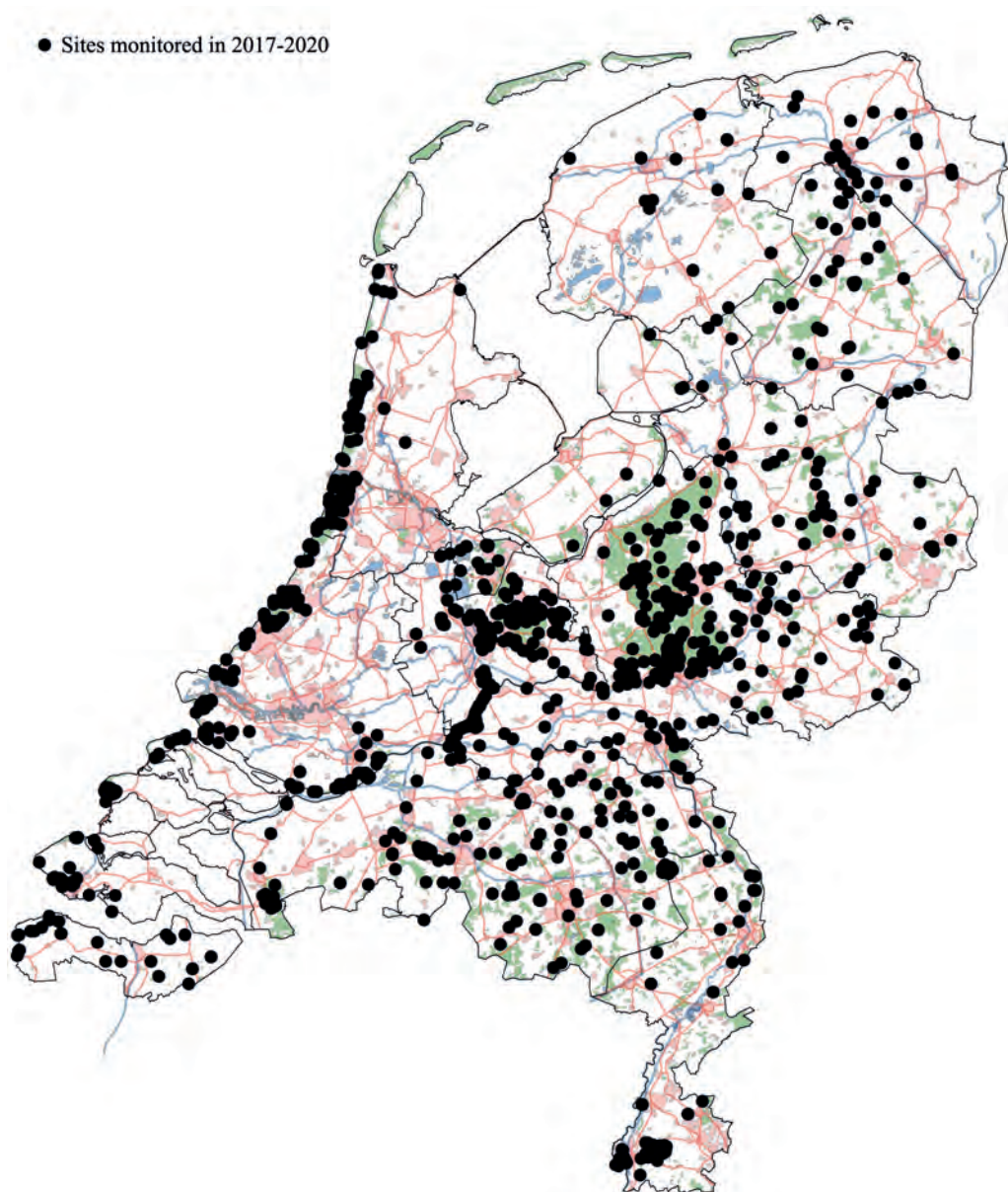


Figure 1. Location of bat hibernacula in the Netherlands in 2020.

the turn of the year is the longest, the most recent calendar year is mostly used as the official monitoring year in reports and articles and also in this *Lutra* special. So the counting year 2020, actually refers to the period 16 December 2019 to 15 February 2020.

Number of hibernacula per province

The provinces of Zuid-Holland and Gelderland, each with more than 300 counted winter quarters, are the provinces with the most hibernacula, but the provinces of Utrecht and Limburg are also of great importance

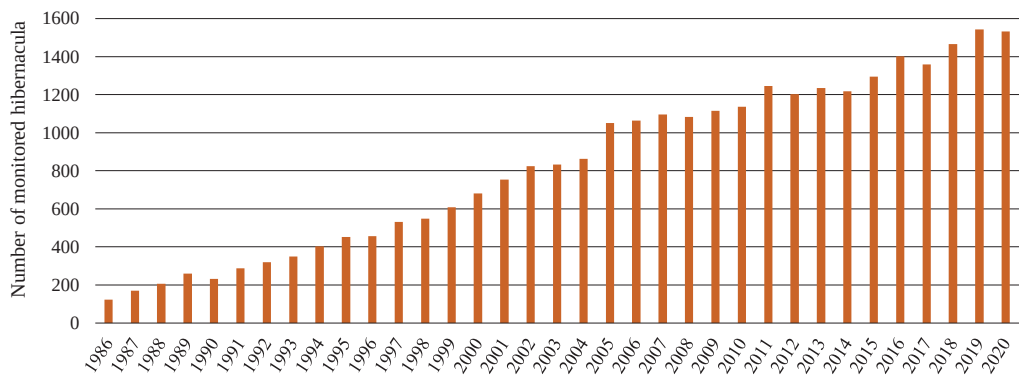


Figure 2. Numbers of monitored bat hibernacula from 1986 to 2020.

(see figure 1). More than 60% of the country's monitored hibernacula are situated in these four provinces, which is due to the presence of marl quarries (Limburg) and historic defense lines (bunker complexes in the coastal zone and on the Veluwe and the New Dutch Waterline (see Buys et al. 2022, in this issue). Possibly, some as-yet-unknown winter quarters might still be discovered in old bricks kilns, sewages pipes, basements under churches or farms or, possibly even, some forgotten ice cellars in the provinces of Groningen and Friesland.

Species and number of bats by province

The numbers of registered bats in each province are shown in figure 3a-c. In the provinces of Utrecht, Gelderland, Zuid-Holland and Limburg several thousand bats are registered each year. The numbers of bats in these provinces are stable or even slightly increasing (possibly related to a larger number of monitored hibernacula). In Noord-Holland, Noord-Brabant and Overijssel, each year around 1000 bats are seen. In the provinces of Drenthe and Zeeland there has been a decrease in the number of bats registered in recent years (which is related to a decrease among specific species), although between 500-600 bats are noted in these provinces annually. In Groningen, less than 300 bats are seen, but the number is increasing every year.

The provinces with the fewest bats are Friesland and Flevoland, with about 100 in Flevoland and about 60-80 in Friesland.

The numbers of monitored hibernacula per province may vary from year to year, which, as mentioned above, can be for many reasons. These fluctuations in the number of monitored hibernacula, and thus the numbers of bats counted, make it more difficult to calculate trends. A solution for this problem is described by Weinreich & Oude Voshaar (1987). These researchers focused on bats in marl quarries and improved the method of Daan (1980), who used average numbers per five-year period, by first making the best possible estimate of expected numbers for missing monitoring seasons based on counts at neighboring winter quarters and previous counts. Their solution is to reconstruct a complete summation of the numbers of hibernating bat species for each season. This approach was then further refined by Statistics Netherlands CBS in Trim, a computer programme that uses a statistical model to estimate data and calculate a trend. Trim uses a formula that assumes that the number of individuals of a specific bat species depends on the differences between years (year effect) and those between winter quarters (plot effect). The trick is to improve the formula in iterative calculation sessions to find a best fit between the calculated values and the counted data. With more monitored hibernacula, and therefore data, it is easier

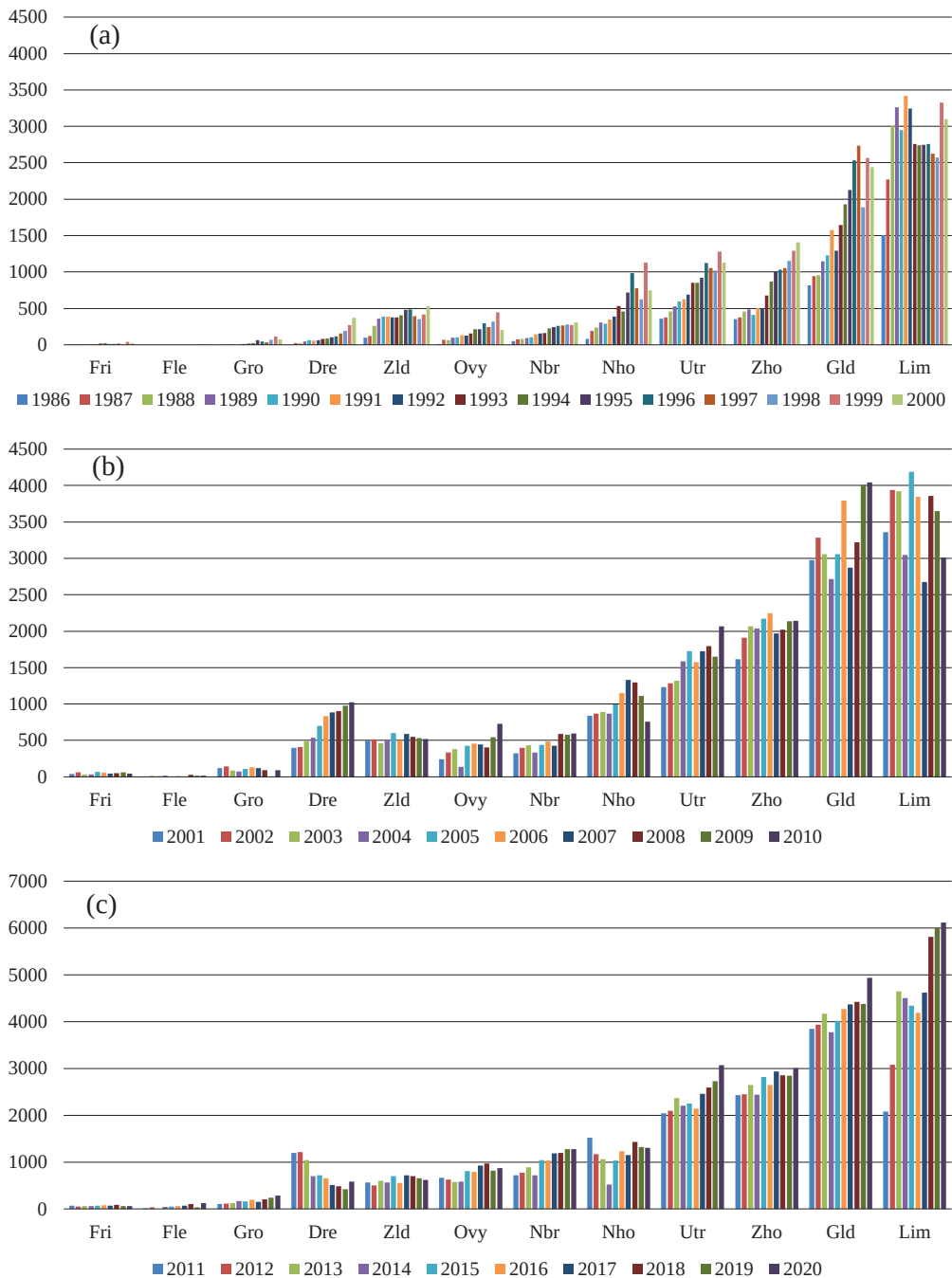


Figure 3. The number of bats registered in each province from from (a) 1986 to 2000, (b) 2001 to 2010, and (c) 2011 to 2020 (note: adjusted y-axis).

to see how well the model fits, but a complete data set is not necessary.

Indexes

Trends of different bat species are shown using index values per year and a trend value over a series of years. The indexes are simply percentages of the calculated numbers relative to a base year, which for the winter monitoring scheme of bat hibernacula is mostly the first year, 1986. Some indexes have a different base year because sufficient data are available to make calculations with an earlier or later starting year.

The index values are based on the actual counts of a specific species plus estimated data for missing counts of that species. Thus, the indices represent population changes but not absolute population sizes of a species. In addition, there are differences between species. For example, only a few dozen individuals of rare species, such as the greater mouse-eared bat (*Myotis myotis*), are seen each year, while for more common species such as the Daubenton's bat (*M. daubentonii*), many hundreds, or even thousands, of individuals are counted each year. The index value for both species starts at 100 in 1986.

Bat hibernacula that were discovered after 1986 and which were included in the NEM Monitoring Program afterwards are included in the trend calculations in an 'adjusted manner'. For the years between 1986 and the start of the monitoring, the number of bats in these sites, as well as incidentally missing counts in other sites, are generated by TRIM, under the assumption that these hibernacula were already accessible for bats and suitable for hibernation. If a site was not previously suitable or accessible to bats, then 'hard zeros' are included for these sites. In order to be able to make the right choice between model-based estimates or zero values, 'start' and 'stop' reasons for all hibernacula are registered. Obviously, a dataset benefits most

from long series of countings in standardized circumstances such as unchanged winter quarters, but in practice small changes and adjustments will play a role.

The NEM Monitoring Scheme of bat hibernacula was created to produce national trends of different bat species, but depending on the number of hibernacula and the location of a selection of hibernacula, it is also possible to produce trends on a smaller scale or even for a specific area. Nowadays it is very common to also make trends by province or, for example, for marl quarries (Weinreich & Verheggen 2022, in this issue), Natura 2000 areas, bunkers in the dunes (see Mostert et al. 2022, in this issue) or sites that are part of the New Dutch Waterline (Buys et al. 2022, in this issue). In theory the possibilities are almost unlimited, although in practice the possibilities are limited by the number of counted hibernacula. The more specific a question becomes, the fewer data there is, which will affect the plausibility of an observed trend.

Results

The *Telganger*, the bi-annual newsletter of the Dutch Mammal Society, publishes information about the NEM monitoring programmes, the national indices, trends and numbers of bats in hibernacula. A distinction is made between the long-term trend from 1986, the official starting year of the trends, and the trend in the last twelve years (short-term trend).

For seven bat species that hibernate in 'classic' sites, the national (winter) trends can be easily calculated (figures 4 to 10); the blue dots represent the calculated index values, the blue line represents the long-term trend and the 'blue band' the confidence interval of the trend. These trends, starting in 1986, are discussed below for each species.

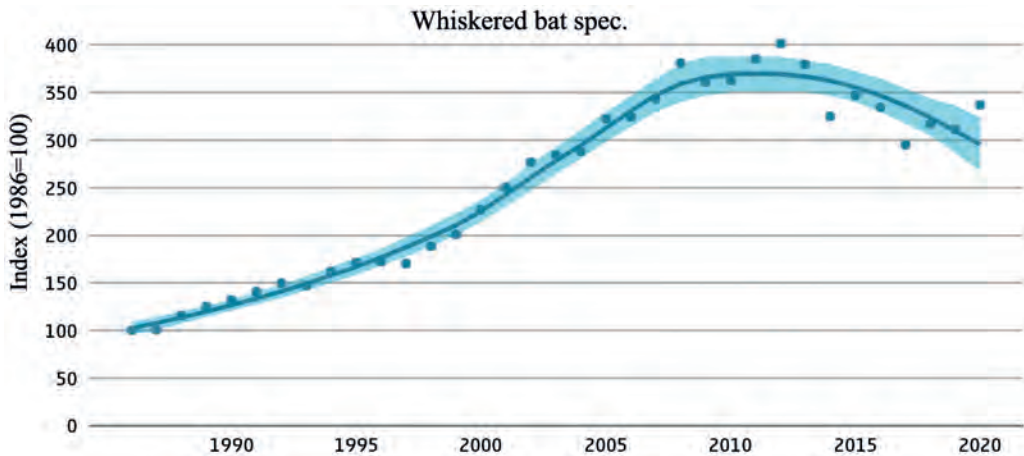


Figure 4. Trend of ‘whiskered bats spec.’ (*Myotis mystacinus/brandtii*) in the Netherlands since 1986. The trend for the entire period is that of a ‘moderate increase’ (significant increase of $\leq 5\%$): over the last twelve years there has been a ‘moderate decrease’ (significant decrease of $\leq 5\%$).

Whiskered / Brandt’s bat (*M. mystacinus / brandtii*)

The trend of ‘whiskered bats spec.’ in hibernacula is actually the combined trend of whiskered bat (*M. mystacinus*) and Brandt’s bat (*M. brandtii*). Distinguishing between these two species is so difficult (Mostert et al. 2005) that individuals must be taken in the hand for a definitive determination on the basis of dental characteristics. This causes too much disturbance during the winter monitoring, so both species are counted as a ‘collective group’ of ‘whiskered bats spec’. In a targeted study of the occurrence of Brandt’s bat in hibernacula in the Netherlands where the animals were taken in the hand (Mostert et al. 2005) three Brandt’s bats were found, 1.7% of the number of examined ‘whiskered bats spec.’ ($n=176$). Therefore, Brandt’s bat seems to be a very rare species in the Netherlands, with a mainly southern and eastern occurrence, although the species is sometimes found in the river area and the western part of the Netherlands. During winter counts whiskered bats are found in large parts of the Netherlands (Twisk 2016). The main focus of the winter distribution is in the river area, the higher sandy soils, the south of Limburg

and the estates zone in the dunes. Nationally, the ‘whiskered bats spec.’ has been experiencing a downward trend for several years (see figure 4), which is certainly related (but not exclusively) to the decline in the number of whiskered bats in the former potato cellar in ‘Kamp Westerbork’ in the Province of Drenthe where the number of whiskered bats has dropped from over 1000 in 2012 to a maximum of a few dozens in recent years (Jansen et al. 2018). An explanation for this decline is lacking and the decline has still not stopped. The species is also declining in the province of Zuid-Holland, although the decline here is small. This makes ‘whiskered bats spec.’ a species-group of concern that needs to be carefully monitored in the coming years. Further research is urgently needed to find the causes of its decline.

Daubenton’s bat (*M. daubentonii*)

Daubenton’s bat is a species that has been increasing in numbers for decades, after a dip in the 1950s (Weinreich & Verheggen 2022, in this issue; figure 5). The largest increase occurred mainly in the period 1970-1988. In some regions, the species has been detected

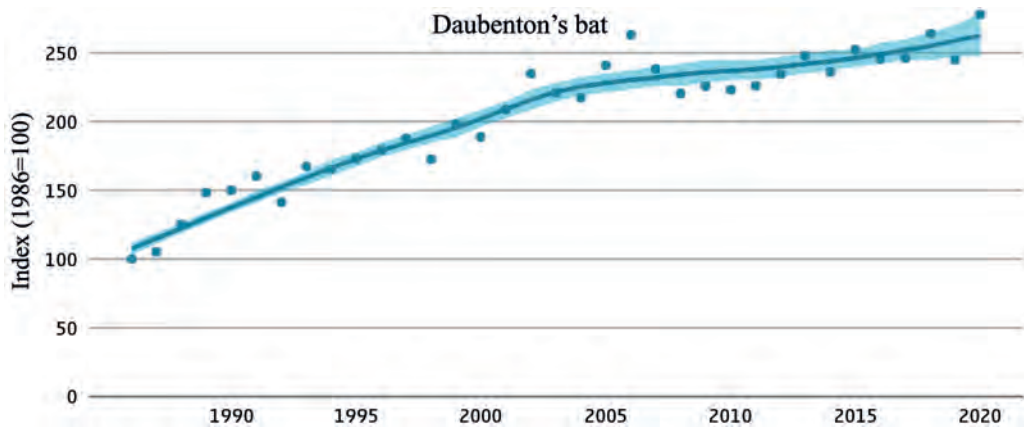


Figure 5. The trend for hibernating Daubenton's bats (*Myotis daubentonii*) in the Netherlands since 1986. The trend over the entire period, and over the past twelve years, is of a 'moderate increase' (significant increase of $\leq 5\%$).

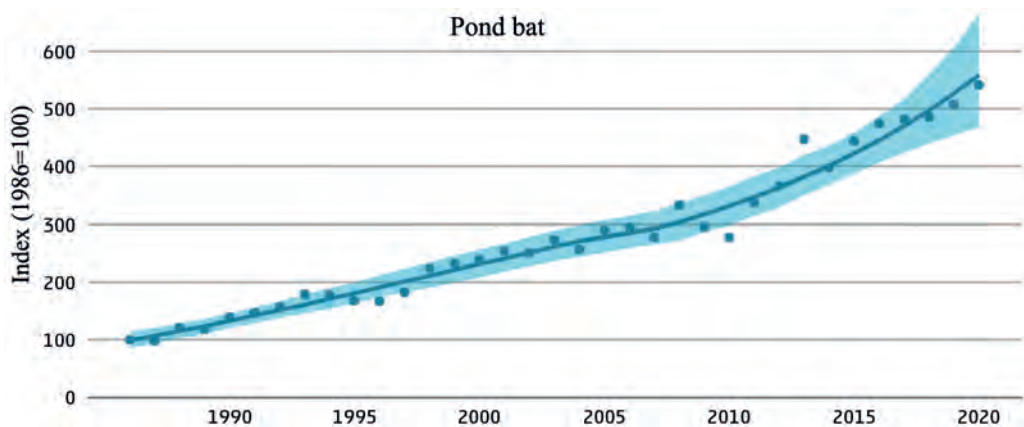


Figure 6. Trend of the pond bat (*Myotis dasycneme*) in the Netherlands since 1986. The trend over the entire period and over the last twelve years is a 'moderate increase' (significant increase of $\leq 5\%$).

relatively recently as a hibernating species, such as in bunkers on the Island of Dordrecht. The trend has been flattening in recent years (figure 5), and has now stabilized in several provinces, and the species is even clearly declining in numbers in marl quarries (Weinreich & Verheggen 2022, in this issue).

The main driving factors of the national trend for this species are not known. Positive effects are to be expected from aging forests and a management that is more focused on mixed forests, but on the other hand avenue trees with many cavities are deteriorating in

many places or have been replaced by young trees with fewer cavities. Changes in water quality may have had both positive and negative effects. For example, eutrophication of surface water leads to increased numbers of Chironomidae (Dietz et al. 2011), but eutrophication can also lead to a closed cover of duckweed preventing Daubenton's bats from hunting (Boonman et al. 1998, Haarsma 2001). It is therefore impossible to predict how the trend will develop in the coming years.

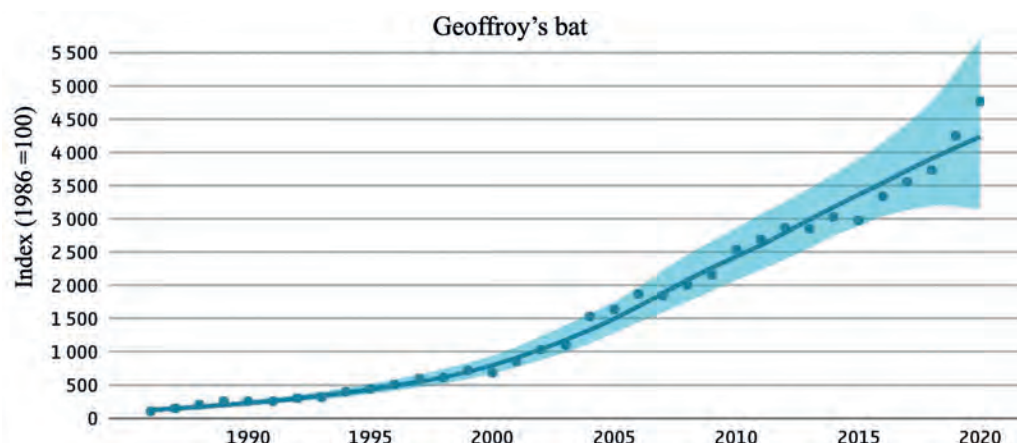


Figure 7. Trend of the Geoffroy's bat (*Myotis emarginatus*) in the Netherlands since 1986. The trend for the entire period is a strong increase, with a 'moderate increase' (significant increase of $\leq 5\%$) over the past twelve years

Pond bat (*M. dasycneme*)

The largest numbers of pond bats in the Netherlands are found in the hibernacula of the marl quarries of southern Limburg, bunkers in the Dutch dune area and several sites on (former) military areas near Arnhem in the Veluwe (Haarsma et al. 2019).

The total number of hibernating pond bats in Limburg was around 400 animals before 1950. In the 1960s and 1970s this number decreased to 200 animals. In the late 1970s, the first observations were made of, predominantly male, hibernating pond bats outside the marl quarries, in Gelderland and Zuid-Holland. The numbers of pond bats in the marl quarries have since recovered to their historic levels (Weinreich & Verheggen 2022, in this issue). However, since 1989 there has also been a strong increase in the numbers of hibernating male pond bats in coastal bunkers, especially in Zuid-Holland (Haarsma et al. 2019), which is the main reason for the positive national trend (figure 6).

Geoffroy's bat (*M. emarginatus*)

Almost all counted Geoffroy's bat in the Netherlands hibernate in marl quarries in the relatively stable and warmer parts of the quarries

(Weinreich & Verheggen 2022, in this issue). One exception was a hibernating Geoffroy's bat found in a bunker on Schouwen-Duiveland (Province of Zeeland) in 2017.

Analysis of the count data of hibernating Geoffroy's bats in quarries which have been counted since 1940 (Weinreich & Verheggen 2022, in this issue) shows that the current numbers present in these quarries now exceed historical numbers. However, some caution is necessary as the historical counts were less accurate and less frequent than the current monitoring.

In addition to the recovery in the numbers of Geoffroy's bats in summer roosts (Weinreich & Verheggen 2022, in this issue), there also appears to be a comparable increase in the Dutch population in winter (figure 7). The cause of this recovery is not known, but a link with the current warmer summers is obvious. The increase does not seem to be caused by an improved summer habitat, since the Geoffroy's bat is considered a species that prefers small-scale agricultural landscapes and that also likes to hunt flies in old barns with cows. This type of landscape and these types of barns are becoming increasingly scarce, so that on the basis of the summer habitat a decline is to be expected rather than the observed increase of hibernating individuals.

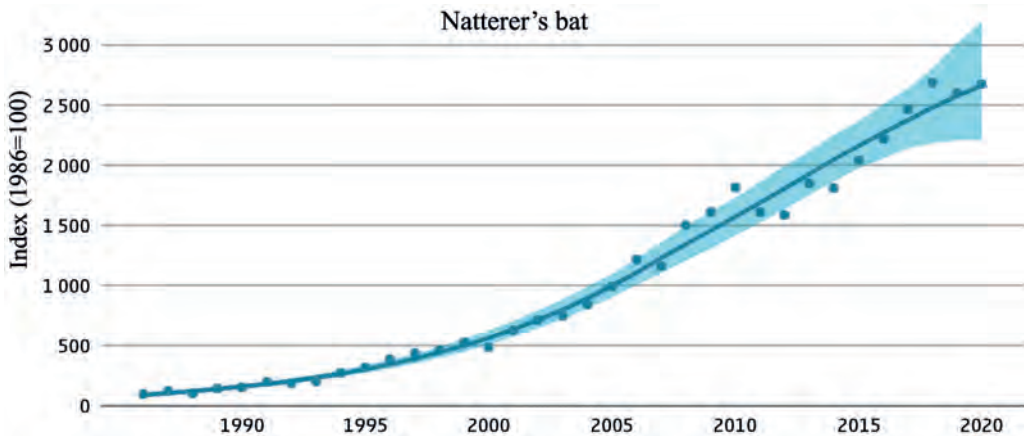


Figure 8. Trend of the Natterer's bat (*Myotis nattereri*) bat in the Netherlands since 1986. The trend over the entire period is of a 'strong increase' (significant increase of > 5%), with a 'moderate increase' (significant increase of ≤5%) over the past twelve years.

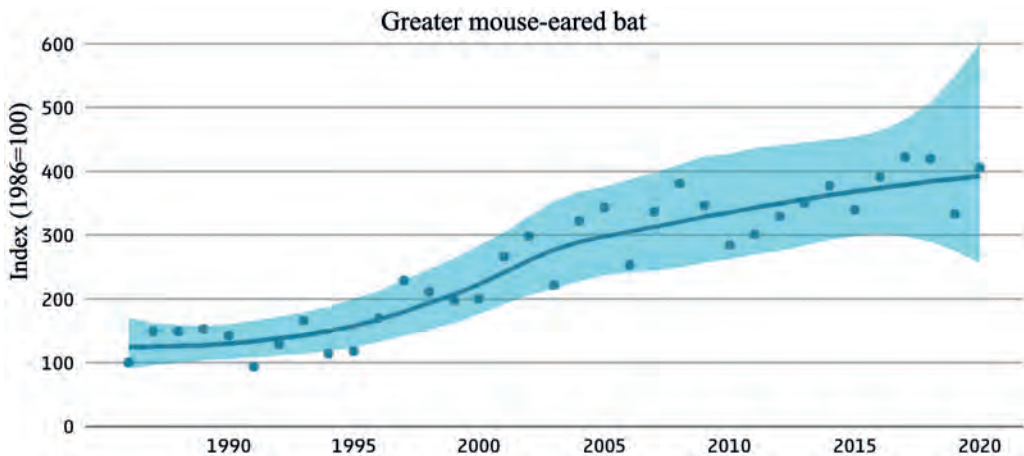


Figure 9. Trend of the greater mouse-eared bat (*Myotis myotis*) in the Netherlands since 1986. The trend over the entire period is a 'moderate increase' (significant increase of ≤ 5%). The trend for the last twelve years is uncertain.

Natterer's bat (*M. nattereri*)

Around 1950, Natterer's bat was regularly found in the marl quarries in southern Limburg, but then the numbers decreased until the 1980s. Since then the species has again increased in numbers and the trend is now positive (figure 8). While the number of hibernating individuals is increasing, new hibernacula are also being discovered, especially in the

coastal areas where Natterer's bats are found in more and more sites, although the numbers have now stabilized (Mostert et al. 2022, in this issue). In Groningen, hibernating Natterer's bats were seen for the first time in 2010. It is not known why the Natterer's bat, a typical tree-dwelling species, is increasing so much, but it could be a positive consequence of more natural forest management in the Netherlands combined with the aging of many forest areas.

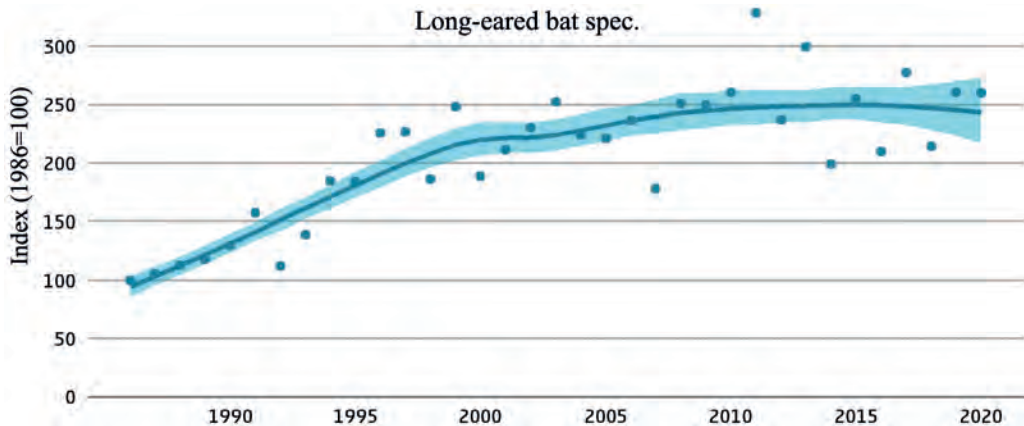


Figure 10. Trend of the long-eared bats spec. (*Plecotus auritus/austriacus*) in the Netherlands since 1986. The trend over the entire period is a 'moderate increase' (significant increase of $\leq 5\%$). The national trend over the last twelve years is stable.

Greater mouse-eared bat (*M. myotis*)

The greater mouse-eared bat mostly hibernates in quarries and cellars, but is sometimes found in (small) bunkers or ice cellars. In the second half of the last century, the number of hibernating individuals in the marl quarries decreased from a few hundred to about 10-15 animals. The species is no longer observed in forts, ice cellars and castle cellars in the central Netherlands, whereas in the past it was found hibernating in these locations with some regularity. The numbers seem to recover somewhat from the late 1990s onwards (figure 9). Today, an average of 50 specimens hibernate in the Netherlands, almost all in marl quarries. The renewed presence of a summer colony in southern Limburg (Norren et al. 2020) may eventually contribute to a further increase in the number of hibernating individuals in marl quarries.

Long-eared bat spec. (*Plecotus auritus / austriacus*)

The brown long-eared bat is usually a 'satisfying' species for bat enthusiasts, as the species seems to find newly built winter quarters

quickly and also hibernates in less suitable winter quarters, which are avoided by other species (Verhees et al. 2022, in this issue). Moreover, the species is widespread throughout the Netherlands and is found in a large number of winter quarters.

The classification 'long-eared bat spec.' is a combination of the brown long-eared bat and the grey long-eared bat (*P. austriacus*) which, as with the 'whiskered bats spec.', are difficult to identify apart without handling them. Since the grey long-eared bat is seldom found in hibernacula and as the species has a very limited distribution in the Netherlands, it is assumed that the trend of the 'long-eared bats spec.' in the NEM mainly reflects the trend of the brown long-eared bat. This trend shows an overall increase, but with substantial annual fluctuations in numbers (figure 10). These fluctuations are presumed to be related to the outdoor temperature in the period preceding the count (see Bekker 2022, Verhees et al 2022, van Zuijlen & Groenendijk 2022, all in this issue): when the period before the count is colder, more long-eared bats are counted in hibernacula than when the period preceding the count is mild. This could mean that if mild winters become more frequent in the future, due to climate change, the number of counted

hibernating long-eared bats will decline and the trend will become negative. This however would not so much be due to a decline in the population but because fewer long-eared bats are hibernating in underground hibernacula.

Discussion

The counts, and numbers, of hibernating bats in the Netherlands have increased significantly in recent decades. In the past the monitoring of bats was concentrated in traditional hibernacula, such as marl quarries, forts and ice cellars, but in recent decades' hundreds of hibernacula, mostly non-traditional types (bunkers and man-made objects), have been added to the monitoring programme. Currently, more than 1500 out of 1800 known hibernacula are monitored annually and this number continues to increase. During the same period, most bat species that hibernate in underground sites have shown an increase in counted numbers, partly as a result of the increased number of known and monitored hibernacula. When calculating trends, corrections are made to ensure that the trends are not influenced by such changes.

It is important to remember that this monitoring scheme produces data on trends of species in hibernacula and that this is not necessarily the trend of (summer) populations of specific species in the Netherlands. Unfortunately, there is insufficient research for the exploration of the underlying causes of trends.

Nevertheless, there are several plausible explanations for the increase in summer and winter populations of a number of species. For example, forest policy in recent decades in the Netherlands has resulted in forests, especially in the higher elevations of the Netherlands, that are older, have a richer and more varied structure and, with more dead wood (lying and standing) (Compendium for the Living Environment 2021). This probably has benefited tree-dwelling and/or species foraging in forest or woodland such as Natterer's

bat, Daubenton's bat, brown long-eared bat and greater mouse-eared bat; we may also see Bechstein's bat (*Myotis bechsteinii*) (currently a rarity) more frequently in the south and east of the country in the future. At the same time, several studies also highlight the negative effects of climate change on bats (see e.g. Rebelo et al. 2010), but it is also possible that some species may benefit from warmer summers. For example, Geoffrey's bat, prefers warm attics and may also benefit from rising temperatures in foraging areas.

Finally, over the years, modifications have been made to many hibernacula to make them more suitable for hibernating bats. These include closing them off to reduce disturbance and/or improving the indoor climate (i.e. closing some openings) and/or enhancing the number of hanging and hiding places. Such measures may not affect the winter population directly, but it may attract bats to hibernate in these sites. Several articles in this issue of *Lutra* explicitly mention such improvements.

The fact that winter and summer populations are not necessarily 'the same' bats (i.e. the animals monitored during winter months are not necessarily the same individuals present in summer) has been proved by banding research on pond bats and Geoffroy's bats. Several individuals have been found in the Netherlands that were ringed abroad: i.e. bats that live in other countries in summer, but hibernate in the Netherlands. The opposite also occurs: bats that live in the Netherlands in summer may spent the winter in hibernacula abroad. This may result in differences between winter and summer trends, as can also be seen, for example, in the pond bat (Haarsma et al. 2019), where male pond bats have apparently recently started to hibernate 'closer to home'.

It is also important to keep in mind that the number of bats in a hibernaculum depends on several factors. Within a winter it is possible that numbers fluctuate as a result of weather conditions, the condition of the animals or the time of year, but also between years there are differences as bats can make different choices

and actively search for the best hibernation locations according to the circumstances. The hibernation of bats is a dynamic event, which makes it difficult to identify the causes of increases or decreases in numbers: monitoring population changes alone is insufficient for this and specific research is very important. Nevertheless, for most species bat-researchers expect a correlation between the number of bats counted in hibernacula and how well (or badly) a specific species is doing on a national scale. Of course, there are exceptions, such as the pond bat, where trends in hibernacula are clouded because of the sex-specific differences in distribution and differ from trends in summer, which complexes finding ‘true’ population trends (Haarsma et al. 2019).

The importance of the Monitoring Scheme of Bat Hibernacula

The importance of the Monitoring Scheme of Bat Hibernacula has increased over the years. Not only because the data series are getting longer (for which reason alone they are becoming more important and reliable), but also because the census data are increasingly playing a role in nature policy, and coming to play a prominent role of the data contained in the Habitat Directive Reports. Every six years the Member States of the European Union are required to report on the state of nature in their country and very specifically on the conservation status of habitat types and species. Since all bat species are included in the Habitat Directive, reporting is required on how well or how badly these species are doing. The pond bat, Geoffrey’s bat, greater mouse-eared bat and Bechstein’s bat are listed in Annex II and IV, the other bat species are only listed in Annex IV (Weinreich & Verheggen 2022). For Annex II species, specific Natura 2000 sites need to be designated, which then need to be optimally protected for these species. The article by Weinreich & Verheggen (2022, this issue) explains in detail what this means for the pro-

tection of the pond bat, Geoffrey’s bat and greater mouse-eared bat in southern Limburg.

Apart from the mandatory EU reports, the monitoring data are also used for the development of provincial nature policy and even contribute to the current energy transition (Schillemans et al. 2021). The use of monitoring series, such as those of bats in hibernacula is of great importance and very valuable in providing information about the state of nature in the Netherlands. It provides insights into the effects of interventions and whether increased additional protection is needed. However, there is still a major shortcoming in the monitoring programmes. In that they are barely linked to, or done in combination with, population ecological studies. Such research would make it easier to ecologically interpret any increases or decreases and whether extra protection measures are necessary. For example, is the increase in Geoffrey’s bat really due to warmer summers? Or, why is there an apparent decline in Daubenton’s bat? And, is the sharp decline of ‘whiskered bats’ in Drenthe a local phenomenon or the prelude to a national decline? There will be more than enough urgent questions to solve in the coming years, and hopefully the NEM Programme can help to find answers and formulate sharp research questions and identify appropriate measures to maintain and enhance bat populations.

Conclusions

Virtually all bat species that hibernate in (underground) hibernacula that are accessible to humans and are monitored in the NEM Monitoring Scheme of bat hibernacula have shown a ‘strong or moderate increase’ (significant increase >5% resp. significant increase ≤5%) since the start of the programme in 1986. While the long-term trends are positive, the mid-term (twelve-year) trends are less positive with stable, or at the provincial level, sometime declining trends in several species. Nowadays some trends are possibly stabiliz-

ing. It remains to be seen how the trends will evolve in the near future.

Acknowledgements: For many volunteers the knowledge that they are contributing to the protection of bats is an important reason for their commitment, as is the pleasure of annually visiting hibernacula, alone or preferably with a group of bat enthusiasts. All these volunteers combine the pleasure of monitoring bats with the conservation of bats and can, should, be proud of all their efforts. This *Lutra special* shows the wealth of information which has been collected over many years and how it has helped contribute to bat conservation in the Netherlands. We therefore thank all these volunteers and other stakeholders, without whose commitment and enthusiasm it would have been impossible to make this analysis.

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Cluysberg, a marl quarry near Bemelen, S-Limburg, the Netherlands.

Photo: Stefan Jerzykowski.

The monitoring of hibernating bats in marl quarries in the period 1979–2020

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Abstract: This paper describes the trend of bats hibernating in marl quarries in the south of Limburg, the Netherlands, since 1986 and puts it into perspective by comparing it with the trend between 1940 and 1980, as described earlier by Daan (1980). There was a general decline in bat numbers during the earlier period, which came to a halt around 1975-1980. Since 1980, the numbers of almost all bat species in marl quarries have increased. Two species (pond bat, *Myotis dasycneme* and whiskered bat, *M. mystacinus/brandtii*) are seen today in about the same numbers as around 1940-1950. The numbers of two other species (Geoffroy's bat, *M. emarginatus* and Natterer's bat, *M. nattereri*) now far exceed that level. Some species: the greater mouse-eared bat (*M. myotis*), brown long-eared bat (*Plecotus auritus*) and lesser horseshoe bat (*Rhinolophus hipposideros*) have not yet recovered to their former numbers. The greater mouse-eared bat is showing a positive trend, but has not yet reached its 1940 level. The brown long-eared bat also shows a positive trend, but remains at a lower level than in the period 1940-50. This may be related to the milder winters, which makes it possible for this species to hibernate outside quarries, for example in trees. The lesser horseshoe bat has not recovered after 1980 and is no longer found in the province of Limburg, and even in the Netherlands. Daubenton's bat (*M. daubentonii*) was the only species to show a positive trend between 1950 and 1980 but since around 1990 it is now (after an initially continuing positive trend) the only species that is in decline. It is possible that this decline is related to the developments in the quality of the surface waters and thus of the insects present. The protection of marl quarries as hibernacula for bats has received considerable policy and financial support since the 1990s, with the introduction and implementation of the Natura 2000 policy. This paper describes these developments, the current state of affairs with regards to policy and what we can glean of their effects. It is important to continue the current (relative) method of volunteers counting hibernating bats for as long as possible. For some years it has not been possible to enter a number of quarries for safety (and legal) reasons. In order to maintain the representativeness of the monitoring network, it is necessary to increase the number of sites counted, which, if these sites cannot be stabilised (and counted again) can also be done using alternative counting methods.

Keywords: bats, hibernation, marl quarries, Natura2000, trend, monitoring network.

Introduction

Studies of hibernating bats in marl quarries have been conducted since the 1930s (Daan et al. 1980). This is probably the longest time series

of any hibernacula in at least the Netherlands. The first studies were not aimed at monitoring but consisted of banding and then re-catching the banded bats in order to find out how loyal bats are to specific quarries and where they stay in summer. Over time the research shifted to monitoring inquiring into the development of bat populations in marl quarries. At around the

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same time bat counts began in other types of sites in the rest of the Netherlands: ice cellars, basements, bunkers and other frost-free, damp spaces. In addition to monitoring (the visible proportion of) hibernating bats, attention was also paid to the ecology of, and the conditions required for, hibernation in hibernacula (Glas 2022, in this issue).

In 1980, through the collaboration of many bat researchers, the first overview of the available national data on this monitoring was published (Daan et al. 1980). The summary overview of the development of the stock of hibernating bats (Daan 1980) was based on data from marl quarries; data from sites elsewhere in the country was very useful, but covered periods that were too short to draw out any long term trends. The message from the analysis was rather gloomy: during the entire evaluation period (from 1940 to 1979), there had been an almost continuous decline in almost all species hibernating in marl quarries. Only Daubenton's bat (*Myotis daubentonii*) increased slightly during this period.

The analysis of the trends of the bat species was based on an annual summation of bat numbers in a fixed set of quarries followed by a comparison of the summation of the following, and so forth (Daan 1980). As not every quarry was counted every year, a five-year average of the numbers per quarry for each species was used. In addition it was only possible to compare bat numbers in those quarries that were counted in the same periods. This meant that the available data were only partly usable.

The problems with irregular counts are not unique to bats but are also encountered in, for example, bird counts. Weinreich & Oude Voshaar (1992) proposed a solution to the problem of irregular counts for bats. They improved Daan's method by first making the best estimate of the expected numbers for the missing counts and then inserting these into the set of actual observations. This allowed a complete sum to be made for each year over a larger number of quarries. The

method was subsequently further refined by CBS and is still in use today (La Haye & van der Meij 2022, in this issue). Such a method is also used for monitoring other fauna groups. Its advantage is that it allows much more data to become usable for making trend overviews.

In this paper we present the numbers of bats in marl quarries in the period after Daan's (1980) survey and discuss the underlying trends. We restrict ourselves to the monitoring of marl quarries. Other articles in this issue discuss monitoring in other types of sites and other parts of the Netherlands as well as Flanders.

Monitoring developments since 1980

Monitoring essentially involves observing a situation at regular intervals, for example every year, and then deducing a development from it. Daan (1980) pointed out that there were some variations in the number of quarries that were counted each year and that the method of counting had gradually evolved. Since 1980, there have been a number of developments, intended to rectify these problems. Firstly, the *method of monitoring* hibernating bats has been gradually standardized. For example, the same quarry is always counted by the same counting group. On the one hand, this is a kind of 'habit': as the bat counting groups visit the same quarries each year they come to know the situation well. At the same time the national body (the Dutch Mammal Society) that coordinates the bat winter counts, has also provided a description of the methodology that should be followed (Dijkstra & Korsten 2005). The positive consequence of this is that the annual counts are increasingly carried out under standardized conditions, which reduces noise in the data.

Part of the increase in the numbers of counted bats might well be due to the ongoing *professionalization of the counts* and increased experience of the counters: this can be summarized as the 'observer effect'. This has never

been properly studied, but it is possible that part of the increase can be attributed to this effect.

The *lighting* used has also improved over time. In the 'old days' (1945-1980) torches with ordinary light bulbs were used. Petro-maxes, petroleum gasifiers and carbide burners were also used for auxiliary lighting. In addition to light, these all produced heat and sometimes stench, both of which may have disturbed bats, leading them to seek more protected, and thus less visible, spaces. Since 1980, rechargeable lamps started to appear and in the 1990s krypton and halogen lamps with rechargeable batteries came into use. From 2000 onwards, LED lamps also began to appear and from 2008 high power rechargeable LED lamps were in use and these are now almost exclusively used. These give more light, produce less heat and no stench. The effect of the improved lighting is that more bats may be found than before. However, this effect is also difficult to quantify.

In the early 1960s, researchers began to make *maps* of quarries to ensure an efficient and complete count. These maps have gradually become more complete and more accurate, and based more on good measurements rather than sketches. This has made counting easier, although one cannot quantify the extent to which this has influenced the outcome of monitoring.

The *attention for bat monitoring* from the policy point of view has incrementally increased in recent years. After the Birds Directive came into force in 1979 and the Habitats Directive in 1992, there was a need for the (then) Ministry of Agriculture (which included nature at the time) to find ecological justifications for implementing these directives. The reports on the monitoring of hibernating bats over the years proved not only to be useful for national policy, but also for reports to the EU concerning the implementation of the Habitats Directive: specifying whether species were in decline, growth or stable at the national level. One result of

this is the NEM¹ project, in which the Dutch Mammal Society coordinates and facilitates the input of a number of separate and independent counting groups. Since 2013, a large part of nature conservation policy and implementation has been decentralized to the provinces. This means that it is now the provinces that are responsible for the designation of Special Areas of Conservation, or Natura 2000 areas under the Habitats and Birds Directives and the preparation of management plans for these areas which must contain a number of specific objectives for each area. There are four areas with objectives for hibernating bats in marl quarries (see the section 'Natura 2000 and hibernating bats' below). The provinces are also responsible for monitoring the status of Natura 2000 sites and file a report on this every six years. There are benefits to reporting at a decentralised level as it shows more clearly how well (or badly) is bat species x is doing in Natura 2000 area y (and how they are responding to any measures that have been taken). Finally the objective has shifted from just monitoring the state of affairs to achieving objectives of maintaining populations of target species at a certain level and, if necessary, taking measures to achieve that end: a shift from passively tracking to actively protecting target species (the term 'population' should be read as 'counted numbers').

There have also been *developments in mining legislation*. Marl quarries are now regarded in policy terms as former extraction sites of raw materials (in this case marl or limestone). All sites where raw materials are or were extracted are subject to the Mining Act. Before this act, passed in 1980, policy implementation and enforcement were centrally regulated by the State Office for the Supervision of Mines (SodM): so local supervision was subservient to national considerations. Since 2010 policy on mining legislation in relation to marl quarries has been decentralized to the province (Thissen & Hollander

¹ NEM: Network Ecological Monitoring

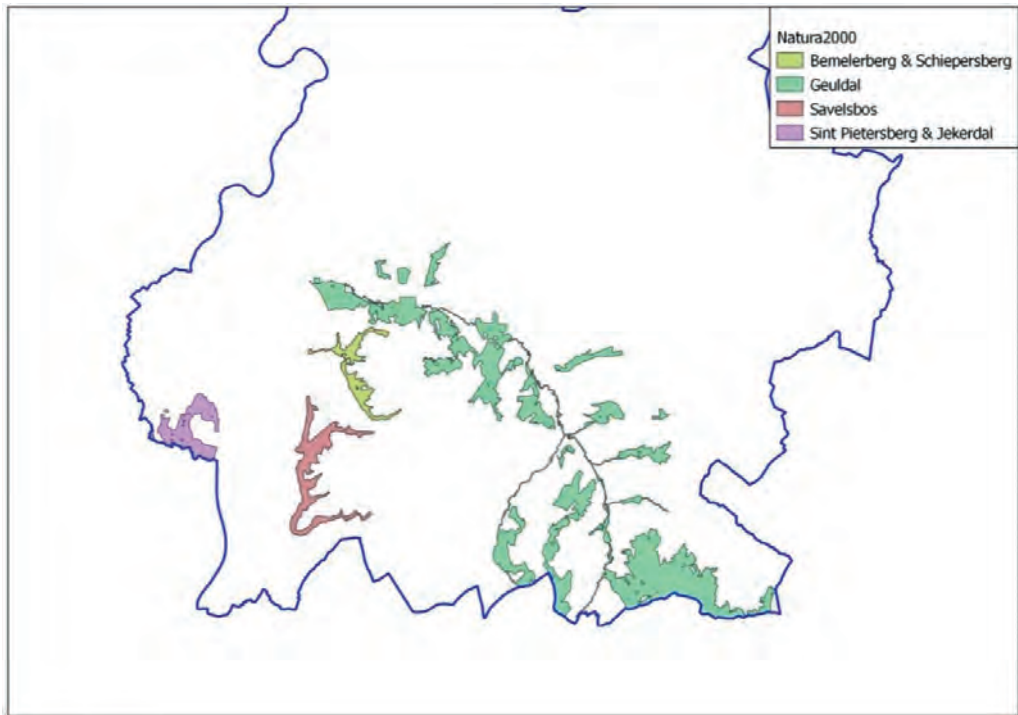


Figure 1. Location of Natura 2000 areas in the south of Limburg with a conservation target for hibernating bats.

2013). The central government (through SodM) only takes care of the main policy decisions and the provinces regulate the issuing of permits and enforcement. The transition from national to provincial governance meant that the system of licensing and enforcing had to be redesigned and that the existing permits had to be revised.

This earlier division of responsibilities created uncertainties about who should, provide the licences for carrying out bat counts in the quarries and, who would be responsible in case of accidents. As a result, many quarries were not counted for some time. Since then things have become clarified and the number of counts has begun to increase again, although not to their previous level. The Province of Limburg (2018) has drawn a guide to regulate and license all the activities in marl quarries, which involves a technician inspecting the quarries to establish that there are no safety issues from likely cave-ins, after which the owner can issue a licence for monitoring. The

organisers of the bat counts in the marl quarries and the Dutch Mammal Society consult with the site owners and with the province over such permits. These discussions have not yet been settled and have led to a decline in the number of sites that are counted: a number of quarries, which were previously included in the monitoring (especially in Savelbos), continue to be excluded from the monitoring because of concerns about their safety. Thus the stricter regulations that have come about as a result of the implementation of the Mining Act have made it more difficult to carry out counts and some previously counted hibernacula are no longer counted.

Natura 2000 and hibernating bats

Under the Dutch implementation of the European nature policy (Habitats and Birds Directive) 146 nature reserves have been designated, with an obligation to meet objectives for spe-

Table 1. Objectives for hibernating bats in four Natura 2000 areas in South Limburg. (<https://www.natura2000.nl>; Provincie Limburg 2020a, 2020b, 2021).

	Species	Proportion (% Dutch population)	Popula- tion	Habitat area	Habitat quality
Sint Pietersberg en Jekerdal	H1318 – Pond bat	30-50%	=	=	=
	H1321 – Geoffroy's bat	30-50%	=	=	=
	H1324 – Greater mouse-eared bat	15-30%	=	=	=
Savelsbos	H1318 – Pond bat	6-15% *	=	=	=
	H1321 – Geoffroy's bat	6-15% *	=	=	=
	H1324 – Greater mouse-eared bat	2-6% *	=	=	=
Bemelerberg en Schiepersberg	H1318 – Pond bat	30-50%	=	=	=
	H1321 – Geoffroy's bat	15-30%	=	=	=
	H1324 – Greater mouse-eared bat	6-15%	=	=	=
Geuldal	H1318 – Pond bat	30-50%	=	=	=
	H1321 – Geoffroy's bat	30-50%	=	=	=
	H1324 – Greater mouse-eared bat	> 75%	>	>	>

* Savelsbos hasn't been monitored for the last ten years. Numbers and proportion are unknown.

cific nature targets. These are classified as Natura 2000 areas and are the 'jewels in the crown' of the Netherlands' nature reserves. For each area, specific conservation objectives have been fixed which cover identified species and habitat types: the natural values may not deteriorate and in some cases need to be improved. These targets are subject to a six yearly monitoring and reporting obligations, which if necessary (i.e. the targets are not being met) will result in a revision of the management plan. While these sites include targets for other species and habitat types, of specific interest here to us are the targets set for the hibernating bats in four Natura 2000 areas in South Limburg: 1. Sint Pietersberg & Jekerdal. 2. Savelsbos. 3. Bemelerberg & Schiepersberg. 4. Geuldal. These four sites cover virtually all the underground marl quarries in South Limburg (figure 1).

The Provincial Executive has adopted, or is in the process of so doing, management plans for each of these areas. Plans for Bemelerberg & Schiepersberg and Sint Pietersberg & Jekerdal were adopted in 2019 (Provincie Limburg 2020a, 2020b), for Geuldal the plan is in the design stage (the draft was adopted in draft 2021 and is expected be adopted in 2022 - Provincie Limburg 2021), and that for Savelsbos

is currently being revised and is expected to be adopted in 2023. Once the management plans are in place, they must then be implemented. For the first three plans, the implementation of measures started in 2021.

The objectives in each area for hibernating bats are shown in table 1. The core task for these four areas is to maintain, improve and expand the number of hibernation sites for bats by improving their quality and reducing and regulating disruptive influences stemming from various forms of co-use.

In connection with these management plans, the Province of Limburg is developing a subsidy scheme, under which landowners and managers can obtain compensation for the management and supervision of underground marl quarries. A budget has also been set aside for remediation and stabilisation work.

Quarry management plans are being drawn up for each quarry to get an overview of feasible measures. A series of research projects has been established to fill knowledge gaps with regard to, for example, climate influence, swarming locations, the sites' functionality outside the winter season and the relationship between hibernation sites and the bats' summer habitats. These measures apply to all four

Natura 2000 area. These research and conservation measures will be carried out over the next six years.

The following section details the situation in each of these areas and their most important quarries, including for the four designated species under Natura 2000 policy. We also describe the key quarries, population trends and the existing opportunities and threats. We mostly discuss three of these Natura 2000 areas: Bemelerberg & Schiepersberg, Sint Pietersberg & Jekerdal and Geuldal. In Savelsbos, where most quarries cannot be entered under safety restrictions imposed by the Mining Act and monitoring has not taken place since 2012.

Sint Pietersberg and Jekerdal

Geographical spread

This Natura 2000 area contains two large complexes with quarries: Sint Pietersberg on the west bank of the Meuse (where the quarries extend into Belgium) and, further to the west, the Louwberg in the Jeker valley. There are some additional quarries located outside these two complexes. In general, the quarries have high corridors, in contrast to many other quarries to the east of the Meuse. Some of the original, underground, marl quarries have disappeared due to opencast marl extraction (e.g. at St. Pietersberg) or due to collapses (e.g. at Fallenberg, Oudberg and Muizenberg). This Natura 2000 area contains 23 underground marl quarries with a total surface area of corridors covering more than 180 ha.

Natura 2000 objectives

The objective here is to maintain the existing numbers of hibernating greater mouse-eared bats (*Myotis myotis*), Geoffroy's bats (*M. emarginatus*) and pond bats (*M. dasycneme*), which implies maintaining the same quality

and size of the habitat. The most important quarries for these species are Zonneberg, De Keel, Apostelgroeve, Kasteelgroeve, Boschberg, Fallenberg, Jezuietenberg, Scharkgroeve and Caestert / Zuidelijk Stelsel.

Numbers of bats and species range

This area is the most important Natura 2000 site in the region for hibernating bats in the Province, Zonneberg system and Pietersberg-Noord quarries (which in the most recent count were found to have about 2200 specimens). In addition around 500 bats were recently counted Louwberg area, scattered over various quarries, the most important of which is Kasteelgroeve. Another 500 specimens have been counted found in the quarries outside these complexes (particularly in Groeve de Keel, a quarry system which lies in Dutch territory, but whose entrance is on the Belgian border).

Sint Pietersberg & Jekerdal hosts more pond bats, whiskered bats (*M. mystacinus/brandtii*), Daubenton's bat and Natterer's bat (*M. nattereri*) than anywhere else in South Limburg. The quarry systems are also of regional importance for greater mouse-eared bat and Geoffroy's bat (table 2). The Zonneberg system has the highest numbers of all these species.

It is notable that many Bechstein's bats (*M. bechsteinii*) are also found in this Natura 2000 area. In the autumn, a large concentration of swarming Bechstein's bats is found in front of the quarry entrances to the Louwberg (Janssen 2009). The number of swarming animals caught is greatly exceeds the number of hibernating animals found, suggesting that the species successfully hides in places that are not amenable to being observed during counts, or that it migrates to other hibernation sites.

Secondary use

A number of the larger quarries in this Natura

Table 2. Minimum and maximum counted numbers per species (including density per 10 ha of corridor area) in the last five consecutive years that the quarries in the Sint Pietersberg & Jekerdal were counted (2016² - 2020).

Sint Pietersberg 182.71 ha	min	max	Density (max) <i>n</i> /10 ha
Pond bat	33	69	3.8
Geoffroy's bat	238	399	21.8
Greater mouse-eared bat	9	20	1.1
Natterer's bat	659	1100	60.2
Daubenton's bat	336	460	25.2
Whiskered bat	399	572	31.3
Brown long-eared bat	6	19	1

2000 area are intensively used for tourism and recreation purposes, including the quarries at Zonneberg, Pietersberg-Noord, Jezuietenberg, Boschberg (a former NATO site) and Scharkgroeve, which are also home to the largest populations of Natura 2000 bat species. Pietersberg-Noord contains a working mushroom farm, and until recently, parts of Kasteelgroeve (also known as Cannerberg) were used to store hay and straw, although this use was terminated after a hay fire in 2018. The original entrance to Kasteelgroeve, on the side of Château Neercanne, was completely rebuilt in 2018 as a party and reception hall and storage space for the castle. The other quarries are mostly still extensively used.

The monitoring and trend calculation

Bats are counted annually in 22 of the 23 quarries in the area. In 2015, Statistics Netherlands (CBS) conducted an analysis of the reliability of the calculated indices for the three designated species (La Haye 2016). This showed that for the Sint Pietersberg & Jekerdal area the number of quarries where bats are counted is sufficient to determine

representative and reliable trends. However, it also noted that a decrease in the number of quarries where counts are made could compromise the trend calculations for the species.

The most important challenge(s)

There is an ongoing assessment (due to be completed in 2026) of the other human usages in the Sint Pietersberg complex to assess whether they are compatible with the Nature Conservation Act. These (mostly) recreational activities, are currently licensed under the Mining Act but fall foul of the Nature Conservation Act. The review will investigate the effects of such activities on hibernating bats and should ensure that any negative effects of these activities will either be mitigated, or compensated for, or will lead to an adjustment or cessation of these activities.

Bemelerberg and Schiepersberg

Geographical spread

The quarry complexes in the Natura 2000 area of Bemelerberg and Schiepersberg can be divided into two clusters: the first to the north of Bemelen, around Bemelerberg, and the second to the southeast of Bemelen from the Mettenberg to the Schiepersberg. These include some large and medium-sized systems, such as the Koelebosch, Roothergroeve and Cluysberg / Winkelberg. However, the majority are smaller systems such as the Gasthuisdelgroeve (4 systems), Bemelerboschgroeve (3) and Mettenberggroeve (5). The Natura 2000 area contains 23 underground marl quarries with a approximate total of 30 ha area of corridors. Bemelerberg & Schiepersberg is the smallest complex of underground marl quarries listed under Natura 2000.

² In this paper January of each year is taken as the winter date, so for example 2016 = the winter of 2015-2016

Natura 2000 objectives

There is a conservation target for the size and quality of the habitat and for the population size of all three designated species in the area. The most important quarry in this Natura 2000 area is Koelebosch. Schoorberggroeve, Roothergroeve, Gasthuisdelgroeven, Cluysberg and Mettenberg also have significant numbers of bats.

Bat numbers and species range

Bemelerberg and Schiepersberg has fewer bats than the other three Natura 2000 areas considered in this article, but this is due to its smaller size. However, the relative density of the species, with the exception of the greater mouse-eared bat, is higher than in the other two Natura 2000 areas: by a factor of between two and six, depending on the species (see table 3). The pond bat is remarkably well represented in this area although relatively few Greater mouse-eared bats hibernate here in low numbers.

Currently about 1070 bats hibernate in Bemelerberg and Schiepersberg. In the quarries around Bemelerberg there are about 700 bats; the most important quarry here is Koelebosch with over 600 bats. The second cluster, southeast of Bemelen, accommodates about 370 bats, with Roothergroeve and Mettenberggroeve 5 as the most important quarries.

The greater mouse-eared bat has never been numerous in Bemelen. The most animals observed of this species here is five individuals, in 2002. Bechstein’s bat is not found hibernating annually. In contrast to the other Natura 2000 areas, there is no record of important swarm sites of Bechstein’s bat in autumn from this area either.

Secondary use

Apart from one small quarry, none of the

Table 3. Minimum and maximum counted individuals number per species (including density per 10 ha of corridor area) in the last five consecutive years that the quarries in the Bemelerberg & Schiepersberg were counted (2016 to 2020). (The large differences between the minimum and maximum can be traced to the Koelebosch, which could only be counted in two out of the five years.)

Bemelen 29.35 ha	min	max	Density (max) n/10 ha
Pond bat	11	44	15
Geoffroy’s bat	34	243	82.8
Greater mouse-eared bat	0	3	1
Natterer’s bat	50	248	84.5
Daubenton’s bat	60	238	81.1
Whiskered bat	96	276	94
Brown long-eared bat	3	17	5.8

quarries in this area are used for intensive (tourist) purposes. Most of the quarries are closed or located on the enclosed grounds of Limburgs Landschap, a land management organization, dedicated to nature conservation. The exception is Bemelerbosch 1 located on Mettenberg, which is privately owned and occasionally, outside the winter season used, to a limited extent, for yoga training, which is not thought to interfere with its suitability for hibernating bats.

The monitoring and trend calculation

Before 2018, it has no longer been possible to visit a number of quarries with high numbers of bats due to the issues surrounding the Mining Act. This undermines the representativeness of the winter census for Bemelerberg & Schiepersberg, as no statistically reliable trends can now be calculated (La Haye 2016). Statistics Netherlands (CBS) has issued a warning that the limited numbers of counts in Bemelerberg & Schiepersberg no longer adequately reflect the population trends of the area. Some quarries have since been stabilized by the Province of Limburg (in 2018) and have

been counted again since then, which has bought the area back into the range in which indexes can be calculated based on a sufficient number of sites. Of the 23 quarries in the area, 10 are currently counted.

Main challenge(s)

Moves are afoot to establish whether Cluysberg, Winkelberg and Gasthuisdelgroeven can be included in the monitoring programme again to strengthen the representativeness and reliability of trend data. These quarries are important for the pond bat, whose numbers are now missing from the winter counts. This possibility is currently being investigated as part of the quarry management plan being drawn up for Bemelerberg & Schiepersberg.

Geuldal

Geographical spread

This is the largest and most dispersed set of marl quarries designated as a Natura 2000 site, which is spread over three main clusters: 1. Along the river Geul between Valkenburg and Meerssen, mostly on the southern slope (Schenkgroeve, Barakkengroeve, Viltergroeve, Bronsdalgroeve and various smaller quarries) but with a few smaller quarries on the northern slope (including Ravensbosch (3x) and Schaelsberg (2x)). 2. In and around Valkenburg, on the north and the south slope of the Geul (Gemeentegrot, Fluwelengrot, Plenkertgroeve, Heidegroeve and various smaller quarries). 3. In, and north of, Sibbe around Sibbergrub (Sibbergroeve, Flessenberg, Vallenberg and a large number of smaller quarries). There are several other smaller quarries (3) at Ransdaal-Klimmen. Just outside the Natura 2000 area.

The total area of corridors in the Geuldal is approximately 167 ha, spread over 84 quarries.

Natura 2000 objectives

The Natura 2000 objectives for the Geuldal are to maintain the habitat quality and size for hibernating pond bats and Geoffroy's bats and expand and/or improve the habitat suitable for the greater mouse-eared bat. The most important quarries for these species are: Schenkgroeve, Viltergroeve, Barakkengroeve, Sibbergroeve, Heidegroeve, Gemeentegroeve, Fluwelengroeve and Bronsdalgroeve. The other quarries also contain these species.

The greater mouse-eared bat established a new maternity colony in an attic located just outside the Natura 2000 area boundary in 2018. This new location is expected to increase the numbers of greater mouse-eared bats hibernating in Geuldal.

Bat numbers and species range

The cluster of quarries located between Meerssen and Valkenburg on the southern slope of the river Geul harbours the largest number of bats in this Natura 2000 area: more than 1600. Most of them hibernate in Schenkgroeve, with 570 bats in 2020. More than 850 bats hibernate in and around Valkenburg, with Gemeentegroeve and Heidegroeve being the most important sites. The quarries in the cluster around Sibbe accommodate about 400 bats, with Sibbergroeve being by far the most important site.

There are very few hibernating pond bats in any of the sites (see table 4). The highest recorded number was six in Schenkgroeve in 2020. However, there are also quarries which are no longer included in the counting programme for the winter censuses, such as Geulhemmergroeve which, when they were last counted had at least twice this hibernating population. Hibernating greater mouse-eared bats are concentrated in a few larger systems, such as Barakkengroeve, Schenkgroeve, Sibbergroeve and Gemeentegrot, with a few being sometimes also found in smaller sys-

Table 4. Minimum and maximum counted numbers per species (including density per 10 ha of corridor area) in the last five consecutive years that the quarries in Geuldal were counted (2016-2020).

Geuldal 167 ha	min	max	Density (max) n/10 ha
Pond bat	23	38	2.3
Geoffroy's bat	308	733	43.9
Greater mouse-eared bat	28	45	2.7
Natterer's bat	570	963	57.7
Daubenton's bat	238	417	25.1
Whiskered bat	321	493	29.5
Brown long-eared bat	29	58	3.5

tems. Geuldal is home to the largest number of hibernating greater mouse-eared bats in the region (and also in the Netherlands) and also has the highest density of this species. Geoffroy's bats now hibernate in almost all medium and large systems; with most found in Schenkgroeve, Sibbergroeve, Gemeentegroeven and Heidegroeve.

The most Natterer's bat and whiskered bats in this complex are found in Viltergroeve, Plenkertgroeve, Bronsdal groeve and the Curfs tunnel. All these quarries are located along the Geuldal between Valkenburg and Meerssen. Daubenton's bats are widely distributed, but are no longer numerous in any single quarry, with the exception of Barakkengroeven, where 81 specimens were counted in 2020.

An arboreal maternity colony of Bechstein's bats has been known to exist in the De Dellen Nature Reserve, near Meerssen, since 2019 (R. Janssen, personal communication). However, hardly any specimens of this species are found in any of the hibernation quarters. Winter sightings of Bechstein's bat in Geuldal are extremely rare.

Secondary use(s)

This area contains the most quarries that continue to be exploited for other purposes, thus reducing their suitability for hibernating bats.

As a result, some have also become permanently unsuitable, such as Steenkolenmijn / Daelhemergroeven, Wilhelminagroeven and Studentengroeven / Caverne. Near Meerssen there are some quarries which are very dilapidated, such as Leeraarsgroeven, Ravengroeven, Vlaberg, Kabouterberg and Groeven Staal. Parts of the quarries at Gemeentegrot and Fluwelengrot are intensively used for recreational purposes during the winter. The permit granting this intensive use includes regulations to compensate for the effects on the permanent resting and residence areas of bats and the negative effects on conservation objectives (for the protection of sites). The compatibility of these activities which bat conservation does require further investigation.

The monitoring and calculation of trends

Of the 55 accessible and countable quarries in the area, bat counts are carried out in 33. A relatively large number of quarries are closed, rejected or extensively exploited for catering and/or tourism and can no longer be entered. The remarks made by Statistics Netherlands about the representativeness of the sample and reliability of counts from Bemelerberg also apply to Geuldal. The counts that are able to be made in Geuldal are thus probably not a good reflection of actual population trends. This could become a problem in the long run, particularly for the pond bat and greater mouse-eared bat. It is important to increase the number of countable sites in this area.

Main challenge(s)

The most important measures in Geuldal are to assess whether the intensive use of many of the quarries is compatible with objectives of the Nature Conservation Act and, if not, whether and how the two can be reconciled. This assessment will be carried out in the coming years.

Savelsbos

Geographical spread

The 17 quarries in Savelsbos are all located on the wooded slope between the plateau of Mar-graten and the Meuse valley. In addition to a large number of smaller quarries, there are also several larger quarries: Keerderberg, De Hel and Riesenbergh.

Natura 2000 objectives

There is a conservation target for the size and quality of habitat and the population size of all three designated species (pond bat, Geoffroy's bat and greater mouse-eared bat) in the area. The most important quarries for this Natura 2000 area are those mentioned in the previous paragraph.

Bat numbers and species range

Savelsbos stands out among the four Natura 2000 areas with marl quarries as barely counts have been carried out here since 2012 and therefore nothing is known about the current bat species, numbers or distribution. In the last year of counting the three protected species were well represented in this area.

Secondary use(s)

Almost all the quarries in the Savelsbos have no secondary use and only have a nature function. Guided tours for visitors are held in the prehistoric flint mines of Rijckholt are held between the start of April and October. Visitors only enter the central corridor and not the historic mines. The historic mines are therefore not accessible to people, but remain so to bats.

The monitoring of and calculation of trends and main challenge(s)

No monitoring has taken place since 2012. Thus there is a lack of data about the numbers and trends of hibernating bats for this area. A solution to this problem needs to be found. Wherever the rock mechanics allow, quarries should be stabilised and, in systems that cannot be restored, alternative (automated) monitoring methods should be set up in quarry entrances. Tests are currently being carried out using counting frames supported by cameras to facilitate the identification of bats and the systematic setting up of surveys of swarming bats (see e.g. Weinreich 2022).

The development of the number of monitored quarries

The extent to which the monitoring of marl quarries provides reliable data for local, provincial and national policy is largely dependent on the proportion of known sites monitored. At every site there will be certain variations in the results and policy should be based on knowledge about the status of (specific species of) bats in marl quarries (or elsewhere) rather than data from a single quarry, with its own specific characteristics. Data from individual quarries are important for the management and granting of permits under the Nature Conservation Act: and is relevant for adjusting a permit, if it is necessary to mitigate against, or compensate for, negative effects. In terms of policy evaluation it is also important to be able to evaluate the status, not only of the quarries as a whole (or even the nation's compliance with the relevant Directive), but also for each Natura 2000 area. As such it is important that as many quarries as possible in each Natura 2000 area are included in the monitoring programme.

Daan (1980) evaluated 16 quarries or quarry complexes and calculated the population trends over the period 1940/44 - 1975/79,

although he did not distinguish between the different sub-areas. Under today's classifications this covers 19 current 'counting units', or quarries of which, for various reasons, seven are no longer included in the counts. Despite this, there is now the opportunity to monitor more quarries than in the past.

The graph (figure 2) shows the evolution in the number of counted quarries since 1940-44. The numbers of quarries counted in the period up to 1979 come from Daan's publication; the numbers thereafter are derived from counts recorded in the Dutch Mammal Society's winter census database.

The figures show that the number of quarries counted in the period 1940-1979, as evaluated by Daan, was between 11 and 18. Between 1981 and 2006, this increased to between 50 and 70, with a maximum of 70 around 1992. This increase is probably related to the increased attention generated by Daan et al.'s publication in 1980. Between 2006 and 2009 there was a steep decline in the number of monitored quarries, which more than halved to 30. This was due to the implementation of the Mining Act within South Limburg, which caused some initial uncertainty whilst all the parties involved became accustomed to the new policy. Although the law did not actually change, its implementation was more stringent than before in terms of identifying and minimising safety risks. This led to permission to count in many quarries being revoked by the owners. The decrease in monitoring activity was particularly noticeable in the Savelsbos (where virtually the majority of sites are no longer monitored to this day), Bemelerberg and Schiepersberg and the Geuldal.

Since 2009, however, there has been a rebound in monitoring intensity which has returned to the same level as in 1990-2004. However, this recovery has not occurred in Savelsbos. In Bemelerberg and Schiepersberg the number of counted quarries also fell sharply, but there has been a more recent revival. This is a result of the increased need for monitoring data for, among other things,

policy matters, and gradual improvements in the way the Mining Act is handled through, for example, regular consultations. The province (via the Dutch Mammal Society) is also stimulating, facilitating and financing the rock mechanic inspections needed to provide quarries with the requisite permits for gathering monitoring data. During these inspections, small defects, which previously prevented approval for monitoring purposes, can be quickly resolved. In some cases, the Province also finances stabilization work in larger quarries with important bat populations, such as the Koelebosch quarry.

The current situation is that no counts can be carried out in the entire Savelsbos area and in Bemelerberg & Schiepersberg there are quite a few quarries where counting cannot take place due to stability problems. Thus, in both these Natura 2000 areas, until recently, it was not possible to make a proper assessment of the state of affairs for bats. With three recently restored sites, the situation in Bemelerberg & Schiepersberg has now improved. As of 2022 bats can now be monitored in 64 of the total 119 quarries in South Limburg: 23 out of 24 in Sint Pietersberg and Jekerdal; 31 out of 84 in Geuldal; 10 out of 23 in Bemelerberg and Schiepersberg and 1 out of 17 in Savelsbos. In practice, however, the number of quarries that are actually monitored is lower.

The aim for the future is that the reliability of monitoring can be further increased by making necessary interventions in the Savelsbos, in the area around Bemelen and in the Geuldal to make facilitate more monitoring. The introduction of a management subsidy for marl quarries may contribute to making more sites accessible for counting, as this allows the quarry owners to reclaim any costs they may incur for supervision and management.

Species trends, by Natura 2000 areas

In this section, we describe the development

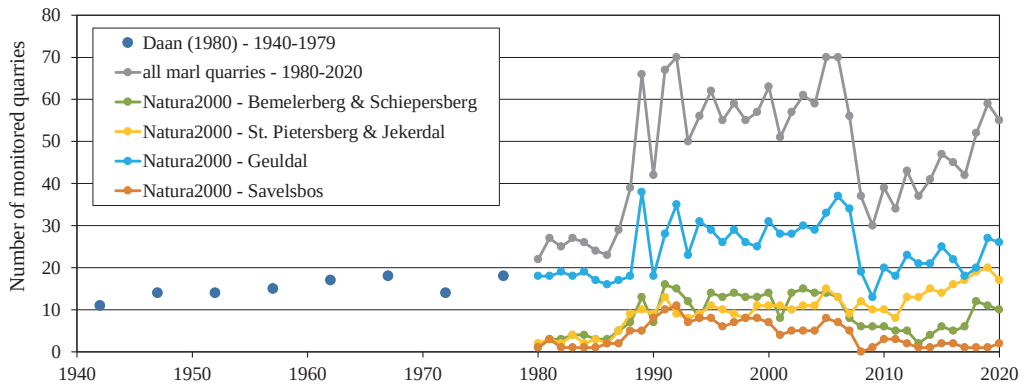


Figure 2. Number of quarries where hibernating bats have been monitored 1940-2020. Early figures (blue dots) are derived from Daan (1980). After 1979 they are derived from the count results in the database of the NEM at the Dutch Mammal Society and subdivided into the four Natura 2000 areas with marl quarries. The dark grey line represents all marl quarries in South Limburg. The largest changes (increases and decreases) have occurred in Geuldal, which also contains the most quarries.

of the numbers of the each of the seven bat species (including three Natura 2000 species) found hibernating in marl quarries in South Limburg between 1940 and 2020. Two graphs are given for each data set. The first shows the trend from 1940-45 to 2020. The left-hand side of these graphs (dotted line) shows the as trend collated by Daan (1980). The right parts of the graphs (solid lines) shows the trend after 1979 as calculated by Statistics Netherlands (CBS) based on the count data available at the Dutch Mammal Society. Because both data sets overlap in 1979, the index for that year is set at 100 – so the rest of the graph shows the numbers in other years compared then. This allows us to show the extent to which the bat population has developed (or not) compared to Daan's evaluation period: 1940-79. Daan's part of the graph is based on the same quarries used for his calculations, calculated again by Statistics Netherlands. The second graphs shows the development of the species in the individual Nature 2000 sites between 1986 and 2020; taking 1986 as the reference point (=100). For this purpose, Statistics Netherlands used the monitoring data collected by volunteers and available in the database of the Dutch Mammal Society.

Trend calculations have been carried out by

Statistics Netherlands, including statements about the statistical reliability of the trend over the relevant period. The method of trend determination essentially involves adding up the results of a large number of quarries, always the same ones. Any missing values are filled in on the basis of the trends at other quarries and on the basis of the share of that quarry in the total population (see La Haye et al. 2022, in this issue, for a description of this methodology). This allows more quarries to be included in the count than in Daan's method, and makes the calculated trend more representative.

While we occasionally mention the absolute numbers of bats of a species that were counted, it is important to realise that only a proportion of the bats within a site are spotted during a count. This is partly due to the crawling behaviour of bats, and partly due to search errors by the observers. Here it is assumed that if monitoring is always carried out (and bats always behave) in the same way, the search error remains the same and the proportion of the population which is found can be considered representative of the whole. As a result, the numbers of specimens found can be declared representative of the whole, giving us insights into a trend.

Estimates of the proportion of bats discov-

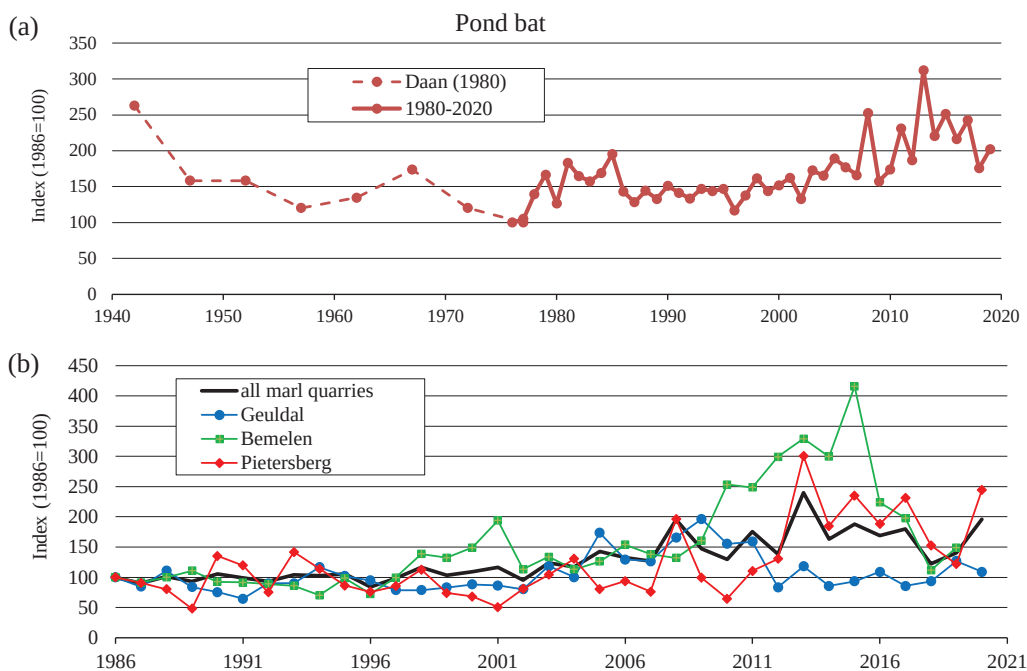


Figure 3. Trend of hibernating pond bats in marl quarries: a. the trend in the period 1940/45 – 1975/79 compared with the trend in 1980–2020 (indexed to the year 1979=100); b. the trend in the period 1986–2020 for all the quarries together (black line) compared with the trends for three Natura 2000 areas (indexed to the year 1986=100).

ered during bat censuses specimens range from 50% to 10% (Lefevre et al. 2022, in this issue, Weinreich 2022), a fraction that will vary according to the species and its behaviour, and gives an indication of the actual numbers.

Pond bat

Between 1940 and 1979, the population of the pond bat, one of the species of protected bats in the Natura 2000 areas, more than halved (figure 3a). The low point was around 1975–1980 when around 40 specimens were counted. The numbers then recovered in the period 1980–2020 to their previous level. In recent years between 100 and 140 pond bats were counted. Between 1986 and 2020 the numbers of pond bats remained more or less the same as the 1986 reference point (figure 3b), after which there was a slight increase, with a peak in 2013 and by 2020 the numbers were double that of

1986. Statistics Netherlands (CBS) classifies the trend since 1986 as a ‘moderate increase’.

Broken down by the three Natura 2000 areas, the development of the pond bat in the period 1986–2020 to 2002 corresponds well to the overall trend. The population in Bemelen and in the Pietersberg has increased slightly, while in the Geuldal the numbers have varied, peaking around 2015 and falling back to their 1986 level in 2020. In each of the three areas, there has been a ‘moderate increase’ since 1986.

Geoffroy’s bat

During the 1940s and 1950s the numbers of counted hibernating Geoffroy’s bats (also a Natura 2000 species) declined (figure 4a) and around 1980 the population then stabilized at a low level of 20–30 specimens. Since then the numbers have increased, at first gradually, and then almost exponentially. In 2020,

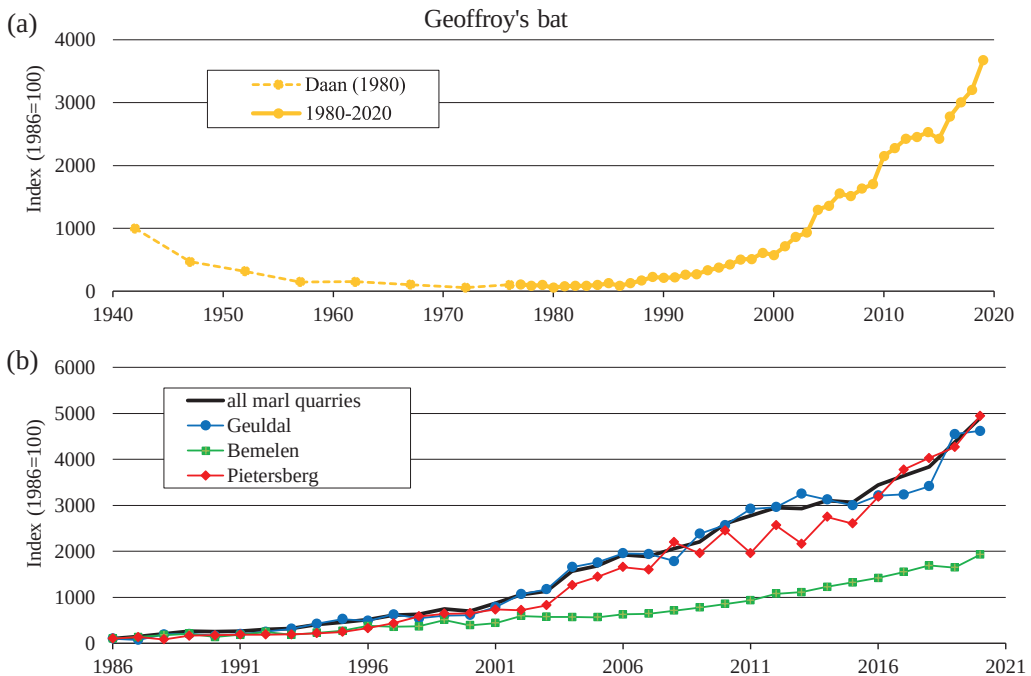


Figure 4. Trend of hibernating Geoffroy's bats in marl quarries: a. the trend in the period 1940/45 – 1975/79 compared with the trend in 1980–2020 (indexed to the year 1979=100); b. the trend in the period 1986–2020 for all the quarries together (black line) compared with the trends for three Natura 2000 areas (indexed to the year 1986=100).

about 1500 Geoffroy's bats were counted in South Limburg's marl quarries. The 2020 figure is a forty fold increase on the low point of 1975-1980 and a 3.5 increase compared to the 1940s. Statistics Netherlands (CBS) classifies the trend since 1986 as 'a strong increase'.

In the period 1986-2020 (figure 4b) the development of the status of Geoffroy's bat was very similar in the three Natura 2000 areas. Since 2002, the development in Bemelen & Schiepersberg, although still positive, lags behind the other areas.

Summer colonies in Central Limburg have been monitored annually since 2001 (Janssen et al. 2014, Dekker et al. 2021). There was a strong increase in summer colonies until 2012, but after that the numbers stabilised. In the summer colonies today about 1200 individuals (females and sub-adults) are counted. The differences in the two trends suggests

they are not the same populations.

In recent years, a number of Geoffroy's bats in Dutch marl quarries have been found to carry bands from the part of Germany bordering Limburg (near Roermond), indicating that a proportion of the animals hibernating in the Netherlands originate from that area. However, monitoring data from colonies on the German side of the border area with the Netherlands is not available.

Greater mouse-eared bat

In the period 1940-1979, the trend of the greater mouse-eared bat (the third species of Natura 2000 bats) was continuously and sharply downwards (see figure 5a). The low point of the trend was between 1975 and 1979, when only about ten greater mouse-eared bats

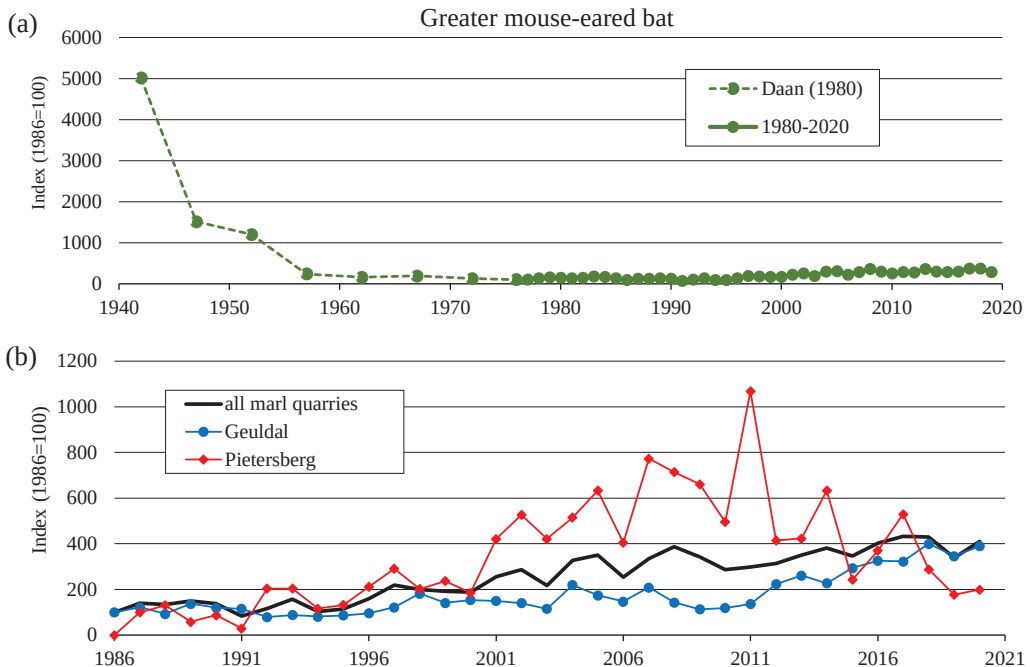


Figure 5. Trend of hibernating greater mouse-eared bats in marl quarries: a. the trend in the period 1940/45 – 1975/79 compared with the trend in 1980–2020 (indexed to the year 1979=100); b. the trend in the period 1986–2020 for all the quarries together (black line) compared with the trends for two Natura 2000 areas (indexed to the year 1986=100).

were counted annually.

Between 1986 and 2020 (figure 5b), the numbers increased fourfold, but the current numbers remain far below the level of the 1940s. Around 60 hibernating greater mouse-eared bats are counted in South Limburg these days. This is higher than in 1979, but still far below the level of the 1940s. Statistics Netherlands (CBS) classifies the trend since 1986 as a 'moderate increase'.

There has been a moderate increase in hibernating greater mouse-eared bats in Sint Pietersberg and Jekerdal and Geuldal (figure 5b). Only a single specimen has been recorded in Bemelerberg, so this area is not included in the graph. In Sint Pietersberg and Jekerdal, numbers have fluctuated quite dramatically between 2001 and 2018 and have since stabilised around their level in the mid 1990s. In Geuldal the numbers have slowly risen since

2012. In both Natura 2000 areas the change is classified as a 'moderate increase'.

It is worth mentioning that a new maternity colony was found in Geuldal in 2018, with in 2019 around 90 greater mouse-eared bats (adults and juveniles together). The discovery of a new maternity colony in the Netherlands was to be expected, but so far this has not been reflected in an increase in the numbers of hibernating greater mouse-eared bats.

Whiskered bat

With a few exceptions, no distinction is made in the monitoring of the (common) whiskered bat (*Myotis mystacinus*) and Brandt's bat (*M. brandtii*). Whilst handling each individual bat can provide a better determination, this has an undesirable disruptive effect, which

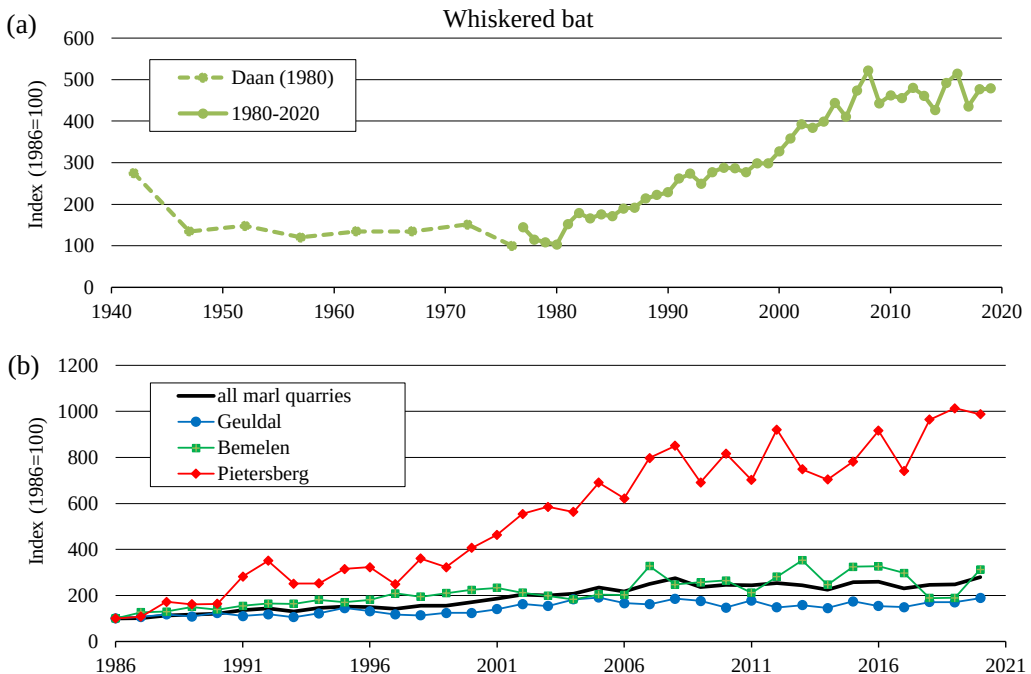


Figure 6. Trend of hibernating Whiskered bats in marl quarries: a. the trend in the period 1940/45 – 1975/79 compared with the trend in 1980–2020 (indexed to the year 1979=100); b. the trend in the period 1986–2020 for all the quarries together (black line) compared with the trends for three Natura 2000 areas (indexed to the year 1986=100).

should always be minimised. As in other articles in this special issue we evaluate the complex 'whiskered bat'.

The trend of whiskered bats declined dramatically between 1940 and 1945 and thereafter remained low. (Daan 1980; figure 6a), bottoming out between 1975 and 1980 when around 100 animals were counted. Since 1980, the numbers have recovered to well above the previous level (figure 6b). Since about 2005, a more stable situation has been reached: the numbers fluctuate, but have not increased much. Statistics Netherlands (CBS) classifies the trend since 1986 as a 'moderate increase'. Around 1400 whiskered bats have been found in marl quarries in the most recent counts.

The development of the whiskered bat in the three Natura 2000 areas (figure 6b) follows broadly the same pattern until about 1996: In two of the three Natura 2000 areas

there has been a 'moderate increase'. However, it is striking that the numbers in the Sint Pietersberg have consistently grown much faster ('strong increase') than elsewhere, although there is no known explanation for this.

Daubenton's bat

The trend for Daubenton's bat in the initial period of monitoring (1945-1950) was downward (figure 7a), but from then onwards the numbers have risen almost constantly (Daan 1980). In the late 1970s, about 400 were counted. And, with some fluctuations, this upward trend continued until around 1990 when the population started to decline. Around 1100 Daubenton's bats have been found in the most recent censuses of the marl quarries.

The graph for the period 1986-2020 also

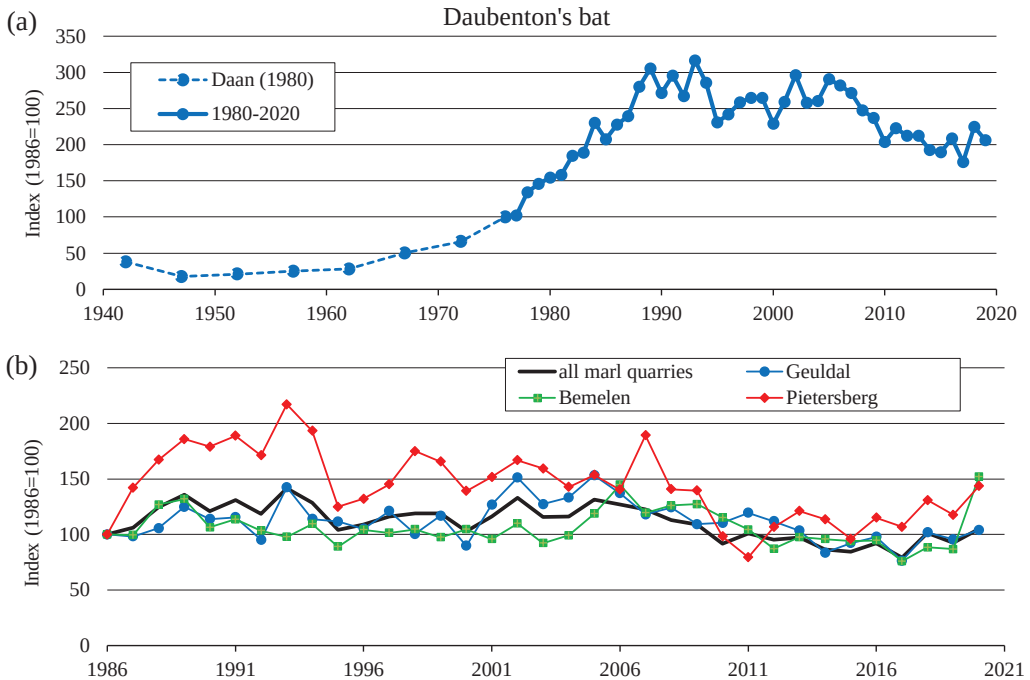


Figure 7. Trend of hibernating Daubenton's bats in marl quarries: a. the trend in the period 1940/45 – 1975/79 compared with the trend in 1980–2020 (indexed to the year 1979=100); b. the trend in the period 1986–2020 for all the quarries together (black line) compared with the trends for three Natura 2000 areas (indexed to the year 1986=100).

shows that the trend stabilized after 1990 and even declined slightly after 2005 (figure 7b). Statistics Netherlands (CBS) classifies the trend since 1986 as 'moderate decline'.

The development of the level of Daubenton's bats in the three Natura 2000 areas follows more or less the same, downward trend, although the trends in Bemelen & Schiepersberg and in Geuldal are qualified as 'stable'.

Natterer's bat

The trend in the period before 1945-1979 (figure 8a) was one of continuous and strong decline (Daan 1980). The low point in the trend was between 1975 and 1985, when about 10-20 specimens were counted. Thereafter, Natterer's bat has recovered well around 2400 Natterer's bats have been found in marl quarries in the most recent censuses.

ries in the most recent censuses.

Since 1986, the numbers of Natterer's bats have been growing continuously (figure 8b); Statistics Netherlands classifies the trend as a 'strong increase'. The figures for 2020 are far higher than those of 1986.

The trend of Natterer's bat in three of the three Natura 2000 areas is more or less the same. However, Sint Pietersberg stands out as having the most positive trend.

Brown long-eared bat

This species saw a steep decline between 1945 and 1950 and numbers continued to decline, more slowly, until the end of the 1970s (Daan 1980, figure 9a). The low point of the trend was around 1970-1980 when around 10-20 specimens were counted. After that, the numbers

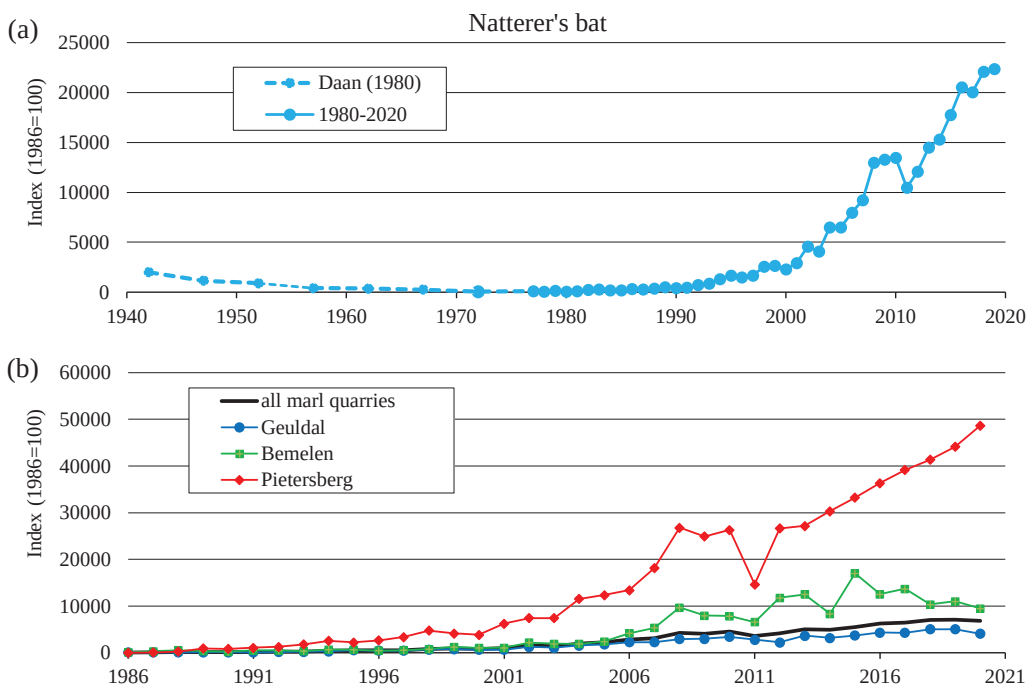


Figure 8. Trend of hibernating Natterer's bats in marl quarries: a. the trend in the period 1940/45 – 1975/79 compared with the trend in 1980–2020 (indexed to the year 1979=100); b. the trend in the period 1986–2020 for all the quarries together (black line) compared with the trends for three Natura 2000 areas (indexed to the year 1986=100).

started to grow again, although quite moderately. Today around 70-100 brown long-eared bats are found in marl quarries.

Since 1986, the numbers of brown long-eared bats have doubled compared to the 1986 reference point (figure 9b). Statistics Netherlands classifies the trend since 1986 as a 'moderate increase'. The final result of 2019-2020 is well below the level of the 1940s, but slightly above the level of the 1986 low.

The populations in the three Natura 2000 more or less follows the same patten although numbers have risen more strongly in Bemelen in the past five years.

Other species

A number of other bat species occur so rarely in quarries that no statements can be made

about their population trends.

The lesser horseshoe bat (*Rhinolophus hipposideros*) was a common hibernator in marl quarries until the 1950s. After that, the species declined sharply and only a few occasional hibernators remained (Daan 1980, Ramakers 2016). The fear was that the population had fallen below a critical minimum level. This fear has proved justified: no individuals have been found in marl quarries in southern Limburg since 1984. However, the northern limit of the species' range, in the Ardennes, is quite close, from where it may be possible for it to resettle in the Netherlands.

The greater horseshoe bat (*Rhinolophus ferrumequinum*) was a rare hibernator in marl quarries in the past. Before 1960, fewer than five specimens were hibernating in marl quarries in southern Limburg. The last time a specimen was seen in Sint Pietersberg was in 1984

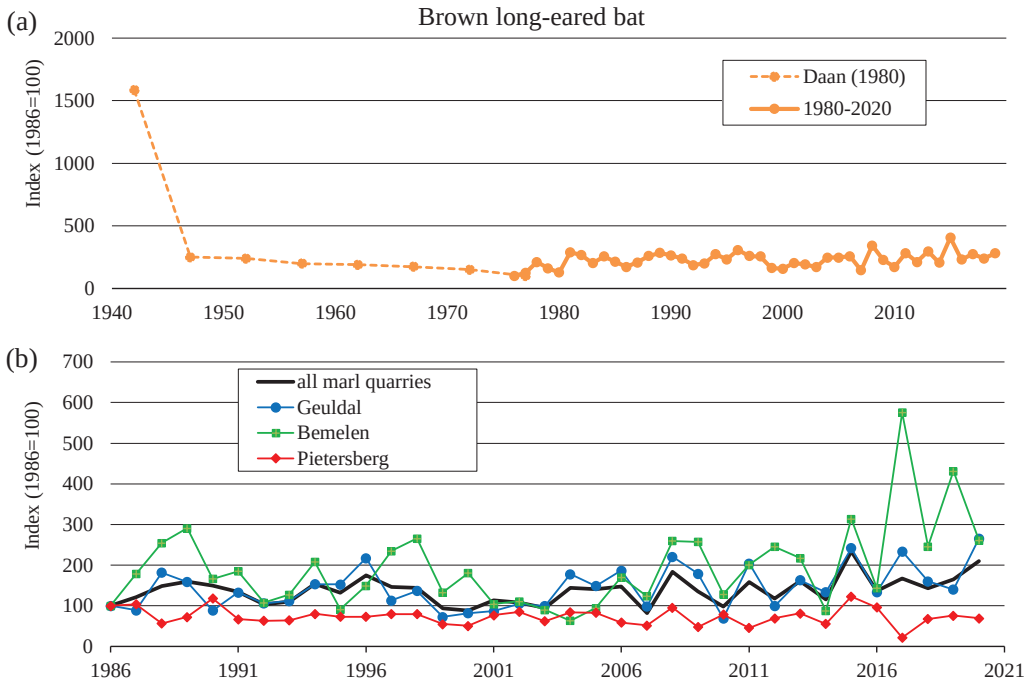


Figure 9. Trend of hibernating brown long-eared bats in marl quarries: a. the trend in the period 1940/45 – 1975/79 compared with the trend in 1980–2020 (indexed to the year 1979=100); b. the trend in the period 1986–2020 for all the quarries together (black line) compared with the trends for three Natura 2000 areas (indexed to the year 1986=100).

(Thissen & van der Coelen 2016). No specimens have found in marl quarries in southern Limburg since then, although a few individuals (< 5) have recently (in 2021 and 2022), been found in a marl quarry just across the border. in Wallonia. Perhaps in the future animals will be found hibernating in the Netherlands again.

Bechstein's bat was occasionally found in quarries between 1940 and 1979 (Daan 1980). In the period 1986-2020, the species has occasionally been found in marl quarries west of the Meuse. Between 1 to 12 specimens are counted annually in the Sint Pietersberg Natura 2000 area. In Geuldal and Bemelen, a single specimen is counted irregularly. There have been reports of maternity colonies in trees in Geuldal and in Savelsbos since 2010 and mist net catches in the autumn show that the species regularly swarms in front of quarry entrances. This suggests that the spe-

cies hibernates more in marl quarries than appears from the figures. The species is known for its secretive behaviour and may therefore be more difficult to find during counts.

There have been no records of barbastelle (*Barbastella barbastellus*) in marl quarries in the period 1980-2020, although between 1940 and 1979 it was occasionally recorded.

The common pipistrelle (*Pipistrellus pipistrellus*) is occasionally found in the censuses, usually in relatively cold hibernating places, especially at the entrances of quarries or even outside them. They are almost always found hidden away in crevices, often using the same crevices as from year to year. Marl quarries are not an important habitat for this species which more often hibernates in buildings. In 2020, around 100 pipistrelles were counted in marl quarries in southern Limburg.

Serotines (*Eptesicus serotinus*) are occasion-

ally found in marl quarries, usually in relatively cold hibernating places, especially at the entrances of quarries or even on the outside. Around 2020, about 15-20 were counted annually. The species rarely hibernates in quarries, but also prefers buildings.

The grey long-eared bat (*Plecotus austriacus*) was found a few times in marl quarries in southern Limburg in the period 1986-2020, but in very limited numbers (1-4 specimens annually). Most of the observations are from Kasteelgroeve (in the Sint Pietersberg Natura 2000 area).

Discussion

In general the pronounced decline in the period 1940-1979 of nearly all species of bats hibernating in Dutch marl quarries came to a halt around 1980. Since then, there has been an upward trend for almost all species, although to different extents.

The populations of Geoffroy's bat and of Natterer's bat have grown and are now much higher than ever recorded: and the trend continues upwards. As yet the reasons for this are unknown. The pond bat and the whiskered bat have also recovered and now exceed their 1940 levels.

The greater mouse-eared bat and the brown long-eared bat have recovered, but their numbers are still below the levels recorded around 1940. The relatively modest recovery of the brown long-eared bat is probably an underestimate of its true population, as with a warmer climate, there is probably less need for it to use quarries as hibernating quarters (see also: Bekker 2022, van Zuylen & Groenendijk 2022, both in this issue). The Netherlands is at the northern edge of distribution range of the greater mouse-eared bat, and this may explain why the population is recovering less quickly. The lesser horseshoe bat has completely disappeared, although its numbers were minimal as early as the end of the 1970s

The trend for Daubenton's bat is in stark

contrast to the other bat species and has been in decline since 2000. Prior to 1980, the hibernating population of this species was increasing, in contrast to the trend among all other species, which was negative.

It is striking that the populations of pond and Geoffroy's bats hibernating in marl quarries do not correspond to those their known summer quarters. The number of pond bats in summer quarters has been declining in recent years (Haarsma & Janssen 2022) while, for Geoffroy's bat, it has stabilized at a high level (Janssen et al. 2014, Dekker et al. 2021). If both series of observations were a measure of the same source population of those species, then the trends in summer and winter should be similar. The existence of a trend difference can only be explained by the summer and winter series of observations consisting of different subpopulations, although actually we know very little about where most bat species go outside the winter period in the quarries.

The similarity of the broad line of trends since 1940 and the change in the trend around 1980 for several species of bats coincides with the emergence and subsequent decline of the use of all kinds of persistent insecticides in the outdoor environment and especially in agriculture and horticulture (DDT, endrin, dieldrin, aldrin, etc) and in the use of wood preservatives in, for example, restorations. There were progressive restrictions on the use of these substances between 1973 and 1990. The effect of these substances on, in the first instance, insects worked up through the food pyramid to insectivorous animals, including bats.

On the other hand, there has been a negative impact on the populations (Daan 1980) due to, among other things: the methods used in bat research in the 1940s and 1950s, the expansion of mushroom farms in marl quarries and their increased recreational use.

The current predominantly positive trend of most bat species is remarkable because when it comes to nature and biodiversity, the general tendency is that it is declining. Strangely enough the decline in insect populations

seems to have little or no effect on population development of hibernating bats in quarries. We conclude that despite the positive trends and the assumed representativeness of the counts, we do not know enough about what bats do, or where they go, outside the winter period (and more specifically: outside the period that the census is carried out: roughly between Christmas and mid-February) in their summer colonies and foraging areas.

Policy attention for hibernating bats in marl quarries has increased. In the four Dutch Natura 2000 areas with marl quarries with an objective for protecting hibernating bats, more work can be done to enhance their attractiveness as hibernacula. For example, it is known that reducing disturbance and erecting fences have a positive effect on numbers (if done properly). Monitoring needs to be continued: the current method has proven to be a representative indicator of the development of numbers of hibernating bats, and as long as it can be carried out by volunteers, it has a wide range and is relatively cheap. Where monitoring can no longer be carried out *in situ* for safety reasons, methods of counting with automated recordings of bats flying in and out of quarries (Lefevre et al. 2022, in this issue, Weinreich 2022) and mist net catches at quarry entrances (van Schaik et al. 2015).

Finally, a considerable number of quarries are counted in three of South Limburg's four Natura 2000 areas. This is large part due to the many tens of volunteers who have been working for many years to organise and carry out the censuses, without whom we would not have such a bountiful store of knowledge.

Acknowledgements: Above all, we would like to thank the many people who contributed every year to the collection of the data. Counting bats is often a hobby, but it provides a nice overview of the developments. We also thank the quarry owners who have enthusiastically contributed to the annual counts over the years. Thanks also to the Dutch Mammal Society and Statistics Netherlands (CBS), who are responsible for collecting and processing the data. We are also very

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The Henisdael quarries, Vechmaal, Flanders. *Photos: Benny Odeur.*

Hibernating bats in Flemish marlland: an overview of the period 1989-2020

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Abstract: Twenty six different marl quarries in Flanders are checked annually for hibernating bats, 18 in the Meuse basin and eight in the Scheldt basin. Most of the quarries were created in the second half of the 16th Century through the extraction of marl as a building material and as a raw material for fertilizing agricultural lands. After the Second World War, mushrooms were grown in both large and small tunnel systems. In 1958, virtually all underground mushroom cultivation ceased. This article provides an overview of the bat counts by the Nature Point Bat Working Group, carried out since 1989, between the last week of December and the end of February. Over the years, a few more quarries have been included bringing the total up to 26 sites, which are counted completely every year. The numbers for 2015 are not included in the data because the count in the Lacroix quarry, the largest of the quarries, which accounts for a substantial proportion of the total bats counted did not take place in that year. In 1989 the two species of whiskered bats, *Myotis mystacinus* and *M. brandtii* (no distinction is made between the two in the counts) were the second most counted species with 158 individuals counted. By 2020 this number had risen to 1,622, making the whiskered bat the most commonly observed bat in the Flemish marl quarries. In 1989, Daubenton's bat (*M. daubentonii*) was the most commonly observed species with 269 individuals. The numbers continued to rise until 2002 to a peak of 949 animals with a low of 340 animals observed in 2013. Initially, Natterer's bat (*M. nattereri*) was still a rarity, but by 2020 there were 1191 hibernating animals. Geoffroy's bat (*M. emarginatus*) is the species that has increased the most. Since 1989, their numbers have increased exponentially. The number of pond bats (*M. dasycneme*) initially increased moderately, to 154 in 2013 and there are now about 100 animals every year. The numbers of brown long-eared bats vary between 30 and 55 animals, which is barely 1% of the total number of bats counted in the Flemish marl quarries. Similarly, Bechstein's bat (*M. bechsteinii*) was a very rare sight during the counts; in 2015-2016 the number increased to 16 animals. Greater mouse-eared bat (*M. myotis*), and common pipistrelle (*Pipistrellus pipistrellus*) were seldom seen, while a serotine (*Eptesicus serotinus*) is very exceptionally observed in the marl quarries. The proportion of 'unidentified bats' was significant in 1989, but has declined steadily thereafter. The Lacroix, Verbiestberg and De Keel quarries have the most bats. The strong increase of counted hibernating bats is possibly due to an increase in the population as a result of efforts made to close the quarries. Better illumination, increased capacity to identify the bats and better knowledge of the cave systems have also all played a role in more hibernating bats being counted and identified.

Keywords: whiskered bats (*Myotis mystacinus*, *M. brandtii*), Daubenton's bat (*M. daubentonii*), Natterer's bat (*M. nattereri*), Geoffroy's bat (*M. emarginatus*), brown long-eared bat (*Plecotus auritus*), pond bat (*M. dasycneme*), Bechstein's bat (*M. bechsteinii*), greater mouse-eared bat (*M. myotis*), Flemish marlland.

Introduction

Twenty six different marl (limestone) quarries

in Flanders, are checked annually for hibernating bats. In the Meuse basin there are 18 quarries connected to the large complex of marl that is linked to the Walloon and Dutch tunnel systems. These quarries are all situated in the municipality of Riemst. In the Scheldt

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basin, the Henisdael quarries are located in Vechmaal, in the Heers sub-municipality (figure 1). The eight systems lie in a semicircular valley basin, which allows migration between the quarries due to the small distance between the different entrances.

Most of the quarries were created in the second half of the 16th Century by the extraction of marl, initially extracted as a building material and as a raw material for fertilizing agricultural lands and later as a raw material for cement production (Walschot 2010). After the Second World War, mushrooms were grown in both large and small tunnel systems. After the serious collapse of the Roosburg quarry in 1958, almost all underground mushroom cultivation stopped because of the risk of collapse (Medaerts 1998), although the cultivation continued in a few quarries until the beginning of 2000 and continues to this day in the Avergat quarry in Kanne.

A total overview of the bat counts is available from 1989. Before then only a few of the quarries were counted (Fairon & Lefevre 1991). Over the years, a few more quarries were added, and since 2007, 26 quarries are fully counted every year. The counts are carried out by the Natuurpunt Bat Working Group, starting from the last week of December and ending at the end of February. More than 50 volunteers annually map the hibernating bats. Each animal is noted on a detailed map. The data is managed by the Natuurpunt Bat Working Group and published in annual reports (Palmans, various years). From 2021, INBO (the Institute for Nature and Forest Research) has taken over managing the data in collaboration with Natuurpunt (Natuur. Studie) to make them available to European monitoring networks.

Species

The four most commonly observed species during the censuses from 1989 to 2020 are the whiskered bat, Daubenton's bat, Natterer's bat and Geoffroy's bat. The proportion of 'other'

(pond bat, brown long-eared bat, Bechstein's bat, greater mouse-eared bat and common pipistrelle) and 'unidentified bats' was significant in 1989, but the number of 'unidentified bats' has steadily decreased over the years, largely due to better identification (see figures 2 and 4j).

Over the years, more quarries have been included in the count (figure 3a, b and c) also contributing to the increase in bats counted: the development in numbers therefore does not reflect the real increase in population. The relevance of the different quarries for all bats over the different time periods is illustrated in figures 3a, b and c., which give these totals for the periods 1989-2020, 2001-2020 and 2011-2020 respectively, showing the relative importance of each quarry in terms of the total number of bats counted. This was done by comparing the quotient of the total number of bats and the number of years to the number of years counted.

The individual species are discussed separately below. Figures 4a to 4j show the counted numbers for these species, although they are not strictly comparable year-on-year values. Data from 2015 are not included in any of these analyses as the count in the Lacroix quarry (with an average share of 30% of total bat numbers) did not take place then. The loss of some counts in other quarries in some years is of a much lesser influence.

Three species are counted each year that are listed in Appendix 2 of the Habitats Directive: Geoffroy's bat, pond bat and Bechstein's bat.

Whiskered bats (*Myotis mystacinus/brandtii*)

During the winter counts, no distinction is made between the two species of whiskered bats, *Myotis mystacinus* and *M. brandtii*, as the two are difficult to distinguish without handling. Only in case of a 100% certain determination, are they distinguished – overall the two species are listed under one denominator.

In 1989 this species was the second most

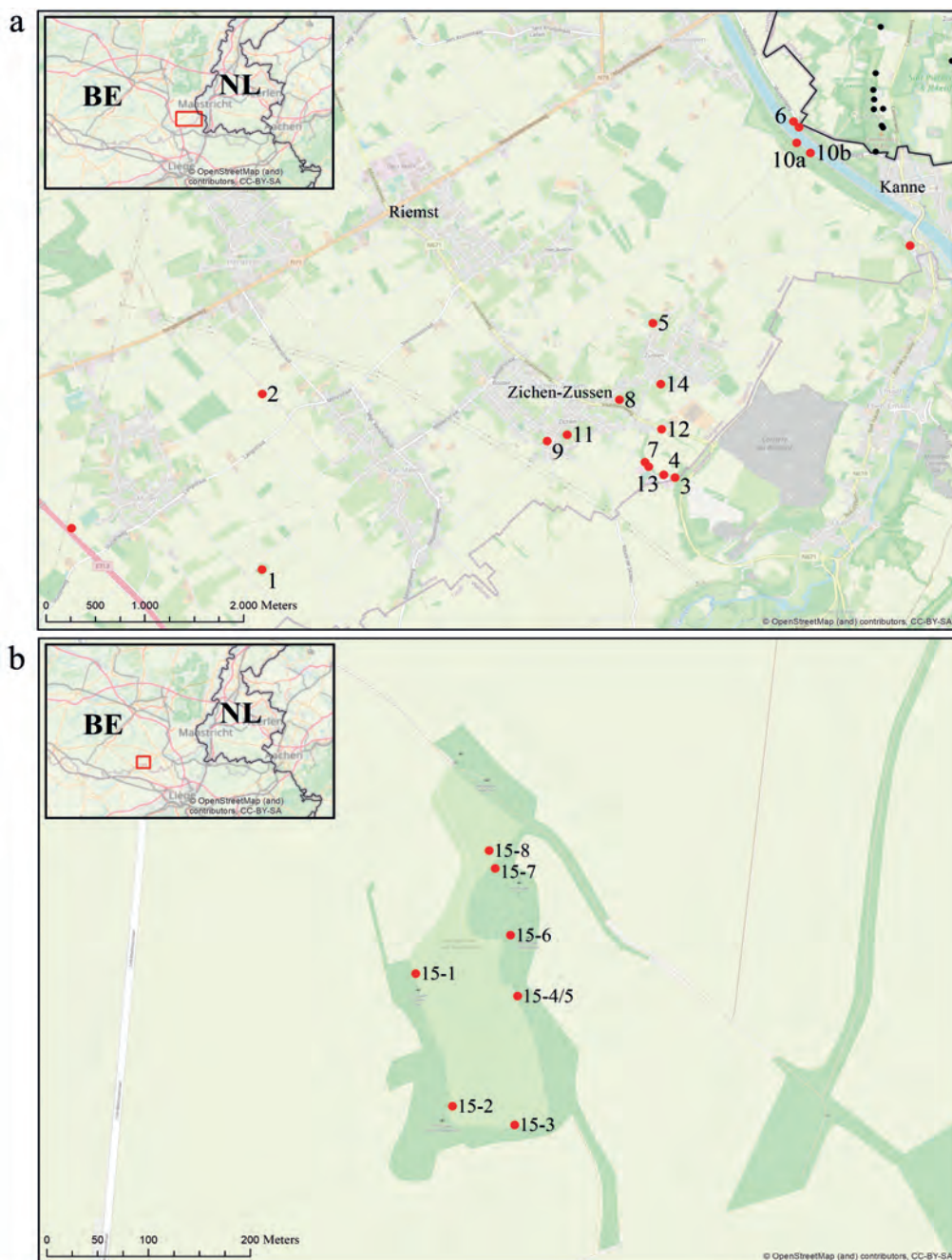


Figure 1. Location of (a) the marl quarries in the Meuse basin and (b) the Henisdael quarries in the Scheldt basin. 1: Coolen; 2: Collas; 3: Drie Dagen; 4: Flessenberg; 5: Juge; 6: De Keel; 7: Koegat; 8: Lacroix; 9: Lindestraat; 10a: Mathuus; 10b: Opcanne IV; 11: Pitjesberg; 12: Verbiestberg; 13: Jagenau's Huiske; 14: Pauly; 15-1: Henisdael 1; 15-2: Henisdael 2 - Champignonkuil; 15-3: Henisdael 3 - Walenkuil; 15-4/5: Henisdael 4 en 5; 15-6: Henisdael 6 - Hussenkuil; 15-7: Henisdael 7 - Waterkuil; 15-8: Henisdael 8; BE: Belgium; NL: the Netherlands.

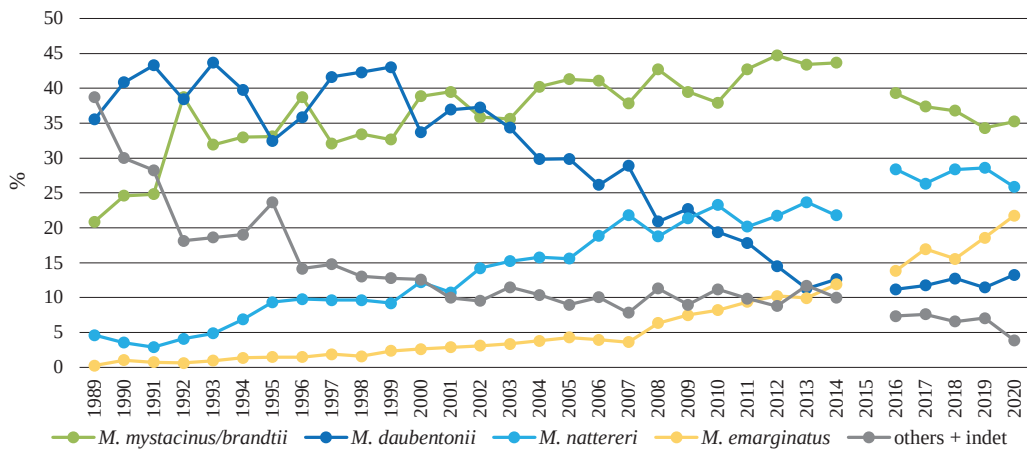


Figure 2. Percentage distribution of the counted numbers of the four most common bat species and the other and unidentified species in the period 1989-2020.

prevalent species. With 158 animals in 1989, the number continued to increase to 1622 in 2020. This makes the whiskered bat the most commonly observed bat in the Flemish marl quarries. The increase is steady, although in some years a temporary, slight, decline can be observed, despite an increase in the number of quarries counted (figure 4a).

Daubenton's bat (*M. daubentonii*)

In 1989 this was the most commonly observed species with 269 animals. The number continued to increase until 2002 to a peak of 949 animals, but from then on the number has steadily decreased. Daubenton's bat was the most counted species until 2000, when it was dislodged by the whiskered bat. In 2013, the species bottomed out with only 340 animals observed. A slight recovery is currently visible and more than 600 animals were counted in the most recent survey (figure 4b). Despite the recovery, it now ranks fourth in percentage in terms of the number of bats observed.

Natterer's bat (*M. nattereri*)

At the end of the 1980s, Natterer's bat was still

a rarity in the Flemish marl quarries. However, this species has a strong preference for hidden niches and crevices in the walls and ceilings and it is likely that, due to poor quality lighting, animals hiding deeper in crevices may have been overlooked.

With today's stronger LED lamps and higher-quality binoculars, it is possible to look much deeper into crevices. Yet these technological improvements probably explain only part of the spectacular increase of this species. With 1191 hibernating animals in 2019-2020, Natterer's bat is firmly in second place in terms of the number of animals observed. The increase is very constant and almost predictable (figure 4c).

Geoffroy's bat (*M. emarginatus*)

Geoffroy's bat has increased more than any other species. In 1989-1990 it was a rarity. Up to 1994, the counters used to gather under individuals after the counting session to admire them with their binoculars. The species was first observed in the Lacroix quarry where two animals were hanging in section 30. Since then, the number of animals in this quarry has increased to 561.

With 1002 animals observed in 2020, Geof-

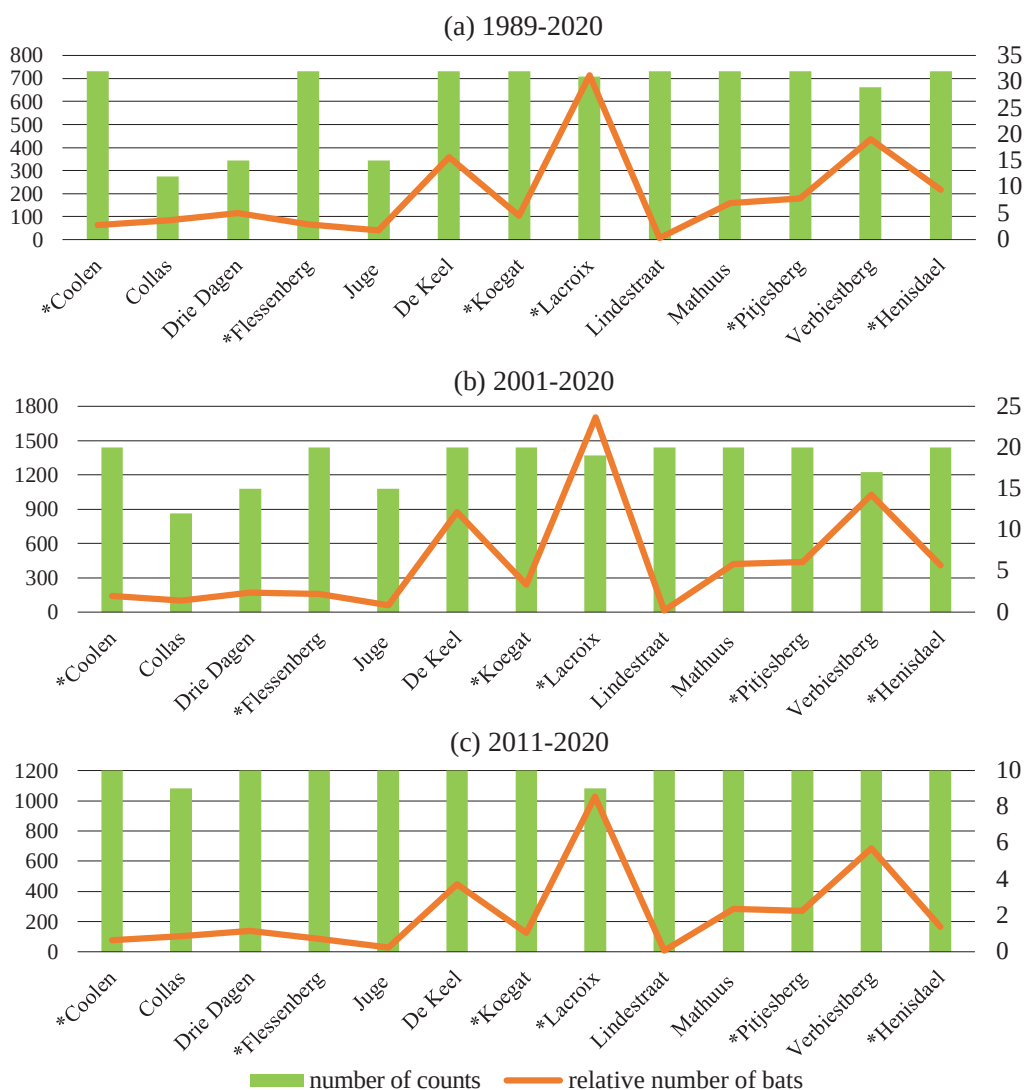


Figure 3. The relative contribution of each quarry to the total of bats counted. Left y-axis: average number of bats per year; right y-axis: number of counts in the periods 1989-2020 (a), 2001-2020 (b) and 2011-2020 (c).

* quarries in which bat counts were made before 1989

froy's bat ranks third in terms of number of hibernators. The increase in the number of animals is spectacular, as well as its appearance in quarries where it did not initially occur (or was not spotted). The species clearly has a preference for larger complexes; where the increase in its numbers is exponential (figure 4d).

Pond bat (*M. dasycneme*)

The number of hibernating pond bats varies greatly. Just over 20 animals were found at the beginning of the counts. The number increased moderately every year, until 154 animals were counted in 2013. Since then, the number has decreased again and about 100

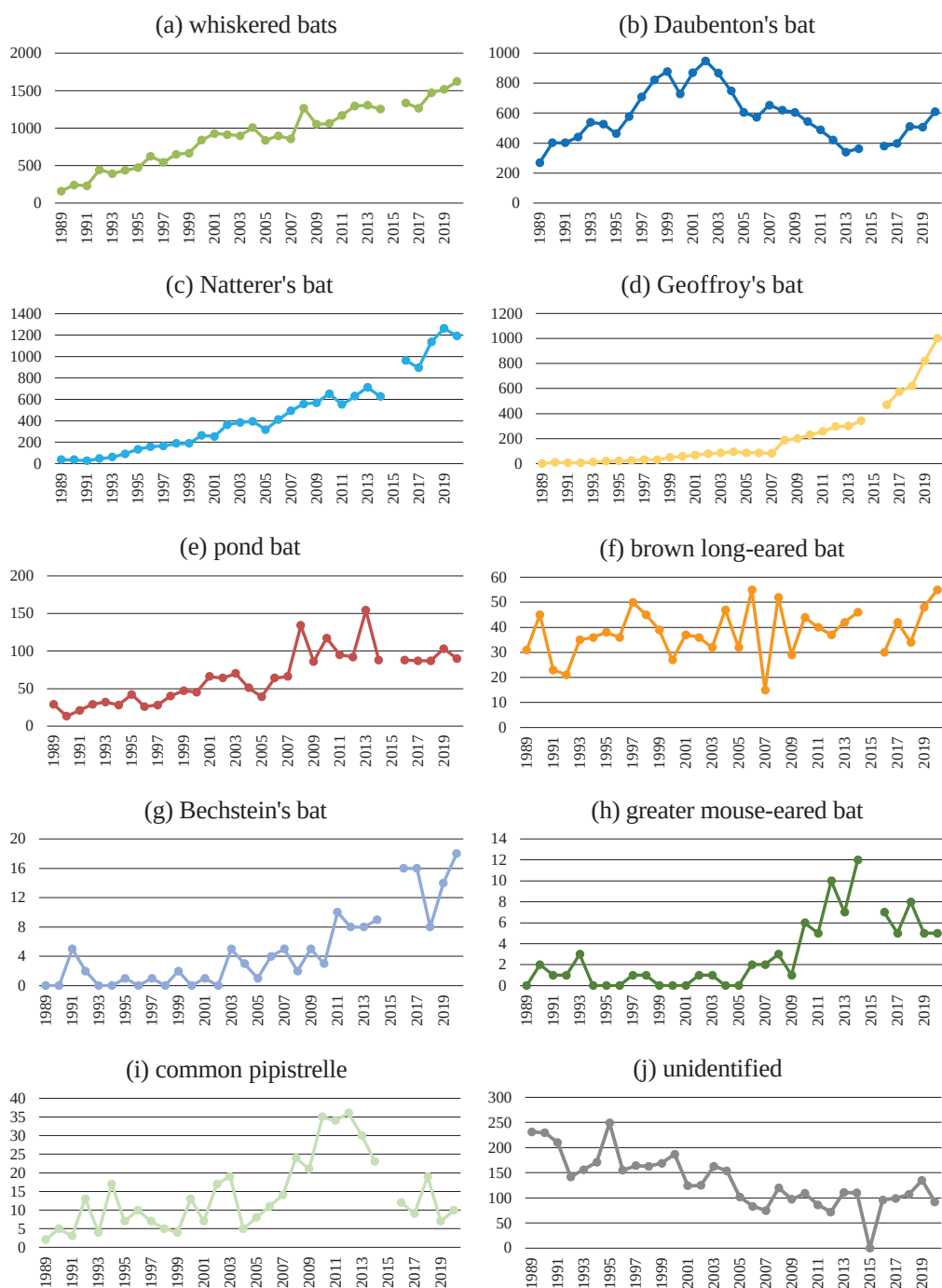


Figure 4. Development of the number of bats per species in Flemish marl quarries in the period 1989-2020.

animals are now found annually (figure 4e).

Brown long-eared bat (*Plecotus auritus*)

More brown long-eared bats are found during cold winters than during milder winters. Over the study period, the numbers varied between 30 and 55 animals (figure 4f). This is barely 1% of the total number of bats found in the Flemish marl quarries.

Bechstein's bat (*M. bechsteini*)

In the late 1980s, Bechstein's bat was a very rare sight during the censuses. The numbers initially remained very low, with a maximum of five animals, until in 2015-2016 the number suddenly increased to 16 animals. Since then, the number has remained this high (figure 4g). There is now a good chance of encountering Bechstein's bat in the large quarries such as Lacroix, De Keel and Verbiest. A few animals are also observed every year in the quarries of Vechmaal.

Greater mouse-eared bat (*M. myotis*)

This species is mostly encountered in De Keel quarry and rarely in any other quarry. It is relatively rare: in 2014 just ten animals were counted (figure 4h). Like pond bats, the animals are creatures of habit and seem to be conservative in choosing the same hanging spot almost every year to hibernate.

Common pipistrelle (*Pipistrellus pipistrellus*)

The number of common pipistrelles found is very variable. In some years only a few animals are found, in other years it is difficult to count the number of animals exactly because a cluster of several animals has retreated into

a very narrow gap. The highest number of common pipistrelles counted was 36 animals in 2012. Normally, the number fluctuates around ten animals (figure 4i).

Serotine (*Eptesicus serotinus*)

Very occasionally a serotine is observed in the marl quarries.

Unidentified bats

Sometimes bats hang in places that make it impossible to identify them at species level. In the first years, the share of unidentified specimens was well above 20% of the total. Due to the use of better light and a more thorough knowledge of the counters, this figure has decreased every year. Currently, approximately just 2% of the hibernating animals cannot be identified (figure 4j).

The relative importance of the quarries

The duration of the research into hibernating bats in quarries in the Flemish marl land varies between the individual quarries. The first census took place in Henisdael quarry in 1942, some quarries were first counted in the 1970s, and many other quarries started to be counted in 1989. In a small number of quarries the counts started in 2006 and 2007 and in the last quarry, Pauly (see figure 1), in 2020. The causes of these differences are various and are explained in more detail in the quarry section (below). The quarries in which bat counts were made before 1989 are marked with an asterisk (*) in figures 3 and 5-18. The relevance of the different quarries for all bats over the different time periods, is illustrated with three figures (3a, b and c). These three figures, for the periods 1989-2020, 2001-2020 and 2011-2020 respectively, give the number of years counted

and the relative importance of each quarry for the total number of bats counted. This was done by comparing the quotient of the total number of bats and the number of years to that number of years counted.

The quarries with the largest bat populations in this area are Lacroix, Verbiestberg and De Keel (figure 3). Missing data in 2015 for Lacroix and from 2005-2007 for Verbiestberg can be recognized in figures 4a-e (and also in figure 19) as marked dips.

Overview of the quarries

Coolen, Val-Meer

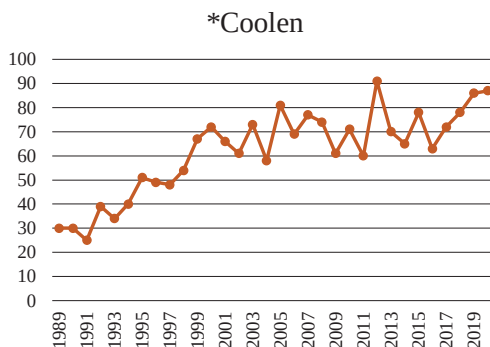
This small quarry (area 2 ha) is completely enclosed in a land consolidation. The quarry lies like an island in vast fields with almost no linear or natural connections and some remains of lynchets (small terraces on a hillside, their steep often covered with shrubs) in the fields. The quarry is located less than 2 km from the village of Val-Meer. Some species that follow linear landscape elements still find their way to this quarry, probably using a concrete allotment road with a few trees and the remains of the lynchets.

Fewer than 100 bats hibernate in the tunnel system each year (figure 5). Yet almost all the species that are also found in the larger complexes can be found here. With seven different species, this is a species-rich quarry.

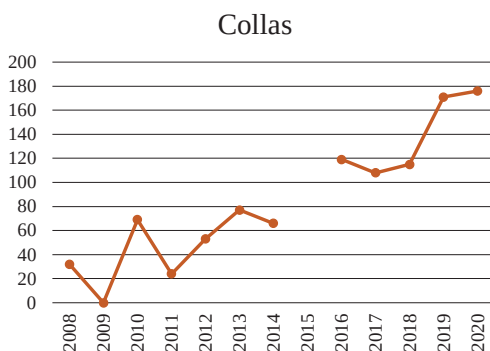
Collas, Zussen

In 2009, the Flemish Community (ANB – Agency for Nature and Forests) bought the land around the Lacroix and Collas Quarries (Lacroixbosjes) thus acquiring the access to the quarry. This marked the definitive end of mushroom cultivation in the quarry by the Peeters family.

Collas is connected to the Lacroix quarry by a tunnel, allowing for underground migra-



Figuur 5. Development of the total number of bats found in the Coolen quarry, Val-Meer.



Figuur 6. Development of the total number of bats found in the Collas quarry, Zussen.

tion between these two systems. Before 2009, incidental bats were observed in the corridors of Collas, but there was no structured counting. In 2016, the main entrance to the quarry was closed – after the mushroom cultivation ended in 2011 – to prevent illegal cavers from accessing the underlying tunnel system. That was the start of a complete absence for the hibernating animals in both Collas and Lacroix. The numbers of bats increased gradually, with over 170 individuals in 2020 (figure 6).

The corridor system has three levels, making the airflow very complex. Due to the vastness and because there are very few animals here, the upper and lower systems are not counted. Ancient inscriptions made by early bat counters such as ‘klhf chamber’ (kleine hoefijzerneus – lesser horseshoe bat chamber) indicate the value of the quarry

before the mushroom cultivation. It is an important quarry for the hibernation of Bechstein's bat and the pond bat. The complex has several 'pockets' – dead-end areas – where the temperature is slightly higher, which have a less dynamic airflow than the rest of the quarry.

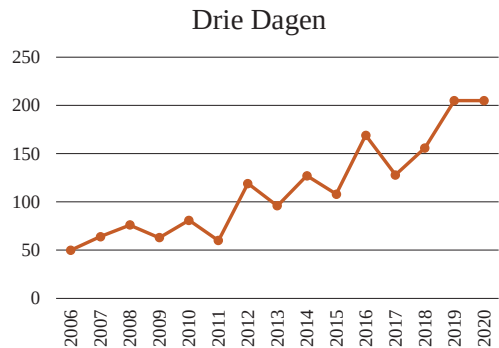
Drie Dagen, Zichen

This quarry, together with Flessenberg, Koegat, Jageneau's Huiske and Verbiestberg, forms the Roosburg complex. Collapses separated the galaxies from each other, so they are now considered separate quarries.

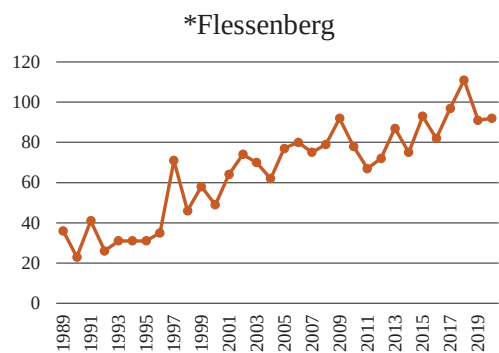
Mushrooms were cultivated in Drie Dagen until the end of the 1980s. After the cessation of cultivation, the front part of the quarry was used as a storage place for agricultural vehicles and potatoes. In 2013, a fire caused considerable damage. A thick layer of soot adhered to walls and ceilings, preventing the bats from entering the most important part of the quarry. Very few bats are found in this area, with a little over 200 counted in 2019 and 2020 (figure 7). The whiskered bat represents more than half of the hibernating animals.

Flessenberg, Zichen

This small complex, barely one hectare in size, was closed off from the Verbiest quarry after the collapse of 1958. The pillars are quite unstable and show multiple cracks. Until 2016 the quarry was used by a compost processing company (Coenjaerts) for the storage of materials. A gate was installed in 2016, to keep unauthorized persons out and provide a safe haven for the bats. From around 30 bats counted in the early 1990s, the number has steadily increased to over 90 individuals (see figure 8). Due to the presence of many fissures and cracks, Natterer's bat is the most counted species here.



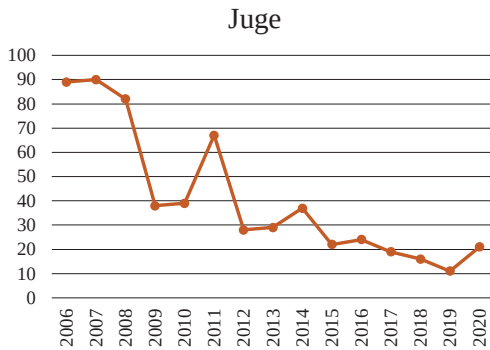
Figuur 7. Development of the total number of bats found in the Drie Dagen quarry, Zichen.



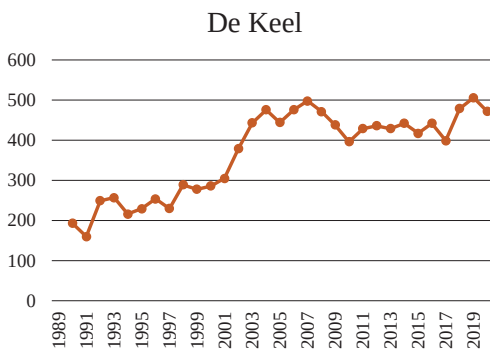
Figuur 8. Development of the total number of bats found in the Flessenberg quarry, Zichen.

Juge , Zussen

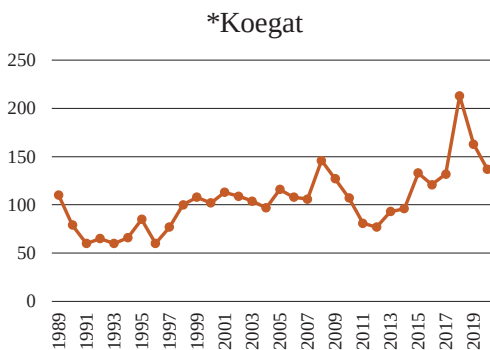
Before 2005 this small quarry was only sporadically visited by the members of the 'Hulp-groep Mergelgroeven' (Marl Quarries Relief Group) to check its stability. Reports of Bechstein's bat led the quarry to be included in the counts from 2005. With 90 animals in 2006 – four of which were Bechstein's bats – expectations were high for the future, but the total number of bats has gradually decreased (figure 9) and the numbers of Bechstein's bats steadily decreased and the species has now disappeared completely. However, the number of hibernating Geoffroy's bats increases every year. The reasons for these changes are unclear and there are no data on temperature and air dynamics.



Figuur 9. Development of the total number of bats found in the Juge quarry, Zussen.



Figuur 10. Development of the total number of bats found in the De Keel quarry, Kanne.



Figuur 11. Development of the total number of bats found in the Koegat quarry, Zichen.

De Keel, Kanne

De Keel is the third largest quarry in Flanders, covering almost 4 hectares. The corridors are quite high and due to the wide variety of mining

methods used in the past, the range of niches, slots, crevices and cavities is very varied. This makes counting in this complex a challenge, as the ability of counters to determine species is critical. Each counting group takes care of at least one section every year, passing its knowledge on to the newcomers.

In 2006 the main entrance to the quarry, more than seven metres high was completely gated off in order to inhibit frequent disturbances from mountain and cross-country cyclists and illegal parties. The gate allows access to counters and a flow of air throughout the complex (Walschot 2010). Since then, the total numbers of bats has consistently exceeded 400 individuals, with peaks of up to 500 (figure 10).

The quarry is important for Geoffroy's bats and Natterer's bat. A varying number of greater mouse-eared bats are counted every year. The pond bat has been in decline in recent years.

Koegat , Zichen

This system has four different sections, each of which has a completely different microclimate. The entrance to Koegat was closed off in 2017, for unwanted visitors, with holes at the top of the closing wall in order to maintain the air dynamics. While this intervention has protected this hibernaculum the number of bats has fallen slightly in recent years (figure 11).

Lacroix, Zussen

Lacroix was the first quarry to be fenced off. The management of the quarry was in the hands of the (then) nature association, Belgische Natuur- en Vogel-Reservaten (BNVR), which later merged with De Wielewaal and became Natuurpunt. Yet the fencing only had a partial effect: cave hikers and 'revelers' gained access to the corridors via other entrances, often disrupting the bats' winter rest. In 1986, two entrances were fitted with solid gates. Cavers could only enter the quarry

on request and this resulted in a sharp decline in cave tourism. It was still possible to enter the quarry illegally via the Collas quarry, until its permanent closure in 2016.

The Grote Berg, which is the name of the entire system, consists of more than 20 reclamations that have formed one gigantic system over the years (Jennekens 2016). Access to the entire complex can only be gained via Lacroixberg.

This, the largest system of Riemst municipality – more than 20 hectares – also contains the most hibernating bats. With almost 1500 animals, it contains more than a third of the total number of animals in all the quarries (figure 12). However, the complex, which is divided into more than 40 sections, has not been fully counted. The lower sections are not, or hardly, used by hibernating bats. The effort of counting does not justify the result here. In the 27 sections that are counted, the animals are not indicated individually on a map, because a detailed map of this system is not yet available.

No count was performed in 2015, due to a collapse in one of the underlying sections. The high number of Geoffroy's bats in this complex is striking. With 561 animals in 2020, this is almost 40% of the number of hibernators in this quarry.

Lindestraat, Zichen

A party hall has been set up in this quarry. A door without an entrance opening for bats prevents unauthorised access to the quarry. The few animals that hibernate here stay in the reception hall of the quarry. Occasionally, some animals are found in the deeper part of the quarry that enter through the only air shaft. The maximum total number of bats in any year is 14 (figure 13).

Mathuus and Opcanne IV, Kanne

Originally the Mathhuus quarry had only one

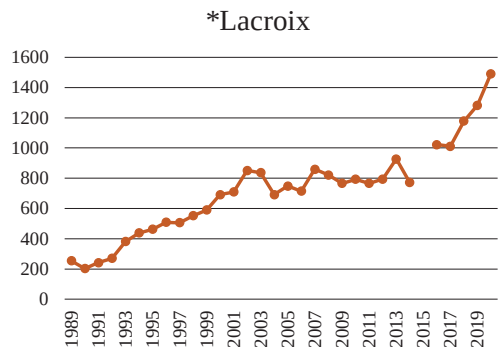


Figure 12. Development of the total number of bats found in the Lacroix quarry, Zussen.

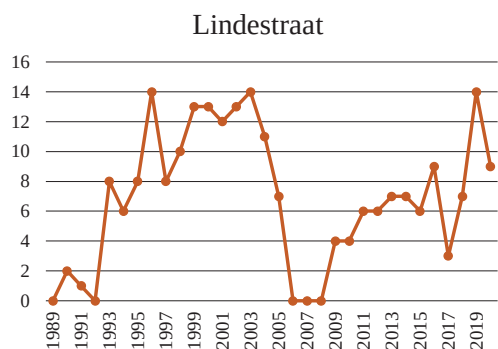


Figure 13. Development of the total number of bats found in the Lindestraat quarry, Zichen.

entrance. In the early 1960s, the widening of the Albert Canal led to a third of the Mathuus quarry being excavated and gave the quarry no fewer than 14 entrances. The air dynamics are therefore very complex (Walschot 2010). Opcanne IV was originally part of this complex, but has now become a separate system, closed to bats from Mathuus.

One of the extraction techniques used here was 'shooting' the marl. Boreholes were made in which charges of explosives were placed. A large proportion of the bats hibernate in the remnants of these boreholes and finding them is quite difficult and requires the counters to have a thorough knowledge of the site and good illumination and binoculars to correctly identify the animals.

After the closure of De Keel in 2006, the problem of disruption by party goers moved

to Mathuus. Every year dozens of bags with beer cans and tea lights were collected, and occasionally even a kitchen cabinet or portable toilet. Since 2016, there has been stricter control by the Municipality of Riemst.

Despite this, more than 300 animals reside in this system each winter (figure 14), nearly half of which are whiskered bats. Occasionally a single greater mouse-eared bat is encountered. In recent years, the number of Geoffroy's bats has increased very gradually.

Pitjesberg, Zichen

This quarry is a fusion of several small systems. A large system – De Kuil – is only accessible via a narrow passage, which was dug out after a mud wash-in. De Kuil only has one open air shaft, so the number of bats in this section is modest. The total surface of the quarry is approximately 5 ha, which makes it one of the larger quarries of Riemst. More than 400 bats have been counted in recent years (figure 15).

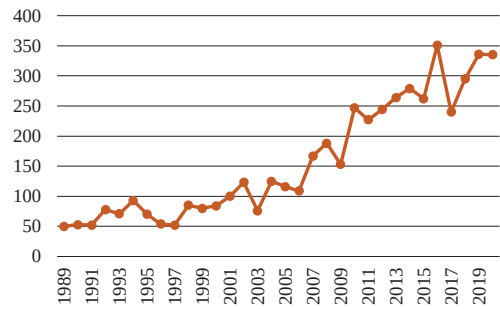
Pitjesberg has two main entrances, one of which has a gate. The other entrance consists of four holes, which makes the air dynamics complex, with low temperatures. This explains why many Natterer's bats hibernate here (almost half of the total number of bats in this complex).

Pauly, Zussen

The Pauly quarry is actually part of the De Grote Berg complex. A collapse in 1962, well before the research period, completely closed off this section from the rest of the system. The air shafts were closed for safety and to facilitate agricultural use. In 2018, one of the shafts was reopened and provided with a safe descent. The shaft is closed with a grid, so that bats can fly down between the bars.

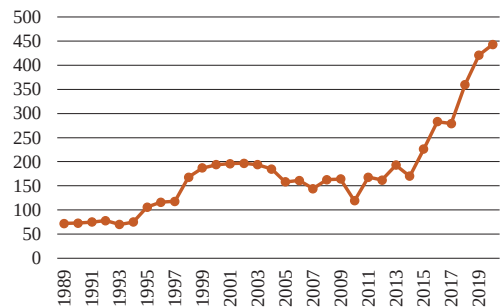
In 2020, the quarry was checked for hibernating bats for the first time. Not a single ani-

Mathuus and Opcanne IV



Figuur 14. Development of the total number of bats found in the Mathuus and Opcanne IV quarries, Kanne.

*Pitjesberg



Figuur 15. Development of the total number of bats found in the Pitjesberg quarry, Zichen.

mal was found. Nevertheless, this is a unique research object. As the quarry has been completely closed off for over 60 years, it will be interesting to see whether and how this system will be discovered by bats and whether a population will develop.

Verbiestberg, Zichen

The second largest quarry in the municipality of Riemst has only two accesses: one via a spiral staircase and the other via a tunnel that starts at ground level. The spiral staircase was made safer in 2019 by completely replacing the handrails. The door of the 'house' above the stairs has been replaced by a heavy steel gate with a small letterbox type entrance. This has not

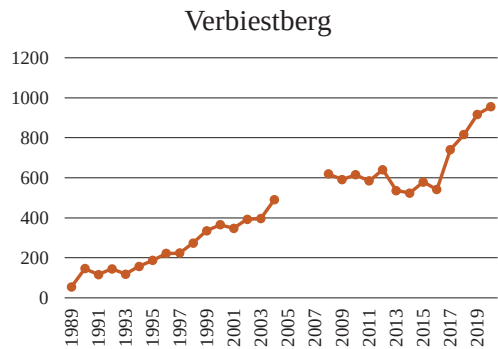
made much difference to the potential for bats to enter as the old gate also only had a narrow strip at the top. The tunnel underwent a significant change in 2012 when a fence made of reinforced steel closed off the entire large opening of the tunnel. Before that a pair of chains was the only obstacle to entering the quarry. The municipality of Riemst has made several structural changes around the entrance, installing a sewage pipe closed off by a steel gate with horizontal bars. This has drastically changed the air dynamics in the tunnel, making it more difficult for cold air to enter and reducing the size of the entrance opening for the bats. Nevertheless, this intervention has had little impact on the number of bats that hibernate in the quarry and since 2016 their number has increased significantly. Due to the large number of air shafts, the climate in the quarry is very variable, with cold and warm sections.

Mushroom cultivation continued in the quarry until the early 1980s. At the end of the 1980s, only 55 animals were found in the system, which covers more than 8 hectares. As with Grote Berg, Verbiestberg is an amalgamation of several small reclamations. Following the great collapse of 1958, Verbiestberg was closed off from the neighbouring systems Koe-gat, Flessenberg and Drie Dagen. In 2019, 955 hibernating animals were counted (figure 16).

The whiskered bat is the most commonly encountered species, accounting for almost 40% of the bats in the complex. Natterer's bat follows with 25% and the numbers of Geoffroy's bat, are rising rapidly and account 20% of the total. The number of bats as a whole has increased spectacularly from 2016; particularly whiskered bats, Natterer's bats and Geoffroy's bats. There was no counting in the quarry between 2005 and 2007, because the owner did not give permission; as a result, the totals for the years 2005, 2006 and 2007 are missing.

The quarries of Henisdael, Vechmaal

Southeast of Tongeren, there are seven



Figuur 16. Development of the total number of bats found in the Verbiestberg quarry, Zichen.

smaller and one large quarries in a cirque, the entrances of which are only a few tens of metres apart. Yet these separate systems each have their own microclimate. As bats are assumed to move easily from one system to another, figure 1 shows the overall picture of all the systems. The quarries are located in the middle of an agricultural enclave, where a hollow road without vegetation is the only accompanying landscape element.

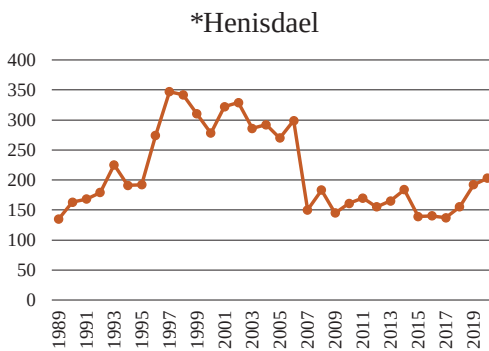
The largest system of corridors (Henisdael 1) was fenced off at the end of the 1980s. However, this construction was not resistant to vandalism, so disturbance continued for some time. In 2012, a new fence was installed that proved to be stronger. The second largest quarry (Henisdael 7 - Waterkuil) was closed in 2014 with a genuinely artistic pair of gates (figure 17). The shutdown of the other systems is in the pipeline.

All of Henisdael's complexes are relatively cold with only a limited number of rooms having higher temperatures. As a result, the majority of the hibernating animals are species preferring colder conditions in their hibernacula.

Whiskered bat accounts for half the numbers counted. The brown long-eared bat, which usually accounts for only a few percent of bats in other quarries, accounts for 10% of the hibernating population here. Geoffroy's bats were first observed here in 2012. At that time there were still two animals, but by 2020



Figure 17. Closure of the Waterkuil, one of the largest quarries of Henisdael.



Figuur 18. Development of the total number of bats found in the Henisdael quarries, Vechmaal.

this had risen to 16 individuals.

There was a sudden drop in the number of bats in 2007, probably caused by the felling of poplars close to the entrance, in the autumn of 2006. During the swarming period, the falling trees caused vibrations, which were probably felt in the quarries and several lumps of marl appeared to have come loose. A gradual increase in the number of animals has only been noticed since 2017 (figure 18).

Discussion

In 1989, only 622 hibernating bats were observed in the 18 accessible quarries. In 2020, 26 quarries were counted and the number had risen to 4493 (figure 19). This strong increase is possibly due to an increase in the

population, probably partly as a result of the efforts made to close the quarries. Progress in illumination and the training and experience of counters has probably also played a role. At the end of the 1980s, the strongest lamps were equipped with 'Krypton Light', whereas current LED lamps have a light output that is many times higher. With stronger light and with better binoculars, animals hidden in the ceiling or higher crevices are easier to find and identify. The knowledge of the counters has also greatly improved year on year, both in terms of the characteristics of the animals and in knowledge of the bats' use of the quarries. Bats often hibernate in the same (hidden) places. Checking those places increases the chance of finding hibernating bats. That is why it is important that counters get a 'fixed section' in the quarry and pass their knowledge on to the next generation of counters.

The end of mushroom cultivation did not immediately mean a major increase in the numbers of hibernating bats. Cultivation involved daily visits to the systems, plastic sheeting closed corridors and the regular use of fungicides. These factors all inhibited bats using these quarries for hibernation. In particular, the effects of strong insecticides, such as DDT, were felt until the mid 1980s.

In Riemst, the first quarries were counted in the early 1970s. René Gilson and Jacques Ferron took the lead in mapping the hibernating bat populations with some local experts at the quarries. The counting data appeared in the publications of the Royal Belgian Institute of Natural Sciences (RBINS) (Fairon & Lefevre 1991). In the beginning, the research was mainly led by Walloonian researchers. At the end of the 1980s, the counts were coordinated by a Flemish working group with the support of Dutch volunteers. The current working group consists of approximately 50 Flemish and Dutch volunteers, who receive regular support from British, French, German or Luxembourg researchers.

The Riemst quarries are much larger than the Henisdael quarries, so the overview of

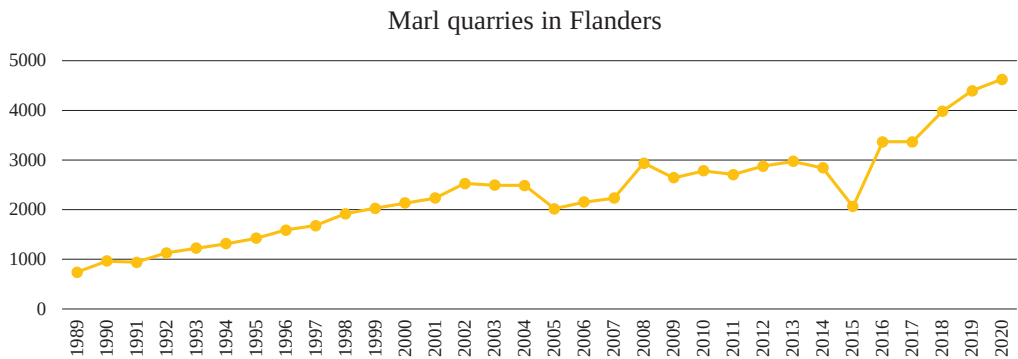


Figure 19. Total number of bats counted in the quarries of the Flemish marlland 1989-2020.

these complexes clearly differs. Counting was first done in Vechmaal in 1942. The most commonly counted species in those early years were the lesser horseshoe bat (*Rhinolophus hipposideros*), greater horseshoe bat (*Rh. ferrumequinum*) and barbastelle (*Barbastella barbastellus*). Yet the figures from 1942 to 1985 are only partial. One cannot compare the quality of the light with that of today. With the limited light of carbide lamps and then weak flashlights, only specimens that hung from the ceiling or against a tight wall could have been seen. Bats hiding in crevices were almost certainly not included in the sightings. The counters were probably not as well trained as they are now. Intensive mushroom cultivation in the quarries and the excessive use of insecticides, led to a decrease in the number of bats in Henisdael. From 1960 the cultivation of mushrooms stopped in Henisdael and the largest quarry was closed in 1989. But by then, the critical species, such as the lesser and greater horseshoe bats and the barbastelles, had already completely disappeared.

The proportions between the different species of bats that hibernate in the Flemish marl quarries have changed radically since 1990. The whiskered bat is the currently most commonly observed species, while the Geoffroy's bat is the species that has increased the most. All the other species also have increased in number.

It is difficult to make comparisons with the

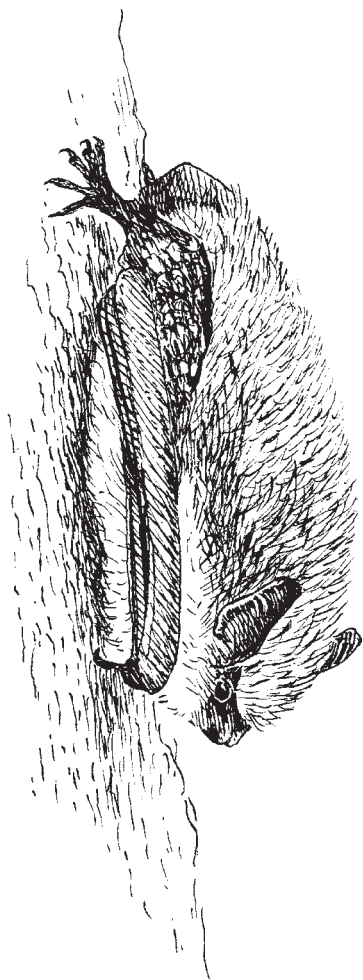
Dutch or the Walloon quarries as there is currently no cooperation in terms of the different working groups exchanging data between, despite several volunteers actively participating in the censuses in the different regions. The picture presented in this overview will hopefully contribute to further cooperation.

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Hibernating bats in fortifications of the New Dutch Waterline 1980-2020: The ups and downs of a dynamic co-existence of natural and cultural heritage

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Abstract: Man-made structures are quite important for bats in a country like the Netherlands with hardly any natural rocks or caves. This paper describes the use that hibernating bats make of buildings that were originally put up for military purposes: the fortifications of the New Dutch Waterline (NDW). Over the past seventy years, when their military usage ceased, many of these buildings grew into important sites for bats, especially for hibernation. However, since the 1990s these buildings have come to be considered as an important cultural heritage and managed as such. Can these two important values co-exist? Part I of this paper describes the use of fortifications by hibernating bats and part II describes the developments in the numbers of hibernating bats as a result of changing use and management.

Keywords: hibernation, bats, population trends, hibernacula, management, New Dutch Waterline.

The New Dutch Waterline

The New Dutch Waterline (NDW) was constructed in the first half of the nineteenth century in order to protect the western part of the Netherlands with the at that time most important cities against hostile armies. The basic idea was to protect these cities from threats coming from the east by inundating large areas of land, thus limiting the lines of westward access. Fortifications were built to defend these access lines. This defence line was updated several times, strengthening and altering existing buildings and adding new buildings. The first buildings were built in brick, later in concrete without steel and

finally in reinforced concrete. Many of the buildings, especially the older ones, were covered around 1880 with thick layers of soil to make them more resistant to artillery fire.

The NDW never has been actually used against invaders, although at the end of World War II the German occupiers put it into action against the liberating forces (albeit in vain). With war methods and technology becoming more and more airborne, the NDW lost its defensive military function. The large fortifications were transformed for other military functions such as explosion disposable sites, truck maintenance, storage and training facilities. Some fortifications were partly or completely demolished because of urban development. Over time, gradually all the fortifications lost their military functions.

Interest in the cultural significance of the

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NDW started to rise at the end of the twentieth century, marked by its nomination to the UNESCO World Heritage List. Subsequently a wide range of policy documents was published and several policy statuses were applied to the NDW. A vision document ('Panorama Krayenhof', 2004) was published, followed by an investment programme of €150 million in 2008 ('Pact van Rhijnauwen', 2008). The strategic baseline of this vision and investment programme is 'Conservation through development': maintaining heritage by giving it appropriate new functions. In this vision, the cultural perspective takes precedence over the ecological importance of the NDW. As a consequence, the fortifications have been adopted for a wide variety of new functions: commercial, educational, residential, recreational, nature conservation, etcetera. The NDW was finally designated as UNESCO World Heritage Site in 2021.

The NDW spans a length of 85 kilometres from Muiden (east of Amsterdam) to Werkendam (southeast of Rotterdam; figure 1). It consists of 45 forts, 6 fortified cities, 2 castles, 85 gun shelters, over 700 concrete shelters and over 100 sluices and other water works (<https://nieuwehollandsewaterlinie.nl/nieuwe-hollandse-waterlinie>). Most fortifications have one or two central buildings, built in brick and covered with several metres of soil. Around these buildings, varying numbers of smaller buildings are situated. The older ones are built in brick, the more recent ones are built in concrete and these too were often covered with soil. Some of the buildings have cellars, designed to store water or goods. Initially, the fortifications were largely covered with grass, but later on trees and copses appeared, sometimes for military purposes and sometimes more spontaneously when military usage ceased. Nowadays, most fortifications have a park-like appearance. The relatively modern concrete shelters have been built throughout the NDW.

The associated inundation areas have a width of 3-15 kilometres. A special military

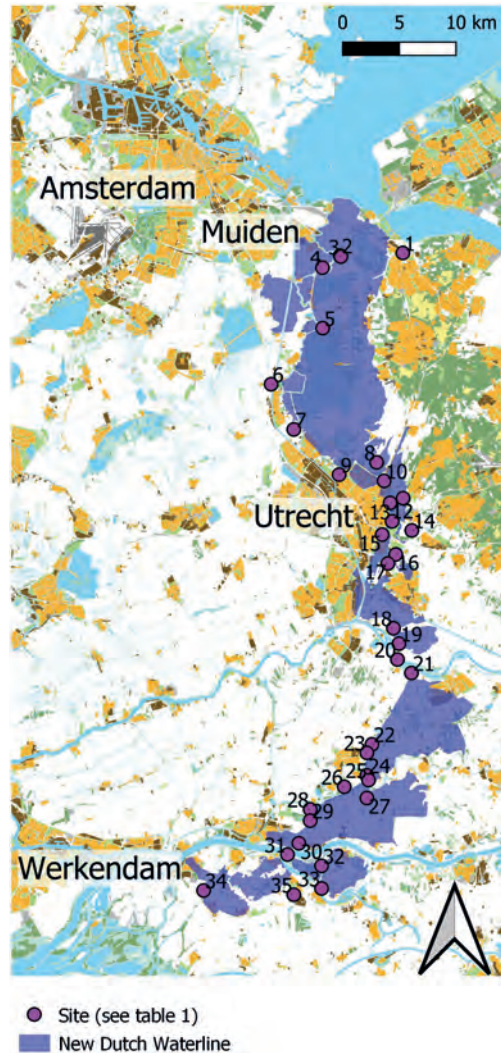


Figure 1. The New Dutch Waterline

planning law, which was effective until 1951, set strict limitations to erecting buildings around the military works. Consequently, the NDW largely consists of open and flat landscapes, mainly used as grassland for dairy farming. There is a low density network of landscape elements, such as avenues, copses and tree lines throughout the NDW. Extensive forests are scarce, apart from on the eastern flank of Utrecht and the northern limit, where the NDW meets the forests of the Utrechtse Heuvelrug and Het Gooi.

Part I. Bats

As the original military defensive function of the NDW disappeared, the use of the fortifications changed and in most cases became less intensive or ceased completely. Subsequently, bats began to utilise the fortifications as a habitat. The importance of the NDW fortifications for hibernating bats was understood as early as the 1950s, when the University of Utrecht started a survey of hibernating bats in the NDW. In the following three decades around ten fortifications were monitored each year and the total number of observed bats varied at around 100 each year (Voûte et al. 1980). Initially their function as a hibernaculum (in the buildings) was understood, but it was later noted that they were important swarming sites during the mating season and that maternity roosts also occur in the fortifications. Limpens et al. (2007) described the habitat use of the fortifications by bats. Boer et al. (2010) analysed the factors determining the fortifications' suitability as bat habitats. They found that the overall volume of the buildings, together with the number of rooms and the availability of crevices and cracks in which bats can crawl away are positively related to the number of hibernating bats. Higher and more stable temperatures (within the range of 4-11°C) enhance species diversity. The intensity of human activities in the buildings is negatively correlated to the number of bats, whereas an open, park-like vegetation, darkness and bat-friendly management are favourable for bats. The impact of the surrounding landscape characteristics on the diversity or total number of bats was less clear.

Methods

Survey and monitoring

The monitoring of hibernating bats in the NDW is part of the nationwide monitoring network, *Netwerk Ecologische Monitor-*

Table 1. The sites.

	Site
1	Naarden
2	Uitermeer, torenruïne
3	Uitermeer, manschap verblijf
4	Hinderdam
5	Kijkuit
6	Nieuwersluis
7	Tienhovense Vaart
8	Ruigenhoek
9	De Klop
10	Blauwkapel
11	Griftenstein
12	De Bilt
13	Utrecht Kromhoutkazerne
14	Rhijnduinen
15	Lunetten
16	Vechten
17	Hemeltje
18	Waalse Wetering
19	Korte Uitweg
20	Honswijk
21	Everdingen
22	Diefdijk Schaaik
23	Leerdam
24	Meerdijk
25	Asperen
26	Nieuwe Zuiderlingedijk zuid
27	Nieuwesteeg
28	Broekse sluis
29	Lingebos
30	Vuren
31	Loevestein
32	Brakel
33	Poederoyen
34	Papsluis
35	Giessen

ing (NEM), which was initiated in 1999 with the purpose of tracking changes in the population size and distribution of protected species, in order to inform policy makers and guide conservation efforts. Between 1980 and 2020, 58 NDW sites have been inspected at least once. However, in this study we only include sites which have been inspected for ten or more years and/or in which ten or more

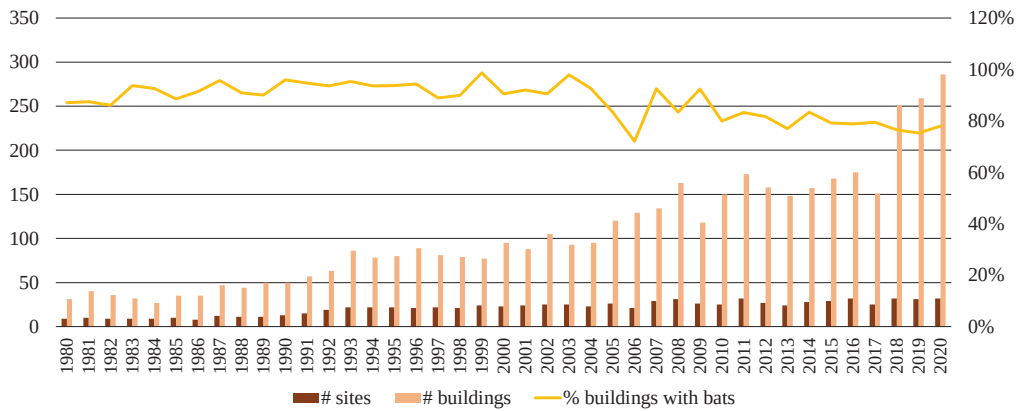


Figure 2. Number of fortifications and number of buildings within the fortifications monitored each year (bars, left axis) and percentage of buildings with bats (line, right axis).

hibernating bats have been observed during this period. This results in a total of 35 sites (figure 1; table 1). Since 1980, the number of monitored sites in this group has increased gradually from 9 to 32 per year (figure 2). The number of inspected buildings within the fortifications has increased to around 150. Since 2018, the number of buildings inspected has almost doubled (figure 2), but this is a methodological artefact, due to the splitting of large sites into separate buildings and sometimes compartments in buildings. The percentage of buildings with hibernating bats decreased from around 90% in 1980 to around 80% in 2020, due to more buildings being included in the census over the past 20 years, not all of which are (yet) suitable for hibernation.

Surveys were first carried out by scientists and students; later on by small teams of professional mammalogists and expert volunteers, using flash lights, mirrors and binoculars to spot and identify hibernating bats (figure 3). The people doing these inspections have a lot of experience and 'new kids on the block' are trained 'on the job', both in finding the bats (knowing where to look, recognizing a (part of a) bat) and species identification. Hence, we consider the expertise to be constant over the period. However, the equipment has improved substantially: flash lights nowadays have more powerful and focusable beams, binoculars



Figure 3. Inspection of Fort Honswijk (20).

have better optics and shorter focusing distances and digital cameras with tele lenses can be used to identify bats in distant positions. In general, this improvement mostly affects the

quality of the identification of species (i.e. a decrease in the proportion of unidentified bats) and much less the number of bats found.

Statistical analysis

Within the NEM, the national trends for hibernating bats have been calculated each year since 1986, which is widely used as the most reliable baseline for national trend estimates. This paper, however, describes the monitoring and population trends of fortifications of the NDW from 1980 till 2020, so we made a separate set of calculations for this period, using the same methods for monitoring and statistical analysis as for the NEM, for the five most numerous (groups of) species: *Myotis mystacinus/brandtii*, *M. nattereri*, *M. daubentonii*, *Pipistrellus pipistrellus/nathusii*, and *Plecotus auritus/austriacus*. We first used the data of the bat counts per building/compartment to calculate trends and indices for each species for each site as well as for the NDW as a whole. The calculation of these species-specific trends, expressed as an average yearly proportional increase or decrease, and indices, expressed as a percentage of the estimates of the first year, was done using the *rtrim* v2.1.1 package (Bogaart et al. 2020) in the R v4.0.3 computer programme (R Core Team 2020). Table 2 shows the trend classes used. The *rtrim* package is an R-implementation of the log-linear regression method originally published as the TRIM computer programme (Pannekoek & van Strien 2001), which was developed specifically for the analysis of wildlife count data and incorporates among-site variation in population size and other aspects, serial correlation per site, weighting of sites and the estimation of missing values based on changes at other sites (ter Braak et al. 1994). The resulting indices were then combined into a mean bat population trend estimate, by calculating a multi-species indicator (MSI) using a Monte Carlo procedure and the geometric mean, as described by

Table 2. Trend classes.

Class	Trend (95% CI)
Strong decrease	<-5%
Moderate decrease	<0%
Stable	-5% - +5%
Moderate increase	>0%
Strong increase	>+5%
Uncertain	<-5% - >+5%

Soldaat et al. (2017). All of these calculations were done separately for the periods 1980-2000 and 2001-2020. Finally, the national population trends were calculated for 2001-2020 for the five abovementioned (groups of) species to facilitate a proper comparison with the trends in the NDW in that period.

Results

A total of eleven species were spotted over the entire period. The yearly total number of observed bats increased more than tenfold: from 150 in 1980 to 1550 in 2020¹. Appendix I² gives an overview of the species and numbers counted in each site. Figure 4 shows the annual numbers of the most numerous (groups of) bat species. Table 3 gives the average number of each (group of) species per year for the four decades covered by this paper. Table 3 and figure 5 present the calculated trends for the first and second half of the period for the five most numerous (groups of) species

Rhinolophus ferrumequinum

From 1992 until 1998 one specimen of *Rhinolophus ferrumequinum* (figure 6) was found hibernating in the main building of Fort Rhij-

¹ In this paper January of each year is taken as the winter date, so for example 2020 = the winter of 2019-2020

² Available at <https://www.Zoogdierveniging.nl/publicaties/2022/lutra-65-1-2022>

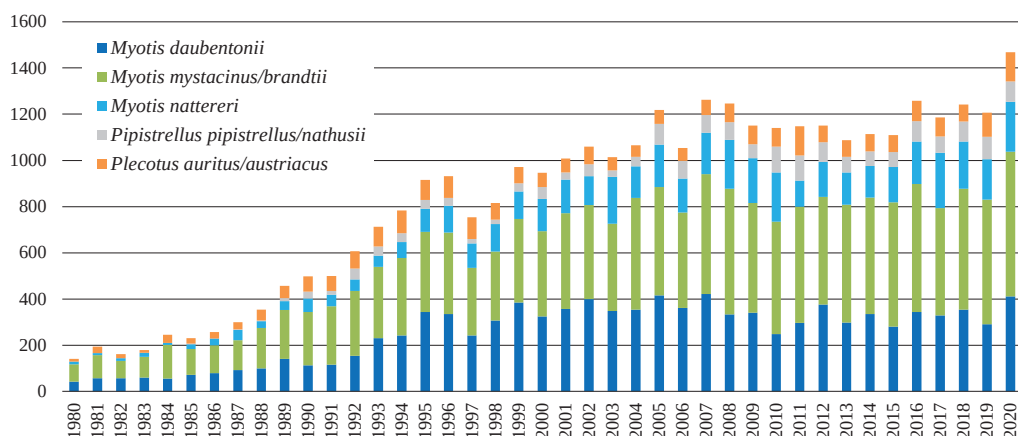


Figure 4. Numbers of the most numerous (groups) of bat species per year.

Table 3. Average number of bats and trends by (group of) species.

Species(group)	1980-1989	1990-1999	2000-2009	2010-2020	Trend1980-2000	Trend 2001-2020
<i>Rhinolophus ferrumequinum</i>	-	0.7	-	-	not available	not available
Indet	20.6	35.3	42.4	47.7	not available	not available
<i>Myotis mystacinus/brandtii</i>	123.7	305.9	447.3	519.7	moderate increase	stable
<i>Myotis nattereri</i>	21.8	83.6	166.6	174.9	strong increase	stable
<i>Myotis myotis</i>	-	-	-	0.2	not available	not available
<i>Myotis daubentonii</i>	75.1	246.6	365.3	323.8	strong increase	moderate decrease
<i>Myotis dascyneme</i>	-	0.3	0.6	-	not available	not available
<i>Pipistrellus pipistrellus/nathusii</i>	2.3	31.9	58.4	84.7	moderate increase	moderate increase
<i>Eptesicus serotinus</i>	0.1	0.9	2.5	0.6	not available	not available
<i>Plecotus auritus/austriacus</i>	28.5	80.8	64.9	88.7	moderate increase	stable

nauwen (14)³. It was probably the same specimens returning each year to the same location.

Myotis mystacinus* and *Myotis brandtii

Myotis mystacinus and *M. brandtii* (figure 7) can only be distinguished accurately by morphological characteristics (teeth and penis, Dietz et al. 2011). When monitoring bats it is common practice not to handle them, in order to minimize disturbance. So all observations of these two species are combined as *M. mystacinus/brandtii*. Mostert et al. (2005) conducted a

survey in which *M. mystacinus/brandtii* were handled in order to identify the exact species and discovered two specimens of *M. brandtii* in Asperen (25), 1.7% of all specimens. In Waalse Wetering (18) three specimens of *M. brandtii* were identified in 2019 and one in 2020. The identification was made by visual inspection by a person with extensive experience with the species (J. van der Kooij, personal communication). In 22 sites specimens of *M. mystacinus* were found (Appendix I). It is beyond the scope of this paper to verify the identifications of both species. According to Mostert et al. (2005) it is likely that *M. brandtii* makes up a very low percentage of the *M. mystacinus/brandtii* specimens observed.

³ Numbers refer to those in figure 1 and in table 1

Table 4. The NDW's share of hibernating bats as a proportion of the total Dutch population and a comparison of national trends with those for the NDW for the five most numerous (groups of) species

Species (group)	The Netherlands 2020	NDW 2010-2020	%NDW	National trend 2001-2020	NDW trend 2001-2020
<i>Myotis daubentonii</i>	9000	324	4%	moderate increase	moderate decrease
<i>Myotis mystacinus/brandtii</i>	3000	520	17%	moderate increase	stable
<i>Myotis nattereri</i>	5000	175	4%	strong increase	stable
<i>Pipistrellus pipistrellus/nathusii</i>	1000	85	9%	moderate increase	moderate increase
<i>Plecotus auritus/austriacus</i>	1600	89	6%	moderate increase	stable

All together *M. mystacinus/brandtii* was spotted 14,468 times, making this species group the most numerous hibernating bat in NDW. These species have been spotted in 32 (91%) sites (see figure 8). Rhijnauwen, Honswijk and Everdingen account for 60% of the observations (appendix I). The average yearly numbers have increased from 124 in first decade to 520 in the last decade (table 3), with a steep increase to 627 in 2020 (figure 4). Between 1980 and 2000 the population showed a moderate increase and between 2001 and 2020 the population was stable (figures 5a-b, table 3).

Myotis nattereri

M. nattereri was spotted 4,644 times (figure 9, Appendix I), in eleven (31%) sites, mainly in the vicinity of Utrecht, with Rhijnauwen (14) accounting for 71% of the observations with a maximum of 176 specimens in 2003. The average yearly numbers increased from 22 in first decade to 175 in the last decade (figures 5c-d, table 3). After a strong increase in 1980-2000 the population was stable in 2001-2020, with a dip halfway through this period and a subsequent recovery (figure 5d).

Myotis myotis

Individual specimens of *M. myotis* were twice spotted in Rhijnauwen (15), in 2011 and 2020.

Myotis daubentonii

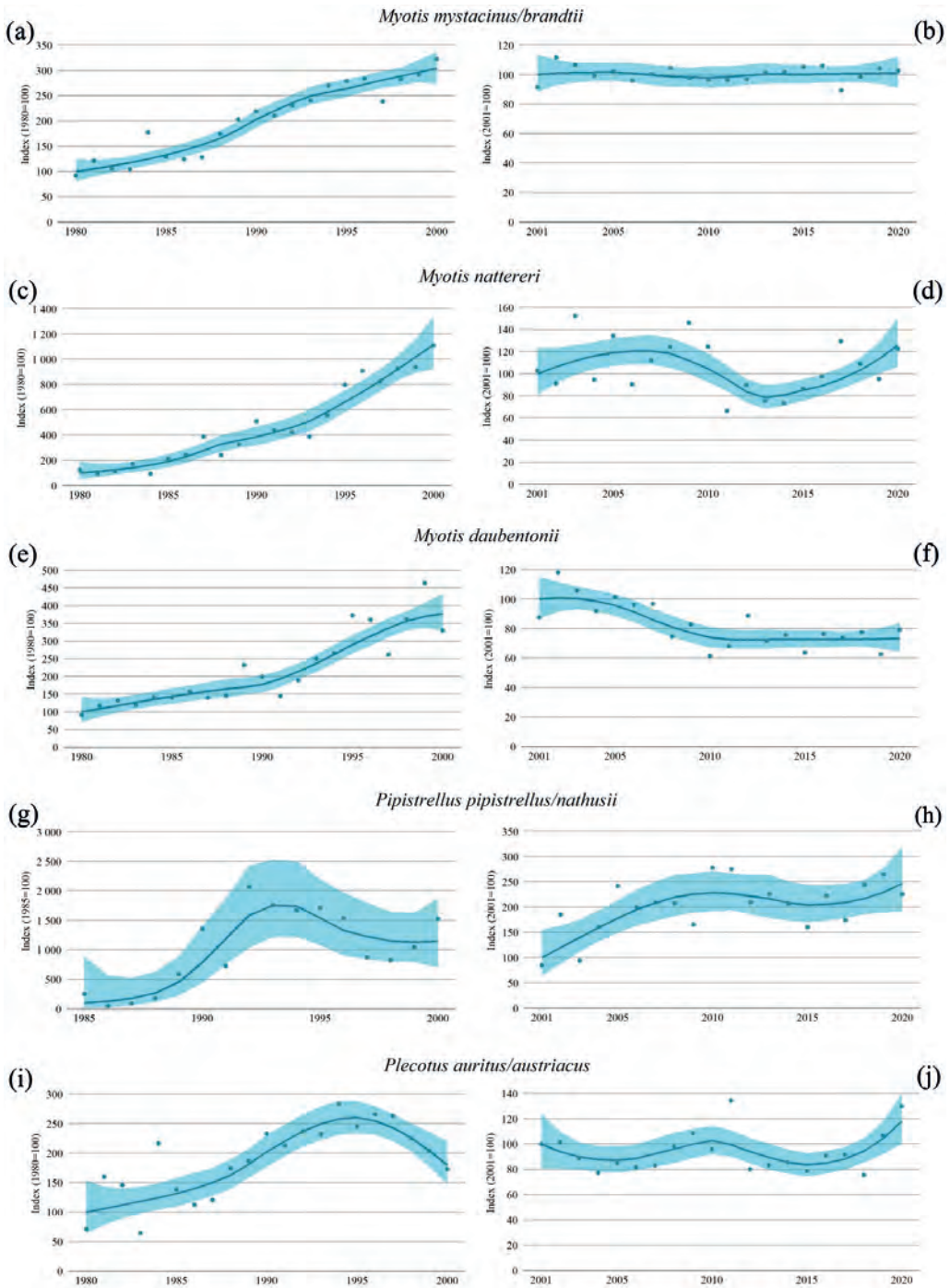
With 10,432 observations *M. daubentonii* (figure 7) is the second numerous species hibernating in the NDW (Appendix I). It is found in 29 (83%) sites throughout the NDW (figure 9), with concentrations east and southeast of Utrecht (sites 13-21) and in the south, in Gies-sen (35). The average yearly numbers increased from 75 in first decade to 324 in the last decade (table 3). In 1980-2000 the population showed a strong increase, and in 2001-2020 a moderate decrease (figures 5e-f, table 3).

Myotis dasycneme

With nine observations in seven years *M. dasycneme* occasionally hibernates in the NDW (appendix I). There have been three observations in Rhijnauwen (14) and Giessen (35) with the other observations made in Naarden (1) and Honswijk (20).

Pipistrellus pipistrellus* and *P. nathusii

Both pipistrelle species have been spotted. As specimens of these two species not always have been identified to species level, we aggregate in this paper the numbers of both species and the unidentified specimens. Bats of this species group account for 1,858 observations (appendix I), in 19 (54%) sites throughout the NDW (figure 10). Rhijnauwen (14), Honswijk (20) and Loevestein (34) host the



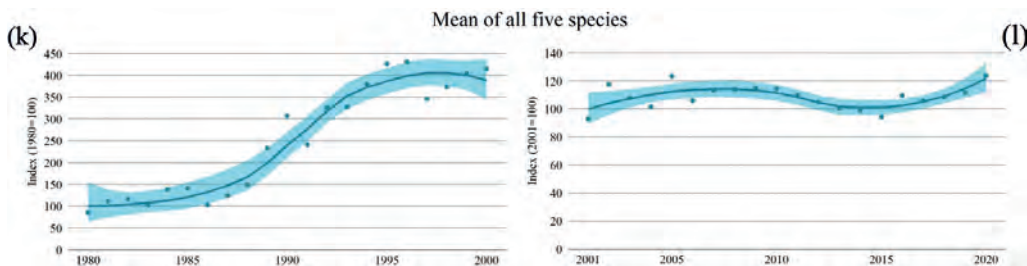


Figure 5. Trends in the NDW for *M. mystacinus/brandtii* (a+b), *M. nattereri* (c+d), *M. daubentonii* (e+f), *P. pipistrellus/nathusii* (g+h), *P. auritus/austriacus* (i+j) and all species (k+l): 1980-2020.

biggest numbers (average around 40 yearly). *P. pipistrellus* has been identified in 14 (40%) sites, *P. nathusii* in 7 sites (20%), see figure 10 and appendix I). The average yearly numbers increased from 2 in first decade to 85 in the last decade (table 3). In both 1980-2000 and 2001-2020 the population showed a moderate increase (figures 5g-h, table 3).

Eptesicus serotinus

With 42 observations in 8 sites (23%) *Eptesicus serotinus* regularly hibernates in low numbers (max. four per year) in the NDW (appendix I). Rhijnauwen (14) and Loevestein (31) account for 71% of the observations.

Plecotus auritus/austriacus

Not all specimens of *Plecotus* were identified to species level. Because of its distribution (Broekhuizen et al. 2016), it is quite unlikely that *P. austriacus* hibernates in the NDW. However in this paper we have aggregated the numbers of *P. auritus* and the unidentified specimens.

Plecotus bats make up for 2,718 observations, in 34 (97%) sites throughout the NDW (figure 11, appendix I) with identifications of *P. auritus* in all of these locations. The average yearly numbers increased from 29 in the first decade to 89 in the most recent decade (table 3). In 1980-2000 the population showed



Figure 6. Hibernating *Rhinolophus ferrumequinum* at Rhijnauwen (14). Photo: Zomer Bruijn.

a moderate increase, and in 2001-2020 the population was stable (figures 5i-j, table 4).

Discussion

La Haye et al. (2020) give an overview of the counted numbers of hibernating bats in the Netherlands in the period 2016-2020. Table 4 presents the average annual counts in the NDW as a percentage of the numbers at the national level. La Haye et al. (2020) also present



Figure 7. Hibernating *Myotis mystacinus/brandtii* and *M. daubentonii* at Honswijk (20). Photo: Jan Buys.

population trends for the period 2009-2020. As this period does not match the period used in this paper, we calculated the national trends for the period 2001-2009. Table 4 compares the national trends with the trends in the NDW.

With 17% of the national hibernating population of *M. mystacinus/brandtii*, the NDW is of national significance for this species group. Three sites (Rhijnauwen (14), Honswijk (20) and Everdingen (21) host ca. 60% of the hibernating specimens of this species group within the NDW and are therefore key hibernacula for this species group in the Netherlands. These hibernacula are also quite important in the swarming season (Limpens et al. 2007). This means that, not only the buildings themselves are important for this species group, but also the lay-out and management of these sites as a whole and their surrounding landscape. The population trend of *M. mystacinus/brandtii* in the NDW was stable between 2001 and 2020, whereas the national trend in the same period shows a moderate increase (table 4), albeit with a moderate decrease over the last twelve years (La Haye et al. 2020). It

seems that in the NDW the population of *M. mystacinus/brandtii* reached its peak earlier than it did nationally and is more stable, as it has not shown a decrease (figure 5b). The three most important sites, Rhijnauwen (14), Honswijk (20) and Everdingen (21) have respectively shown a moderate increase, a stable trend and a moderate decrease, while the two next important sites, Nieuwersluis (6) and Asperen (25), have both shown a moderate decrease. As a result, the importance of the NDW for *M. mystacinus/brandtii* is becoming increasingly dependent on fewer sites, which makes the population more vulnerable. In part II we discuss the developments underlying this phenomenon.

The share of other species of bats hibernating in the NDW is rather limited (table 4). Nevertheless the sites of the NDW are important at a regional level, especially for *M. daubentonii* and *M. nattereri*. The trend for *M. daubentonii* (a moderate decrease) is less favourable than the national trend (a moderate increase). One possible explanation is the disappearance or decrease of summer colonies in several for-

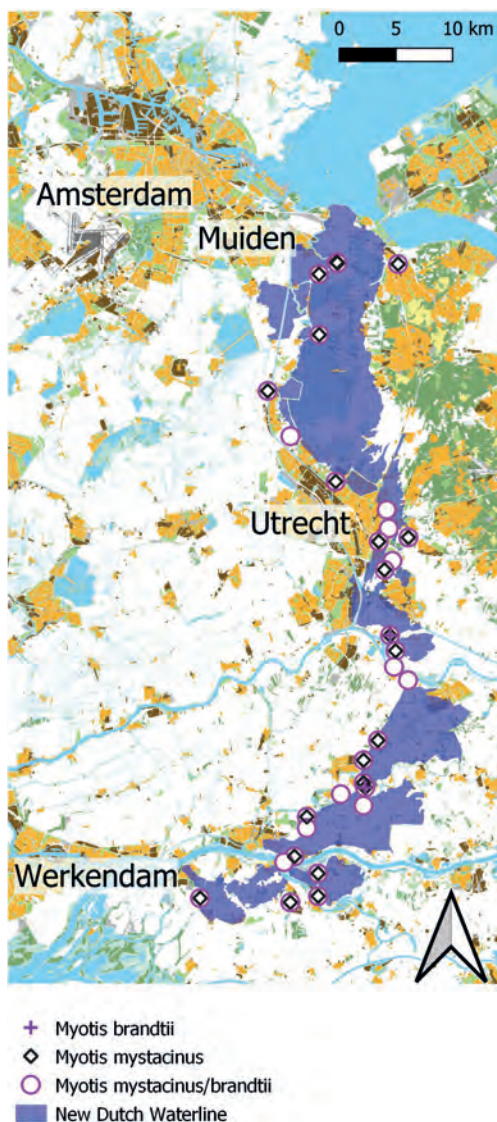


Figure 8. Presence of *M. mystacinus/brandtii* and presence of *M. mystacinus* and *M. brandtii*.

tifications: Uitermeer (2), Nieuwersluis (6), Rhijnauwen (14), Honswijk (20) and Asperen (25). A second possible explanation is that other suitable hibernacula have been developed within the region outside the NDW and that these hibernacula have been discovered by *M. daubentonii*.

It is remarkable that *M. dascyneme* only rarely hibernates in the NDW, as it is close

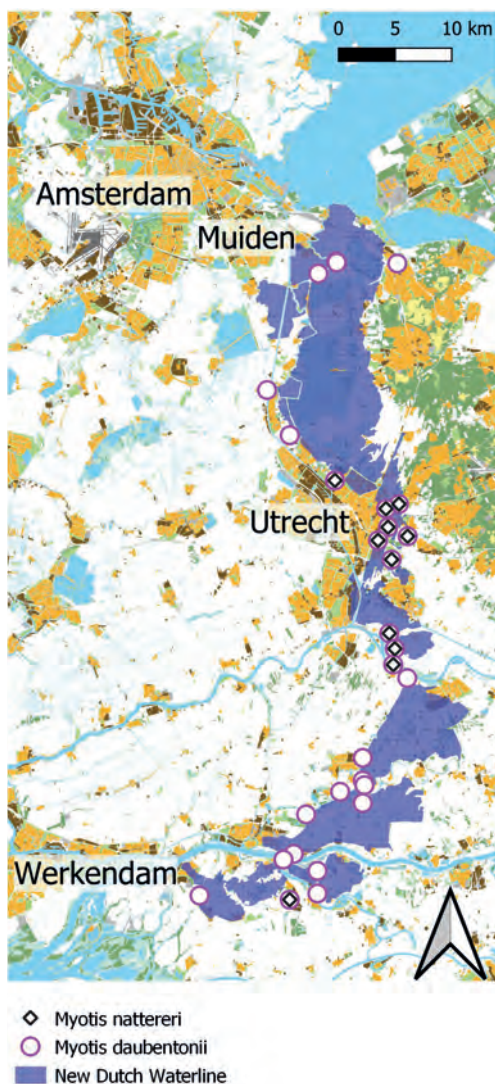


Figure 9. Presence of *M. nattereri* and *M. daubentonii*.

to its summer habitat. Haarsma et al. (2019) describe males shifting their hibernating sites from the (distant) limestone quarries in Limburg to hibernacula in the coastal dunes and the Veluwe, closer to their summer habitat. The Veluwe is further away from their summer habitat than the NDW. Three possible (overlapping) explanations are (A.J. Haarsma, personal communication): 1. The bunkers in the coastal dunes are closer to the summer habitat and migration routes of males.

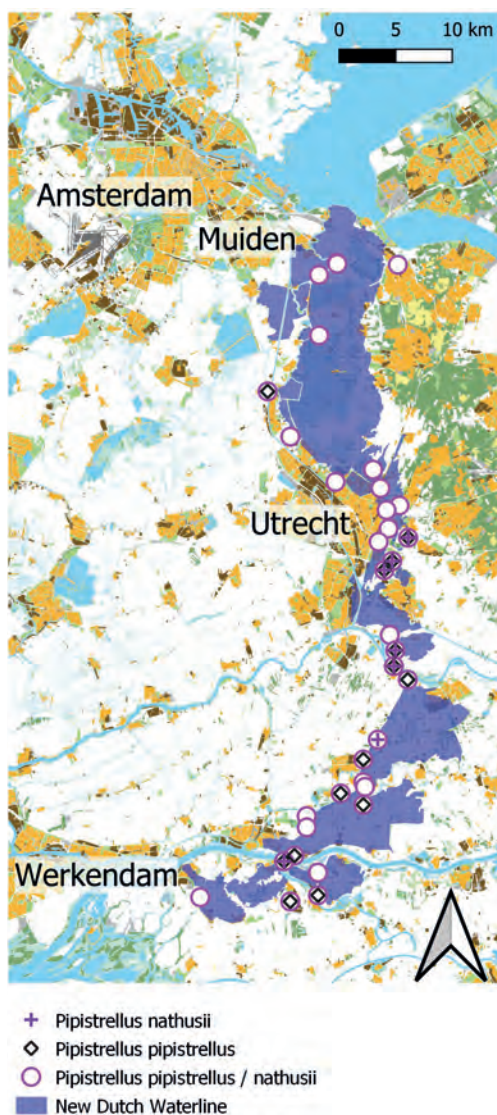


Figure 10. Presence of *P. pipistrellus/nathusii* (circles) and presence of *P. pipistrellus* (◇) and *P. nathusii* (+).

2. Bunkers in the coastal dunes and Veluwe have a more suitable climate: more dynamic and with less long cold periods. 3. *M. dasycneme* arrives early in the hibernacula and leaves late. The bats therefore are more easily exposed to human activity in structures in the NDW, even when this stops in winter.

The numbers of *M. nattereri* are stable in

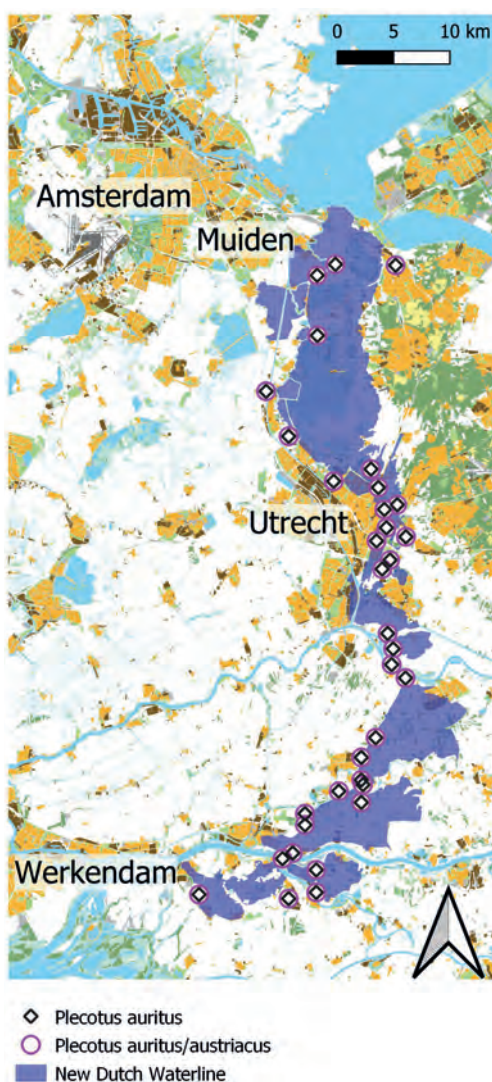


Figure 11. Presence of *P. auritus/austriacus* (circles) and presence of *P. auritus* (+).

the NDW, whereas nationwide it has shown a strong increase (table 4). As 70% of the observations of this species have been made in Rhijnauwen (appendix I) it is quite likely that the cause of this difference in trends is linked to this site (see part II).

The NDW apparently offers an important set of hibernacula for *Pipistrellus pipistrellus* / *nathusii* (table 4). However, this a methodo-

logical artefact, as most bats of these species hibernate in other, mostly hard to inspect, roosts and therefore are underrepresented in the NEM (Broekhuizen et al. 2016). Taking this into account the trends in the NDW and the national trend are quite similar, both showing a moderate increase.

Plecotus auritus / *austriacus* shows a stable trend in the NDW and a moderate increase nationwide (table 4). This difference is again mainly methodological, caused by more variation within the period (with an increase towards the end) and a smaller sample size in the NDW than nationwide.

Predation or the presence of predators is another aspect which is likely to affect hibernating bat numbers. Though data on predation is not systematically collected, several bat workers report predation or disturbance by birds of prey such as *Tyto alba*, and mammalian predators such as *Martes martes* and/or *M. foina*. These species have increased their distribution substantially, and are widely present throughout the NDW nowadays (SOVON Vogelonderzoek Nederland 2016, www.verbreidingsatlas.nl). *Strix aluco* is also present on many sites. We therefore cannot exclude that predation or disturbance by these species is affecting the population trends of bats in the NDW.

Deeper investigation into both the data of (hibernating) bats in and around the NDW and nationwide is needed to verify these suggested explanations and identify more explanations for the differences in trends.

Four of the five most abundant species (figures 6-9) are present throughout the NDW. *P. auritus* / *austriacus* and *P. pipistrellus* / *nathusii* are relatively evenly distributed throughout the NDW, whereas *M. mystacinus* / *brandtii* and *M. daubentonii* are concentrated to the south and east of Utrecht. *M. nattereri* is only present in the sites near Utrecht and in the very south.

These distribution patterns are consistent with the known summer habitat use of these species (Dietz et al. 2011). The sites near

Utrecht are close to the (dominantly coniferous) forests of the Utrechtse Heuvelrug and its adjacent relatively small-scale agricultural landscapes (figure 1) and well connected through landscape structures (tree lines, avenues, copses). Other parts of the NDW to the northwest of Utrecht and south of the river Lek have a more open landscape with scattered copses (poplar, willow, alder), tree lines, avenues and lots of water. The very north and south of the NDW are linked to the more forested areas of Het Gooi and the province of Noord-Brabant respectively. In this respect it is remarkable that *M. nattereri* is absent in the north, where it could be expected because of suitable nearby summer habitat and the presence of the species in hibernacula outside the NDW.

Part II. Fortifications

Methods

We obtained information on (the developments in) the use and management of structures in the NDW during the last two decades by interviewing the bat workers performing the monitoring. More detailed information and information from earlier times is very limited due to incomplete data on management in the NEM database.

The volume of the different buildings is an important indicator for the presence of hibernating bats (Boer et al. 2010). The same goes for the availability of crevices, faults etc. for bats to find adequate shelter. Unfortunately, collecting this data is not a requirement of the NEM and so no systematic data is available in the NEM database on these two important characteristics of buildings used as hibernacula. In general, both the volume and the possibilities to creep away will be larger in forts than in concrete shelters.

The calculation of trends of bats per site is described in part I of this paper.



Figure 12. Fort (Honswijk, 20). Photo: Jan Buys.

Results

Site characteristics

Appendix II⁴ lists the 35 sites which are discussed in this paper. As each site is a complex of a varying number of separate (and sometimes parts of) buildings, the number of buildings in each fortification which are monitored for bats is also shown in this appendix. In the database we distinguish several types of buildings:

- *Fort* (figure 12). Built in brick with very thick walls (>1 metre thick) and usually covered with a thick layer of soil. These buildings were built in the nineteenth century (1815-1870). Due to their age, the construction materials and periods of little maintenance, most forts have numerous crevices, faults and other places where hibernating bats can hide.
- *Concrete shelter* (figure 13). Concrete buildings, built in the first half of the twentieth century. Some are covered with a layer

of soil. Over the last two decades several of these structures have been managed to improve their quality as bat hibernacula. Most shelters are quite smooth inside though some develop crevices as a result of the ceilings peeling and cracking.

- *Corridor*. These were built in brick in de Vesting Naarden (1) in the seventeenth century and in Loevestein (31).

In some sites other types of structures (cellars, attics) are present.

Appendix II also presents an overview of the present characteristics of each fortification:

- *Ownership*: government (ministry, province, water board, municipality etc.), nature management organisation (Staatsbosbeheer, Natuurmonumenten, Brabants Landschap), heritage foundation or private.
- *Protection status*: inside or outside the Natura 2000 Network (five inside) and National Nature Network (24 inside).
- *Function of the buildings monitored*: hibernaculum (exclusively, no other use), tourism ((guided) tours), catering (café, restaurant), education, storage.

⁴ Available at <https://www.Zoogdiervereniging.nl/publicaties/2022/lutra-65-1-2022>



Figure 13. Shelter (near Honswijk, 20). *Photo: Jan Buys.*

- *Accessibility for the public.*
- *Vegetation cover:* open (grassy vegetations), closed (bush, shrubs, trees), half open.

Bat numbers

Appendix I gives an overview of the hibernating bats counted in surveys for each site. Two sites, Rhijnauwen (14) and Honswijk (20) host 51% of the bats. Five more sites, Nieuwersluis (6), Vechten (16), Everdingen (21), Asperen (25) and Giesen (35) account for another 31% of the total bats counted. On average 4.2 species were observed per site (appendix I), ranging from 1 (Ruigenhoek, 8) to 10 (Rhijnauwen, 14).

The presence of bats in the different building types is summarised in table 5. Forts host 92% of the hibernating bats, shelters and corridors each host 3% and the rest 2%.

Table 6 displays the trends in the total number of hibernating bats for each site and the NDW as a whole for the five most numerous (groups of) species for the periods 1980-2000 and 2001-2020. Figures 5k and 5l show the average population trend of NDW as a whole. Insufficient data was collected from 14 sites to calculate a reliable trend between 1980 and 2000; in 2001-2020 this was the case for just two fortifications. Overall, there was a strong increase of hibernating bats in the NDW in

the first period, 1980-2000, which stabilized in the second period, 2001-2020. There were no sites which showed a (strong) decrease in the first two decades of our survey, whereas in 2001-2020, eleven sites showed a moderate decrease and one showed a strong decrease. Between 2001 and 2020 four sites showed a moderate increase and five sites a strong increase.

Discussion

General picture

The most important site is Rhijnauwen (14), which accounted for 34% of all bat observations and hosted ten species (appendix I). The next most important site is Honswijk (20) with 16% of the observations and seven species. Five more sites provided the next 31% of observations (appendix I). Two of these, Vechten (16) and Everdingen (21), together with Rhijnauwen (14) and Honswijk (20) constitute a cluster that is relatively close to the forest of the Utrechtse Heuvelrug. Other important sites include Nieuwersluis (6), which lies more to the north, in the vicinity of the mainly deciduous estates of the Vechtstreek along with Asperen (25) and Giesen (35) which both lie more to the south, and have complexes of small deciduous woods

Table 5. Numbers of (groups of) species by building type. Chir = Chiroptera species; R fe = *Rhinolophus ferrum-equinum*; M my/br = *Myotis mystacinus/brandtii*; M na = *M. nattereri*; M my = *M. myotis*; M da = *M. daubentonii*; M ds = *M. dasycneme*; P pi/na = *Pipistrellus pipistrellus/nathusii*; E se = *Eptesicus serotinus*; P ar/au = *Plecotus auritus/austriacus*.

Building type	Chir	R fe	M my/br	M na	M my	M da	M ds	P pi/na	E se	P ar/au	Total	%
Fort (brick, soil cover)	1,438	7	13,859	4446	2	9323	7	1442	28	2193	32,745	91.7%
Concrete shelter (partially without soil)	42	-	264	146	-	213	-	38	-	336	1039	2.9%
Corridor (brick)	17	-	244	-	-	579	2	3	1	141	987	2.8%
Cellar (brick)	3	-	68	1	-	283	-	-	-	27	382	1.1%
Attic and other	8	-	51	51	-	34	-	375	13	21	553	1.5%
Total	1508	7	14,486	4644	2	10,432	9	1858	42	2718	35,706	

in their vicinity.

Fort-like buildings account for 92% of the observations (table 5), even though they only make up 53.6% of the buildings (appendix II). Although we don't have consistent quantitative data, it is quite probable that this can be largely explained by the average larger volume of forts (hence offering more area of walls and ceilings and a more stable climate) that offer more possibilities for bats to crawl away into faults and crevices.

Across the entire NDW the number of hibernating bats increased over the first two decades and stabilized over the last two decades (figures 5k-l). As, in general terms, the numbers of hibernating bats has tended to grow in the Netherlands (La Haye et al. 2020), it is quite probable that the differences are caused by site specific factors, linked to restorations, human use and (changes in) management of the sites and their surroundings. In the rest of this section we explore the possible causes of the differences in trends between the sites in four groups: sites with a positive, a stable, a negative and an uncertain trend between 2000 and 2020. Of two sites (Tienhoven (8, no data) and Griffensteyn (11, low numbers)) no trends could be calculated for this period.

The focus on sites with more than ten years of monitoring excludes several sites (Spion, Voordorp, Uppelsedijk) which have completely lost their function as hibernacula due to

restoration and intensified (commercial) use.

Whilst interpreting the calculated trends it needs to be remembered that the trends in the two periods are a generalization and that actual, local, population trends may have varied within these periods.

Sites with increasing numbers

Nine sites show a (moderately) increasing trend in hibernating bats (table 6), and these accounted for 33% of the bat observations in the period 2000-2020. Naarden (1) show a steady increase in numbers of hibernating bats. This is a recovery from a steep drop in numbers in the 1960s, a period of intensive restoration works (even during wintertime) and increased commercial use of buildings. In the period covered by this paper the use and management situation is, though varying through the years, relatively stable. Buildings in which bats hibernate are being used extensively with little access to the public. The numbers of bats in the last decade of this paper are similar to the numbers in the 1950s.

Vechten (16) was redeveloped in the late 1990s, when a management plan was adopted which combines educational and commercial use, and was preceded by improvements of the hibernacula. The half open scenic structure was largely kept intact. Most importantly

the management plan is being followed consistently (Bankert et al. 2014).

Honswijk (20) shows a continuous, yet moderate, positive trend. This site was in military use until quite late on (around 2010). As early as the 1950s, whilst still in military use, the most important building for bats, the tower, was managed as a bat hibernaculum and improvements were made to its cellars. Its redevelopment has proceeded quite gradually since that time, speeding up in recent years after a management plan was adopted in 2019. One of the aims of this plan is to maintain the site's importance as a bat hibernaculum. *Tyto alba* was a breeding resident in this fortification for quite some years but due to the increased intensity of the use of the site it no longer breeds in here, which might favour the bat population. Time will tell whether the management plan proves effective in bat conservation.

The other sites (Kijkuit (5), Diefdijk (22), Meerdijk (24), Lingebos (29) consist of (groups of) relatively small shelters of reinforced concrete, which have been made (more) suitable for hibernating bats in the past two decades. These buildings were accessible to the public until 2004. Since 2009 a management plan has been implemented to improve these sites for bats. Brakel (32) is a small fort which suffers from regular illegal entries but nevertheless shows a positive trend.

Sites with a stable trend

Four sites show a stable trend (table 6), and account for 42% of the bat observations. Rhijnauwen (14) is the most important site in this group, accounting for 30% of the observations. In the 1990s some of its buildings were restored and two others were demolished and since then the population growth stopped, although it is now stable and at a high level. It is quite likely that this is the result of the combination of its geographical position (see part I) and a relative long and good protection status: this site has little commercial use;

Table 6. Trends of bat numbers by site (for the five most numerous (groups of) species). NA: not available.

Site	1980-2000	2001-2020
Naarden	+	+
Uitermeer, torenruïne	?	-
Uitermeer, manschap verblijf	?	?
Hinderdam	?	--
Kijkuit	?	++
Nieuwersluis	++	-
Tienhovense Vaart	?	NA
Ruigenhoek	?	?
De Klop	NA	-
Blauwkapel	NA	?
Griftenstein	NA	NA
De Bilt	NA	?
Utrecht Kromhoutkazerne	NA	?
Rhijnauwen	++	0
Lunetten	NA	?
Vechten	++	+
Hemeltje	NA	0
Waalse Wetering	++	-
Korte Uitweg	++	-
Honswijk	++	+
Everdingen	?	0
Diefdijk Schaaik	NA	++
Leerdam	?	-
Meerdijk	NA	++
Asperen	+	-
Nieuwe Zuiderlingedijk zuid	NA	?
Nieuwesteeg	NA	+
Broekse sluis	NA	?
Lingebos	NA	++
Vuren	?	0
Loevestein	NA	-
Brakel	0	++
Poederoijen	++	-
Papsluis	?	-
Giessen	++	-
New Dutch Waterline	++	0
# strong increase	8	5
# moderate increase	2	4
# stable	1	4
# moderate decrease	0	11
# strong decrease	0	1
# uncertain	10	8
# not available	14	2

only a single building has been rented out and the (numerous) guided tours take place outside the hibernation period. Only *M. mystacinus/brandtii* shows a positive trend over the last two decades, compensating for a decrease in numbers among the other four main species (groups). The decrease of *M. daubentonii* is possibly linked to the disappearance of a spring colony of this species and/or a strong increase in numbers in another hibernation site (the former airbase at Soesterberg) nine km away. Another possible cause is predation or disturbance by *Martes foina* and/or *Tyto alba* in some of the buildings. In recent years some measures have been taken to prevent these predators from entering the hibernacula. A third possible cause could be the increase of guided tours and other nocturnal activities in and around some buildings, which may particularly affect swarming.

Hemeltje (17) consists of four moderately sized buildings with low numbers of bats on an otherwise commercially used fortification. In the new management scheme only one building is managed as hibernaculum.

Everdingen (21) showed a decline in bat numbers around 2010, linked to the intensified use of the fort at that time by the army for training with explosive devices. After this stopped, new forms of use (commercial and educational) were introduced and bat numbers rose again, though adequate management for bats is a continuous point of concern. More and more buildings on Vuren (30) are being turned into intensive commercial use. The most important building for hibernating bats was recently restored, mainly during wintertime, after which bat numbers dropped. Adequate management is also an issue here.

Sites with a negative trend

Eleven sites, which provide 21% of the observations, show a (moderately) negative trend (table 6). In Uitermeer (2) it is quite likely that

the negative trend is linked to the combination of management not sufficiently taking bats into account (although this has improved in recent years) and the disappearance of a summer colony of *M. daubentonii*, due to floodlighting the main building. The strong decrease in Hinderdam (4) is most probably linked to illegal entries by the public and, in recent years, to predation or disturbance by *M. foina*. In Nieuwersluis (6) numbers have dropped from 1998, most likely due the combination of changes in the surroundings (a massive enlargement of the nearby A2 motorway), restoration, educational use and the disappearance of a summer colony of *M. daubentonii*. The presence of *S. aluco* at the site might also have had a negative impact. The commercial use of the upper part of De Klop (9), the poor management of the cellars and the felling of all the trees has negatively influenced its quality as a hibernaculum, in spite of the compensating measures of thick sound and temperature insulation. Waalse Wetering (18) was cleared of all its upgoing vegetation in the late 1990s, is consistently used for storage and, during the summer and autumn, for parties. Recently plans for more intensive use are being made, with plans to shift the hibernaculum to a newly built one. Korte Uitweg (19) saw a period of bat-unfriendly restoration and use around 2000, although since then a more bat friendly management plan has been adopted, combining commercial use with a small hibernaculum. In Leerdam (23) there are no indications that the decline is linked to the management or presence of predators. In Asperen (25) restoration works, the subsequent disappearance of a summer colony of *M. daubentonii* and the intensive mixed use of the building outside the hibernation period (guided tours and art installations, amongst others in a swarming site) are all plausible causes of the decline in bat numbers. The same holds for Loevestein (31) and Poederoyen (33). Papsluis (34) was restored in 2006, and lost almost all possibilities for hibernating bats. Giessen (35) was restored by

volunteers over a long period. A few years ago it got a full, intensive, professional restoration including improvements for hibernating bats in one building.

Sites with an uncertain trend

For eight sites (3%) it is not possible to calculate a trend as the numbers are low and vary too much (table 6). The six sites north and east of Utrecht (3, 8, 10, 12, 13, 15) all have a mixed use, putting pressure on their function as hibernacula. Nieuwe Zuiderlingedijk zuid (28) and Broekse sluis (30) have recently been improved as hibernacula.

Reflections

As described above, the NDW is quite important for hibernating bats, especially for *M. mystacinus/brandtii*. From this perspective it is remarkable that there is no co-ordinated management plan for the NDW as a bat habitat and hibernaculum and that the major fortifications lack the highest protection status: Natura 2000. The fortifications which do have this status (appendix II), have it 'coincidentally', being located in areas with this status for other species. In order to legally support the preservation of hibernacula as much as possible, at least the seven of the most important fortifications should be added to Natura 2000 and managed accordingly: Nieuwersluis (6), Rhijnauwen (14), Vechten (16), Honswijk (20), Everdingen (21), Asperen (25) and Giesen (35). The urgency of establishing good co-ordination is evident as the national importance of the NDW for bats is becoming increasingly dependent on fewer sites. Moreover, unlike the national trends, numbers of hibernating bats in the NDW as a whole hardly increases anymore.

Maintaining or improving the importance of fortifications as hibernacula can co-exist with other uses, including commercial

activities, as is the case at Vechten (16). But, as we see in other fortifications such as Nieuwersluis (6), Waalse Wetering (18) or Asperen (25) it is far from easy to ensure a good balance, even when the fortification is owned by a nature management organisation, which often rent parts of the fortifications to commercial tenants. Proper conservation and development of fortifications as good bat habitats requires an adequate construction (adapted or improved for bats) of the buildings and appropriate management of the buildings and the vegetation on and around the buildings, with a good and unlit connection with surrounding landscapes. Above all, it is crucial that the people responsible for the management of the sites show an intrinsic dedication to bat conservation.

The positive trends in relatively small hibernacula where measures have been taken to make them (more) suitable as a hibernaculum show that a further improvement of the NDW as a bat (winter) habitat is possible. However, this can by itself never compensate for any further decline in numbers caused by the more intensive exploitation of the bigger sites with large buildings. These fort-like buildings are very important and highly suitable as hibernacula. The conservation and optimisation of these larger brick buildings is a more cost effective conservation method and should therefore be a priority.

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Hibernating bats along the Dutch coast

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Abstract: Hibernating bats along the coast of the Dutch provinces of Noord-Holland, Zuid-Holland and Zeeland are described from the first counts in the early 1960s until the winter of 2020, with an emphasis on trends since 1990. The main hibernacula complexes are located in the Natura 2000 dune areas of Meijndel-Berkheide and Kennemerland-Zuid, the Noord-Holland dune area, Kapittelduinen, Voorne and Schouwen. The inner dunes of the remaining coastal areas and the Delta also contain significant numbers. Until now, no hibernating bats have been found on the Wadden Islands. In most areas the numbers counted have increased strongly, though a large part of this may be due to hibernacula being better protected from disturbance. Much of the increase in bats counted is due to a strong increase in the numbers of Daubenton's bat (*Myotis daubentonii*), which is by far the most numerous hibernating species along the Dutch coast (around three quarters of the total), with record numbers counted over the last few winters. Pond bats (*M. dasycneme*) are the second most populous species (around 13%), hibernating in bunkers between IJmuiden and Hoek van Holland. During the winter of 2019, a maximum of 682 animals of this species were counted, of which 578 were in Meijndel-Berkheide. This Natura 2000 area is by far the most important hibernating area for the pond bat in the Netherlands. Brown long-eared bats (*Plecotus auritus*) and whiskered bats (*M. mystacinus*) account for around (8% and 5% resp.) of the total each with up to 400-300 respectively counted per year. Their numbers can fluctuate strongly, and the later species is mostly found in the dune area between The Hague and Wassenaar. Natterer's bats (*M. nattereri*) hibernate in modest numbers (just 1%) of several dozen (41-86) animals each year along the Dutch coast between IJmuiden and The Hague and on the islands of Schouwen, Walcheren and Goeree. The most important complex for this species is the Kop van Schouwen, with several dozen winter visitors. The remaining of the twelve hibernating bat species found hibernating in the coastal area during this period are Geoffroy's bat (*M. emarginatus*), greater mouse-eared bat (*M. myotis*), common pipistrelle (*Pipistrellus pipistrellus*), Nathusius' pipistrelle (*P. nathusii*), serotine (*Eptesicus serotinus*), barbastelle (*Barbastella barbastellus*) and grey long-eared bat (*Pl. austriacus*). The figures from the counts are compared with the national trend, calculated by Statistics Netherlands (CBS), which shows an increase in the numbers of most species, but less pronounced than the numbers recorded in these censuses. In the last ten years there has been a decline and/or fluctuations in the numbers of some species counted, notably the whiskered bat, Natterer's bat and the brown long-eared bat. In the first case this may be due to milder winters leading this species to hibernate in tree hollows, etc. In the later case it reflects a national decline in numbers. A long term comparison between bunkers that are privately managed and those managed by nature conservation agencies shows that the latter are more effective in attracting increasing bat populations.

Keywords: Dutch coast, hibernating bats, Natura 2000, bunkers, bat trends, whiskered bat, Natterer's bat, Daubenton's bat, pond bat, brown long-eared bat.

Introduction

The Dutch coastal zone covers three Provinces, (from north to south) Noord- and Zuid-Holland and Zeeland. Ecologically it contains the outer dunes, and the inland dune area of the mainland dunes, together with the islands of Zeeland and Zuid-Holland and the former estuaries in the Delta area. Scattered over this area are hundreds of sites in which bats hibernate (figure 1). Many of these sites are bunkers from World War II that formed a defence against an Allied attack. There are also a few bunkers on the Wadden Islands, but since no hibernating bats have yet been found there, this area is not considered further here.

The first count of bats in hibernacula along the Dutch coast dates from 1963 when the Middenduin ice-cellar near Overveen was visited. From 1967, an increasing number of abandoned ice cellars were established as hibernacula for bats, using patio blocks, and counted including Landgoed Waterland and Belvedere. Ten years later, Huis te Manpad (1977; years in brackets after a location indicate the first count in this particular hibernaculum) and the Elswout estate (1979) were added.

The first incidental counts in Zuid-Holland were made in 1968, when three whiskered bats (*Myotis mystacinus*) were found in the burial vault at Warmond and one whiskered bat (van Wijngaarden et al. 1971) and a pipistrelle (notes of Mr. Wey, SBB) in the Prins Hendrik fort in Ooltgensplaat. The first annual counts in the coastal area took place in 1977 in the bunker complexes near Meijendel (Lina et al. 2022, in this issue).

This contribution provides an overview of all the known hibernacula of bats along the Dutch coast. Although the entire history of hibernating bats along the Dutch coast is outlined, the emphasis is on the period starting in the 1990s. Since then, most sites have been counted annually, enabling an estimation of annual trends.

In this paper, the coastal area is subdivided

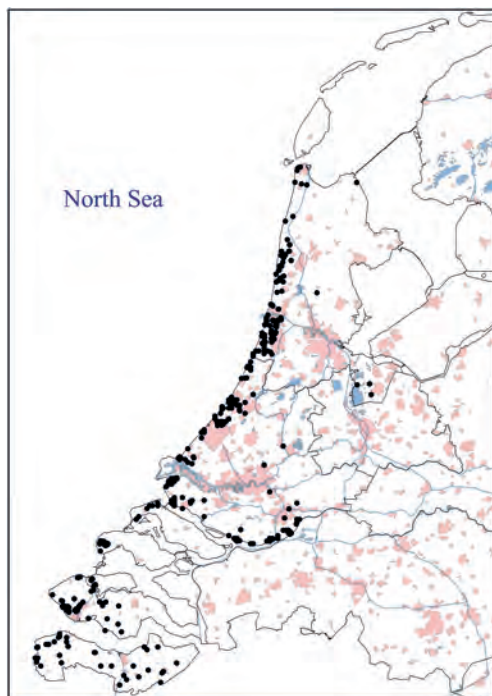


Figure 1. Hibernacula of bats along the Dutch coast and in the delta region.



Figure 2. Broken lintel ceiling with hibernating Daubenton's bats, Haamstede. Photo: Kees Mostert.

into 17 subareas and the results of the bat counts/surveys are discussed from north to south, based on these sub-areas. This is followed by a general picture for the entire Dutch coast, followed by a separate discussion of all the bat species encountered. We then compare developments in the coastal area with the national trend, calculated by the Netwerk Ecologische Monitoring (NEM) since 1986 (La Haye et al. 2022, in this issue). Finally, the relationships between summer roosts and hibernacula and the opportunities and threats facing different bat species are discussed.

Descriptions of winter quarters

Types of sites in the coastal area

The majority of the sites with hibernating bats along the Dutch coast consist of bunkers in the dune area (92%). Groups of bunkers at a short distance from each other ('complexes') are present in the Noord-Holland dune area (Castricum-IJmuiden), Kennemerland-Zuid (IJmuiden-Noordwijk), Meijendel and Berkeheide, the Staelduinse Bos and Hoek van Holland (Kapittelduin), Voorne, Goeree, Schouwen and Walcheren. These complexes, sometimes have underground tunnel systems connecting various bunkers with each other. Some bunkers still remain in the inner dune area although most were removed shortly after the Second World War. The bunkers are mostly made of reinforced concrete with a wall thickness ranging from 50 cm up to two metres. The thickness of the ceilings can be up to three and a half metres. There are many different types of bunkers, from small artillery bunkers, '*tobroeks*', to large bunkers, consisting of several rooms. In general, it is easy to investigate these bunkers quite thoroughly. The spaces are clearly arranged and the places to hide in the different types of bunkers can be found in predictable places. Bats are regularly found in air and ventilation shafts that are closed off from above and in cable ducts.

The flat ceilings and walls are easy to view and the recesses for support beams at different heights are also easy to inspect. Special mention should be made of the lintels, consisting of four tubes, with which the ceiling is covered. A number of bat species have a preference for the spaces in partially broken lintels (figure 2) (Bekker 2019). These constructions were used in ammunition bunkers on Goeree, in four storage bunkers in the Slotbos Haamstede and in six air raid shelters in Oranjestad.

In most hibernation sites, bats hide in crevices and holes, preferring closed air vents, cracks and crevices behind, for example, loose plaster. The original windows and doors are often bricked up. In a number of bunkers, measures have been taken to improve the indoor climate.

A total of 819 hibernacula have been used by bats in the coastal region, of which 203 are in Noord-Holland, 474 in Zuid-Holland and 142 in Zeeland (figure 3). In the inner dune area, there are a small number of ice cellars on country estates, where bats hibernate. There are eight ice cellars in Kennemerland-Zuid in Noord-Holland. The ice cellar in Middenduyn near Overveen is particularly popular among hibernating bats. In the 1980s, inventories were started in the ice cellars at the Duin en Kruidberg, Nova Zembla (1983) and Midden-Herenduyn (1986) estates. In Zuid-Holland there are three ice cellars in the inner dune area, at Wittenburgh, the Horsten and Endegeest. However, the Horsten is closed off (but accessible to bats) and no bats have so far been found in Endegeest. Of particular interest is the ice cellar on the Dordwijk estate in Dordrecht, which was first counted in 1981. The only ice cellar in Zeeland (in Middelburg) was bricked up in the 1980s and is therefore inaccessible to bats. Besides ice cellars, there are a limited number of other underground storage sites (e.g. potato cellars) where bats hibernate, such as in Zeeuws-Vlaanderen.

On the islands of Zuid-Holland and in Zeeland there are several forts and ruins where hibernating bats have been found

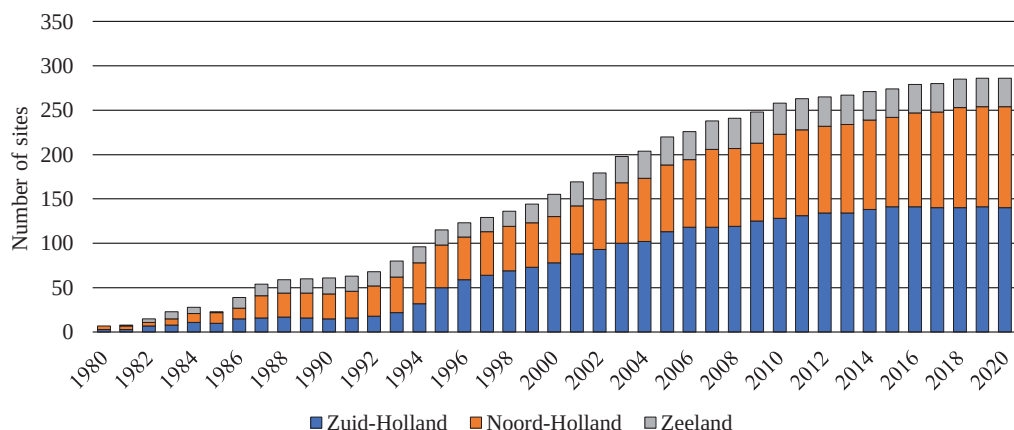


Figure 3. The number of surveyed bat hibernacula along the Dutch coast (sites with no bats or occasionally with a few animals are not taken into account).

in the cellars or in closed corridors. These are: Fort Nieuwenhoorn on Voorne, Fort Hoeksche Waard, Fort Rammekens, the Keldermanspoort near Hulst and the Stenen Beer near Sluis. There are two sites, the Ruïne van Brederode and the Dom van Veere, where hundreds of pipistrelles hibernated in some years in the higher parts of the buildings. These hibernating groups of pipistrelles are not considered further in this article because the vast majority spend the winter mainly in cavity walls or similar places (Kapteyn 1997). Other hibernation sites include several artificial caves on estates in the inner dune area in Zuid-Holland and three drainage sluices and a lime kiln in Zeeuws-Vlaanderen.

The locations of the hibernacula

The first bat counts of hibernation sites along the Dutch coast took place in the mid-1960s. From the second half of the 1970s onwards, the bats in several sites were counted annually and since the 1990s approximately 140 up to 280 are counted annually.

In the vicinity of Den Helder and Callants-oog, there are a small number of sites in the coastal area. These are the Hospitaal St. van Den Helder (1987), Julianadorp (1988), Wild-

rijk (1991), Pettemerduin Korfwater (1994), the Julianadorp aan Zee bunkers (2009), the ammunition bunker behind Huisduinen (2015) and the dog training bunker at Streepjesberg (2018).

The vast majority of these sites are located in the Noord-Hollands Duinreservaat and Schoorlse Duinen near Bergen (1992) and the Wimmenummerduinen near Egmond (1994), while Klimweg Schoorl (1983) and Abdij Egmond-binnen (1993) are more remotely located.

There are many bunkers in the subarea south of the Noordzeekanaal down to Noordwijk (in Zuid-Holland) particularly in the Kennemerland-Zuid dune area, including in the Amsterdamse Waterleidingduinen (hereinafter AWD) (see Lange et al. 2022, in this issue). To the south of this, in the vicinity of Noordwijk, there is a large bunker complex and a few small bunkers. In the 1980s, counting started at Duinen Kruidberg, Nova Zembla (1983), Klimweg Schoorl (1983), Kraansvlak A and B, Kennemerduinen (1983), Landgoed Leyduin (1984), AWD (1986), Midden-Herenduin (1986) and Landgoed Beeckesteijn (1989). The first counts of the bunkers north of Noordwijk were done in 1982 and the Ruïne van Brederode has been counted since the early 1990s.

In Meijendel and Berkheide, between The



Figure 4. Above-ground bunker Staelduinse Bos, Hoek van Holland. *Photo: Kees Mostert.*

Hague and Katwijk, there are a number of large bunker complexes, namely Delfland-bunker, the DWL bunker, Wassenaarse Slag, Uilenbosch and Moffenslag. These complexes are among the most important hibernacula for bats along the Dutch coast, especially for the pond bat (*Myotis dasycneme*). Lina et al. (2022, in this issue) provide an extensive overview of trends in these large bunker complexes. In addition, there are a number of small bunkers scattered throughout the area with small numbers of bats. The first counts took place here in the late 1970s when most of the sand was dug out of the bunkers. In 1993 and 1995 the small bunkers near Zwarte Pad and the Klip were first counted, as well as a number of bunkers in Berkheide.

In the inner dune area, bunkers are to be found on the Nieuw-Leeuwenhorst estate (1994), the Zuidwijk Estate (2000), the Maaldrift defence site near Wassenaar (1999) and private bunkers on the Wassenaar estates (1996). Bunker complexes on the Clingendael Estate (1995) and in Rijksdorp (1998) and Valkenburg (1997) harbour large numbers of bats. Some locations have become part of the built-up area of The Hague, including a tennis club (2001), a park and Arendsduin Estate and the Ockenburgh Cemetery (both 1999). Some

other estates such as the Voordes in Rijswijk have bunkers, but bats are only sporadically seen there.

In the Westduinpark (1998), near The Hague, there is a complex of dozens of small bunkers with a long corridor. As this narrow dune area is very close to The Hague and Scheveningen, the bunkers attract a number of unwanted visitors. Since the late 1990s, a number of these bunkers have been closed off to improve their suitability for hibernating bats.

The first census in Hoek van Holland was conducted in 1981. The Kapittelduinen dune area, a Natura 2000 site, which lies between Hoek van Holland, the Staelduinse Bos and the Nieuwlandse Dijk contains a number of bunkers and there are some more just outside the site in the Galgweg. Hoek van Holland has both a large network of corridors and a number of small bunkers. The Staelduinse Bos contains many dozens of above-ground bunkers and the Nieuwlandse Dijk has a number of small bunkers, which are regularly broken into (figure 4). The Hoek van Holland dune area and the Staelduinse Bos were both previously owned by the Ministry of Defense, and ownership of these areas was transferred to Het Zuid-Hollands Landschap in the late

Table 1. Number of sites and complexes per subarea with hibernation sites which are counted annually. Also shown is first the winter season in which the vast majority of hibernating bats (>90%) were counted in these sites.

	Number of sites	Complexes	>90% of bats counted since
Den Helder-Callantsoog	7	4	1993
NH Duinreservaat [& Schoorlse Duinen]	43	14	1994
Wimmenumerduinen	11	1	2001
AWD	47	6	1987
Remaining Kennemerland-Zuid	95	26	1992
Noordwijk	24	5	2005
Meijendel-Berkheide	103	18	1986
Binnenduin Den Haag-Wassenaar	58	11	1998
Westduinpark	23	7	2005
Kapittelduinen	83	15	1986
Dunes of Voorne	119	24	1996
Dunes of Goeree	25	8	1994
Hoeksche Waard	21	6	2005
Eiland van Dordrecht	18	7	2001
Kop van Schouwen	65	8	1986
Manteling Walcheren	47	13	2000
Zeeuws-Vlaanderen	30	10	2002

1980s and early 1990s. The first counts were made here in 1981 and 1986 respectively.

In the remaining Delta area (Hoeksche Waard and the Eiland van Dordrecht, both 2000) a number of casemates can be found along the dikes of Haringvliet and Hollands Diep. Some of these sites are equipped for hibernating bats.

The first counts on Voorne took place in 1982 at Wasserman, Haringvlietdam and polder Quack. The dunes of Voorne contain a large number of small bunker complexes, of which Wasserman, the Biberbunker, Hesterhof and the Bernhard complex (1994) are the most important for hibernating bats. The inner dune area also has several dozen privately owned bunkers. Since the mid-1990s, the number of sites counted has increased sharply.

On Goeree (2001) there are a number of scattered small bunkers, in the inner dune area of Oostduinen, the Punt van Goeree and along the Grevelingendijk near the Preekhilpolder (Mostert 2005).

In the province of Zeeland, the first count

was carried out in the Stenen Beer near Sluis in 1981. In the following years, Fort Rammekens (1982), the former boarding school in Sluis (1982), the Kop van Schouwen (1983), Groede and the Keldermanspoort near Hulst (1985) were also counted. Since the late 1980s, these hibernation sites have been visited annually.

In the Kop van Schouwen, a large number of bunkers in the Slotbos Haamstede and scattered bunkers in the adjacent dune area are used as hibernacula.

A few suitable hibernation sites have been counted on Walcheren since the 1980s: Fort Rammekens, the bunkers at Valkenisse (1986) and Oranjezon (1988). Since 1998, the bunkers in the Toorenvliet Park and some old sewer ditches in Middelburg have also been counted regularly. The counts here have been more complicated because a number of bunkers were regularly broken open and then closed again, so some bunkers were not always accessible for counting. A number of scattered above-ground bunkers in the arable areas have also been included in the annual count. Since 1999, six bunkers along the Onrustweg

in Noord-Beveland (directly bordering Walcheren) have also been counted.

In the 1980s, a small number of suitable hibernation sites were discovered in Zeeuws-Vlaanderen, including the former boarding school St. Joseph in Sluis which was in use until 1944 after which it fell into disrepair. The demolition of the building only started in 1990 and in 1995 the cellars were also demolished. A number of hibernation sites are no longer accessible for research or are no longer suitable, such as the Suatieluis Reigersbosch and the Keldermanspoort near Hulst.

Table 1 shows the number of sites and complexes per subarea and the first year when hibernating bats were counted in these sites, allowing for a reliable trend calculation. The number of counted sites has increased over the years, especially until around 2010, after which the trend levelled off (figure 3). The increase was mainly caused by bunkers that had previously been buried under a layer of sand being exposed and dug open by bunker searchers.

Results

First, we discuss the number of hibernation sites per subarea (from north to south) and the average number and species of hibernating bats within them. These subareas are arranged as much as possible by Natura 2000 area. We then go on to present the population trend for each species along the entire Dutch coast, showing both the absolute numbers counted and the trends, both for the coastal zone and the Netherlands a whole (calculated by Statistics Netherlands (CBS)).

Number of sites and bats per subarea

Most sites in the coastal area are found in the mainland dunes, especially in the inner dune area between IJmuiden and The Hague (fig-

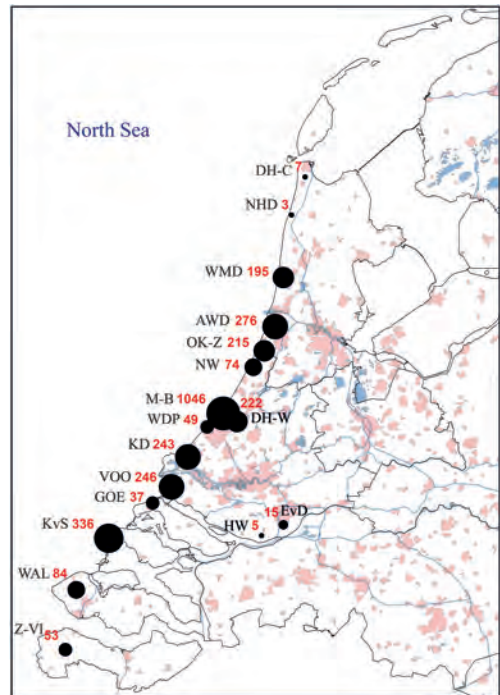


Figure 5. The average number of annual hibernating bats per subarea over the period 1990-2020.

ure 1). A large number of hibernation sites can also be found in the dune areas of the Zuid-Holland and Zeeland Islands. The Hoeksche Waard and the Eiland van Dordrecht have a number of casemates along the dikes of the former sea inlets of Haringvliet and Hollands Diep, which are also considered part of the coastal area.

The division into areas is based on the Natura 2000 areas as much as possible. From north to south these are: Den Helder-Callantsoog, Noord-Hollands Duinreservaat and Schoorlse Duinen, Kennemerland-Zuid, Meijendel-Berkheide, Westduinpark, Solleveld & Kapittelduinen, Voorne, Goeree, Schouwen and Walcheren. Areas that are not designated as Natura 2000 sites are the inner dune of The Hague-Wassenaar, the inner dune near Haarlem, the Hoeksche Waard, Eiland van Dordrecht and Zeeuws-Vlaanderen.

In most subareas the numbers of bats has increased significantly since 1980, mainly

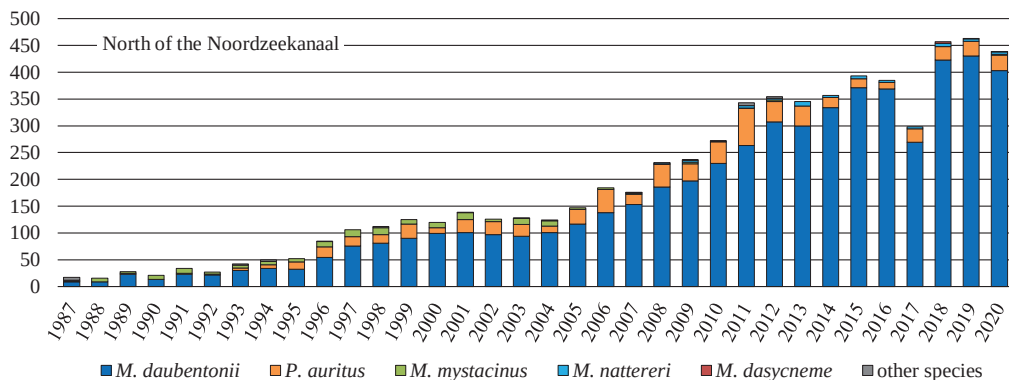


Figure 6. Number of hibernating bats north of the Noordzeekanaal (excluding Wimmenummerduinen).

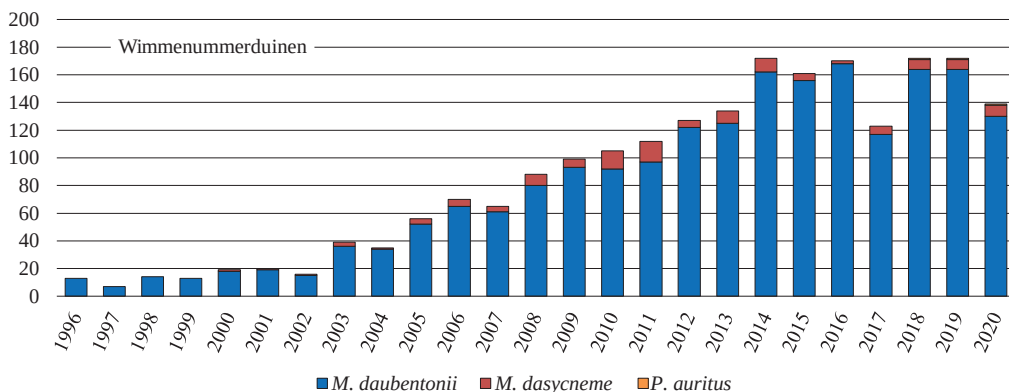


Figure 7. Number of hibernating bats in the Wimmenummerduinen (Castricum).

due to an increase in Daubenton's bat (*Myotis daubentonii*). Year on year changes in the absolute numbers of hibernating bats counted are not strictly comparable as an indicator of the total bat population as many new sites were found and/or included in the counts in the 1980s and 1990s. However, the index values calculated by Statistics Netherlands (CBS) also show an increase in the numbers of most species, although somewhat less pronounced than the increase in absolute numbers.

The average numbers of hibernating bats per year for the period 1990-2020 are presented in figure 5. This shows that the most important areas on the Dutch coast for hibernating bats are Kennemerland-Zuid and the AWD,

Meijendel-Berkheide, Kapittelduinen (Stael-duinse Bos and Hoek van Holland), Voorne and Schouwen. The results in the Natura 2000 areas and other subareas are explained in more detail below.

Dunes north of the Noordzeekanaal

The coastal strip between Den Helder and Callantsoog, the Noord-Hollands Duinreservaat and the Schoorlse Duinen, forms an almost continuous dune area north of the Noordzeekanaal. The numbers of bats counted since 1987 shows a clear upward trend (figure 6). In the vicinity of Den Helder, initially only a few brown long-eared bats (*Plecotus auritus*) hibernated, while Daubenton's bats were also found

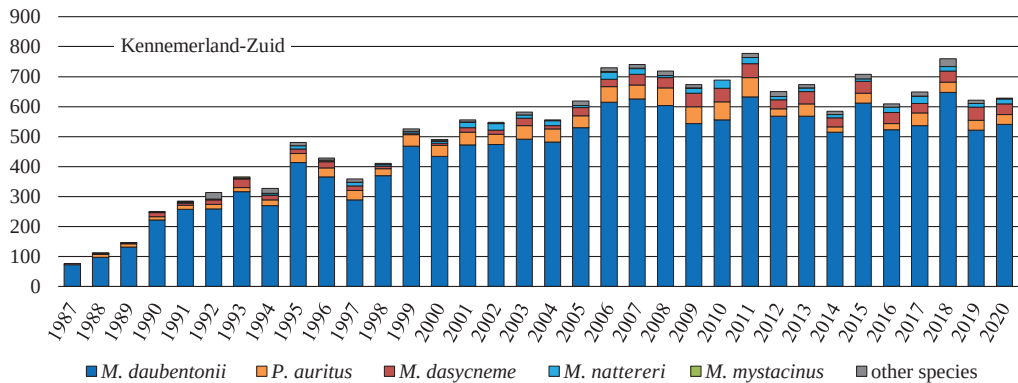


Figure 8. Number of hibernating bats in Kennemerland-Zuid (IJmuiden-Noordwijk including the AWD).

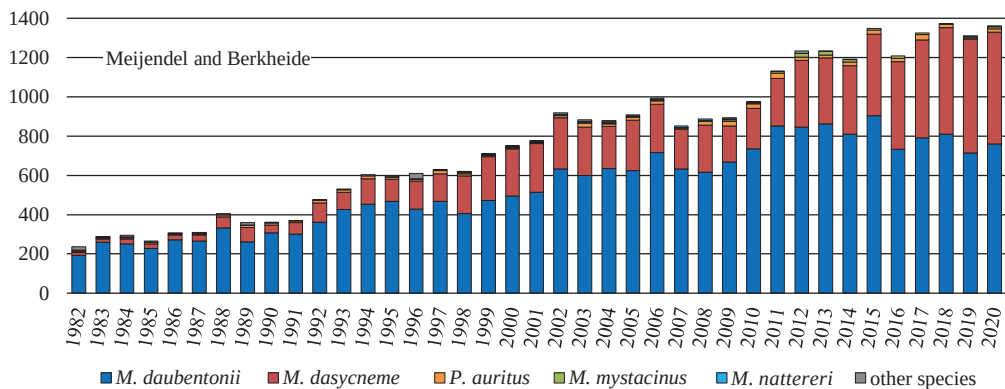


Figure 9. Number of hibernating bats in the Meijndel and Berkheide Natura 2000 area.

in the vicinity of Callantsoog. In recent years, more bats have been counted in the Wildrijk, with 30 Daubenton's bats and three brown long-eared bats in 2019.

The numbers of bats in the Wimmenumerduinen, in the south of the subarea, have increased rapidly since 1996 (figure 7). However, an increase has also been noted at other sites, with several Natterer's bats and a single pond bat counted in recent years. In recent years, the whiskered bat has disappeared as a regular hibernating visitor from Schoorl and Egmond-binnen.

There are two other sites in the vicinity of Beverwijk. The allotment garden complex near Beverwijk was counted from 1998 to 2016. Small numbers of Daubenton's bats and brown

long-eared bats hibernated there every year but since 2014, no bats have been found there. The Forteiland near IJmuiden was only counted in 1997 and 1998. This resulted in one to four whiskered bats, seven to eleven Daubenton's bats, a pond bat and a brown long-eared bat. No counts were made in other years.

Kennemerland-Zuid (IJmuiden-Noordwijk including the AWD)

The number of hibernating bats in this part of the coastal zone increased from 249 in 1990 to 778 in 2011, followed by a slight downward trend (figure 8). The pond bat and brown long-eared bat show a sustained increase with maximum numbers in 2011 of 47 and 64 animals respectively, since then the numbers have

fluctuated somewhat. The same goes for Natterer's bat, which increased to a maximum of 27 animals in 2010, but whose numbers have fluctuated since. The whiskered bat has always been scarce (up to four animals), and in recent years has not been spotted hibernating.

The large bunker complex near Noordwijk has been examined for bats since 2005, after having being closed for years. The number of bats counted increased from seven in 2005 to 33 in 2020.

Meijendel and Berkheide

There is a central complex of bunkers at Meijendel en Berkheide and a small number of bunkers spread around. These have been investigated since 2000 and dozens of hibernating bats are counted each year (figure 9; see also Lina et al. 2022, in this issue). This is the only place in the coastal zone where a greater mouse-eared bat has been spotted hibernating since 2014 (figure 10).

The inner dune area of The Hague and Wassenaar

Up to 400 bats hibernate here (figure 11) and the large number of whiskered bats (100-150) is striking. This makes it the most important stronghold for this species in the coastal area of the Netherlands. There has also been an increase in the number of pond bats here (figure 12).

There are a few known ice cellars in the Horsten, Wittenburgh and Endegeest and a few artificial caves on the estates of Berensteyn and Backershagen. In addition, there is an underground space under a church building, a lime kiln in Katwijk and a burial vault in Warmond. The ice cellar in the Horsten was opened once, in 1995, following a restoration, when eight Daubenton's bats were counted. Apart from this, this site has not been counted.

Westduinpark

Since the late 1990s, the number of hibernating Daubenton's bats in the Westduinpark near The Hague has increased almost



Figure 10. Greater mouse-eared bat, Meijendel, The Hague. Photo: Kees Mostert.



Figure 12. Hibernating pond bat, The Hague. Photo: Kees Mostert.

every year (figure 13). Initially there were a few dozen, but in 2013, 100 Daubenton's bats were counted for the first time and also four

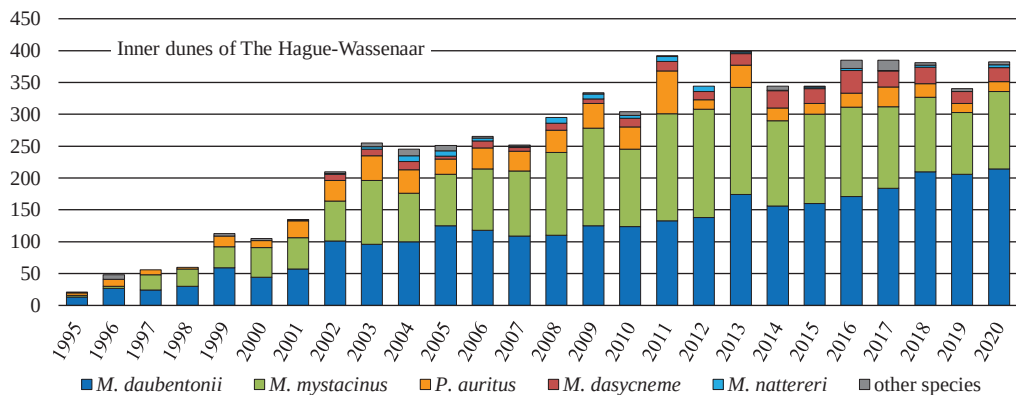


Figure 11. Number of hibernating bats in the inner dune area of The Hague-Wassenaar.

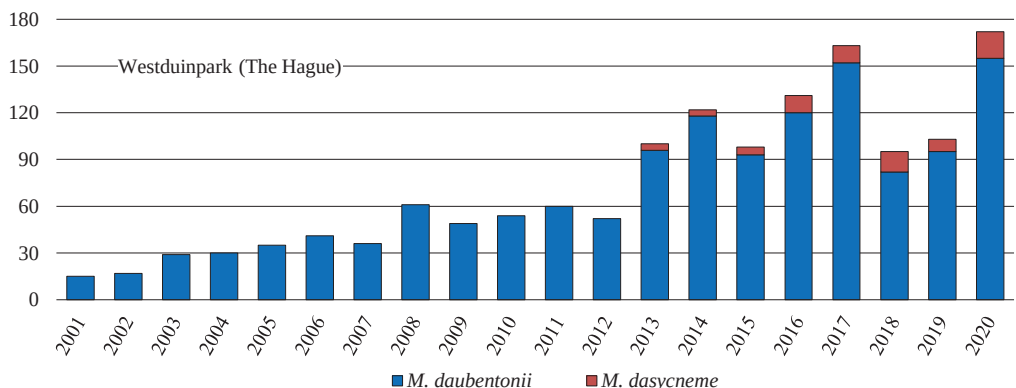


Figure 13. Number of hibernating bats in the Westduinpark near The Hague.

hibernating pond bats were found here for the first time. In the winter of 2020, a total of 172 hibernating bats were counted, the largest count during the whole period: 155 Daubenton's bats and 17 pond bats. This makes the Westduinpark an important hibernation site for Daubenton's bats and increasingly, for the pond bat. It is the only dune area where only two bat species have been observed during the study period.

Kapittelduinen (Hoek van Holland and Staelduinse Bos)

The counts in Hoek van Holland in the 1980s initially yielded relatively few bats (5-16 animals), with 26 animals in 1988. When the regular winter census was resumed in 1994,

58 bats were counted and then the number increased to 97 animals in 1999 (figure 14). Since then, a period of regular break-ins has caused a sharp decline in numbers. Only when intensive measures were taken to prevent disturbances did the annual counts increase again. Since 2011, the pond bat has been encountered almost annually.

The first count in the Staelduinse Bos in 1986 yielded 23 bats. The number increased from 38 to 97 animals between 1992 and 1993, partly due to the efforts of the volunteer fire brigade, which made a number of bunkers much more humid. Subsequently, the number of bats counted grew further to several hundred per year (figure 15). Several dozen bats also hibernate along the Galgeweg and the

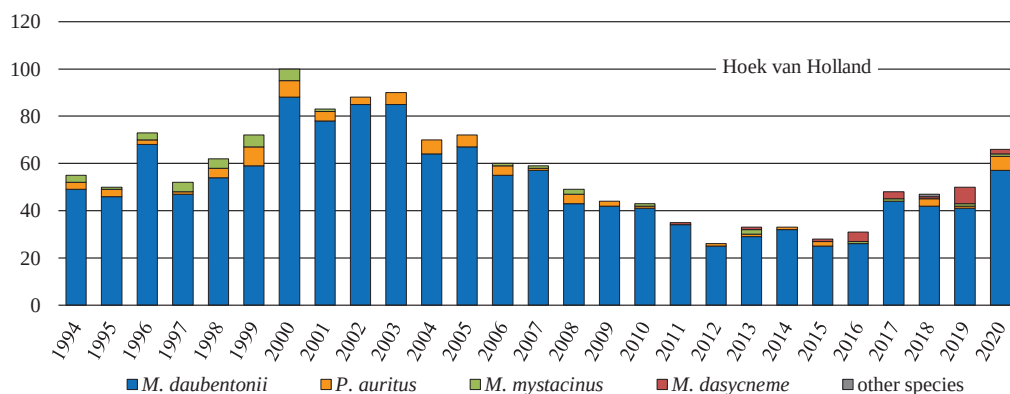


Figure 14. Number of hibernating bats in Hoek van Holland.

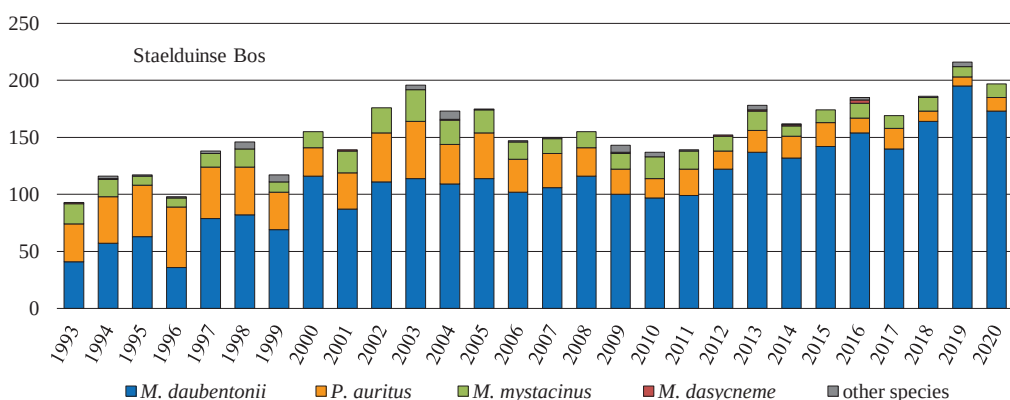


Figure 15. Number of hibernating bats in the Staelduinse Bos.

Nieuwlandse Dijk. In recent years, the number of pond bats has clearly increased in these sites. However, the number of whiskered bats and, especially, the number of brown long-eared bats has decreased over the years (figure 15). The largest numbers of these species were counted in 1994 (18 whiskered bats) and 1995 (53 brown long-eared bats). For many years a maternity colony of brown long-eared bats was present in summer and occasionally a solitary Daubenton's bat (Mostert 1990a).

The dunes of Voorne

The dunes of Voorne have a large number of small bunker complexes, of which Wasserman, the Biber bunker, Hesterhof and the Bernard complex are the most important for

hibernating bats. In the inner dune area, there are also several dozen bunkers that are privately owned.

During the 2020 census, 441 bats were found in the dunes of Voorne, including 389 Daubenton's bats, 42 brown long-eared bats and seven pipistrelles (figure 16). This makes it clear that the winter habitats in the dunes of Voorne are an important hibernating spot for bats on the Dutch coast. The whiskered bat has not been seen hibernating here since 2013.

Goeree

The number of bats counted on Goeree has fluctuated between 37 and 56 each year since 2000 (figure 17). The bats found are mainly Daubenton's bats (30-50 animals) and some

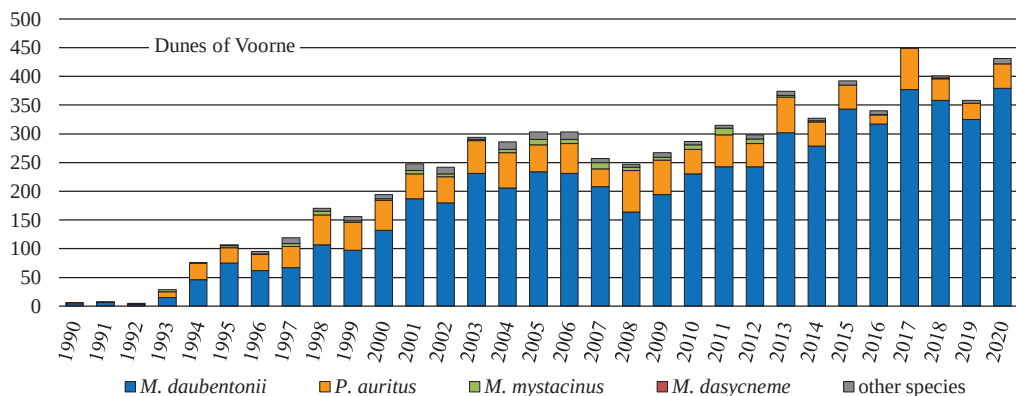


Figure 16. Number of hibernating bats in the dunes of Voorne.

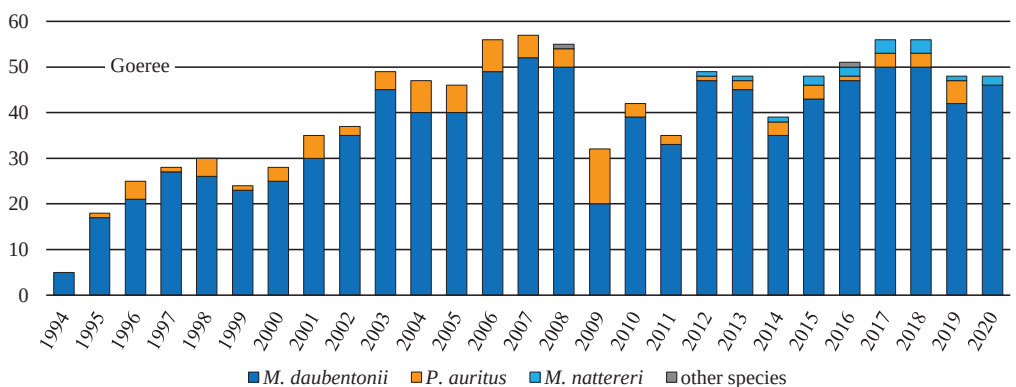


Figure 17. Number of hibernating bats on Goeree.

brown long-eared bats (up to seven animals). Since 2012, Natterer's bat has become a regular hibernator here, although the numbers remain modest (one to three animals). Other species have not yet been recorded here.

The remaining Delta area

In the Hoeksche Waard and on the Eiland van Dordrecht there are a number of casemates along the dikes of the Haringvliet and the Hollands Diep. Some of these sites are suitable for hibernating bats, mainly lodging brown long-eared bats. In most years a few whiskered bats were counted in the ice cellar on the Dordwijk estate, but since its restoration a few years ago no further animals have been found there.

In the casemates and bunkers on the dikes, there is a relatively small number of brown long-eared bats, whose numbers are increasing slowly but surely. Since 1994 more sites are visited in the winter, including the Tong and Zuidplaat. More and more bunkers appear to be used as hibernating quarters. The first Daubenton's bat was reported in 2001, and their number had grown to nine individuals by the 2020 census.

The first count in the Hoeksche Waard took place in 2000. So far, only hibernating brown long-eared bats have been found there, with less than ten individuals in most years, except in 2015, when 15 individuals were counted (figure 18).

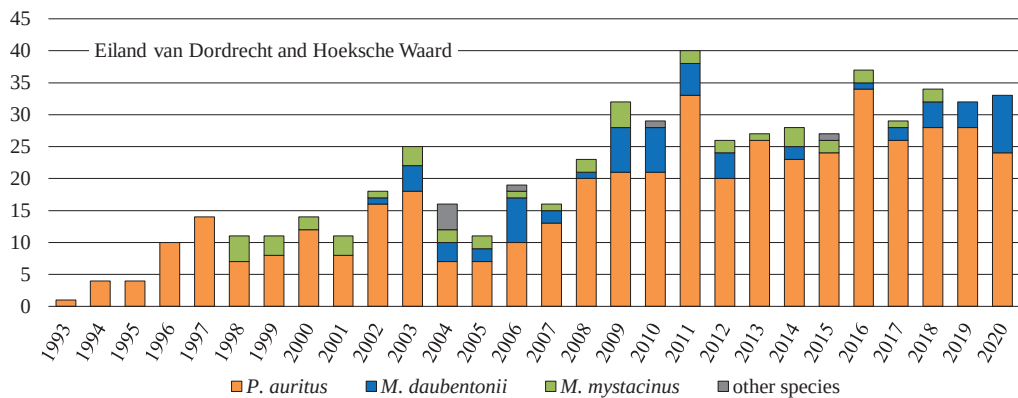


Figure 18. Number of hibernating bats on the Eiland van Dordrecht and the Hoeksche Waard.

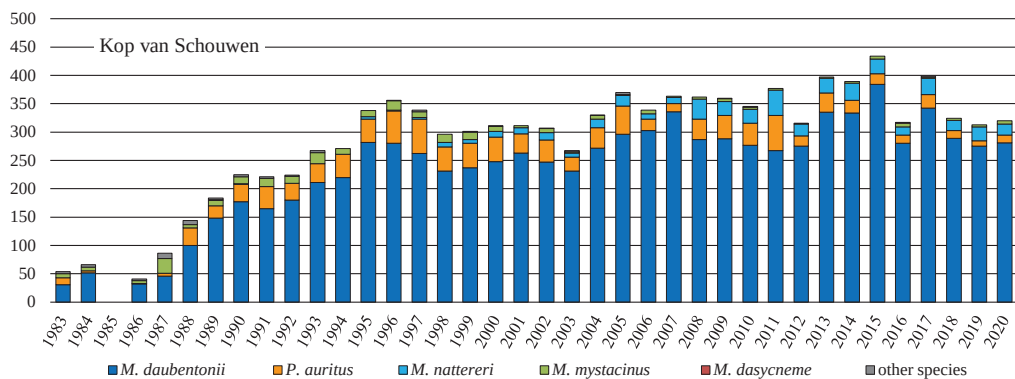


Figure 19. Number of hibernating bats on the Kop van Schouwen.

Kop van Schouwen (Slotbos Haamstede and the adjacent dune area)

The Slotbos Haamstede on Schouwen is by far the most important hibernation area in Zeeland, with several hundred hibernating bats each year. In the adjacent dune area there are also small numbers of bats in a few scattered bunkers. The first census took place here in 1983, finding 54 bats. After measures to protect the hibernacula were taken, the count increased sharply in the second half of the 1980s to 228 animals in 1990 and then to 358 animals in 1996. Since then, the count has started to fluctuate annually at a high level, peaking in 2005 (370 animals) and 2017 (383 animals). Daubenton's bat accounted for most of the growth in numbers. Initially, the num-

ber of brown long-eared bats counted also increased to a high number of 61 animals in the winter of 1997, but since then has declined steadily, with only 10-13 hibernating animals in recent years (figure 19). The number of whiskered bats has also decreased slowly, with only three to six animals in recent winters. The first Natterer's bat in the Slotbos Haamstede was noticed in 1990 and four specimens were counted in 1995. Since then, the numbers have increased annually to several dozen hibernating individuals, with a peak in the winter of 2011 of 45 hibernating individuals. Hibernating pond bats were found twice and once, in 2017, a single Geoffroy's bat (figure 20) (Mostert & Bekker 2017).



Figure 20. Geoffroy's bat, Haamstede. *Photo: Kees Mostert.*

Walcheren

Oranjezon is now the preferred location for hibernating bats on Walcheren. The first count took place here in 1988. Until the mid-1990s, a small number of brown long-eared bats were found here, although the number remained below 20 animals. Since 2000, the number of bats has steadily increased, to more than a hundred animals in recent years. The largest increase was among Daubenton's bats. The number of brown long-eared bats initially increased to 21 in the winter of 2010, after which the numbers started to fluctuate. The first Natterer's bat was seen here in the winter of 2002 and nine individuals were counted during the 2020 census (figure 21).

Fort Rammekens, with some water cellars, was one of the first sites on Walcheren where small numbers of bats were found when counting began in 1982. In the 1990s, less than ten bats were usually counted although there 18 in 1999. From 2005 the numbers increased to several dozen animals, with a maximum of 41 Daubenton's bats and one brown long-eared bat in the winter of 2007.

The bunkers at Valkenisse have been counted since the mid-1980s. At the time it sheltered some Daubenton's bats and whiskered bats and an occasional Natterer's bat. In the 1990s, the numbers started to increase to a limited extent, reaching a maximum of 20 animals in 2008 (14 Daubenton's bats and six brown long-eared bats).

Small numbers of Daubenton's bats have been counted periodically since the 1990s in Toorenvlietpark in Middelburg. A maximum of 21 Daubenton's bats (in 2011) and of three brown long-eared bats were counted (in 2007 and in 2018). Occasionally, a few bats hibernated in the sewer ditches of Middelburg, including a Natterer's bat in 1999; since 2001 no more animals have been found here.

Since the 1990s, several scattered, above-ground bunkers in the fields on Walcheren have been periodically surveyed, and a few hibernating Daubenton's bats and brown long-eared bats occasionally observed along the Strandweg and Koudekerkseweg. Over the last 20 years, more of these bunkers have been counted, such as those on the Lageweg, Verbrande Hofweg, Abeelseweg and Groeneweg, Westkapelle and Buttinge. Because of this, the number of bats counted has increased somewhat. Every year several dozen hibernating bats are encountered, with a maximum of 42 Daubenton's bats and ten brown long-eared bats in the winter of 2008.

Adjacent to Walcheren, a few hibernating Daubenton's and brown long-eared bats have also been found on Noord-Beveland along the Onrustweg in recent winters.

Zeeuws-Vlaanderen

In the 1980s, a small number of suitable hibernation sites were known about in Zeeuws-Vlaanderen. Since then, a number of them have disappeared (the former boarding school near Sluis), are no longer accessible for research, but still suitable for bats (the Suatie-sluis Reigersbosch) or are no longer suitable, such as the Keldermanspoort near Hulst.

There is no clear trend in the numbers of

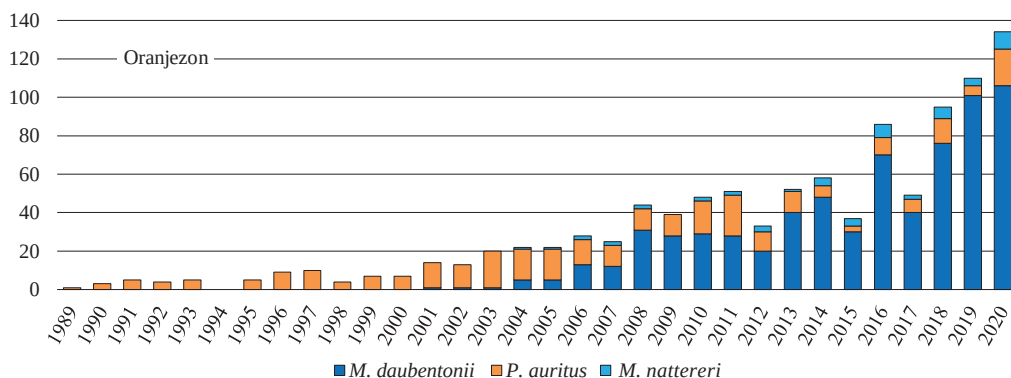


Figure 21. Number of hibernating bats in Oranjezon (Walcheren).

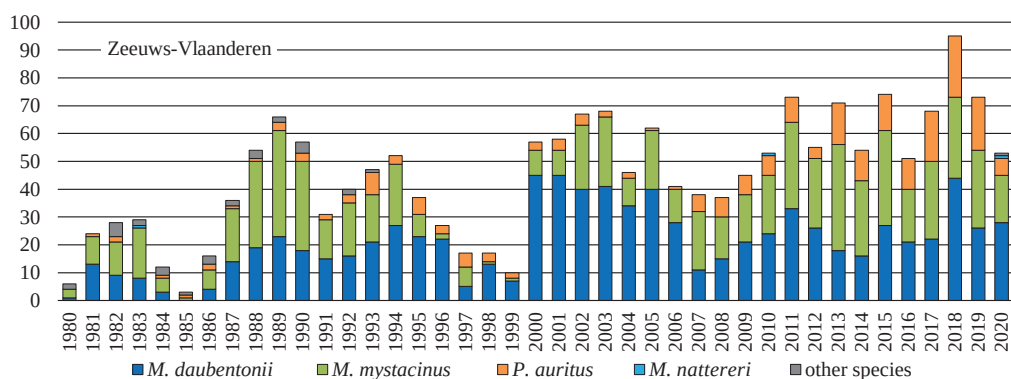


Figure 22. Number of hibernating bats in Zeeuws-Vlaanderen.

hibernating bats here (figure 22). In most years, several dozen Daubenton's bats, whiskered bats and brown long-eared bats are present, scattered across a varying number of sites.

In the 1980s the ruins at Sluis accommodated small numbers of bats (8-21) in the cellars, including whiskered bats (up to 14), Daubenton's bats (up to eight) and brown long-eared bats (up to three). A small number of barbastelles (*Barbastella barbastellus*) hibernated there every year, with a maximum of five animals in 1982 (figure 23). In the 1980s and early 1990s, this was the only winter population of this species in the Netherlands (Glas 1986, Bekker & Mostert 1995). Twice, in 1983 and 1985, a hibernating grey long-eared bat (*Plecotus austriacus*) was found here, its only known hibernating location along the Dutch coast (Glas 1986). The ruins were demolished in 1994.

In the Suatiesluis Reigersbosch a maximum of 14 hibernating animals were counted in the period 1988-1991. The first Daubenton's bat was found in 2007 in the Suatieluis Vlaamsekreek, after it was restored in 2001. Since then, a maximum of nine whiskered bats (2015) and three brown long-eared bats (2011) have been found here. In the Hellegat Suatieluis, which has been visited since 2004, one brown long-eared bat was observed during the first visit.

A small and varying number of bats, between 10 and 20 animals, in most years, hibernate in the Stenen Beer near Sluis. In 1989, 32 animals were counted. During the 2020 census, 15 animals were counted, including a Natterer's bat. This species has only twice before been counted in Zeeuws-Vlaanderen, in 1981 and 1982, at the same site. Most years between 2 and 14 whiskered bats are counted here, with a peak

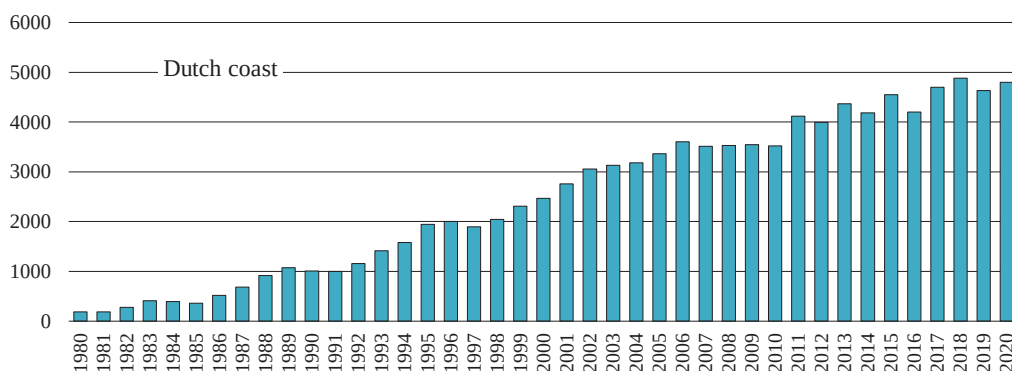


Figure 24. Number of hibernating bats along the Dutch coast.



Figure 23. Barbastelle, Sluis, Zeeuws-Vlaanderen.
Photo: Dick Klees.

of 18 animals in 2013.

The first bat (a whiskered bat) was identified in the bunker complex northwest of Groede in 1982, but it was only from 1994 that more bats were counted in the bunkers every year. The number grew to 41 animals in 2002 and then decreased to 18 animals by the 2020 census. In 1998, the bunker complex was redesigned and made more suitable for bats. Whiskered bats have always had a significant share in this complex with three to nine animals annually, and 16 and 15 animals in 2017 and 2018, respectively.

The Keldermanspoort has accommodated a number of whiskered bats (a maximum of twelve animals) for many years. Since its restoration in 2000, its significance for bats has diminished. In 2006, 13 whiskered bats were counted, but since 2010 only a few animals have been seen and none since 2015.

In the 1990s scattered bunkers were counted at Breskens, Sluis and Oostburg, with occasional whiskered and brown long-eared bats being spotted. In the last 20 years, a larger number of bunkers spread across Zeeuws-Vlaanderen have been counted, including Retranchement, Axelse Vlakte and Tragel-west. Small numbers of bats are counted here every year: whiskered bat (up to seven), Daubenton's bat (up to six) and brown long-eared bat (up to 12). In the other sites, which have mainly only been counted since 2008, the number of bats has slowly increased from 12 in 2008 to a maximum of 38 animals in 2018 and 2019. The proportions of whiskered bats, Daubenton's bats and brown long-eared bats has remained about the same.

Numbers of hibernating bats along the Dutch coast

Every year, several thousand bats hibernate in the coastal area of the Netherlands. Since the first censuses in the second half of the 1970s, the number of animals counted has steadily grown. In 1980, there were only a few hundred animals, in 1990 more than 1000, in 2002 more than 3000 animals were counted, in 2010 more than 3400 and in 2020 almost 5000 animals (figure 24). This increase is partly due to the ever-increasing number of sites being surveyed, partly to the closure of a large number of

Table 2. Trends of hibernating bat species over the study periods (source: Statistics Netherlands (CBS)).

	Coast trend 1986-2020	Coast trend 2009-2020	National trend 1986-2020	National trend 2011-2020
<i>M. mystacinus</i>	Moderate increase	Moderate decrease	Moderate increase	Moderate decrease
<i>M. nattereri</i>	Strong increase	Stable	Strong increase	Moderate increase
<i>M. daubentonii</i>	Moderate increase	Moderate increase	Moderate increase	Moderate increase
<i>M. dasycneme</i>	Strong increase	Strong increase	Moderate increase	Moderate increase
<i>P. auritus</i>	Moderate increase	Moderate decrease	Moderate increase	Moderate decrease

sites, making more suitable for bats and, possibly, also due to an actual population increase of the species found. The individual contribution of these factors on the growth in numbers of bats counted cannot be deduced from the research methodology and the results.

A total of twelve species of bats were found hibernating in the coastal area during the period: whiskered bat, Geoffroy's bat, Natterer's bat, greater mouse-eared bat, Daubenton's bat, pond bat, common pipistrelle, Nathusius' pipistrelle, serotine, barbastelle, brown long-eared bat and grey long-eared bat. Daubenton's bat has the largest share of the counted animals (76%), followed by the pond bat (10%), long-eared bat (8%), whiskered bat (5%) and Natterer's bat (1%).

Daubenton's bat is by far the most numerous hibernating species in bunkers, cellars and other structures along the Dutch coast: between 2010 and 2020, between 2730 to 3740 animals were counted in the annual censuses. For other species in the past decade, between 320 and 670 pond bats, 170-430 brown long-eared bats, 170-310 whiskered bats and 41-86 Natterer's bats have been counted in hibernation along the Dutch coast. The trends are predominantly positive, although during the last decade, the whiskered bat and brown long-eared bat have declined in numbers.

Numbers and trends by species

Figures 25 to 29 show the number of counted hibernating bats along the Dutch coast bats by species and compares these figures with the

indexed values calculated by Statistiscs Netherlands (CBS) for both the Dutch coast and for the whole of the Netherlands. The index is the ratio to indicate the development of a bat species based on the same winter hibernacula (also calculated by the CBS). In these figures, the number of bats counted is indicated on the left y-axis and the index values in percentages are indicated on the right y-axis. For all trends 1986 is the starting year (index value=100; except for Natterer's bat, for which the starting year is 1987). More recent trends of the hibernating bat species over the period 1986 to 2020 and over a recent period are shown separately: along the coast (2009-2020) and the national trend (2011-2020) (table 2).

Whiskered bat (*Myotis mystacinus*)

Several hundred whiskered bats hibernate in the sites studied along the Dutch coast, with between 170 and 310 animals counted annually in the past decade. Since the 1990s, the number of animals counted initially increased until the winter of 2011. Since then, there has been a remarkable decline, with the species abandoning more and more areas where it previously occurred in small numbers (figure 25).

The trend along the coast shows a moderate increase from 1986 to 2012, although in the last census year (2020) there was a moderate decrease (table 2). This is reflected by, the national trend which also shows a less pronounced increase from 1986-2012, and in the last period (2012-2020) a less pronounced decrease.

Most whiskered bats on the coast hibernate

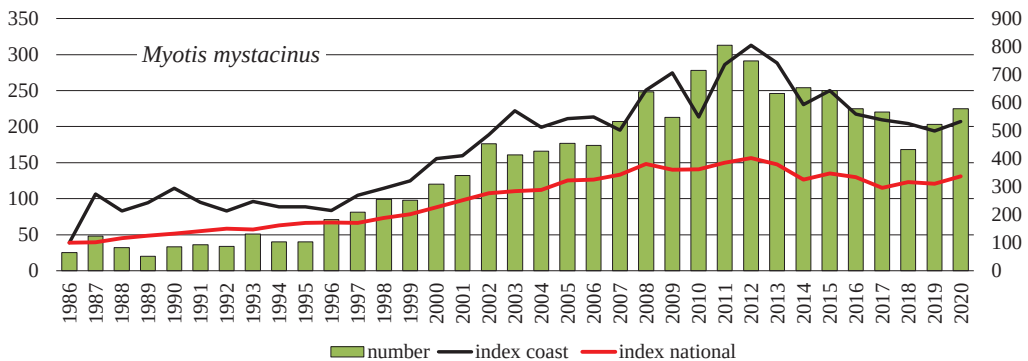


Figure 25. Number and index of hibernating whiskered bats along the Dutch coast compared with the national index (NEM/CBS). Explanation: numbers of columns shown on the left Y-axis, indexes in percentages on the right Y-axis; the percentages of both trends are based on 1986 numbers.

in the inner dune area between The Hague and Wassenaar, where the count increased to 212 in 2008 (Mostert et al. 2009). The most popular locations are the eastern edge of Berkheide, Rijksdorp, Valkenburg, the Wittenburgh ice cellar and Clingendael. In the adjacent dune area of Meijendel-Berkheide, small numbers, of up to 15 animals have been found.

In the Kapittelduinen (Staelduinse Bos and Hoek van Holland) several dozen specimens have been counted annually since the 1990s (22 in 2001) with a total of 15 animals in 2020. In addition, Zeeuws-Vlaanderen also still accommodate hibernating specimens in the Keldermanspoort, Groede, Breskens and the Stenen Beer at Sluis, Retranchement and a few other small sites. The highest counts here were of 38 animals (in 1990 and 2013).

The whiskered bat is rare or even absent in other areas of the Dutch coast, such as the AWD, the Westduinpark near The Hague, on Goeree, Walcheren and in the vicinity of Noordwijk. In other areas, such as in the coastal area of Noord-Holland and on Voorne, the species has declined or even disappeared.

North of the Noordzeekanaal, the whiskered bat initially hibernated in small numbers (up to 13 animals annually), mainly in the vicinity of Schoorl and Egmond-Binnen and occasionally near Bergen. Between 2005 and 2013, a maximum of three animals were found there,

but since then numbers have increased again. In the vicinity of Haarlem, the whiskered bat is no longer found every year (three reports in the past ten years), while before 2010, up to five animals were found annually. There have also been declines on the islands of Zuid-Holland and Zeeland. On Voorne a small number of animals were counted annually in hibernation sites (with a maximum of nine animals in 2005), but the species has not been found in the last five years. On Schouwen, the number of animals has been limited to three or four specimens in the last few winters.

In the period 1998-2001, a broader research programme was conducted into the twin species *M. mystacinus* and *M. brandtii*, which included the coastal area of the Netherlands (Mostert et al. 2005). It is difficult to distinguish between the two species: the characteristics of the dentition are useful and Brandt's bat has a lighter coloured ear base. In the winters of 1999, 2000 and 2001, 134 whiskered bats were identified throughout the Netherlands, of which 29 were in Zuid-Holland, 9 in Noord-Holland and 12 in Zeeland (Mostert et al. 2005). Since observations of Brandt's bat in the Netherlands are almost completely limited to the border area with Germany, we assume that only *M. mystacinus* hibernates in the Dutch coastal area.

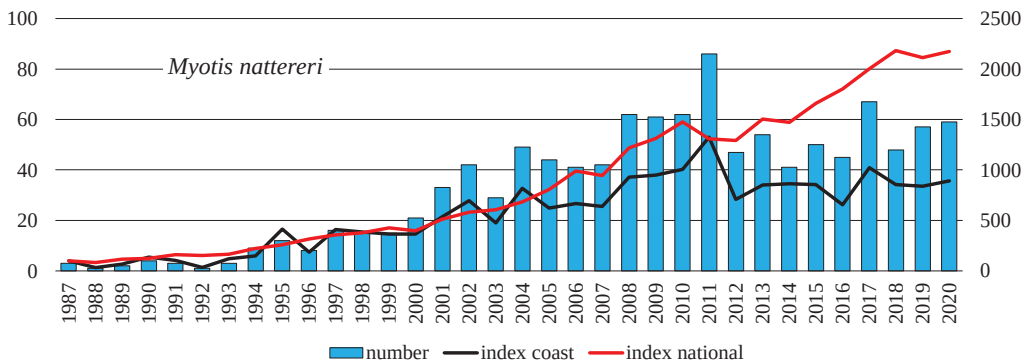


Figure 26. Number and index of hibernating Natterer's bats (*M. nattereri*) along the Dutch coast compared with the national index (NEM/CBS). Explanation: see caption fig. 19.

Natterer's bat (Myotis nattereri)

Natterer's bat hibernates in modest numbers of several dozen animals (annually between 41-86 animals) along the Dutch coast between IJmuiden and The Hague and on Schouwen, Walcheren and Goeree. Both the numbers and the indexed values show an increase (figure 26). Along the coast bat numbers increased from 1987 until 2011 but then dipped and have fluctuated since then. This is in contrast to the national trend, which shows a strong increase over the entire period; with the exception of 2010-2012 (table 2).

In the area between IJmuiden and The Hague, the first hibernating Natterer's bats were noticed in the IJskelder Middenduyn near Haarlem (three animals in 1970) and in the large bunker complexes near Wassenaar (occasionally one or two animals in the 1980s). In the 1990s, the numbers of Natterer's bats began to increase annually and they were found in more locations. In the years 2001-2012 there were between 22 and 36 animals in the area. Since then, the number has decreased somewhat, but 25 animals were counted again in the winter of 2020. Since 2008, Natterer's bat has established itself as a hibernator north of the Noordzeekanaal, with up to eight specimens in recent years at various locations around Castricum and Egmond.

In Zeeland, Natterer's bats were occasionally encountered in the 1980s on Schouwen,

Walcheren and Zeeuws-Vlaanderen. However, they only got a foothold in 1995 when four animals were found on Schouwen and the number has continued to increase every year since then. In 2011, a record 45 animals were counted, but since then the number has fluctuated at around 18-24 animals. This makes Schouwen the most important stronghold for this species along the Dutch coast. Possibly under the influence of this increase, the first specimen was found on nearby Goeree in the winter of 2011, and up to three specimens have hibernated here annually since then (Mostert 2011). The species has also been spotted a few times in Zeeuws-Vlaanderen; a hibernating animal was found in the Stenen Beer near Sluis during the 2020 census.

Daubenton's bat (Myotis daubentonii)

Daubenton's bat is by far the most numerous hibernating species in bunkers, cellars and other hibernation sites along the Dutch coast, with up to 3740 animals counted in the last decade. More than three quarters of all hibernating bats along the Dutch coast are Daubenton's bats, whether in Noord- or Zuid-Holland, Zeeland and sites in the dune area, in the inner dunes or elsewhere. Since the start of the censuses in the 1970s, the numbers of this species constantly increased, with the highest count in recent winters (figure 27). Both the numbers and the indexed values show a moderate

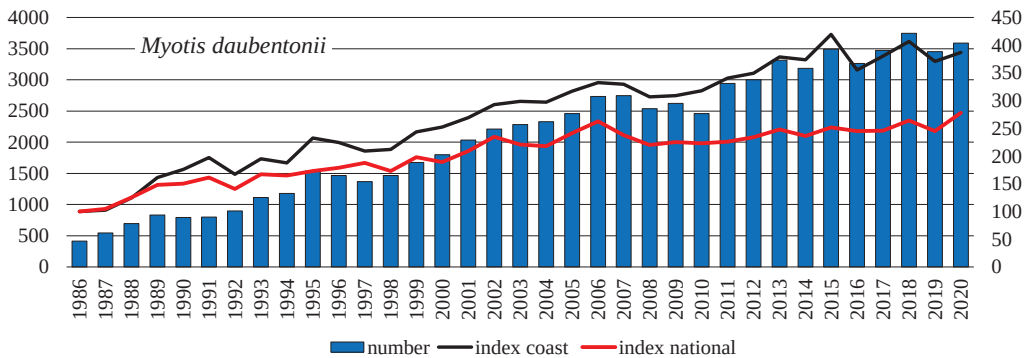


Figure 27. Number and index of hibernating Daubenton's bats (*M. daubentonii*) along the Dutch coast compared with the national index (NEM/CBS). Explanation: see caption fig. 19.

increase throughout the period 1986-2020, but the increase in the indexed values along the coast is stronger than nationally (figure 27). The increase in the numbers of hibernating bats along the coast (figure 24) is largely due to the increase of this species.

The most important strongholds of this species along the coast are Meijendel-Berkheide (maximum 1032 counted specimens in 2015), Schouwen (maximum 384 in 2015), Voorne (maximum 379 in 2020), Staelduinse Bos and Hoek van Holland (298 in 2020), AWD (222 in 2012) and Egmond-Bergen (430 in 2019). Not only have the numbers of Daubenton's bat increased, but it has also appeared in an increasing number of sites where it was initially absent, such as Wildrijk and on the Eiland van Dordrecht. Only brown long-eared bats were counted in the bunkers at Oranjezon from 1989, until the first Daubenton's bat was reported in 2001. Twenty years later, 106 specimens were counted.

Pond bat (Myotis dasycneme)

The pond bat hibernates in large numbers in bunkers between IJmuiden and The Hague. This makes the species, the second most common bat species, after Daubenton's bat, accounting for 10% of hibernating bats on the Dutch coast. During the winter of 2019, a record number of 682 animals were counted, of which 578 were found in Meijendel-Berkheide (figure 28). This Natura 2000 area is by far the most

important hibernating area for the pond bat in the whole of the Netherlands. In the same year, smaller numbers were counted in the adjacent inner dune area (20 animals), the area around Noordwijk (19), Westduinpark (17) and Kapittelduin (11). Smaller numbers also hibernate in neighbouring Noord-Holland, in Kennemerland-Zuid (44 animals).

Both the numbers and the indexed values show a strong increase in the period 1986-2020, with the increase in these values along the coast being stronger than nationally (figure 28). The trend along the coast has shown a strong increase since 1987, and in the period 2009-2020 (table 2). The national trend shows a moderate increase over the entire period and over the past decade (table 2, see also La Haye & van der Meij 2022, in this issue).

The species is virtually absent north of the Noordzeekanaal and on the Zuid-Holland and Zeeland islands. Only a few incidental hibernating specimens have been found on Schouwen (two animals in 1989 and one in 2016), in the dunes of Voorne (one animal in 2018), in the Wimmenummerduinen (one animal in 2019 and in 2020), at Wijk aan Zee (two animals in 2018) and at Egmond aan Zee (one annual hibernating animal in 2018-2020).

In Meijendel-Berkheide, the species has continued to increase, from a few dozen animals in the 1980s to a maximum of 588 animals in recent years. In the AWD (counted since 1986), the species has been found

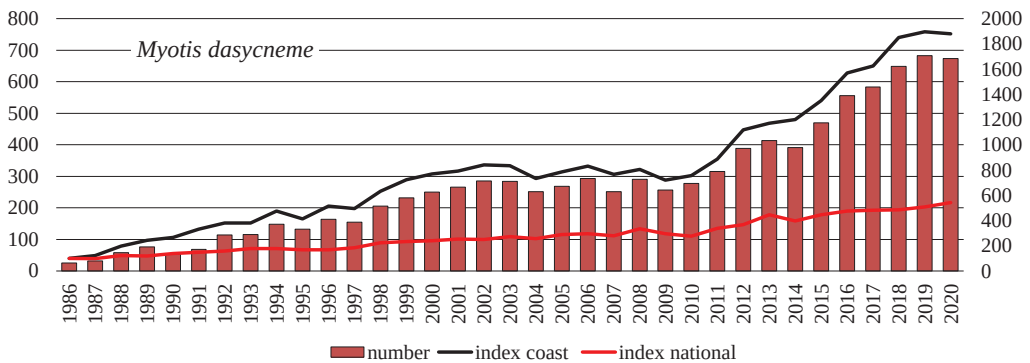


Figure 28. Number and index of hibernating pond bats (*M. dasycneme*) along the Dutch coast compared with the national index (NEM/CBS). Explanation: see caption fig. 19.

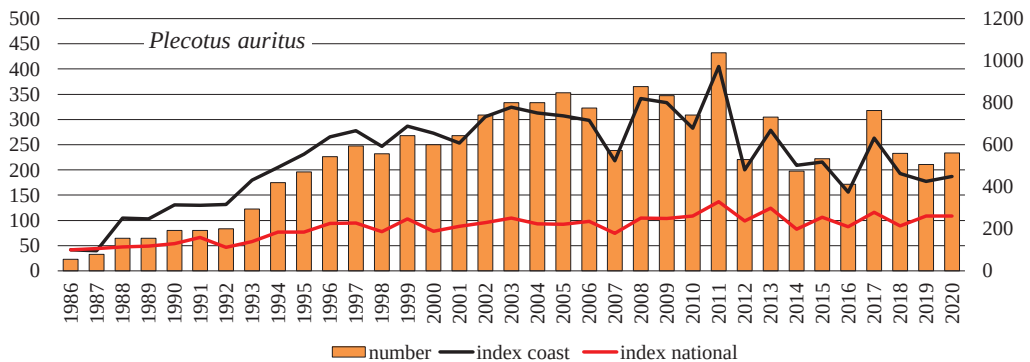


Figure 29. Number and index of hibernating brown long-eared bats (*P. auritus*) along the Dutch coast compared with the national index (NEM/CBS). Explanation: see caption fig. 19.

annually in increasing numbers since 1999, with up to 22 individuals in 2019. In recent years, the pond bat has continued to expand both southwards and northwards. Hibernating pond bats are now regularly encountered in the Westduinpark, Hoek van Holland and the Staelduinse Bos.

Brown long-eared bat (Plecotus auritus)

The brown long-eared bat is the third most numerous hibernating species along the Dutch coast. The number of brown long-eared bats account for 8% of the total and though the numbers can fluctuate strongly there are, as a rule, generally several hundred hibernators (with a maximum of 430 in the winter of 2011) (figure 29). The brown long-eared bat is the most widely distributed bat species along the

coast, and hibernates in many small sites where other species are absent. Over the past decade, the number of animals in a number of subareas has declined. However, it is possible that this is partly due to milder winters, which may lead more animals to hibernate in tree holes and other habitats (Mostert 1997, Bekker 2022, in this issue).

The development of the numbers and the indexed values of brown long-eared bats showed a steady increase (with occasional dips) until 2011, after which the numbers spotted declined sharply (again with fluctuations): in 2011 there were almost 450 individuals spotted, in 2020 it was less than 200. The national index also increased between 1986 and 2011 but has decreased slightly since then, again with fluctuations (figure 29 and table 2).

After an initial increase in some subareas in the 1990s, the numbers have declined noticeably. In the 1990s, 50 specimens were counted in the Staelduinse Bos, but in recent years only up to twelve specimens have been found there. The casemates in the Hoeksche Waard and the harbour on the Eiland van Dordrecht house several dozen brown long-eared bats and there has been modest increase in the numbers counted there. In Haamstede, the highest number of 61 animals was counted in 1995, while in recent years a maximum of 14 animals were counted.

Other species

There are some bat species that have been reported occasionally in winter quarters along the Dutch coast: Geoffroy's bat (*Myotis emarginatus*), greater mouse-eared bat (*Myotis myotis*), common pipistrelle (*Pipistrellus pipistrellus*), Nathusius' pipistrelle (*Pipistrellus nathusii*), serotine (*Eptesicus serotinus*), barbastelle (*Barbastella barbastellus*) and grey long-eared bat.

Geoffroy's bat was found hibernating in 2016 in the bunkers in the Slotbos Haamstede on Schouwen (Mostert & Bekker 2017) and seems to be an occasional hibernator there. There is also an older report of two animals collected in September 1953 in the Kennemerduinen (Kapteyn 1995).

A greater mouse-eared bat was found hibernating on 2 February 2001 in the bunker in the Oostduinpark in The Hague. Since 2014 one hibernating animal has been present in one of the bunkers at Meijendel. Only two other hibernating cases are known of: in the Nova Zembla ice cellar near Duin- en Kruidberg, in 1984 and 1991.

Although the common pipistrelle is by far the most numerous bat species in the Netherlands, this species is only exceptionally found in hibernation sites such as bunkers, (ice) cellars and fortresses, apart from the hundreds of specimens that were recorded in the Ruïne van Brederode in several years. In Zuid-Holland, its hibernation is limited to a few dry bunkers in

the inner dune area of Voorne, with up to five hibernating in most years and a maximum of 14 specimens in the winter of 2004. There are also incidental reports from the Staelduinse Bos and Berkheide. In Zeeland, up to two animals were regularly reported from Fort Rammekens, once in 1987 in Sluis and once in 2020 in Groede. In the 1990s there was a large winter roost behind wooden beams in the church tower of Veere. A maximum of 95 animals were counted in 1991.

Nathusius' pipistrelle is sometimes found during the winter census. Since 2014, the species has been counted annually in small numbers (up to seven animals) in the bunkers at Zuidwijk; in the winter of 2017, twelve animals were found. There are also incidental reports, from Clingendael (one in 2003), Berkheide (one in 2005-2007) and the Staelduinse Bos (one in 2017).

Up to five serotines were found hibernating annually between 1984 and 2005 in the gatehouse of Elswout and a solitary hibernating animal was found in the Ruïne van Brederode in 2007 and 2018. In Zeeland, a few solitary hibernating specimens were spotted in the church tower of Veere in 1986-1990, 2000 and 2003 and in the Keldermanspoort near Hulst in 1992.

In the 1980s and early 1990s, the barbastelle hibernated annually in the former boarding school near Sluis, where up to five specimens were counted. The last sighting was in 1994. This site has since been destroyed. Since then, the species has not been found in Zeeuws-Vlaanderen, and has not been spotted hibernating in the Netherlands. A hibernating grey long-eared bat was found twice in the same former boarding school, in the 1983 and 1985.

Conclusions and discussion

General trends along the coast

The trend in numbers of hibernating bats along the Dutch coast shows a remarkable growth since the 1990s (see figure 24). Since 1995,

this is only to a limited degree a result of an increasing number of counted sites (see figure 3). Daubenton's bat is by far the most numerous hibernating species along the Dutch coast, accounting for over three-quarters of the number of hibernating animals. The increase in the number of bats shown in figure 24 is therefore largely the result of an increase in this species. Since the 1970s, the number of Daubenton's bats has continued to increase, with the highest count in the last few winters. The pond bat only hibernates in large numbers in bunkers between IJmuiden and The Hague, with a maximum of 682 animals in the winter of 2019. In recent years there has been an expansion of the population in both a southerly and northerly direction and pond bats have become regular hibernators in the Westduinpark, Hoek van Holland, the Staelduinse Bos and also north of the Noordzeekanaal.

The number of whiskered bats initially grew from the 1990s until the winter of 2012, but since then there has been a marked decline. They have abandoned more and more subareas, such as the coastal area of Noord-Holland and Voorne, where the species previously occurred in small numbers.

Natterer's bat initially increased in numbers, but numbers have stagnated since 2010. Numbers of brown long-eared bat have also declined somewhat in the last decade. This is possibly partly due to the milder winters, as a result of which bats, particularly brown long-eared bats, more often hibernate in trees and other roosts. In summary, three of the five main hibernating species have shown a stagnation in growth or decline between 2011 and 2020.

In the 1970s, 1980s and sometimes later, many sites were closed to unauthorized persons and converted into bat roosts, reducing disturbance and making the quarters more suitable for hibernating bats. The trends calculated by the NEM / Statistics Netherlands (CBS), show progress for most species, although somewhat less strongly than on the basis of absolute numbers.

The question is whether the adjustments

are the only reason for the increase or would the numbers have otherwise increased in the sites concerned? This question that cannot be answered. What is certain is that the modified sites contribute to a favourable conservation status for the species that hibernate there.

Relationship between winter quarters and maternity roosts

The extent to which the hibernating bats in the coastal area are related to the maternity colonies in the hinterland, especially the wooded inland dune area, is an intriguing question.

In the past few decades dozens of colonies of Daubenton's bats have been found in the inner dune area. Most colonies have been found in old deciduous trees; old country estates with many oaks and beech trees in a water-rich environment are especially suitable sites. The water catchment areas in the dunes near The Hague, Haarlem and Castricum are important foraging areas for bats. In the 1990s, the summer population of Daubenton's bats in the inland dune area in the west of the Netherlands was estimated at 1800 to 2000 adults (Mostert 1990b, 1993, Limpens et al. 1997). In the years 2015-2020 it was estimated to be at least 2500-3300 adult animals (table 3).

In Noord-Holland the summer population of Daubenton's bat was estimated at 1100 to 1400 individuals in the early 1990s, of which 900-1150 were in the inner dune area (Kapteyn 1995). The most northern colony in the dune area was found in Schoorl. More recent estimates are not available. However, the hibernation counts imply that the size of the summer population has probably increased.

In the inner dune area of Zuid-Holland, there have been 1150-1600 adult Daubenton's bats in recent years (Mostert 2011, 2012, 2020). The largest colony was 177 animals in Ockenburgh near The Hague. All the estates in and around The Hague were intensively examined in both 2009-2011 and 2015-2017 (Mostert 2012, Mostert & van der Kuil 2020).

Table 3. Number of colonies of Daubenton's bats in the inner dune area of the western Netherlands

	number of colonies	population size	min.-max.
<i>Province of Noord-Holland</i>			
Noord-Hollands Duinreservaat	8	10	300-400
Kennemerland-Zuid	15	20	600-750
Behind Polder Area	6	8	200-250
<i>Province of Zuid-Holland</i>			
Kennemerland-Zuid ZH	3	3	100-150
Leiden and surroundings	3	3	100-150
The Hague-Wassenaar	4	7	300-450
The Hague and surroundings	10	16	450-500
Delft	1	1	50-50
Staelduinse Bos	2	2	50-100
Voorne	3	3	100-150
<i>Province of Zeeland</i>			
Schouwen	3	4	150-150
Walcheren	2	3	50-100
Zeeuws-Vlaanderen	2	3	50-100
<i>Total</i>	<i>28</i>	<i>73</i>	<i>2500-3300</i>

In the first period, 16 maternity colonies were found with an estimated 350-400 Daubenton's bats, (largely based on counts of fledglings) and there were an estimated 450-500 adults in the second period. So, both the number of bats and the number of colony sites have increased.

On the islands of Zeeland, colonies have been found in the wooded inner dune of Schouwen and Walcheren (Mostert 1991). In addition the species has also been found in small numbers in the canals of old towns such as Zierikzee, Goes and Middelburg, although no colonies have been found there. A bat box in the Veerse Bos was once used as a maternity roost (Bekker 1990). Colonies also have been found in Zeeuws-Vlaanderen near Aardenburg and along the fortifications of Sluis and an unconfirmed sighting in the vicinity of Hulst. Two breeding colonies of Daubenton's bats were found in Aardenburg with 88 and at least 35 animals (Mostert 2017). In Zeeland, 250-350 Daubenton's bats are estimated to be present in the summer.

It is likely that a vast majority of the hibernating Daubenton's bats in the coastal area (2730-3740) spend the summer on the estates

of the inner dune area (estimated 2500-3300 animals, see table 3). Reports of banded specimens suggest the same. In August 1990, 28 sub-adult Daubenton's bats were banded at the Overvoorde estate in Rijswijk (Mostert 1990b). In the following years, several banded animals were found in hibernation sites in the dune area. In January 1991, a banded animal was found in one of the bunkers in the Staelduinse Bos, 12 km southwest of the summer location. A second banded specimen was found in a bunker along the Galgeweg in Westland, about 8 km southwest of the banding site (Mostert 1993). In December 1993 and December 1994, two banded Daubenton's bats were found in the bunkers of Hoek van Holland (14 km southwest of the banding site). In December 1995 there was one specimen and in December 1996 three. The last banded specimen was found in December 1997. In total, at least five different individuals were found during the hibernation counts.

Some whiskered bats have also been observed in the wooded inner dunes. Most observations in Noord-Holland are from the area of Bergen and Haarlem; however, no

colonies or roosts have been found here. In the peat meadow area, up to 40 whiskered bats have been observed in West-Friesland, in Ilpendam and Abbekerk (15-20 animals), but since 2004 and 2010 these colonies have been abandoned. Based on old observations (Kapteyn 1995), droppings were collected from bats at five churches, in Aartswoud, Hoogwoud, Wognum, Spanbroek and Benningbroek (van den Tempel & Veldhuijzen van Zanten 2020). DNA from whiskered bats was found in all five attics. However, as the church attics were never cleaned, the droppings found may have been very old. Visual observations of whiskered bats were also made in two churches, in Opperdoes and in Spanbroek.

In Zuid-Holland, small colonies of the whiskered bat were known in Oostvoorne (under a roof moulding) and in the Staelduinse Bos (in a hollow oak). However, both colonies have not been present for a long time.

On Zuidwijk estate near Wassenaar a pregnant female whiskered bat was caught in 2006, but no roost was found (Achterkamp 2012). In June 2012, another attempt was made to find roosts by catching and tracking animals with transmitters. This led to the identification of three different roosts for an adult female within a radius of 1600 m from the first location. However, it did not lead to a maternity colony. Only a few foraging animals have been spotted around The Hague and Wassenaar and there are no recent reports from Zeeland.

In 2013, a group of six Natterer's bats were caught on the Elswout estate near Haarlem, including a female that had recently suckled a young and a young animal. Animals were also recorded in this environment with a bat detector (Hoogenboom et al. 2014). For the time being, this is the only known report of a colony of this species in the coastal area.

Between 1986 and 1993, the summer population of brown long-eared bats in Noord-Holland was estimated to be around 250-500 adults (Kapteyn 1995). Hoogenboom et al. (2014) estimate the summer population of brown long-eared bats in the same area to have

been between 60 and 150 animals in the period 1994-2014. However, these numbers may be an underestimate, as the species is difficult to detect due to its soft sonar.

In Zuid-Holland the brown long-eared bat is known to occur in the summer in estate forests in the inner dunes and in a number of church buildings, especially in the east of the province. The population is estimated at 150 to 300 animals.

In Zeeland, the number of colonies of brown long-eared bats is limited (Bekker et al. 2010). In the Slotbos Haamstede, four small colonies, with a total of 23 animals, were found in trees (Mostert 2017) and in bat boxes on the Goudplaat (Noord-Beveland). In the Veerse Bos two colonies of approximately 30 and 20 animals were counted. Including specimens counted in church attics, the estimate for Zeeland thus amounts to 100 to 150 animals.

It is likely that the maximum summer population of brown long-eared bats along the entire coast, is around 600 individuals, which exceeds the maximum hibernating number of 430. This difference may be explained as brown long-eared bats also use other types of winter quarters.

The relationship between the hibernating pond bats and colonies of males has been demonstrated through banding. This relationship is discussed among others by Haarsma & Tuijter (2009).

Opportunities and threats

Hibernacula in the immediate vicinity of aging woodland areas, generally offer good opportunities for various bat species. The felling of old trees and the removal of dense undergrowth around bunkers may be the cause of a temporary decline in the numbers of counted hibernating bats (for example on Schouwen).

Intact bunkers in the dune areas of the Staatsbosbeheer, Natuurmonumenten or those of the three Landschappen (Noord-Holland,

Zuid-Holland and Zeeland) are usually well protected. Most of the complexes are not accessible to unauthorized persons and many bunkers frequented by bats in the winter are closed with steel doors or a fence. In many cases, these measures have resulted in a higher occupancy of hibernating bats. Nevertheless, a large number of bunkers are still entered by unauthorized people. The frequent breaking open and disruption of sites remains a source of constant concern, especially when fireworks are set off (for example in Hoek van Holland). Indications of overnight stays are regularly found and in a few cases bunkers are used as a base for poaching.

There are also indications that partial opening until late summer or autumn for other management objectives has a detrimental effect on hibernating bats.

A number of bunkers, built on unstable ground, are slowly sinking into the clay soil (for example on Walcheren). There are also some bunkers in dynamic dune areas that are gradually being covered by drifting sand (for example on Schouwen).

A comparison between bunkers on Voorne that are managed privately and by nature conservancy agencies point out that the former category shows a less favourable long term trend in bat numbers than the later. Changes of ownership and the bunkers being used for other purposes are the main causes of this.

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Bats in the Voorberg and the Jezuïetenberg

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Abstract: The numbers of hibernating bats in the Voorberg-Jezuïetenberg marl quarry complex, southwest of Maastricht, were monitored between 1987 and 2020 by means of annual counts at the turn of the year. The numbers counted in that period grew from 30 to 99, mainly as the result of an increase in the number of Geoffroy's bats. In the 2008-2009 season, it was investigated whether bats are home-steady during the hibernation season. It turns out that all species regularly woke up and moved around. The three-weekly counts in 2008-2009 also showed that most species gradually move towards the exit during the hibernation period, with only the Geoffroy's bats remaining in the rear part of the complex. Most species leave the quarry around the end of March, with the exception of Geoffroy's bats, which stay until mid-May.

Keywords: Voorberg, Jezuïetenberg, Boschberg, Geoffroy's bat, greater mouse-eared bat, Bechstein's bat.

Introduction

The marl quarries in southern Limburg form a special category among the Dutch winter roosts for bats. There are large differences between them, which are related to, among other things, the period of exploitation / mining, the extent of the quarry, the stability of the system (whether there are any cracks or have been collapses), the number of floors, differences in height and the quarry's climate. Together with fellow observers, the author of this paper has systematically surveyed the hibernating bats in the Jezuïetenberg and the Voorberg quarries, southwest of Maastricht, every winter period since 1987. In 2005 he first became a volunteer guide in the Jezuïetenberg. After his appointment as a guide, during his tours through the tunnel system throughout the year, his interest was aroused by the bats present in the entrance areas outside the winter period, which were present in places not visited by them during the winter period. This prompted him to look more closely at changes

in the seasonal distribution of hibernating bats with the objective of determining whether the hibernation of bats in these two quarries is a dynamic event or a static, uninterrupted activity. The climate in the Jezuïetenberg is much more constant than in the Voorberg, because this quarry does not have its own direct connection, via an entrance, with the outside air. One has to go through a more than 100 m long corridor from the entrance of the Voorberg to get to the Jezuïetenberg. The difference in climate between these two systems, with the Jezuïetenberg as the 'warm' part of the quarry and the Voorberg as the 'cold' part, offers the possibility of characterizing the hibernating bats here as heat-loving or cold-loving.

Location of the Voorberg and the Jezuïetenberg

South of Maastricht, on the west bank of the river Maas, there are two parallel ridges, separated by the valley of the river Jeker: Sint Pietersberg to the east the Louwberg to the west. In both ridges underground marl has been extracted for building and arable farming,

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which has created several corridor systems.

There are four medium-sized quarries in the Louwberg. From north to south, these are the Apostelgroeve, the Fallenberg, the Boschberg and the Kasteelgroeve. The second and third of these lie almost next to each other, undergoing changes in the twentieth century (natural and man-made) that made their structures more complex.

The collapse of the middle part of the Fallenberg quarry in 1920 led to the rear part becoming isolated in 1920 and it is now known as the Jezuïetenberg. This collapse only prevents humans from entering it. Bats can still fly through.

In 1944 the northern part of the Boschberg was separated from the rest of the quarry as a result of the construction of thick walls around the then underground war industry. The isolated northern part is now called the Voorberg. In 1954 a connection was made from the back part of the Voorberg to the isolated rear part of the Fallenberg in order to make the artistic expressions of the Jesuits that exist in that part accessible (figure 1; see also www.jezuïetenberg.eu). There is a passage that joins the Voorberg and the Jezuïetenberg but this is sealed off by a door, which has small openings to allow bats to pass through. Various works have been carried out in the Voorberg - Jezuïetenberg complex to stabilize it since then. The Jezuïetenberg is slightly higher than the Voorberg, so the climate in the Jezuïetenberg is relatively warm compared to the Voorberg, where colder air flows in through the entrance. These two quarries were visited during the bat counts and the migration research described below.

On 14 October 1996, the Jezuïetenberg was awarded the status of a protected national monument. Management is in the hands of the Jezuïetenberg Foundation, which organizes guided tours of the quarry. The quarry is open for visitors almost all year round. Previously, kerosene gasifiers, which gave off heat and combustion smoke, were initially used as lighting during the tours. Since 2018, only LED lighting has been used by the guides; which



Figure 1. The Voorberg and the Jezuïetenberg.

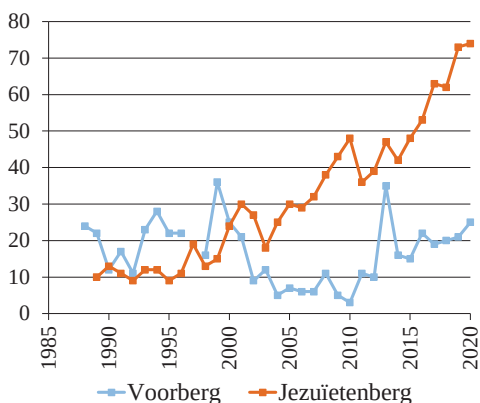


Figure 2. Changes in the total number of bats in the Voorberg-Jezuïetenberg complex from 1987-2020.

releases less heat.

Method

The annual counts of hibernating bats in the Jezuïetenberg and the Voorberg are tradition-

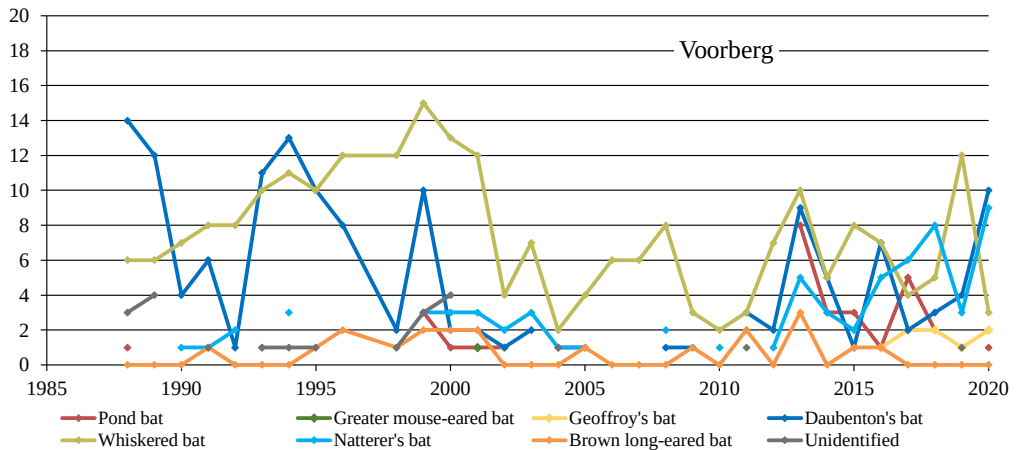


Figure 3. Changes in the numbers of bat species in the Voorberg 1987-2020.

ally carried out on 29 December each year. All the bats found in the area are noted, although not every bat present can be traced. Some bats are not visible because they have crawled away deep into crevices or cracks and, above all, because in both quarries, especially the Jezuïetenberg, certain corridors cannot be entered for safety reasons.

In order to gain insights into seasonal changes in the distribution of bats, a standard count was conducted every three weeks in the winter of 2008-09. The first took place on 8 October 2008 and the last on 20 May 2009. On these days, one bat counting group each time visited the Voorberg and the adjacent Jezuïetenberg in rotation with another counting group. Each time the bats found were located on a map of the two corridor systems.

Results

Winter censuses 1987-2020

The numbers of bats counted in the Voorberg - Jezuïetenberg quarry complex have increased over the years, as in many other quarries. Figure 2 shows the results of the annual counts. Between 1987 and 2020 the overall numbers more than tripled: initially 30 bats were

counted and by 2020 this had increased to 99.

A closer look (figures 2, 3, 4 and 5) shows that the increase in numbers in the complex has mainly occurred in the Jezuïetenberg and that the increase there is due to an increase in Geoffroy's bat (*Myotis emarginatus*); this species now makes up half of the total numbers there. The other species have remained more or less constant in numbers. In the Voorberg, the numbers of all species of bats have remained roughly the same over the whole period. Over the years, eight species of bats have been found hibernating. Whiskered bat (*Myotis mystacinus*) and Brandt's bat (*M. brandtii*) are taken together here because these species cannot readily be distinguished without handling them. It is worth noting that:

- the number of Natterer's bats (*M. nattereri*) is slowly increasing;
- the number of whiskered bats (*M. mystacinus/brandtii*) is slowly decreasing;
- the number of Daubenton's bat (*M. daubentonii*) in the complex follows the trend of the Daubenton's bats in other quarries in South Limburg: slowly descending;
- the pond bat (*M. dasycneme*) and the greater mouse-eared bat (*M. myotis*) both occur in low numbers fluctuating from 1-5 specimens;
- Bechstein's bat (*M. bechsteinii*) is occasion-

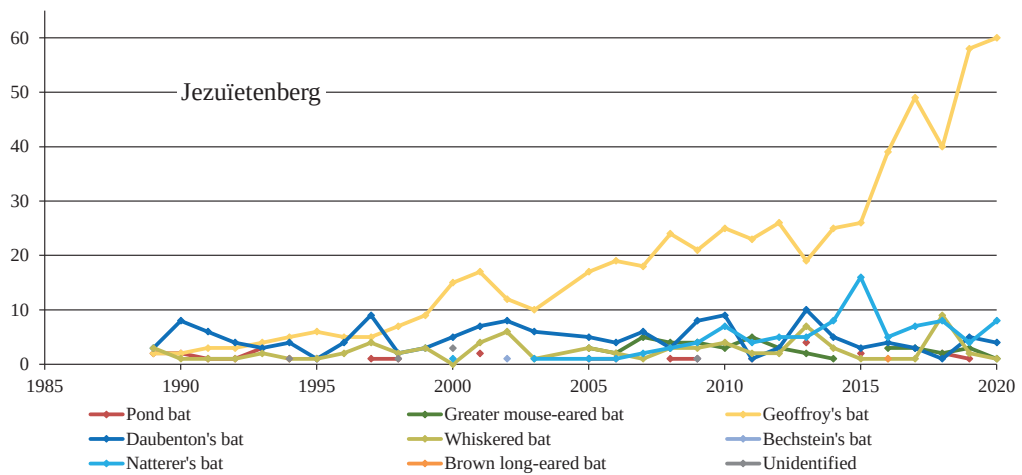


Figure 4. Changes in the numbers of bat species in the Jezuïetenberg 1987-2020.

Table 1. Distribution of the number of observed / expected bats in the Voorberg and in the Jezuïetenberg during the period 1989-2020, with significance levels; n.s.=not significant, n.a.= not applicable.

	Voorberg		Jezuïetenberg		P
	observed	expected	observed	expected	
<i>M. emarginatus</i>	9	56.5	612	564.5	<0.001
<i>M. daubentonii</i>	148	27.4	153	273.6	<0.001
<i>M. nattereri</i>	65	14.2	91	141.8	<0.001
<i>M. mystacinus</i>	246	29.5	78	294.5	<0.001
<i>M. myotis</i>	1	4.1	44	40.9	n.s.
<i>M. dasycneme</i>	38	6.0	28	60.0	<0.001
<i>P. auritus</i>	21	2.1	2	20.9	<0.001
<i>M. bechsteinii</i>	0	0.2	2	1.8	n.s.
unidentified	22	2.5	6	25.5	n.a.

ally observed;

- brown long-eared bats (*Plecotus auritus*) are rarely seen.

The bats' preference for hibernating in the Jezuïetenberg or the Voorberg is shown in table 1. By means of a chi-squared test, the observed number in the Voorberg or Jezuïetenberg is compared with the expected number, derived from the corridor length in both systems (ratio: 11:1). It appears that Geoffroy's bat has a significant preference for the more climatically stable and warmer Jezuïetenberg, while Daubenton's bat, the whiskered bat, Natterer's bat, the pond bat and the brown long-eared bat show a sig-

nificant preference for the colder Voorberg, where the climatic conditions are more variable. No preference could be determined for the greater mouse-eared bat and Bechstein's bat due to their low numbers.

These observations confirm those in other marl quarries that hibernating Geoffroy's bats move further into the quarries to hibernate and that they rarely stay in the relatively colder entrance areas. Bechstein's bats and greater mouse-eared bats exhibit similar behaviour. When they are (rarely) found in the vicinity of a quarry entrance, the animal is not hanging freely on a marl wall, but has crawled into an uneven spot (crevice, niche)

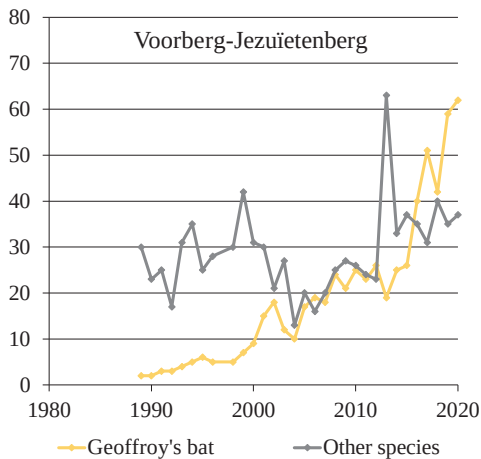


Figure 5. Trends in the number of Geoffroy's bat and other species in the Voorberg-Jezuïetenberg complex 1987-2020.

where it would be less exposed to air currents; thus seeking their own local microclimate.

Temporal distribution in the complex during the 2008-2009 winter season

During the winter season of 2008-2009, during twelve bat countings, all bat observations were accurately mapped on counting maps. Comparison of these maps showed that bats did not stay in the same place for long periods of time. Only a few individuals were found at the same roost after three weeks. However, they sometimes stayed in the immediate vicinity, ranging from one metre to a few corridors away. Of course, it is not certain that in any particular case it was one and the same bat because the animals could not be recognized individually. Figure 6 shows the distribution of the observed bats on three different dates.

Daubenton's bats, and especially whiskered bats, appear to move frequently: these two species were almost never found at the previous roost during a subsequent count. In other words, hibernation appears to be a dynamic event for these species. By contrast, Geoffroy's bats appeared to move very little.

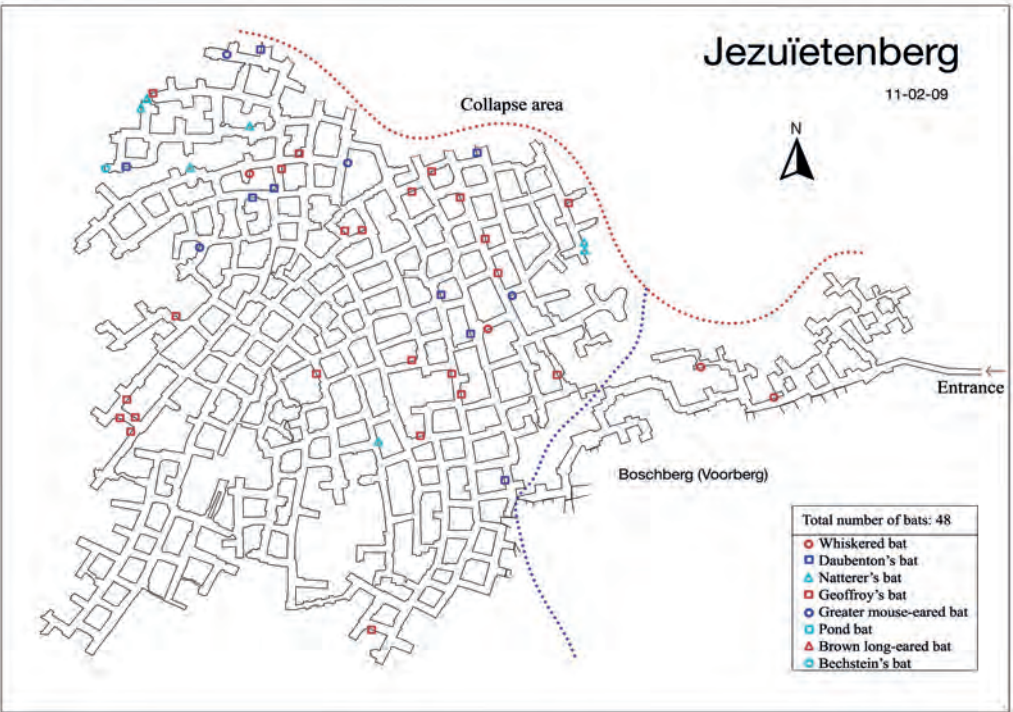
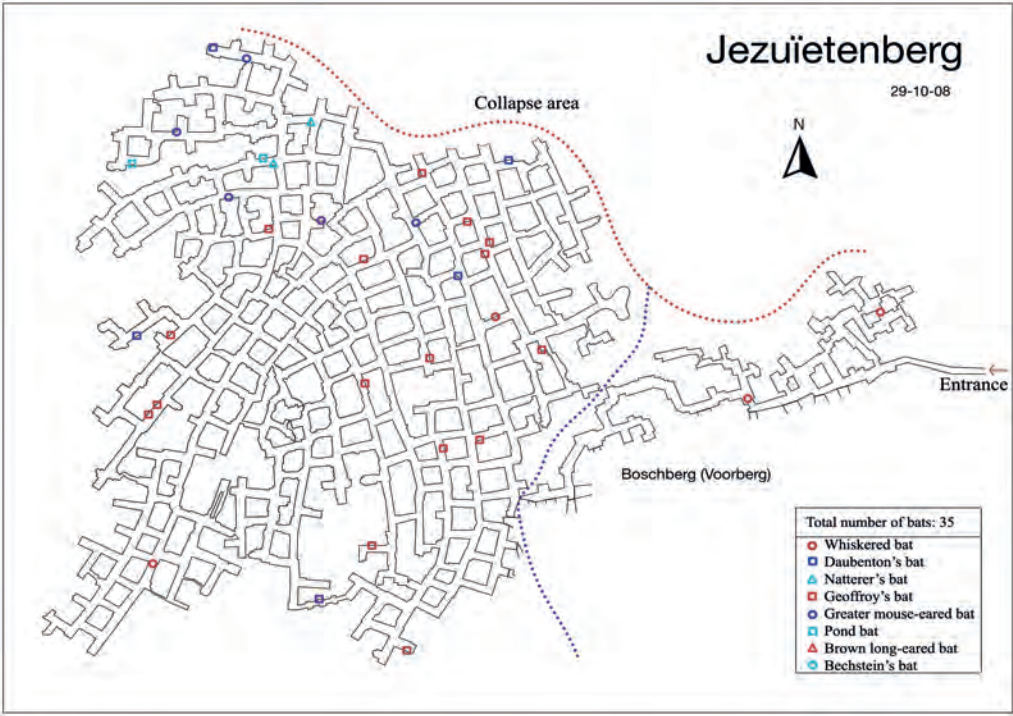
Changes in numbers during the 2008-2009 winter season

During the winter season of 2008-2009, a total of 378 bat sightings of eight species were recorded, spread over twelve counting events. The numbers of bats in the quarry increased over the course of the autumn (figure 7): by the end of September, half of the bats were present. The maximum number was reached in January. The bats then gradually left the quarry and by mid-May the last ones had left. However, this picture varied in the two parts of the quarry complex. The increase in numbers in the Voorberg was considerably slower and lasted longer: the maximum numbers were only reached in March and by the beginning of April the bats had all already left.

Because there has been a large increase in numbers of Geoffroy's bats in the complex over the years and because they are only found in the Jezuïetenberg, figure 8 shows the seasonal pattern of the Geoffroy's bat against that of the other species with a division between the two parts of the quarry. The other species appear to leave the Jezuïetenberg earlier than Geoffroy's bats. It is possible that the increase in the number of the other species in the Voorberg is the result of their departure from the Jezuïetenberg. Yet, it has also been observed that Geoffroy's bats remain in the Jezuïetenberg throughout the winter and then leave the quarry directly from there at the beginning of May. It was also observed that the bats move towards the entrance during the course of the winter. This process of internal migration was previously described by Daan (1973), who studied this phenomenon in the Geulhemergroef near Berg en Terblijt.

Conclusions

Between 1987 and 2020, counts of hibernating bats were carried out in the Voorberg-Jezuïetenberg complex and the total number of hibernating bats increased threefold in this



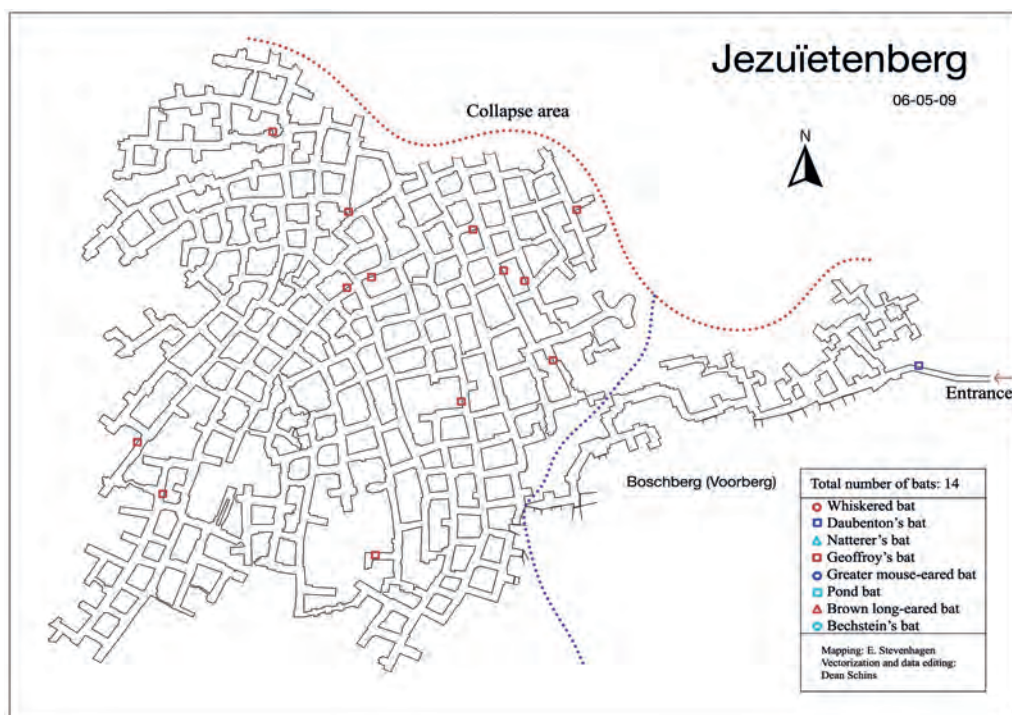


Figure 6. Locations of bat observations, by species, in the Voorberg and the Jezuietenberg on three counting dates in the winter of 2008-2009.

period, although this increase is mainly due to the Geoffroy's bat. The numbers of the other species, have remained about the same, with some fluctuations. Geoffroy's bats are known to be on the increase in several other quarries, so what is happening in the Voorberg-Jezuietenberg is consistent with this (Weinreich & Verheggen 2022, this issue). The Voorberg is closer to the entrance for bats than the Jezuietenberg. This means that the former is more exposed to external temperature fluctuations. This is reflected in the internal distribution of the species: the Geoffroy's bats mainly hibernate in the back of the quarry. Daubenton's bats, whiskered bats and Natterer's bats hibernate throughout the quarry complex, but with a preference for the Voorberg. In the 2008-2009 hibernation season, the seasonal development of bat numbers and their distribution was monitored by means of counts taken every three weeks. By following the roost positions of

species over the course of the season, it became clear that hibernating is not a process in which bats always stay in the same place, but that it is a more dynamic event. Bats move around internally on a regular basis and the extent to which this happens varies between species.

Overall Geoffroy's bats stayed in their hibernaculum for a longer time: from the end of September to the beginning of May than the other species which stayed a much shorter period from the end of September to the end of March/beginning of April.

Acknowledgements: A word of thanks goes out to the Jezuietenberg Foundation for their many years of hospitality and to the Dutch Mammal Society for allowing our counters to attend various courses to recognize hibernating bats. We also thank John Hageman for sharing information from the migration research in the period 2008-2009, the Natuurhistorisch Genootschap in Limburg bat counting group for participation

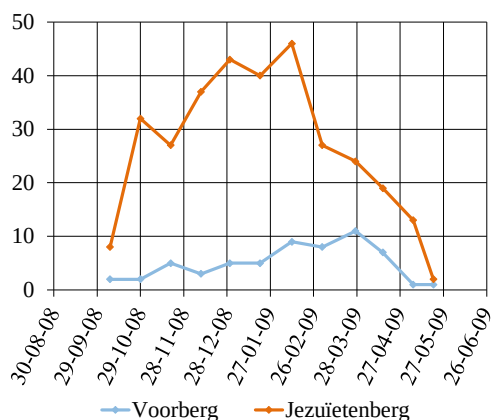


Figure 7. Changes in the number of bats in the Voorberg-Jezuietenberg complex during the winter season 2008-2009.

in the censuses, Dean Schins for creating the vector maps and Hans Weinreich for assisting in the compilation of this article.

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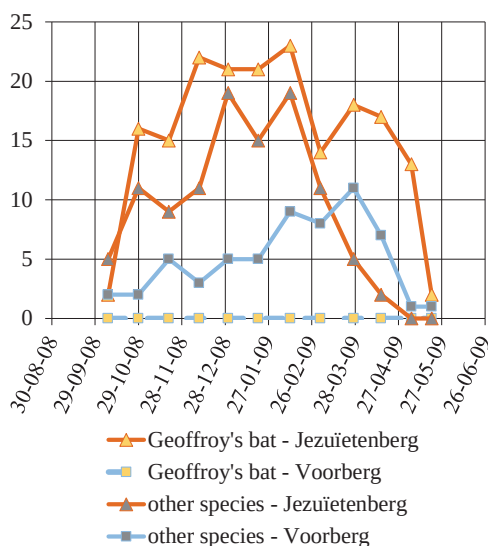


Figure 8. Changes in the number of Geoffroy's bats in the Voorberg-Jezuietenberg complex during the winter season 2008-2009.

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Long-term trends of bats hibernating in small artificial hibernacula in northern Limburg and population dynamics explained by climatic conditions

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Abstract: Hibernation site selection by bats depends on various environmental and physiological factors, microclimatic conditions, and species-specific requirements. For successful overwinter survival, efficient use of stored fat reserves is crucial. Current predicted climate change may alter microclimatic conditions of hibernacula, stimulate arousal, and cause shifts in hibernation site use. A better understanding of these effects is needed to improve bat conservation. Between 1986–2020, we annually monitored 18 small (mean: 70 m³) and artificial hibernacula, assessed long-term trends, and analysed population dynamics of hibernating bats in northern Limburg, the Netherlands. In *Myotis daubentonii* and *M. nattereri*, we found a significant population increase in these hibernacula, with a yearly mean growth of 5.8% and 11.7%, respectively. The trend of *Plecotus auritus* remained stable throughout the study period. Yearly population growth rate dynamics of these species could be best explained by climatic factors in terms of winter severity. In *M. nattereri* and *P. auritus*, yearly population growth rates positively correlated with the number of ice days per winter, but not in *M. daubentonii*. In all three species, temperature fluctuations during winters did not significantly affect population dynamics. Our results show that population growth rates of both *M. nattereri* and *P. auritus* increased during more severe winters. However, during relatively mild winters, *M. nattereri* but especially *P. auritus* was less abundantly present in the monitored hibernacula. As winters are expected to become warmer as a results of climate change, this species most likely select more exposed hibernacula such as tree cavities. Hence, availability of different types of hibernacula that provide a wide variety of microclimatic conditions throughout the winter could improve future conservation of this cold dwelling bat species.

Keywords: climate change, Chiroptera, heterothermy, hibernacula, hibernation, population dynamics, population growth rate, thermoregulation, torpor, TRIM.

Introduction

To bridge winter, bat species differ in their strategy to overcome this period of low

temperatures and low food availability. For bats in the temperate zone, a common strategy is to enter a state of torpor, which is characterized by low body temperatures and reduced metabolic rates (Geiser et al. 2004). In the temperate zone in Europe, bats are predominantly insectivorous and all species

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hibernate during winter, hence they can only rely on stored fat reserves when their food source is mostly unavailable. To use these reserves efficiently, temperate bats hibernate in sites that have reduced exposure to harsh environmental conditions, such as in bunkers, caves, cellars, fortifications, and tree cavities (Dietz & Kiefer 2016). The selection of suitable hibernation sites differs between bat species (Altringham 2011) and depends on factors such as season (Ransome 1990), microclimatic conditions (de Boer et al. 2013), and ambient temperature (De Bruyn et al. 2021). Hibernation is not a continuous process throughout winter; arousal in for example *Rhinolophus ferrumequinum* is synchronized with dusk (Park et al. 2000) and depends on external temperature (Ransome 1971). Moreover, arousal depends on a bat's body condition (Boyles et al. 2007) and can be induced for physiological processes such as drinking, excretion and reproduction, but also occurs spontaneously (Altringham 2011). Bats that wake up from torpor bouts frequently switch to different parts within the same -or less frequently- between hibernation sites (Daan 1973). However, arousal from a deep state of torpor and subsequent flights come at a cost: they are highly energy consuming (Currie et al. 2015), in particular when induced by a perturbation such as human activity (Speakman et al. 1991).

Under current predicted climate change, winters are expected to become milder with higher temperatures and fewer frost days (IPCC 2021). Bat species that hibernate at low temperatures, such as *Barbastella barbastellus* and *Plecotus auritus*, are expected to face major reductions in their distribution area (Rebelo et al. 2010). In *B. barbastellus*, warmer winters have recently led to a shift in hibernation site as this species selects colder (Gottfried et al. 2020) and more stable hibernacula (De Bruyn et al. 2021). Despite this plasticity, changes in winter conditions due to climate change are expected to have an impact on hibernation ranges of bats (Humphries et al. 2002) and may alter microclimatic conditions within

roosts (Rebelo et al. 2010). Since hibernation patterns are closely related to the reproductive cycle in temperate bats (Racey & Entwistle 2000), climate change is likely to have a significant impact on reproduction (Jones et al. 2009) and overwinter survival (Pryde et al. 2005). Because temperature is one of the main drivers of winter energy requirements in heterothermic bats (Humphries et al. 2002), also larger temperature fluctuations may facilitate passive warming and stimulate costly arousal during torpor bouts (Geiser et al. 2004). However, the impact of climate change on patterns of hibernation and torpor in bats is complex (Sherwin et al. 2012) and not fully understood. A better understanding of the effects of climate change on species population sizes and both site and species-specific hibernation site use is therefore urgently needed (Staswki et al. 2014).

We expect that yearly population growth rates of bats hibernating in small artificial hibernacula depend on winter climatic conditions. Here, we define *population growth rate* as the yearly change in total numbers of hibernating bats in these hibernacula and assume that these rates change in response to winter climatic conditions. Demographic stochasticity, i.e., changes in birth or death rates, could not be quantified, as we had no information on the number of hibernating bats outside these hibernacula. We hypothesize that population growth rates of hibernating bats increase during severe winters, as for example observed in *R. hipposideros* hibernating in a large traditional hibernaculum (Martínková et al. 2020). Cold-dwelling bat species that hibernate in more exposed roosts, such as *B. barbastellus* (Gottfried et al. 2020) and *P. auritus* (Altringham 2011), are expected to shift to hibernacula that offer more stable conditions during severe winters (Swift 1998, De Bruyn et al. 2021). Contrary, due to milder winters, hibernacula are more subject to passive warming, and since hibernating at warmer temperatures increases energy expenditure

(Boyles et al. 2007, Geiser et al. 2014), this is expected to negatively affect growth rates. Furthermore, population growth rates are hypothesized to decrease during winters that are subject to larger temperature fluctuations because this increases flight activity during hibernation (Berková & Zúkal 2010). After arousal induced by temperature fluctuations, and dependent of ambient temperature and season, we expect bats to select different hibernation sites to compensate for increased arousal frequency (Ransome 1971), which may lead to reduced growth rates. Since *P. auritus* is, compared to two of our other studied *Myotis* species, more cold-dwelling (Swift 1998), we discuss that the surveyed hibernacula will become less suitable in the near future and that other available hibernation site types will become more important for *P. auritus*. To test these hypotheses we carried out the above analyses on a 35 year database of bats hibernating in small artificial hibernacula in northern Limburg, the Netherlands, between 1986–2020.

Material and methods

Study area

Surveying bat hibernacula by counting individual hibernating bats is a reliable method that allows assessing species trends and conservation statuses (van der Meij et al. 2015). In the Netherlands, annual surveys of bat hibernacula have resulted in long-term databases (e.g. Weinreich & Oude Voshaar 1992, Dijkstra et al. 2006). This particularly applies to the monitoring of bats hibernating in limestone quarries in the South Limburg region, that traditionally has been carried out for more than 80 years (Daan 1980, Akkermans et al. 2016, Weinreich & Verheggen 2022, in this issue). Apart from these limestone quarries, there are approximately 60 bat hibernacula of another type scattered throughout the province of Limburg (Verboom 2006). The monitoring of 18 of

these hibernation sites, which are all situated in the north of the province of Limburg (figure 1), is carried out annually since 1986 (Buys 1991). This resulted in a long-term database with annual numbers of bats hibernating in small hibernacula. The 18 surveyed hibernation sites primarily consist of relatively small and single space cellars ($n=15$) with a mean volume of 70 ($sd \pm 90$) m^3 . Other surveyed hibernation site types are one former brick kiln, a bunker, and a water reservoir (table 1). Human use of the sites differs; some are specifically assigned as a bat roost while others are parts of the year in use for recreational purposes (e.g., Verhees et al. 2019). The surveyed hibernation sites are surrounded by a landscape that primarily consists of agricultural land, fragmented forests and dispersed villages (Schmitz 2010).

Fieldwork

All hibernation sites were monitored almost annually from 1986 onwards or later when a site became accessible to bats (table 1). Yearly surveys took place between 25 December and 13 February. From 1992 and onwards, the monitoring was more standardized by annually surveying all sites during one day in January and by the same group of people. Hibernation sites were systematically searched for the presence of hibernating bats with the use of torches. Bats were identified while hibernating and without handling. In case that insufficient characteristics were observed or no consensus was reached by the observers, bats were identified as “species unknown”. No distinction was made between *Myotis brandtii* and *M. mystacinus*, since identification to species level is not possible without handling (Dietz & Kiefer 2016). The surveys were carried out as part of a national bat monitoring programme (NEM) (La Haye et al. 2020) and under provision of an annual permit issued by the Dutch Mammal Society.

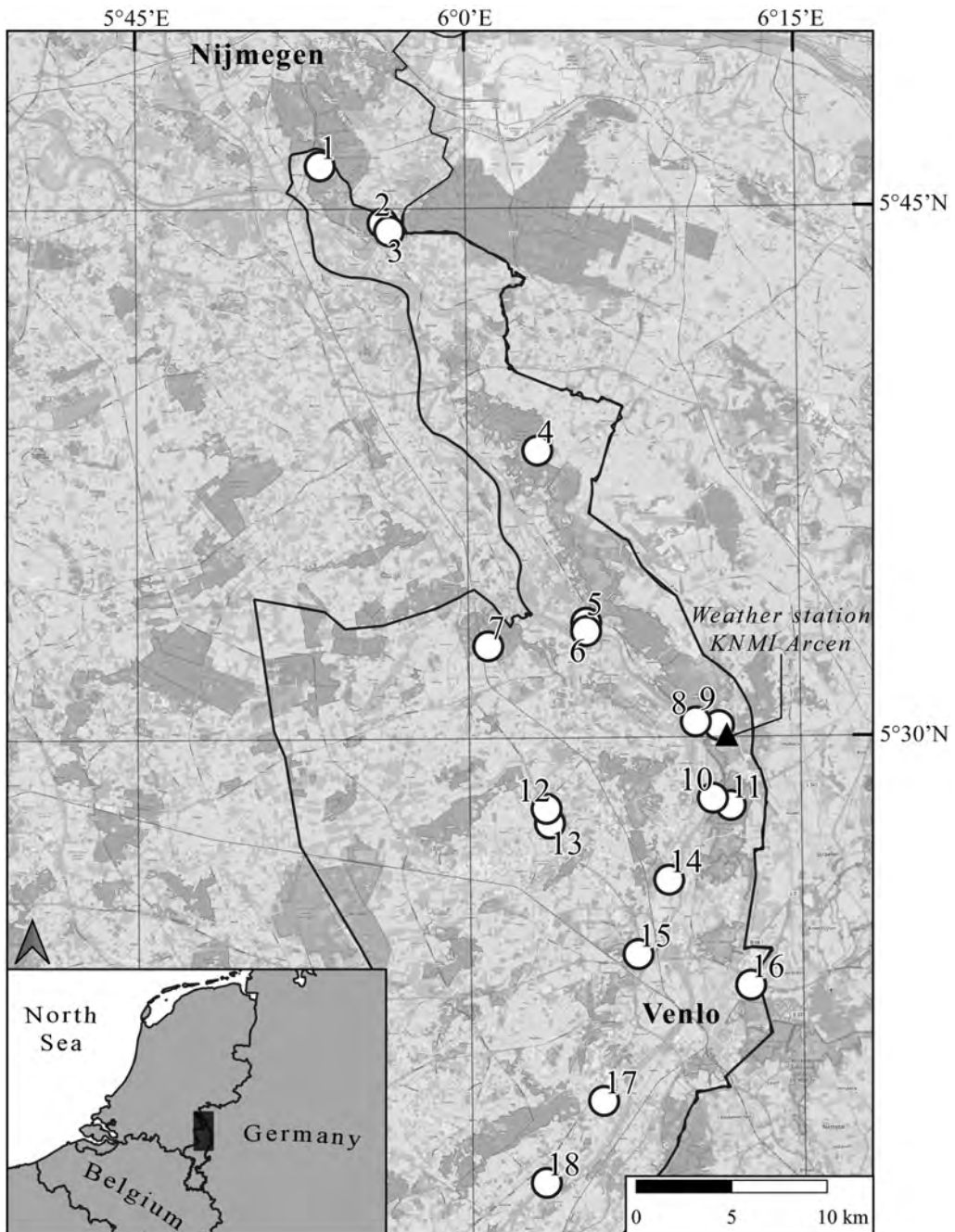


Figure 1. Locations of the 18 hibernation sites in northern Limburg under study and the Royal Netherlands Meteorological Institute (KNMI) weather station in Arcen (triangle). The black line indicates the province of Limburg. Site numbers: see table 1.

Table 1. Hibernation site characteristics (site type, volume and number of separate spaces), year since accessible to bats, start year of the monitoring and total number of years that the monitoring took place. Site numbers correspond to those in figure 1.

Site number	Hibernation site name	Site type	Volume (m ³)	Number of separate spaces	Accessible to bats since	Monitored since	Years monitored
1	Wildkelder Bethanië	Cellar	30	1	<1986	1992	29
2	Ijskelder Sint-Jansberg	Cellar	20	1	<1986	1986	34
3	Waterkelder Sint-Jansberg	Cellar	5	1	<1986	1991	30
4	Ruïne Bleijenbeek	Cellar	125	4	<1986	1986	34
5	Kruitkelder kasteel Well	Cellar	100	1	<1986	1988	33
6	Tunnel kasteel Well	Cellar	20	1	<1986	1989	32
7	Waterreservoir Boshuizerbergen	Water reservoir	5000	1	2017	2017	4
8	Keldertje De Hamert	Cellar	10	1	<1986	1987	15
9	Vleermuiskelder Walbeckerheide	Cellar	20	1	2017	2017	4
10	Keldertje Oranjerie Arcen	Cellar	300	1	<1986	1988	30
11	Ijskelder Arcen	Cellar	20	1	<1986	1987	34
12	Kasteel Huys ter Horst	Cellar	250	5	<1986	1986	34
13	Vleermuiskelder A73 Horst	Cellar	40	1	1996	1996	24
14	Bakoven Kaldenbroek	Cellar	15	1	<1986	1986	32
15	Vleermuiskelder A73 Zaarderheiken	Cellar	40	1	1996	1996	25
16	Bunkertje Herungerberg III	Bunker	20	1	<1986	1987	11
17	Kelder kasteel d'Erp Baarlo ^a	Cellar	20	1	<1986	1986	7
18	Kelder kasteel Keverborg Kessel ^b	Cellar	50	5	<1986	1986	8

^a Accessible to bats until 2005.

^b Accessible to bats until 1994.

Trend analysis of hibernating bats

Our database contains counts of hibernating bats at 18 sites over 35 years (1986–2020). The long-term changes in numbers of hibernating bats were analysed using *rtrim* v2.1.1 (Bogaart et al. 2020). This package is a reimplementation of the software TRIM (Trends and Indices for Monitoring Data), originally developed to analyse temporal variation in monitoring data (Pannekoek & Van Strien 2005). Using loglinear Poisson regression, *rtrim* estimates populations trends based on incomplete count data (only 11.2% of the data i.e. site and year combinations were missing). The analysis was conducted using ‘model 2’, assuming

populations vary across sites but show similar growth everywhere (Bogaart et al. 2020). Models were deployed with a stepwise selection of changepoints and with a correction for both overdispersion and serial correlation. The trend of *P. auritus* was improved by including a binary covariate for hibernacula that consists out of a single space or concern relatively large sites (>50 m³) consisting out of multiple separate spaces. Due to the lack of positive counts in a few site/year combinations, this covariate could not be included to model trends of *M. daubentonii* and *M. nattereri*. No trends could be calculated for other bat species due to low numbers. Calculated trends were classified into one out of six categories depending

on the yearly rate of change. A yearly significant change of >5% represents a strong in- or decrease; <5% a moderate in- or decrease, and non-significant changes of <5% as stable (Bogaart et al. 2020). Any other case was classified as an uncertain trend.

Climate data

Temperature data from 1990–2020 were obtained from the Royal Netherlands Meteorological Institute (KNMI) in Arcen (WGS coordinates 51.501, 6.191), situated at an average distance of 14.6 (sd $\pm$ 10.8) km to the hibernation sites. The daily mean, minimum, and maximum temperatures were obtained based on 24 hourly measurements (KNMI 2021). Since this station is operative since 1990, no temperature data were available during the first four years of the study period (1986–1989). As a measure of winter severity, four parameters were calculated based on temperature data between 1 November and the annual census date, on average after 76 (sd $\pm$ 7.5) days. These are: 1. Mean winter temperature. 2. Average minimum winter temperature. 3. Number of frost days (days with a minimum temperature below 0 °C). 4. The number of ice days (days with a maximum temperature below 0 °C). As a fifth parameter, the sd of daily mean winter temperature was calculated as a measure of temperature fluctuation.

Effects on species-specific yearly growth rates

In order to analyse population abundance dynamics, the yearly population growth rate was calculated per species using the equation: $\lambda = (N_{t+1} - N_t) / N_t * 100$, where 'N' represents the population at year 't'. Subsequently, λ was included as a response variable in General Linear Models (GLMs). Since all winter severity parameters were highly correlated to each other (Pearson's r (29) >0.823, $P < 0.001$), only

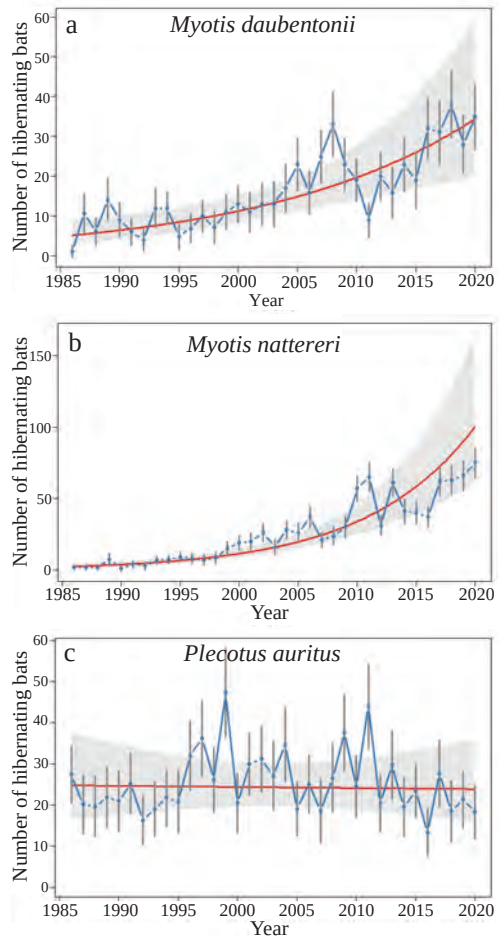


Figure 2. Trends of hibernating *Myotis daubentonii* (a), *Myotis nattereri* (b), and *Plecotus auritus* (c) between 1986–2020. Vertical lines represent the $\pm$ standard errors and the grey areas display the 95% confidence intervals. Note the differences in y-axes.

one of each was included as an explanatory variable, together with the sd of the mean winter temperature. An interaction term between the winter severity parameter and the sd of the mean winter temperature was also included as a potential term in all full models. Before analysis, all explanatory variables were log+1 transformed. Model selection was based on Akaike's Information Criterion (AIC), considering models significantly better with an AIC value of two or more units lower. All

Table 2. Trend estimate of the multiplicative slope and standard errors ($\pm$ S.E.) of the number of hibernating *Myotis daubentonii*, *Myotis nattereri*, and *Plecotus auritus* in northern Limburg between 1986–2020. The slope values represent the mean yearly rate of change, for example 0.997 implies an average decrease of 0.3% while 1.118 implies an average increase of 11.8%. Trend descriptions are based on the classification of Bogaart et al. (2020).

Species	Multiplicative slope	$\pm$ S.E.	Trend description	AIC
<i>Myotis daubentonii</i>	1.058	0.016	Moderate increase ($P < 0.001$)	-12.20
<i>Myotis nattereri</i>	1.118	0.018	Strong increase ($P < 0.001$)	-133.84
<i>Plecotus auritus</i>	0.997	0.009	Stable ($P = 0.782$)	2.63

analyses were conducted in R v4.0.3 (R Core Team 2020).

Site-specific species composition

Two principal component analyses (PCA) were performed to display changes in the species composition of hibernating bats between sites and during the study period. Based on splitting the dataset in two approximately equal periods, the mean number of hibernating bats per site and per species from 1986–2004 was used as a response variable for the first PCA, whereas the second PCA used this data from 2005–2020. To calculate the mean number of hibernating bats per site, only those years that a hibernation site was accessible for bats were included. In case of missing counts, the imputed values calculated with *rtrim* were used for that year. Before analysis, response variables were log+1 transformed, species were centred and standardized, and plots were standardized to norm. Both PCAs were conducted in Canoco5 v5.12 (ter Braak & Šmilauer 2018).

Results

General results and long-term trends

During the study period of 35 years (1986–2020), hibernating bats were found in 17 out of 18 monitored sites (94,4%; supplementary

table S1¹). In total 2372 bat observations were done, divided over five species and one species group (*M. brandtii/mystacinus*). In decreasing order of observations these were: *M. nattereri* ($n=920$), *P. auritus* ($n=818$), *M. daubentonii* ($n=561$), *M. brandtii/mystacinus* ($n=3$), *P. austriacus* ($n=2$), and *Eptesicus serotinus* ($n=1$). Sixty-five times, a bat observation was noted as ‘species unknown’, and twice as *Plecotus* sp. (supplementary table S1¹). The total number of hibernating bats per year varied among years between 13–138 individuals, mainly due to a relatively recent increase in the numbers of *M. daubentonii* (figure 2a) and *M. nattereri* (figure 2b). Between 1986–2020, the overall trend of *M. daubentonii* showed a significant moderate increase with a mean growth of 5.8% per year (table 2). *Myotis daubentonii* was found hibernating in half of all surveyed sites, of which 44.4% got occupied from 2000 and onwards (supplementary table S1¹). The trend of *M. nattereri* significantly strongly increased by 11.8% per year on average (table 2). Also this species was found present in half of all sites (supplementary table S1¹). *Plecotus auritus* occupied most roosts and was found hibernating in 17 out of all surveyed sites (supplementary table S1¹). The trend of *P. auritus* was classified as stable, but overall this species slightly decreased by 0.25% per year on average (figure 2c; table 2).

¹ <https://www.Zoogdiervereniging.nl/publicaties/2022/lutra-65-1-2022>

Table 3. Final models including parameters, coefficients plus standard errors ($\pm$ S.E.), and corresponding t , P , and AIC-values of the yearly population growth models per species. *: $P<0.05$; **: $P<0.01$.

Species	Final model parameters	Coefficients	$\pm$ S.E.	t -value	P -value	AIC
<i>Myotis daubentonii</i>	Intercept	107.19	62.47	1.716	0.079	350.18
	Number of frost days (log+1 transformed)	-28.39	19.95	-1.423	0.166	
<i>Myotis nattereri</i>	Intercept	-27.47	24.26	-1.133	0.267	350.13
	Number of ice days (log+1 transformed)	26.0	10.68	2.435	0.021*	
<i>Plecotus auritus</i>	Intercept	-29.907	13.864	-2.516	0.039*	315.45
	Number of ice days (log+1 transformed)	18.894	6.102	3.096	0.004**	

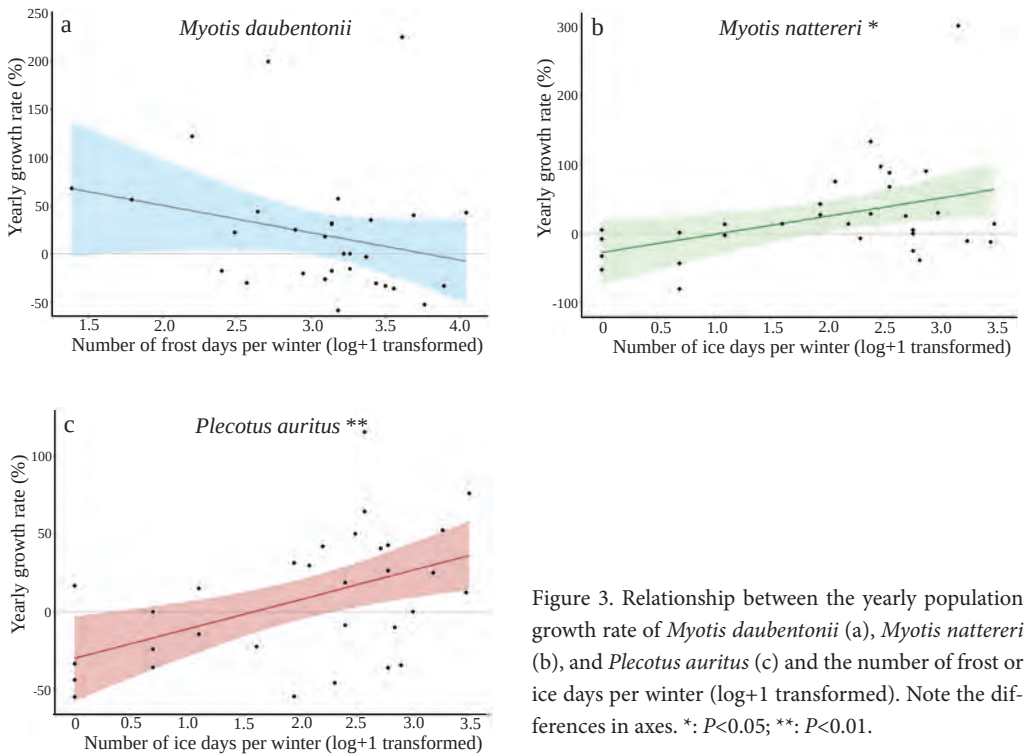


Figure 3. Relationship between the yearly population growth rate of *Myotis daubentonii* (a), *Myotis nattereri* (b), and *Plecotus auritus* (c) and the number of frost or ice days per winter (log+1 transformed). Note the differences in axes. *: $P<0.05$; **: $P<0.01$.

Climatic factors and species specific population growth rates

In *M. daubentonii*, no relation was observed between the yearly population growth rate and any of the four winter severity parameters, the sd of the mean winter temperature, nor their interaction (table 3). The model with the lowest AIC only included the number of frost days, but this was not significant (GLM, $t=-1.423$, $P=0.166$; figure 3a). In *M. nattereri*, a significant positive correlation was found

between the yearly population growth rate and the number of ice days (GLM, $t=2.435$, $P<0.05$; figure 3b), but not when the sd of the mean winter temperature nor their interaction term were included. The yearly population growth rate of *P. auritus* significantly correlated with all four winter severity parameters. The model with the lowest AIC included the number of ice days and this correlated significant and positively with the yearly population growth rate (GLM, $t=3.096$, $P<0.01$; figure 3c). No parameters correlated significantly with

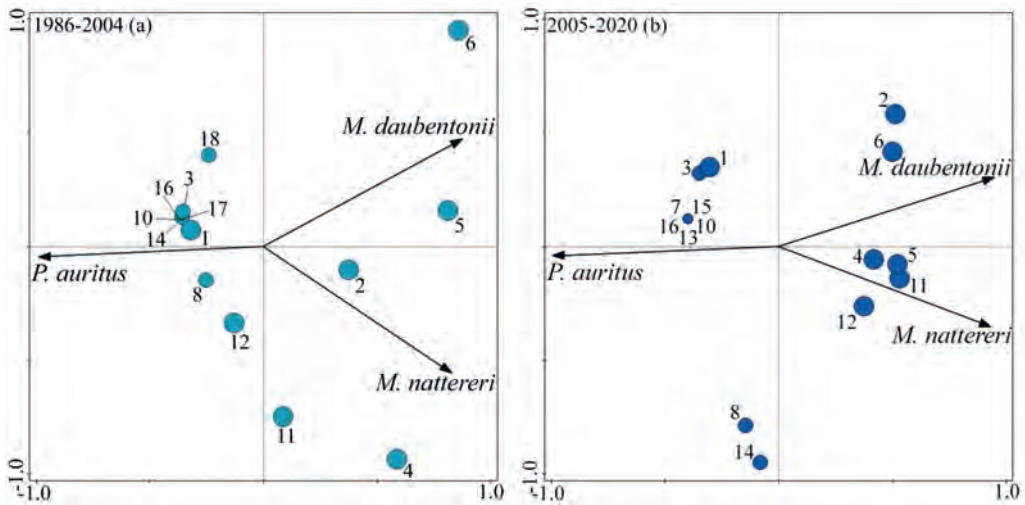


Figure 4. Graphical visualisation of two PCAs for the periods 1986–2004 (a) and 2005–2020 (b). The size of the symbol indicates the number of displayed species (1–3) that make use of the hibernacula. Site numbers: see table 1.

yearly growth rates when the sd of the mean winter temperature nor their interaction were included in these models. Hence, yearly population growth rates of bats hibernating in the surveyed sites are not significantly affected by temperature fluctuations.

Shifts in species composition

The PCA on the species composition during the first period of the study (1986–2004) was rather similar to the one from 2005–2020 (figure 4). All but one accessible hibernation sites were occupied by *P. auritus*, and in six sites this was the only species present. Hence, *P. auritus* strongest correlated to the first axis. In the first period, the total variation explained by the PCA was 42.0%. The first PCA axis explained 81.0% of that variation, the second axis 17.8%. During 2005–2020, more sites became occupied by both *M. daubentonii* and *M. nattereri* (figure 4b). In hibernacula where these species already were present, their numbers increased and sites became relatively more important for these species, while the abundance of *P. auritus* remained approximately equal. The total variation in the PCA during 2005–2020 was 29.0%,

with the first axis explaining 81.9% of that variation, the second axis 17.4%.

Conclusion and discussion

General

To analyse long-term bat trends and population dynamics, we surveyed 18 artificial hibernation sites in northern Limburg by annually counting individual hibernating bats between 1986–2020. Even though this method is widely applied to monitor hibernating bats in underground hibernacula (Haysom et al. 2013), it is also subject to bias since underestimations frequently occur (Kugelschafter 2009). However, we expect deviations from the actual number of hibernating bats during our survey to be small or even negligible. Even though hibernating bats trends can deviate from those in summer (La Haye et al. 2020), we assume that our estimations represent local populations trends *M. daubentonii*, *M. nattereri*, and *P. auritus* in northern Limburg.

In the surveyed sites, we found a total of five different bat species and one species group.

The latter concerns only three observations of *M. brandtii/mystacinus*. Even though this species group is often present in comparable hibernation sites throughout the Netherlands that accommodate a similar species composition (La Haye & van der Meij 2022, in this issue) its nearly absence is somewhat remarkable. Even though the surrounding habitat does seem appropriate and the hibernacula accommodate a wide variety of microclimatic conditions, it is unclear why this species group hardly makes any use of hibernation sites in northern Limburg.

Population trends

Our findings are very similar to previously reported *M. daubentonii*, *M. nattereri*, and *P. auritus* trends in central and western Europe (Uhrin et al. 2010, Haysom et al. 2013, van der Meij et al. 2015, Bernard et al. 2019). Between 1986–2020, the same overall population trends of *M. daubentonii* and *M. nattereri* are also observed in the Netherlands (van der Meij et al. 2015). However, since approximately 2010 and onwards, the national trend of *M. daubentonii* has flattened (La Haye et al. 2020), hence deviating from the continuously growing *M. daubentonii* population trend in our study area. Also the stable trend of *P. auritus* deviates from the overall increasing trend in the Netherlands (La Haye et al. 2020), but recently this species is moderately declining. The exact causes for the observed population increases in *M. daubentonii* and *M. nattereri* are difficult to determine and are probably affected by various factors. Several bat species, including *M. nattereri*, are possibly still recovering from a dramatic decline between 1940–1980 (Daan 1980), a result of negative effects caused by an intensive bat banding programme and severe disturbances during hibernation (Akkermans et al. 2016). Furthermore, the banning of certain pesticides and wood preservatives most likely contributed to population recoveries from this period and onwards for various bats species

in the Netherlands, including *M. daubentonii* and *M. nattereri* (Weinreich & Oude Voshaar 1992, Akkermans et al. 2016). Additionally, in the Netherlands and elsewhere in Europe, a plausible theory of Kokurewicz (1995) is that the increase of *M. daubentonii* is a result of higher prey availability, caused by eutrophication of water bodies. However, Boonman et al. (1998) found that eutrophication also can reduce foraging possibilities of this species, therefore possibly resulting in negative effects on *M. daubentonii* populations. Since current water management strategies aim for less eutrophicated water bodies through improved water quality, it is unlikely this is an important factor nowadays. *Myotis daubentonii* and *M. nattereri* likely also benefitted from improved forest management, as a shift from forests mainly maintained for production to more natural forests took place (Limpens et al. 1997). A management strategy that focusses on the aging of trees, forest composition and structure, preservation of dead trees, and an abundance of tree cavities as well as loose bark results in improved foraging conditions as well as increased roosting possibilities for all forest-dwelling bat species.

Lastly, in our study area, both *M. daubentonii* and *M. nattereri* assumingly also benefitted from hibernation sites refinements, such as minimizing human disturbance, improvements of microclimatic conditions, and increased hiding possibilities (i.e., Buys 1991, Verhees et al. 2019). A combination of these factors likely enhanced the selection and occupation of newly suitable hibernation sites during the study period, therefore contributing to the population increases of *M. daubentonii* and *M. nattereri*.

Yearly population growth rates and climatic factors

We found no significant relationship between abundance dynamics in terms of yearly population growth rates and climatic factors in *M.*

daubentonii, since no winter severity parameter and/or the sd of the mean winter temperature correlated with these rates. These results are comparable to those of Fuszara et al. (2010), who also did not find a relationship between ambient temperature and numbers of hibernating *M. daubentonii* during a comparable long-term study. However, our results do show a pattern that population growth rates are lower during severe winters. During such winters, *M. daubentonii* possibly crawls further away into deep crevices allowing them to hibernate less exposed to environmental conditions, hence lowering detectability during surveys.

In *M. nattereri*, yearly population growth rates were positively correlated with the number of ice days per winter. Even though all four winter severity parameters highly correlated to each other, only the number of ice days significantly correlated with yearly growth rates of this species. This indicates that the presence of higher numbers of *M. nattereri* are only in response to climatic conditions during relatively severe winters (with many ice days), and that other factors are likely to affect yearly growth rates in this species during milder winters. Lower growth rates during relatively mild winters are possibly the result of foraging conditions that are still appropriate (Hope et al. 2014) and allow roosting during daytime in other site types. The winter diet of *M. nattereri* in England predominantly consists of lepidopteran larvae, indicating that this winter prey is caught by a 'gleaning' foraging strategy, complementary to their way of foraging (aerial hawking/gleaning) in summer (Hope et al. 2014). Since *M. daubentonii*, a trawling bat species (Boonman et al. 1998), is perhaps not able to complement or shift this strategy during winter, this possibly explains the observed contrasting patterns in population growth rates in both *Myotis* species in relation to winter severity.

In *P. auritus*, growth rates significantly correlated with all four winter severity parameters, but strongest, and positively, with the

number of ice days. A significant relationship between hibernating numbers of *P. auritus* and ambient temperature was previously reported by e.g., Klys & Woloszyn (2005), and is also found by Bekker (2022, in this issue) and Van Zuijlen & Groenendijk (2022, in this issue) in similar sized hibernacula. After arousal and in response to changes in ambient temperatures (Bezem et al. 1964), individual *P. auritus* likely leave their hibernacula to forage (Hays et al. 1992, Blomberg et al. 2021) and to (temporarily) roost elsewhere under more suitable conditions for thermoregulation (Swift 1998). This plasticity shows that *P. auritus* actively selects and thus relies more on stable hibernacula with reduced exposure to environmental conditions during severe winters (Bezem et al. 1964). Especially in such winters, apparently our surveyed hibernation sites offer these requirements, however during mild winters, mainly other hibernacula (types) are preferred.

Climate change and conservation implications

The vulnerability of species to climate change depends on various factors such as exposure, sensitivity, and adaptive capacity (Aguilar et al. 2016). Mammalian species that have already evolved the capacity to remain torpid during relatively warmer temperatures may thus be favoured by natural selection (Frank 2012). However, in slowly reproducing species such as bats, the evolutionary response to climate change may take considerable time to become apparent (Sherwin et al. 2012). Negative effects of climate change are expected to affect many bat species, but especially those that are cold-dwelling (Rebelo et al. 2010). In order to mitigate the first stages of climate change, a partial habitat shift in response to warmer winters was observed in *B. barbastellus* (De Bruyn et al. 2021), a typical cold-dwelling Eurasian bat species. In response to warmer winters, such plasticity is also likely to occur in one of our studied cold-dwelling

species, *P. auritus* (Swift 1998). During severe winters, we found significant higher population growth rates, and in terms of absolute abundances, the numbers of hibernating individuals were approximately four times higher than those during relatively mild winters. *Plecotus auritus* prefers hibernating at lower temperatures compared to *Myotis* species (Daan 1980, Siivonen & Wermundsen 2008) and generally at more exposed sites (Altringham 2011), such as close to hibernation site entrances and in tree cavities (Dietz & Kiefer 2016). Since hibernation depends on a bat's body condition (Boyles et al. 2007), but also on microclimatic conditions (de Boer et al. 2013) and ambient temperature (Blomberg et al. 2021), it is expected that due to warmer winters our monitored sites become relatively less important for this cold-dwelling bat species. Currently, relatively little is known about alternative roosts that may serve as appropriate hibernacula, such as tree cavities (Cryan & Veilleux 2007), likely due to their inaccessibility for humans. However, it is likely that during warmer winters these more exposed tree cavities become increasingly important for such bat species in the near future. In forest management, therefore, trees and their importance as bat hibernacula should be integrated in conservation strategies of forest-dwelling bat species. Prior to the harvesting of trees, which is typically done in winter, it is of crucial importance to determine the presence of hibernating bats. Even though forest management recently has shifted from production forest as primary objective to more natural forests (Limpens et al. 1997), retention of high numbers of tree cavities should be included and improved in management practices (Lučan et al. 2009). The availability of different types of hibernacula, including tree cavities, allow bats to respond to altered winter conditions and enable them to select hibernacula that (temporarily) meet the right microclimatic requirements for thermoregulation, vital for overwinter survival. Further optimization of these hibernacula and minimization of overall human distur-

bances that cause perturbations of bats (Speakman et al. 1991) could enhance future safeguarding of these regional bat populations in northern Limburg.

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Entering a site may require some effort. Like here in the dunes of the Amsterdamse Waterleiding Duinen (Jan. 2010; *photo: Rogier Lange*) and Voorne (below; Jan. 2009; *photo: Kees Mostert*).

Hibernating bats in the Amsterdamse Waterleidingduinen

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Abstract: This article discusses the results of 35 years of research (1986–2020) on hibernating bats in the Amsterdamse Waterleidingduinen (Amsterdam Water Supply Dunes; AWD), the Netherlands. About 70 bunkers are surveyed every January. Bat counts have steadily increased to a maximum of 265 in 2011; after that the numbers gradually decreased to below 200. Bats have been found in an average of 40 bunkers in the last 15 years. The most numerous species is Daubenton's bat (*Myotis daubentonii*), followed in the initial period by the brown long-eared bat (*Plecotus auritus*). Since 2012, more pond bats (*M. dasycneme*) have been counted on average than brown long-eared bats. Since the turn of the century, the number of Natterer's bat (*M. nattereri*) has increased, followed by a decrease in recent years. The whiskered bat (*M. mystacinus/brandtii*) has only been observed incidentally in the early years. A total of 29 bunkers have been closed since 1989, and in most of them the interior has been modified in hope of making them more suitable for hibernating bats. Although it is difficult to formulate a final conclusion due to various contributing factors, closing off (and adjusting) the bunkers seems to have a favourable effect on the numbers of bats in some cases. Repeated counts in several winters have shown that the bats move in and between the bunkers during the winter and that the numbers of animals in the bunkers vary during the winter. On average, the numbers of counted animals are highest in January. Finally, we briefly discuss the summer research conducted on bats and the opportunities and threats for bats in the AWD.

Keywords: Amsterdamse Waterleidingduinen, bunkers, bats, hibernation, protection.

Introduction

The Amsterdamse Waterleidingduinen (AWD), in the western part of the Netherlands, are a large, varied, wetland nature reserve. Research on bats in this area started in 1984. At that time a start was made with the observation of bats with the aid of bat detectors, as well as with the search for suitable winter habitats. It soon became apparent that the AWD and the immediate vicinity are important for bats in both winter and summer. The research has now been running for more than 35 years, so

that a detailed picture can be drawn up of the results obtained. This article focuses on the methods and results of the winter survey. In the discussion, the results are interpreted and a relationship is established with the results from the summer survey.

Material and methods

Description of research area

The AWD measure approximately 34 km² and are located on the border of the provinces Noord- en Zuid-Holland, between the villages of Zandvoort and Noordwijk. The area has

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been used as a water extraction area for Amsterdam since the mid-19th century; due to the excessive extraction of water, water from the river Rhine has been supplied since 1950 and infiltrated into the dunes in an extensive system of channels and gullies. There are also a few ponds scattered in the open dune area. Many of these waters are important as a foraging site for bats.

In the immediate vicinity of the AWD, Zandvoort and the wooded villages of Bentveld and Aerdenhout are situated on the north side, and the villages of Vogelenzang and De Zilk to the south. Also of importance are a few old estates in the inner dune edge.

Especially since World War II, the area has been increasingly regarded and managed as a nature reserve. The AWD are part of the Kennemerland-Zuid Natura 2000 area designated in 2013. Most of the AWD has always been unexploited, but used as a hunting ground. Water extraction caused desiccation and desertification. Since Rhine water has been infiltrated, the area has become wetter and much more vegetated, but is now under great grazing pressure due to the very large population of fallow deer (*Dama dama*). For several years now, culling is taking place to regulate the population.

Bunkers as hibernacula

During World War II, the Germans built lines near the sea but also in the inner dune edge with a total of more than 130 visible bunkers, mainly in the northern half of the area. In addition, it is estimated that a double number of bunkers are buried under a layer of sand. With the exception of a few solitary bunkers, the bunkers counted annually are located in five clusters, hereinafter referred to as bunker groups (figure 1).

Most bunkers are crew quarters measuring approximately 4 x 4 x 2.5 m, consisting of a reinforced concrete floor and roof and plastered masonry walls, but there are also larger

bunkers consisting of more rooms. Immediately after the war, the bunkers were cleared and bricked up or buried under sand; however, some were reopened later. In the winter of 1985, it was discovered that bats hibernate in these bunkers. The water supply company had a detailed map showing the bunkers. They were searched in 1985 and 1986 and assessed for suitability as a hibernation place for bats. Since the winter of 1987, approximately 70 bunkers and a decommissioned pump cellar have been systematically examined around mid-January. Most objects are, sometimes with difficulty, accessible for research.

At the start of the winter research, it soon became apparent that especially the bunkers with little contact between the interior and the outside air (thick walls, covered by a thick layer of soil, small openings) are used by hibernating bats. The indoor climate (temperature, humidity, draught) in these bunkers is relatively constant, little or no light can enter and there is less chance of disturbance by people compared to bunkers that have large openings. In some bunkers, whose indoor climate was not optimal, bats were found to hibernate in crevices in walls or pipes in the ceiling, where the microclimate was apparently favourable enough.

Adjustments to the objects

After a few investigations, the idea arose to do something to protect the hibernating bats. The bunkers were freely accessible and this presented the risk of disturbance by people. A bunker at Zandvoort was unsuitable for years as a bat shelter after a fire had been lit in it. In the summer of 1989, the Stichting Ecologisch Beheer closed four bunkers, in which at least ten hibernating bats had been observed, with an iron barred gate with a padlock. If necessary, the number of openings was reduced to achieve a more stable and humid indoor climate. Inside, the situation was improved by attaching pieces of wire mesh and pieces of aerated

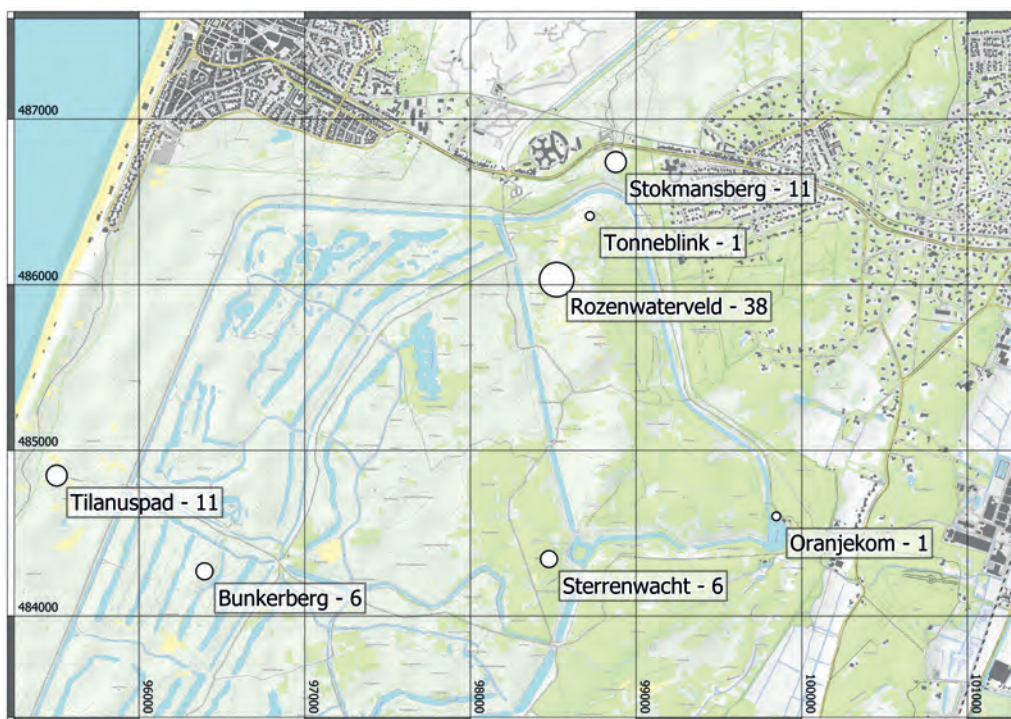


Figure 1. Location of the bunkers in the Amsterdamse Waterleidingduinen in which the hibernating bats are counted every year; the numbers indicate the number of bunkers examined annually.

concrete or patio blocks to walls or ceilings as extra hiding places for bats. Horizontal holes were also drilled here and there and areas in some bunkers were cleared of sand. Over the years, 29 bunkers were fitted with a lock gate and adjustments were made in more than 20 bunkers, often in consultation with the Bat Working Group AWD.

Counting method

From 1987 onwards, the bunkers considered suitable are visited once every winter in January by members of the Bat Working Group AWD. Every winter a counting group of six to eight people is composed, largely consisting of experienced bat counters, supplemented by a few novice counters or other interested people. Depending on the size and surveyability, bunkers are usually examined by one to two

counters. In the bunker, all walls and ceilings, including crevices and pipes, are systematically searched with a flashlight and the bats are identified and counted, while minimizing the chance of disturbance. The counting method has not essentially changed over time. However, some counters have introduced inspection mirrors from around 2005, which can be used to examine places that would otherwise not be (well) visible. Also, the flashlights used have improved over the years. However, because the interior of the bunkers is in most cases uncluttered, the chance that bats are overlooked is very limited and the counting results are considered reliable. The number of objects examined annually has remained almost constant over time. Incidentally, a single bunker has been added to the counting list, for example if it was initially completely covered by sand, but was later dug open by bunker seekers. The solitary bunker at Tonneblink (figure

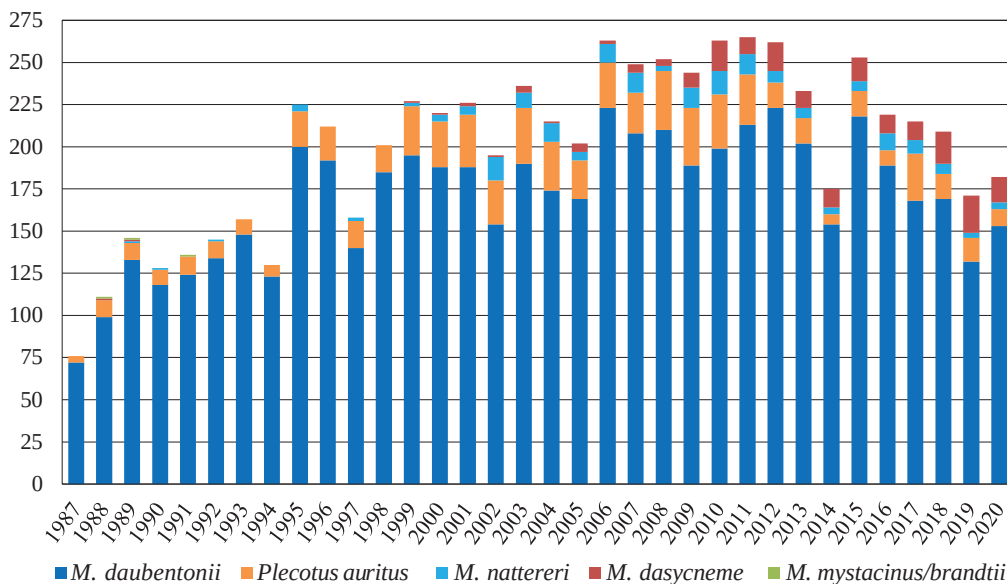


Figure 2. Counted numbers of hibernating bats in the bunkers of the AWD per species.

1) was also added to the census later. All results are entered annually in a cumulative summary table immediately after the investigation.

Apart from the annual winter count, additional counts were performed during some winters, in particular to investigate possible movements of bats within bunkers or to other bunkers. It is known from the Limburg limestone quarries, among other places, that bats initially stay relatively close to the entrance and move deeper into the tunnel system as it gets colder (Dorgelo & Punt 1969, Daan 1973). This is not possible in the small bunkers in the AWD, but here bats could initially hang freely on a wall or ceiling, and then crawl away in pipes or crevices when colder air enters. They could also first stay in a (presumably) less suitable bunker (a relatively small bunker or a bunker with a large opening to the outside) and later move to a (probably) more suitable bunker (a bunker that is less influenced by the outside climate).

Later on, as a follow-up to this research, an infrared camera was installed in a bunker during one winter, which took a photo of a fixed part of the bunker every hour in order

to be able to register movements of animals within the bunker.

Results

Bat numbers from 1987 to 2020

Figure 2 shows the numbers of bats counted per species and cumulatively per count. It is clear to see that the numbers counted initially showed an upward trend, from 76 in 1987 to an average of 210 from 1995 to 2005. From 2006 to 2013, the average count was more than 250 bats, after which the numbers decreased again to an average of just over 200 in the years 2014 to 2020.

The number of bunkers in which bats have been found has increased over the years. It started with 13 (1987) and quickly increased to around 30. From 1999 the average number of occupied bunkers was about 35, after which this increased to an average of 40 with a maximum of 46 in 2015. The average number of bats observed per occupied bunker fluctuates between 4.5 and 7.5 with an average of 5.9.

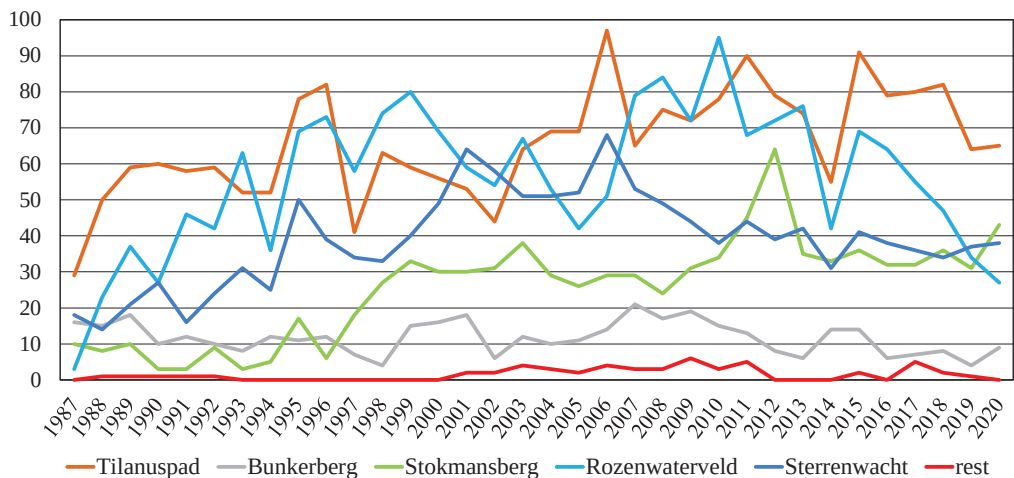


Figure 3. Counted numbers of hibernating bats in the bunkers of the AWD per bunker group.

The largest number of bats counted in a bunker is 30; this was a bunker in the Rozenwaterveld that was closed in 1993.

Numbers per bunker group

When elaborating the numbers of bats counted per bunker group (figure 3), it is notable that the development in numbers in the bunkers around the Tilanuspad, the Sterrenwacht and in the Rozenwaterveld more or less follow the total number trend (figure 3). The numbers in the bunkers around the Stokmansberg and around the Bunkerberg show a somewhat different picture. The numbers on the Stokmansberg have fallen less in recent years than in other areas, while a relatively stable number of bats has been counted in the bunkers on the Bunkerberg, with a slight decrease during the last five years.

Bat numbers in closed versus unclosed bunkers

The changes in bat numbers in the (later) closed bunkers versus the freely accessible bunkers were also examined. It can be seen that the average number of bats counted per bunker in the non-closed bunkers has increased slightly, but has not risen above 1.8, while this number in the closed bunkers has increased from about three to about nine (figure 4). In recent years,

however, the average number of bats in closed bunkers has fallen again to about five.

Furthermore, it was investigated whether there was a visible effect of closing bunkers by means of a railing. To this end, for the ten bunkers that were closed between 1992 and 1999, the numbers of bats in the five years before the closure were compared with those in the same period after the closure (figure 5). This concerns a representative group of bunkers with sufficient data before and after the closure. The closure seems to have had a favourable effect on the number development in this group of bunkers: after a period without a clear trend, there was on average a clear increase in the number of bats in the years after closure. In other bunkers a less clear effect of the closure was visible.

Number trend per bat species

By far the most numerous species in the bunkers in the period 1987-2020 was Daubenton's bat (*Myotis daubentonii*), with a maximum number of 223 individuals in the years 2006 and 2012. After an increase in the early years, the average number of Daubenton's bats counted from 1995 to 2015 was nearly 200; from 2016 a downward trend set in to an average number of just over 150 animals per year.

The second most commonly found bat was

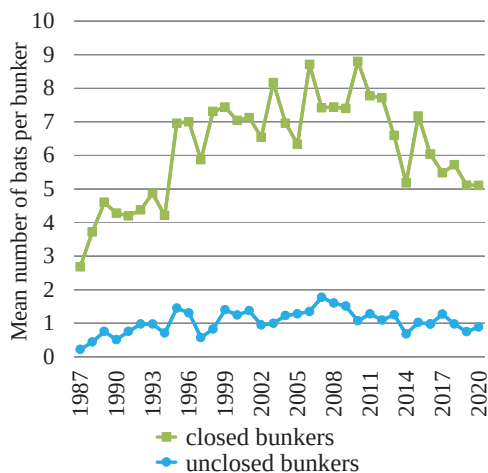


Figure 4. Average number of bats in closed and unclosed bunkers.

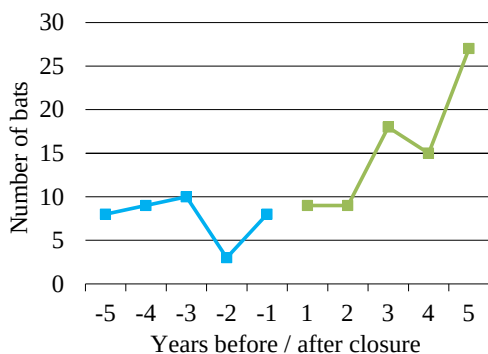


Figure 5. Evolution of the total number of bats in ten bunkers in the five years before and five years after closure.

the brown long-eared bat (*Plecotus auritus*) with a maximum number of 35 individuals (2008). The number development shows an increasing trend to an average of more than 25 in the years 1995 to 2011, after which the number decreased to an average of just over 15.

This is followed by the pond bat (*M. dasycneme*), with a maximum number of 22 individuals in 2019. Up to and including 2008, no more than five animals were found, but after that an increasing trend followed to an average of almost 15 animals per year.

The fourth species is Natterer's bat (*M. nattereri*), with a maximum number of 14

specimens in the years 2002 and 2010. Until 2001, no more than five animals per year were observed, after which the average increased to almost ten. After 2016, a downward trend appears to have started.

Finally, a single whiskered bat (*M. mystacinus/brandtii*) was occasionally observed in the early years. After 1992, this species was no longer found in the bunkers.

Additional research

While closing and adjusting the first four bunkers in 1989 the question arose whether the bunkers where the highest numbers of hibernating bats were found in January were the most important throughout the winter season. To investigate this, from November 1989 to March 1990, a count was carried out every third week of the month in the three bunker groups that included closed and modified bunkers: Tilanuspad, Bunkerberg, Sterrenwacht. In the bunkers of the Sterrenwacht, the number of hibernating Daubenton's bats clearly increased until January and then decreased again (figure 6). The same increase was seen in the bunkers of Tilanuspad, but here the number also increased somewhat on 23 February. The number of Daubenton's bats on the Bunkerberg was low during all months (in December no count could take place here). At the end of March, only a few animals were still present in the Sterrenwacht. In all three bunker groups, the number of Daubenton's bats present on January 26 was about twice as high as on November 21. In the winter of 1990, brown long-eared bats were only found in the bunker groups Sterrenwacht and Tilanuspad, from November to February and always in small numbers of a maximum of three. In March 1990 no more animals were found here. No brown long-eared bats were observed on the Bunkerberg during the counts. Also notable was the pond bat in a bunker at the Tilanuspad in February, which was not present in the other counts.

In the winter of 1994, the monthly count was

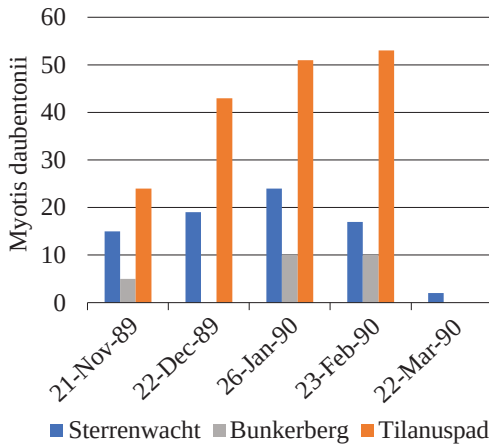


Figure 6. Number of Daubenton's bats in three bunker groups during five counts in the winter of 1990.

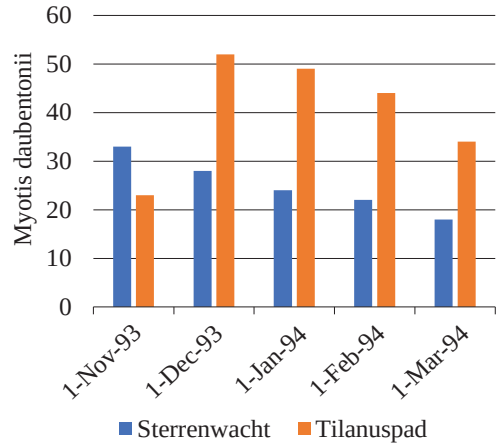


Figure 7. Number of Daubenton's bats in two bunker groups during five counts in the winter of 1994.

repeated in two bunker groups (Sterrenwacht and Tilanuspad) (figure 7). The number of Daubenton's bats in these counts in the bunker group Sterrenwacht was highest in November and gradually decreased in the following months. In the Tilanuspad bunker group, the highest number was reached in December, with the number almost doubling compared to November. After December there was a gradual decline, but in March 1994 there were still considerably more Daubenton's bats present on the Tilanuspad than in March 1990. The explanation seems to be that it was still quite cold in February and the first half of March 1994, while in March 1990 it was already warmer. The number of brown long-eared bats was slightly higher than in 1990: now a maximum of seven animals in a bunker group were counted. In both bunker groups, the behaviour of long-eared bats under the influence of frost was noticeable: the numbers increased when it started to freeze (in December and February) and decreased after the end of the frost period. In 1991, after the total count in January, a period of several weeks of moderate to severe frost set in. It was assumed that the hibernating bats would concentrate in a small number of bunkers in which the temperature remained relatively high. This assumption turned out to be incorrect. During an additional count on 18

February in the above three bunker groups, the number of bats was lower than in January and no clear shift in numbers in favour of certain bunkers was observed.

The influence of weather conditions was also investigated in 2006. In that year it was constantly cold from January to mid-March, with frost almost every night. On 15 March, 57-60 Daubenton's bats, one brown long-eared bat and one to four Natterer's bats were found in the bunker group Sterrenwacht. Due to their hanging position, identification of three animals was not possible. This was about the same as during the regular January census, when 62 Daubenton's bats, one brown long-eared bat and five Natterer's bats were counted; the bats seemed to have stayed in the bunkers because of the cold. In November 2006 it was unusually warm (18 °C on 15 November). On 16 November, 42 Daubenton's bats were already present in the Sterrenwacht bunkers. During the January 2007 census, 52 Daubenton's bats and one Natterer's bat were observed. Despite the warm weather, there were already many bats in the bunkers in November.

In order to gain more insight into the number development of bats in the first part of the hibernation period, eleven counts were performed from 5 October 1994 to the regular count on 20 January 1995 in the five suitable

bunkers of the Sterrenwacht (table 1). On 5 and 10 October, approximately ten Daubenton's bats passed along a flight route that was frequently used in summer. On both dates, two, presumably the same, Daubenton's bats were hanging in one of the bunkers. From 21 October there was no more activity on the flight route and at some foraging areas that are crowded in summer, and numbers increased steadily from that counting date. The position of the bats found has been recorded in all counts. This showed that the animals moved frequently. The numbers of Daubenton's bats per bunker during the counts performed are shown in table 1. The numbers of other species were too low to draw conclusions and are therefore not listed.

In the winter of 2015, a camera in one of the bunkers automatically took an infrared photo every hour of the walls with wire mesh and pieces of aerated concrete: the places where most of the bats hibernate in this bunker and are well visible. Frequent displacement was also observed here. Because only part of the bunker was in view, the possible change in the total number of bats in the bunker, and also whether they had flown in or out, remained unknown. It was however clear that there was bat activity at night and hardly during the day.

Discussion and conclusions

Number trend in total and per species

This article summarizes the results of approximately 35 years of bat research in the bunkers in the AWD. About 70 bunkers that were found to be potentially suitable in the mid-1980s are examined annually. Over the course of the study period, hibernating bats were found in a growing number of bunkers. The total number of bats counted has been increasing for years, but shows a downward trend after 2015 (figure 2). This number development has also been observed in some other dune areas in the Netherlands, but not everywhere. On average, there appears to be a stabilization in bat numbers in

the dune areas from around 2015 (Mostert et al. 2022, in this issue). However, it should be taken into account that in most of these areas the number of objects examined has increased over the years. This is not the case in the AWD; the number of objects examined annually has remained virtually the same since the start of the counts. Therefore, the counted numbers of hibernating bats are a good reflection of the actual number development.

Daubenton's bat is by far the most numerous of the observed bat species. The downward trend in the total number of bats counted since 2015 can be attributed to this species. The cause of this recent decline is unknown. It could possibly be related to the disappearance of summer habitats in the area or other factors that have hindered reproduction.

For many years, the second species was the brown long-eared bat, but this species has also been declining in number in recent years. We can only speculate about the cause, but this trend is also visible in other dune areas.

However, the pond bat has shown an increasing trend for years and as of 2012, more pond bats are usually encountered than brown long-eared bats. The increasing trend of the pond bat is visible in the entire dune area.

Natterer's bat showed a slightly increasing trend until 2010, but numbers have decreased again after that. In other dune areas the numbers have stabilized in recent years.

Finally, the whiskered bat was only incidentally encountered in the first years of the study period; no more observations of this species have been made after 1991. This species is mainly found in the dunes of Zuid-Holland, although the numbers decreased after about 2012. In Zeeland (particularly in Zeeuws-Vlaanderen) whiskered bats are observed in lower, but stable numbers in hibernation sites.

It is tempting to perform all kinds of calculations and analyses on the observed number developments. However, because several factors may play a role, it is impossible to give an unambiguous explanation for the observed number fluctuations.

Table 1. Number of Daubenton's bats in five bunkers (B1-B5) ('Sterrenwacht' group) between the beginning of October and the end of December 1994; in the last column the numbers during the regular count on 20 January 20 1995. -- not counted.

Date	5 Oct	10 Oct	21 Oct	1 Nov	8 Nov	15 Nov	28 Nov	2 Dec	8 Dec	20 Dec	28 Dec	20 Jan
B1	2	2	4	1	3	2	4	2	2	1	2	3
B2	--	--	3	4	5	6	6	5	5	5	5-6	5
B3	0	--	4	9	13	14	12	11	12	19	15	20
B4	0	--	2	2	4	8	9	8	14	6	14	15
B5	0	--	0	0	3	1	0	3	2	4	2	2
tot	2	2	13	16	28	31	31	29	35	35	38-39	45

Effect of bunker modifications

The increase in the average number of bats in the closed bunkers is greater than that in the freely accessible bunkers (figure 4). However, this does not directly mean that the stronger increase is due to the closure and/or adjustments in the bunkers. A number of bunkers have been closed off because a relatively large number of hibernating bats were found in them. It may well be that an increase in the population manifests itself more clearly in suitable bunkers.

The difference in numbers between the five years before and the five years after the closure of ten bunkers closed in the 1990s is clear (figure 5). Because the same objects are compared, the only variable is the closure. However, since the population may also have grown in the same period, in this case too we are not sure whether the closure is the only cause of the increase in numbers.

Closure seems to have had the most favourable effect on the number of bats in the group of bunkers in which, on average, only a few bats were encountered before the closure. Particularly in bunkers in which a relatively large number of bats were counted before the closure, a less clear or even no effect of the closure can be seen.

Extra counts during the winter

From the various extra counts carried out

in a number of winters, it can be concluded that bats start visiting the bunkers early in the winter and that the numbers usually increase gradually until January (figures 6 and 7). Bats seem to come to the bunkers from unknown hibernation sites and gradually leave these after January, although the hibernation period has not yet ended. Furthermore, there are many movements, both within bunkers and (presumably) from one bunker to another.

A disadvantage of this research is the possible disruptive effect due to the more frequent entering by researchers of the bunkers. Possible disturbance has been kept to a minimum by keeping the stay in the bunkers as short as possible. In addition, it has regularly been seen that bats also stimulate each other to activity, for example when they are clumped together or hang on or behind wire mesh. The movement of one bat transmits a vibration to the others and this regularly leads to awakening and displacement, an effect that is also known from the literature (Thomas 1995). However, many movements and displacements were also detected with an infrared camera, which obviously had no disruptive effect.

Summer research

In the same period as the winter research described here, regular summer surveys were conducted on bats. Nursery colonies of Daubenton's bats, noctules (*Nyctalus*

noctula) and common pipistrelles (*Pipistrellus pipistrellus*) were found in trees on the estates in the inner dune and also in a few houses and a barn.

A number of fixed commuting routes have been discovered between the estates and the open dune area, where many counts have been carried out over the years. In the dune area itself, many counts were also performed above the waterways, using bat detectors. Several hundred foraging bats were often encountered here, especially Daubenton's bats and smaller numbers of common pipistrelles and, in the autumn, also Nathusius' pipistrelles (*Pipistrellus nathusii*). In addition, serotines (*Eptesicus serotinus*), noctules and occasionally whiskered bats and brown long-eared bats were observed on the commuting routes.

It is likely that at least part of the Daubenton's bats found in the bunkers belong to the same population as the animals observed in the summer. The numbers counted roughly correspond, as has also been established in other parts of the coastal area (Mostert et al. 2022, in this issue). How bats move between the summer and winter habitats can only be determined by means of banding.

Opportunities and threats

Over the years a large number of bunkers suitable for hibernating bats have been closed off to prevent intrusion and disturbance by humans. However, every year attempts are made to force locks; this is a permanent point of concern and attention. Due to the construction of an ecoduct over the road to Zandvoort, a bunker where bats spend the winter every year has disappeared under the sand of the bank. However, this bunker has been kept accessible for bats and bat researchers by constructing a concrete shaft.

The dune area is dynamic; occasionally

'new' bunkers or openings of known bunkers are exposed, whether or not after digging actions by bunker enthusiasts. If the bunkers important to bats remain closed to public, no threats to hibernating bats are expected. However, there is still room to provide a barred gate in a number of bunkers where bats spend the winter to prevent disturbance. Adjustments have been made in almost all closed bunkers to create suitable hanging spots for bats. It is conceivable that further adjustments will further increase the numbers counted.

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Annual numbers of hibernating Daubenton's bats (*Myotis daubentonii*) and pond bats (*M. dasycneme*) in the dune areas of Meijendel and Uilenbosch

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Abstract: Since the winter of 1977, the populations of hibernating bats have been monitored in five complexes of bunker corridors of the former Atlantic Wall remaining from World War II in the dune areas of Meijendel and Uilenbosch, which are located in the municipalities of Wassenaar and The Hague (Province of Zuid-Holland, the Netherlands). Through management measures, such as closing the entrances for uncontrolled human trespassers and increasing the number of safe hanging locations, significant numbers of Daubenton's bats (*Myotis daubentonii*) and pond bats (*Myotis dasycneme*) now use these complexes. In addition, small numbers of the whiskered bat (*Myotis mystacinus*), brown long-eared bat (*Plecotus auritus*) and Natterer's bat (*Myotis nattereri*) occasionally hibernate in these complexes. The dune areas in which these complexes are located have been designated as Natura 2000 areas in which the presence of the large numbers of pond bats hibernating there has played an important role. The five complexes together form the most important mating and winter sites of the pond bat in Western Europe.

The authors dedicate this paper to Christiaan Smeenk (1942-2017), formerly mammal curator of Naturalis Biodiversity Center, for his years of enthusiastic participation in the winter monitoring of bats in the Meijendel dune area. His wisdom will remain with us.

Keywords: dune areas, Meijendel, Uilenbosch, pond bats, Daubenton's bats, hibernation, annual numbers, Natura 2000.

Introduction

The dune areas of Meijendel and Uilenbosch are situated just north of The Hague (Province of Zuid-Holland, the Netherlands). The area of Meijendel is predominantly a drink-

ing water extraction area that is managed by Dunea Duin & Water (Dunea), a water supply company. The area has a number of artificial lakes that exist due to the infiltration of river water. The area is mostly owned by the State Forestry Service (Staatsbosbeheer) and is leased to Dunea. Most of the seawall is managed by the Rijnland Water Board and a small part, in the south, by the Delfland

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Figure 1. Locations of the bunker-corridor complexes in the dune areas of Meijndel and Uilenbosch.

Water Board. The adjacent Uilenbosch area is owned, managed and used by the Ministry of Defence. The Delfland, DWL and Moffenslag complexes are managed by Dunea, the Wassenaarse Slag complex by the State Forestry Service and the bunkers and corridor complexes in the Uilenbosch area by the Ministry of Defence. Once a year in the winter between 15 December and 15 February, the bats hibernating in these complexes are monitored with the minimum possible disturbance. In addition to the winter counts, other studies focused on the pond bat were carried out in the complexes in the period 2002–2015 (Haarsma et al. 2019, Haarsma et al. in prep.). The locations of the complexes are shown in figure 1.

This paper provides an overview of the annual numbers of hibernating Daubenton's bats (*Myotis daubentonii*) and pond bats (*M. dasycneme*) in the dune areas of Meijndel and Uilenbosch from 1977 to 2020.

The hibernation sites

The Wassenaarse Slag complex

This complex of subterranean man-sized corridors and some remaining bunkers is located on the Wassenaarse Slag. The complex is more than 800 metres long and has more than 100 ventilation shafts. The history of the construction, the various functions of the complex and its use during World War II have been described by Neisingh & Verbeek (1994) and Kras (2014).

Shortly after World War II, the bunkers and corridors fell into disuse. The corridors were substantially filled up with sand. From the 1960s onwards, most of the bunkers that were connected with the corridors were demolished. This was done by blowing up the bunkers or crushing them with heavy machinery. However, a large part of the corridors that connected the bunkers



Figure 3. A cluster of Daubenton's bats and a single pond bat, seen from below in bat box. Photo: Christian Dietz.



Figure 2. The type of bat box installed in the bunker complexes. Photo: Christian Dietz.

remained intact. Just before the complete demolition of the complex, 35 bats were observed (33 Daubenton's bats and two whiskered bats) on 20 December 1976 in a part of the corridors that was accessible at that time. This observation gave rise to the plan to set up the corridor complex and the remaining bunkers for bats. This led to the entrance of the complex being provided with a grille in 1977¹. From then onwards, under the supervision of the State Forestry Service, a process of de-sanding and provisional restoration of the complex began with the ventilation and exit shafts being sealed with tiles or concrete plates. This work took place over a number of years.

¹ In this paper January of each year is taken as the winter date, so for example 1977 = the winter of 1976-1977

Between 1993 and 2007, guided tours within the complex took place during summer months. Due to observed cave-ins of, and cracking in, the roof, the complex was closed to visitors from 2007. Between 2014 and 2017, repair work was carried out in which most of the cracks and crevices were closed (Noort et al. 2021).

A special type of bat box was installed to the walls to provide additional shelters throughout the complex (figures 2 and 3). From 2015, guided tours were again organized in a part of the complex. Another part of the complex is reserved as a bat reserve all year round. A separate entrance has been made for visitors to minimize negative effects on the climate in the bat section (Noort et al. 2021).

After the first discovery of hibernating bats in the Wassenaarse Slag complex in December 1976, hibernating bats in the complex were counted annually, usually in the third week of December. The first two hibernating pond bats were observed in the winter of 1979. These animals were the first winter record of this species outside the limestone area in southern Limburg. The annual numbers of hibernating Daubenton's bats and the pond bats from the winter of 1977 until the winter of 2020 are given in figure 4. Since 2013, both Daubenton's bat and the pond bat have been in decline, for reasons that are unclear. The animals may have suffered from the renovation works, which has changed the humidity and temperature in the complex, with the

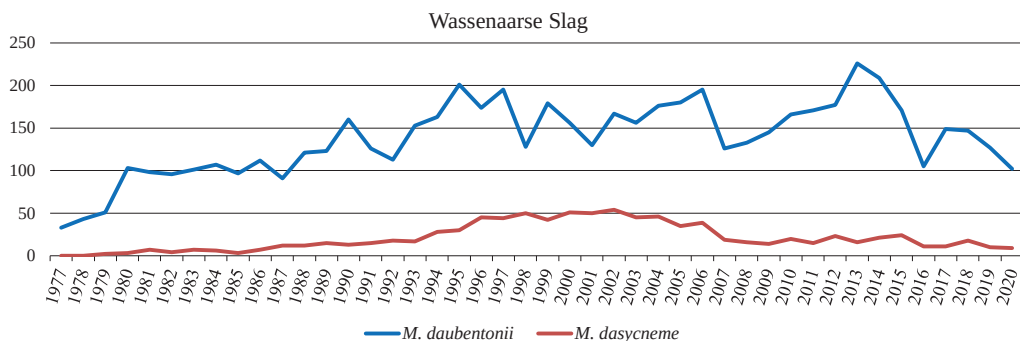


Figure 4. Annual numbers of hibernating *Myotis daubentonii* and *M. dasycneme* in the Wassenaars Slag complex.

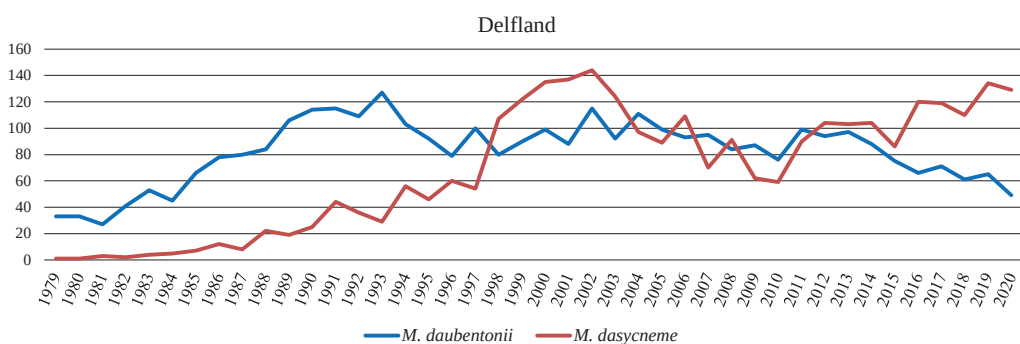


Figure 5. Annual numbers of hibernating *Myotis daubentonii* and *M. dasycneme* in the Delfland complex.

complex becoming drier. The tours in the summer months have possibly also played a role (Noort et al. 2021).

The Delfland complex

The Delfland complex also has subterranean, man-sized corridors, connected to a number of bunkers. The complex has a length of 320 metres. The complex used to be part of the former, and larger, Stützpunkt Marine Seeziel Batterie Scheveningen-Nord XXXX ML complex of corridors (Ambachtsheer 1995) to which the DWL complex also belonged. Despite regular monitoring and enforcement, the Delfland complex is regularly broken into, often in the autumn and winter season, which has very negative consequences for the bats (Noort et al. 2021). The complex has been inspected for hibernating bats since the win-

ter of 1979 and an entrance grille was installed during the summer of 1980. In the summer of 2011 bat boxes (figures 2 and 3) were installed to the walls throughout the complex to provide additional hiding places (Noort et al. 2021). The annual numbers of Daubenton's bat and the pond bat from the winter of 1979 until the winter of 2020 are shown in figure 5.

The DWL complex

As mentioned above, the complex used to be part of the former larger Batterie Scheveningen-Nord corridor complex. It is also a complex of underground, man-sized corridors connecting several bunkers. As with the Delfland complex, the censuses began in the winter of 1979 and the entrance was grilled during the summer of 1980. For a long time, the complex had an accessible corridor length

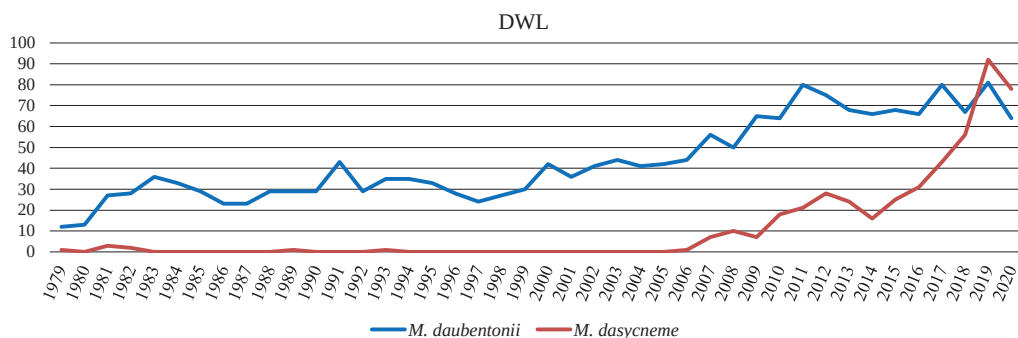


Figure 6. Annual numbers of hibernating *Myotis daubentonii* and *M. dasycneme* in the DWL complex.

of just 80 metres and only two bunkers. In 2007, more than 350 metres of corridors and three bunkers were added which had not been accessible before to people (and probably for bats as well). While there was a steady increase of hibernating Daubenton's bats after the closure, until the winter of 2006 hardly any pond bats were found, in contrast to the very nearby Delfland complex. It was not until the winter of 2007 that the number of this species increased. Occasionally, a few hibernating brown long-eared bats (max. four), whiskered bats (max. two), and Natterer's bats (max. two) were observed. Since the complex was optimized in 2014, the use by the pond bat has grown to about 90 animals. Bat boxes (figures 2 and 3) were also installed in this complex. Banding research has shown that there is no exchange of pond bats between the Delfland and the DWL complexes despite the short distance between the two complexes (110 metres as the crow flies) (Noort et al, 2021). The annual numbers of both Daubenton's bat and the pond bat from the winter of 1979 until the winter of 2020 are given in figure 6.

The Moffenslag complex

This complex is located between the Delfland and DWL complexes and the Wassenaarse Slag complex and also has underground man-sized corridors and some bunkers. The censuses here started in 1984. In the first three winters, no

bats were found. It was not until the winter of 1987 that the first hibernating Daubenton's bats were found and then in the winter of 1994, the first pond bats. Since then, the number of animals of both species has steadily increased. Since 2011, the complex has been closed with a solid steel grille. A dramatic decline occurred in 2017 and the numbers had not yet recovered to the previous levels by the winter of 2020. Bat boxes have also been installed in this complex (figures 2 and 3). The annual numbers for both species from the winter of 1984 until the winter of 2020 are given in figure 7. A few hibernating brown long-eared bats (max. six), whiskered bats (max. two), and Natterer's bats (max. one) have occasionally been observed.

The Uilenbosch complex

The Uilenbosch complex is a cluster of 23 larger and smaller bunkers and corridors. Between 1983 and 2000, most of the bunkers and corridors were de-sanded and closed with solid doors. Bat boxes were installed in five of the seven largest corridors in 2015 and in the other bunkers (except one) in 2019. The censuses began in the winter of 1982 but were interrupted for two years in the winters of 1990 and 1991. Illegal trespassing frequently occurs every year. The repair, and increasing strengthening of, the constructions and doors has the full attention of the Ministry of Defence.

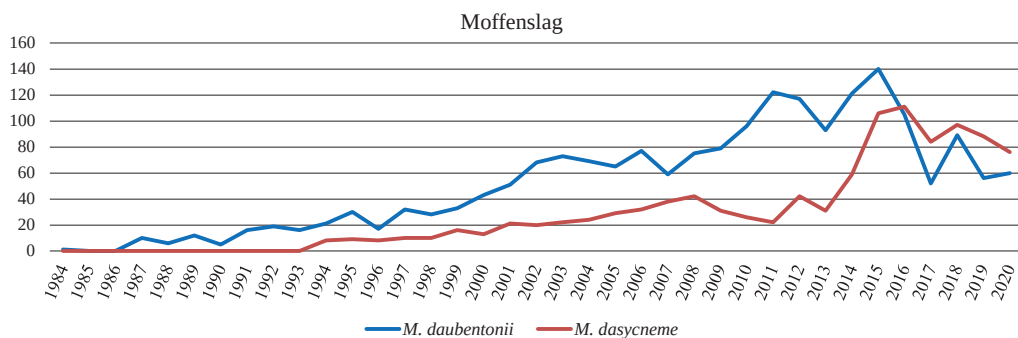


Figure 7. Annual numbers of hibernating *Myotis daubentonii* and *M. dasycneme* in the Moffenslag complex.

Daubenton's bats and pond bats are the dominant hibernating species in the Uilenbosch cluster. Figure 8 shows the annual numbers between 1982 and 2020 of both species in the cluster. In the smaller bunkers, the brown long-eared bat, whiskered bat and Natterer's bat are also observed. The population of hibernating pond bats here has strongly increased to numbers exceeding 250 (272 in 2020) and accounts for about 27% of the hibernating pond bats in the Netherlands and about 8% of the known hibernating individuals of this species in Europe (Noort et al. 2021).

Discussion and Conclusions

Voûte & Lina (1986), who also refer to similar studies abroad, have shown that closing potential hibernation sites of bats with grilles or doors with fly-in slits, thereby avoiding uncontrolled human access, can lead to an increase in the numbers of hibernating bats. Their research drew upon evidence of substantially higher numbers of hibernating Daubenton's bats and pond bats, in the Wassenaarse Slag, Delfland and DWL complexes after the entrances of these complexes were closed. However, extreme caution is recommended with closing measures with doors and walls, as in some situations (such as large limestone mines) this has caused a decline of species that prefer a more dynamic climate (Daan & Wichers 1968, Baranauskas 2006, Haarsma 2011).

Uncontrolled access to hibernation sites can lead to disturbance of bats and can cause a shift in hanging positions (from clusters on the ceiling to hidden in crevices, Haarsma, 2011). The direct effect of human disturbance is often hard to measure, as other (indirect) human activities may also have an effect. It is possible that the public summer excursions into part of the Wassenaar Slag complex is influencing the downward trends of the populations of Daubenton's bats and pond bats there and the part of the complex that is used for public excursions should probably be completely physically closed off from the core part where most bats usually hibernate. The objectives of Natura 2000 should take priority here.

In the absence of sufficient shelters in the complexes, the installation of bat boxes appears to have a great added value, which the pond bat especially benefits from; large groups of up to 30 pond bats have been observed in the boxes (Noort et al. 2021). In each of the bunkers, on average over 80% of the pond bat population can be found hidden in these bat boxes. The use of such boxes is recommended for similar hibernation sites elsewhere, particularly where pond bats hibernate.

Acknowledgements: The authors would like to express their gratitude to the managers of the complexes, (Dunea Duin & Water, the State Forestry Service and the Ministry of Defence) for their years of dedication to the preservation of the complexes for the conservation of the populations of hibernating bats, which

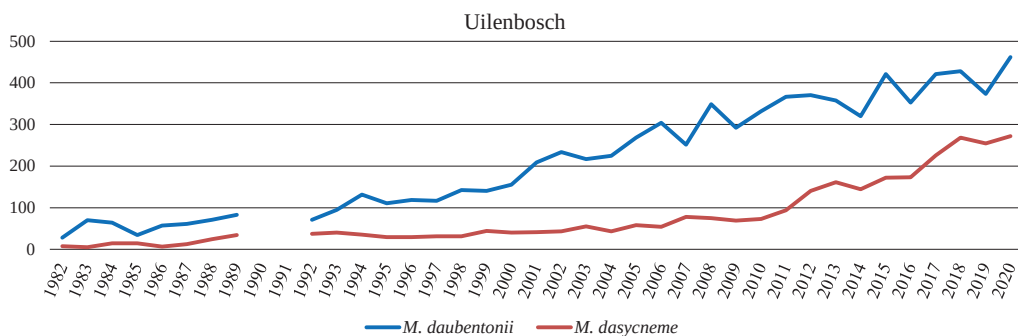


Figure 8. Annual numbers of hibernating *Myotis daubentonii* and *M. dasycneme* in the Uilenbosch cluster of complexes.

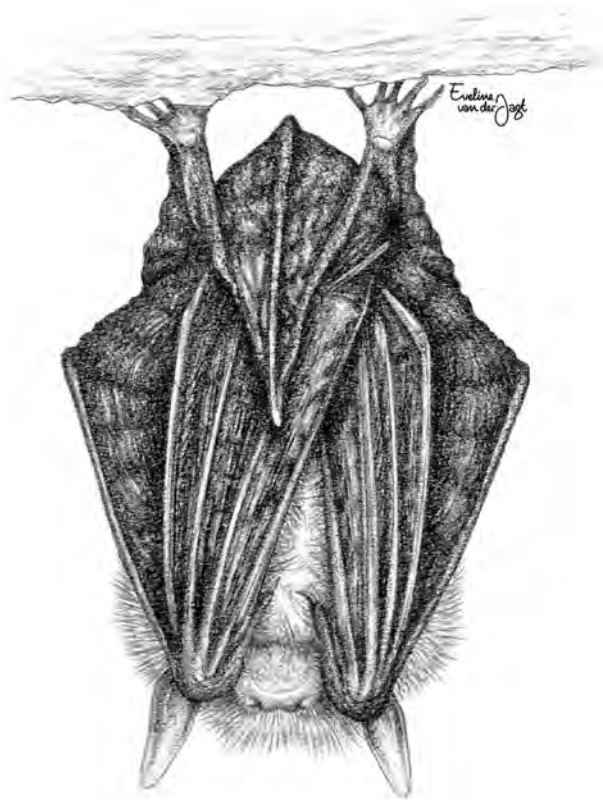
have significantly increased over the years. Our special thanks go to Peter H. van Deursen of the State Forestry Service for his initiatives to preserve the bunker complexes. The authors also want to thank the many volunteers who have helped monitoring the bats, which has significantly increased the knowledge about the hibernating bats in both dune areas.

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Effects on hibernating bats of ambient temperatures and the characteristics of winter roosts in a dune area

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Abstract: The Dutch dune areas between Zandvoort and Bergen aan Zee contain various sites, such as bunkers and ice cellars, in which bats hibernate. The bats in these sites are counted annually each winter. This study investigates whether the ambient temperatures and other characteristics of these winter roosts influence the number of bats hibernating in them. The relationship between the number of bats counted (average number per location) and the ambient temperatures appears to depend on the species. This relation was absent in Daubenton's bats (*Myotis daubentonii*). The more cold-tolerant brown long-eared bat (*Plecotus auritus*) and Natterer's bat (*M. nattereri*) showed a negative relationship with the ambient temperatures: the warmer it was, the fewer bats of these species were observed in the studied locations. This also applies to the pond bat (*M. dasycneme*), which is known to be less cold-tolerant. The number of bats counted in the winter roosts seems to be mainly related to the size of the sites: the larger the volume of the hibernaculum, the more bats were found there. The humidity, susceptibility to disturbance, the number of rooms and the hiding opportunities in the winter roosts also had an effect on the number of bats. However, the effects of these characteristics were less pronounced than the influence of the size of the sites and differences were not always significant. This knowledge is important in determining guidelines for management and to be able to evaluate the censuses. This approach, can help ensure that there are enough sites available to provide suitable hibernacula.

Keywords: winter roosts, outdoor temperatures, dimensions, humidity, susceptibility to disturbance, hiding possibilities, pond bat, Daubenton's bat, brown long-eared bat, Natterer's bat.

Introduction

In Zuid-Kennemerland National Park (Nationaal Park Zuid-Kennemerland; NPZK) and the Noordhollands Duinreservaat (NHD) there are many bunkers and other structures, such as ice cellars, in which bats hibernate. To maintain a sustainable population of bats, it is important that all the habitats they require are in a suitable condition. Winter roosts are an important part in this network. Hibernating bats are counted annually within

the framework of the national programme, 'the Ecological Monitoring Network' (NEM). These annual censuses are carried out within a fixed period between mid-December and mid-February on the assumption that this is when the maximum number of bats are present in the hibernacula. It is important to know whether or not this is actually true. Therefore, in this study, we look at the relationship between the number of bats in the winter roosts and the ambient temperatures. In addition, there is a need for clear guidelines for managing hibernation roosts. We know which sites are attractive, but less is known about the properties that

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determine the success of these winter roosts. Such information can allow us to make direct investments in adapting the sites that have the highest potential as winter roosts.

Research shows that the number of animals in a roost can vary greatly during the course of a winter. This is partly because some individuals, especially of cold-tolerant species such as Natterer's bat (*Myotis nattereri*) and brown long-eared bat (*Plecotus auritus*), do not arrive until it gets too cold for them outside, when other winter roosts, such as tree holes and poorly insulated spaces in buildings, become unsuitable. Pond bats (*M. dasycneme*) and Daubenton's bats (*M. daubentonii*) are known to occupy winter roosts relatively early in the year, although it is not known whether this is related to ambient temperatures, insect supply or an early mating season in these species (Haarsma 2013).

Weather conditions during the winter census therefore can influence the bats' choice of specific winter roosts and the numbers present in each. This can cause the numbers to be underestimated in warm weather conditions because not all the animals are in the winter roosts. When determining trends, it is assumed that the maximum numbers of bats are present in the hibernating roosts on the date of the census. To assess the accuracy of counts, it is important to know the influence of the outside temperatures on the number of counted bats.

The most important factors that determine the suitability of winter roosts for bats are: temperature, humidity, human disturbance and darkness (Limpens et al. 1999, Haarsma 2018). Temperatures in the hibernacula should not drop below freezing point and should not fluctuate much, and there should not be too much light. The size of the hibernaculum, the number of rooms, entrances and other openings can influence these characteristics. Humidity must be high and the walls sufficiently rough for bats to be able to hold on. The importance of these properties in winter roosts differs between species (Siivonen & Wermundsen 2008). Some spe-

cies prefer to hide in crevices, cracks and other holes in the walls, while other species hang free and exposed on the walls. This means that there should be sufficient suitable opportunities for bats to hide and hang and the dimensions, number of rooms and the internal design of the roosts are important for these aspects. Disturbance is unfavourable as it causes the air to move and the temperature in the roost could rise. This may wake up the bats from torpor, causing them to lose extra energy, and lowering their chances of surviving the winter period and reproducing in spring (Haarsma & de Hullu 2012). Disturbance is diminished by a remote and sheltered location or the physical closure of the site. Finally, the bats must also be able to easily find and approach the winter roosts. The location in the terrain, the orientation and shelter of the entrance and the location in relation to other sites (i.e. in a cluster or alone) can influence this.

Although it is known which sites are more attractive as winter roosts, little research has been done into why one roost does better than another. It seems that large, damp sites (with very high humidity and/or water on the bottom and/or the walls and ceilings) are the most successful, but relatively large numbers of bats are also regularly found in smaller and/or drier roosts. Currently, winter roosts are often managed without any substantiated information. Research of the influence of these traits on the number of hibernating bats is therefore valuable for the management of winter roosts.

Material and methods

This study covered 116 hibernacula located within the NPZK and the NHD. Of these, 71 are in the NPZK and 45 in the NHD (figure 1). Among many others, these are the sites where bat numbers are counted annually. The majority are bunkers, but there are also some ice cellars, a water cellar and a gatehouse. Data from the NEM from 1990 onwards, where available, were used for each hibernac-



Noordhollands Duinreservaat



Zuid-Kennemerland National Park

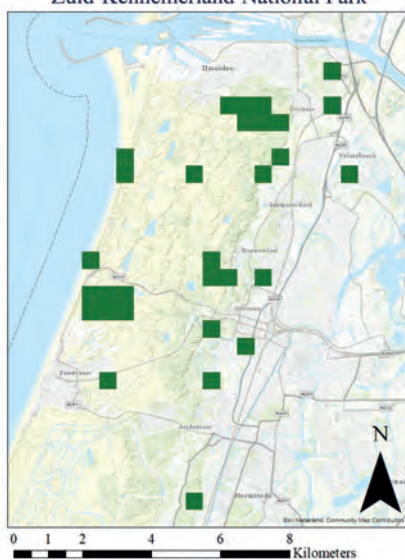


Figure 1. Location of the Zuid-Kennemerland National Park and the Noordhollands Duinreservaat. Below: 500x500 metre squares in which the winter enclosures were located in both areas.

Table 1. Overview of the properties examined, the corresponding categories and their classifications.

Characteristic	Category	Division
Dimensions	Small	0-35 m ³
	Medium	36-150 m ³
	Large	151-400 m ³
Landscape zone	Zeeduin	Location as defined in Natura 2000 Management Plans (Provincie Noord-Holland 2017a, 2017b)
	Middenduin	
	Binnenduin	
Sensitivity to disturbance	Very sensitive to disturbance	Not locked and easy to find
	Fairly / Moderately sensitive to disturbance	Closed but easy to find or not closed and relatively difficult to find
	Not sensitive to disturbance	Closed and not easy to find or not closed and very difficult to find.
Shelter entrance	Sheltered	Entrance partly or completely shielded from surroundings by vegetation
	Exposed	No vegetation in front of entrance
Humidity	Wet	Water on the bottom, walls and ceilings
	Humid	Water on the walls and ceilings, bottom dry
	Dry	Dry bottom, walls and ceilings
Climate stability	Stable	Little draft, only one opening
	Moderately stable	Moderate draft, several openings
	Not stable	Many drafts, many openings
Hiding possibilities	None	As documented in the Portal of the Mammal Society
	Cracks, crevices and clefts	
	Holes	
	Ventilation pipes	
	Behind boards/bricks/stones	
	Combinations of the above	
Number of rooms	1 room	Orientation of entrance
	2 rooms	
	3 or more rooms	
Orientation of entrance	N	Orientation of entrance
	NE	
	E	
	SE	
	S	
	SW	
	W	
Location in a cluster	NW	Mean distance to the four nearest sites.
	Not applicable	

ulum. To determine the relationship between the number of bats and the outside temperatures, the average daily temperature over the five days prior to the census was calculated, based on the recorded weather data (KNMI, undated) from the nearest KNMI weather sta-

tions at IJmuiden and Wijk aan Zee, if available. If data were not available from either station, data from the Schiphol weather station were used. The relationship between these temperatures and the average number of bats per location and per counting date was stud-

ied and the relationships were established for the following species: Daubenton's bat, pond bat, Natterer's bat and brown long-eared bat. Dates on which bats were recorded in less than four sites were omitted.

The internal characteristics of as many sites as possible (divided into a number of categories) were detailed (table 1). Some of these categories were based on the Mammal Society's portal (climate stability, hiding possibilities) and others were determined by available local knowledge. Due to the Covid-19 pandemic, the 2021 winter census did not take place and not all the characteristics of the sites were recorded *in situ*. The data gap was filled with information available from the portal of the Mammal Society, supplemented with the knowledge of counters and managers. Where information was lacking for particular variables these were omitted from the analysis. The number of bats per site was taken from the average recorded number of hibernating bats in the 2016-2020 annual censuses.

Statistical analysis

The relationship between the number of bats and the ambient temperatures was determined using simple linear regression. The influence of the different properties of the inhabited sites on the number of bats found was determined using a Kruskal-Wallis test. Subsequently, a post hoc test, the Dwass-Steel-Critchlow-Fligner pairwise comparison (The Jamovi Project 2020), was conducted to determine significant differences between categories. Jamovi, SPSS and Excel were used for the statistical analyses.

The relative influence of the properties studied was determined using multiple linear regression. The scored variables were combined to determine their relative influence on the number of bats counted. Only the statistically significant variables were included in the model. In advance, the multicollinearity was investigated to determine whether any proper-

ties in the regression analysis were too strongly correlated with each other to be included in the analysis. Further explorations were carried out, in which the models were built in several different ways (de Vocht 2012) but this did not show any deviating abnormal results.

Results

Influence of external temperatures on the number of bats counted

In both the NPZK and the NHD, no relationships were found between the number of Daubenton's bats and the outside temperature (Linear regression NPZK: $F(1,27)=1.15$, $P=0.29$; NHD: $F(1,34)=1.4$, $P=0.25$). However, there was a clear negative relationship between the number of brown long-eared bats and the outside temperature. The higher the average daily temperature measured over the five days prior to the count, the fewer hibernating brown long-eared bats were found (NPZK: $F(1,27)=4.6$, $P<0.05$; NHD: $F(1,34)=6.7$, $P<0.05$). The same relationship was found for Natterer's bat ($F(1,27)=7.5$, $P<0.05$) and pond bat ($F(1,27)=9.3$, $P<0.01$) in the NPZK (figure 2 and figure 3). There were insufficient observations of these two species in the NHD to analyse.

The influence of the sites' properties

The analysis of variance on the different properties of the sites showed that a large size ($\chi^2(3)=12.5$, $P<0.01$) and a large number of different spaces ($\chi^2(2)=7.1$, $P<0.05$) had a positive effect on the number of hibernating bats. High humidity ($\chi^2(2)=6.9$, $P<0.05$) also seemed to contribute, given the almost significant relationship (post hoc, wet-dry: $P=0.06$). A high susceptibility to disturbance ($\chi^2(2)=20.9$, $P<0.001$) and the absence of hiding possibilities ($\chi^2(7)=15.3$, $P<0.05$) had a negative effect on the number of hibernat-

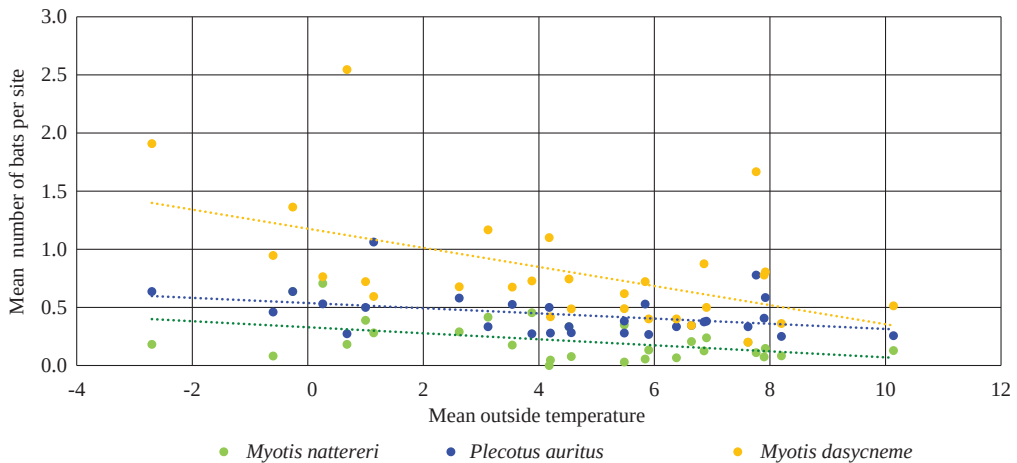


Figure 2. The relationship between the outside temperature and the average number of bats per site in the Zuid-Kennemerland National Park.

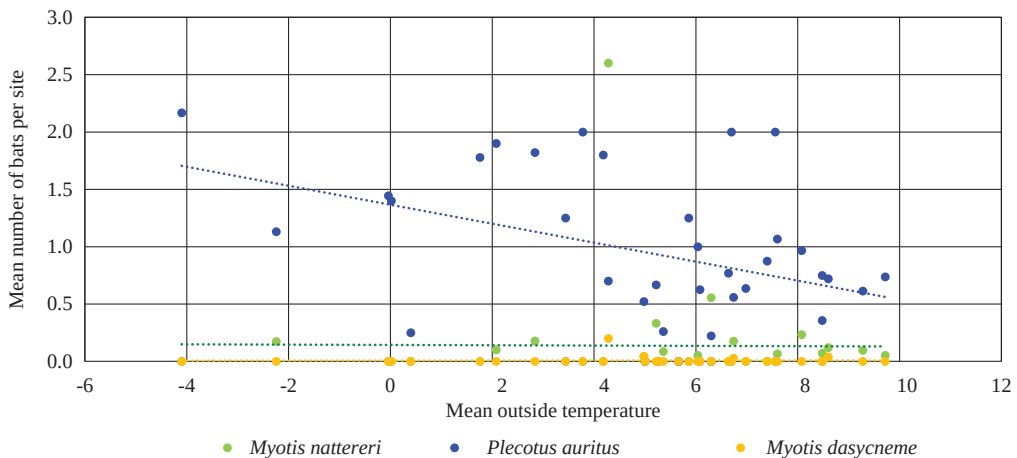


Figure 3. The relationship between the outside temperatures and the average number of bats per site in the Noord-hollands Duinreservaat.

ing bats (figure 4). The multiple linear regression resulted in a statistically significant model ($F(3,30)=19.4$, $R^2=0.66$, $P<0.001$). The model shows that 66% of the variance in the number of bats counted can be traced back to the categories 'large', 'dry' and 'cracks/crevices', with size having the greatest effect ('large': $\beta=26.6$, $P<0.001$; 'dry': $\beta=-5.6$, $P<0.05$; 'cracks/crevices': $\beta=8.5$, $P<0.05$). The location in the terrain, shelter, location in a cluster and orientation of the entrance had no demonstrable influence on

the number of bats, or there were insufficient data to demonstrate a relationship.

Discussion

Temperatures

Several studies have demonstrated or suggested a link between ambient temperatures and numbers of hibernating bats

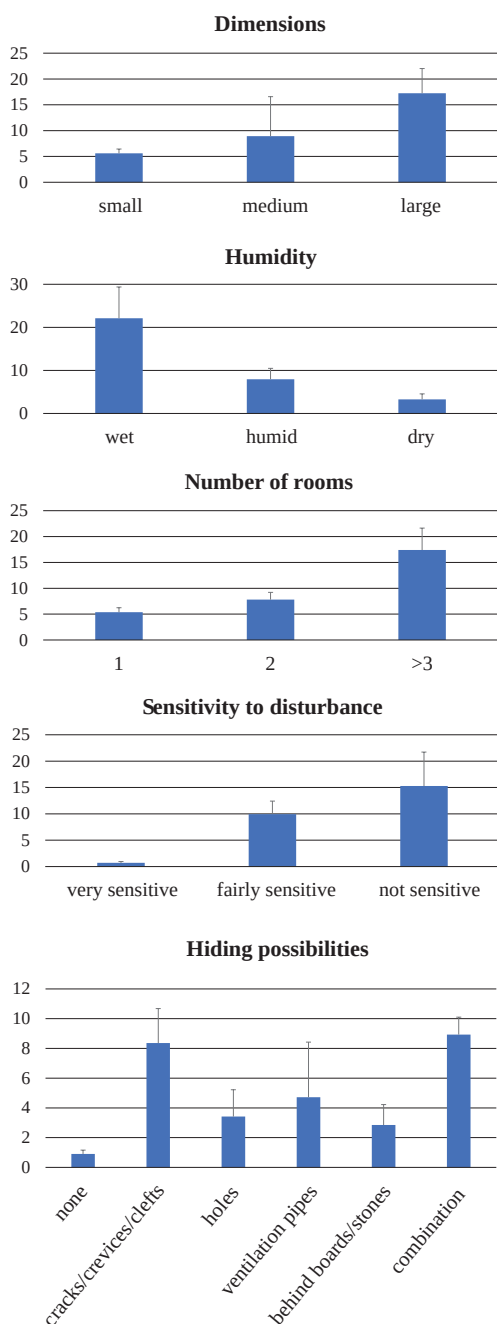


Figure 4. The influence of characteristics with a significant influence on the average number of bats counted per site in the years 2016-2020. Error bars display standard errors.

(Haarsma 2013; see also the contributions of Bekker and Verhees et al. 2022, in this issue). Bats may benefit from the persistent low winter temperatures in climatic zones with severe winters as they are in a deeper state of torpor, wake up less easily and therefore lose less energy (Haarsma & Kaal 2016). This study found a relationship between the outside temperatures and the numbers of counted specimens for some species of bats, although not Daubenton's bats. However, there was a negative relationship between the outside temperature and the number of hibernating brown long-eared bats and Natterer's bats, which are both more tolerant of the cold. The higher the temperature, the fewer bats of these species were found hibernating in these sites. It may be that during relatively warm winters these cold-tolerant species choose other, less temperature-buffered, hibernacula like hollow trees and buildings. Pond bats show the same relation: while they are not known to be pronouncedly cold-tolerant they are, nonetheless, often found in relatively cold places within bunker complexes (Batweter 2021). An increase in winter temperature, due to climate change, could in the future lead to a decrease in numbers of hibernating pond bats, brown long-eared bats and Natterer's bats in winter roosts where bats are counted.

The size, complexity and humidity of hibernacula

This analysis showed that larger hibernating roosts, with more complex sites, contained more hibernating bats. This suggests that a lack of hiding opportunities negatively affects the numbers of hibernating bats. High humidity also contributed greatly to the number of hibernating bats. Other studies have found the size of a winter roost, combined with the number and diversity of hiding opportunities, to be important in bats' choice of winter accommodation (Haarsma 2011, de Boer et al. 2013). A positive relationship between the

size of the cave and the population size and species richness has also been demonstrated in caves. Both number of bats and species also appeared to be related to the diversity in hiding opportunities (Furey & Racey 2016). Although humidity in winter roosts has not been considered a crucial factor in previous studies (Haarsma 2011, de Boer et al. 2013), moisture is important for hibernating bats. Bats sometimes have to interrupt their hibernation to replenish moisture loss (Ben-Hamo et al. 2013). These arousals cost a lot of energy, so it is important to limit these.

Sensitivity to disturbance

This research has shown that fewer bats hibernate in winter roosts with a high risk of disturbance. Perhaps bats anticipate disturbance by not choosing these sites as winter roosts, or perhaps they move to quieter places if disturbed. It is not known whether any disturbances actually took place in these disturbance-sensitive sites.

Multiple studies show that disturbance of bats during hibernation has a negative effect on their chances of surviving the winter (Speakman et al. 1991, Thomas 1995, Haarsma 2011, Furey & Racey 2016). Hibernating bats respond to non-tactile stimuli such as light, sound, temperature differences, air flow as well as to tactile stimulation. Bats often awaken after a (non-tactile) disturbance caused by a human visit and may subsequently wake up other bats. As a result, the disturbance can last much longer than the actual visit. Upon awaking, bats burn extra fat reserves, which can damage the chance of female bats bearing young in the spring. Young animals with a relatively small fat supply are most at risk of death.

Conclusions

This study shows the aspects that are important for bats when choosing suitable winter roosts.

In particular, the size and the presence of sufficient hiding opportunities are important. High humidity also seems to have a positive effect. For a site manager, it may be important to secure sites so as to minimize disturbance, if necessary, by closing them off to unwanted visitors. These findings may help improve the suitability of sites as winter roosts for bats, that are able to harbour healthy bat populations. In addition, the correlation found between bats and ambient temperatures can be used to critically assess trends among certain species and to determine the optimal census period.

Acknowledgements: You never perform a study on your own, therefore we want to thank all the bat experts who helped us set up this research, especially our colleagues from PWN, Natuurmonumenten and Staatsbosbeheer for their input about winter roosts. We also thank all the counters who have been selflessly committed to the protection of bats for years and, especially, Jan Boshamer, who has coordinated these counts for years and ensured that the counts are as accurate as possible. We also thank the Dutch Mammal Society for collecting and sharing this information. Without all of you, this research would not have been possible. Thanks also to Nick Parrott for his valuable suggestions to improve the English of the manuscript.

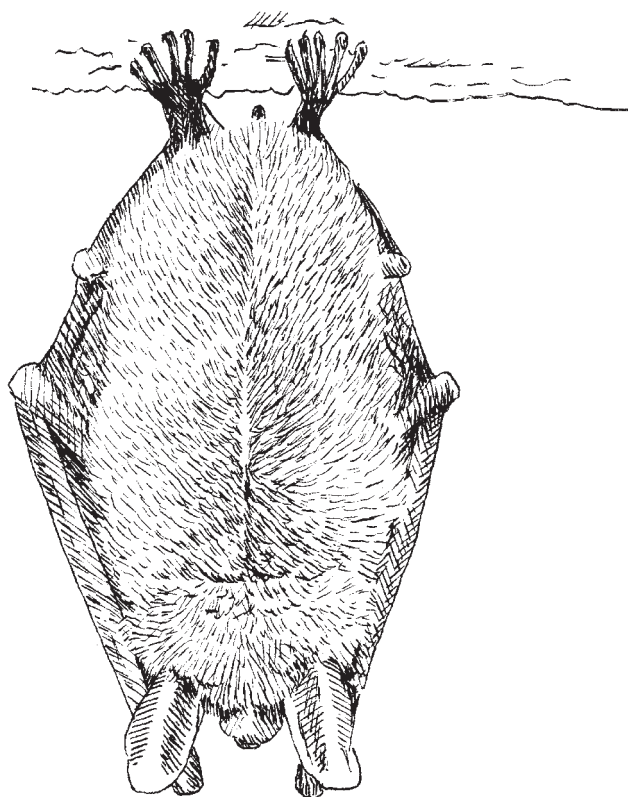
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Hibernating bats at Klein Heidekamp (Schaarsbergen, Arnhem, the Netherlands)

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Abstract: The Klein Heidekamp complex is a military encampment functionally connected with the Deelen air force base, north of Arnhem, the Netherlands. Bats hibernate here in two rather large cellars (670 and 375 m³), in the remains of a destructed large building, and in two smaller sites (120 and 56 m³). Bats were surveyed here for the first time in 1982, when 81 animals were found while only the largest cellar was accessible. Since 1988 all four sites could be inspected and the total number of bats increased steadily to more than 1000 in cold winters with 1580 as a maximum. On average more than 890 bats have been counted here annually over the last five winters (2016-2020). The dominating species by far is Daubenton's bat (*Myotis daubentonii*) with Natterer's bat (*M. nattereri*) as a runner-up from zero in the first winters to a level of around 300 in the past five years. The presence of two specimens of pond bat (*M. dasycneme*) during the first visit in 1982 made Klein Heidekamp the second known hibernation locality of this species in the Netherlands outside the marl quarries in the south of the province of Limburg. The number of pond bats increased to around 60 animals annually in recent winters. Whiskered bat (*Myotis mystacinus/brandtii*) was represented yearly by less than ten specimens over the whole period. Brown long-eared bat (*Plecotus auritus*) usually counts up to less than 20 animals with more than 30 as an exception. Solitary specimens of greater mouse-eared bat (*M. myotis*) occur here on rare occasions. Being situated within a military settlement the location is fenced in and well-guarded, hence it is a safe hibernaculum for the highest numbers of bats in the province of Gelderland.

Keywords: Daubenton's bat *Myotis daubentonii*, Natterer's bat *M. nattereri*, pond bat *M. dasycneme*, brown long-eared bat *Plecotus auritus*, whiskered bat *M. mystacinus/brandtii*, greater mouse-eared bat *M. myotis*, safe (well-guarded) hibernaculum, Province of Gelderland.

Introduction

Deelen airfield is located north of Arnhem, province of Gelderland, the Netherlands (figure 1). It was built here starting in 1940 by the German occupiers ("Fliegerhorst Deelen") and is still in use as a military airport. Around a centrally located open area with runways, there are several complexes with service buildings. The Klein Heidekamp complex, built during the war, is the closest to Arnhem.

This contribution describes the development of the number of hibernating bats from the first count in 1982 until 2020 in four sites at this location, which are so close together that they are considered one hibernation site.

Description of the sites

Three of the four sites are the unconnected cellars (KHK1: 670, KHK2: 375 and KHK3: 56 cubic metres) of one large building that was bombed in the war. Afterwards, the above-ground remains were completely demolished

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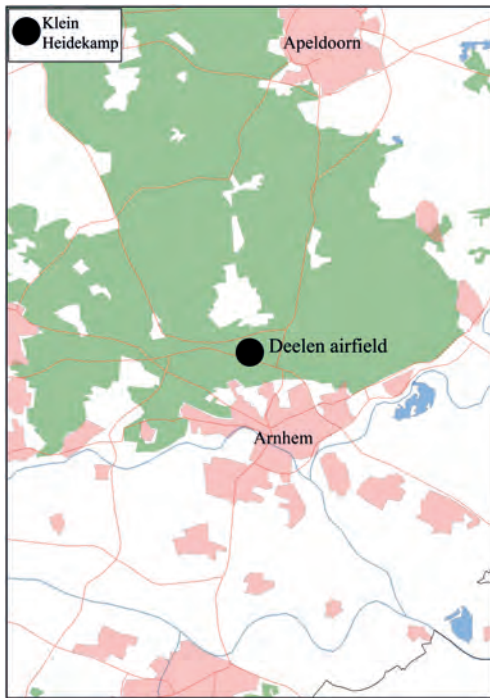


Figure 1. Location of the military complex 'Klein Heidekamp'.

and the cellars were covered with a layer of soil. The cellars have brick and plaster walls. The two large cellars (KHK1 and KHK2) are internally subdivided and therefore have a lot of wall surface. All three cellars are about 2.4 metres high, the largest (KHK1) has a central part of about 2.9 metres high (figure 2). The fourth site (KHK4) is an enclosed section (about 120 metres long, 1 metre wide and 1.2 metres high) of a masonry pipe duct that lies below ground level and held the pipes of the original central heating system. Both large cellars (KHK1 and KHK2) are accessible via an external staircase and a standing door with an entrance opening for bats, the two other sites (KHK3 and KHK4) via a horizontal hatch on a masonry entrance with entrance openings for bats (figure 3). The Klein Heidekamp military complex as a whole can be characterised as a wooded area with scattered service buildings.

The surveys

The largest cellar (KHK1) was first visited in 1982, when 81 bats were found. Outside the marl quarries, this number was only exceeded in Fort Rijnauwen and the Wassenaarse Slag bunker complex. Until 1987, the numbers in this cellar rose to 378 bats. In retrospect, the results of the first counts were too low because certain areas had been overlooked earlier, especially covered window wells in the outer walls of the cellars. Cellar KHK2 was initially inaccessible to both bats and inspection until the entrance was excavated in 1987. In the first winter census after that, 15 bats were counted in this cellar. The difference in the number of bats between the two shelters (KHK1 and KHK2) gradually became smaller. The smallest cellar (KHK3) and the section of the pipe duct (KHK4) were made safer for inspection in 1996 and since then have been surveyed simultaneously with the larger cellars. Since 1994, more than 700 bats have been counted annually in the four sites together, with the highest numbers being 1530 in 1997 and 1580 in 2006 (figure 4). The results of two bat surveys in 1996 are remarkable. During the "official" count in mid-January (included in the graph) 1021 bats were counted in the four cellars, the first count above 1000 for this location. During a visit (for technical reasons) to the cellars at the beginning of February, it was found that the numbers had clearly increased. Therefore, a second survey was conducted in mid-February, resulting in 1576 bats. The increase was explained a result from frost as low as -15 degrees Celsius shortly after the first count. In 1997, when 1530 bats were counted, there was also a sharp drop in temperature (from +7 to -7 degrees) shortly before the survey date. In other years with high numbers (more than 1000 bats in 2002, 2006, 2009, 2010 and 2013) too, there was a drop in temperature to below zero shortly before the count (source: www.wintergekte.nl). The high numbers could not be explained by strikingly lower survey results in other more or less



Figure 2. Interior of the largest cellar (KHK1). Photo: Ruud Kaal.

nearby known winter roosts.

Whiskered/Brandt's bat (*Myotis mystacinus/brandtii*)

From the first counts onwards, the number of whiskered/Brandt's bats has remained low. Usually zero to five specimens are found, with eight specimens in 1983 at the maximum. Twice (1982, 1998) seven and twice six specimens (2005 and 2011) were counted. On a few occasions the presence of a Brandt's bat was suspected, but this could not be confirmed by experts with the help of photographs.

Natterer's bat (*Myotis nattereri*)

In the first two counts (1982 and 1983), no Natterer's bats were found. This is in line with the then existing image of Natterer's bat as a rare species with greatly reduced numbers

(Daan 1980). From 1984 onwards, the species was present in small numbers and gradually increased to more than 50 specimens in 1998. From 2005 onwards, the numbers remained above 100 and the species increased further. In the five most recent winters (2016-2020), an average of more than 300 Natterer's bats were counted. During this period, one out of three bats at Klein Heidekamp was a Natterer's bat.

Daubenton's bat (*Myotis daubentonii*)

At Klein Heidekamp, Daubenton's bat has been the most numerous species ever since the first surveys. The increase in the total number of bats in the first twenty years was mainly due to the increase in the number of Daubenton's bats. On three occasions, more than 1000 Daubenton's bats were counted (1342 in 1997, 1019 in 2002 and 1265 in 2006). In mild winters, the numbers are sometimes lower by hundreds. During the last ten winters



Figure 3. Entrance of one of the two smaller sites. *Photo: Ruud Kaal.*

the number has varied between 468 (in 2019) and 680 (in 2012). During surveys in 2017 and 2018, a flavistic ('yellow') Daubenton's bat was found and in 2019 even two specimens (Glas 2019) and in 2020 again one specimen.

then, around 60 specimens have been found here. Elsewhere in Gelderland, but only on the Veluwe, the species is also found in small numbers. Including Klein Heidekamp, there are less than 100 specimens in total.

Greater mouse-eared bat (*Myotis myotis*)

For four winters in a row (2000-2003), one specimen was found at Klein Heidekamp. Afterwards, in 2007 and 2020, one specimen was present. In the province of Gelderland, the greater mouse-eared bat is only rarely found in winter quarters.

Brown long-eared bat (*Plecotus auritus*)

At Klein Heidekamp brown long-eared bats are present in varying numbers. Twice they were completely absent (1992 and 2007) and the maximum was 43 specimens (1997). In most winters less than 20 specimens were found. After counting 31 specimens in 2013, fewer than 10 brown long-eared bats have been found every year since.

Pond bat (*Myotis dasycneme*)

During the first census (in 1982), two pond bats were found as a surprise. Outside the marl quarries, hibernating pond bats had only been found in the bunker complexes between The Hague and Wassenaar. At Klein Heidekamp the number gradually increased to a maximum of 73 specimens in 2012. Since

Relationship between winter and summer roosts

Hardly anything can be said about the possible relationship between the numbers of bats found in winter at Klein Heidekamp and summer roosts and maternity colonies in the

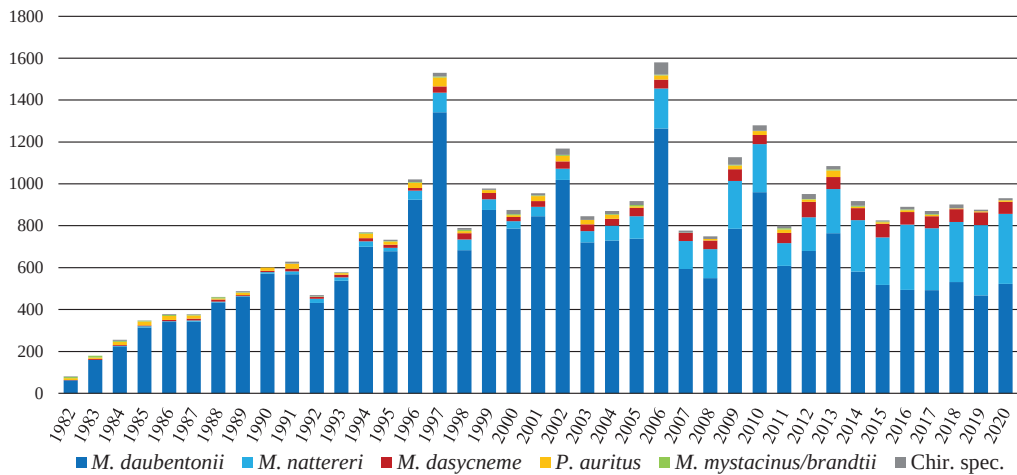


Figure 4. Evolution of the number of bats at the four sites at Klein Heidekamp; since 1988 these sites are counted simultaneously each year. In the years 2000-2003, 2007 and 2020 the number of unidentified bats (Chir. spec.) includes one specimen of *Myotis myotis*.

vicinity due to the almost complete lack of focused studies in summer. During a survey at the airport and one neighbouring complex, brown long-eared bats were found in the attics of five buildings. In addition, a tree on the airport itself was found to be a roost of Daubenton's bats (Staro Bos- en Natuurbeheer 2005). Brown long-eared bats, including juveniles, were also found by the second author on attics of buildings on Klein Heidekamp and three other complexes around Deelen airfield at a distance of 1 to 5 kilometres from Klein Heidekamp. Because no simultaneous count of all these attics took place, it is not possible to determine the numbers of long-eared bats this concerns. A summer roost of this species was found by coincidence in a tree about 2.5 km from Klein Heidekamp. No summer colonies of Daubenton's bat and Natterer's bat are known around Klein Heidekamp. Foraging Daubenton's bats are found in summer over nearly all water bodies in the north of Arnhem (Arnhem-Noord) and to a lesser extent in the south of Arnhem (Arnhem-Zuid). The numbers of these are difficult to estimate, but they appear to be far below the numbers of hibernating

specimens at Klein Heidekamp. In summer, small numbers of pond bats are seen foraging above the river Rhine near Arnhem. North of Arnhem individual Natterer's bats have been found in bat boxes. This also applies to brown long-eared bats, of which several were found in one box on two occasions.

Opportunities and threats

Klein Heidekamp is a fenced and guarded military area. The chance of disturbance of the roosts by people is therefore virtually zero. A second very favourable circumstance is the cooperation of the service responsible for the maintenance of the buildings, which includes the winter roosts. From the very first winters, improvements and repairs have been made possible. In 2004, for example, steel supports were placed in both large cellars to reinforce the ceilings with the largest spans (figure 2).

Bat mortality due to predation has been recorded. From the first year of visits until 2006, it was found that domestic cats were catching bats when they were flying in and/or out. The numbers of bats found dead and

sometimes regurgitated outside of the cellars KHK1 and KHK2 were not systematically recorded but at times there were several dozen animals. From around 1996 onwards, gnawed on and injured bats were regularly found in cellars KHK1 and KHK2. Again, no systematic records were kept, but there were at times dozens of these. In 2010, camera recordings made it clear that this was caused by wood mice. The third predator, a marten, has been observed in the pipe duct (KHK4) several times. No cats have been spotted since 2006, in 2010 the cracks under the cellar doors were closed with wire netting against wood mice (*Apodemus sylvaticus*) and in 2016 the pipe duct was made inaccessible for martens by narrowing the entrance.

Klein Heidekamp offers the opportunity for new members of the Vleermuiswerkgroep Gelderland (the Gelderland bat working group) to become acquainted with hibernating bats. Nearly every year an excursion to Klein Heidekamp is organized in September, when several dozen bats are already present but have not yet begun their hibernation. At that time, there are mainly Daubenton's bats and pond bats, as has been described for other winter roosts (Haarsma 2013).

Discussion and conclusion

Members of the Vleermuiswerkgroep Gelderland have surveyed over 200 winter roosts with bats each year for the past five years. In those years (2016-2020), a yearly average of 4586 bats were found, of which 894 (19.5%) on average at Klein Heidekamp (Vleermuiswerkgroep Gelderland, 2016-2020). For Daubenton's bats this is 24.1% (501 of 2077) and for Natterer's bats 25.8% (312 of 1206). For pond bats Klein Heidekamp is by far the most important winter roost in Gelderland. As can be seen in the graph (figure 4) the numbers of bats counted per winter vary widely, by up to 50% (1580 in 2006, 777 in 2007). This variation mainly concerns Daubenton's bat

and Natterer's bat and may be related to differences between winters with and winters without frost prior to the surveys. It is possible that at the onset of (severe) frost, Daubenton's bats and Natterer's bats leave other, as yet unknown (perhaps not frost-free) roosts for more climatically stable roosts such as Klein Heidekamp. Based on differences in numbers between milder and more severe winters, this behaviour has long been attributed to long-eared bats by bat counters. Bekker (2022, in this issue) has investigated, partly based on the data from Klein Heidekamp, whether this presumed behaviour is statistically testable for long-eared bats. The differences per winter between the numbers of pond bats at Klein Heidekamp are too small to assume this presumed behaviour for this species.

Domestic cats, martens and wood mice have been known as predators of bats for some time (Bekker & Mostert 1991). In a number of winter quarters in the province of Zuid-Holland, the predation pressure by wood mice has been calculated at up to 2.7% per month (Haarsma & Kaal 2016, with images from Klein Heidekamp). No such calculations can be made for Klein Heidekamp, but given the count results, mortality by predation seems to have had little or no influence on the numbers of hibernating bats here.

Klein Heidekamp harbours by far the highest number of hibernating bats in Gelderland. This seems to be particularly significant at population level for Natterer's bat, Daubenton's bat and pond bat. This idea is supported by the higher numbers in counts after a period of frost. The winter quarters at Klein Heidekamp also have a function in late summer as a swarming location, as was recently confirmed by research into the significance of the Veluwe for pond bats (van Adrichem & Jansen 2021). Conservation and management of the sites mentioned is therefore of great importance from the point of view of bat protection and a great responsibility, which fortunately is recognised and assumed by all concerned, especially by the Ministry of Defence.

Acknowledgements: Our thanks go out to the employees of the successive departments that have been and still are responsible for the management of the cellars on behalf of the Ministry of Defence over the years. Especially F. Yperlaan †, A. Varkevisser and W. Vreman have taken an important role in this and have facilitated various works. The importance of Klein Heidekamp (and other hibernacula on military terrains in Gelderland and elsewhere) is also promoted by the national Vleermuiswerkgroep Defensieterreinen (Bat Working Group for Defence Domains in the Netherlands). All counts at Klein Heidekamp were carried out by the authors, initially also by G. Hanekamp. From about 2002 onwards one or two other members of the Vleermuiswerkgroep Gelderland participated in the counts. Alternately they were M. van der Valk †, F. Bosch, H. Bosch, T. Kooy, T. Bosch and T. Molenaar. Because of the pond bat research A.J. Haarsma also participated in the counts.

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In the winter of 2021-2022, during the Covid-19 pandemic, counters were asked to wear face masks. Amerongen, Province of Utrecht, the Netherlands. *Photo: Ben Verboom.*

Automated long-term registration of bat activity at Fort Steendorp (Flanders, Belgium)

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Abstract: Fort Steendorp (east of Temse, East Flanders, Belgium) is a large former military brick fortification, which is nowadays one of the most important bat hibernation sites in Flanders. The fortification is part of two, 19th and early 20th century defensive 'belts' of fortifications around the city and port of Antwerp. Standardized winter census counts were started in 1989. From 1999 to 2022, the overall number of hibernating bats counted varied between 734 and 1209, belonging to eight species. Each year the population is made up of approximately 69% Daubenton's bat (*Myotis daubentonii*). This is by far the most abundant species, but it has been sharply decreasing in numbers. Bats can be hard to detect during hibernation, with visual census counts representing only part of the actual number of hibernating bats. In order to quantify the proportion of bats that are missed during visual counts, an automated bat count experiment was set up using an infrared light barrier system, measuring bat activity and passes in and out an enclosed part of Fort Steendorp. All year round data collection also allowed us to collect bat activity data outside the hibernation season. An important difference with the visual method is that it is not possible to determine the species with this type of automated bat survey. The paper presents the data from four consecutive years, starting from April 2014. We observed two distinct periods of high activity at Fort Steendorp. A first peak of activity (movements in and out of the infrared light barrier portal) was seen from the second half of May, going on into the first half of June (an average 1000 bat passes through the portal per night). This coincided with the spring swarming/mating season of most bat species. An even more notable increase of activity in and out of the enclosure was seen between mid-August up to October, preceding hibernation ('autumn swarming', with an average of 5000 bat passes per night). From mid-October onwards, a net movement of bats into the study zone took place, with a gradual build-up of bats going into hibernation. Between 1761 and 2066 bats were found to hibernate in the study zone. When comparing visual counts with infrared light barrier portal data, both observing the same enclosure and same study period, only 37% of the observed total bat population were detected visually. This figure indicates that around two thirds of the bats hibernate in inaccessible 'water corridors', or are tucked away in cracks and crevices, going unnoticed in a visual count. Secondly, our results show that hibernation is not a continuous uninterrupted process. From December onwards, before the coldest part of winter, bats move out of the enclosure, presumably to other parts of the fort, despite hibernation conditions in other parts of the fort being

unlikely to be more favourable. We cannot say when bats start to leave Fort Steendorp, ending their hibernation season, but by the last week of March, all the hibernating bats had left the study zone, and by deduction also Fort Steendorp. There was little to no activity until the spring swarming in May and June. After this, the activity in and around the infrared light barrier dropped again to almost zero until August. This paper provides strong evidence that for complex bat hibernacula, with plenty of crevices and inaccessible or hidden shafts and corridors, the actual numbers of hibernating bat are far higher than the numbers counted visually. This has important consequences, at least for large brick hibernation sites such as Fort Steendorp, and for bat conservation efforts at sites with a high value for bats. When around 1000 bats are seen in Fort Steendorp in yearly census counts, the actual number of bats hibernating will be closer to 3000, elevating the importance of the site for bat conservation. Peak activities in sites like this in May-June and August-November lead to the conclusion that, for the optimal protection of bats, conservation measures should not be limited solely to the hibernation period.

Keywords: automated monitoring, hibernation, bat activity, underground sites, fortification.

Introduction

In temperate regions, bats need to hibernate due to a limited food supply and to conserve their energy. Studies in both the Netherlands and Belgium (Daan 1980, Dekeukeleire et al. 2011, van Schaik et al. 2015, Boeraeve et al. 2019) have shown the importance of hibernacula during autumn, spring and even summer. Most long-term bat population monitoring programmes are based upon one or more censuses of hibernating animals in hibernation sites (Daan 1980, Voûte & Sluiter 1980, Kervyn et al. 2009, Haysom et al. 2013). These annual census programmes are performed visually by counting each individual bat spotted.

During autumn, bats assemble around underground sites for swarming. Autumn swarming behaviour, prior to hibernation, is thought to primarily be mating behaviour (Saucy 2019), but may also be related to the localization and assessment of hibernacula (van Schaik et al. 2015). Different authors (Degn et al. 1995, Encarnação 2005, Furmankiewicz 2008) have also observed swarming during spring among brown long-eared (*Plecotus auritus*) and Daubenton's bats (*Myotis daubentonii*). In addition, studies with banded bats have indicated large internal migrations within marl caves (de Wilde & van Nieuwenhoven 1954, Punt 1957). It seems that bat species awake during hibernation and change

their location within, or even between, hibernation sites due to slight changes of ambient temperature in the hibernaculum depending on the outside temperature (Daan 1973, Ransome 1990). In the annual bat census programmes in forts, movements of bats during autumn, spring and even summer, have rarely been taken into account and this may indicate an underestimation of the total numbers of bats and the importance of some sites for bats (Kugelschafter 1994). In addition, forts differ in their size, number of entrances and hidden spaces that are not accessible and/or not visible to humans. To date, we lack knowledge on the seasonal use of forts by bats over the whole year and how this is related to outside temperatures, especially on daily activity during the swarming period. In addition, entrance to most of the forts is only allowed by special permission from the Agentschap voor Natuur & Bos (Brussels, Belgium), due these constructions having unstable and unsafe areas. These safety restrictions can be expected to increase the missing counts; other options for monitoring bat populations and determining the importance of these forts for bats need to be investigated.

Research presented at the First European workshop on the Automatic Monitoring of Bat Roosts, held in Bad Segeberg (Germany) showed that the use of infrared light barriers enhances our knowledge about hibernacula (Jansen et al. 2014). The hidden proportion of

hibernating bats has been estimated to range between 22% up to 99% (de Rue & Daan 1972, Kugelschaffer 1994, Degn et al. 1995, Jansen et al. 2014).

This paper looks at year round bat activity in a closed study zone of a fort, measuring net movements registered by an automated infrared light barrier and evaluates how effective such a system is as an indicator for bat activity in a large winter hibernaculum. Additionally, we seek to compare the number of bats visually counted with those registered with an automated system. Our last topic of interest is the seasonal use of underground structures by bats over a year long period and how these are related to outside temperatures, with specific attention to daily activity during different periods of the year. The relevance of using an automated infrared light barrier system for bat conservation is also discussed.

Materials and methods

Study Site

In temperate regions, in the absence of natural caves, man-made underground structures (quarries, military forts, ice cellars, etc.) offer environmental conditions that are suitable for bat hibernation. There are 35 19th and early 20th century forts belonging to two defensive ‘belts’ of fortifications remaining around the city and port of Antwerp. In Flanders, as in the rest of the EU, most major bat hibernation sites are protected by national, regional and/or EU legislation.

Fort Steendorp (51.1269°N 4.2561°E, Temse, Belgium) is one of the most important hibernation sites for bats in Flanders. The first efforts to protect bats on site go back to 1978 with an agreement between the owner at that time – the Ministry of Defence – and the Royal Belgian Institute of Natural Sciences. Standardized winter counts started from 1989. Due to the gradual closing of access to the underground structures, the population

of hibernating bats increased steadily. The site received a higher status of protection as a ‘natural landscape’ in 1995. After being acquired by the Flemish government in 2001 it was recognized as a Natura 2000 area by the Flemish Agency for Nature and Forests.

Fort Steendorp is a large star shape brick structure built between 1882 and 1892, and covers an area of about 20 hectares. It is one of the largest military defensive structures ever built in Belgium. It is a very complex structure of brick halls, rooms and corridors, battery structures reinforced with concrete and covered by a layer of earth. The bricks used to build the structure were locally-produced traditional red fired bricks. The fort was surrounded by a dry moat, overlooking the river Scheldt, 15 km from the city of Antwerp (figure 1) (Colaes & Gils 1991, Gils 2000). Fort Steendorp was part of an EU co-sponsored LIFE-project ‘BatAction’ that ran from 2006 to 2011 (Verwimp 2006). The fort’s design is quite different from all the others around Antwerp. Most of the other forts consist of concrete structures and a limited number of bricks, which are built above the ground. The fort has been heavily damaged over the course of history by several large explosions caused by retreating Belgian or foreign forces. Due to a lack of maintenance after 1945, the fort continued to fall into disrepair. The site evolved naturally and was partially replanted into a woodland type of environment. Over time, some of the underground chambers, corridors and service corridors became a moist, partially flooded environment making them highly suitable for hibernating bats.

Infrared light barrier data recording

The centrally located extra-fortified part of the fort (*‘reduit’*) was selected for this study. An automated infrared light barrier system was placed in the flight opening of the door closing off the right hand side entrance to the circular corridors of the *reduit* (in blue, fig-

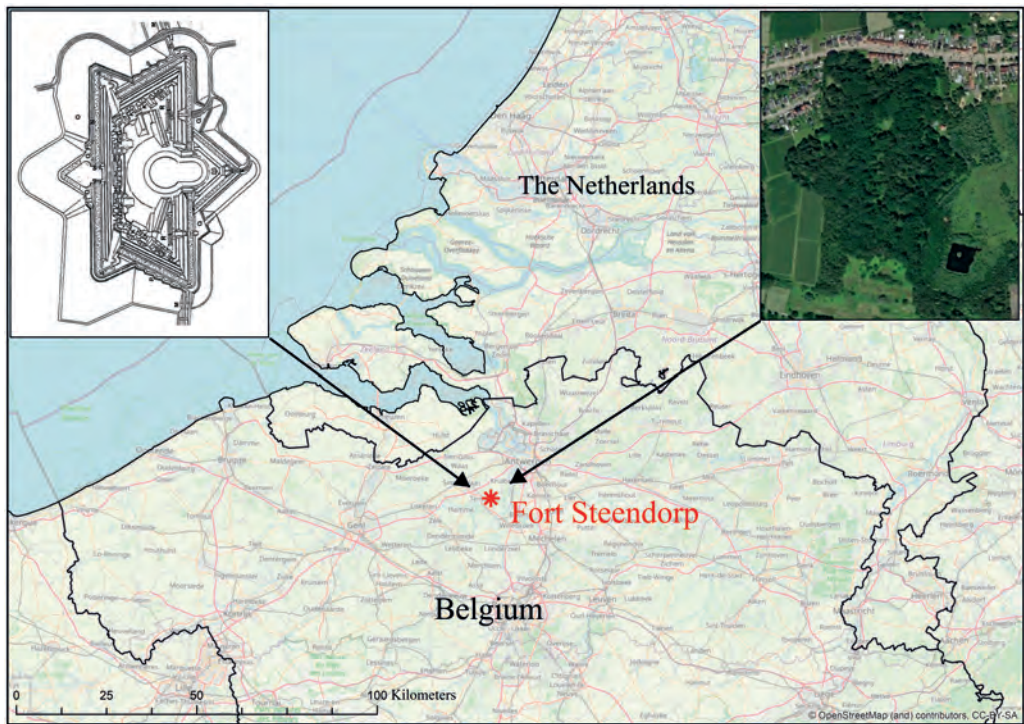


Figure 1. Location of the star shaped Fort Steendorp, Temse, East Flanders, Belgium. The fort has an outer earth walling, dry moat and brick structures. *Ground plan (upper left): ANB. Aerial photo (upper right): Google Maps 2022. <https://goo.gl/maps/rg9gfRYuikDGfXyc7>.*

ure 2). The left hand entrance is obstructed by debris caused by damage to the fort (in grey, figure 2). All other possible flight entrances were sealed off. This left only one point of entry to the circa 250 metres of brick corridors.

Narrow service corridors that are meant to drain water run alongside the main circular corridors. These are known as water corridors and not easily accessible for census counts. They are often partially flooded and therefore highly favourable for bat hibernation. The temperatures at the infrared light barrier and in most parts of the enclosure are 9-10 °C all year round. Temperatures in the larger hallway and the chambers of the front part of the '*reduit*' barely fluctuate in response to outside temperatures (internal: 4.5-4.6 °C vs. external: -0.2-2.4 °C) (Meermans 2004). From the yearly visual bat census, we know that between 2014 and 2017 Daubenton's bat

accounted for an average 73% of the total population, with Geoffroy's bat (*Myotis emarginatus*) at 15% and whiskered and/or Brandt's bat (*Myotis mystacinus/brandtii*) on average 7%.

The infrared light barrier system was designed and constructed by Anne-Jifke Haarsma and has proven to be an efficient tool for counting bat passes in and out of sites (Haarsma 2006, Steck & Brinkmann 2015). We installed a double barrier of infrared beams mounted in a frame in a metal door at a height of 1.6 metres. Each barrier encompassed two parallel rows of twelve infrared light transmitters linked to 24 photoelectric receivers on the opposite side with three cm between the first and the second rows of infrared lights. The light barriers were powered by an external 12V battery, which was replaced every 2-3 weeks. The system triggers a signal when an infrared light beam is

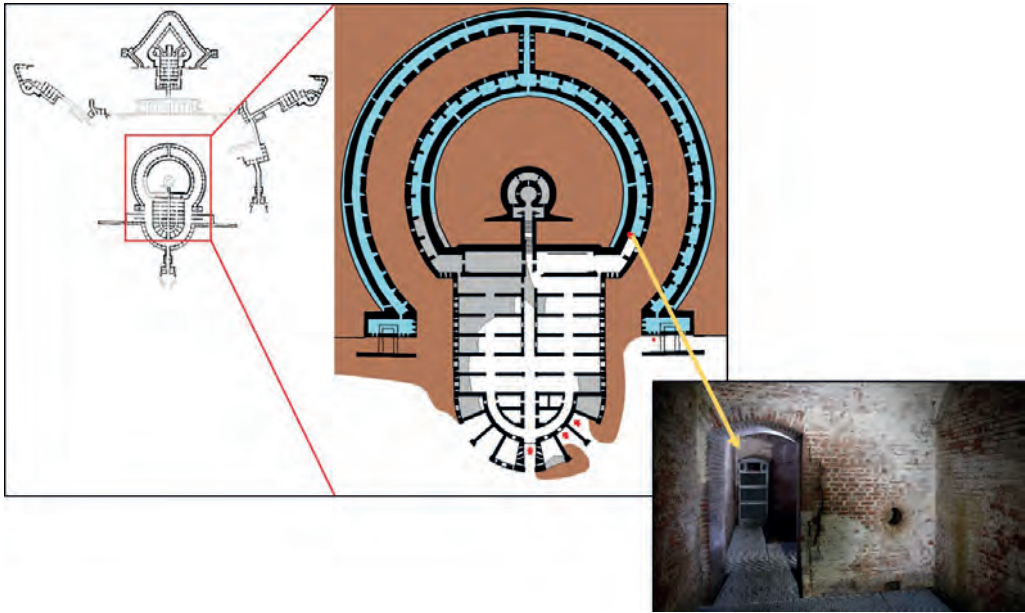


Figure 2. schematic view of the *reduit* of Steendorp Fort. The yellow arrow indicates where the infrared light barrier was placed. The blue coloured part is our study zone. The grey coloured sections are damaged and /or collapsed parts of the fort. Red arrows indicate entrances to the *reduit* that were closed off. Source: Figure adopted from Gils (1991) by the authors. Photo: J. Goossens.

blocked to reach the receiver. Visual observations indicate that birds do not reach the study area, which is over 50 metres from the outer entrance of the *reduit*. Moths were expected to not trigger the infra-red sequence, but if they did so, they cannot be filtered out.

The infrared light barrier recorded seven different types of signals (figure 3):

- i: one or more of the infrared light beams of the first row are blocked, without interfering with the second row of beams. Conclusion: no 'true' pass, e.g. bats were swarming on the outside of the barrier.
- I: one or more of the beams of the first row are blocked, followed by the second row of beams being blocked. The second row of beams is cleared first before the first row of beams becomes clear. Conclusion: the bat returned via the first row = no 'true' pass.
- IN: one or more of the beams of the first row are blocked and thereafter (within 0.5 sec) the second row of beams is blocked. The first row of beams is cleared first before the

second row of beams becomes clear. Conclusion: a bat has passed the infrared light beam system from the outside, going in.

The same applies in reverse for bats going out from the inside (o, O and OUT; figure 3). Again the movement cycles are expected to happen within 0.5 second. For obvious reasons, the species of bat cannot be identified by this infrared method.

A last type of signal was an 'error' signal indicating that more than ten beams were blocked simultaneously, indicating a large animal passed the infrared light barrier. Slow moving animals (e.g. snails) will not be recorded.

Recordings of bat passes for this study ran during almost four consecutive years from 11 June 2014 to 10 January 2018. For the data analysis only 'true' passes (IN (= -1) and OUT (= +1)) were used. Upon eight occasions, between 24 hours up to 83 days (due to long repairs or battery failure) the times series was temporarily disrupted.

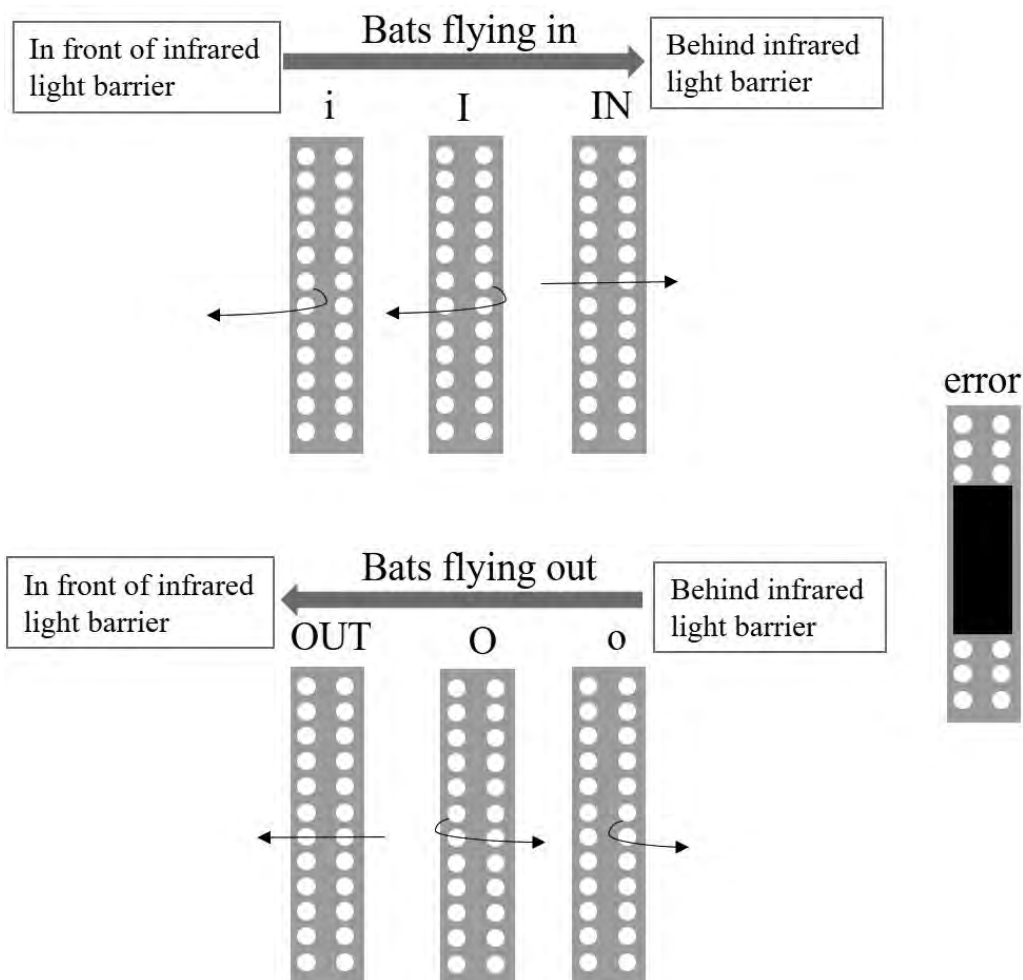


Figure 3. The seven different types of signals recorded by the infrared light barrier. The arrow indicates which row of infrared beams is blocked and in which direction the bats were flying.

We aligned our twelve months of recordings with the biological seasons, starting from 1 April up to 31 March the following year. Bat passes 'IN' and 'OUT' of the portal were used to calculate the cumulative numbers of bats remaining behind the portal at any given moment. This allowed us to see the net movement of bats moving into the *reduit*, and into hibernation. While it is possible that at any time, a small number of bats may have been in the enclosure during daytime even outside the hibernation season, the lowest number of each yearly cycle was set as the zero reading (assum-

ing that all the bats had left the compound).

Activity Graphics were made using free software for statistical computation and graphics R version 4.1.1 and Microsoft Excel 2016.

Climate data

Climate data (daily data of the minimum and maximum temperatures in degrees Celsius) were obtained through the European Climate Assessment & Dataset ECA&D project. The closest climate data location to Temse was

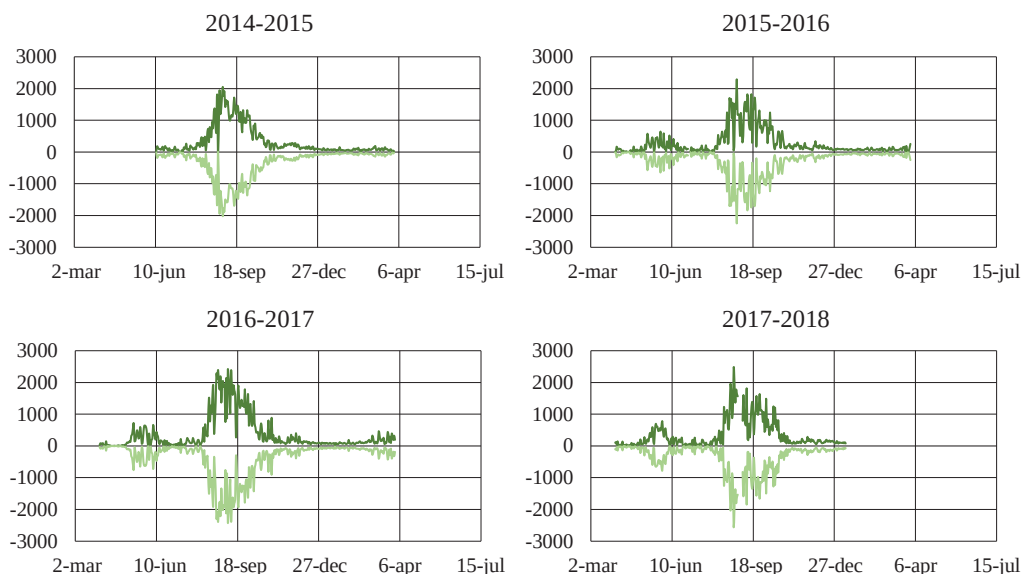


Figure 4. One-year bat activity (noon to noon; 1 April to 31 March), showing passes 'IN' (upper part of the graph) and 'OUT' (lower part of the graph) of the infrared portal. Data from June 2014 to the end of January 2018.

selected, which was Melsele, 10 km distance from Fort Steendorp.

Yearly on-site annual census counts

Since 1998-1999, between 10 to 20 well-trained bat observers from the Flemish bat-working group of Natuurpunt vzw carry out annual census counts. All accessible areas, including non-flooded water corridors, are surveyed. The location and species of each observed bat is noted on detailed maps. Due to safety concerns at the time, no census counts were carried out between 2007 and 2010 and in 2021 due to the Covid-19 pandemic. Sometimes there were difficulties in differentiating between whiskered and Brandt's bats so we have grouped these two species together.

Results

Bat passes through the infrared light barrier

From 11 June 2014 to 10 January 2018 a total of 875,385 bat movements were registered, with 431,262 (49.3%) bats passes 'IN' the closed study area, 430,073 (49.1%) flight movements 'OUT', and 14,050 'other' invalid movements (i, I, o, O, or error) (1.6%) (table 1). We aligned our data along bat 'seasons' starting from 1 April and the end of hibernation, ending the following 31 March.

Throughout the year there were two periods of high bat activity. A first peak of activity - spring swarming - was seen during the second half of May going on into first half of June, with a maximum of 1000 daily movements per night through the infrared light barrier but no 'building up' of bats staying 'behind the infrared light barrier' (figure 4). A second, much larger peak, with heavy flight activity through the infrared portal started in August, going to a maximum around the last week of August and the first week of September (autumn swarming). At maximum, up to 5000 'passes' were recorded per night (table 1). We cannot tell how many bats were involved in these activity patterns or how long the bats were active in and around the hiberna-

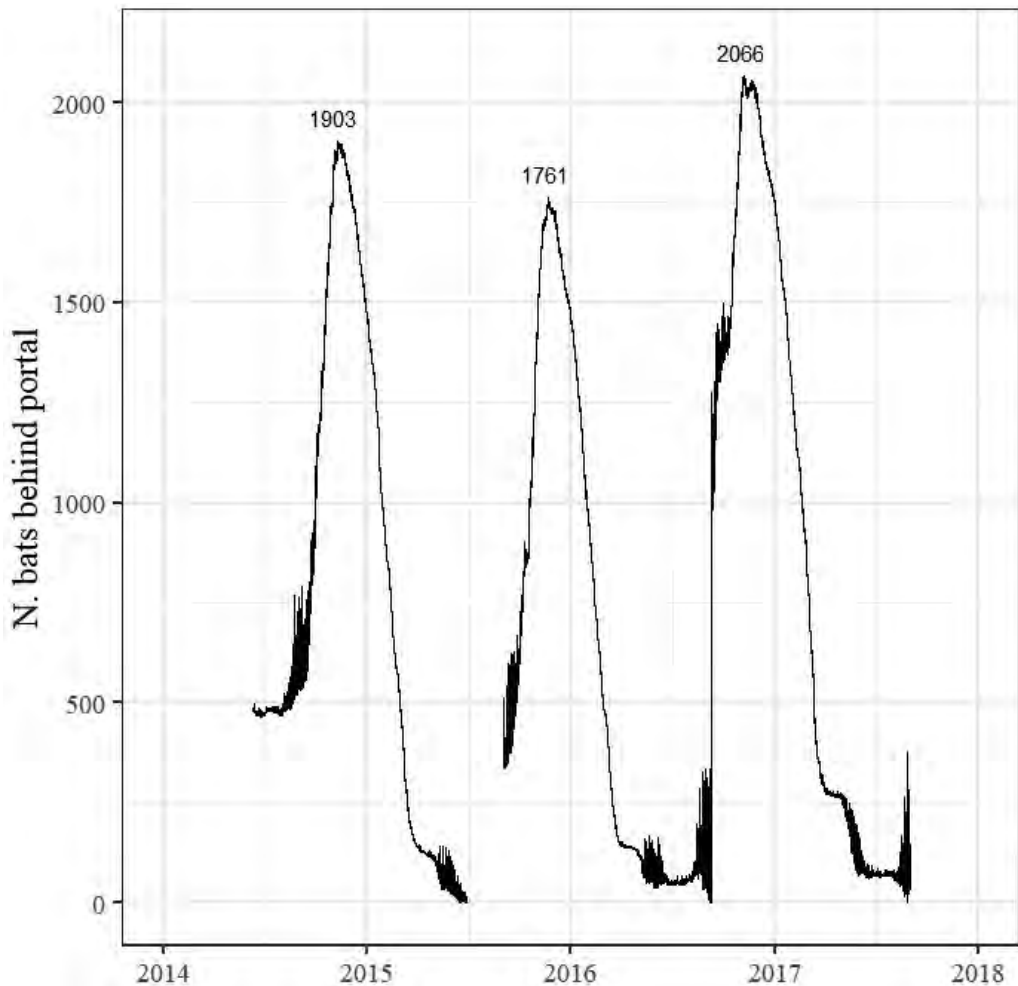


Figure 5. Number of bats behind the infrared light barrier for three continuous data sessions from April to March. The graphs are set to zero at the lowest number for each year. The highest number of bats 'behind the portal' for each winter is indicated on the graph.

tion site before going into hibernation. From the second half of September on, bat activity decreased with bats gradually going into hibernation and staying 'behind the portal'. Awakening from hibernation and leaving the site does not lead to a high number of bat passing through the portal. The bats just leave, and do not stick around.

The net movement of bats into the *reduit* starts from the second week of September, with bats staying behind the barrier and assumed to be in hibernation by the first week of Novem-

ber. By the end of November, most bats have moved into the *reduit*, and into hibernation.

The maximum numbers of bats 'behind the portal' varied between 1761 and 2066 (figure 5, table 1). This number is a maximum calculated from the net number moving 'IN' and 'OUT'. The maximum numbers of bats were registered during second half of November for all years.

Figure 6 compares the cumulative build-up of bats 'behind the portal' (a) and bat activity through the infrared portal in and out of the *reduit* (b) with the actual outside temperatures

Table 1. Overview of recorded IN and OUT passes by the IR (infrared) portal between 11/06/2014 and 10/01/2018.

start session	end session	IR portal passes (IN)	IR portal passes (OUT)	total passes	difference IN-OUT	max passes/ night	max <i>n</i> behind portal
11/06/2014*	31/03/2015	98,630	98,286	196,916	344	4074	1903
01/04/2015	31/03/2016	102,033	101,564	203,597	469	4539	1761
01/04/2016	31/03/2017	134,008	133,183	267,191	825	4793	2066
01/04/2017	10/01/2018*	96,591	97,040	193,631	449	5022	Incomplete**

*2014 May/beginning June swarming missed; **monitoring stopped 11/01/2018

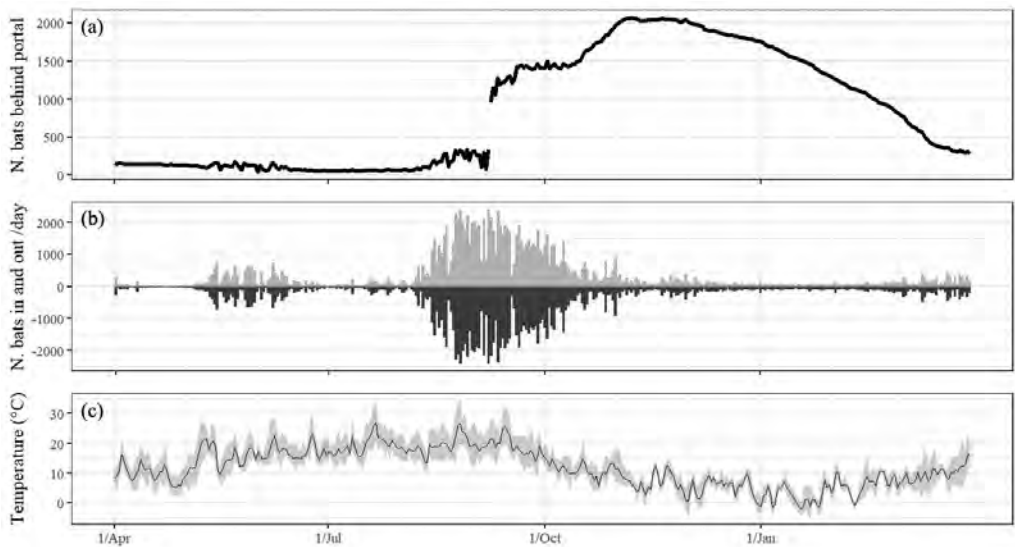


Figure 6. The cumulative build-up of bats ‘behind the portal’ between 1 April 2016 and 31 March 2017. From top to bottom: a. Number of bats behind the infrared light barrier; b. 24-hour activity in (grey) and out (black) of the infrared portal; c. Outside temperature measured at the weather station of Melsele, 10 km from the study site.

(c) for the 2016-2017 season. The net movement of bats into the *reduit* coincides with the gradual decrease of the outside temperature, leading to a maximum number of bats ‘behind the portal’ at the end of November. However, even at the moment when it is generally assumed that bats are in hibernation, the flights through the portal did not stop. Throughout the month of January, on average 20 bat passes were recorded in and out of the flight opening leading to the study zone.

Even more striking is that bats start moving out of the stable environment of the *reduit* area as early as the end of December: a month before the coldest part of winter. By Febru-

ary, half of the hibernating bats had already moved out of the *reduit* enclosure, probably relocating towards the entrance of the fort. More or less all the bats had left the ‘*reduit*’ (and maybe the fort) by the end of March. There was little to no activity until the activity peak of May/June.

The population of hibernating bats at Fort Steendorp, a comparison of counting methods

We also looked at overall numbers of bats hibernating at Fort Steendorp. Figure 7 shows

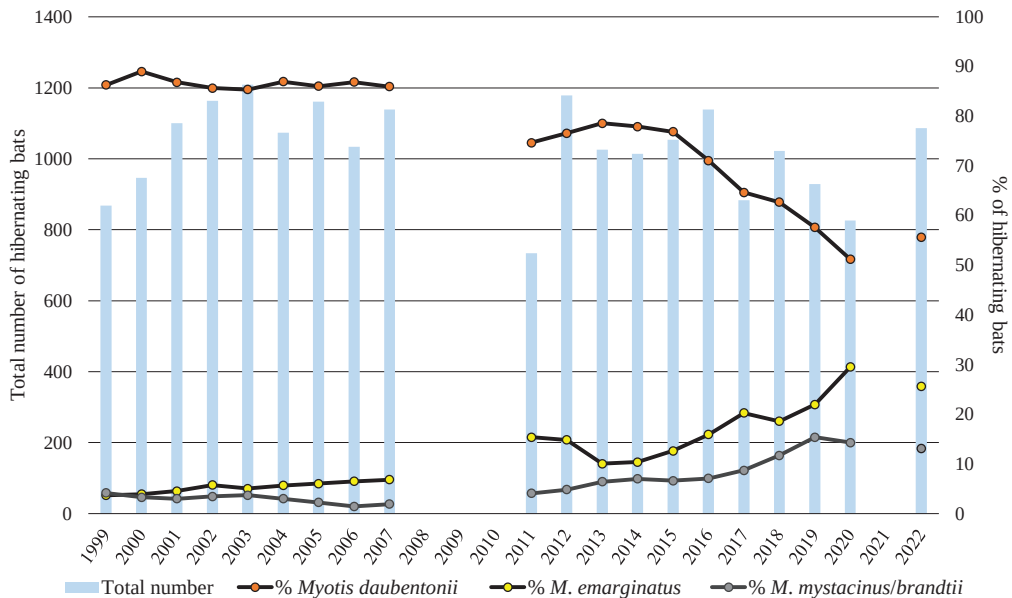


Figure 7. Total number (left axis) and proportion (% right axis) of hibernating bats in Fort Steendorp (entire fortress) since the winter of 1998-1999 and the three most abundant species: Daubenton's bat, Geoffroy's bat and whiskered and/or Brandt's bat. Data: Natuurpunt vzw bat working group. Due to safety concerns, no winter counts were carried out from 2007-2008 to 2009-2010 and in 2020-2021 due to the covid-19 pandemic. 2010-2011 = incomplete count.

the result of a longer term series of annual bat census counts between 1999 and 2020, for the whole of Fort Steendorp; the total numbers vary from 734 to 1209. Due to security concerns, no counts were carried out during three seasons (2007-2008 till 2009-2010), as well as the 2020-2021 season, due to the Covid-19 pandemic. The 2010-2011 season was an incomplete count. Up to the winter of 2006-2007, annual census counts were done in mid January; since 2010-2011 they have been performed during the weekend closest to 15 February.

In total ten different species have been found hibernating in Fort Steendorp. These main species found are Daubenton's bat, Geoffroy's bat, Natterer's bat (*Myotis nattereri*) and whiskered and/or Brandt's bat. Pond bat (*Myotis dasycneme*), brown long-eared bat, grey long-eared bat (*Plecotus austriacus*), common pipistrelle (*Pipistrellus pipistrellus*) and serotine (*Eptesicus serotinus*) each represent less than

1%. Nathusius' pipistrelle (*Pipistrellus nathusius*) and noctule (*Nyctalus noctula*) have been recorded hunting in the fortress, but so far do not hibernate on site.

One of our goals was to try to evaluate how to compare bat census counts with actual numbers of bats hibernating in this type of hibernaculum. For this, we compared the bats counted 'behind the door with the infrared portal' with the data collected from the automated system. From the literature, and from personal experience, we know that the hidden proportion of hibernation bats varies greatly depending on the type of site (de Rue 1972, Kugelschafter 1994, Degn et al. 1995, Jansen 2014, Weinreich 2022). Visual annual census counts in the month of February in the *reduit* area varied from between 271 in 2015 to 340 in 2017 (table 2). Over the same time period, the cumulative data of bats 'behind the portal' varied between 703 and 991. On average, only 37% (a ratio of 2.7) of hibernating bats

Table 2. Comparison of the total number of bats behind the automated infrared portal and a standard on site visual count, at the given census date in February.

hibernation season	date of comparison	bats behind the portal	same zone manual count	%	ratio
2014-2015	15/02/2015	703	271	38.5	2.6
2015-2016	21/02/2016	621	252	40.6	2.5
2016-2017	18/02/2017	991	340	34.3	2.9
	mean	772	288	37.8	2.7

‘on site’ are actually detected during in visual census counts. A major reason for this is that large numbers of bats are probably tucked away in the flooded water corridors or in hollow spaces in between walls, which are inaccessible to the bat workers.

By deduction, with the latest numbers of around 1000 bats counted during the annual censuses in Fort Steendorp, the actual number is probably closer to 3000, making the site even more important for bat conservation than previously thought. This 2.7 factor does not necessarily apply to other man made or natural underground hibernation structures.

Bat activity over 24 hour periods (noon to noon)

We also looked at the activity patterns in relation to the time of night and day. Our infrared portal was 50 metres deep into the complex. In the absence of daylight and other influences from the outside world, it seemed interesting enough to find out if there were peaks in bat flight activity, and if so when. A closer data analysis showed that at some points in the year up to 5000 bat passes were recorded over one night (during autumn early swarming), during which, at peak moments, up to 600 bats passes were recorded in a single hour.

Figure 8 shows different 24-hour activity patterns (noon to noon) for some single chosen dates during the survey period (2015 to 2018), depending on the period of the year. These were: A. The end of May with spring swarming. B. The end of August at the begin

of autumn swarming. C. The end of October, at the end of autumn swarming. D. The beginning of January when bats are supposed to be in hibernation.

During spring swarming (May) activity through our portal tended to be highest from 10 pm to 7 am, peaking between 3 and 5 am. At the beginning of August, portal passes started at sunset (10 pm), peaking towards 2 to 5 am with up to 400 bat passes per hour, although bat flight activity stretched well into the next day: 12 pm and even 2 pm. A different pattern was seen at the end of October, with flight activity only between 9 pm and 5 am. In the middle of the hibernation period (end of January) smaller activity patterns were also spread over the whole day, and not linked to outside diurnal rhythms.

Discussion

Census surveys of bats in hibernacula are typically performed by direct count of visible bats, using torches, headlights and a lot of effort. Site-specific underrepresentation of the true numbers of hibernating bats is likely, and is likely to vary according to the internal characteristics of each site (e.g. size, number of cracks and crevices, inaccessible tunnels etc.). Different techniques have been used to estimate the total number of hibernating bats: e.g. mark and recapture method with banded bats, passive integrated transponder PIT tags readers, genetic testing, radar beam (Punt 1957, Kugelschafter 2009, Jansen et al. 2014). Automated systems using infrared light

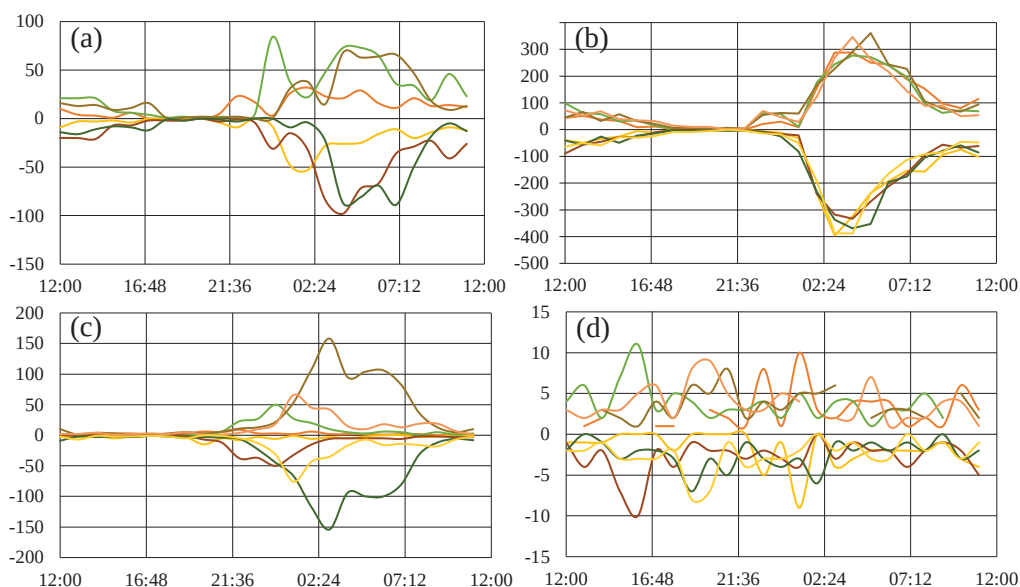


Figure 8. 24-hour activity, noon to noon the next day, for different consecutive years. a. 25 May (spring swarming); b. 29 August (beginning of autumn swarming); c. 29 October (end of autumn swarming); d. 8 January (bats in hibernation). N.B. The scales of the Y-axes differ.

beams have been applied for over fifty years (Daan 1970, Berková & Zúkal 2006, Jansen et al. 2014, Kugelschafter 2014, Weinreich 2022) bringing new insights on the value of some hibernacula for bats. Based on long term data, research pioneers, such as Punt (1957) and Kugelschafter (2009), showed that the difference between counted versus actual numbers of hibernating bats can be considerable (even up to 90%) due to the existence of invisible bat ‘reservoirs’ in hibernating quarters.

Most studies using infrared portals monitor activities and the numbers of bats in hibernation at the entry points to forts and caves (de Rue & Daan 1972, Daan 1973, Kugelschafter 2009, Steck & Brinkmann 2015, Weinreich 2022). Only the study of de Rue & Daan (1972) at the ice cellar of Middenduín, the Netherlands, made recordings both at the entrance and further down the corridor, allowing an estimation of the direction of the winter movements from the rear to the entrance.

This study monitored activity and hibernation patterns over a four-year period, using an

infrared light barrier system at the entrance of a favourable and totally enclosed part of Fort Steendorp. The door with the monitored flight opening is the only way into the study zone, the *reduit* of the fort. We limited the chance that bats entering the same zone would be ‘missed’ by blocking off the other entry points. Different visual observations suggested that the infrared portal in the flight opening of the door to the *reduit* did not seem to have any influence on bats entering the zone. Comparing the visual counts and those from the infrared portal allows us to come up with a more accurate estimate of how many bats actually hibernate in Fort Steendorp. We know that ‘invalid movements’ on account average for only 1.6% of registrations. This number is low, and not unexpected when, at some moments, 600 bat passes were registered in an hour.

Activity patterns and hibernation

Our study shows high spring activity peaks

through the infrared portal leading to the *reduit*, in May into June, and an autumn activity starting mid-August with bats are assembling and getting ready to go into hibernation. No building up of bats 'behind the portal' takes place at that moment. From the end of September, the number of bats flying in but no longer coming out of the study area builds up, reaching maximum numbers by the end of November. From visual observations, we know that by then, most bats are in hibernation. From on-site observations, we know that by the end of March most hibernating bats have left, with the exception of some Geoffroy's bat that tend to remain on site into the first half of May.

In 1932, the observation that large numbers of bats visit caves and mines in autumn, few months before hibernation, was first described by Poole in North America and termed "swarming" (Saucy 2019). Different hypotheses have been put forward for this phenomenon: assessing suitable hibernacula and introducing juveniles to hibernation locations, but the most common explanation is that swarming is considered as a mating event (Saucy 2019). Swarming occurs at night; the first individuals usually arrive sometime after sunset and show a peak of activity between 4–6 hours after sunset (Rivers et al. 2006). The activity then gradually decreases until 4 am. Most of the swarming occurs in late summer and autumn.

In most cases, swarming is observed from mid-August to mid-November, peaking between mid-September to mid-October (Rivers et al. 2006, Saucy 2019). Encarnação (2005) did similar observations showing that young males accompanied adult male Daubenton's bats entering hibernacula from mid August until mid September to get to know their mating places. Some bats also visit more than one hibernaculum per night, which might explain the considerable night-to-night variation in activity (Humphrey & Cope 1976). However, swarming during spring has been highlighted for brown long-eared bat (Furmankiewicz

2008) and for Daubenton's bat (Encarnação 2005).

Bats stay in hibernation in high numbers during November and December, but even then, there is still a limited activity of bats moving in and out of the portal. Remarkably, bats already started to move out of the zone behind the infrared barrier during the second half of November. We do not know where the bats relocate to, but we may assume that with low outside temperatures, most bats relocate within the underground structures of Fort Steendorp. Similar events have been described for ice cellars, limestone quarries and natural caves (de Rue & Daan 1972, Daan 1973, Berková & Zukal 2006).

The cumulative numbers of bats 'behind the portal' in this study were set to zero once every season (April to March the following year) in order to estimate the total numbers going into hibernation, and to correct for small inconsistencies in the cumulative numbers that arise gradually. These inconsistencies might result from small errors in the recordings of 'IN' and 'OUT', but are also related to the enclosure never being empty at any moment in time. Very small numbers of bats will use Fort Steendorp as a temporary or permanent roosting site in the summer as well, as indicated by the all year activity patterns..

There were very small differences between bat passes 'IN' and 'OUT', with resp. only 0.3, 0.5 and 0.6% more bats moving inwards (table 1). Some bats might not have left by March 31, some might have perished through predation or death. In order not to accumulate these discrepancies, curves were set to zero every year at the lowest point in June. Two, three and five day gaps in the recordings at the end of June and August 2015, and August 2017 do not influence in any way maximum numbers hibernating 'behind the portal'.

We recorded movements and passes of bats during the entire winter, indicating that hibernation is not a continuous process. Previous studies showed that in a great number of cases, spontaneous awakening occurs (de

Wilde & van Nieuwenhoven 1954). The average sleeping period is 12-14 days; although the lengths of the sleeping periods of different species of bats differ. Repeated censuses by the Flemish bat working group of hibernating quarters towards the second half of winter, show that individual bats had moved from the locations that they previously occupied. Based on banding experiments De Wilde & van Nieuwenhoven (1954) concluded that bats show a high fidelity to their hibernation quarters, but some specimens are only present during a certain part of the winter. They found that individuals of some species disappear, sometimes without being replaced and sometimes being replaced by individuals of a different species.

An important element to take into account is the location of the infrared light barrier, half way in the hibernation quarter, more or less 50 m from the main entrance of the site. Berková (2006) found a significant positive relationship between the number of bat passes, measured by an infrared light barrier, and the mean outside temperature at the entrance of a cave. Ransome (1990) showed that European bats do leave the caves they hibernate between December and February, mostly in low numbers, in the order of 0.5% per day. Interestingly, many outward flights were immediately (within one minute) followed by inward flights (Daan 1970). However, the number of flight movements inside the hibernating quarters during the same hibernating period were at least ten times higher (Daan 1970). In addition, studies with banded bats indicated large internal migrations within marl caves (de Wilde 1954, Punt 1957). It seems that bats awake during hibernation and change their location within or even between hibernation sites due to slight changes of the ambient temperature in the hibernaculum, linked to outside temperature conditions (Daan 1973, Ransome 1990).

Daan (1973) showed that bat populations in limestone quarries rapidly increased from the middle of September to the middle of Novem-

ber, although the number of Daubenton's bat continued to increase at a slower rate until the middle of January. During warmer periods bats relocated to the front part of the limestone quarry or left the site altogether. In Fort Steendorp, changes in the outside temperature are slowly reflected in the inside temperature after, on average, six days (Meermans 2004), which can trigger bats to interrupt their winter torpor. De Bruyn et al. (2021) found that hibernating bat populations use warmer parts of the system as winter progresses.

When outside temperatures start rising by the end of February, hibernating bats started moving out of the zone behind the IR barrier. By the end of March, more or less all bats had left the '*reduit*' (and maybe the fort), with exception of some Geoffroy's bats, the second most common species in the fort. This could explain why some flight activity was also seen in April. On-site observations (A. Lefevre, personal observations) showed that some Geoffroy's bats remained in their hibernating quarter up to early June.

It is unclear if the higher activity peak in May-June is linked to foraging, swarming or other patterns and it cannot be excluded that this is contributed to Geoffroy's bat coming out of hibernation. A study performed by Kugelschafter (2014) on a limestone cave in Bad Segeberg, Germany, found what was called 'springtime visits'. In this study, species identification was based on video sequences showing large clusters of adult male Daubenton's bats entering the cave during spring. This has also been described by Degn (1989) and Harrje (1994).

Comparison with visual counts

Research presented at the First European Workshop on Automatic Monitoring of Bat Roosts in 2014 at Bad Segeberg, Germany showed that the use of infrared light barriers improves our knowledge about hibernacula (Jansen et al. 2014). The hidden proportion of

hibernation bats is estimated to range between 22% to 99% (de Rue 1972, Kugelschafter 1994, Degn et al. 1995, Jansen et al. 2014).

A drawback of infrared light barrier systems is that the species flying through the system cannot be identified. However, our main goal was to get a year-round overall assessment of the activity of the total number of bats active in the fort. Species composition and the number of each species present on site are already known, based on captures during swarming and annual census counts. Dekeukeleire et al. (2011) performed a netting experiment at Fort Steendorp during three nights between mid-August and the end of September. Most of the captured individuals were Daubenton's bats (85-95%). It is worth mentioning that no maternity colonies have so far been found in Fort Steendorp.

February visual census counts show a significant decrease (35%) in the numbers of Daubenton's bat: 604 were counted in the 2021-22 season, compared to a stable average of 931 prior to 2007. Despite investments and a sustained high level of management, the number of hibernating Daubenton's bat at Fort Steendorp dropped by a third. We cannot put a finger on the reason for this decline, but likely reasons are chronically poor surface water quality, and the relentless felling of trees in the area that are suitable for this tree-dwelling species. In contrast, the numbers of Geoffroy's bat, whilst lower, are on the rise from $n=58$ (mean of nine years prior to 2007) to $n=278$ in the 2021-22 hibernation count. The rise of Geoffroy's bat seems to result from an overall increasing population, which runs parallel to a growing number of summer colonies. The numbers of whiskered and/or Brandt's bats counted hibernating at Fort Steendorp have also increased lately, from $n=31$ (mean of 9 years prior to 2007) to $n=142$ in 2021-2022). Based upon visual counts in February, Geoffroy's and whiskered and/or Brandt's bat, have seen an almost fivefold increase in numbers in the last 15 years or so.

Our extrapolation factor of 2.7 (37% of bats

visible) differs from the factor of 1.2 found by Jooris & Goossens (1980) in February 1978 that was calculated from a mark-recapture experiment at the same site. Over five months they marked a total of 162 hibernating bats (142 Daubenton's bats) with small stickers on the head. The proportion of marked animals sighted after a one month varied considerably over the winter season, with 34% and 39% of the total number of sighted bats marked respectively in November and December, increasing to 52% in January and 82% for February, and (on a smaller sample size) 80% in March. During the five 'recapture' moments 15-20 bats were selected, and checked for a marking on the head, irrespective of the total number of bats present. However interesting the study is, it is not a valid mark-recapture, because the bats, being in hibernation, do not move around at random. Some probably do not move at all, or do not move during a given month. The system is also not closed, bats move in and out.

What our method measures is the fraction of visible bats against the total number present. In doing so, we also measure the fraction of bats 'in hiding' in February. What Jooris & Goossens (1980) measured is how many unmarked bats shifted place in one month, or more specifically came out of hiding or arrived from elsewhere. In November 1977, 15 bats were sampled. Nine unmarked bats came into sight, six bats were marked but we do not know how many marked bats left or moved into hiding. February 1978, 20 bats were sampled, four unmarked bats came into sight, 16 of the bats were marked but again we do not know how many marked bats left or moved into hiding. The percentages used in this 1980 publication to extrapolate for total numbers are therefore dubious. As to the conclusions on the possible 'coming out of hiding' of bats, it shows that there is more such activity in November and December than in February.

Similar research performed in an ice-cellar (Middenduyn, the Netherlands) on the activity of hibernating bats with infrared sensors

showed that the bat population present was two to three times higher than the on-site censuses numbers (de Rue & Daan 1972). Other studies with infrared light barrier systems in (marl)caves showed that, depending on the site and its characteristics, the censuses capture between 20 and 50% of the actual bat population (Weinreich 2022), 20% (Berková & Zukal 2006), or even less than 10% (Kugelschafter 2014). If our figure of 37% is scaled up to the censuses of the entire Steendorp Fort, the real number of hibernating bats would be closer to 3000 instead of the average 1016 bats counted over the ten last winter seasons. This could have an impact on the evaluation and reporting of overall bat numbers in Flanders, Belgium. This factor of roughly one third may apply to similar historical red brick underground structures.

Census counts at Fort Steendorp are now standardly performed in February, while the numbers in hibernation in the enclosed and, for bats highly favourable, *reduit* of the fort, peak from November to the beginning of December. By the 1st of February, over half of the bats had left the enclosure (2017 portal data, peak November $n=2066$, mid February $n=991$). It is unclear what this means for overall numbers hibernating at Fort Steendorp, whether or not the estimated 1075 bats that left the enclosure are included in the overall census count of February, or if they left for other places. In conclusion, we are sure that a correction of 37% or thereabouts should be applied to the number of bats visually counted in February. We cannot, however, ascertain whether a visual count in November would yield markedly higher numbers of bats. If so, again this would have implications for the overall estimate of bats hibernating at Fort Steendorp. However, repeated census counts at the equally important fortifications of Brasschaat and Oelegem show that two or more counts during the same winter usually show a difference of around just 10%, occasionally going up to 20% in both directions (Natuurpunt bat working group, unpublished data).

Conclusions

This study underlines the importance of man-made underground structures, such as Fort Steendorp, providing hibernacula for underground-dwelling bat populations in regions with few or no natural caves. Based on our data gathered by an infrared portal, we conclude that, at least, for the *reduit* study site and, by deduction, for the entire brick fort, the numbers of hibernating bats deduced by on-site census counts have to be multiplied by a factor of at least three. This factor coincides with earlier findings, will roughly apply to all similar structures and should not vary within the deep winter season.

The study reveals in detail the main swarming seasons for bats at Fort Steendorp (the end of May – beginning of June, and from the end of August to the end of October) and how the number of bats going into hibernation gradually builds up behind the portal, with a maximum number reached in the first half of November. Even then, a low level of flight activity is seen in and out of the enclosure. By December, even before the coldest part of winter, some bats already move out of the protective environment of the deeper *reduit*, most probably to other parts of the fort.

Even given the underestimation of hibernating bats from censuses, and in stark contrast to the trends for other species, Daubenton's bat is in sharp decline at Fort Steendorp, as in the rest of Belgian Flanders. This should trigger awareness about the ongoing logging of trees with cavities and the overall quality of surface waters, both of which are important for this species.

Our results, combined with previous studies, show that protective measures for bats at forts like this should not be limited to the mid-winter season. Clearly, Fort Steendorp is important for populations of bats all through the year. Management plans should be adopted likewise. This should include stricter criteria when repurposing important bat hibernation sites and the extension of the non-disturbance

time for major parts of hibernacula from September to the end of May.

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The relationship between the numbers of hibernating brown long-eared bats (*Plecotus auritus*) and weather conditions (ambient temperatures and precipitation)

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Abstract: This study investigates the relationship between outdoor temperatures, periods of prolonged precipitation and the numbers of brown long-eared bats (*Plecotus auritus*) in hibernacula during the annual bat census. It draws on census data from three complexes: in the Amsterdamse Waterleidingduinen, the Kop van Schouwen and Klein Heidekamp, in which an average of more than ten bats were present per winter over a period of 25 years. The weather indices were examined at nine points in time prior to the day of the census (42, 35, 28, 21, 14, 7, 5, 3 and 1 day respectively). KNMI weather observations from nearby weather stations were used to calculate the mean temperature ($\bar{x}TG$), the number of (adjusted) frost days (nTN) and the sum of the negative minimum temperatures (ΣTN). In addition, the duration (ΣDR) and volume of precipitation (ΣRH) were summed for the nine periods. Pearson correlation tests were used to calculate the degree of correlation between the numbers of bats in each hibernaculum and these weather indices. It was found that more frosty days and a high cold count between 42 and 21 days prior to the count were associated with higher numbers of long-eared bats in hibernacula. Conversely, during the same periods, a negative association was found between mean outdoor temperatures and numbers of long-eared bats. No significant correlation was found between the precipitation indices and the numbers of long-eared bats in any of the hibernacula for any period prior to the census day. In conclusion, the article discusses the possible significance of some ecological adaptations by the long-eared bat to cold conditions.

Keywords: Brown long-eared bat (*Plecotus auritus*), hibernacula, mean temperature (TG), frost days, precipitation duration, precipitation amount, Pearson's correlation coefficient.

Introduction

The brown long-eared bat (*Plecotus auritus*) (here after referred to as the long-eared bat) is known as a cold-resistant bat species that usually resides in hibernacula at an ambient temperature of 2-5 °C, but which can tolerate temperatures as low as -3.5 °C for a few days (Braun & Häussler 2003). It occupies a special place among bats in Europe. Leaving aside the

subspecies *P. a. begognae* of the Iberian Peninsula, *P. auritus* (sensu stricto) has one of the most extensive north-south distributions of European bats, extending across the west of the continent from central Norway (63-64 °N) (Entwistle 1999) to just south of the Pyrenees (30 °N) (Horáček & Đulić 2004, Juste et al. 2004).

Long-eared bats are known to be highly sedentary, usually with flight distances of less than ten km and further wanderings rarely exceeding 30 km (Dietz et al. 2007). Horáček & Đulić (2004) mention displacements over

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Figure 1. Brown long-eared bat with ears folded under forearms and only the tragus protruding. The long guard hairs also are clearly visible. *Photo: Ben Verboom.*

15 km being unusual, with maximum recorded flight distances of 88 km. Long-eared bats have some special characteristics that enable them to survive conditions with low outside temperatures, up to a few degrees below freezing. The GH2 guard hairs (guard hairs with an angle between the shaft and shield) in their fur are among the longest of the West European bats and long-eared bats also have the most waves in these GH2 guard hairs (Teerink 1991): properties that provide relatively good insulation. In addition, long-eared bats almost always fold their long ears under their forearms when resting (figure 1). This position, not only limits heat loss through the ear to the environment, but also provides an extra insulating layer of air around the body. The tendency to partially drape the wings around the body in the hanging position further insulates the body (figure 2).

Movements of long-eared bats between summer habitats, such as (abandoned) build-



Figure 2: Brown long-eared bat in hibernation with the wings partly covering the body. *Photo: Stefan Jerzykowski.*

ings, tree holes or crevices, bat boxes and hibernacula are part of their phenology. Heise & Schmidt (1988) report the first finding of long-eared bats in hibernacula in Germany at the beginning of November. In general the hibernation period is between October/November and the end of March/beginning of April (Braun & Häussler 2003).

Between the autumn of 2020 and the spring of 2021, 50 bat boxes in the Veerse Bos were checked from the bottom every week. From October onwards the number of long-eared bats in the boxes gradually decreased from about 30-34 individuals to 7-10. Long-eared bats were found in the boxes during these weekly checks, except for the week of 7-12 February 2021, when the maximum temperature did not exceed 0 °C. A week later (when the temperatures were higher), ten long-eared bats were recorded in these boxes (Bekker 2022). These observations of long-eared bats gradually leaving bat boxes raises the question of where they go? A more temperature-buffered tree hollow in the forest, a nearby building or other unknown hibernacula? Lichačev (1980,

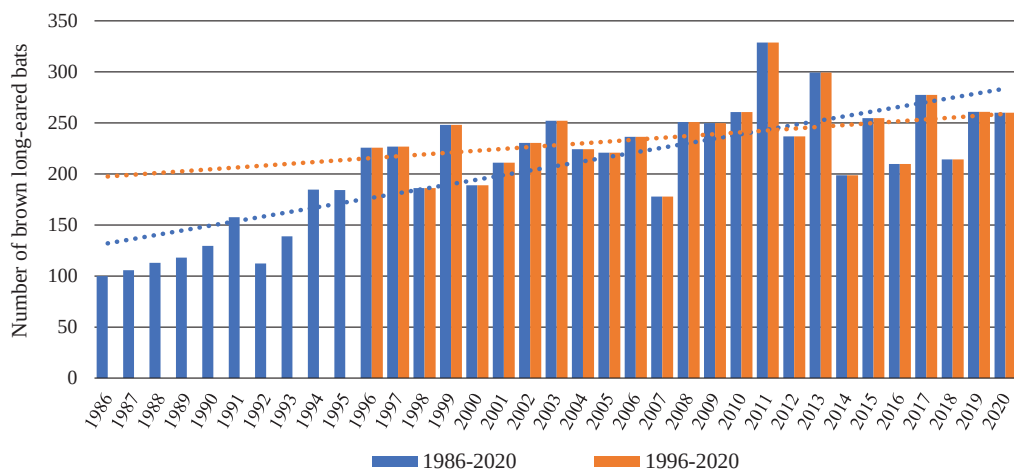


Figure 3. Trends of hibernating brown long-eared bats in the Netherlands.

in: Horáček & Đulić 2004) mentions that prolonged periods of precipitation, in combination with cold periods in the autumn, could play a role in the moment when long-eared bats leave their summer habitats. The gradually decreasing numbers of long-eared bats in bat boxes in autumn could be influenced by the lower mean outside temperature or periods with high precipitation. Conversely, the number of long-eared bats counted in hibernacula could possibly be directly related to the weather conditions (cold and/or precipitation) preceding the count. This study tests this theory with the initial hypothesis that a mean lower outside temperature prior to the census, is associated with more long-eared bats being counted in hibernacula. Secondly it is hypothesized that long-eared bats respond to previous frost periods by congregating in hibernacula in greater numbers. Finally, a third hypothesis is tested: that long-eared bats congregate in hibernacula in greater numbers after high and prolonged precipitation.

Material and Methods

Stable population

In order to test these hypotheses, it is impor-

tant to assume a more or less stable population of long-eared bats over time. The national trend of long-eared bats in the Netherlands shows that in the period 1986 to 2019/2020 there was an average increase of two and a half to three times (source NEM, La Haye & van der Meij 2022, in this issue) (figure 3). The trend over 25 years, from 1996 up to 2020, is noticeably flatter, as shown by a comparison of the trend lines for the periods 1986-2019/2020 ($y=4.3661x + 128.68$) and 1996-2019/2020 ($y=1.62x + 199.17$). Therefore, in this study the correlation is studied over this shorter period of 25 years.

Hibernacula

Hibernacula were selected based on the presence of on average at least ten long-eared bats per winter over a 25-year period, with (at least) one counting taking place in each of these years, on a known census day for each year. Based on these criteria, the number of hibernacula in the three study locations are shown in table 1. The characteristics of the hibernacula in the Klein Heidekamp cellar complex are described in Glas & Kaal (2022, in this issue). The bunker complexes in Amsterdamse Waterleidingduinen and in the Kop van Schouwen are detailed in Lange et al.

Table 1. Characteristics of selected winter roosts. KVS: bunkers in Kop van Schouwen, AWD: bunkers in Amsterdamse Waterleidingduinen and KHK: cellars in Klein Heidekamp.

	Number of locations	Earliest-median and -last census dates (total census period)	Average number of brown long-eared bats
AWD	70	10-Jan.-16 Jan.-25 Jan. (16 days)	22.4
KVS	58	19 Dec.-27-Dec.-30 Dec. (12 days)	32.5
KHK	4 (+30*)	13 Jan.-22 Jan.-30 Jan. (18 days)	14.6

* there are around 30 hibernacula in the immediate vicinity of Klein Heidekamp.

(2022) and Mostert et al. (2022), respectively, both in this issue). Permission was obtained from the census leaders of these hibernacula to use the census data. Notably, the median of the census data for the Amsterdamse Waterleidingduinen and Klein Heidekamp are respectively 20 and 22 days later in the winter than those from the Kop van Schouwen.

Weather conditions

It is not known how quickly long-eared bats react to changing weather conditions and how long it takes for a long-eared bat, arriving from a summer or autumn habitat, to move into a hibernaculum. Therefore, the weather variables for a number of different days prior to the count were analysed, using nine periods of different durations prior to the days of the census: 42 days, 35 days, 28 days, 14 days, 7 days, 5 days, 3 days and 1 day. To this end we collected the observations of temperatures and precipitation from the KNMI stations closest to the hibernaculas' locations: Schiphol (weather station no. 240) for the Amsterdamse Waterleidingduinen, Vlissingen (no. 310) for the Kop van Schouwen and Deelen (no. 275) for Klein Heidekamp.

A complete list of climate variables, together with the international abbreviations used here and their definition, can be found on the KNMI website. Different methods were adopted to quantify the coldness of a winter over different periods of time. First, the mean temperature (TG) was determined over different periods prior to the day of the census. Secondly, the

number of days on which the minimum temperature (TN) dropped below 0° Celsius over the various periods was determined, referred to here as the (adjusted) number of frost days. Thirdly the sum of the negative minimum temperatures (TN) was determined over the relevant periods. This sum of negative temperatures, which omits the minus sign, is referred to as the 'cold number' (ΣTN). In this study, the definition of the terms 'frost days' and 'the cold number' deviates somewhat from the standard: first of all, the duration over which the numbers of frost days and the cold number are calculated is limited to the days preceding the census, as opposed to the end of the meteorological winter. In addition the ΣTN calculation, is based on the minimum temperature (TN) on each day, rather than the mean temperature (TG) over 24 hours. To quantify periods of 'long-term precipitation' the variables duration (DR) and the amount of precipitation (RH) were used. The precipitation duration (DR), expressed in units of 6 minutes per day, and the precipitation amount (RH), expressed as the 24-hour sum of precipitation, were added annually and per period.

Statistics

The Pearson correlation test was used to calculate the degree of correlation between the numbers of long-eared bats per winter home on each census and the indices for cold and precipitation. The outcome, the *r*-value, is a variable that can vary between 1 (positive = complete correlation) and -1 (negative = com-

pletely negative correlation). The terminology of Van Heijst (2022) is used to indicate the correlation strength: very low or barely present ($r=0-0.3$); low or weak ($0.3-0.5$); moderate ($0.5-0.7$); high or strong (0.7 and 0.9) and very high or strong ($0.9-1.0$). In addition to the r -values, the P -values associated with the specific correlation were calculated in Excel®, using the Student T-distribution (2-tailed). This allows one to conclude whether or not the determined correlation value is significant. The results (the r -values) of the weather indices are presented in figures with all the available results of the Pearson correlation tests for the hibernacula. These figures are always comparable, with the X-axis showing the periods over which the relationships have been calculated (42 days, 35 days, etc. up to and including one day prior to the census) and the Y-axis the extreme values within which r is located (from -1 to +1).

Results

The relationship between the numbers of hibernating long-eared bats and the weather indices for the nine different periods prior to the census days in the years 1996-2020, on the three different complexes of hibernacula are summarized in the table 2. The significant differences for each weather variable are explained below.

Mean temperature

The results show that a higher mean temperature prior to the census day is related to fewer hibernating long-eared bats and vice versa (figure 4a; details in table 2). The effect of this relationship can be seen in all three complexes, but is most pronounced in the Kop van Schouwen, where for all periods, except one day prior to the count, a pronounced negative association was found between the mean temperature and the numbers of hibernating long-eared bats

(figure 4a, table 2). This (significant) coherence was not found in the complexes of Klein Heidekamp and the Amsterdamse Waterleidingduinen for the preceding periods of 7 and 21 days (figure 4a, table 2). The correlations are stronger for the longer, rather than shorter periods before the census day (figure 4a).

Number of frost days

The correlation between the annual numbers of frost days and the annual numbers of hibernating long-eared bats shows a positive correlation for periods from 42 to 28 days before the census date for all three complexes (figure 4b). For the Kop van Schouwen bunkers, the correlation is highest at 42 days ($r=0.79$, $P<0.01$) and decreases gradually up to and including 3 days before the census day ($r=0.51$, $P<0.01$). At 42 days, the correlation for the Amsterdamse Waterleidingduinen ($r=0.52$, $P<0.01$) and Klein Heidekamp ($r=0.53$, $P<0.01$) complexes is approximately the same, and is significant in both cases. In these two complexes, the association gradually decreases up to and including 28 days ($r=0.44$, $P<0.05$) and 14 days ($r=0.50$, $P<0.01$) at the two sites respectively. The correlations are stronger for the longer periods before the census day than for the shorter ones.

The sum of negative minimum temperatures

The annual sum of negative minimum temperatures prior to the day of the census and the annual numbers of hibernating long-eared bats showed the strongest correlation for the hibernacula in Klein Heidekamp and the Kop van Schouwen at 42 days ($r=0.74$ and 0.67 respectively, both $P<0.01$) (figure 4c). For the bunkers of the Amsterdamse Waterleidingduinen, the correlation was lowest at 42 days ($r=0.39$, $P<0.05$). In general, the correlations for longer periods before the census day are stronger than for the shorter periods.

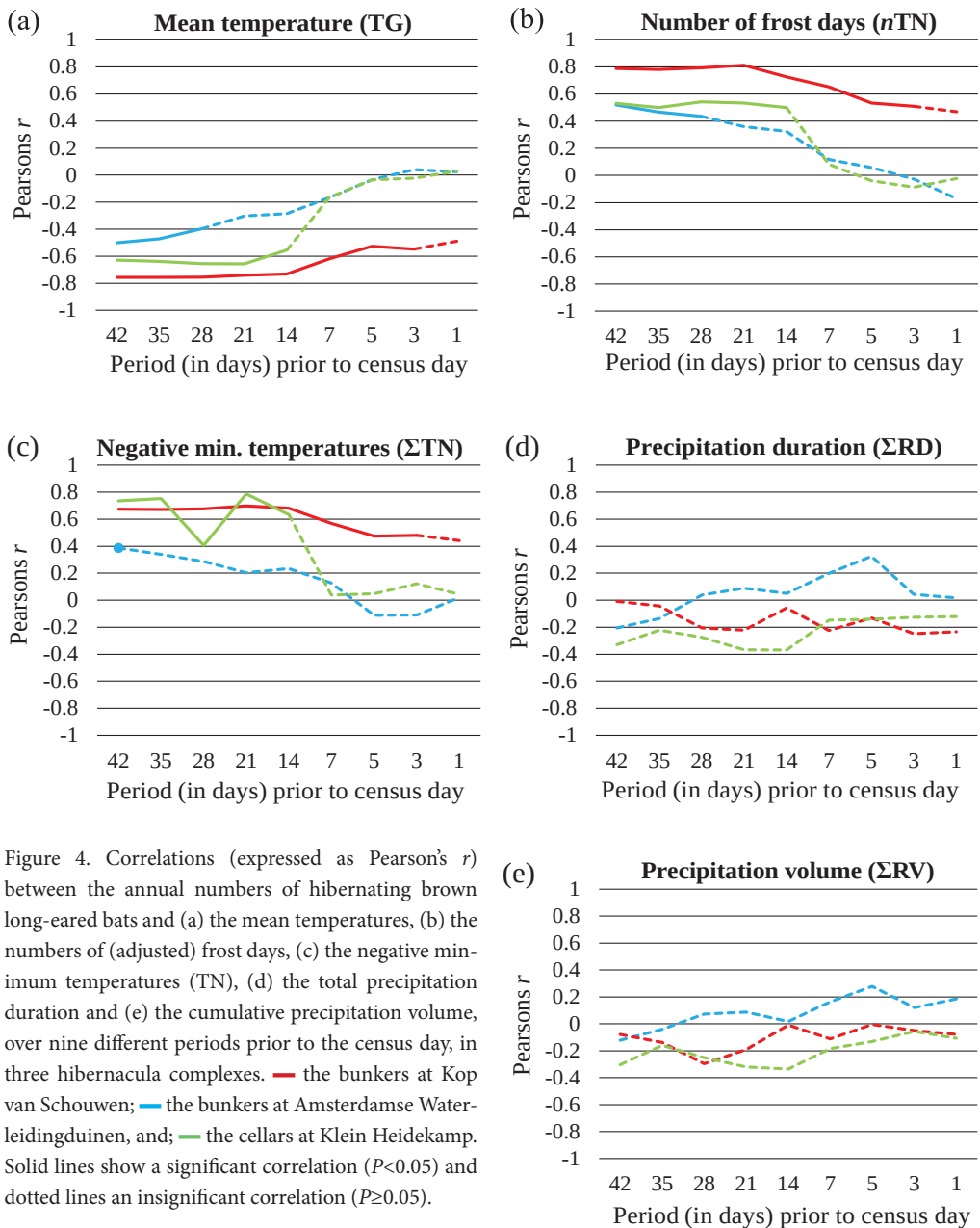


Figure 4. Correlations (expressed as Pearson's r) between the annual numbers of hibernating brown long-eared bats and (a) the mean temperatures, (b) the numbers of (adjusted) frost days, (c) the negative minimum temperatures (TN), (d) the total precipitation duration and (e) the cumulative precipitation volume, over nine different periods prior to the census day, in three hibernacula complexes. — the bunkers at Kop van Schouwen; — the bunkers at Amsterdamse Waterleidingduinen, and; — the cellars at Klein Heidekamp. Solid lines show a significant correlation ($P < 0.05$) and dotted lines an insignificant correlation ($P \geq 0.05$).

The duration and amount of precipitation

There is hardly any correlation between the total duration of precipitation for the different periods prior to the day of the census and the numbers of hibernating long-eared bats, the

r -values are around zero or slightly negative, and are not significant ($P > 0.05$). The strongest correlation was found for the bunker complex of the Klein Heidekamp, with slightly negative values ($r = 0.32$, $P > 0.1$) for the period 14 days before the census day (figure 4d). At

Table 2. The results of Pearson's correlation tests (Pearson's r) with associated significance values ($P < 0.01$, $P < 0.05$ and non-significant values: n.s. and $P < 0.1$), for the periods of 42, 35, 28, 14, 7, 5, 3 and 1 day prior to the census day, for the Amsterdamse Waterleidingduinen (AWD), the Kop van Schouwen (KVS) and Klein Heidekamp (KHK), showing the correlation between bat numbers and: the mean temperature ($\bar{x}TG$); the number of frost days (nTN); the sum of negative temperatures (ΣTN); the total duration of precipitation (ΣRD), and; the total precipitation (ΣRH).

Period (in days) before census	42	35	28	21	14	7	5	3	1
AWD $\bar{x}TG$	$\bar{x}TG-42$	$\bar{x}TG-35$	$\bar{x}TG-28$	$\bar{x}TG-21$	$\bar{x}TG-14$	$\bar{x}TG-7$	$\bar{x}TG-5$	$\bar{x}TG-3$	$\bar{x}TG-1$
Pearson's r	-0.5	-0.47	-0.4	-0.3	-0.29	-0.17	-0.03	0.04	0.02
P -value	$P < 0.01$	$P < 0.05$	$P < 0.05$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
AWD nTN	$nTN-42$	$nTN-35$	$nTN-28$	$nTN-21$	$nTN-14$	$nTN-7$	$nTN-5$	$nTN-3$	$nTN-1$
Pearson's r	0.52	0.47	0.44	0.36	0.33	0.12	0.06	-0.03	-0.17
P -value	$P < 0.01$	$P < 0.05$	$P < 0.05$	$P < 0.1$	n.s.	n.s.	n.s.	n.s.	n.s.
AWD ΣTN	$\Sigma TN-42$	$\Sigma TN-35$	$\Sigma TN-28$	$\Sigma TN-21$	$\Sigma TN-14$	$\Sigma TN-7$	$\Sigma TN-5$	$\Sigma TN-3$	$\Sigma TN-1$
Pearson's r	0.39	0.34	0.29	0.2	0.24	0.13	-0.11	-0.11	0.02
P -value	$P < 0.05$	$P < 0.1$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
AWD ΣRD	$\Sigma RD-42$	$\Sigma RD-35$	$\Sigma RD-28$	$\Sigma RD-21$	$\Sigma RD-14$	$\Sigma RD-7$	$\Sigma RD-5$	$\Sigma RD-3$	$\Sigma RD-1$
Pearson's r	-0.21	-0.14	0.04	0.09	0.05	0.2	0.32	0.04	0.02
P -value	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
AWD ΣRV	$\Sigma RV-42$	$\Sigma RV-35$	$\Sigma RV-28$	$\Sigma RV-21$	$\Sigma RV-14$	$\Sigma RV-7$	$\Sigma RV-5$	$\Sigma RV-3$	$\Sigma RV-1$
Pearson's r	-0.12	-0.04	0.07	0.09	0.02	0.16	0.28	0.12	0.19
P -value	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
KVS $\bar{x}TG$	$\bar{x}TG-42$	$\bar{x}TG-35$	$\bar{x}TG-28$	$\bar{x}TG-21$	$\bar{x}TG-14$	$\bar{x}TG-7$	$\bar{x}TG-5$	$\bar{x}TG-3$	$\bar{x}TG-1$
Pearson's r	-0.76	-0.76	-0.76	-0.74	-0.73	-0.62	-0.53	-0.55	-0.49
P -value	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.1$
KVS nTN	$nTN-42$	$nTN-35$	$nTN-28$	$nTN-21$	$nTN-14$	$nTN-7$	$nTN-5$	$nTN-3$	$nTN-1$
Pearson's r	0.79	0.78	0.79	0.81	0.73	0.65	0.53	0.51	0.47
P -value	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.1$
KVS ΣTN	$\Sigma TN-42$	$\Sigma TN-35$	$\Sigma TN-28$	$\Sigma TN-21$	$\Sigma TN-14$	$\Sigma TN-7$	$\Sigma TN-5$	$\Sigma TN-3$	$\Sigma TN-1$
Pearson's r	0.67	0.67	0.68	0.7	0.68	0.57	0.47	0.48	0.44
P -value	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.05$	$P < 0.05$	$P < 0.05$
KVS ΣRD	$\Sigma RD-42$	$\Sigma RD-35$	$\Sigma RD-28$	$\Sigma RD-21$	$\Sigma RD-14$	$\Sigma RD-7$	$\Sigma RD-5$	$\Sigma RD-3$	$\Sigma RD-1$
Pearson's r	-0.01	-0.04	-0.21	-0.22	-0.06	-0.22	-0.13	-0.25	-0.23
P -value	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
KVS ΣRV	$\Sigma RV-42$	$\Sigma RV-35$	$\Sigma RV-28$	$\Sigma RV-21$	$\Sigma RV-14$	$\Sigma RV-7$	$\Sigma RV-5$	$\Sigma RV-3$	$\Sigma RV-1$
Pearson's r	-0.08	-0.14	-0.3	-0.19	-0.01	-0.11	0	-0.05	-0.08
P -value	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
KHK $\bar{x}TG$	$\bar{x}TG-42$	$\bar{x}TG-35$	$\bar{x}TG-28$	$\bar{x}TG-21$	$\bar{x}TG-14$	$\bar{x}TG-7$	$\bar{x}TG-5$	$\bar{x}TG-3$	$\bar{x}TG-1$
Pearson's r	-0.63	-0.64	-0.66	-0.66	-0.55	-0.17	-0.03	-0.02	0.03
P -value	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	n.s.	n.s.	n.s.	n.s.
KHK nTN	$nTN-42$	$nTN-35$	$nTN-28$	$nTN-21$	$nTN-14$	$nTN-7$	$nTN-5$	$nTN-3$	$nTN-1$
Pearson's r	0.53	0.5	0.54	0.53	0.5	0.08	-0.04	-0.09	-0.02
P -value	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$	n.s.	n.s.	n.s.	n.s.
KHK ΣTN	$\Sigma TN-42$	$\Sigma TN-35$	$\Sigma TN-28$	$\Sigma TN-21$	$\Sigma TN-14$	$\Sigma TN-7$	$\Sigma TN-5$	$\Sigma TN-3$	$\Sigma TN-1$
Pearson's r	0.74	0.75	0.41	0.79	0.63	0.04	0.05	0.12	0.04
P -value	$P < 0.01$	$P < 0.01$	$P < 0.05$	$P < 0.01$	$P < 0.01$	n.s.	n.s.	n.s.	n.s.

KHK ΣRD	ΣRD-42	ΣRD-35	ΣRD-28	ΣRD-21	ΣRD-14	ΣRD-7	ΣRD-5	ΣRD-3	ΣRD-1
Pearson's <i>r</i>	-0.33	-0.22	-0.28	-0.37	-0.37	-0.15	-0.14	-0.13	-0.12
<i>P</i> -value	n.s.	n.s.	n.s.	<i>P</i> <0.1	<i>P</i> <0.1	n.s.	n.s.	n.s.	n.s.
KHK ΣRV	ΣRV-42	ΣRV-35	ΣRV-28	ΣRV-21	ΣRV-14	ΣRV-7	ΣRV-5	ΣRV-3	ΣRV-1
Pearson's <i>r</i>	-0.3	-0.16	-0.25	-0.32	-0.34	-0.18	-0.13	-0.06	-0.11
<i>P</i> -value	n.s.	n.s.	n.s.	n.s.	<i>P</i> <0.1	n.s.	n.s.	n.s.	n.s.

42 days before the census date, the degree of coherence of precipitation for all the complexes varies from -0.01 to -0.33 ($P>0.1$).

Equally, no significant correlation was found in any of the complexes, for any period prior to the census day, between the amount of precipitation and the numbers of hibernating long-eared bats. Hardly any correlation was found between the amount of precipitation and the numbers of hibernating long-eared bats for the period 42 days before the census day: with the *r*-value varying from -0.08 ($P>0.1$) to -0.30 ($P>0.1$) (figure 4e, table 2). The difference between the complexes were greatest on the fifth day before the census ranging from almost -0.4 ($P>0.1$) to 0.3 ($P>0.1$), both values 'low to weak' or 'very low'.

Discussion

The Pearson correlation tests show a clear positive correlation between the number of frost days and a high cold count and the number of long-eared bats found in hibernacula. This is especially pronounced for the periods of 42 to 21 days prior to the count. This correlation was not significant in any of the complexes for shorter periods. Conversely, during the same periods, a negative association was found between mean outdoor temperatures and the numbers of counted long-eared bats.

No significant association between the duration or amount of precipitation and the numbers of hibernating long-eared bats was found. The difference between the outcome of the precipitation indices in this study and the relationship reported by Lichačev (1980) for the Moscow area may be explained by the stronger influence of the continental climate

in the Moscow area, almost certainly leading to early autumn periods of precipitation being accompanied by frosty days, when summer roosts are abandoned. In autumn (calculated from the beginning of October to the end of December), the period when long-eared bats leave their summer habitats for hibernacula, the mean temperature in the Netherlands appears to high enough to allow long-eared bats sufficient opportunity to continue to forage outside during periods of precipitation. This may explain why part of the long-eared bat population only moves to hibernacula at a later stage in the autumn or after the start of winter. In the absence of low temperatures in the winter period, part of the population may not even move to hibernacula at all.

The differences between the three complexes in the degree of correlation between the numbers of hibernating long-eared bats and the cold indices are probably due to differences in local conditions. The combination of mature trees in the Slotbos in Haamstede (with many potential colony trees for long-eared bats) in the immediate vicinity (<500 m) and the relatively isolated location of the Kop van Schouwen bunker complex (which, on the eastern side mainly consists of an agricultural landscape, without forests, and surrounded on the other sides by the salt waters of the North Sea, Grevelingen and the Oosterschelde) can explain the significant positive relationship that was found between cold weather variables and the numbers of hibernating long-eared bats for shorter periods than at the other sites. Under these circumstances, long-eared bats may respond more quickly to changing weather conditions, i.e. periods of frost, by moving to the bunkers. Less than 500 m from the bunker complex in the Amsterdamse

Waterleidingduinen, there are less bulky trees with hollows or fissures, while the inner dune forests (Leyduin, Vinkenduin and Woestduin) are more than 1.5 km away. The cellar complex at Klein Heidekamp is located in the middle of a forest that has recently emerged on a heathland and also there are few old trees with holes or cracks in the immediate vicinity. There are also extensive forested areas in the area, such as the Deelerwoud, about 1 km away.

Long-eared bats in the Netherlands do not always exclusively hibernate in underground winter roosts; Jansen & Buys (1997) also mention church towers as winter roost. The presence of tree holes in the neighbourhood may also provide important hibernacula for long-eared bats (Dietz et al. 2007). A series of incidental observations confirm that long-eared bats very occasionally reside in well-insulated tree holes in winter (Macdonald & Barrett 1993). Aulagnier et al. (2009) also mention tree holes as hibernacula in areas with a temperate climate. Mostert (1997) also established that some long-eared bats spend the winter in tree crevices in the Netherlands. There are also several observations from Belgium of long-eared bats occupying tree holes and cracks, in the winter period, even during light frosts and snow (personal communications, Bob Vandendriessche and Marc Van De Sijpe). It is not clear why part of a population of long-eared bats in the western part of the distribution area, such as the Netherlands and Belgium, tends to stay in tree cavities or bat boxes during the winter period, with the exception of severe frost periods. This might be related to obtaining a favourable position for swarming sessions in spring, an important swarming period for the species (Furmankiewicz & Altringham 2007). There are concrete indications that this subpopulation is mainly composed of males: for example, in the Kop van Noord-Holland, during the winters of 2006 to 2020, seven long-eared bats, including at least six males, were found in bat boxes, as long as it did not freeze severely for at least 14 days beforehand (personal communication, Jan Boshamer).

Horáček & Đulić (2004) mention rock crevices as places that are mainly occupied by male long-eared bats in autumn, as well as spring and that these can serve as potential mating sites. Slit-shaped roosts, such as cracks in trees, loose, protruding tree bark and perhaps also nest and bat boxes give long-eared bats direct contact with the outside world allowing them to react more swiftly to the first signs of spring.

How can these results be explained alongside the findings, outlined in the introduction, that over the winter period the number of long-eared bats in bat boxes decreases, although they remain almost permanently present? A possible explanation is that in the course of the weeks preceding the regular bat census, the majority of long-eared bats leave the bat boxes for regular hibernacula, but some remain in boxes and (tree) holes or cracks that offer relatively good temperature buffering. During periods of frost that last for a few days, when the maximum daytime temperature does not exceed 0° Celsius, these last long-eared bats also leave for the hibernacula. It is quite possible that the tree holes, cracks, bat boxes and possibly also church attics in the immediate vicinity of summer roosts continue to play a role in swarming sessions in the autumn period. In this context it is significant that long-eared bats are almost absent from swarming sessions at the entrances of hibernacula such as the marl quarries in Zuid-Limburg (van Schaik et al. 2015).

Other articles in this issue describe the positive correlation between the numbers of other species such as Daubenton's bats (*Myotis daubentonii*) and Natterer's (*M. nattereri*) found in hibernacula and low outside temperatures van Zuijlen & Groenendijk 2022, Verhees et al. 2022, both in this issue. Further research could help show how these other species relate to temperature (and precipitation) variables over different periods prior to the bat census.

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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

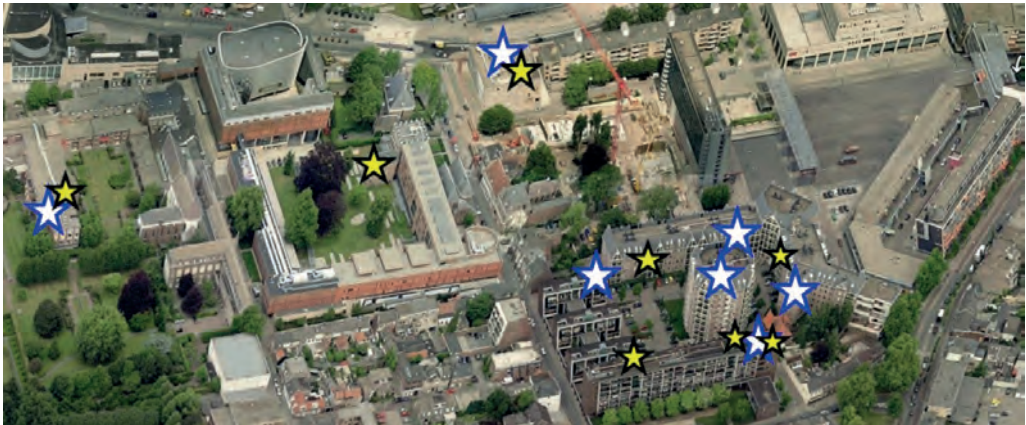


Figure 1. Overview of sites with repeated reports of bats (yellow stars: nuisance, invasions) and observed swarming sites (blue stars), an apartment block at Kloosterstraat (left), the former courthouse (upper-middle) and the Anna Paulownahof high rise buildings (lower right) in Tilburg. Photo: Creative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

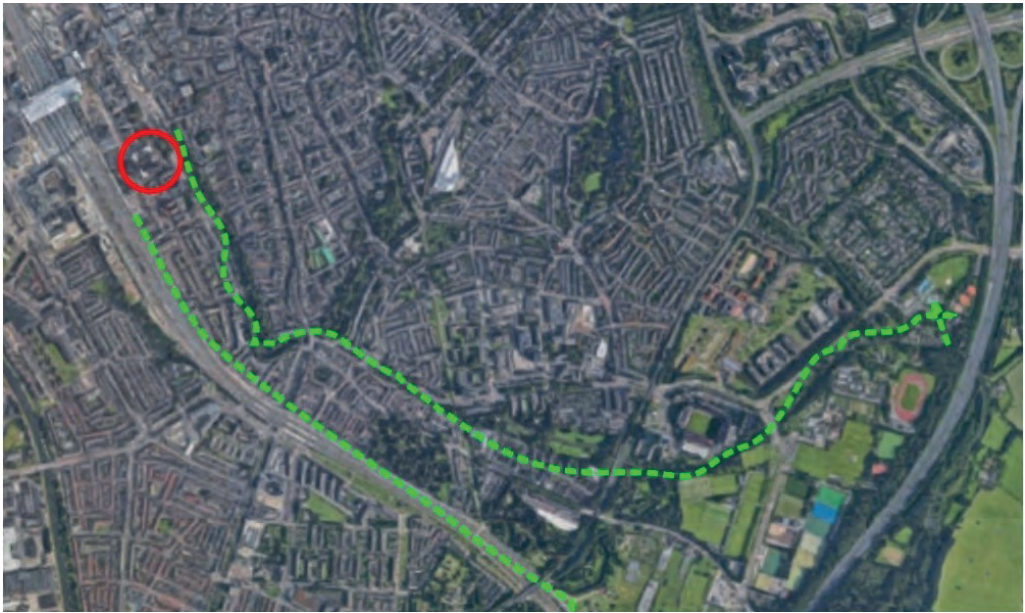


Figure 3. Potential flight pathways via canals, groves and a river, as well as along railway tracks to the 'Inktpot', a mass-hibernaculum in the city of Utrecht. *Photo: Creative Commons Google Maps.*

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

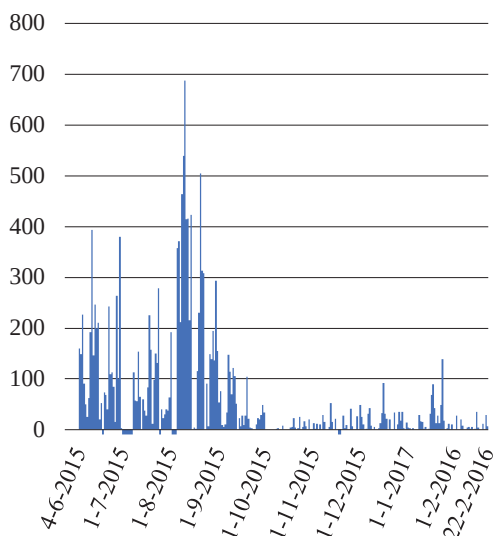


Figure 5. Number of recordings of common pipistrelles at a swarming site at the Tilburg Courthouse between 4 June 2015 and 22 February 2016. Negative values indicate occasions when the recording unit was not functioning.

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 – $+25^{\circ}\text{C}$, 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.

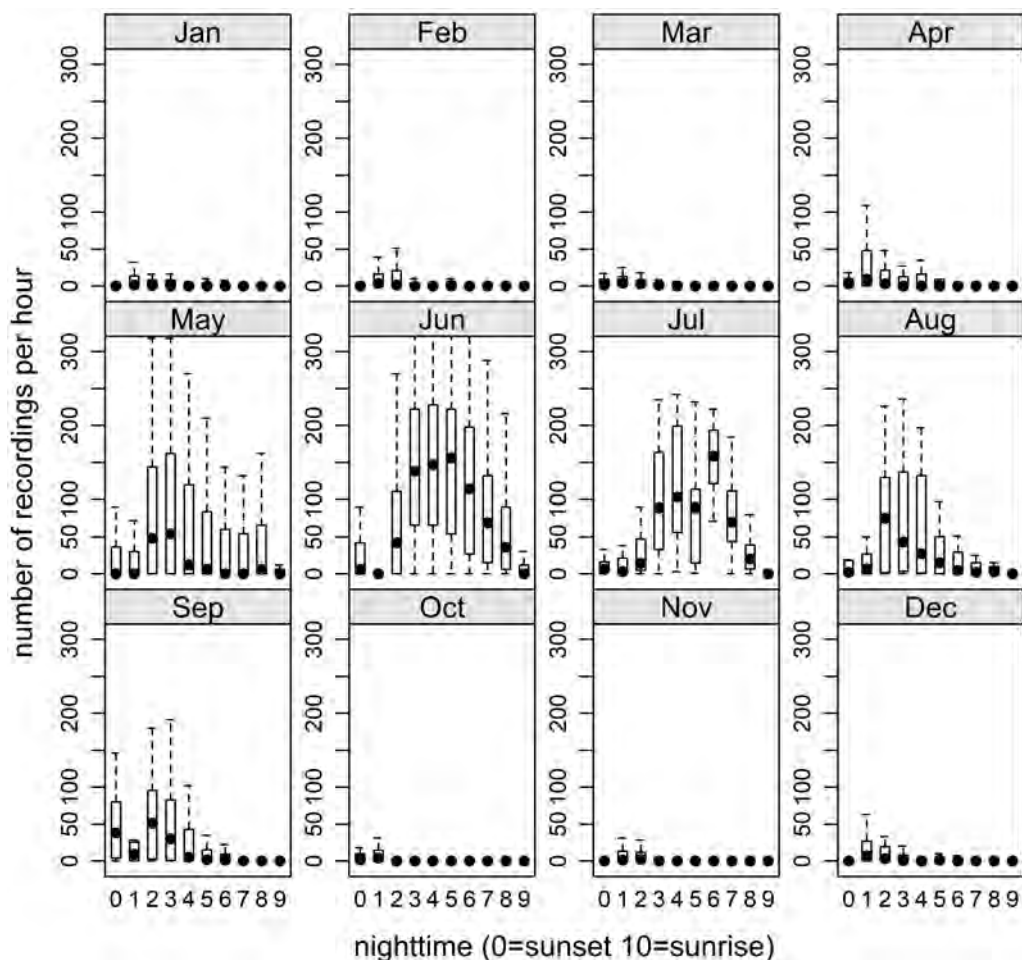


Figure 6. Seasonal differences in the acoustic activity patterns of common pipistrelles at the Tilburg Courthouse. The number of recordings per hour is given for standardized night time categories. The high numbers in May and June are the result of a summer roost of approx. 25 pipistrelles. Acoustic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

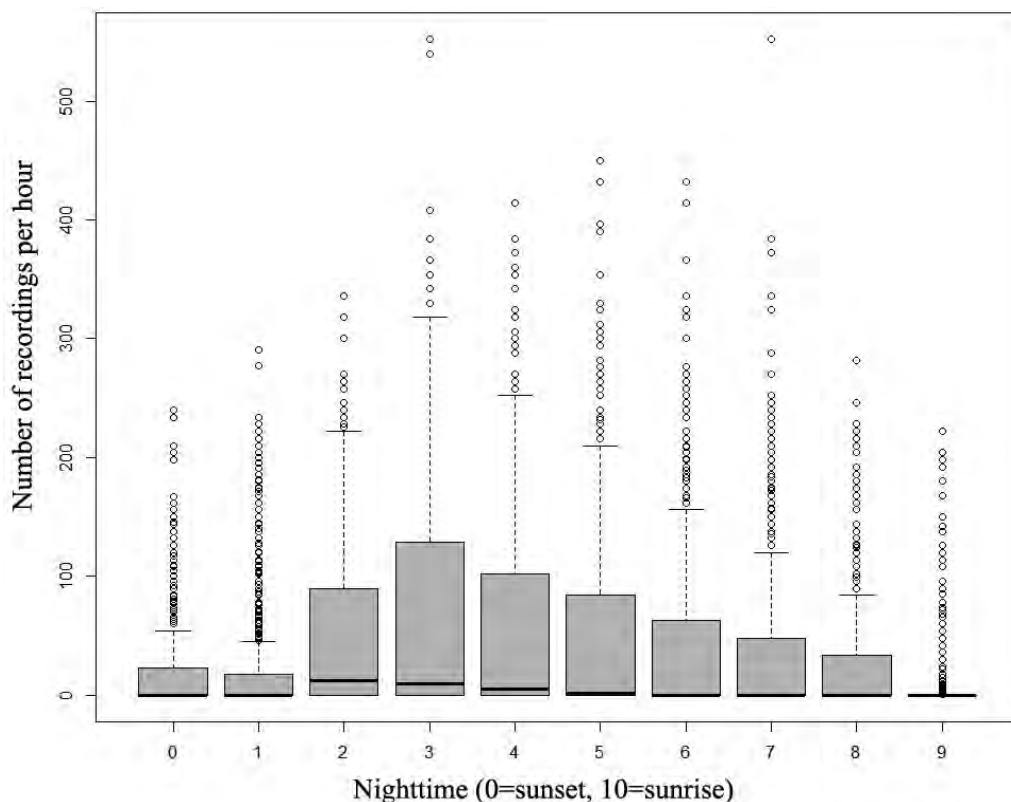


Figure 7. Acoustic activity of common pipistrelles, measured as the number of recordings per hour, in the course of the night. The boxplot with median presents the data, cumulated over August 2010, for the Tilburg Courthouse. 0 indicates sunset. Acoustic monitoring terminated at sunrise.

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.

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

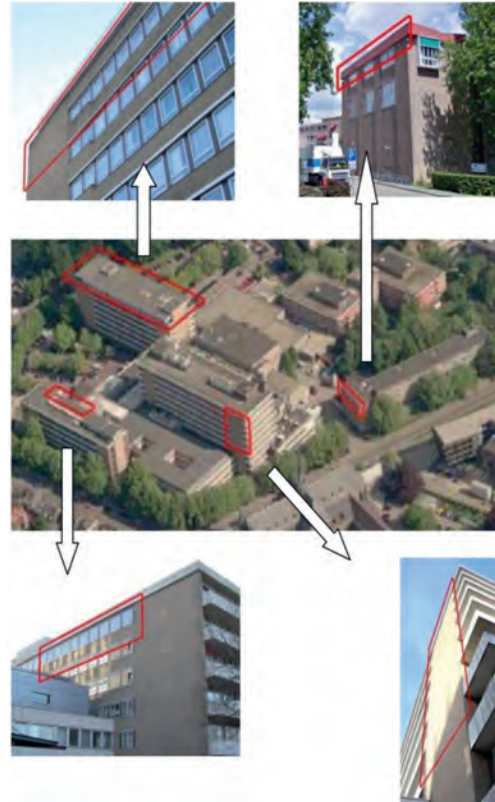


Figure 10. Micro-sites where autumnal midnight swarming was observed at a former hospital building in Weezenlanden.

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.

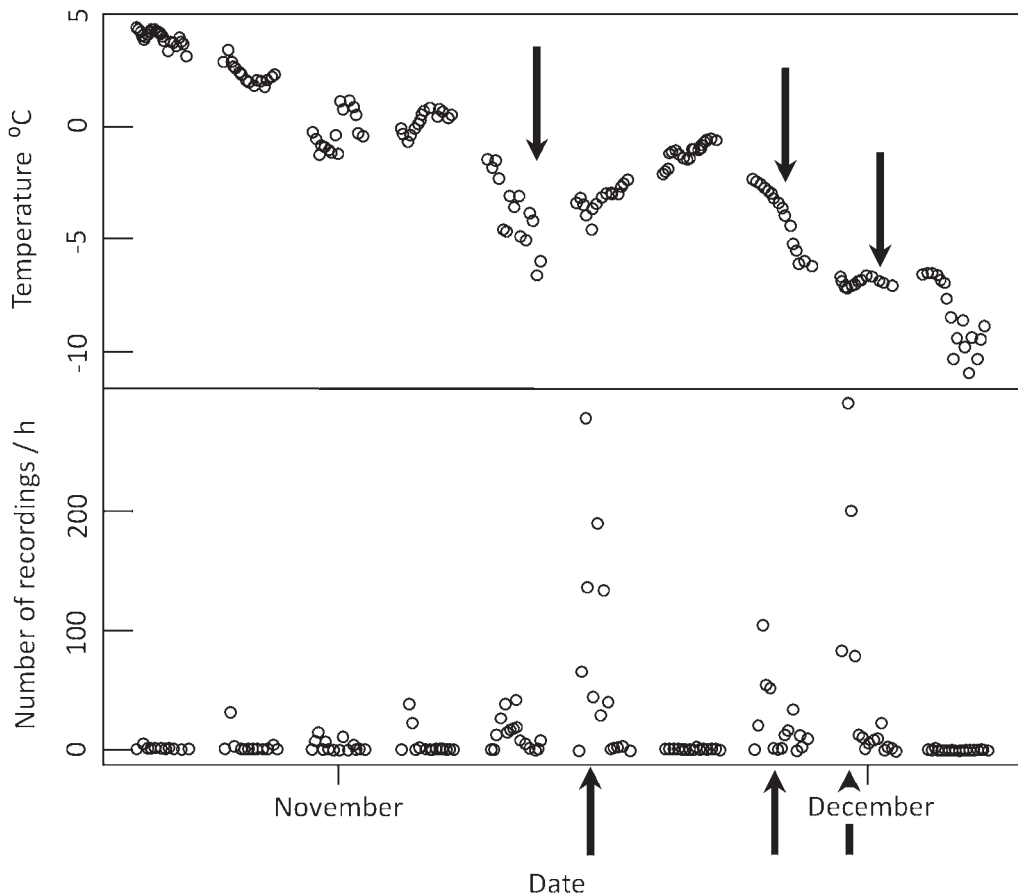


Figure 13. Number of recordings of common pipistrelles at the mass hibernaculum at the Courthouse in Tilburg (below), relative to outside temperature (data from the KNMI weather station at Gilze-Rijen) in the winter of 2010-2011. Arrows indicate the onset of cold spells, and peaks in activity.

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

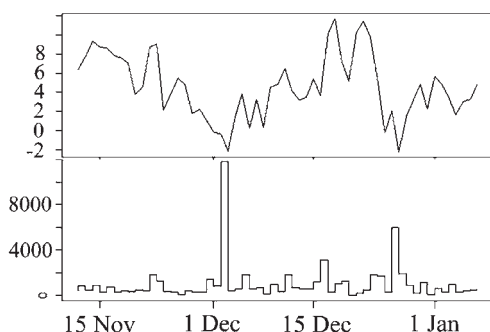


Figure 14. Temperature (KNMI weather station Heino / upper graph) and the number of recordings of common pipistrelles (lower graph) at the former Weezelanden Hospital in Zwolle in the winter of 2014-2015.

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.

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A bunker on Kop van Schouwen (prov. of Zeeland, the Netherlands) that was previously buried under sand. *Photo: Kees Mostert.*

A hibernating greater horseshoe bat (*Rhinolophus ferrumequinum*) in the mainland coastal dunes of Zuid-Holland

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In response to a number of reports of break ins at various places along the coast of Zuid-Holland, an enforcement check by Buitengewoon Opsporings Ambtenaar (BOA / community service officer) J.A. Dijkhuizen took place on 28 January 2021 in a small number of accessible bunkers in the Natura 2000 area Solleveld-Kapittelduinen, located between Den Haag and Hoek van Holland (province of Zuid-Holland). During this check, which was performed according to COVID-19 measures which were in place at the time, a free-hanging and notably unusual bat was found in the entrance area. Since the bunker was freely accessible and was in fact entered regularly by members of the general public, the help of a census coordinator (first author of this article) was called in. Once arrived on the spot, he determined the bat in question was a greater horseshoe bat (*Rhinolophus ferrumequinum*, figure 1). Since the entrance of the bunker, which had been broken open, was to be sealed off with brickwork that same afternoon on request of the BOA, the check needed to be done as soon as possible (flight entrances for bats were already present). To prevent vandalism or an onrush of interested public, and to prevent people from entering nearby bunkers which had been broken open as well, it was decided to keep quiet on the discovery for the time being.

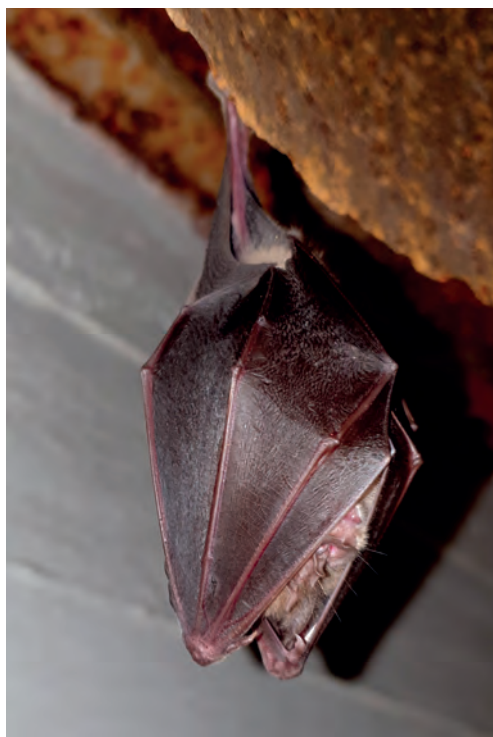


Figure 1. Greater horseshoe bat Natura 2000 area Solleveld-Kapittelduin, January 2021. Photo: Kees Mostert.

During the following yearly census on 18 December 2021, it was found that the bunker had been broken open once again. The greater horseshoe bat was not found again. After some enquiries, it transpired that the bunker had been broken open late spring 2021. Everything points to the bat having left the bunker under its own power.

The greater horseshoe bat is predominantly a Mediterranean species in Europe. The northern limit of its distribution has shifted ever further south during the second half of the twentieth century. In Germany, the species has practically disappeared (Dietz et al. 2011) and in southern England only a small population remains. In recent years a few were found in the border area of Flanders and Wallonia.

According to De Selys-Longchamps (1841) the species was commonly found in the Netherlands during the winter in the marl quarries near Maastricht. Between 1908 and 1935, only nine specimens were still found here. The species was found regularly during winter census in the quarries after 1937. The increase in observations was presumably related to the discovery in 1939 of a summer colony of 75-80 bats in the Caestertgroeve marl quarry, in the Belgian part of the Sint-Pietersberg. The maternity colony in the Caestertgroeve disappeared in the 1940 and the last summer observation there was made on 23 June 1951 (Thissen & van der Coelen 2016). The last winter mentions of hibernating animals in the Caestertgroeve date from the autumn of 1984 and the winter of 1986 (Vergoossen & van der Coelen 1986).

In the 1970-1974 period, a hibernating greater horseshoe bat was still found in the Riesenberggroeve quarry and in 1982 and 1984 another one was found in the Sint-Pietersberg. The use during the 1950s, 1960s and early 1970s of pesticides such as DDT, to which this particular bat species is very sensitive, and disturbance of winter and summer roosts are probably the causes of its disappearance. Remarkably, a solitary animal was found in the winter of 1992 and the four subsequent winters in Fort Rijnauwen near Utrecht (van Vliet & Mostert 1997).

Does this case of a hibernating greater horseshoe bat in the coastal area of Zuid-Holland stand on itself or is there more going on? In the winters of 2021 and 2022, the presence of a hibernating greater horseshoe

bat in the direct vicinity of the Caestertgroeve was established (Hans Weinreich, personal communication). Climate change may be playing a role here and as a consequence of it, the species may re-establish itself as a hibernating species in the Netherlands. Based on the historical distribution, the chances of this occurring are probably the greatest in the marl quarries of Zuid-Limburg.

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Abstract: In response to a number of reports of break ins, an enforcement check took place on 28 January 2021 in bunkers in Natura 2000 area Solleveld & Kapittelduinen. During this check, which was performed according to the COVID-19 measures which were in place at the time, a free-hanging greater horseshoe bat was discovered by coincidence in the entrance area. The entrance, which had been

broken open, was subsequently bricked up to prevent disturbance since flight entrances were already present elsewhere in the bunker. During the most recent census in December 2021, the animal was no longer found. Everything points to the animal having left the bunker on its own power. Apart from a solitary animal near

Utrecht during four winters in the 1990s, the species was last found in the Netherlands in 1986 in the Sint-Pietersberg in the province of Limburg.

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