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# Comparative effectiveness of acoustic devices for monitoring bat species: a case study of *Plecotus macrobullaris* in Thomatal

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**ABSTRACT**

The current study reports on the presence and activity of bats at the St. Georg Parish Church, Thomatal, Salzburg, Austria. This site was known in previous years to host a maternity roost of the alpine long-eared bat (*Plecotus macrobullaris*). Passive acoustic monitoring (PAM) and traditional roost emergence counting techniques were used to document bat activity. The study compared the effectiveness of three ultrasonic detection devices: Song Meter Mini Bat, Echo Meter Touch 2 Pro, and batcorder. Following expert verification, the study confirmed the presence and seasonal emergence phenology of *P. macrobullaris* and documented additional bat species including *Eptesicus nilssonii* and *Myotis daubentonii*. The results highlighted variations in the accuracy and species detection capabilities of the devices. While differences in device performance were clear, the findings emphasize the applicability of PAM for monitoring bat populations. Findings underscore the importance of proper device handling and appropriate data analytical techniques to ensure reliable species identification.

**KEYWORDS**

- bat
- passive acoustic monitoring
- *Plecotus macrobullaris*
- Thomatal
- ARU

***Vergleich der Effektivität akustischer Geräte zum Monitoring von Fledermausarten: Eine Fallstudie zu Plecotus macrobullaris in Thomatal***

***ZUSAMMENFASSUNG***

*Die vorliegende Studie berichtet über das Vorkommen und die Aktivität von Fledermäusen an der Pfarrkirche St. Georg in Thomatal, Salzburg, Österreich. Dieser Standort war in den vergangenen Jahren dafür bekannt, ein Wochenstubenquartier der Alpen-Langohrfledermaus (Plecotus macrobullaris) zu beherbergen. Passives akustisches Monitoring (PAM) und traditionelle Methoden der Zählung beim Quartierausflug wurden verwendet, um die Fledermausaktivität zu dokumentieren. Die Studie verglich die Effektivität von drei Ultraschalldetektoren: Song Meter Mini Bat, Echo Meter Touch 2 Pro und batcorder. Nach Verifizierung durch Expertinnen bestätigte die Studie die Präsenz und das saisonale Auftreten von P. macrobullaris und dokumentierte weitere Fledermausarten wie Eptesicus nilssonii und Myotis daubentonii. Die Ergebnisse zeigten Unterschiede in der Genauigkeit und Artbestimmung zwischen den Geräten. Während die Leistungsunterschiede der Geräte deutlich waren, betonen die Ergebnisse die Anwendbarkeit von PAM zur Überwachung von Fledermauspopulationen. Die Ergebnisse unterstreichen die Bedeutung einer fachgerechten Handhabung der Geräte und geeigneter Datenanalysetechniken, um eine zuverlässige Artbestimmung zu gewährleisten.*

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## INTRODUCTION

Passive acoustic monitoring (PAM) is an approach that utilizes autonomous recording units (ARUs) to record sounds in the environment [1]. PAM enables wildlife researchers to monitor animal species that produce sounds in the audible, ultrasonic, and infrasonic spectra without disturbing them. Recorded wavelengths of sound outside the range of human hearing are captured as electronic signals that can then be converted into forms audible to people. Despite the advantages, PAM is prone to potential sources of error including call misclassification. Misclassification may occur due to inadequate recording quality or incomplete call libraries that cannot differentiate calls among closely related species [2]. However, sound clips can be reanalyzed upon improvements to acoustic libraries or a reviewer's ability to validate them.

ARUs create original and permanent records of animal activity and offer several advantages over traditional monitoring of sound-producing animals. Their semi-permanent installation allows researchers to non-invasively document animal activities or rare species. ARUs enable long-term and continuous recording of soundscapes, including periods in which expert-based monitoring is difficult due to timing of animal activity [3]. Ultrasonic detectors are a class of ARUs configured to record frequencies that are produced by mammals such as bats and shrews, as well as certain insects [4, 5]. Most bat species use echolocation to survey their environment, for communication, and to locate prey. Most species are difficult to observe.

The alpine long-eared bat, *Plecotus macrobullaris* (syn. *P. alpinus* and *P. microdontus*), is a Eurasian species found in Southern Palearctic mountainous regions [6]. Although *P. macrobullaris* is listed on the European Red List as Near Threatened [7], in Switzerland the species is considered Endangered with unknown population trends [8]. In Europe, it is restricted to the Pyrenees, Alps, and Dinaric mountainous regions [9]. In parts of its distribution area the species is known to roost in rock crevices, and there the three main factors predicting roosting sites include close proximity to rocks (within 1 km), steep slope, and elevation above 1000 m (optimal elevation 1600 m) [10]. In flight, *P. macrobullaris* emits faint, brief, downward modulated frequency calls that feature sonic characteristics similar to the brown long-eared bat *P. auritus* and grey long-eared bat *P. austriacus* [11]. Morphologically, *P. macrobullaris* resembles an intermediate of *P. auritus* and *P. austriacus*. Physical characteristics of *P. macrobullaris* include the presence of white fur on its ventral side, its relatively large thumb, claw, and forearm [12], long ear covers, and a concave chin pad on the lower mandible [13, 14].

The St. Georg Parish Church is located at the base of Schwarzenberg Mountain in the community of Thomatal, within the Lungau region of the Salzburger Lungau and Kärntner Nockberge Biosphere Reserve. The Mires of the Schwarzenberg, a conservation area designated under the Ramsar Convention, includes 14 protected bogs near the mountain's summit [15]. In 1998 a population of *Plecotus* sp. was observed at the St. Georg Parish Church. During the early 2010s, A. Kiefer confirmed the species as *P. macrobullaris* on a morphological basis (M. Jerabek, pers. comm.).

This study served as a test of the ability of commercially available ARUs to detect bat activity at a known maternity roosting site of *P. macrobullaris*. Previous species inventories across Salzburg Province indicated that *P. macrobullaris* was restricted to the Lungau region, with only two summer roosting sites identified there [16]. The area surrounding St. Georg Parish Church in Thomatal - at an elevation of 1055 m - satisfies the main explanatory variables in species habitat models [10]: about 150m from a steep rocky slope of Mt. Schwarzenberg (summit elevation of 1779 m), indicating the suitability of the area for *P. macrobullaris* summer activity.

## METHODS

### Traditional methods

To compare different monitoring methods on detecting bat species at St. Georg Parish, traditional roost emergence counts were conducted in combination with ARU deployments. Voucher photographs were taken of bats roosting in the church attic as evidence of species occupancy at the maternity roost. As the composition of the diet of *P. macrobullaris* was investigated in a parallel study, clean sheets of paper were laid out along the attic floor once per month from May to September to collect bat fecal pellets directly below the roosting site. The final paper deployment was retrieved the night of October 7th. Roost emergence counts followed established protocols [17, 18] and occurred from the churchyard at twilight once per month from June to October, starting approximately at sunset and ending after a period of about 10 minutes of no flight activity following previous activity. A bat was counted using a hand-held click counter if it was observed to fly out of the bell tower into the landscape, but it was not counted if it flew immediately back into the bell tower. Additionally, bats entering the bell tower from the surrounding environment were not counted. Roost emergence counts lasted 30-45 minutes.

### Passive acoustic monitoring

Three types of ultrasonic sensor were used for comparison of their utility for PAM of bats (Table 1). While monitoring occurred from the period of May 6th 2022 – October 11th 2022, all devices were used together at St. Georg Parish Church on only one date, June 6th. Two ARUs are designed to record the soundscape for long periods of time (scale of days to weeks), while the third ARU is designed to be used for short, targeted periods (scale of minutes). The purpose of simultaneous device deployment was to gain perspective on the advantages and disadvantages provided by each ARU.

Song Meter Mini Bat (SMU, Wildlife Acoustics, Inc., Maynard, MA, USA) is a commercially available full-spectrum ARU that is designed to detect ultrasonic wavelengths up to 500kHz. When an incoming signal reaches the sensor, the device is activated and the signal is recorded. Song Meter devices are managed through the Song Meter Configurator (Version 3.0) smartphone app and can be programmed to be active at particular times of the day. A SMU was installed in the flight pathway of the alpine long-eared bats at the northeast corner of the churchyard on May 6th and was removed during the day on October 11th. It was set to record incoming ultrasonic signals each day from 30 minutes before sunset until 30 minutes after sunrise [19]. The acoustic settings were: sample rate of 256kHz, a gain of 12, and a trigger window of three seconds. Data were backed up onto a computer and batteries replaced every 3-4 weeks during the season, based on when data storage capacity was expected to be met or battery life was projected to expire, according to the configuration app.

Echo Meter Touch 2 Pro (EMT2P, Wildlife Acoustics, Inc., Maynard, MA, USA) is a small device that connects directly to a smartphone and transforms bat echolocation signals into frequencies that are audible to humans. It is controlled by the Echo Meter Touch Bat Detector (Version 2.8.11) app and automatically records incoming ultrasonic signals up to 384kHz. EMT2P suggests the most likely bat species in real time based on their calls. Data and suggested species identities are saved directly onto the smartphone. In this study EMT2P was connected to a smartphone on June 6th and September 5th. On both dates, the device was stationed about 10 m to the east of the exit flight path of the bell tower and about 5 m south of the SMU.

The batcorder (EcoObs GmbH, Nuremberg, Germany) is an ARU designed to record ultrasonic signals. This full-spectrum ARU is designed to detect ultrasonic wavelengths

up to 500kHz. When an incoming signal reaches the sensor, the device is activated and the signal is recorded. Data are saved onto a SDHC card and can be analyzed afterwards with the computer programs bcAdmin, bcIdent, and bcAnalyze. In this study the batcorder was installed 2-3 m above ground atop a pole for the observation periods with a sample rate of 500kHz and a gain of 16. Batcorders enable observation periods from several hours up to 10 days or more with the normal battery pack. Configured as a box-extension – in a robust plastic box, a 6V to 17V battery, solar panel and GSM module – it can work for several weeks and is limited by the SDHC card´s capacity. The aerial configuration of the batcorder reduces echoes, allowing for an expert to identify clearly recorded calls in a later step. In this study, the batcorder was stationed inside the churchyard about 2 m to the southwest of the SMU and was used on June 6th, July 3rd, August 8th, and October 7th.

### Data analysis

The call analyses for SMU and EMT2P were performed in a multi-step process. First, automatic species identification was recorded as assigned by Kaleidoscope Pro 5.6.8 software (Wildlife Acoustics, Inc., Maynard, MA, USA) (Table 1). To verify the automatic classification of the calls from Kaleidoscope, all detected bat calls were subjected to manual review by an expert in a following step [20–23]. This allowed assessment of the accuracy of the automatic species identification classifications. A minimum of three calls (N calls) is required for the identification of many bat species [22, 23]. Additionally, an arbitrary threshold of 75% identification probability, called Matching Rate, was applied to the manual analysis of SMU and EMT2P devices to increase the likelihood of accurately identifying the correct species.

The calls that were recorded using the batcorder were first analyzed by the automatic species identification software bcAdmin, bcIdent, and bcAnalyze. In a second step, the bat calls were manually checked by an expert from the Coordination Centre for Protection and Research of Bats in Austria, KFFÖ.

Tab. 1

| Feature | Song Meter Mini Bat | Echo Meter Touch 2 Pro Android | batcorder |
|---|---|---|---|
| **Version** | 1.0 | 1.0 | |
| **Firmware version** | 3.0 | App 2.8.11 | 3.1 |
| **Latitude, Longitude** | 47.072, 13.749 | 47.072, 13.750 | 47.072, 13.749 |
| **Make** | Wildlife Acoustics, Inc. | Wildlife Acoustics, Inc. | ecoObs GmbH |
| **Sample rate (Hz)** | 256000 | 256000 | 500000 |
| **Analytical software** | WA\|Kaleidoscope v. 5.4.6 | WA\|Kaleidoscope v. 5.4.6 | bcAdmin4 |
| **Classifier version** | Bats of Europe 5.4.0 | Bats of Europe 5.4.0 | bcAdmin4 |
| **Classifier settings** | min freq :8000, max freq:120000, min dur:0.002000, max dur:0.500000, cf min freq:0, cf max freq:0, cf max bw:0, min calls:2, enhance: on, sensitivity: balanced | min freq :8000, max freq:120000, min dur:0.002000, max dur:0.500000, cf min freq:0, cf max freq :0, cf max bw :0, min calls:2, enhance: on, sensitivity: balanced | Min freq:16000, max frq:150000 |
| **Audio settings** | Rate:256000, gain:12, trig window:3.0, trig max len :60.0, trig min freq:16000, trig max freq:128000, trig min dur:0.0000, trig max dur:0.0000 | Rate:256000Hz, gain:0.00, trig level:0.00, trig max len:0.00, trig window:0.00, trig min freq:0.00, trig max freq:0.00, prefix:null | Rate: 500000, gain:16, threshold:-36 dB, quality/ sensitivity:20, critical freq:14000, post trigger:800 ms |

**Table 1:** Settings and configuration of Song Meter Mini Bat, Echo Meter Touch 2 Pro and batcorder devices and analytical software

***Tabelle 1:*** *Einstellungen und Konfiguration der Geräte Song Meter Mini Bat, Echo Meter Touch 2 Pro und batcorder sowie der Analysesoftware*

## RESULTS

### Traditional methods

Visual confirmation of the roost of *P. macrobullaris* was based on morphological features of bats observed inside the church attic [13] during the first site visit on May 6th (Figure 1). No other bat species were observed in the church attic during the study. Most guano samples found in the roost were composed of small fecal pellets; however, on each survey date a specific location always contained fecal pellets of a larger size consistent with *Myotis myotis* [24]. When evaluated against a comparative collection, the small pellets were evidence of continuous occupation by *P. macrobullaris*, while the large pellets indicated the cohabitation of small numbers of *M. myotis*.

Fig. 1

**Figure 1:** Alpine long-eared bats on May 6th, 2022 in the St. Georg Parish Church, Thomatal, Lungau, Salzburg, Austria (source: © Wolfgang Forstmeier)

***Abbildung 1:*** *Alpen-Langohrfledermäuse im Wochenstubenquartier in der Pfarrkirche St. Georg, Thomatal, Lungau, Salzburg, Österreich am 6. Mai 2022 (Quelle: © Wolfgang Forstmeier)*

Roost emergence counts revealed that the seasonal flight activity at St. Georg Parish Church was dominated by a small- to medium-sized bat, with occasional sightings of larger individuals. Flight activity peaked in July and decreased each following month (Figure 2). Animals could not be visually confirmed to the species level during roost emergence

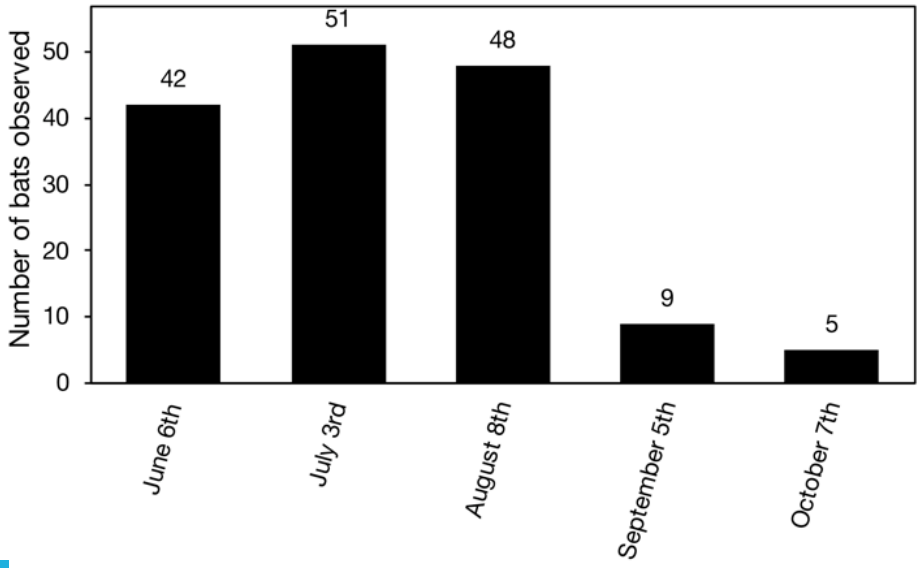


Fig. 2

**Figure 2:** Number of bats observed at the St. Georg Parish Church during monthly emergence counts in 2022

***Abbildung 2:*** *Anzahl von Alpen-Langohren, die 2022 bei den monatlichen Ausflugszählungen an der Pfarrkirche St. Georg beobachtet wurden*

counts, but animal sizes and habitus as well as the flight behavior were consistent with those expected of *P. macrobullaris* and *M. myotis*. Furthermore, the monthly collected guano samples were consistent with the presence of *P. macrobullaris* and *M. myotis*.

## PASSIVE ACOUSTIC MONITORING

The original intention of the study was to compare the performance of the three ARUs against each other on multiple dates from spring to fall. Due to equipment error and limited availability of trained volunteer personnel, data were obtained from all devices on one date, restricting our comparisons to this single event. Data from the three ARUs deployed on June 6th are shown below. In total, 136 recordings from the SMU, 53 recordings from the EMT2P, and 66 recordings from the batcorder were analyzed. These devices produced a total data volume of 603 MB.

### Song Meter Mini Bat

The SMU collected ultrasonic data from 20:48 to 23:58 CEST. After the manual reclassification of the 136 recordings, four bat species were identified: the northern bat (*Eptesicus nilssonii*), Daubenton's bat (*Myotis daubentonii*), common noctule (*Nyctalus noctula*), and common pipistrelle (*Pipistrellus pipistrellus*) (Figure 3). However, there were too few recordings of *N. noctula* to reliably confirm the presence of the species. Two non-specific genera (*Myotis* sp. and *Plecotus* sp.) and a species group (Nyctaloid [20]) were further classified. Given the historical presence of *P. macrobullaris* at the St. Georg Parish Church and the visual confirmation of the species at the beginning of the monitoring period, recordings of *Plecotus* sp. were assigned to *P. macrobullaris.* Ten recordings contained only 'noise' (artificial or natural noises but no bat calls), and for 27 recordings no further identification of the bat calls was possible.

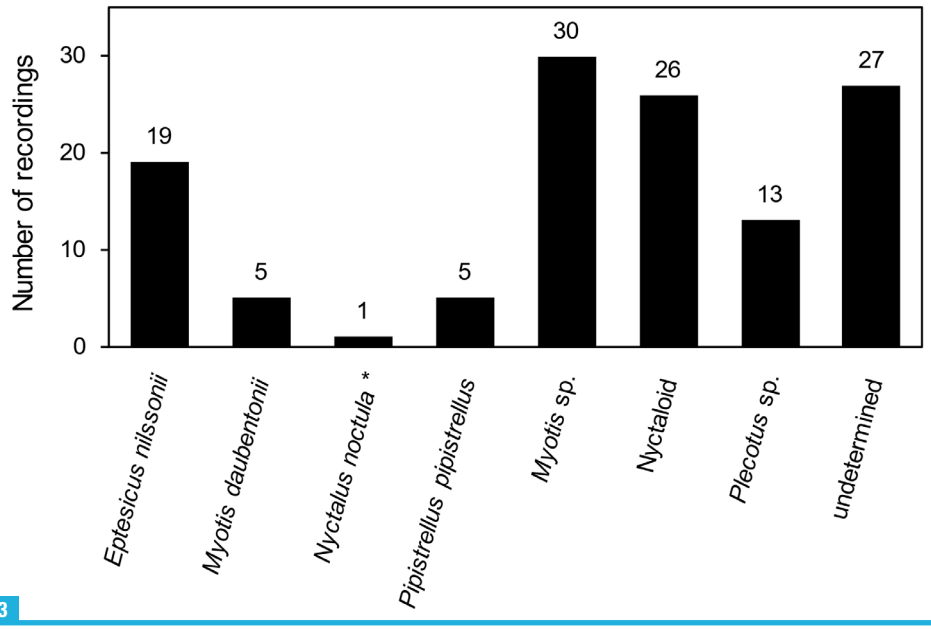


Fig. 3

**Figure 3:** Number of recordings with Song Meter Mini Bat on June 6th, 2022, in Thomatal, after verification (*uncertain species identification due to too few recordings)

***Abbildung 3:*** *Anzahl von Aufnahmen mit Song Meter Mini Bat am 6. Juni 2022, in Thomatal, nach Verifizierung (*unsichere Artbestimmung wegen zu wenigen Aufnahmen)*

Of the 136 recordings, 25% were correctly classified by the automatic classifier in Kaleidoscope (Table 1, Figure 4). When only recordings with a classification probability of ≥ 0.75 and a minimum number of three calls were considered [20], the proportion of correctly classified recordings was increased to 66%, and the same four bat species as identified through expert review remained (Figure 5).

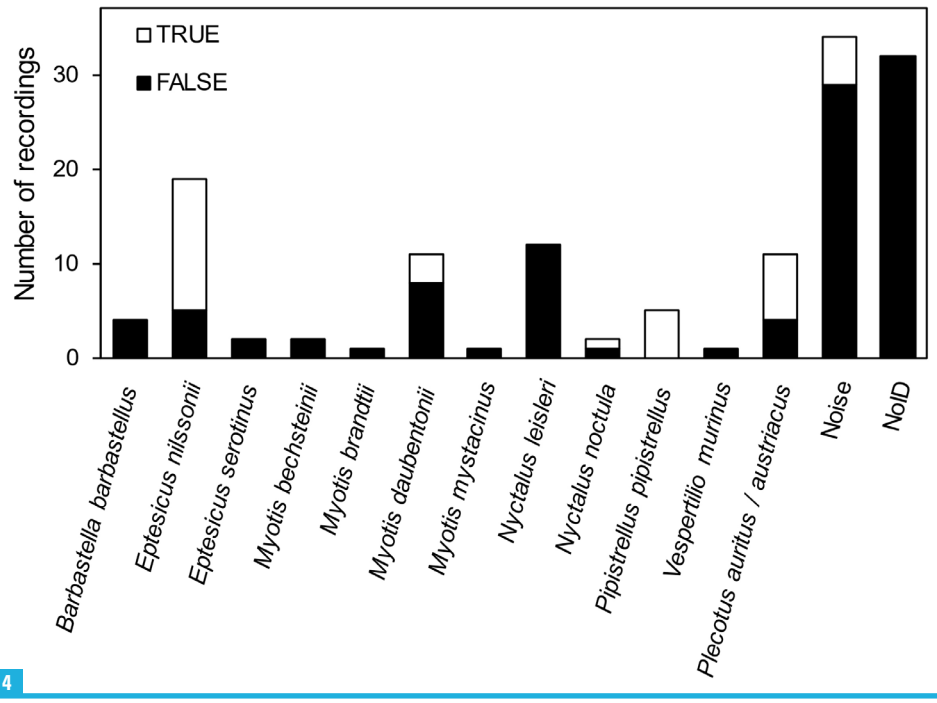


Fig. 4

**Figure 4:**
Number of Song Meter Mini Bat recordings correctly identified by the automatic classification in Kaleidoscope

***Abbildung 4:***
*Anzahl von Song Meter Mini Bat Aufnahmen, die durch die automatische Klassifikation von Kaleidoscope korrekt identifiziert wurden*

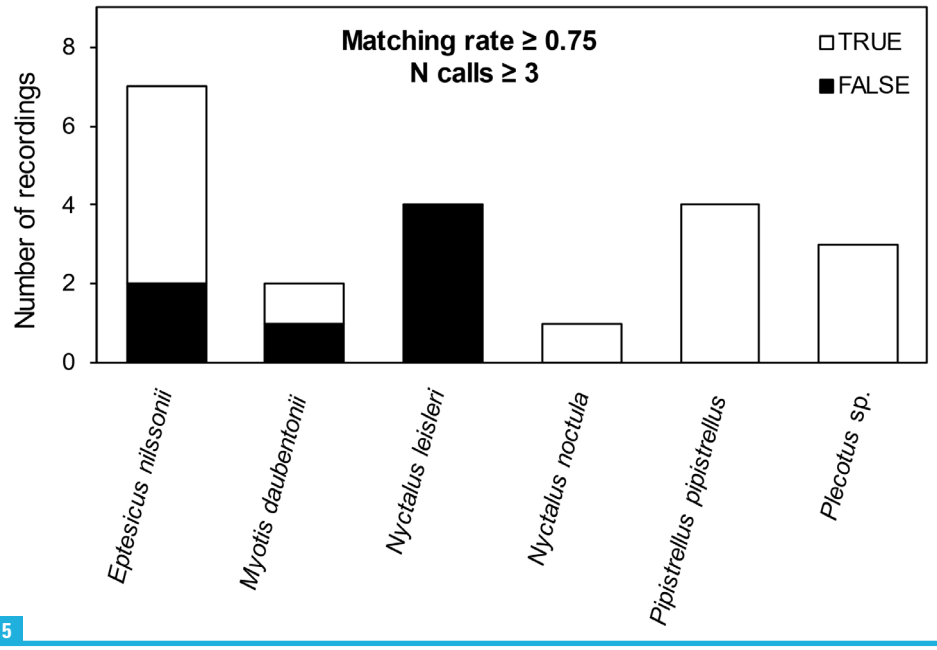


Fig. 5

**Figure 5:**
Number of Song Meter Mini Bat recordings correctly identified by the automatic classification in Kaleidoscope, filtered by identification probability (Matching Rate) and minimum number of call sequences (N calls)

***Abbildung 5:***
*Anzahl von Song Meter Mini Bat Aufnahmen, die durch die automatische Klassifikation von Kaleidoscope korrekt identifiziert wurden, gefiltert nach Identifikationswahrscheinlichkeit (Matching Rate) und Mindestanzahl von Rufsequenzen (N calls)*

Tab. 2

| Species | **Common name** | **SMU** | **EMT2P** | **batcorder** |
|---|---|---|---|---|
| *Eptesicus nilssonii* | northern bat | 19 | 1 | 1 |
| *Myotis daubentonii* | Daubenton's bat | 5 | - | - |
| *Nyctalus noctula** | common noctule | 1 | - | - |
| Pipistrellus pipistrellus | common pipistrelle | 5 | - | - |
| *Myotis* sp. | mouse-eared bat | 30 | 1 | 27 |
| Nyctaloid | | 26 | 2 | 5 |
| *Plecotus* sp. | long-eared bat | 13 | 8 | 30 |
| undetermined | | 27 | 4 | 3 |
| | Total | 126 | 16 | 66 |

**Table 2:**
Number of recordings per bat species and method (* uncertain species identification due to too few recordings)

***Tabelle 2:***
*Anzahl von Aufnahmen pro Fledermausart und Methode (*unsichere Artbestimmung aufgrund zu wenigen Aufnahmen)*

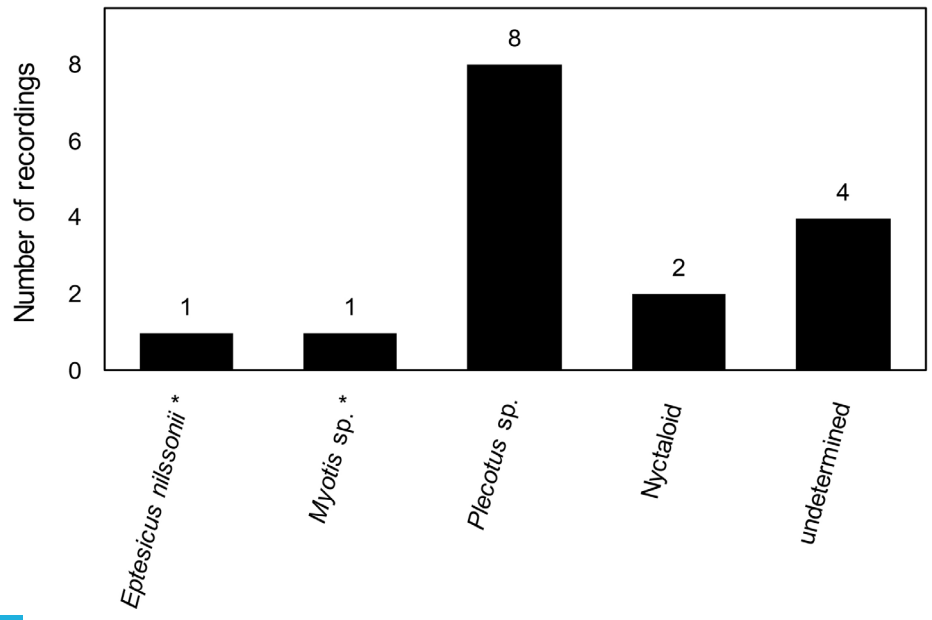


Fig. 6

**Figure 6:**
Number of recordings with the Echo Meter Touch 2 Pro on June 6th, 2022, in Thomatal, after verification (*uncertain species identification due to too few recordings)

***Abbildung 6:***
*Anzahl von Aufnahmen mit Echo Meter Touch 2 Pro am 6. Juni 2022 in Thomatal, nach Verifizierung (*unsichere Artbestimmung wegen zu wenigen Aufnahmen)*

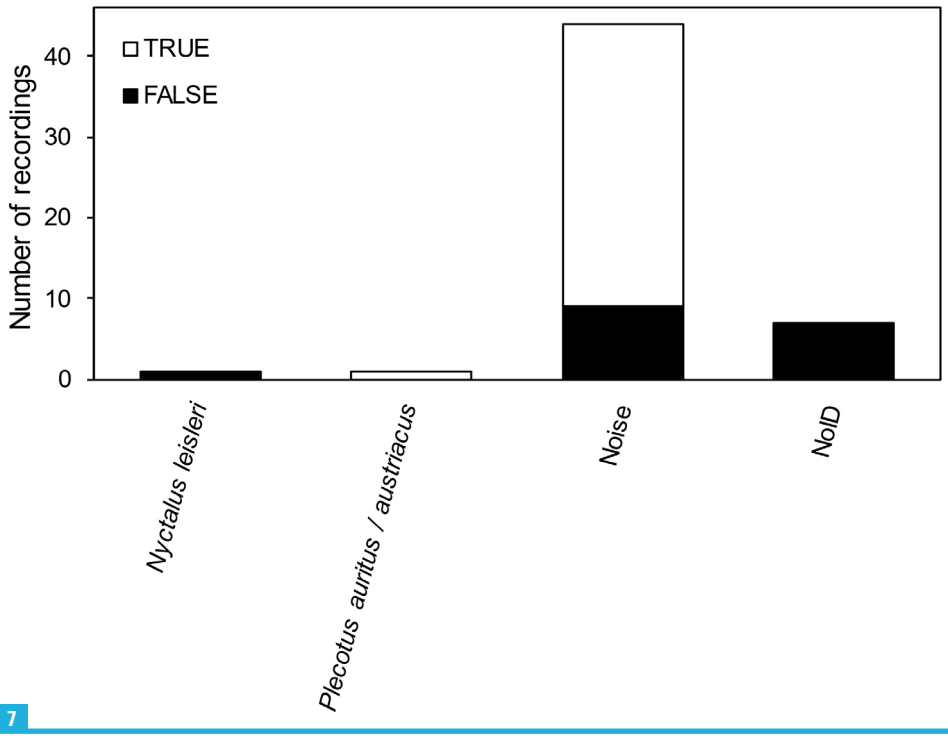


Fig. 7

**Figure 7:**
Number of Echo Meter Touch 2 Pro recordings correctly identified by the automatic classification in Kaleidoscope

***Abbildung 7:***
*Anzahl von Echo Meter Touch 2 Pro Aufnahmen, die in Kaleidoscope durch die automatische Klassifikation korrekt identifiziert wurden*

## Echo Meter Touch 2 Pro

The EMT2P was deployed between 21:26 and 21:49 CEST on June 6th, 2022. The automatic classification of the device identified 44 noise recordings, seven recordings with unclassifiable bat calls, and one classification of each of two species. During the manual review, 16 recordings with bat calls from at least four bat species were identified. Two recordings could be assigned to the Nyctaloid species complex but were not identifiable in finer resolution. Eight recordings indicated presence of *P. auritus / P. austriacus*, and one recording showed the presence of *E. nilssonii* (Figure 6). One recording showed calls from an unclassifiable *Myotis* sp. However, a single recording is generally not sufficient for a reliable species identification [20]. Overall, 32% of the automatic classifications were correctly assigned (Figure 7), and only *Plecotus* sp. bat calls could be detected with an identification probability ≥ 0.75.

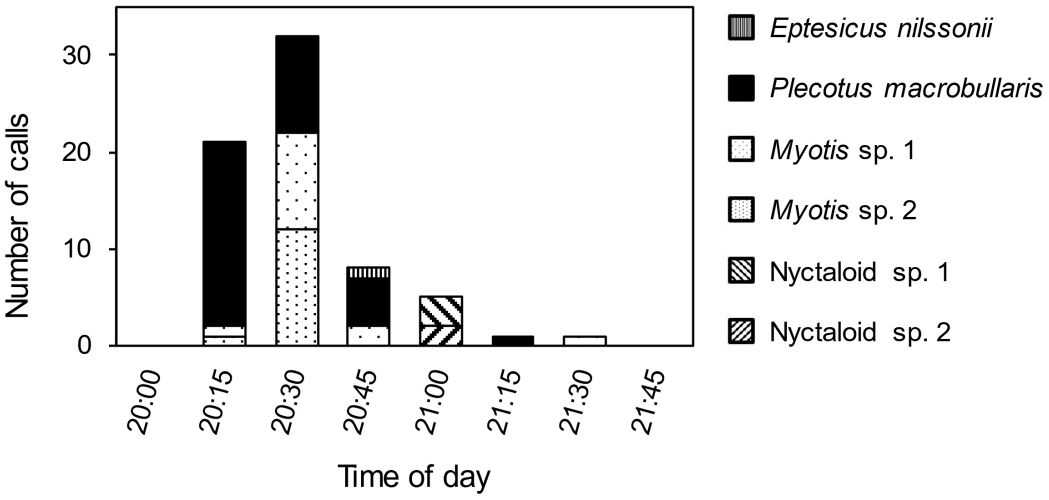


Fig. 8

**Figure 8:** Occurrence of bat calls at St. Georg Parish Church on June 6th 2022, as recorded by the batcorder

***Abbildung 8:*** *Vorkommen von Fledermausrufen an der Pfarrkirche St. Georg am 6. Juni 2022, aufgezeichnet mit batcorder*

### Batcorder

The batcorder was programmed to work on June 6th, 2022 from 20:00 CEST onwards. The first bat calls were registered at 20:43, the last bat calls were recorded at 21:15, and then the batcorder was deactivated manually upon leaving the churchyard. Out of 68 sequences detected by the batcorder, 66 sequences could be determined as bat calls, and the dominant species in the soundscape was recorded as *Plecotus* sp. The automated species detection of the bc suite of analytical tools identified 12 out of the 30 *Plecotus* calls, and 12 additional call sequences had an indication of *Plecotus* in the details of the call identification (without assigning them to *Plecotus*). The rest of the calls could be identified manually. Additionally, *Myotis* sp. emitted calls. Classifications for *E. nilssonii* and the Nyctaloid species complex appeared in the data from June 6th (Figure 8).

## SUMMARY

Overall, at least five bat species could be detected during the study period (Table 2). After the manual reclassification and verification provided by the two experts, two species could be identified with the recordings of the batcorder, one species with EMT2P, and four species with SMU. Where fewer than 3 recordings can be assigned to a species, these classifications should be considered uncertain. However, the recordings from the Nyctaloid group clearly indicate activity of at least one more species in addition to *E. nilsonii*. The Nyctaloid species group also includes the Leisler's bat (*Nyctalus leisleri*), the parti-colored bat (*Vespertilio murinus*), and the serotine bat (*Eptesicus serotinus*).

## DISCUSSION

Due to differential behaviors and call signatures of bat species, scientists have long recognized the necessity to combine multiple sampling techniques to determine the full range of community diversity [25]. The primary target species of the study, *P. macrobullaris*, was visually identified in a maternity roost by experienced chiropterists. However, it is currently missing in the Kaleidoscope automatic classification species list. With Kaleidoscope, the automatic classification software attributed calls of *Plecotus* sp. to either *P. auritus* or *P. austriacus* during the classification process (Figure 4, Figure 7). Classifications from analysis of batcorder data did not differentiate calls of *Plecotus* sp. This output is in agreement with previous findings on structural similarities of *Plecotus* sp. calls [11]. Our archived recordings were made in close proximity to the confirmed

roost of *P. macrobullaris* and serve as permanent voucher records of activity of the species. This study provides guidance into further research on PAM of *P. macrobullaris*, serving as a basis of knowledge on the suitability of three different acoustic devices, their effectiveness and limitations in identifying not only *P. macrobullaris*, but also other bats of Central Europe and the Alpine region, including *M. myotis*, *M. daubentonii*, and representatives of the Nyctaloid species group. The research demonstrated advantages of ARU deployment compared to traditional methods, while also showing the importance of the correct use of devices and appropriate data storage.

In comparing the methods, differences in quality and quantity are evident and depend primarily on how the device is handled. The batcorder was used by a professional chiropterist with considerable experience on handling the device, as well as the automatic and the subsequent manual verification processes. Many *Plecotus* sp. recordings may have been missed by the automatic detection due to very quiet calls [11]. In contrast, some difficulties occurred while handling the SMU and EMT2P for the first time. The batteries of the SMU were not replaced frequently enough, resulting in interruptions to continuous data recording. SMU and batcorders save sound files directly onto SD cards, and data from the cards can be quickly uploaded onto a computer for further analysis. The EMT2P device was used only twice, as the smartphone required for its operation was damaged and some data were lost before uploading. The loss of data highlights not only the importance of timely data transfer, but also the greater convenience of SD card storage for data management. The automatic classification capabilities of SMU and EMT2P, while useful for a first assessment, had a high rate of misclassification (Figure 4, Figure 7). Kaleidoscope produced a high rate of 'NoID' and 'Noise', which if troubleshooting its sensitivity settings to 'more sensitive' should result in greater percentage of correct identifications [26]. ARUs and identification software are prone to type I error (false positives) or type II error (false negatives) because they are susceptible to interferences caused by nearby reflective surfaces such as water or vegetation. But even poor-performing classifiers may provide important information for monitoring purposes [26, 27]. Kaleidoscope and bcAdmin can process a large amount of data, but manual verification by an expert is still mandatory, particularly when dealing with species that have similar call signatures or are not represented in the underlying automatic identification algorithm [2]. This underscores the importance of expertise both in deploying acoustic devices and the subsequent analysis of recorded data. *Plecotus macrobullaris* is not yet included in the species list of the automated classification of Kaleidoscope or the bc analytical suite of tools for batcorder analysis. However, in our study, since the recordings were made in close proximity to the known roost of *P. macrobullaris*, it can be assumed that the recorded *Plecotus* sp. call sequences belong to this species.

The EMT2P was used for a shorter period than the SMU and batcorder. Its short deployment time and limited ability to accurately classify bat species highlight the role of the EMT2P as a supplementary tool rather than a primary method for comprehensive species inventories. The SMU recorded the presence of *P. pipistrellus* and *N. noctula* outside the operating period of the EMT2P and the batcorder. The multi-day to month deployment capacity of SMU and batcorder is a chief advantage because a fuller picture of the bat community can be illustrated, including migratory species. During the parallel deployment of the three devices, only *M. daubentonii* could be identified to the species level by the SMU, while the other acoustic devices identified *Myotis* sp. at the genus level, and the batcorder identified Mkm ("Myotis klein-mittel") as a *Myotis* species group.

One of the study's noteworthy findings is the confirmation that *P. macrobullaris* maintained a maternity roost at the site of St. Georg Parish Church in 2022, confirming the area's

suitability for the species. Greater monitoring efforts should be invested to characterize the diversified bat community in the Thomatal region, as suggested by the potential presence of other species including *E. nilssonii* and *M. daubentonii*. Particularly given the singular identification event for *N. noctula*, additional surveys would be required to confirm the presence of this species. Considering the poor resolution of sound profiles produced by species in genus *Plecotus*, a legacy of this study is the initiation of a sound library containing examples of *P. macrobullaris*. This sound library can be resampled following future improvements to sound classification algorithms and can potentially be scanned for other species of interest, such as bush crickets [28].

In conclusion, while PAM has proven to be an effective method for studying bat populations, the choice of device, approach toward data management, and the experience level of the operator are critical factors that influence the quality of the data collected. The batcorder is a highly efficient tool designed for experts with advanced skills in device operation and bat identification. For a cost-effective alternative, the SMU is a solid choice for monitoring bats; however, it still requires substantial expertise to use effectively, particularly for validation. Meanwhile, the EMT2P is particularly well-suited for citizen scientists and enthusiasts seeking to deepen their understanding of bats, but bears risks associated with storage of the data on a hand-held device. The study also highlights the need for continued refinement of automated classification algorithms to reduce the reliance on manual verification, which is time-consuming and requires specialized expertise.

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