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Comparative analysis of five passive ultrasonic recorders for bat detection

Biodiv-Wind

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SUMMARY

Résumé

Le fonctionnement des éoliennes industrielles de production électrique peut occasionner une mortalité significative de chiroptères. Ce phénomène est aujourd'hui largement documenté à travers le monde (Hein & Schirmacher, 2016 ; Marx, 2017 ; Rydell *et al.*, 2010 ; Zimmerling & Francis, 2016). Une mesure très répandue de réduction de ces mortalités consiste à étudier localement l'activité des chiroptères afin d'élaborer des modèles prédictifs de cette activité en fonction de variables environnementales, le plus souvent temporelles (saison, heures de la nuit…) et météorologiques (vitesse du vent, température extérieure…). Lorsque les conditions environnementales sont favorables à l'activité des chiroptères, les éoliennes sont alors mises préventivement à l'arrêt.

L'analyse de l'activité des chiroptères s'appuie aujourd'hui très majoritairement sur des dispositifs électroniques et informatiques de détection automatique des ultra-sons, d'enregistrement et parfois d'identification des espèces, en temps réel ou a posteriori (Barataud, 2015).

La robustesse d'un modèle prédictif repose donc en premier lieu sur la qualité des données d'activité et dès lors sur les performances des dispositifs de détection, d'enregistrement et d'identification. Pour autant, comme l'indique T. Disca (Fondation Biotope, 2023), très peu de travaux comparatifs de la performance des dispositifs commercialisés ont été mis en œuvre.

Considérant l'importance de ce sujet, tant pour la protection efficace des chiroptères qu'au regard des impacts économiques pour les exploitants éoliens (coût des études, perte de productible), nous avons souhaité reproduire l'analyse comparative menée par T. Disca en 2023. Pour ce faire, nous avons repris les mêmes équipements, avons utilisé les mêmes paramétrages et avons répliqué son protocole de test, en y ajoutant un équipement plus récent et non testé par Disca (2023), le *Smart System* de Wildlife Acoustics.

Nos résultats sont très proches de ceux obtenus par Disca (2023) et montrent des écarts de performance significatifs entre les différents systèmes testés. Toutefois, les disparités entre les dispositifs ne semblent pas affecter les conclusions des modèles prédictifs. En effet, quels que soient les dispositifs utilisés, tous les modèles prédictifs ont indiqué qu'un bridage éolien à des températures situées entre 9°C et 16°C permettrait de couvrir 90% de l'activité des chiroptères, activité mesurée en nombre de fichiers de détection. Ces 90% d'activité peuvent aussi être

couverts en utilisant le taux d'humidité relative (90% des contacts entre 55% et 85% d'humidité). Ces conclusions ne peuvent cependant être généralisées du fait des conditions de notre étude : sur le mois de mars uniquement et avec une surreprésentation de *Miniopterus schreiberi* (60% des contacts). Une limite similaire existait cependant déjà dans l'étude de Disca, avec une surreprésentation de *Nyctalus leisleri*.

Si les dispositifs technologiques de détection acoustique des chauves-souris sont devenus incontournables pour l'étude de ces espèces, il apparaît cependant surprenant que l'étude comparative des performances de ces dispositifs ait suscité aussi peu d'intérêt. Cela contraste avec, par exemple, les démarches actuellement engagées pour normaliser l'évaluation de la performance des dispositifs de détection des oiseaux diurnes. In fine, cela interroge sur l'efficience des mesures de bridage préventif et sur l'homogénéité des contraintes d'exploitation imposées aux parcs éoliens. A tout le moins, il semble indispensable que les études chiroptérologiques mobilisant ces moyens de détection automatique précisent systématiquement les matériels utilisés et les paramétrages retenus. Dans le cas contraire, la pertinence des modèles prédictifs peut être questionnée.

Abstract

Industrial wind turbines for electricity production can cause a significative number of bat mortality. This phenomena has been widely studied around the world (Hein & Schirmacher, 2016 ; Marx, 2017 ; Rydell *et al.*, 2010 ; Zimmerling & Francis, 2016). A very widespread measure to reduce this mortality is to study the local activity of bats to develop predictive models of this activity depending on environmental variables, most often temporal (seasons, hours during the night...) and meteorologic (wind speed, outside temperature...). When environmental conditions are favorable to bat activity, wind turbines are preventively shut down.

Today, the analysis of bat activity is mainly based on electronic and computer devices for automatic ultrasound detection, recording and identification in real time or a posteriori (Barataud, 2015).

Thus, the strength of a predictive model is first based on the quality of the activity data, and therefore on the detection, recording and identification performances of the devices. However, as T. Disca (Biotope Foundation, 2023) points out, very little comparative research has been conducted on the performance of marketed devices.

Considering the importance of this subject for both bat conservation and the economic impact on wind farm operators (study costs, loss of production), we wanted to reproduce the comparative analysis conducted by T. Disca in 2023. To do this, we used the same equipment, the same settings and we reproduced its test protocol, while also incorporating more recent equipment that was not tested by Disca (2023), the *Smart System* from Wildlife Acoustics.

Our results are very close to those obtained by Disca (2023) and show that the performance differs significantly between the tested devices. However, these disparities do not seem to affect the conclusions of the predictive models. Indeed, all predictive models indicate that a curtailment when the temperature is between 9°C and 16°C would cover 90% of bat activity, which is measured in number of bat recordings. These 90% of bat activity can also be covered by the humidity level (90% of bat recordings between 55% and 85% humidity). These conclusions must be qualified by the fact that bat activity was measured in March, with an overrepresentation of *Miniopterus schreiberi* (60% of the bat recordings). A similar limit was already present in Disca's study with an overrepresentation of *Nyctalus leisleri.*

Although technological devices for the acoustic detection of bats have become essential for the study of these species, it is surprising that the comparative study of the performance of these devices has attracted so little interest. This contrasts with, for example, the current measures being taken to standardize the evaluation of the performance of detection devices for the diurnal birds. This, ultimately, raises questions about the effectiveness of preventive curtailment measures and the homogeneity of the constraints imposed on wind farms. It seems essential that chiropterological studies using automatic detection systematically specify the equipment and the settings used. Otherwise, the relevance of predictive models, can be questioned.

Introduction

There are 36 species of bat in mainland France, each with its own specificities in terms of diet, habitat and life cycle (SFEPM, 2024). As populations appear to have sharply declined since the 1950s-1960s, several national (Plan National d'Actions pour les Chiroptère de France; Ministère de la Transition Écologique et Solidaire; 2016) and international (EUROBATS; Rodrigues et al. 2008) action plans have been drawn up to limit the anthropogenic impact on these species.

Electricity-generating wind farms are among the human activities with a measurable and potentially significant impact on bats (Hein & Schirmacher, 2016; Marx, 2017; Rydell et al., 2010; Zimmerling & Francis, 2016). There is therefore a contradiction between the development of renewable wind energy and the conservation of protected species such as chiropterans.

The documented impact of wind turbines includes the risk of collision mortality on the blades, the risk of barotrauma mortality (although the latter is still debated) (Lawson et al., 2020) and the disturbance of bat habitats (Rodrigues et al. 2008).

To reduce the risk of collision, a widespread measure imposed by environmental authorities is to preventively shut down wind turbines when bat activity is considered significant. To achieve this, wind farm operators are required to conduct bat activity surveys, which are subsequently cross-referenced with environmental data. Predictive activity models are then developed, allowing for the preventive shutdown of wind turbines when activity exceeding a certain threshold is expected.

Bat activity studies are, in most cases, carried out using electronic and computer systems for automatic ultrasonic detection, recording and manual or automated analysis of the recorded sequences in order to identify the different species and their behavior.

Indeed, all bat species in Europe use echolocation to navigate and locate prey (Schnitzler et al., 2003). Echolocation is based on the emission of an acoustic signal, known as a *call* or *pulse*, which is modified by the obstacles encountered, and reflected back to the emitter (Schnitzler et al., 2003). The emitter can then deduce the location and nature of the obstacle by comparing the reflected sound with the original call. It was only in 1938 that we discovered bats are capable of using echolocation by emitting ultrasound (sounds with frequencies that exceed those audible to

humans, i.e. 20 kHz) (Barataud, 2015). Since then, technological advances have considerably increased ultrasound detection capabilities and recording quality. Today, this acoustic detection has taken on a predominant role in the study of bats, enabling the monitoring of their activity but also distinguishing the different species present in a given location (Barataud, 2015).

Many devices are currently on the market. However, there are only a limited number of studies comparing the performance of these devices. The best known is that of Adams et al. 2012, dating back more than 10 years. Recently, T. Disca (Fondation Biotope, 2023) carried out a study comparing four passive ultrasonic recorder devices: the Batlogger WE-X, the GSM-batcorder, the Batmode S+ and the SM3BAT). The aim of the study was to assess their capacity to detect and produce quality recordings. The results of this study show a strong disparity between recorders in terms of detection and recording quality.

We wanted to reproduce this study using the same equipment, settings and protocols, but adding an equipment not tested by T. Disca, the SMART System recorder produced by Wildlife Acoustics.

In addition, we wanted to go a step further by comparing the predictive models of activity that could have been derived from each of the devices tested.

Materials et Methods

1. Devices

Five devices are tested here:

- The Batlogger, produced by Elekon, Switzerland

- The GSM-batcorder, produced by ecoObs, Germany

- The Batmode, produced by bioacoustictechnology, Germany

- The SM4BAT, produced by Wildlife Acoustics, USA

- The SMART System, produced by Wildlife Acoustics, USA

The Batlogger, GSM-batcorder and Batmode devices are those evaluated by T. Disca.

The SM3BAT, used by Disca (2023), is no longer available for sale, and has been replaced here by the SM4BAT, which corresponds to the new version of the SM3BAT.

To expand our comparative study, the SMART System produced by Wildlife Acoustics was added to the devices tested (Table 1).

Unlike Disca (2023), which included a microphone comparison between the SMM-U1 and SMM-U2, both connected to SM3BATs, we chose to dispense with this comparison and test the SM4BAT only with the SMM-U2 microphone. This choice is justified by the fact that a study published in 2024 demonstrates better performance of the SMM-U2 microphone than the SMM-U1 in terms of detection rate, recording quality and number of classifiable files at species level (Goodwin et al., 2024).

Table 1: Description of the five devices used in this study.

Device	Manufacturer	Detector	Microphone	Additional sensors
SMART System	Wildlife acoustics	SMART Controller	SMART MIC-1	No additional sensors
SM4BAT	Wildlife acoustics	Song Meter SM4BAT FS	SMM-U2	No additional sensors
Batlogger	ElekonAG	Batlogger WE-X2	FG	• Temperature sensor • Humidity sensor • Pressure sensor
GSM-batcorder	EcoObs Gmbh	GSM-batcorder	Disc microphone (included in the housing box)	• Temperature sensor
Batmode	Bioacoustic technology	BATmode 2S+	FG GM-50	• IR precipitation sensor • Temperature sensor

2. Test site

The five devices were installed in a single location, on the facade of a building in a peri-urban area of Boujan-sur-Libron, in the Hérault département (Figure 1), with a mix of older and more recent residential buildings, as well as wasteland and wooded areas. The building itself is bordered by a wooded hedge and wasteland. The site conditions were ideal for ensuring the presence of a large number of bats and easy access to electrical and computer networks.

Figure 1: Test site at Boujan-sur-Libron in the Hérault department. The facade of the building on which the devices are placed is marked with a red arrow.

The microphones were mounted on the south-west facade of the building at 8 m from the ground for the Batmode and GSM-batcorder, 8.3 m for the Batlogger and 8.5 m for the SMART System and SM4BAT (Figure 2). Each microphone was connected to its housing detectors box via the cable provided by the manufacturer.

The housing detector boxes (Batlogger, Batmode, SmartController and SM4BAT) were positioned indoors to facilitate data access. As the GSM-batcorder's microphone is integrated into its waterproof housing detector box, the latter was placed directly on the building's facade (Figure 2).

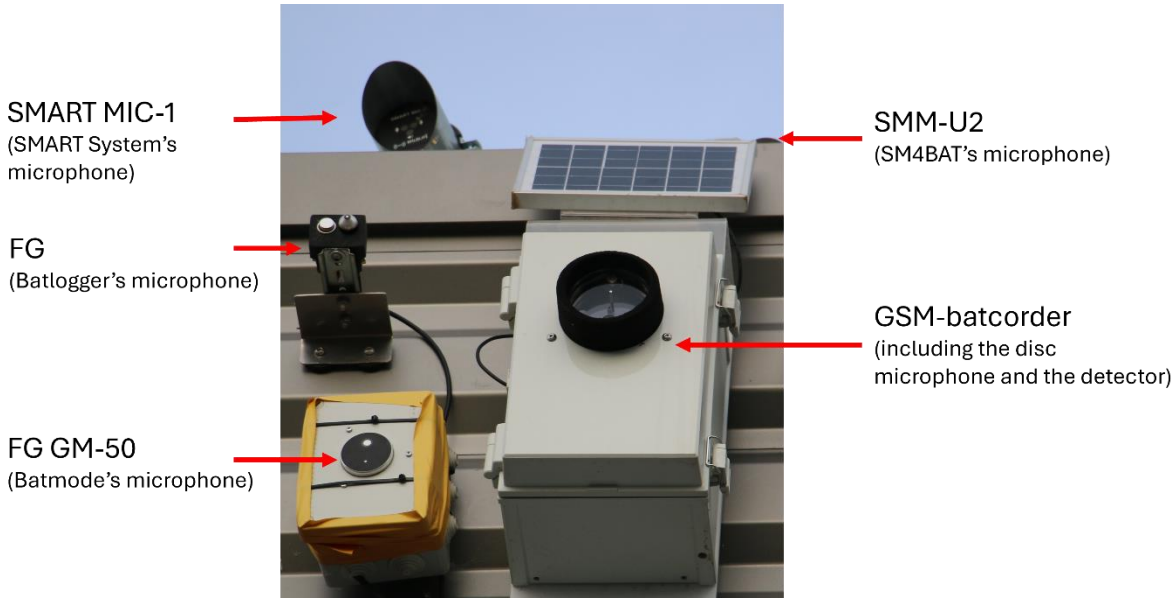

Figure 2: Installation of the devices at 8 m from the ground on the building facade.

3. The settings of the recorders

We configured the settings for each device in line with those used by Disca (2023) (Table 2).

Regarding the settings of the SMART System, not tested in the Disca, 2023 study, we chose settings as close as possible to those used for the other devices. Thus, the sampling rate was set at 256 kHz with a gain of 12 dB (Table 2; Figure 3). The reference level for the SMART System was set to -25 dB by default. As recommended by Wildlife Acoustics, the minimum time for detecting and recording a signal was set at 2 ms, with a frequency sensitivity range from 8 to 160 kHz, (Table 2; Figure 3).

Table 2: Settings used for each of the five devices.

Variable	Definition	SMART System	SM4BAT	Batlogger	GSM-batcorder	Batmode
Gain	Amplification of the received signal	12 dB	12dB	18 dB	Overall-gain : 96 dB SPL at 1 meter with 40 kHz	Sensitivity: -53 dBA
Sampling rate	Frequency sampling	256kHz	256 kHz	256 kHz	500 kHz	250kHz
Frequency range	Frequency range for the detection	8-160 kHz	10-128 kHz	8-160kHz	14 - 150kHz	8-125kHz
Maximum recording duration	Maximum duration of each recording	5s	5s	5s	Non-configurable	9s
Pre-trigger time	Reccording time before signal	0.5s	Non-configurable	0.5s	Non-configurable	0.5s
Post-trigger time	Recording time after signal	1s	Trigger window :1.5s	1.1s	0.6s	Hold tm: 0.5s
Threshold for trigger	Amplitude threshold to start recording	25 dB SPL	12 dB above the background noise	25 dB SPL	36 dB SPL	37 dB SPL
Bat call filter	Filtre applied for the automatic detection of bat calls	•Min pulse duration: 2ms •Max pulse duration: 500ms •Max inter-pulse duration: 800ms •Min number of pulses: 2	Min pulse duration: 1.5ms	•Min crest factor: 4 •Period trigger: 150	Quality: 20	•Min sweep rate: FM: -20kHz/ms; CF: -3kHz/ms •Max sweep rate: FM:-1kHz/ms; CF:1kHz/ms •Min duration: FM: 1ms ; CF : 4ms

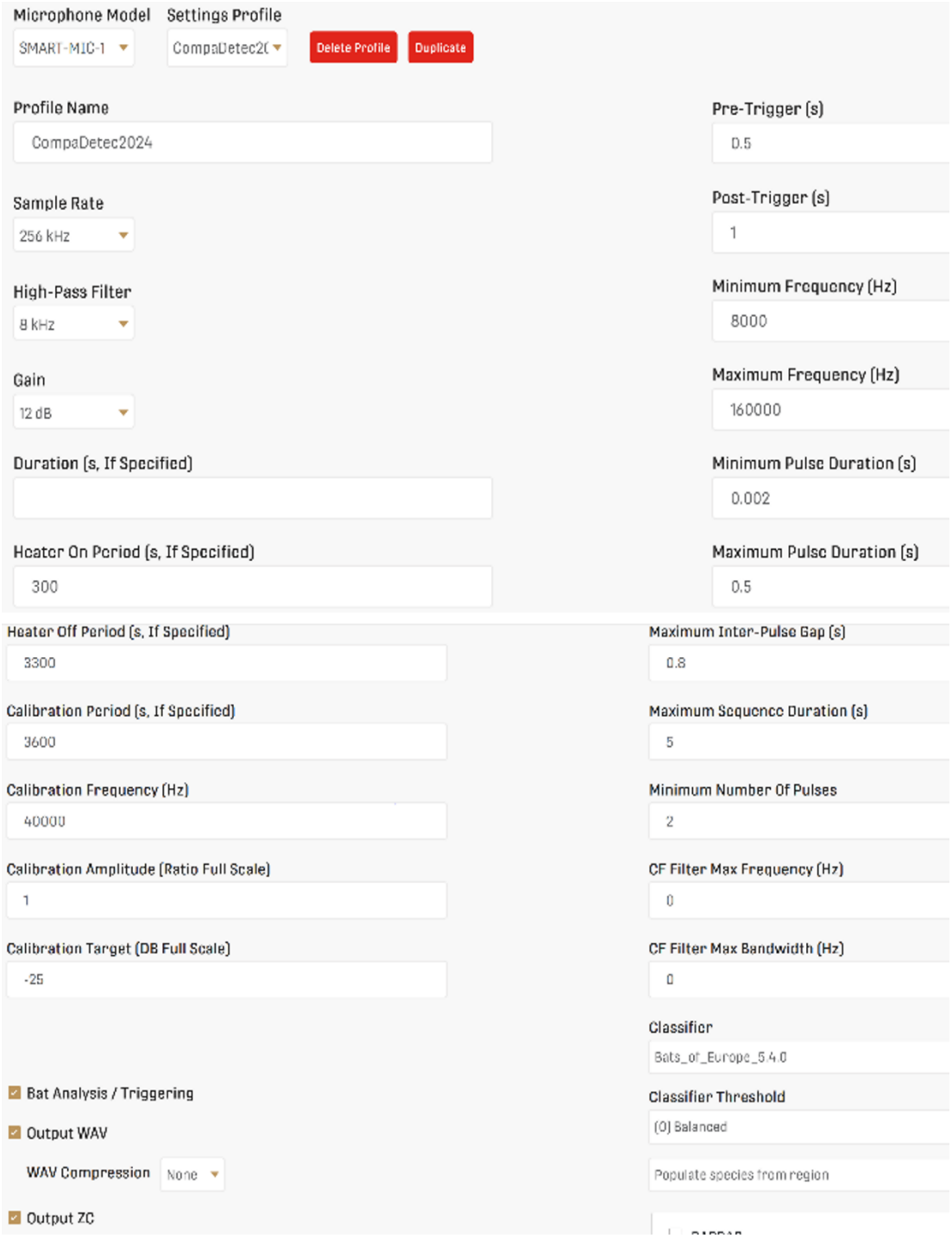

Figure 3: Screenshots of the SMART System device parameters.

4. Recording analysis

The study ran from March 06 to 26, 2024, recording a total of 20 nights (the night of March 9 to 10 was not taken into account, as a power failure occurred on some detectors). The recorders were programmed to start detection at sunset (legal time between 6.41pm and 7.08pm for the studied period) and stop at sunrise (legal time between 6.36am and 7.10am for the studied period).

Following the protocol described by Disca 2023, the acoustic data recorded by the various devices were retrieved and analyzed using Sonochiro software (version 4.1.). Each 5-second sequence identified by Sonochiro was visually checked with Sonoview and then using the method of Barataud (2020). This method extracts the values of the acoustic parameters used to identify bat species (call duration, frequency bandwidth, terminal frequency and frequency with maximum energy). Unlike Disca (2023), who used Batsound Pro (version 4.1) to extract these values, we chose to use Audacity (version 3.4.2), which has the advantage of being free and, from our persepective, more ergonomic. After verification, sequences containing one or more bat calls are termed *contacts*. Like Disca (2023), bat activity is measured in terms of the number of 5-second contacts and the number of *positive minutes*, i.e. minutes with at least one recording including bat calls (Miller, 2001).

Recording quality was assessed using Audacity software, by observing the oscillograms and spectrograms of recordings of the same sequence of bat ultrasonic emissions. In order to compare the attenuation of background noise by the different devices, the parts of the recording containing only background noise (cf. black box in Figure 4) were extracted and a spectral density graph was produced (using the *view spectral slice* function with *cepstral smoothing* at 500Hz in Praat software version 6.4.20).

To take things a step further, we also decided to evaluate the signal-to-noise ratio for 10 randomly selected 5-second contacts recorded by the 5 devices using RStudio software (version 2023.12.1). These contacts were selected on different nights to avoid pseudo-replication (Hurlbert, 1984). For each of the 10 contacts, the 5 recordings were synchronized, and the sound level of the signal was measured on the call with the highest amplitude peaks. The noise level was then measured over the same duration as the selected call, and on a section presenting only background noise (Figure 4). Finally for each recording from each of the 5 devices, the signal-to-noise ratio was calculated using the formula: : $SNR = 20 \times \log 10(\frac{V_{signal}}{V_{bruit}})$ (Oppenheim & Schafer ; 2010).

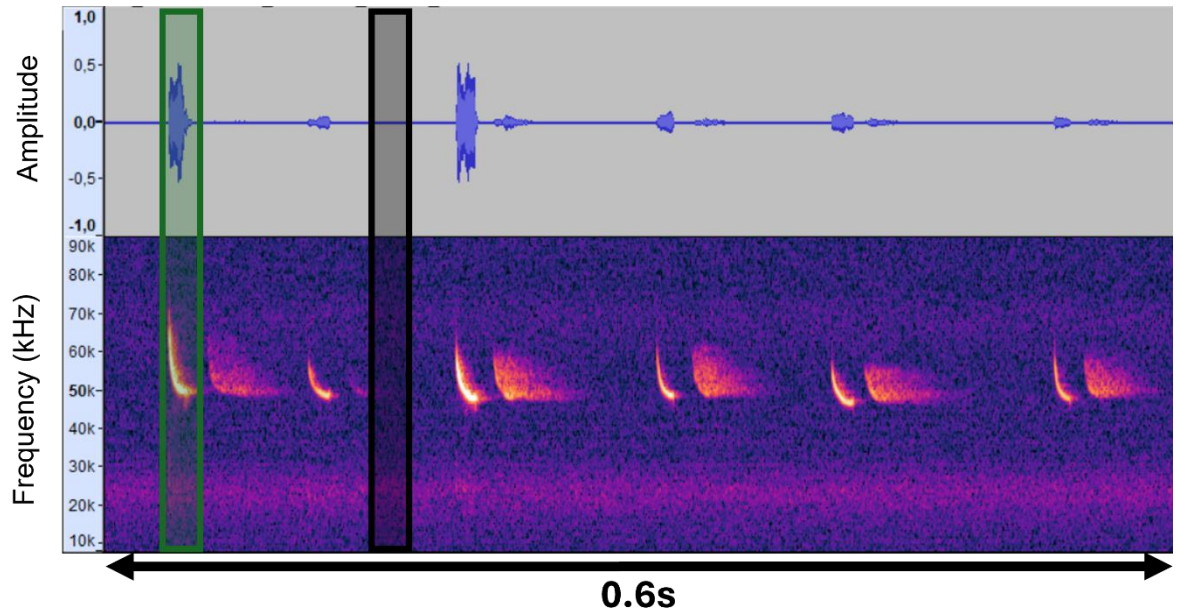

Figure 4: Extract from a 5s contact on which the signal-to-noise ratio was calculated. The green box represents the part of the recording on which the signal level was measured, and the black box the part on which the noise level was measured.

Results

1. Recording quality

A. Background noise, interference and distortions

When analyzing 10 contacts detected by the 5 devices, clipping was observed in 8 out of 10 Batlogger recordings, 3 out of 10 SM4BAT recordings and 2 out of 10 SMART System recordings. The Batmode and GSM-batcorder did not show any saturation phenomena on the 10 recordings analyzed.

To illustrate the quality of the recordings produced by the various devices, a sequence of Schreibers' Minioptera calls recorded on March 14, 2024 at 9:30 p.m. was taken as an example (Figure 5; Figure 6; Figure 7).

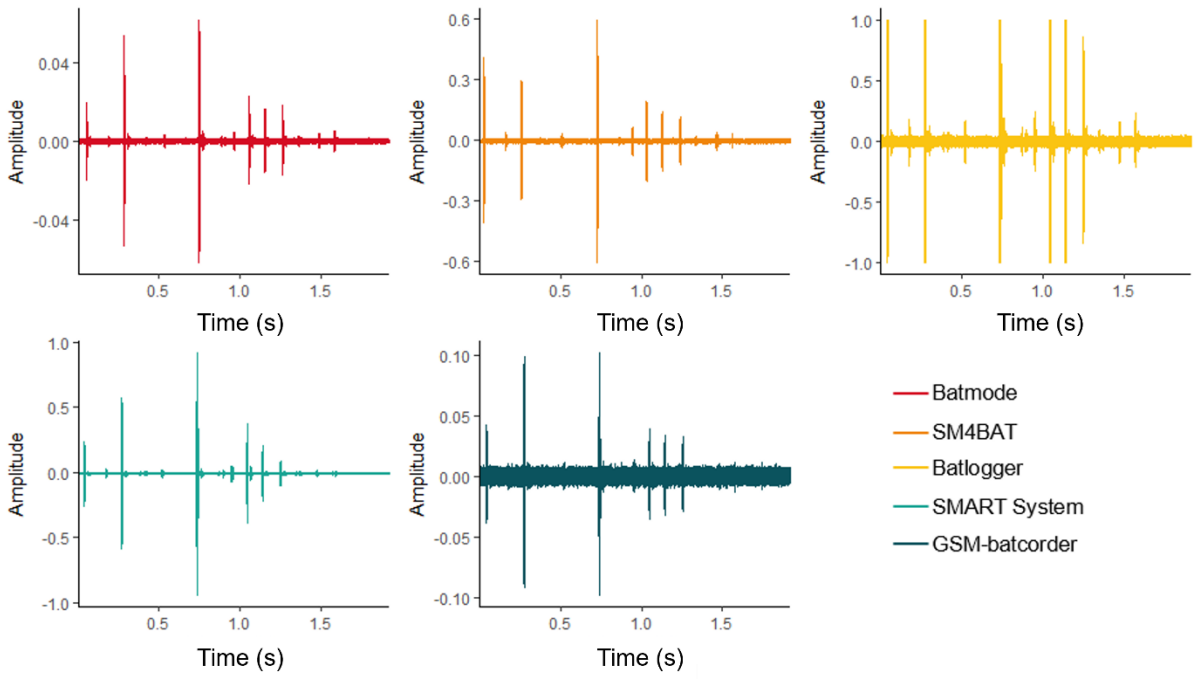

Figure 5: Comparison of a portion of the oscillograms obtained by each of the five devices (Batmode, SM4BAT, Batlogger, SMART System and GSM-batcorder) recording the same sequence of Schreibers' Minoptera calls.

The oscillogram of the Batlogger recording (Figure 5) highlights the phenomenon of clipping, with most bat calls (peaks on the oscillogram) reaching maximum relative amplitude (amplitude from 1 to -1). The Batlogger spectrogram (Figure 6) shows the presence of acoustic distortions due to this clipping. This problem of Batlogger clipping, also mentioned by Disca (2023), may be linked to the gain, the microphone sensitivity or the distance between the emitting bat and the microphone. This phenomenon can significantly alter signal quality and can potentially induce problems in the detection or misclassification (Reiss & McPherson, 2014).

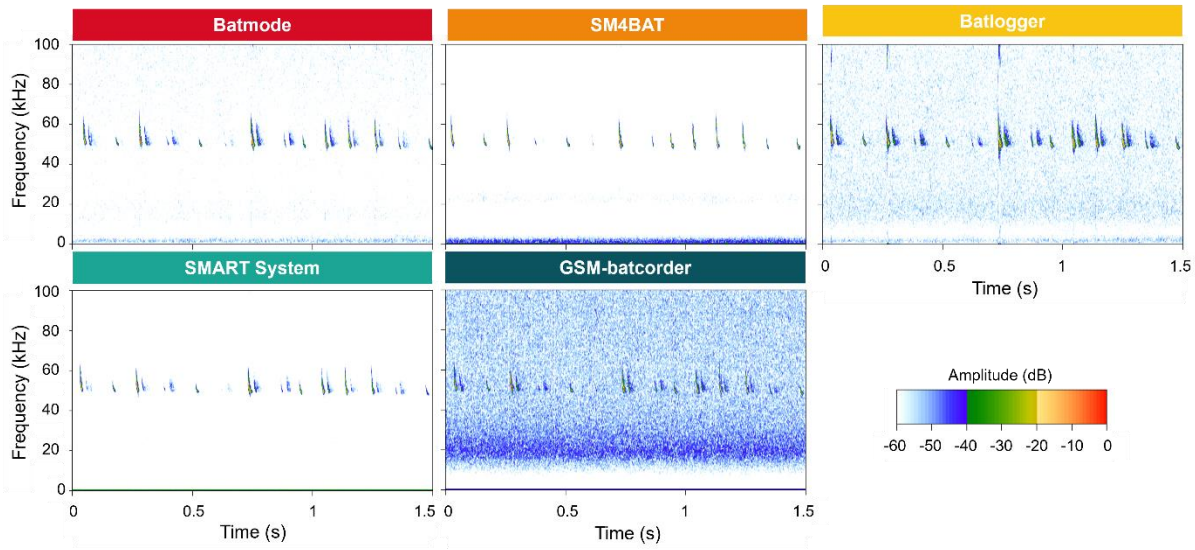

Figure 6: Comparison of spectrograms obtained by each device recording the same sequence of Schreibers' Minoptera calls.

On the other hand, the ability of the detectors to suppress noise is very heterogeneous. The GSM-batcorder is much more affected by background noise than the other detectors (Figure 5; Figure 6). The Batmode, with its calibration system to reduce unwanted noise, is the least affected by background noise, which remains homogeneous across all frequencies (Figure 7). The SMART System and the SM4BAT have similar noise power (Figure 5; Figure 6) with heterogeneity in their spectrum (Figure 7). In fact, the background noise is accentuated by around 10 dB in the 18 kHz to 30 kHz band (Figure 7).

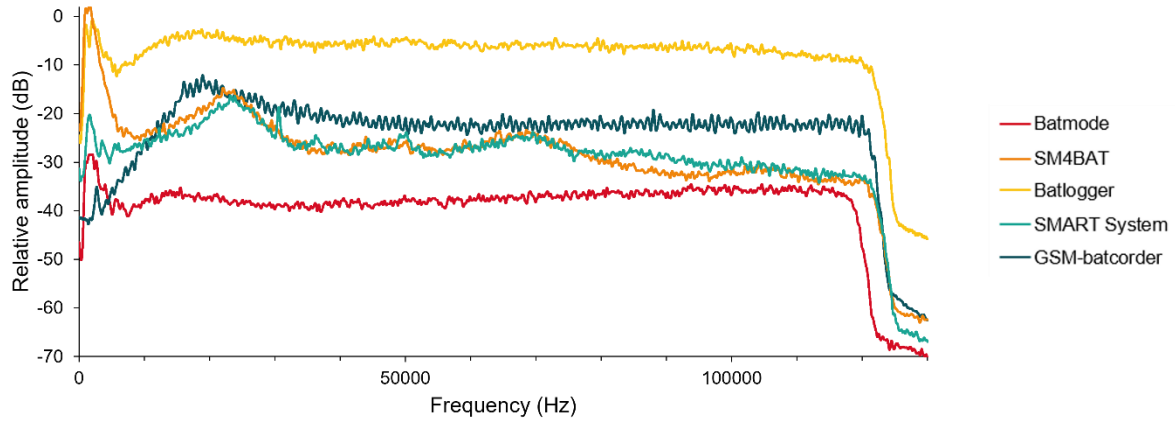

Figure 7: Spectral density of the background noise for each device.

B. Signal restitution

Out of the same random sample of 10 recordings, the Batmode, Batlogger, SM4BAT and SMART System have average signal-to-noise ratios (SNR) above 20 dB, corresponding to good recording quality (Figure 8). Of the 10 GSM-batcorder recordings, only 3 had an SNR above 20 dB, with an average of 17 ± 5 dB. The Batlogger has the highest average SNR, at 31 ± 4 dB, with a minimum of 22 dB. The Batmode, SM4BAT and SMART System show higher heterogeneity in the SNR of their recordings, with respective standard deviations of 6 dB (SNR minimum: 17 dB; SNR maximum: 37 dB), 7 dB (SNR minimum: 14 dB; SNR maximum: 36 dB) and 7 dB (SNR minimum: 8 dB; SNR maximum: 33 dB). A better signal to noise ratio is a performance factor that can increase the species detection and identification.

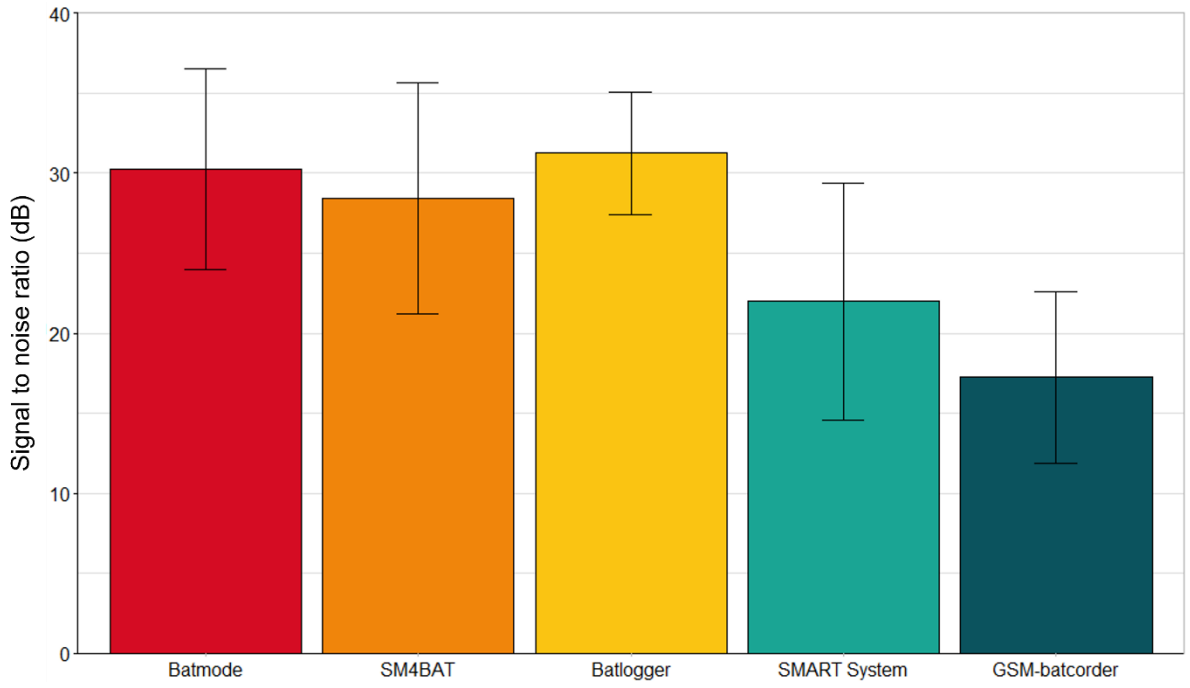

Figure 8: Comparison of signal to noise ratios calculated on a sample of 10 bat calls sequences detected by the five devices.

2. Detection performance

A. Number of species detected

Over the period from March 6 to 26, 2024, the recorders positively identified eight bat species, including four classified as priority species by the *Plan Régional d'Action pour les Chiroptères en Occitanie* (Table 3).

Table 3: Conservation status of species contacted during this study.

Common name	Scientific name	Status on the national IUCN Red List (IUCN France, 2017)	Priority species PRAC** (Bareille *et al.*, 2018)	Collision risk (Rodrigues *et al.*, 2008)
Common Pipistrelle	*Pipistrellus pipistrellus*	NT	X	X
Kuhl's Pipistrelle	*Pipistrellus kuhlii*	LC		X
Nathusius' Pipistrelle	*Pipistrellus nathusii*	NT	X	X
Soprano Pipistrelle	*Pipistrellus pygmaeus*	LC		X
Savi's Pipistrelle	*Hypsugo savii*	LC		X
Leisler's Bat	*Nyctalus leisleri*	NT	X	X
Schreiber's Bent-winged Bat	*Miniopterus schreibersii*	VU	X	X
Grey Long-eared Bat	*Plecotus austriacus*	LC		X

**PRAC : *Plan Régional d'Actions pour les Chiroptères in Occitanie*, France
IUCN Red list Categories: Least Concern (LC), Near Threatened (NT), Vulnerable (VU)

In terms of species detection, the Batlogger and SMART System proved the most effective, detecting all eight bat species, unlike the Batmode and GSM-Batcorder, which failed to detect the single Gray-Eared Owl sequence (Table 4).

Table 4: Detection capability of the five devices tested for different bat species.

Common name	Scientific name	Batlogger WE X	Batmode	SM4BAT	Smartsystem	GSM-Batcorder
Common Pipistrelle	*Pipistrellus pipistrellus*	X	X	X	X	X
Kuhl's Pipistrelle	*Pipistrellus kuhlii*	X	X	X	X	X
Nathusius' Pipistrelle	*Pipistrellus nathusii*	X	X	X	X	X
Soprano Pipistrelle	*Pipistrellus pygmaeus*	X	X	X	X	X
Savi's Pipistrelle	*Hypsugo savii*	X	X	X	X	X
Leisler's Bat	*Nyctalus leisleri*	X	X	X	X	X
Schreiber's Bent-winged Bat	*Miniopterus schreibersii*	X	X	X	X	X
Grey Long-eared Bat	*Plecotus austriacus*	X		X	X	

B. Number of detections

First of all, all the files obtained by the 5 devices were checked, enabling us to compare the false positive rate detected by each device.

The SMART System was the most effective device, with only 1% false positives out of a total of 15676 files. The Batlogger, Batmode and SM4BAT also performed well, with a percentage of false positives close to that of the SMART System. For the GSM-batcorder, out of the total number of files (n= 15377), it produced only 11% of true positive recordings, the rest being false positives (Figure 9).

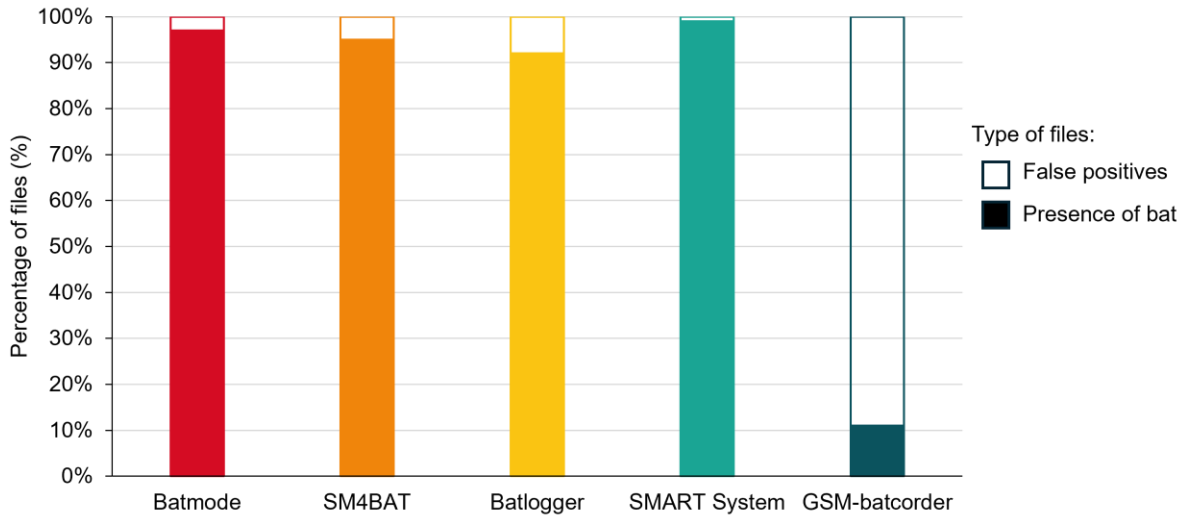

Figure 1 : Proportion of false positives relative to the total number of files.

Secondly, the files, verified as bat call recordings, are expressed as "5-second contacts" or aggregated into "positive minutes" (Figure 10).

Contrary to the results of Disca (2023), the Batmode did not record a higher number of 5s contacts than the other devices. In fact, it recorded the lowest numbers of contacts and positive minutes over the entire study period, comparable to the file numbers of the GSM-batcorder (Figure 10). The Batlogger recorded 13018 5s contacts and 4662 positive minutes, which are similar to the numbers obtained by the SM4BAT (13464 5s contacts and 4821 positive minutes) (Figure 10). The SMART System came out on top with 15573 5s contacts and 5232 positive minutes (Figure 10).

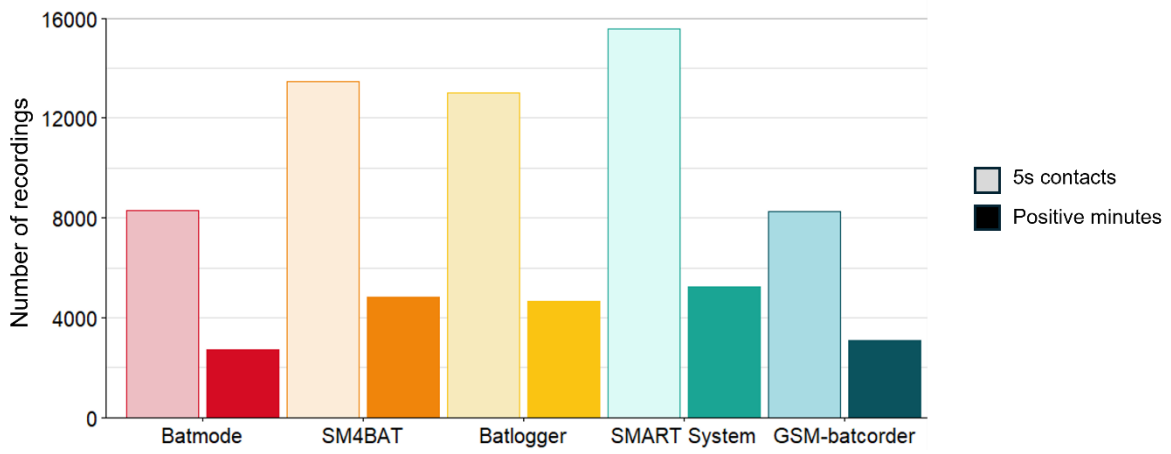

Figure 10: Comparison of the number of recordings obtained by the five devices tested (expressed in 5s contacts or positive minutes) over the 20 nights studied.

According to Figure 11, all detectors recorded less data on the first and last days, compared with the nights of March 13 to 20. During the period of low activity (early March), the Batmode and GSM-BATCORDER recorded almost no files, while the Batlogger, SM4 and SMART System always recorded a certain number of contacts and positive minutes (Figure 11).

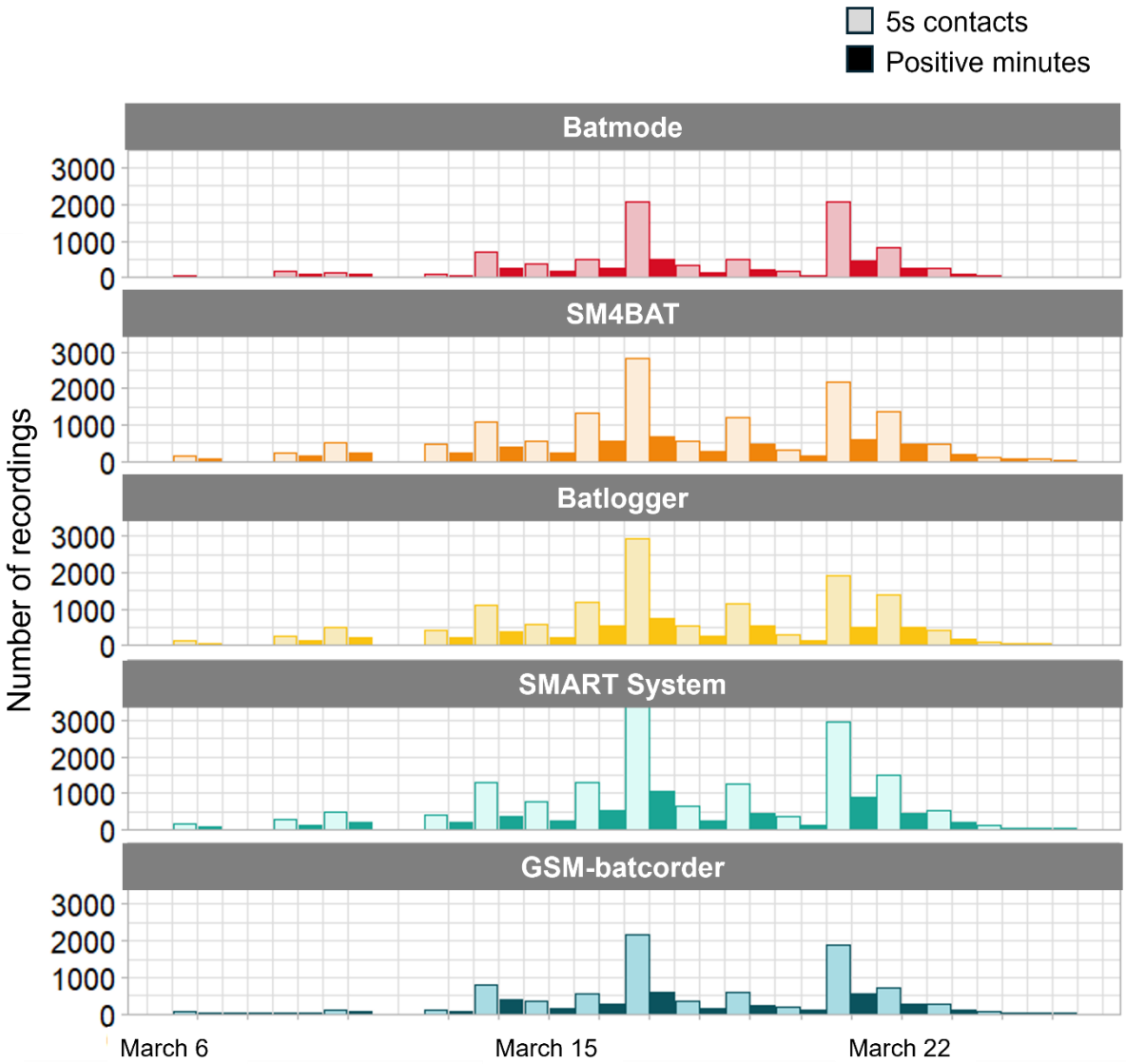

Figure 11: Number of recordings (5s contacts or positive minutes) over time according to the different devices.

The same sequence of Schreibers' Minioptera calls, detected and recorded by all the devices, was chosen in order to compare the different recordings obtained (Figure 12). Thus, the SM4BAT and SMART System are the detectors recording the most calls (36 and 35 calls respectively) (Figure 12). The Batlogger recorded 7 fewer calls than the SMART System, while the Batmode and GSM-batcorder recorded 15 and 17 fewer calls respectively (Figure 12). This difference can be explained by the *Post-trigger* parameter, which is set to 1000 and 1100 ms for the SMART System and Batlogger, respectively, whereas for the Batmode it is set to 500 ms.

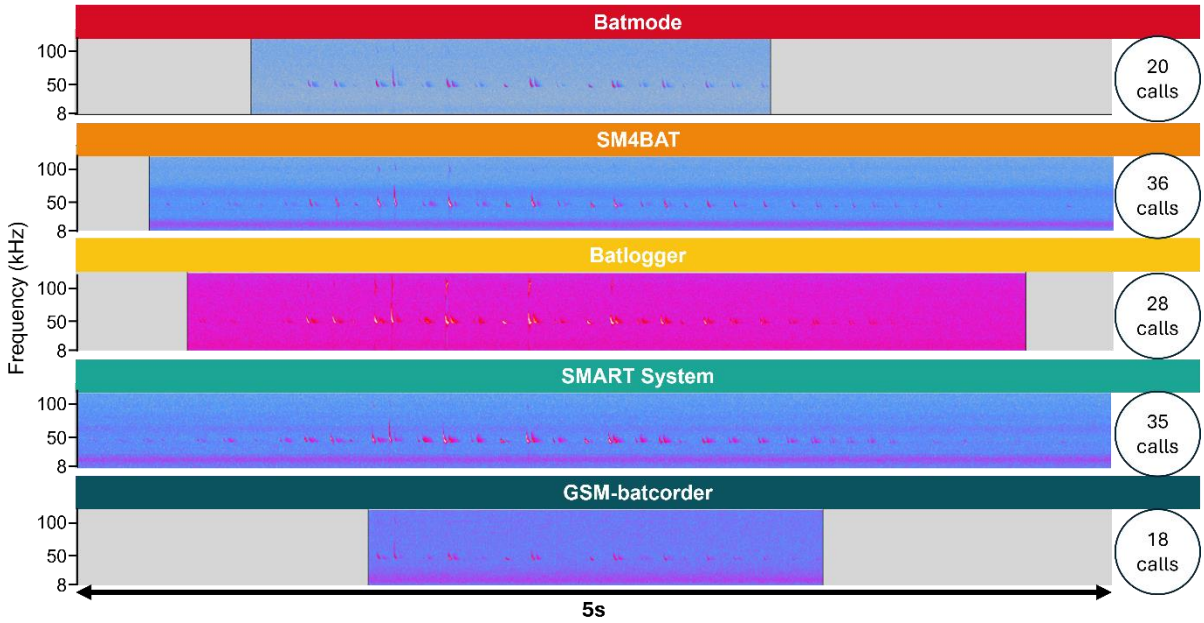

Figure 2 : Illustration of the number of bat calls inside files recorded during the sequence of Schreibers' Minioptera calls.

According to Figure 12 and Figure 13, the GSM-batcorder detects fewer cries and records files of shorter duration than the other devices. The Batmode behaves in the same way, but with slightly longer files (Figure 13). The SMART System records files that are longer and more regular in duration than the other recorders, making it easier to identify the species detected (Figure 13).

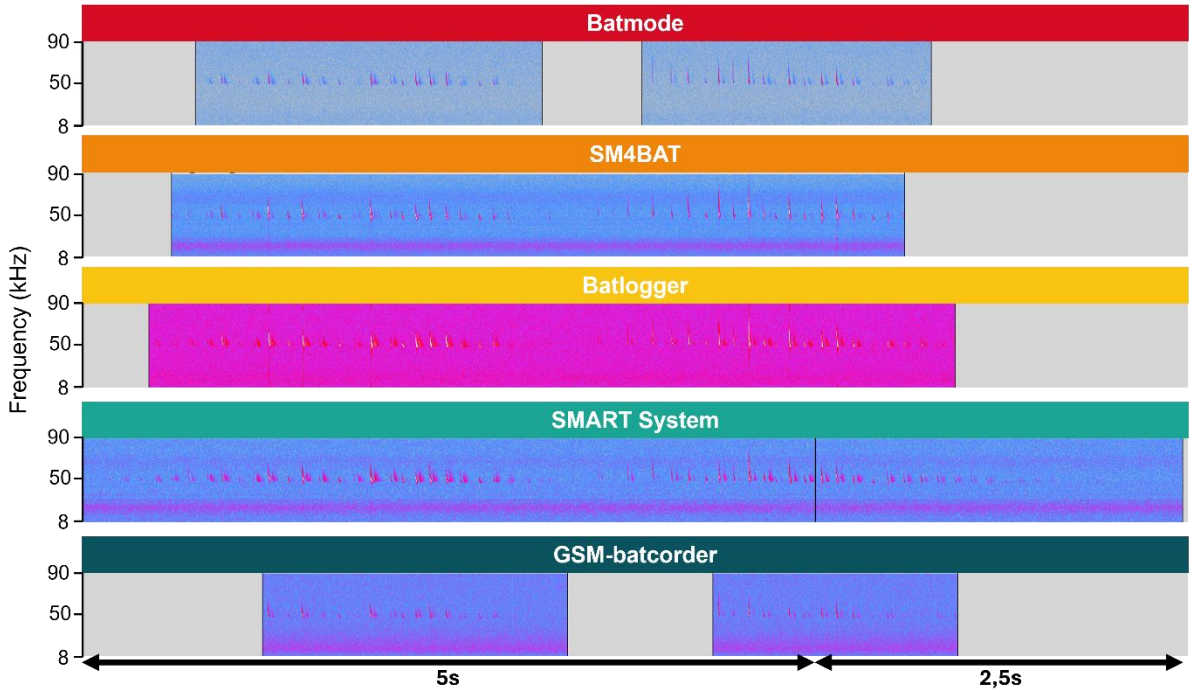

Figure 13: Comparison of the number of files obtained and their duration during the sequence of Schreibers' Minioptera calls detected and recorded by the five devices.

Regarding the activity of the different species detected by the recorders, the Schreibers' Minioptera is largely over-represented whatever the device, with an average of 60 ± 6% (mean ± standard deviation) of 5s contacts identified as Schreibers' Minioptera calls. The SMART System obtains a higher number of 5s contacts for species such as Kuhl's Pipistrelle (n = 3340), Common Pipistrelle (n = 1376) and Pygmy Pipistrelle (n = 2371) (Figure 14). The SM4BAT and Batlogger have a number of contact recordings of 5s comparable to the SMART System, but generate fewer positive minutes than the SMART System for 4 out of 8 species (Figure 15). The Batmode and GSM-batcorder produce significantly fewer files for each species than the other three detectors (Figure 14; Figure 15).

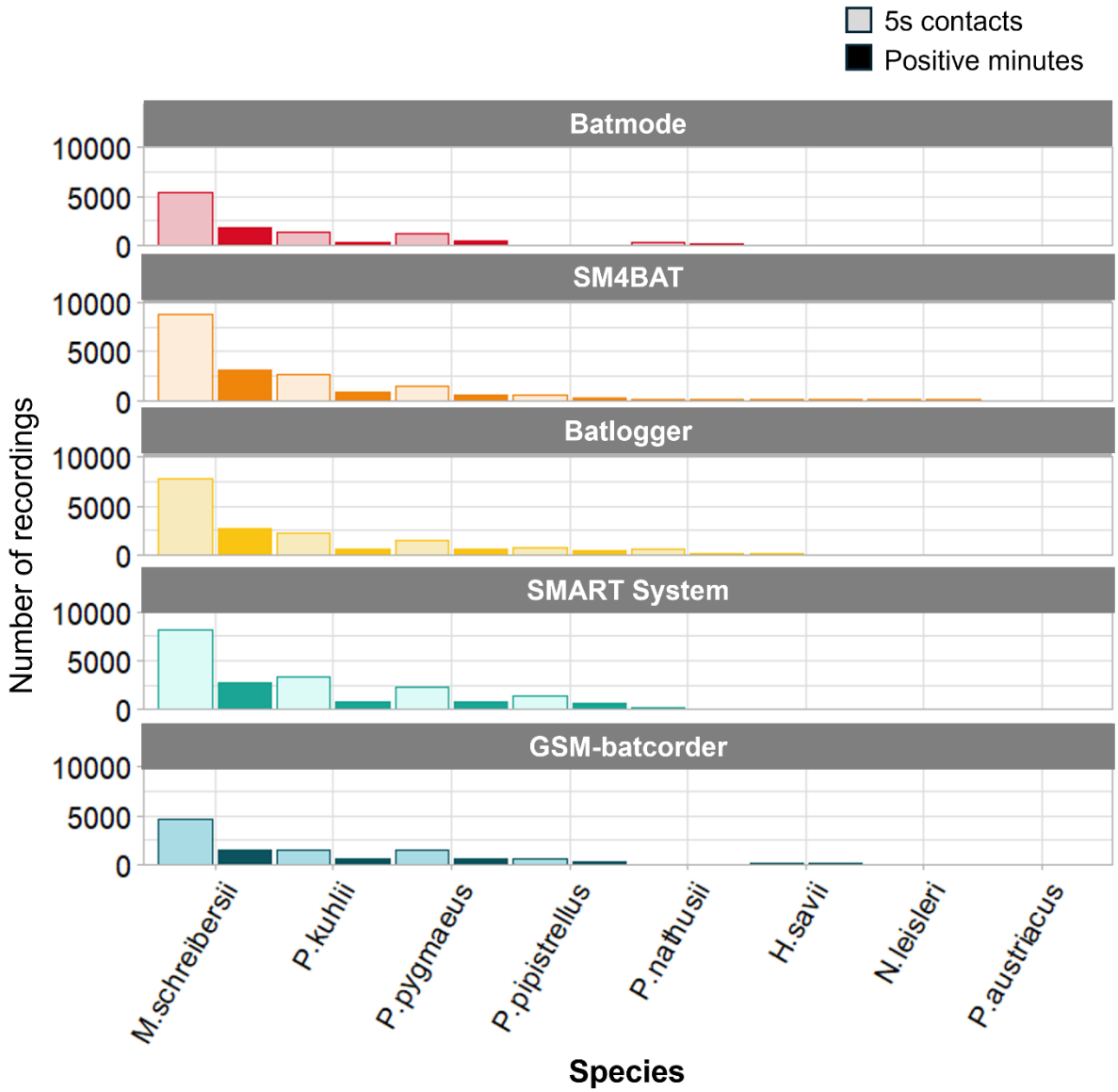

Figure 14: Number of recordings (contacts of 5 s or positive minutes) by species for each device.

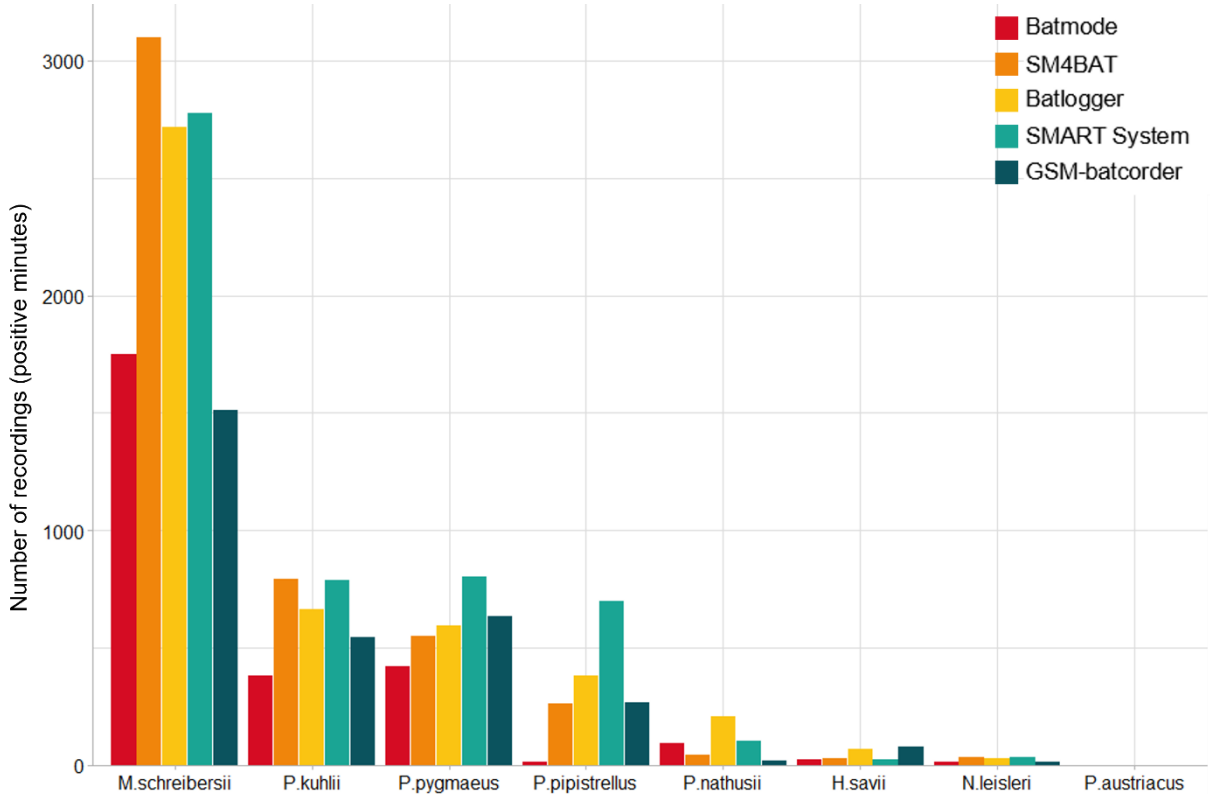

Figure 3 : Comparison of the number of positive minute recordings obtained by the five devices for each species detected.

3. Results in relation to the meteorological parameters

A. Meteorological conditions recorded during the test period

Unlike Disca (2023) it was not possible to take wind speed values into account, as the devices were placed sheltered from the wind, which would have biased the results. However, we did find useful to add humidity percentages to our analysis, in addition to temperature values. These data were all measured by the Batlogger at 15-minute intervals.

During our study period, temperatures ranged from 3°C to 18°C (Figure 16), with the majority of days over 10°C (Figure 17). So, although this temperature range is slightly cooler than that obtained by Disca (2023), it nevertheless enabled significant bat activity.

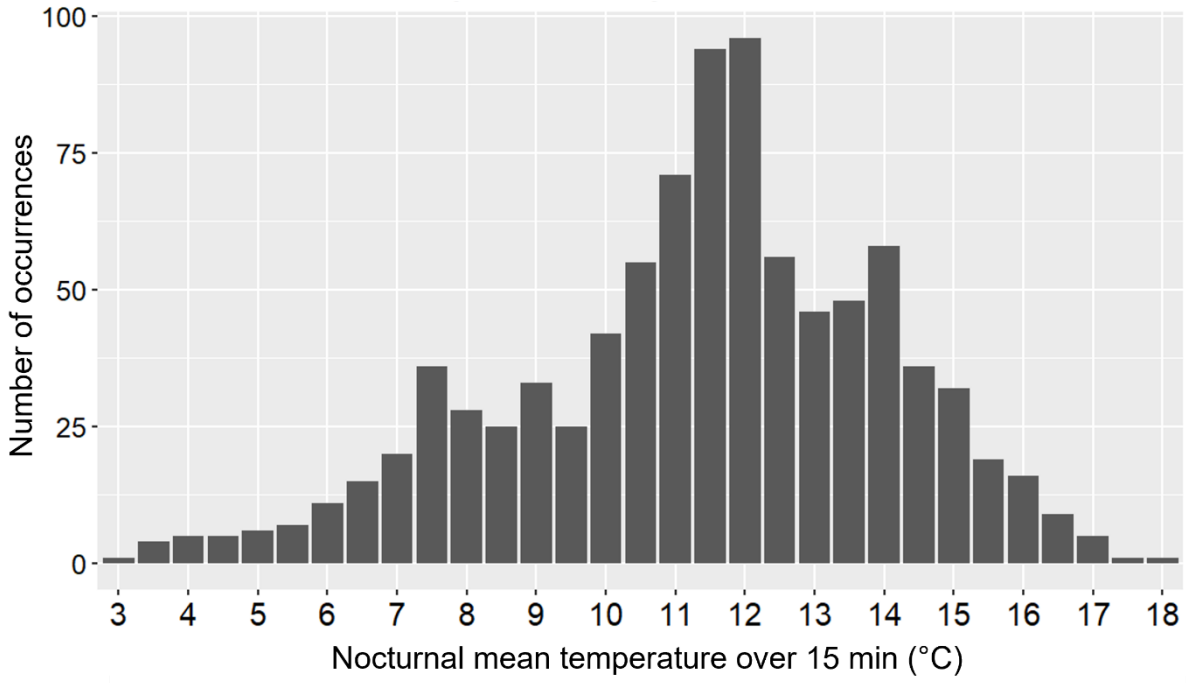

Figure 4 : Temperature distribution during record production over the study period from March 6 to 26, 2024.

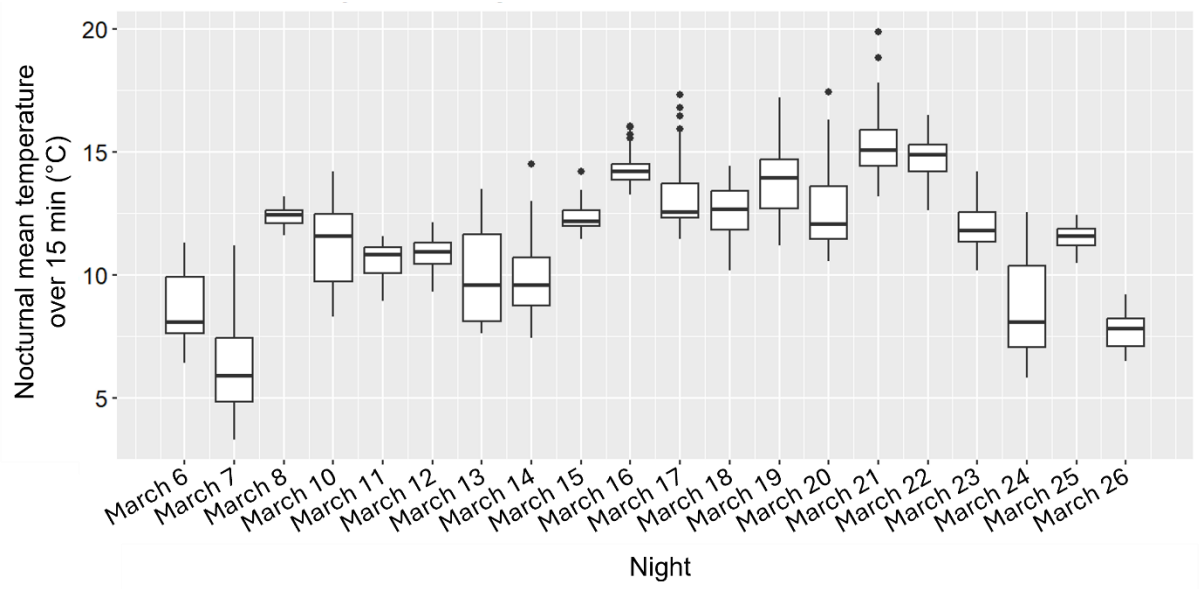

Figure 17: Temperature monitoring over the study period from March 6 to 26. The night of March 9 to 10 has not been taken into account due to a power supply problem on the Batlogger.

In terms of humidity, the minimum percentage was 38%, while the maximum was 96% (Figure 18). During the study period, the majority of nights presented a humidity percentage above 70% (Figure 19).

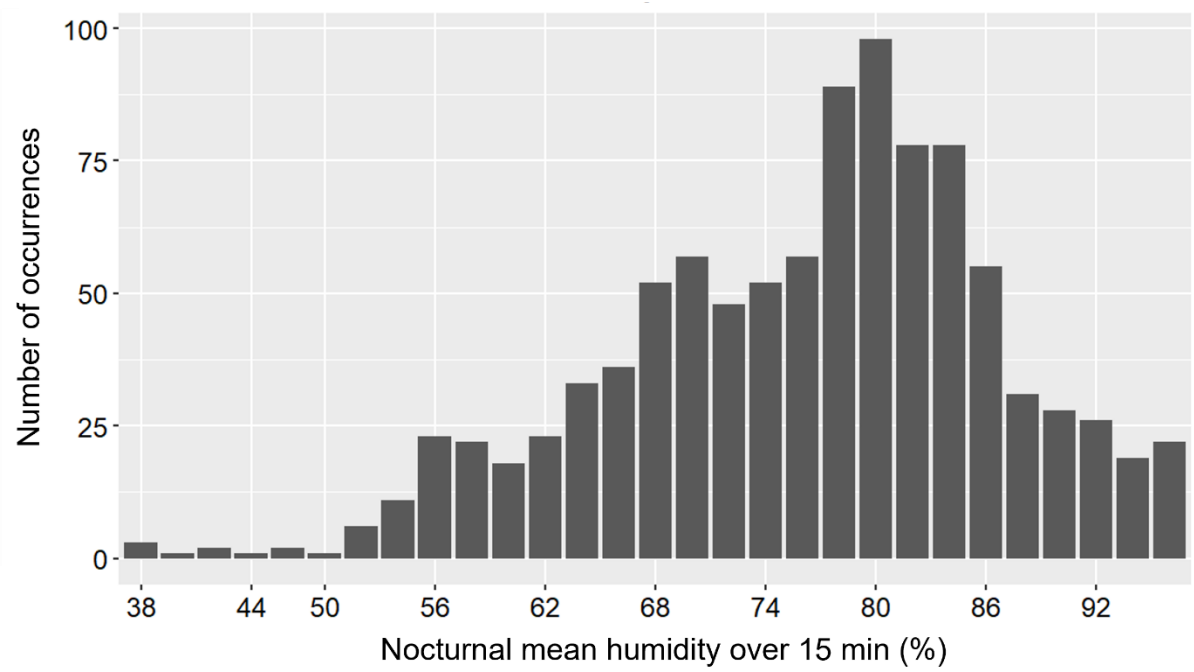

Figure 5: Distribution of humidity percentages recorded at night over the period March 6 to 26.

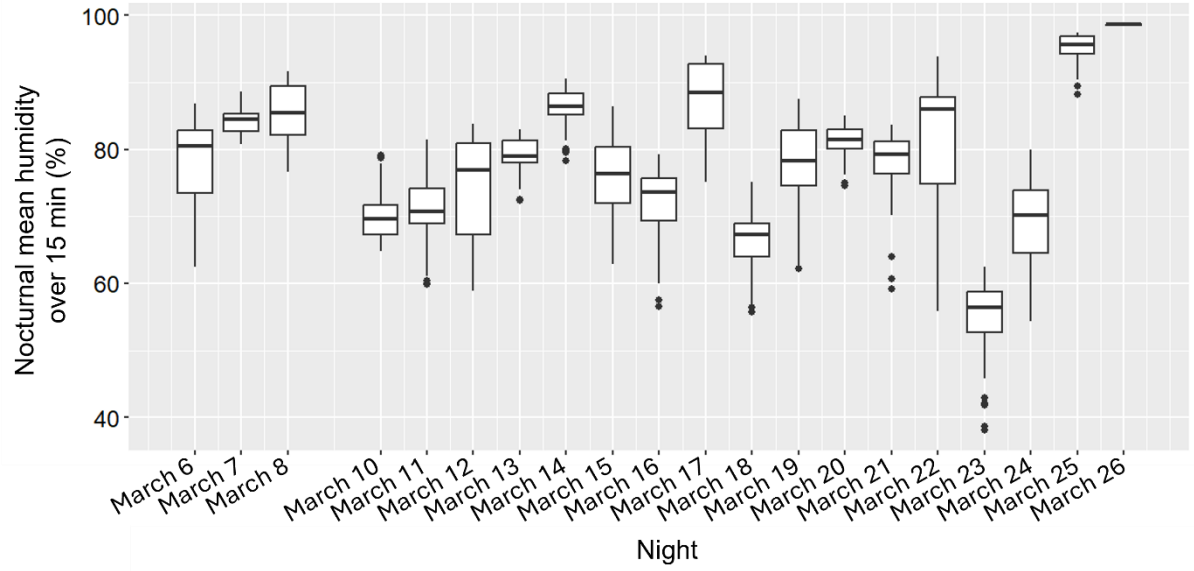

Figure 6 : Distribution of humidity percentages recorded per night over the period March 6-26.

B. Phenology of bat activity over the period

As in the Disca,2023 study, the SM4BAT (an updated version of the SM3BAT) was used as the reference detector to represent bat activity over the study period.

According to Figure 20, bat activity is highest between March 13 and 21. Over the study period, bats appear to be more active in the first half of the night than in the second half.

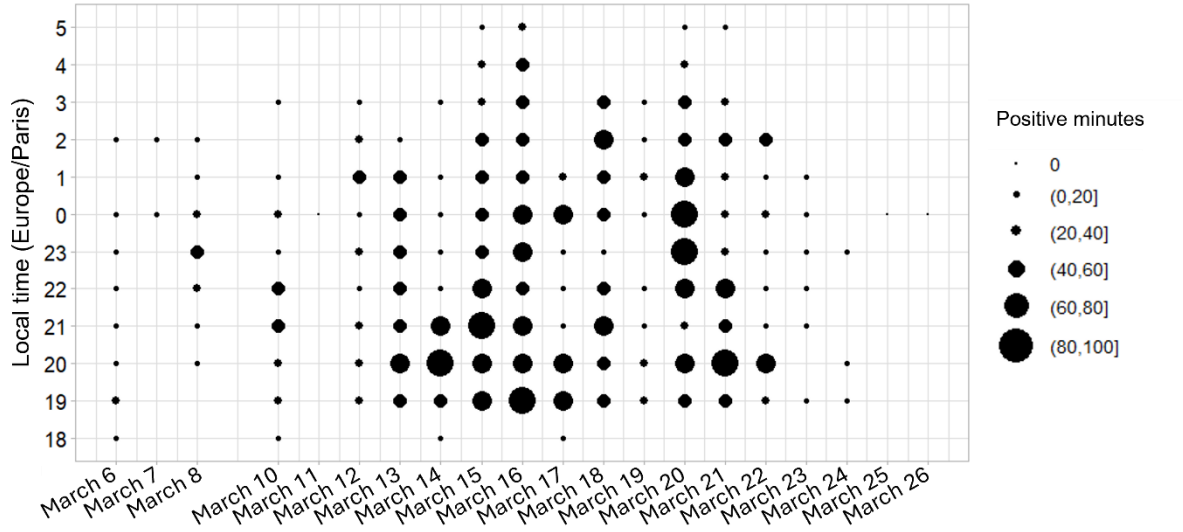

Figure 20: Distribution of bat detections (recordings in positive minutes) as a function of time and date over the period studied (March 6 to 26, 2024).

C. Correlation with the meteorological conditions

The proportion of cumulative number of recordings by the SM4BAT shows a significant onset of activity at 9°C and a humidity level of 55% (Figure 21; Figure 22). Bats increase their activity as the temperature rises, up to 15°C, after which their activity slows (Figure 21). Schreibers' Minioptera, the dominant species in our study, is less sensitive to low temperatures than other species, with activity starting at a temperature of 5°C (Figure 21). The least tolerant seems to be Leisler's Noctule, whose activity only begins when the temperature exceeds 11°C (Figure 21). Kuhl's and Nathusius' Pipistrelles are more active than other species at humidity levels below 60% (Figure 22).

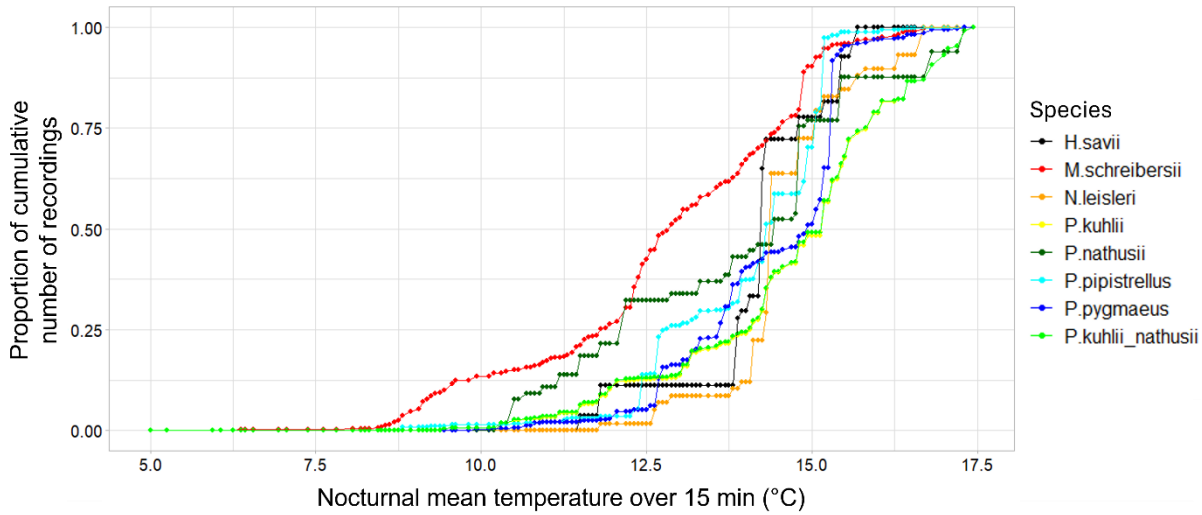

Figure 21: Proportion of cumulative recordings per species as a function of mean night-time temperature (averaged over 15-minute periods).

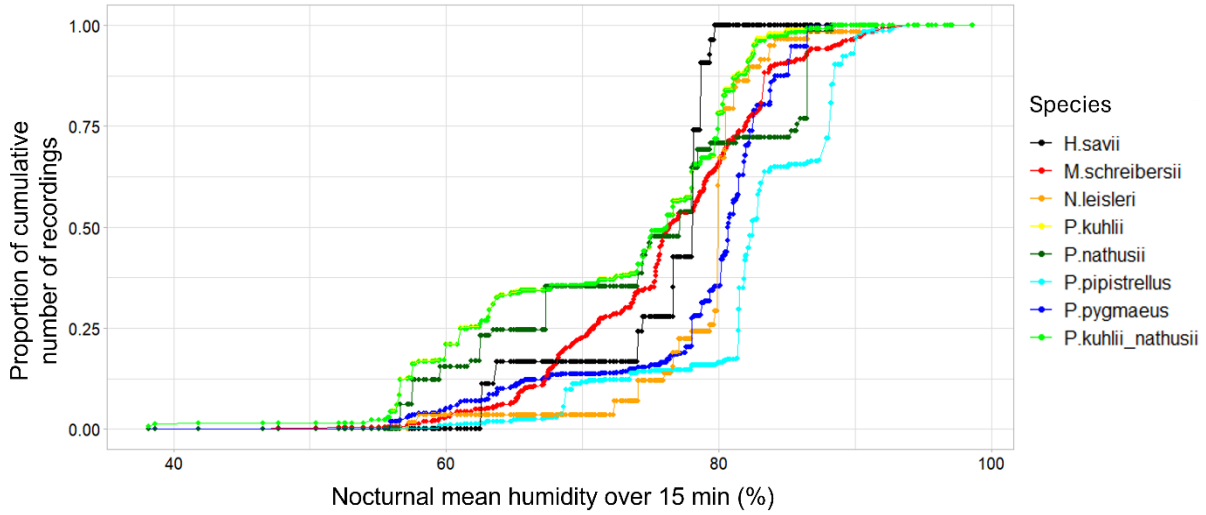

Figure 22: Proportion of cumulative recordings per species as a function of mean nocturnal humidity.

D. Comparison of the modeling with data from other recorders

In general, there were few differences in the activity models across the devices. Thus, according to these models, 90% of the contacts recorded during our study took place at temperatures between 9°C and 16°C (Figure 23) and at a percentage of humidity between 55% and 85% (Figure 24). Based on these detections, curtailment could therefore occur between 9°C and 16°C and at humidity levels between 55% and 85%, in order to avoid periods of high activity.

It's important to remember here that the majority of recorded calls come from Schreibers' Minioptera. As a result of this over-representation, the assessment of overall bat activity as a function of meteorological parameters cannot be generalized. Our study, which only took place in March, is also not representative of annual activity.

Among the differences observed, we noted that, unlike the Batlogger and SM4BAT, which produce files regularly over the entire observed temperature range, the Batmode, GSM-batcorder and SMART System experience a slight slowdown in file production between 14 and 15°C (Figure 23). Compared with the SMART System and SM4, the GSM-batcorder and Batmode produce slightly less data when humidity is between 65 and 75% (Figure 24). However, these differences do not alter the pattern of bat activity, which remains very similar for all devices.

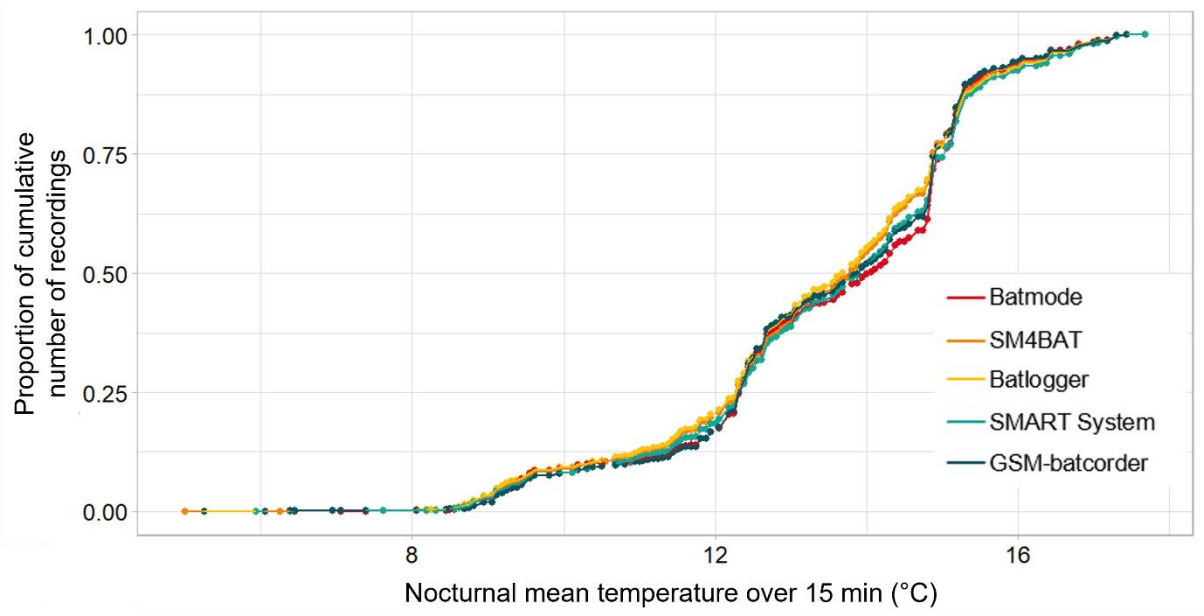

Figure 7 : Proportion of the bat activity expressed as the cumulative number of detections obtained for all species included in relation to temperature.

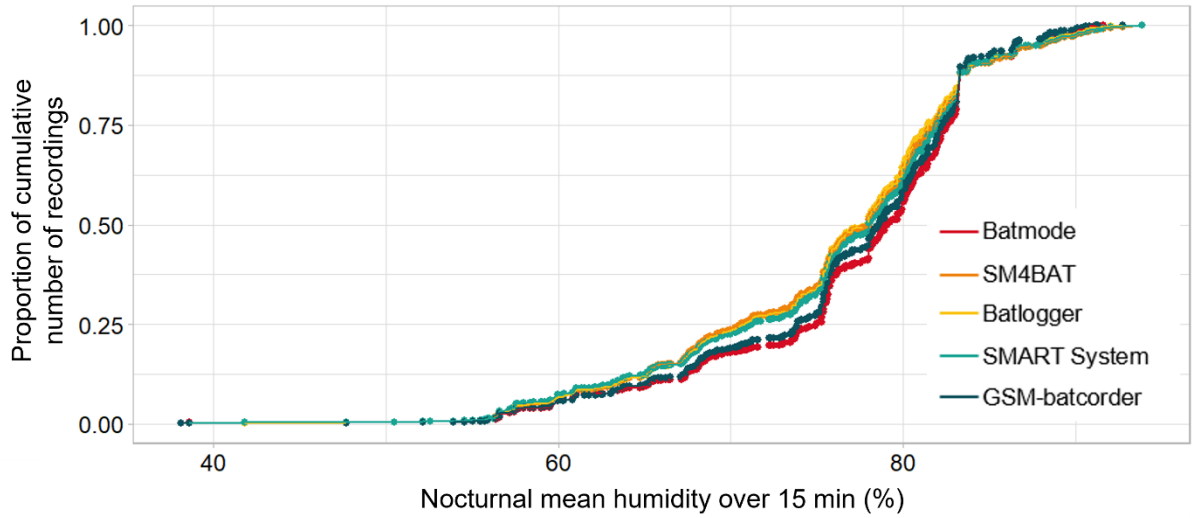

Figure 8 : Proportion of the bat activity expressed as the cumulative number of detections obtained for all species included in relation to humidity.

Discussion

The aim of this study was to reproduce the comparative analysis of several bat detection devices carried out by T. Disca, while adding the SMART System device. Disca's study (2023) was reproduced by testing the following devices: Batlogger WE-X, GSM-batcorder, Batmode 2S+, SM4BAT (new version of SM3BAT) equipped with a SMM-U2 microphone and the SMART System.

Our study was carried out over 20 nights, recording an average of 9376 5 seconds contacts per device. This represents more than 30 times the average number of 5 seconds contacts recorded in the Disca study (2024), which took place over 48 nights. This demonstrates the relevance of the site and study period chosen for our analysis.

In terms of recording quality, we chose to add a quantitative dimension to our analysis by calculating the signal-to-noise ratio on a sample of 10 5 seconds contacts recorded by the 5 devices. All the devices, except the GSM-batcorder, were judged to be of good quality (signal-to-noise ratio greater than 20 dB; Haykin, 2013), enabling good visualization of bat calls.

Although the background noise of the GSM-batcorder recordings is homogeneous over the frequency range of interest (20kHz to 120kHz), as observed by Disca (2023), it is particularly high. In fact, most of the recordings selected from the GSM-batcorder had a signal-to-noise ratio of less than 20 dB, with an average of 17 ± 5 dB. This low signal-to-noise ratio can be explained by excessive filtering on the GSM-batcorder. Regarding the SMART System and SM4BAT, we find the heterogeneity in background noise attenuation noted by Disca (2023) in terms of frequency range, with a lower attenuation capacity in the 18 to 30 kHz frequency range, but also among the different recordings selected, where we find strong heterogeneity in the calculated signal-to-noise ratios. Despite a tendency towards clipping, noted by Disca (2023) and confirmed in our study, the Batlogger presents the best average signal-to-noise ratio with homogeneous background noise attenuation over the frequency range of interest. It would probably be worthwhile reducing the gain of the Batlogger in order to obtain better quality recordings and avoid any resulting detectability problems or misclassification.

Detection performance is an essential point in our case study, as it determines whether the device is capable of detecting the greatest possible number of bats present around the wind turbines in order to prevent possible collisions. The SM4BAT, the Batlogger and the SMART System are the 3 devices that stand out for the large number of recordings they produce (over 12,000 in 5s contacts and over 4,000 in positive minutes), even though they produce longer recordings than the Batmode and the GSM-batcorder. In terms of reliability, all except the GSM-batcorder have a false-positive rate of less than 10%, with the best rate for the SMART System, which has only 1% false positives among all its recordings. In contrast to the Batmode and GSM-batcorder, the other three devices (Batlogger, SM4BAT and SMART System) were able to detect the single occurrence of Common Gray-Ear, a species not previously recorded by Disca (2023). On the other hand, we did not detect any Cestoni's Molossus during our study period, unlike Disca (2023). This difference could be explained by a different environment and study period, which favors the presence of certain species over others.

Although the majority of species detected in our study are common to those detected by Disca (2023), the proportion of each species is different. Indeed, Disca's (2023) study showed an over-representation of Leister's Noctule, whereas in our study we have an over-representation of Schreibers' Minioptera, which accounts for over 60% of the 5 seconds contacts recorded. In this context, conclusions on detection performance are strongly influenced by this over-representation and cannot be generalized to all bat species.

Weather conditions can affect the reliability of the devices and impair bat detection. Unlike Disca (2023), it was not possible to test the variability of detection as a function of wind speed, since the devices were placed sheltered from the wind, thus favoring bat activity but inducing a bias in the measurements. However, like Disca (2023), we were able to measure detection variability as a function of hygrometry, and we also added a variable we felt was relevant: humidity level. No device seems to be greatly affected by the weather conditions observed in our study. Thus, all the predictive models indicate that wind turbine curtailment at temperatures between 9°C and 16°C and humidity levels between 55% and 85% would cover 90% of bat activity and therefore potentially 90% of exposure to the risk of collision. These conclusions must be qualified by the fact

that bat activity was measured in March only, and with an over-representation of Schreibers' Minioptera.

It's important to stress the difficulty of this type of comparative study. Indeed, the various devices do not have the same sensitivity, the same parameter-setting capability (e.g. it is not possible to set the GSM-batcorder's pre- and post-trigger), the same parameter names (e.g. post-trigger is called hold tm for the Batmode) or even use the same units of measurement (e.g. threshold trigger is in dB SPL for most recorders, except for the SM4BAT, which is measured in relative dB). This is why it can be advantageous to follow the manufacturer's recommendations for an overall comparison of devices, as Disca (2023) and us did in this study.

Unlike Disca (2023), we don't think it is appropriate to rank these devices according to their performance, since the settings used are not equivalent. Performance is closely linked to the parameters selected. Moreover, the choice of a device also depends on other criteria such as price, durability, availability, ergonomics, and its ability to be used in situations that can vary widely (possibility of installation, autonomy, storage capacity, etc.).

About the practical outcome of our study, it should be noted that, despite the differences in the performance of the devices tested, the activity models would have been more or less identical, with the same implications for operators, if these results had been used in the context of preventive wind turbine curtailment.

However, in view of the differences noted, it seems essential that chiropterological studies using these automatic detection methods should systematically specify the equipment used and the parameters selected. Otherwise, the results obtained may be questioned, and the robustness of the resulting activity models may be questionable. Ultimately, the relevance of predictive activity models, and hence the effectiveness of preventive wind turbine curtailment, may be undermined.

The importance of assessing the quality of the equipment used to detect bats is not limited to the wind power sector. Ultrasound recorders are also used to document species composition and bat activity over broad temporal and spatial scales (Parsons and Szewczak, 2009), and to assess the influence of meteorological variables on bats (Erickson and West, 2002; Parsons et al., 2003).

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