Appendices

Appendix A: Overview of scientific literature on bat diel activity patterns

To assess previous knowledge on bat diel activity patterns, we conducted a non-exhaustive review on scientific literature. In Google Scholar, for each species studied, we performed the following research: *("activity pattern" OR "pattern of activity" OR "activity rhythm" OR "rhythm of activity") AND "Species latin name" AND "sunset"*. "*Sunset*" was chosen as an additional filter because of its almost systematic use in papers dealing with bat diel activity patterns. We acknowledge that by only using English sources, our database does not reflect all published studies, however, we assume that it is a representative sample.

For the Great *Myotis* (group composed *Myotis myotis* and *Myotis blythii*) we performed separate researches on *M. myotis* and *M. blythii* (for the latter species, we also performed researches on *Myotis oxygnathus* as this Latin name is used in some studies). *Pipistrellus pygmaeus* was first described as a distinct species from *Pipistrellus pispitrellus* in 2003 (Jones and Froidevaux, 2020). Thus, studies published before 2003 and conducted in areas were both species can be found were attributed to (1) *P. pipistrellus* if the authors focused on a "45 kHz phonic type", to (2) *P. pygmaeus* if the authors focused on a "55 kHz phonic type" and to (3) the *P. pipistrellus/pygmaeus* complex if the authors gave no information on the phonic type studied.

We only kept studies that were conducted in Europe and that provided information on the diel activity patterns of given species (i.e. we discarded papers in which the diel activity patterns of all bat species combined were studied). We discarded studies on diel activity patterns inside hibernacula, swarming or nursery roosts. For each study kept, we specified the method used to give information on activity patterns. We considered that a study focused on the local scale when information on diel activity patterns was provided by monitoring a small number of individuals and/or by monitoring a small number of sites (less than 25). We specified whether the information on diel activity patterns provided by each study was related to the diel activity patterns at roost or at foraging/commuting sites.

We found 44 studies, 34 (77 %) only provided information on the diel activity pattern of a single species studied in this paper, nine (20 %) provided information on the diel activity pattern of two to four species and only one provided information on the activity pattern of five species or more. *P. pipistrellus* and *P. pygmaeus* were well represented (11 studies between the two of them, 25 %), followed by *Myotis daubentonii*, *Rhinolophus hipposideros* and *Nyctalus noctula* (eight, six and five studies respectively). The other species were less studied: six were in four studies, one in three studies, one in two studies and six in one study. We did not find any study (conducted in Europe) on the diel activity pattern of *Pipistrellus kuhlii*.

Different methods were regularly used simultaneously to provide information on bat diel activity patterns. Visual observations were used in 18 studies (41 %), acoustic monitoring in 17 studies (39 %), radiotracking in 14 studies (32%), other methods used were, for instance, infrared devices, cameras traps or GPS. Ten, 19 and 15 studies (23 %, 43 % and 34%) provided information on diel activity patterns at foraging/commuting sites, at roosts and at both roost and foraging/commuting sites respectively. There was hence a bias toward roost monitoring, with many studies focusing on the time of emergence. Almost all studies were conducted at local scales (41 studies, 93 %) with only three studies at the regional scale or more. The studies were unevenly distributed across Europe. For instance, 19 studies were conducted in the United-Kingdom (43 %) and six in Germany (14 %) while only one was conducted in France.

Table A.1: Overview of the scientific literature on the diel activity patterns of the 20 species studied in this paper. Species are named with their species codes (correspondence between codes and full Latin and English names in Table F). *“Myossp*” means *Myotis spp*. “*Yes*” in “*Roost*” means that the study provided information on diel activity patterns at roosts, “*Yes*” in “*For. site*” means that the study provided information on diel activity patterns at foraging/commuting sites.

Citation	**Journal**	**Species**	**Country**	**Roost**	**For. site**	**Local**	**Method**
(Ancillotto et al., 2018)	Behavioural Processes	Hypsav	Italy	Yes	No	Yes	Radiotracking
(Bartonička et al., 2008)	Annales Zoologici Fennici	Pippyg	Czech Republic	Yes	Yes	Yes	Radiotracking
(Bartonička and Řehák, 2004)	Mammalia	Pippyg	Czech Republic	No	Yes	Yes	Acoustic
(Boldogh et al., 2007)	Acta Chiropterologica	Myobly, Myoema, Rhifer	Hungary	Yes	No	Yes	Visual observations
(Bullock et al., 1987)	Journal of Zoology	Pippip/pyg	UK	Yes	No	Yes	Visual observations
(Catto et al., 1995)	Journal of Zoology	Eptser	UK	Yes	No	Yes	Infra-red/camera traps/video
(Ciechanowski et al., 2009)	Mammalia	Pipnat	Poland	No	Yes	Yes	Acoustic
(Day et al., 2015)	Animal Conservation	Rhifer	UK	No	Yes	No	Acoustic
(DeCoursey and DeCoursey, 1964)	The Biological Bulletin	Myomyo	Germany	Yes	No	Yes	Visual observations
(Dietz and Kalko, 2007)	Canadian Journal of Zoology	Myodau	Germany	Yes	Yes	Yes	Radiotracking
(Downs et al., 2016)	Acta Chiropterologica	Rhihip	UK	Yes	Yes	Yes	Radiotracking
(Duvergé et al., 2000)	Ecography	Rhifer, Rhihip	UK	Yes	No	Yes	Radiotracking + visual observations
(Encarnação et al., 2006)	Folia Zoologica - Praha	Myodau	Germany	Yes	Yes	Yes	Radiotracking + visual observations
(Entwistle et al., 1996)	Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences	Pleaur	UK	Yes	Yes	Yes	Radiotracking
(García-Ruiz et al., 2017)	Acta Chiropterologica	Minsch, Myobly/myo	Spain	Yes	No	Yes	Acoustic + infra-red/camera traps/video
(Gelhaus and Zahn, 2010)	Vespertilio	Pipnat	Germany	Yes	No	Yes	Visual observations

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Citation	Journal	Species	Country	Roost	For. site	Local	Method
(Goodenough et al., 2015)	Wildlife Biology	Myonat, Nycnoc, Pippip, Pippyg	UK	No	Yes	Yes	Acoustic
(Guixé et al., 2016)	Barbastella	Rhihip	Spain	Yes	Yes	Yes	Infra-red/camera traps/video
(Hooker et al., 2022)	Environmental Pollution	Myospp	UK	No	Yes	Yes	Acoustic
(Jenkins et al., 1998)	Animal Behaviour	Pippyg	UK	Yes	No	Yes	Visual observations
(Kapfer and Aron, 2007)	Lutra	Myodau, Pipnat, Pippip	Belgium	No	Yes	Yes	Acoustic
(Lino et al., 2015)	Galemys, Spanish Journal of Mammalogy	Rhihip	Portugal	Yes	No	Yes	Infra-red/camera traps/video
(Maier, 1992)	Journal of Zoology	Pippip/pyg	UK	Yes	No	Yes	Visual observations
(Mariton et al., 2022)	Environmental Pollution	Eptser	France	No	Yes	No	Acoustic
(Marques et al., 2004)	Acta Chiropterologica	Tadten	Portugal	Yes	Yes	Yes	Radiotracking
(McAney and Fairley, 1988)	Journal of Zoology	Rhihip	Ireland	Yes	No	Yes	Acoustic + visual observations
(Newson et al., 2015)	Biological Conservation	Barbar, Eptser, Pipnat, Pippip, Pippyg, Pleaur, Myodau, Myomys, Myonat, Nyclei, Nycnoc	UK	No	Yes	No	Acoustic
(Rachwald, 1992)	Acta Theriologica	Nycnoc	Poland	No	Yes	Yes	Acoustic
(Razgour et al., 2011)	Biological Conservation	Pleaus	UK	Yes	Yes	Yes	Radiotracking
(Robinson and Stebbings, 1997)	Myotis	Eptser	UK	Yes	Yes	Yes	Radiotracking + visual observations
(Roeleke et al., 2016)	Scientific Reports	Nycnoc	Germany	Yes	Yes	Yes	GPS tracking

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Citation	**Journal**	**Species**	**Country**	**Roost**	**For. site**	**Local**	**Method**
(Ruczyński et al., 2017)	Mammal Research	Nyclei, Nycnoc	Poland	Yes	Yes	Yes	Radiotracking + visual observations
(Rudolph et al., 2009)	Acta Chiropterologica	Myomyo	Germany	Yes	Yes	Yes	Radiotracking
(Russo et al., 2007)	Acta Oecologica	Barbar	Italy	Yes	No	Yes	Infra-red/camera traps/video
(Ružinská et al., 2022)	Scientific Reports	Myodau	Slovakia	Yes	No	Yes	Passive integrated transponders
(Rydell et al., 1996)	Oikos	Myodau, Pippyg, Pleaur	UK	Yes	Yes	Yes	Acoustic + radiotracking + visual observations
(Shiel and Fairley, 1999)	Journal of Zoology	Nyclei	Ireland	Yes	No	Yes	Acoustic + visual
(Shiel et al., 1999)	Journal of Zoology	Nyclei	Ireland	Yes	Yes	Yes	Radiotracking
(Stone et al., 2009)	Current Biology	Rhihip	UK	No	Yes	Yes	Acoustic + visual observations
(Swift, 1980)	Journal of Zoology	Pippip/pyg	UK	Yes	No	Yes	Visual observations
(Swift, 1997)	Journal of Zoology	Myonat	UK	Yes	No	Yes	Acoustic + visual observations
(Swift and Racey, 1983)	Journal of Zoology	Pleaur, Myodau	UK	Yes	Yes	Yes	Visual observations
(Thomas and Davison, 2022)	Ecology and Evolution	Myodau, Myonat, Myospp	UK	Yes	No	Yes	Acoustic + infra-red/camera traps/video
(Voortman and Bakker, 2020)	Deinsea	Pippip	Netherlands	Yes	No	Yes	Acoustic + visual observations

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Appendix B: Acquisition and curation of biological data

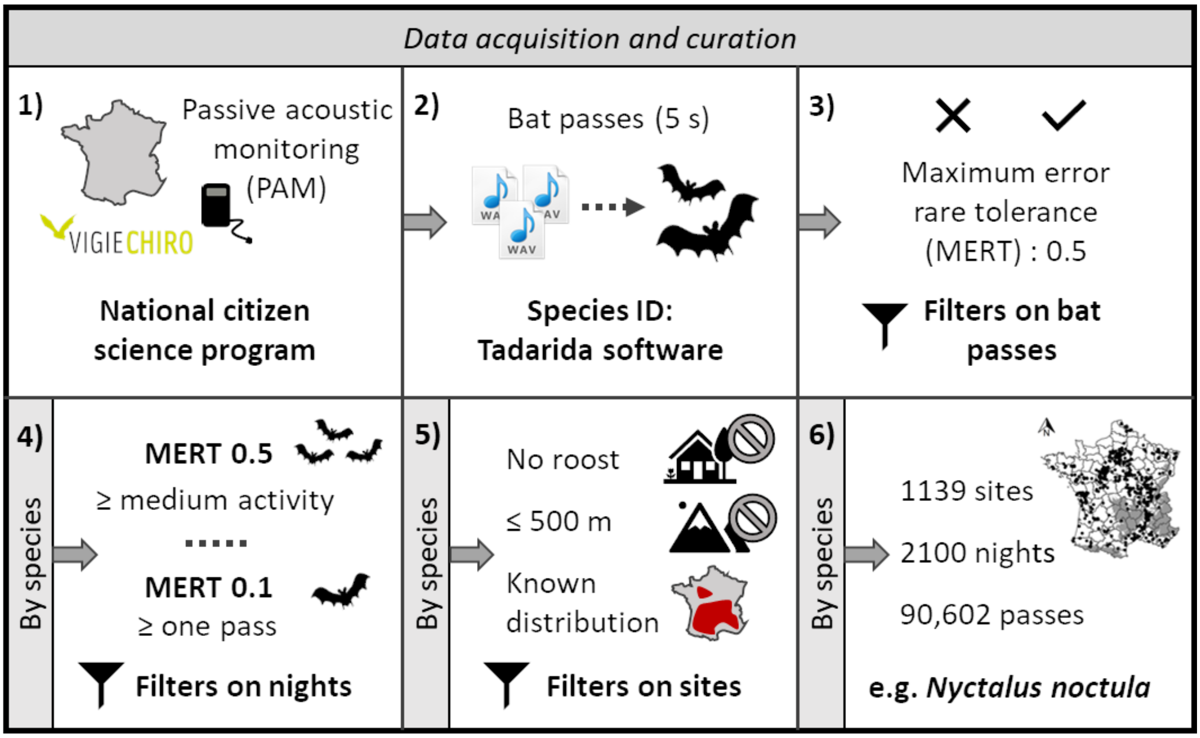

Fig. B.1: Schematic process of data acquisition (1-2) and curation (3-5), and example of final results for *Nyctalus noctula* (6).

1. Vigie-Chiro program

We used data from the “stationary points protocol” of the French citizen science bat monitoring program Vigie-Chiro which has been coordinated since 2014 by the French National Museum of Natural History (https://www.vigienature.fr/fr/chauves-souris) (Fig. B.1 *1)*). As part of this protocol, volunteers were asked to set up ultrasonic recorders on potential bat foraging sites for at least one full-night (from 30 min before sunset to 30 min after sunrise). All recorders had to be configured with recommended settings to limit heterogeneity between devices. Overall, we used data from 9807 nights monitored on 4409 sites (below 500 m above sea level, roosts excluded, see Appendix B *3) Data curation*).

As this program was originally design to study bat population trends in France, the

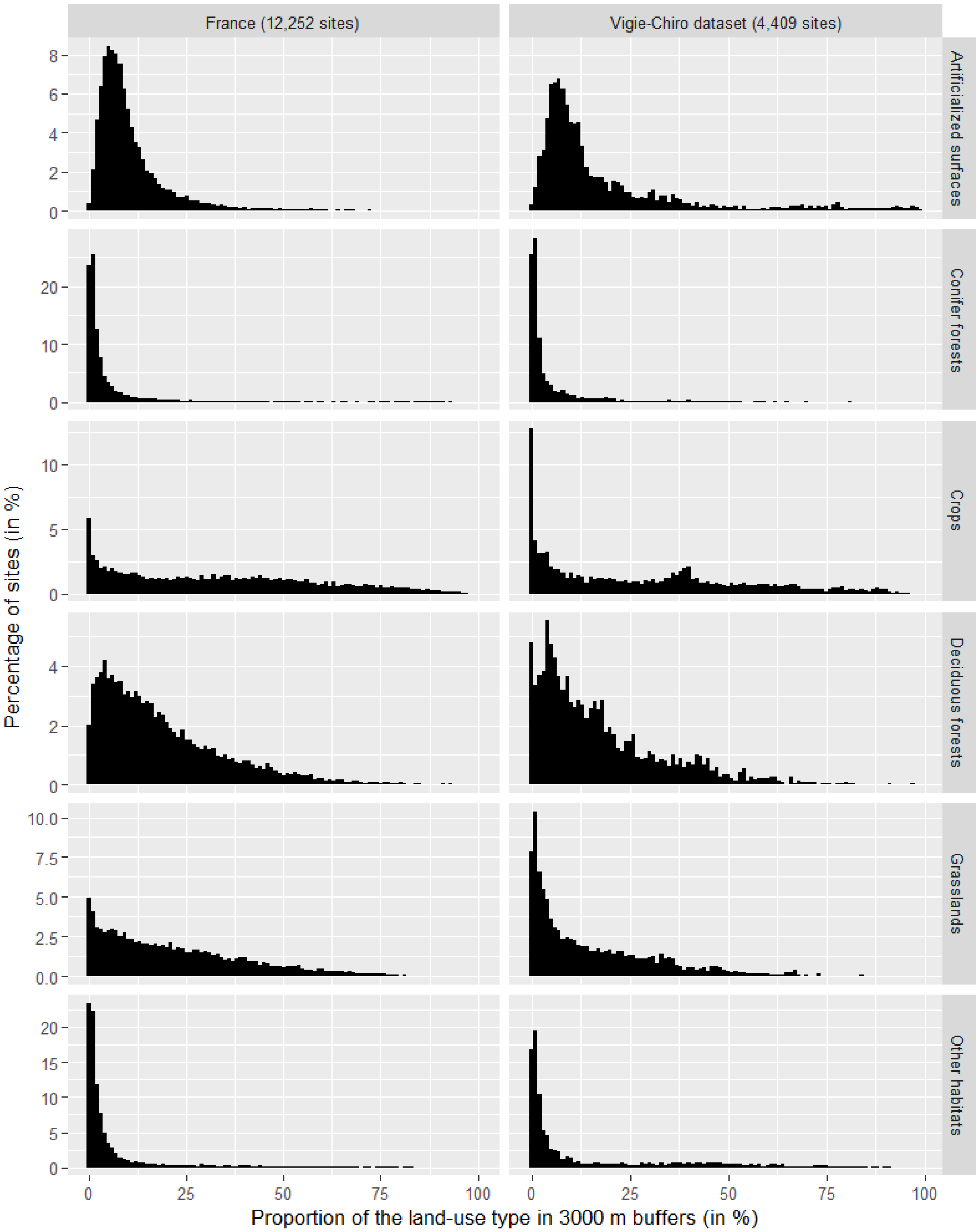

Fig. B.2: Gradients of the proportions of each land-use type in 3000 m buffer zones around randomly sampled sites in France (every 6000 m, below 500 m above sea level) and the sites of the Vigie-Chiro dataset (below 500 m above sea level)

representativeness of the sample design was a major concern. When a volunteer wanted to participate to the “stationary points protocol”, he was thus encouraged to survey randomly sampled sites near a municipality that he had selected. He could also choose where he wanted to carry out the sampling sessions. To ensure that the sample of surveyed sites was representative of the distribution of habitats in France, we randomly sampled sites in a square grid (6000 m * 6000 m) in France and discarded sites that were above 500 m above sea level (as we only kept Vigie-Chiro sites that were below this altitude, see Appendix B *3) Data curation*). For each of these randomly sampled sites (12,252), we extracted the proportion of each land-use type in 3,000 m buffer zones and compared it to the proportion of each land-use type in the buffer zones around the studied sites of our dataset. Overall, the buffer zones around the sites of our dataset covered the same gradients of land-use type as the buffer zones around sites randomly sampled in France (Fig. B.2).

Volunteers were asked to carry out the sampling sessions when weather conditions were relatively favourable for bats, i.e. no rain was forecasted, windspeed below 30 km.h^{-1} (8.33 m.s^{-1}) and a relatively clement temperature at the beginning of the night (depending on the local context).

Table B.1: After data curation, by studied species: number of passes recorded, nights monitored and sites monitored. In the column “*Medium activity*”: medium activity thresholds in number of passes per night (Bas et al., 2020) used for data curation. In the column “*Departments*”: distribution range according to Arthur & Lemaire, (2015), the numbers are the official geographical codes of the French departments (see Figure B.3 for a spatial representation of the distribution range of each species according to Arthur & Lemaire, (2015)). Species are ranked according to their number of sites in the dataset after curation.

Species	**Passes**	**Nights**	**Sites**	**Medium activity**	**Departments**
Pipistrellus pipistrellus	5 700 561	7683	3658	41	*All France*
Pipistrellus kuhlii	1 965 676	5654	2732	18	Absent from: 52,54,57,59,88
Nyctalus leisleri	213 943	4984	2512	4	*All France*
Eptesicus serotinus	222 265	4299	2323	4	*All France*
Myotis nattereri	80 068	4056	2217	2	*All France*
Barbastella barbastellus	119 900	3651	1879	2	Absent from: 75,92,93,94,95
Myotis daubentonii	366 494	2248	1205	3	*All France*
Rhinolophus ferrumequinum	60 765	2076	1187	1	Absent from: 59,67,75,78,92,93,94
Plecotus austriacus	28 916	1909	1164	2	*All France*
Nyctalus noctula	90 602	2100	1139	3	Absent from: 2A,2B
Rhinolophus hipposideros	36 173	1842	1097	1	Absent from: 59,75,78,91,92,93,94
Pipistrellus pygmaeus	625 166	1895	1011	8	Absent from: 23,53,61,70,71
Pipistrellus nathusii	136 276	1822	958	7	Absent from: 32
Myotis emarginatus	17 099	1481	911	2	Absent from: 75,92,93,94
Myotis mystacinus	85 893	1492	862	4	*All France*
Hypsugo savii	53 694	1292	783	4	Present in: 01,03,04,05,06,07,09,11,12,13,15,16,19,24,25,26,2A,2B,30,31,33,34,36,38,39,42,43,46,47,48,55,63,64,65,66,69,73,74,81,82,83,84,90
Myotis myotis/blythii	7746	1127	783	1	Absent from: 2A,2B,75,92,93,94
Miniopterus schreibersii	26 848	1343	776	2	Absent from: 02,08,14,27,28,29,45,50,51,58,59,60,61,62,67,75,76,77,78,80,90,91,92,93,94,95
Tadarida teniotis	87 988	926	568	4	Present in: 01,04,05,06,07,09,11,12,13,15,25,26,2A,2B,30,31,34,38,39,42,43,46,48,64,65,66,69,70,73,74,81,82,83,84
Plecotus auritus	2965	290	226	1	Absent from: 2A,2B

2. Species identification

Species identification was performed with the Tadarida software, which automatically detects and extracts sound parameters of recorded sound events (Figure B.1 *2)*). Using a random forest algorithm, it classifies them into classes according to a confidence index value (https://github.com/YvesBas/Tadarida-C/; Bas, Bas, & Julien, 2017). We considered bat passes, defined as the occurrence of a single or several bat calls during a 5-s interval (Millon et al., 2015) as a proxy for activity.

We discarded species for which there was not enough data (i.e. species that, after data curation, were found in less than 200 sites) and/or species for which we considered that automatic identification was not robust enough: *Eptesicus nilssonii*, *Myotis alcathoe*, *Myotis bechsteinii*, *Myotis brandtii*, *Myotis capaccinii*, *Myotis dasycneme*, *Myotis punicus*, *Nyctalus lasiopterus*, *Plecotus macrobullaris*, *Rhinolophus euryale*, *Rhinolophus mehelyi* and *Vespertilio murinus*. We chose to keep *Myotis blythii* and *Myotis myotis* despite their high acoustic similarity (Barataud and Tupinier, 2020) by grouping them in a class named Great *Myotis*. Eventually, we focused on 20 species or group of species (Table B.1).

3. Data curation

We only kept passes whose confidence index value was greater than 0.5, to obtain, for each species, a maximum error rate tolerance of 0.5 (minimisation of false positives while keeping a high number bat passes, Barré et al., 2019) (Figure B.1 *3)*). For each species, we retained only the monitored nights with (1) at least one pass of the species with a high confidence index value (maximum error rate tolerance greater than or equal to 0.1), (2) at least a medium activity. The thresholds used to characterise the level of activity for each species were those of the national reference scale developed with the Vigie-Chiro dataset (the quantile 0.25 of the total number of this species' passes per night being the threshold for having at least a medium

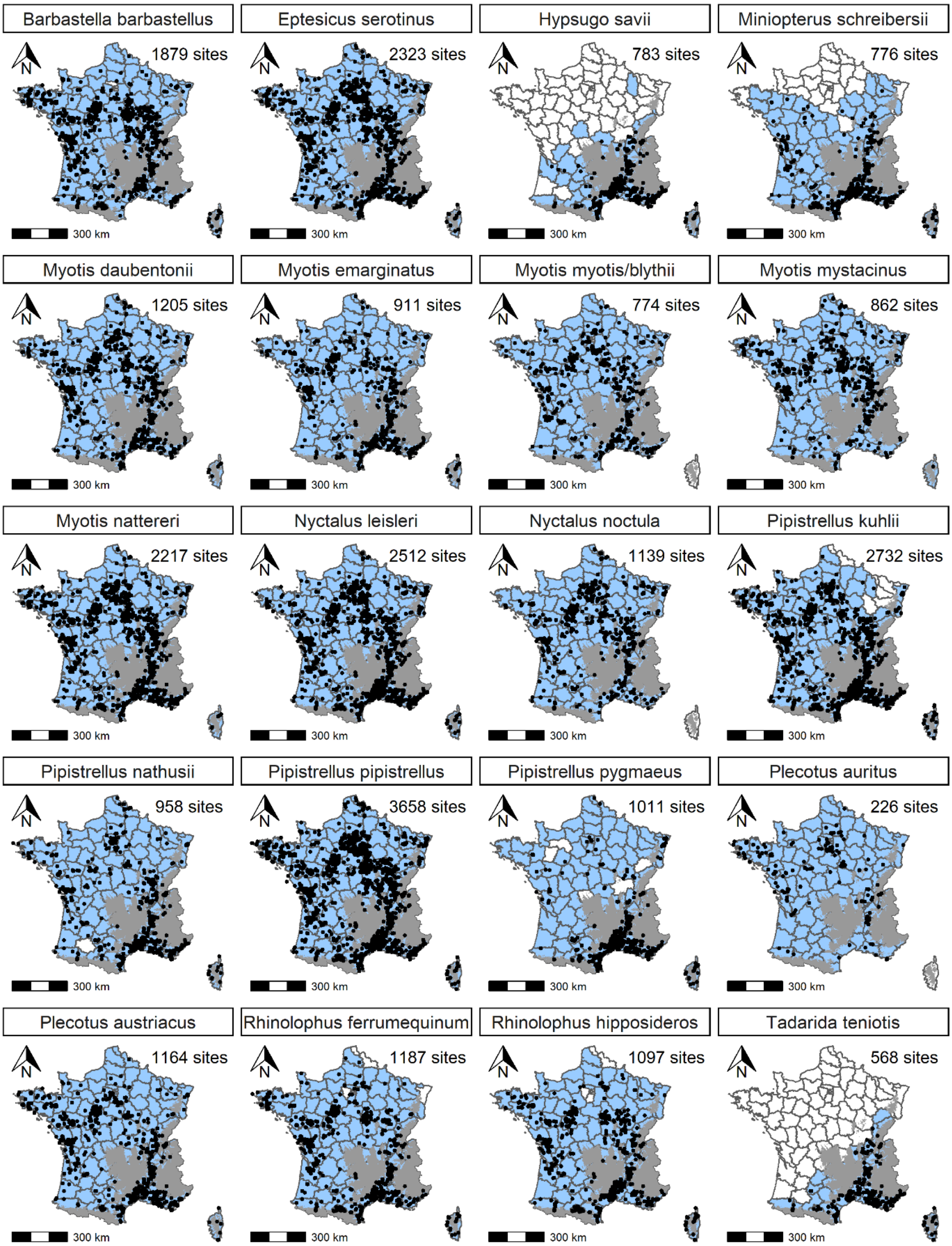
Barbastella barbastellus
1879 sites
Eptesicus serotinus
2323 sites
Hypsugo savii
783 sites
Miniopterus schreibersii
776 sites
Myotis daubentonii
1205 sites
Myotis emarginatus
911 sites
Myotis myotis/blythii
774 sites
Myotis mystacinus
862 sites
Myotis nattereri
2217 sites
Nyctalus leisleri
2512 sites
Nyctalus noctula
1139 sites
Pipistrellus kuhlii
2732 sites
Pipistrellus nathusii
958 sites
Pipistrellus pipistrellus
3658 sites
Pipistrellus pygmaeus
1011 sites
Plecotus auritus
226 sites
Plecotus austriacus
1164 sites
Rhinolophus ferrumequinum
1187 sites
Rhinolophus hipposideros
1097 sites
Tadarida teniotis
568 sites
N
300 km

Fig. B.3: Sites monitored by species (black dots) after data curation. In grey, mountain environments (defined as areas above 500 m above sea level), sites in these areas were discarded. In white, French departments where the species is absent (has never been found) according to Arthur & Lemaire (2015), sites in these departments were discarded. In blue, departments where the species has been found at least once according to Arthur & Lemaire (2015) (including departments where the species may have disappeared since, departments where the species is present but little known, departments where the species is exceptionally observed, departments where the species is rare or fairly rare, departments where the species is uncommon or locally common and departments where the species is fairly common to very common).

activity, Table B.1) (Bas et al., 2020) (Figure B.1 *4)*). The objective of these filters was to consider only the sampling sessions during which the presence of the species was highly probable and high enough to be studied.

To avoid bias due to specific diel activity patterns near bat roosts (e.g. earlier activity at the beginning of the night), we excluded sampling sessions carried out near potential bat roosts. We also discarded surveys carried out in mountain environments (defined as sites above 500 m above sea level) to avoid biases due potential particular behaviours in such environments (Cryan et al., 2000; McCain, 2007). To discard some of the remaining false positives, for each species, we excluded sites that where outside their known distribution range according to Arthur & Lemaire (2015) (Table B.1, Figure B.3) (Figure B.1 *5)*). To ensure result robustness against automated identification errors that could persist despite the precautions we took when filtering data, we chose to follow the approach of Barré et al. (2019) (Appendix C). We showed that our results were not sensitive to the error rates considered and were robust against automated identification errors.

The total number of passes, nights and sites eventually studied by species are presented Table B.1.

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Appendix C: Robustness of the automated identification

As the confidence in the automated identification is an important issue in such a study, we provide in this appendix additional information on the robustness of the identification.

Firstly, Tadarida-C (i.e. the software module of the Tadarida toolbox which handles the classification of all detected sound events, Bas et al., 2017) is now integrating a contextual classifier in addition to classification based on acoustic features. It uses similar random forest algorithms as those in Metcalf et al., (2022) and is trained over more than 90,000 bat occurrences in recording files. Like in Metcalf et al., (2022), this greatly reduces error rates (by a factor of three) by taking into account the relative abundance of each species during the night, and the distribution of confidence scores among detection events.

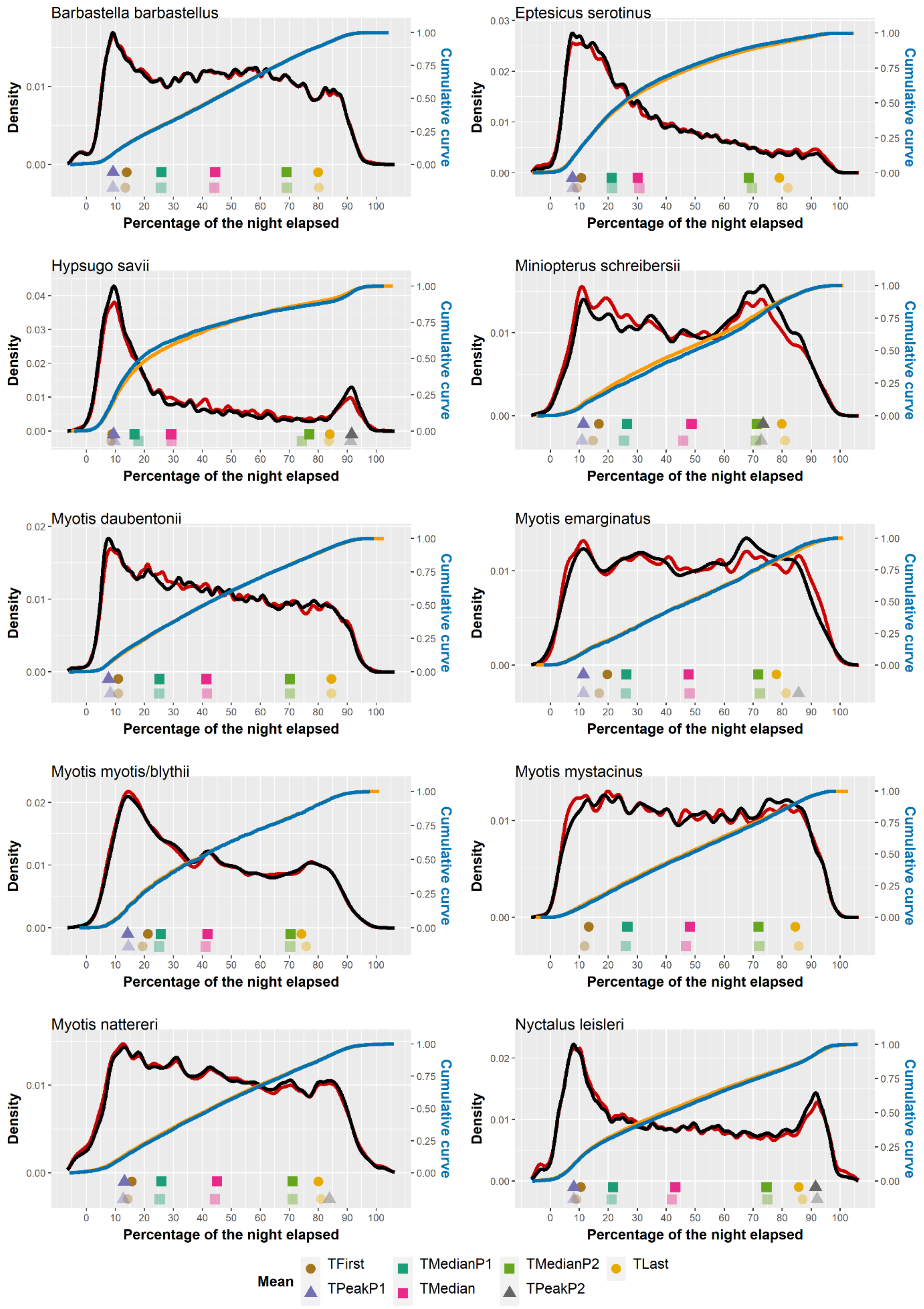
Secondly, several filters applied to the dataset during the **data curation** (detailed in Appendix B) were designed to reduce the number of false positives per species as much as possible. By applying these filters, we considerably reduced the number of bat passes, nights and sites for species whose identification through Tadarida was not robust enough. These species therefore ended up not being considered as they were found in less than 200 sites after data curation.

Eventually, to ensure the robustness of the results against automated identification errors that could persist despite the precautions we took when filtering and analysing the data, we chose to follow the approach of Barré et al. (2019). For each species, this consisted in comparing:

(1) the results we obtained with a maximum error rate tolerance (MERT) of 0.5 which minimises false positives while keeping a high number of bat passes (*main analyses in the manuscript)*

(2) with the results we obtained with a MERT of 0.1 which limits false positives but discards more true positives.

As shown in Fig. C.1, the results are highly consistent whether we used a MERT of 0.5 or a MERT of 0.1. This confirms that our results are not sensitive to the error rates considered and are robust against automated identification errors.


Barbastella barbastellus
Eptesicus serotinus
Hypsugo savii
Miniopterus schreibersii
Myotis daubentonii
Myotis emarginatus
Myotis myotis/blythii
Myotis mystacinus
Myotis nattereri
Nyctalus leisleri
Density
Cumulative curve
Percentage of the night elapsed
0
10
20
30
40
50
60
70
80
90
100
0.00
0.25
0.50
0.75
1.00
0.01
0.02
0.03
0.04
Mean
● TFirst
▲ TPeakP1
■ TMedianP1
■ TMedian
■ TMedianP2
▲ TPeakP2
● TLast

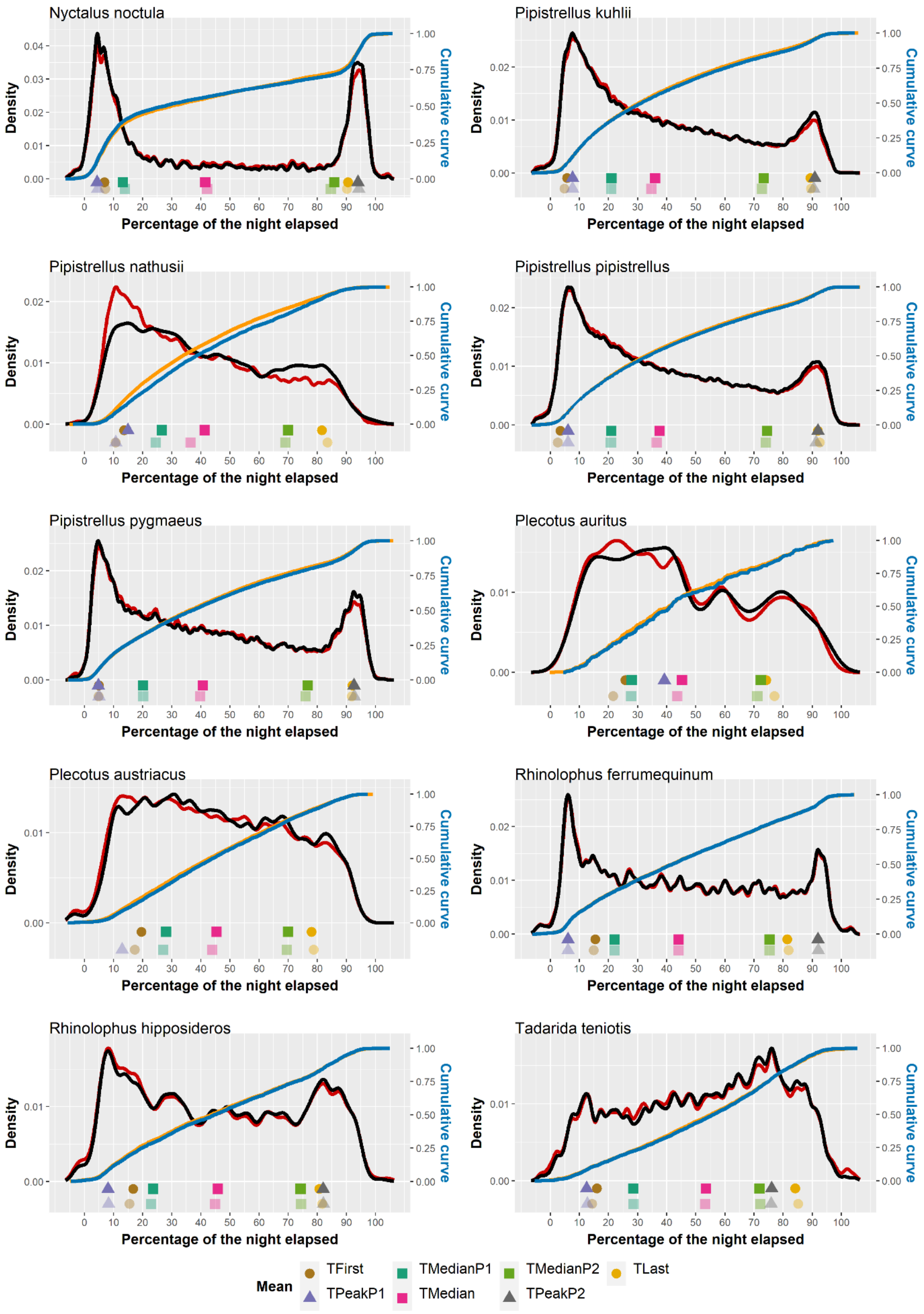

Nyctalus noctula
Pipistrellus kuhlii
Pipistrellus nathusii
Pipistrellus pipistrellus
Pipistrellus pygmaeus
Plecotus auritus
Plecotus austriacus
Rhinolophus ferrumequinum
Rhinolophus hipposideros
Tadarida teniotis
Density
Cumulative curve
Percentage of the night elapsed
0.00
0.01
0.02
0.03
0.04
0.25
0.50
0.75
1.00
0
10
20
30
40
50
60
70
80
90
100
Mean
TFirst
TPeakP1
TMedianP1
TMedian
TMedianP2
TPeakP2
TLast

Fig. C.1: Comparison of the results obtained with a MERT of 0.1 and a MERT of 0.5 for each species studied. In black and red, estimated density of activity according to the percentage of the night elapsed with a MERT of 0.1 and of 0.5 respectively. In blue and orange, cumulative curve of weighted bat activity with a MERT of 0.1. and 0.5 respectively. The symbols represent the mean times of the key descriptors and the times of the activity peaks detected. The top symbols are for a MERT of 0.1 and the lighter symbols at the bottom are for a MERT of 0.5.

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Bas, Y., Bas, D., Julien, J.-F., 2017. Tadarida: A Toolbox for Animal Detection on Acoustic Recordings. Journal of Open Research Software 5, 6. https://doi.org/10.5334/jors.154

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Appendix D: Additional information on the methods designed to characterise and compare bat diel activity patterns

1. Key descriptors

To compute the times of the key descriptors, we had to consider the hierarchical structure of our dataset. Monitored sites were composed of one or several monitored nights during which bat passes were recorded. Hence, we applied the following workflow for each species:

(i) **By night** (kept for the species after data curation): we calculated the times of the five key descriptors.

(ii) **By site**: if there were several monitored nights, we calculated a mean time by site for each key descriptor. We postulated that the more passes of a species during a night there are, the more robust the estimation of the times of the key descriptors. We hence calculated the following weighted mean:

$$\boldsymbol{descr_j} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{N_j}} \boldsymbol{descr_{i,j}} \times \boldsymbol{descr_{j,i}} \qquad \text{(Eq D.1)}$$

With:

$$\boldsymbol{weight_{j,i}} = \frac{\mathbf{log(1} + \boldsymbol{P_{j,i}})}{\sum_{\boldsymbol{i=1}}^{\boldsymbol{N_j}} \mathbf{log(1} + \boldsymbol{P_{j,i}})} \qquad \text{(Eq D.2)}$$

With:

$\mathbf{j}$ = site ID; $\mathbf{i}$ = ith night of a site;

$\mathbf{drecr_j}$ = “mean” time of a given key descriptor at the site$_j$;

$\mathbf{descr_{,i}}$ = time of a given key descriptor during the ith night of the site$_j$;

$\mathbf{N_j}$ = number of surveyed nights at the site$_j$, $\mathbf{P_{j,i}}$ = number of passes of the night$_{i,j}$

(iii) **Over the whole dataset**: we calculated a weighted mean of the mean time of the key descriptors by site based on the number of passes by site. We hence had to define the mean number of passes by site, to reflect the weight applied on the calculation of the times of the key descriptors, we defined it as follows:

$$\mathbf{P_j} = [\textstyle\sum_{\mathbf{i=1}}^{\mathbf{N_j}} \mathbf{P_{j,i}} \times \mathbf{log(1 + P_{j,i})}] \;/\; [\textstyle\sum_{\mathbf{i=1}}^{\mathbf{N_j}} \mathbf{log(1 + P_{j,i})}] \qquad \text{(Eq D.3)}$$

With:

j = site ID; **i** = ith night of a site; **P_j** = “mean” number of passes of the site$_j$;

$P_{j,i}$ = number of passes of the night$_{j,i}$; **N_j** = number of surveyed nights at the site$_j$

We then calculated the following weighted mean:

$$\boldsymbol{descr} = \sum_{\boldsymbol{j=1}}^{\boldsymbol{S}} \boldsymbol{descr_j} \times \boldsymbol{weight_j} \qquad \text{(Eq D.4)}$$

With:

$$\boldsymbol{weight_j} = \frac{\mathbf{log(1} + \boldsymbol{P_j})}{\sum_{\boldsymbol{j=1}}^{\boldsymbol{S}} \mathbf{log(1} + \boldsymbol{P_j})} \qquad \text{(Eq D.5)}$$

With:

j = site ID; **descr** = “mean” time of a given key descriptor over the whole dataset;

$descr_j$ = “mean” time of a given key descriptor at the site$_j$; **S** = number of sites;

P_j = “mean” number of passes of the site$_j$

2. Activity distribution throughout the night

To characterise the activity distribution throughout the night of each species, we estimated a density of activity (kernel density estimates, R function *density*). In previous studies (e.g. Day et al., 2015; Newson et al., 2015), some authors considered the number of bat passes during given time periods (e.g. every hours, every 15 min). In comparison, density estimation better accounted for the continuous aspect of our data. We chose a Gaussian smoothing kernel and the data-based bandwidth selection method proposed by Sheather and Jones (1991) which has been widely recommended for its overall good performance (Sheather, 2004). We used the default setting (n = 512) for the number of equally spaced time points at which the density was to be estimated, ranging from the time of the earliest bat pass in our dataset to the latest (i.e. from about -7 to 106 % of the night elapsed).

To estimate the activity distribution throughout the night of a given species, we used all its passes kept after data curation as, for rare species particularly, there were not enough passes by night to characterise their activity distribution by night. We had to account for the hierarchical structure of our dataset so that, for instance, the activity distribution throughout the night would not be based on a few nights with many passes or a few sites with many monitored nights. Thus, we attributed a weight to each pass so that:

(i) a site weight (Eq C.5) in the density calculation would be based on the mean number of passes of that site (Eq C.3),

(ii) a night weight inside a site (Eq C.2) would be based on the number of passes during this night,

(iii) each pass of a given night in a given site would have the same weight.

Eventually each pass weight in the density calculation was calculated as follows:

$$\boldsymbol{weight_{j,i,k} = \frac{weight_{j,i} \times weight_{j}}{P_{j,i}}} \qquad \text{(Eq D.6)}$$

With:

j = site ID; **i** = ith night of a site; **k** = kth pass in a night; $\mathbf{P_{j,i}}$ = number of passes of the night$_{j,i}$

$\mathbf{weight_{j,i,k}}$ = weight of the kth pass of the ith night of the site$_j$ in the density estimation;

$\mathbf{weight_{j}}$ = see (Eq C.5); $\mathbf{weight_{j,i}}$ = see (Eq C.2)

We constructed 95% confidence bands for the estimated densities using bootstrap. We computed 1000 resamples – with replacement – of as many sites as in the original dataset for each species. For the 1000 resamples, we estimated the density of activity with the same parameters as above (the weight of each pass being updated according to the resample considered). The lower limit of the confidence band was then defined as the value of the quantile 0.025 of all these resamples at each time points (as a reminder: 512 equally spaced time points between -7 to 106 % of the night elapsed) and the upper limit as the value of the quantile 0.095.

To detect the times of the activity peaks based on the estimated density of activity (TPeakP1 for peaks occurring during the first part of the night, TPeakP2 for peaks occurring during the second part):

(i) We detected local maxima in a window equivalent to a quarter of the night (169 time points) around time points for which the density was estimated (with reflecting boundary condition).

(ii) We calculated a peak score for each time point as follows:

$$\textbf{peak score}_{\mathbf{x}} = \textbf{density}_{\mathbf{x}} - \textbf{mean}\ (\textbf{density of the temporal neighbours}) \quad \text{(Eq D.7)}$$

With:

x = a time point for which the density of activity was estimated;

density$_{\mathbf{x}}$ = the density of activity estimated at x;

temporal neighbours = temporal window equal to a quarter of the night around x (i.e. 64 time points to the left and the right of x, with reflecting boundary condition).

(iii) We detected time points that corresponded to the times of local density maxima and whose peak score was greater than the quantile 0.9 of all the peak scores (R package *scorepeak* (Ochi, 2019)).

We calculated a cumulative curve of weighted bat activity throughout the night using the cumulative weight of all passes ranked by increasing percentage of the night elapsed. For a given time period during the night (starting at time 1 and ending at time 2), the value of the cumulative curve at time 2 minus the value of the cumulative curve at time 1 corresponded to the percentage of weighted bat passes occurring during this time period in our dataset, hereafter called percentage of weighted activity.

To assess whether the weighted activity of a species was concentrated around activity peaks or more evenly distributed throughout the night, we searched for the 15 % interval of the night during which its weighted activity was maximum. To do this, we considered each pass of this species and we calculated the percentage of its weighted activity occurring during the 15 % interval of the night starting from the time of that pass. If the weighted activity was evenly distributed throughout the night, the maximum percentage of weighted activity occurring during a 15 % interval of the night would be close to 15 %. If the weighted activity was concentrated around peaks, the maximum percentage of weighted activity occurring during a 15 % interval of the night would be much higher than 15 % and this 15 % interval of the night would cover the time of an activity peak.

3. Clustering of the species

To determine whether species could be grouped according to similarities in their diel activity patterns, we performed a Hierarchical Clustering on the Principal Components (HCPC) of a Principal Component Analysis (PCA) (R package *FactoMineR* (Lê et al., 2008)) using the times of the key descriptor and the times of the activity peaks. As we did not detect activity peaks for some species (during the first part of the night and/or the second part), we imputed the missing values with the PCA model, so that the imputed values had no weight on the results of the PCA (R package *missMDA* (Josse and Husson, 2016)). We compared the average of each variable (mean time of key descriptors and times of activity peaks) for the species in each cluster with the overall average (i.e. the average for all species studied). We tested whether the average in each cluster was equal to the overall average (see test in Husson et al., 2010, 2009).

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Table E: Mean time of the key descriptor s and time of the activity peaks in percentage of the night elapsed. Species are named with their species codes (correspondence between codes and full Latin and English names in Table F). Species are ranked by increasing value of TFirst. "Sd" is the weighted standard deviation of the times of the key descriptors calculated by site. For TFirst and TMedianP1, the ealier the time, the yellower the cell, and the later the time, the greyer the cell. For TLast and TMedianP2, the later the time, the yellower the cell, and the earlier the time, the greyer the cell. The clusters into which the species were classified according to the HCPC (C: crepuscular species, I: intermediate species, D: late species) are in the column "*Cl.*".

Species	**Cl.**	**TFirst**		**TPeakP1**	**TMedianP1**		**TMedian**		**TMedianP2**		**TPeakP2**	**TLast**	
		Mean	*Sd*	/	Mean	*Sd*	Mean	*Sd*	Mean	*Sd*	/	Mean	*Sd*
Pippip	C	2.55	4.33	6.06	20.81	8.95	36.55	18.39	74.08	10.19	91.34	92.56	7.08
Pipkuh	I	4.84	4.77	7.61	20.94	9.31	34.73	18.77	72.74	10.56	90.45	89.58	7.85
Pippyg	C	4.89	5.44	4.96	20.20	9.68	39.82	20.75	75.97	11.51	92.66	91.82	7.52
Nycnoc	C	7.14	8.42	4.52	13.86	10.96	42.12	32.94	84.70	12.35	94.21	90.24	10.11
Hypsav	I	8.58	6.55	9.60	17.93	9.87	29.34	20.86	74.32	12.51	91.12	83.67	11.71
Nyclei	I	8.98	8.59	8.05	21.16	11.10	42.02	23.86	74.89	11.84	92.00	86.99	10.66
Eptser	I	9.12	7.00	7.83	21.27	9.83	30.72	17.77	69.60	11.01	NA	81.94	11.66
Pipnat	I	10.68	6.42	10.70	24.47	9.37	36.41	17.17	68.97	9.01	NA	83.54	9.26
Myodau	I	10.99	8.69	8.27	25.12	9.61	41.60	17.70	70.22	8.84	NA	84.51	9.74
Myomys	L	11.78	9.08	NA	26.01	10.35	46.86	19.46	72.03	9.63	NA	85.68	8.90
Barbar	L	13.50	9.84	9.16	25.75	10.99	44.21	18.85	69.23	9.69	NA	80.28	10.44
Myonat	L	14.26	10.97	12.69	25.29	10.73	44.30	19.54	71.16	10.30	83.83	80.96	11.28
Tadten	L	14.38	11.58	12.69	28.58	11.49	53.21	20.51	72.15	9.99	75.87	85.19	10.68
Minsch	L	14.71	9.60	10.92	25.42	10.18	45.95	19.00	70.92	9.12	72.78	80.96	10.09
Rhifer	I	14.95	12.54	6.06	22.07	12.56	44.07	24.47	75.34	12.53	92.00	81.89	13.26
Rhihip	L	15.44	12.01	8.27	22.90	12.04	44.89	23.49	74.41	10.79	82.06	81.66	11.63
Myoema	L	16.89	11.50	11.36	25.98	11.21	48.11	20.51	72.32	10.29	85.59	81.29	11.23
Pleaus	L	17.33	10.89	12.91	27.00	10.84	43.81	19.02	69.52	9.86	NA	78.76	11.00
MyoGS	L	19.43	10.50	14.46	25.07	10.59	41.09	21.13	70.31	10.30	NA	75.87	11.24
Pleaur	L	21.61	12.17	NA	27.77	10.25	43.64	21.36	71.15	11.94	NA	77.03	12.94

Table F: Correspondence between species codes (first three letters of the Latin genus name and first three letters of the Latin species name) and Latin and English full names.

Species code	**Latin name**	**English name**
Barbar	*Barbastella barbastellus*	Western barbastelle
Eptser	*Eptesicus serotinus*	Serotine bat
Hypsav	*Hypsugo savii*	Savi's pipistrelle
Minsch	*Miniopterus schreibersii*	Common bent-wing bat
Myodau	*Myotis daubentonii*	Daubenton's bat
Myoema	*Myotis emarginatus*	Geoffroy's bat
MyoGS	*Myotis myotis/blythii*	Great *myotis*
- Myomyo	- *Myotis myotis*	- Greater mouse-eared bat
- Myobly	- *Myotis blythii*	- Lesser mouse-eared bat
Myomys	*Myotis mystacinus*	Whiskered bat
Myonat	*Myotis nattereri*	Natterer's bat
Nyclei	*Nyctalus leisleri*	Lesser noctule
Nycnoc	*Nyctalus noctula*	Common noctule
Pipkuh	*Pipistrellus kuhlii*	Kuhl's pipistrelle
Pipnat	*Pipistrellus nathusii*	Nathusius's pipistrelle
Pippip	*Pipistrellus pipistrellus*	Common pipistrelle
Pippyg	*Pipistrellus pygmaeus*	Soprano pipistrelle
Pleaur	*Plecotus auritus*	Brown long-eared bat
Pleaus	*Plecotus austriacus*	Grey long-eared bat
Rhifer	*Rhinolophus ferrumequinum*	Greater horseshoe bat
Rhihip	*Rhinolophus hipposideros*	Lesser horseshoe bat
Tadten	*Tadarida teniotis*	European free-tailed bat

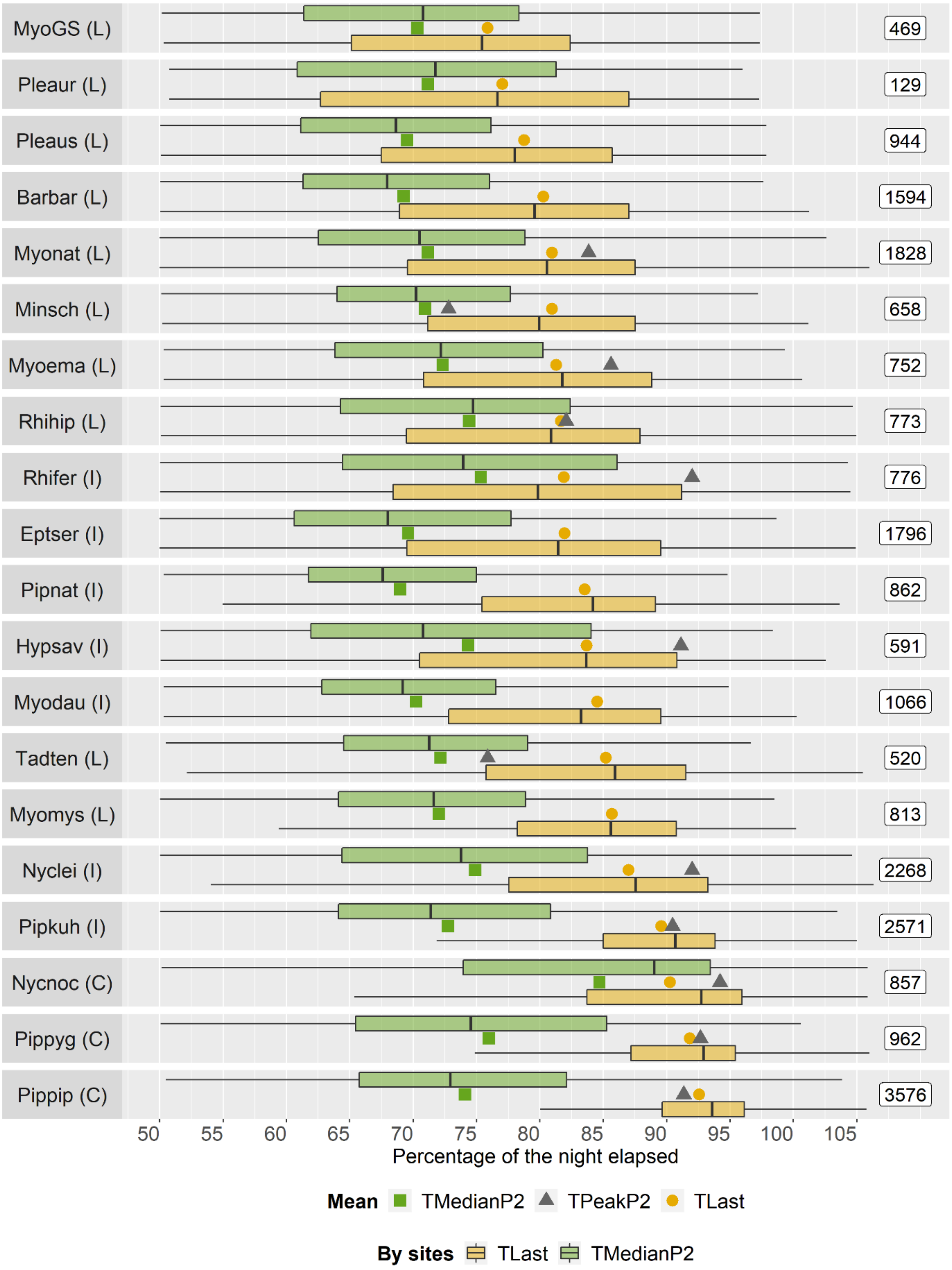
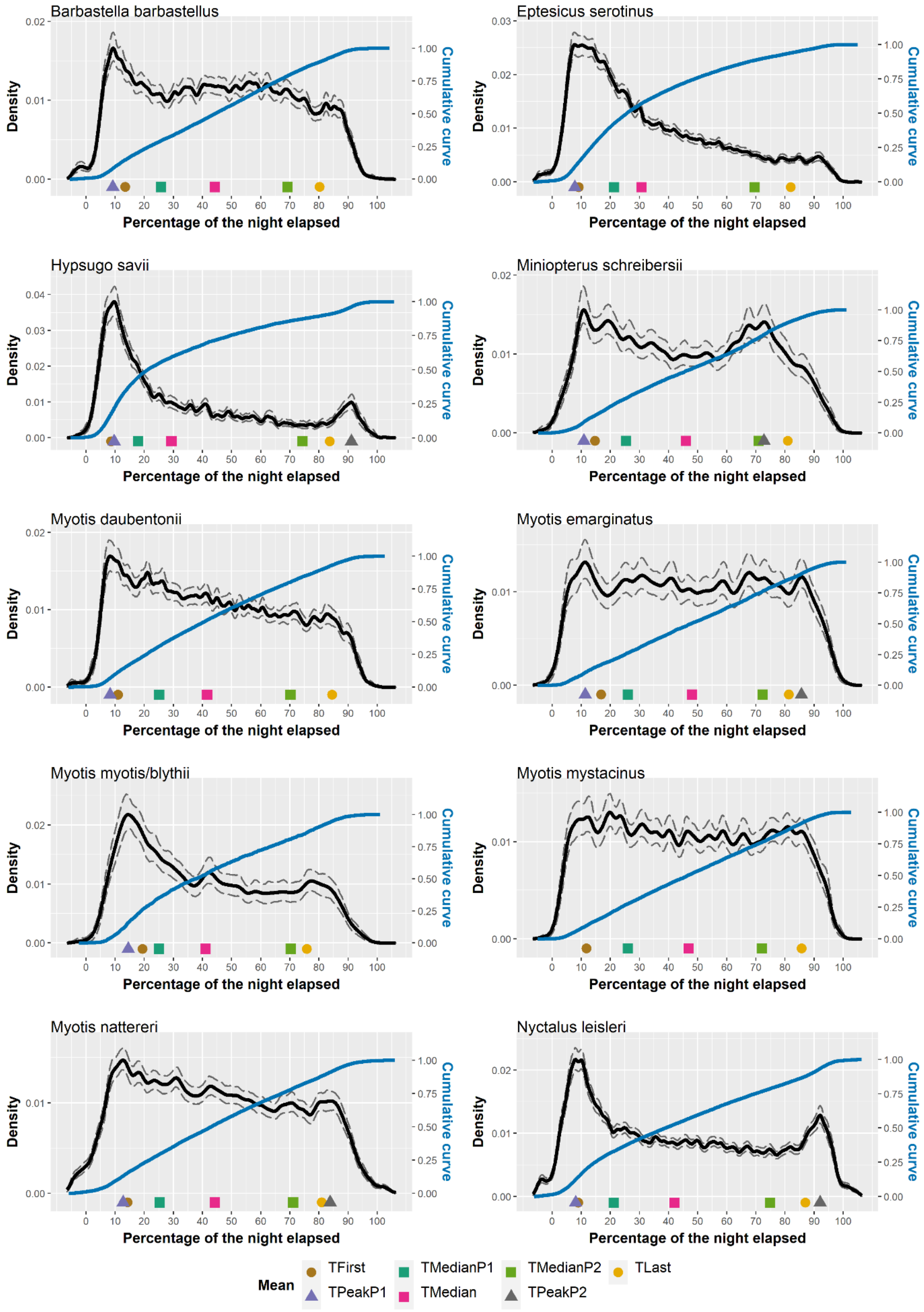


Fig. G: TLast, TPeakP2 and TMedianP2 for each bat species. On the left are the codes of the species studied (correspondence between the codes and the full Latin and English

names in Table F), followed by the cluster in which they were classified according to the HCPC (C: crepuscular species, I: intermediate species, L: late species). On the right is the number of sites by species. Species are ranked by increasing value of mean TLast.


Barbastella barbastellus
Eptesicus serotinus
Hypsugo savii
Miniopterus schreibersii
Myotis daubentonii
Myotis emarginatus
Myotis myotis/blythii
Myotis mystacinus
Myotis nattereri
Nyctalus leisleri
Density
Cumulative curve
Percentage of the night elapsed
0
10
20
30
40
50
60
70
80
90
100
0.00
0.01
0.02
0.03
0.04
0.25
0.50
0.75
1.00
Mean
TFirst
TPeakP1
TMedianP1
TMedian
TMedianP2
TPeakP2
TLast

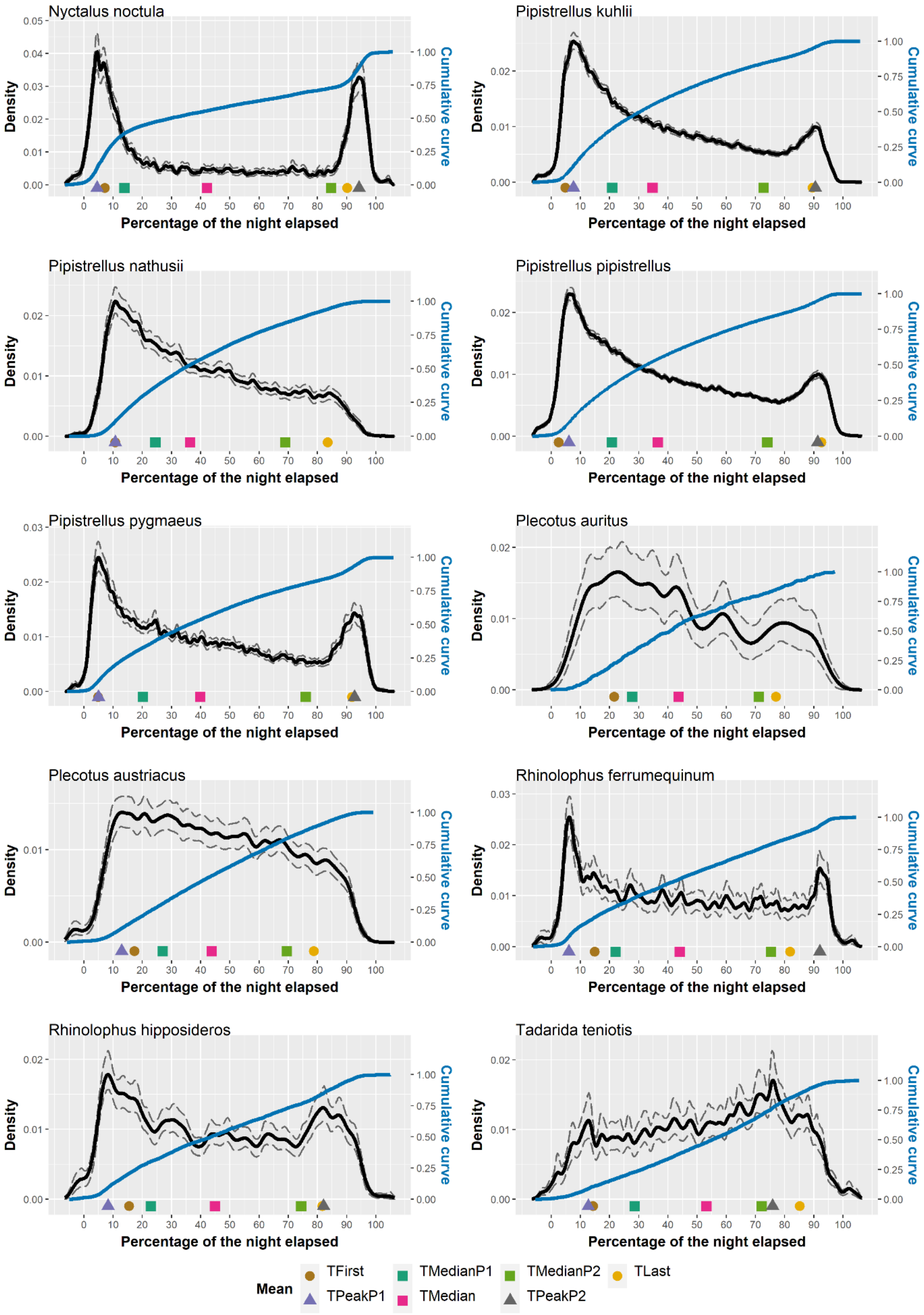

Nyctalus noctula
Pipistrellus kuhlii
Pipistrellus nathusii
Pipistrellus pipistrellus
Pipistrellus pygmaeus
Plecotus auritus
Plecotus austriacus
Rhinolophus ferrumequinum
Rhinolophus hipposideros
Tadarida teniotis
Density
Cumulative curve
Percentage of the night elapsed
0
10
20
30
40
50
60
70
80
90
100
0.00
0.01
0.02
0.03
0.04
0.05
0.25
0.50
0.75
1.00
Mean
TFirst
TPeakP1
TMedianP1
TMedian
TMedianP2
TPeakP2
TLast

Fig. H: Activity distribution throughout the night for the twenty species studied: in black, estimated density of activity according to the percentage of the night elapsed. In blue, cumulative curve of weighted bat activity. The dashed lines represent the 95 % confidence bands for the estimated density. Symbols represent the mean times of the key descriptors and the times of the activity peaks detected.

Table I: Descriptive metrics on bat activity distribution throughout the night: *"Activity 15%"* is the maximum percentage of weighted activity in a 15 % interval of the night. "*Interval 15 %*" is the lower and upper limits (in percentage of the night elapsed) of the 15 % interval of the night during which the percentage of weighted activity was equal to "*Activity 15*". "*Activity before 10 %*" and "*Activity after 90 %*" correspond to the percentage of weighted activity occurring before 10 % of the night had elapsed and after 90 % of the night had elapsed respectively. Correspondence between the codes and the full Latin and English names can be found in Table F. Species are ranked by increasing "*Activity 15 %*".

Species	Activity 15 %	Interval 15 %	TFPeak	Activity before 10 %	Activity after 90 %
Hypsav	43.1	[4.0 , 19]	9.6	23.0	4.9
Nycnoc	38.3	[0.6 , 15.6]	4.5	31.3	22.8
Eptser	35.7	[5.3 , 20.3]	7.8	16.7	2.8
Pipkuh	31.5	[3.8 , 18.8]	7.6	17.7	4.7
Pipnat	29.2	[6.7 , 21.7]	10.7	9.4	1.7
MyoGS	29.0	[8.8 , 23.8]	14.5	6.5	1.4
Pippip	28.2	[3.1 , 18.1]	6.1	18.2	6.2
Pippyg	26.9	[2.3 , 17.3]	5.0	18.7	9.9
Nyclei	26.0	[3.8 , 18.8]	8.1	16.5	9.1
Pleaur	24.7	[11.6 , 26.6]	NA	4.2	3.5
Rhifer	24.6	[3.8 , 18.8]	6.1	16.0	9.2
Rhihip	23.4	[5.1 , 20.1]	8.3	12.5	5.4
Myodau	22.4	[6.3 , 21.3]	8.3	9.9	2.5
Tadten	21.6	[63.7 , 78.7]	12.7	6.0	5.5
Minsch	21.2	[8.2 , 23.2]	10.9	7.2	2.8
Barbar	20.9	[5.9 , 20.9]	9.2	9.7	1.8
Pleaus	20.6	[10.7 , 25.7]	12.9	6.5	2.2
Myonat	20.2	[7.5 , 22.5]	12.7	9.3	3.3
Myomys	18.5	[9.0 , 24]	NA	8.4	4.2
Myoema	17.4	[4.2 , 19.2]	11.4	8.3	4.6

Appendix J: Clustering results

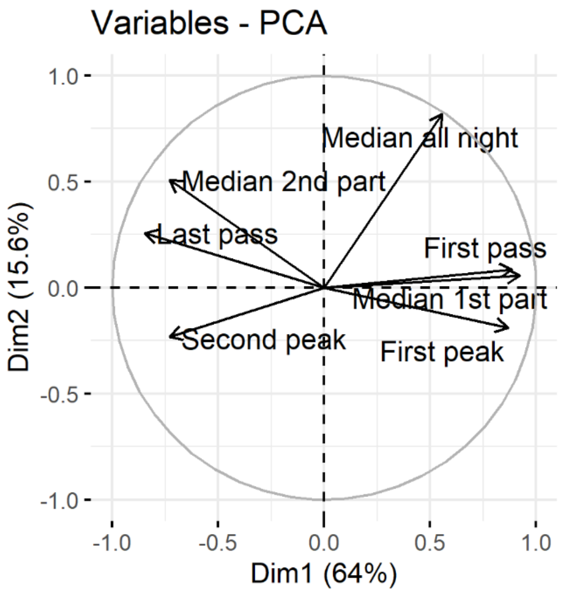


Fig. J.1: PCA graph of variables (R package *factoextra* (Kassambara and Mundt, 2020)). The two first dimension explain 79.6% if the total inertia.

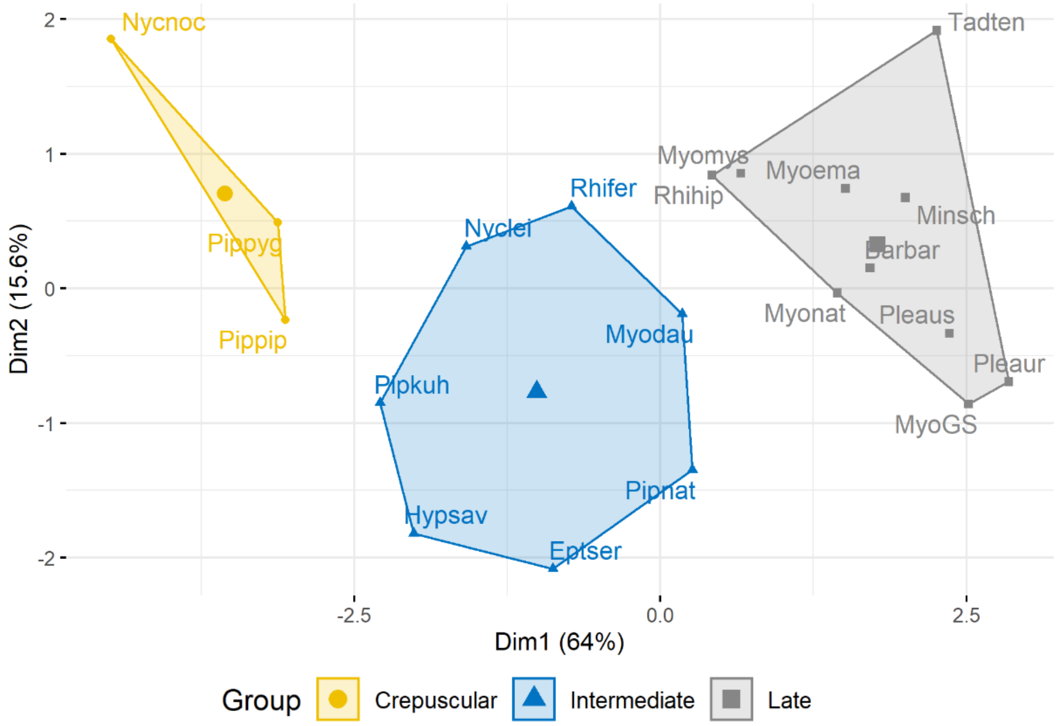


Fig. J.2: Visualisation of the clustering results: species (correspondence between the codes and the full Latin and English names in Table F) are represented by points in the plot, using principal components of the PCA. An ellipse is drawn around each cluster.

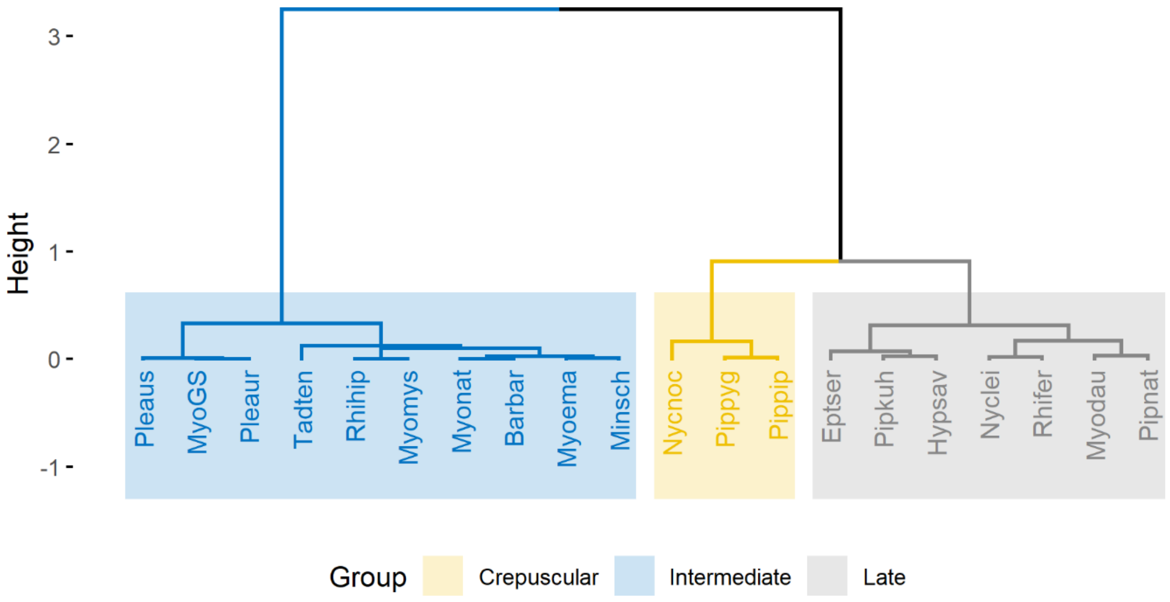


Fig J.3: Visualisation of the clustering results: cluster dendrogram (correspondence between the species codes and the full Latin and English names in Table F).

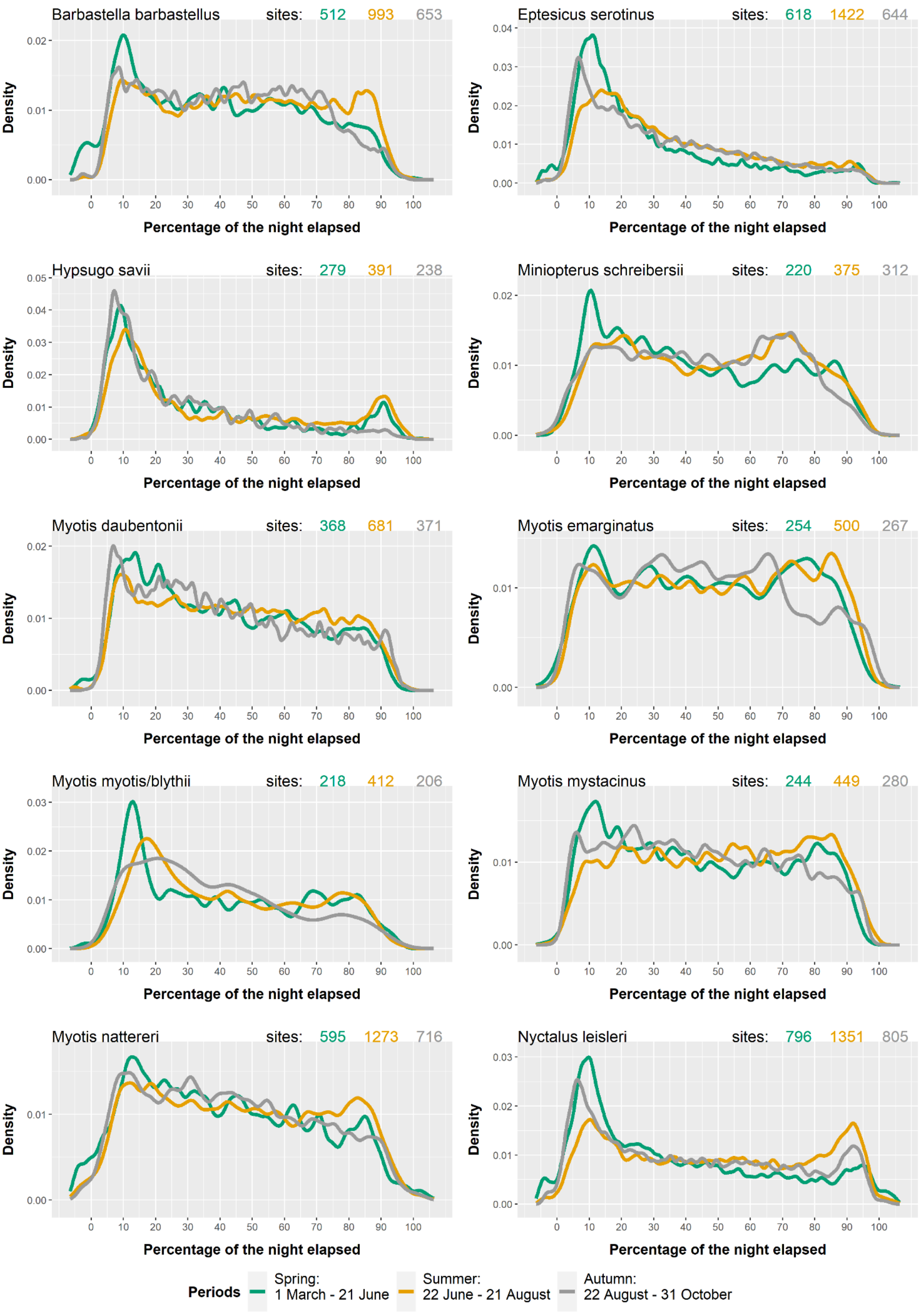
Table J.1: Description of the clusters: "*Average in cluster*" and "*Sd in cluster*" correspond respectively to the average and the standard deviation of the variables (mean times of the key descriptors or times of the activity peaks) for the species in the cluster, "*Overall average*" and "*Overall sd*" correspond respectively to the overall average and the standard deviation of the variables for all species. In the columns "*v.test*" and "*p.value*", the following hypothesis was tested: "*the average of the cluster is equal to the overall average*": the sign of the v.test indicates if the average of the cluster was greater or lower than the overall average and a value of the v.test > 1.96 corresponds to a p-value < 0.05. The "*Cluster*" column indicates according to which cluster the variable was considered (C: crepuscular species, I: intermediate species, L: late species). Only variables for which the p-value was lower than 0.05 for the cluster are shown.

Key descriptors	v.test	Average in cluster	Overall average	Sd in cluster	Overall sd	p.value	Cluster
TLast	3.1524	91.5432	83.7215	0.9669	4.5433	0.0016	C
TMedianP2	2.9308	78.2486	72.7010	4.6240	3.4660	0.0034	C
TPeakP2	2.0884	92.7357	85.8413	1.1736	6.0449	0.0368	C
TPeakP1	-2.5868	5.1786	9.6639	0.6504	3.1750	0.0097	C
TMedianP1	-2.6466	18.2917	23.3792	3.1399	3.5200	0.0081	C
TFirst	-2.6873	4.8600	12.1035	1.8755	4.9356	0.0072	C
TMedian	-2.6583	36.9832	41.6701	5.3433	5.6393	0.0079	I
TFirst	-2.6598	36.9832	41.6724	5.3433	5.6390	0.0078	L
TMedianP1	3.3827	15.9338	12.1035	2.7818	4.9356	0.0007	L
TPeakP1	3.2153	25.9757	23.3792	1.4885	3.5200	0.0013	L
TMedian	3.1553	11.9622	9.6639	2.4694	3.1750	0.0016	L
TLast	3.0422	45.6081	41.6724	3.1213	5.6390	0.0023	L
TPeakP2	-2.8332	80.7684	83.7215	2.9510	4.5433	0.0046	L

Bibliography:

Husson, F., Josse, J., Pagès, J., 2010. Principal component methods-hierarchical clustering-partitional clustering: why would we need to choose for visualizing data? (Technical Report of the Applied Mathematics Department). Agrocampus.

Kassambara, A., Mundt, F., 2020. factoextra: Extract and Visualize the Results of Multivariate Data Analyses.


Barbastella barbastellus sites: 512 993 653
Eptesicus serotinus sites: 618 1422 644
Hypsugo savii sites: 279 391 238
Miniopterus schreibersii sites: 220 375 312
Myotis daubentonii sites: 368 681 371
Myotis emarginatus sites: 254 500 267
Myotis myotis/blythii sites: 218 412 206
Myotis mystacinus sites: 244 449 280
Myotis nattereri sites: 595 1273 716
Nyctalus leisleri sites: 796 1351 805
Density
0.00
0.01
0.02
0.03
0.04
0.05
0
10
20
30
40
50
60
70
80
90
100
Percentage of the night elapsed
Periods
Spring: 1 March - 21 June
Summer: 22 June - 21 August
Autumn: 22 August - 31 October

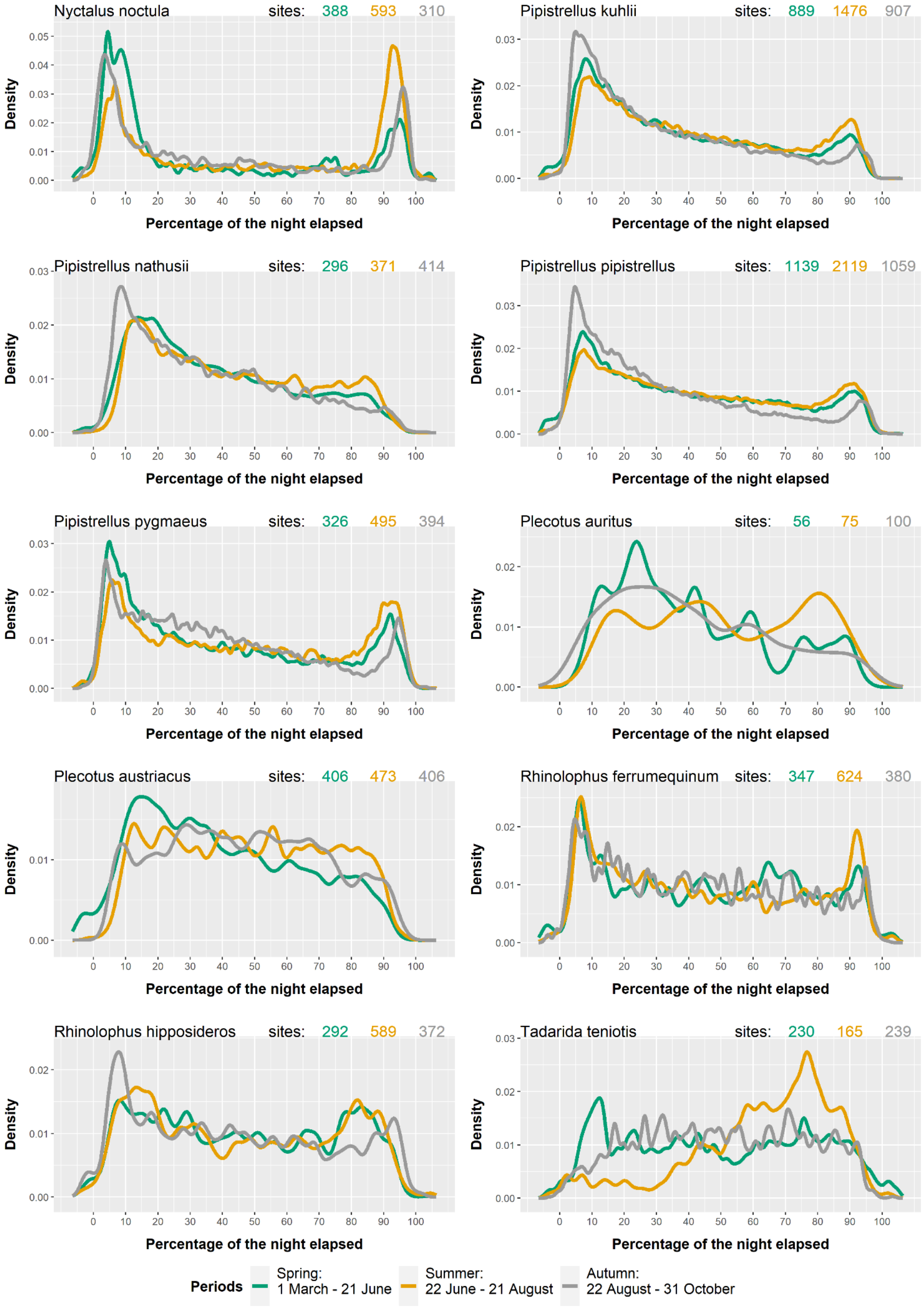
Nyctalus noctula
sites: 388 593 310
0.05
0.04
0.03
0.02
0.01
0.00
Density
Pipistrellus kuhlii
sites: 889 1476 907
0.03
0.02
0.01
0.00
Pipistrellus nathusii
sites: 296 371 414
Pipistrellus pipistrellus
sites: 1139 2119 1059
Pipistrellus pygmaeus
sites: 326 495 394
Plecotus auritus
sites: 56 75 100
Plecotus austriacus
sites: 406 473 406
Rhinolophus ferrumequinum
sites: 347 624 380
Rhinolophus hipposideros
sites: 292 589 372
Tadarida teniotis
sites: 230 165 239
0
10
20
30
40
50
60
70
80
90
100
Percentage of the night elapsed
Periods
Spring: 1 March - 21 June
Summer: 22 June - 21 August
Autumn: 22 August - 31 October

Fig. K: Activity distribution throughout the night for the 20 species studied according to season, in percentage of the night elapsed. Top right, number of sites considered for each season.