

Stridulation rate as a thermometer in *Tettigonia viridissima*: a season-long automated record and a test against archive recordings

Thirty-seven nights in one garden, and a test against 178 archive recordings

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Abstract

That an insect's song rate follows its temperature has been known since Dolbear proposed reading a cricket as a thermometer in 1897. The relation is not in doubt; its functional form is. Walker (1975a) found stridulation rate approximately linear in ten species of *Orchelimum* and, reanalysing fifteen published datasets, found linear fits better than exponential in thirteen — but his data were hand-timed and spanned 12–26 °C.

Here I report a season-long automated record. A phone recorder and an on-site weather station logged the nightly chorus of *Tettigonia viridissima* — identified acoustically from the recordings by two specialists working independently — in one garden in the Vexin français from 26 June to 24 September 2026. Echeme repetition rate was measured automatically from the amplitude-modulation spectrum of the 9–12 kHz carrier band and paired with air temperature logged every five minutes at the microphone. Thirty-seven nights spanned 14.6–28.3 °C and a 2.89-fold range of rate; rate and temperature correlate at $r = 0.986$, with residual scatter equivalent to 0.63 °C.

Comparing five functional forms on common residuals, a quadratic fits best, and all seven nights below 17.4 °C fall below an exponential extrapolated from the warmer thirty. Walker's split-half test cannot separate linear from exponential here either, but admitting a quadratic resolves it out of sample: the relation is convex and sub-exponential, refining his finding rather than contradicting it. Decomposing the two-syllable echeme shows its two intervals carrying different apparent activation energies (55.5 and 36.1 kJ/mol), so the measured rate is a composite.

Tested against 178 archive recordings from 22 recordists in 14 countries, the relation reproduces but its coefficient does not: precision is 0.65 °C where calibrated and about 1.6 °C where not, though for four of five recordists the uncalibrated curve is accurate to roughly half a degree. Archives collected for other taxa may therefore carry a usable temperature record, at a precision set by what the recordist wrote down.

Keywords: stridulation, thermometry, *Tettigonia viridissima*, passive acoustic monitoring, Arrhenius, ectotherm, bioacoustics

1. Introduction

Ectotherm signal rates depend on body temperature, and the idea of reading an insect as a thermometer is Victorian. Dolbear (1897) published a single page in *The American Naturalist*

proposing that the number of cricket chirps counted in a fixed interval gives the air temperature, and offering a linear rule to convert one to the other. The note contains two measurements. It is nonetheless the ancestor of a rule of thumb that survives in field guides, in almanacs and on the internet to this day, usually in the form "count the chirps in thirteen seconds and add forty."

What is already established is more than the popular rule suggests, and less than the rule's confidence implies. The physiological basis is secure: song rate tracks thoracic rather than ambient temperature, and in some katyids the two differ substantially. Heath and Josephson (1970) measured thoracic temperatures 5–15 °C above ambient in singing *Neoconocephalus robustus*, with the gradient largest on the coldest nights, and observed a warm-up period before song began. Any relation measured against screen temperature is therefore an empirical calibration, not a direct reading of the process that generates the rate, and this has consequences that run through the whole of what follows.

The functional form of the relation is contested, and the exponential should not be taken as the default. Walker (1975a) recorded the calling songs of ten species of *Orchelimum*, 9 to 52 recordings per species over ranges up to 20 °C, and found wingstroke rate approximately linear in every one of them: r^2 from 0.76 to 0.99, mean 0.93, slopes from 0.9 to 5.1. Extrapolated to zero rate, the ten regression lines converged at 10.9 ± 1.9 °C. He then reanalysed fifteen published datasets spanning 12–26 °C and found that thirteen fitted a straight line better than an exponential; in a split-half prediction test, the linear model won twenty-six times out of thirty. He noted that thirteen datasets with r^2 above 0.90 showed the same convergence behaviour, and that seven species of electric fish converge at 4.0 ± 1.8 °C. His conclusion was explicit: Q_{10} presupposes an exponential, poikilotherm nervous systems are generally not exponential, and the slope and intercept of a linear fit are more informative than a Q_{10} . A companion paper (Walker 1975b) examined temperature, humidity and age in *Atlanticus* and found humidity without effect on stridulatory rate.

Walker's work is fifty years old and has not been superseded, which raises the obvious question of what is left to do. The answer is in the structure of his own data rather than in any defect of it. Over a range of 12–26 °C, a linear and an exponential function differ by less than the scatter of hand-timed field recordings, so the choice between them turns on the error model rather than on the observations. Resolving the form requires either a wider range or a tighter error, and preferably both. What has not been available is a season-long record in which the rate is measured automatically by a fixed algorithm and the temperature is logged at the microphone rather than read from a nearby station or a thermometer held in the hand.

There is also a new reason to care about the answer. Passive acoustic monitoring now generates archives far larger than the questions they were collected to answer (Gibb et al. 2019), and those archives are almost always analysed one taxon at a time. Newson et al. (2017) showed what else is in them: taking the Norfolk Bat Survey, a citizen-science deployment of passive detectors aimed at bats, they extracted over 260,000 recordings of Speckled Bush-cricket and detected Great Green Bush-cricket (*Tettigonia viridissima*) at two sites, one of them a new record for the species. They also observed that the Speckled Bush-cricket's song lies above the hearing range of most human observers and that the species is consequently under-recorded. Their question was which species the archives contain. The question here is one step further on: whether the same recordings also carry a record of what temperature it was.

This paper reports thirty-seven nights of stridulation from a single garden in the Vexin français, one species, identified acoustically and independently by two specialists and never collected or seen, with air temperature logged on site every five minutes and the echeme repetition rate

measured automatically from the amplitude-modulation spectrum. Rate and temperature correlate at $r = 0.986$, with residual scatter equivalent to $0.63\text{ }^{\circ}\text{C}$.

I claim four things, and not the relation itself, which is Walker's and Dolbear's before him. First, a season-long automated record with temperature logged at the microphone, where the existing work is hand-timed and short-run. Second, a decomposition of the two-syllable echeme showing its two constituent intervals carrying different apparent activation energies, so that the quantity conventionally measured is a composite. Third, a test against 178 archive recordings by 22 recordists in 14 countries, which supports the relation while showing its coefficient to be non-transferable. Fourth, a result at the cold end: with thirty-seven nights, a convex but sub-exponential form fits better out of sample than either a straight line or an exponential, which refines Walker's finding rather than overturning it. If rate does carry temperature at the precision reported here, the existing acoustic archives hold a second climatic record alongside the biological one they were gathered for.

2. Materials and methods

2.1 Site and season

All recordings were made in one garden at Longuesse, Vexin français, France (49.0667° N , 1.9333° E , 160 m a.s.l.), a hedgerow-bordered garden of about 1500 m^2 with mature shrubs, bramble and unmown grass margins. Recording ran from 26 June to 24 September 2026. Thirty-seven nights met the acceptance criteria set out in §2.6 and form the dataset analysed here.

The chorus was treated throughout as a single acoustic source. Individual singers were not localised or counted, and no attempt was made to separate them; the measured rate is that of the dominant singer in the clip, which the consistency checks of §2.6 are designed to confirm.

2.2 Recording

Audio was captured with a smartphone recorder at 44.1 kHz, 32-bit float, written as uncompressed WAV. The phone was placed on a fixed exterior sill approximately 4 m from the nearest singing perch, in the same position on every night of the season.

Uncompressed audio is not a stylistic preference here but a requirement. The signal of interest occupies 9–12 kHz, a region where perceptual codecs allocate few bits and synthesise content to fill the gap. A single test clip re-encoded as HE-AAC and decoded returned a spectral flatness of 0.93 in that band, against 0.42 for broadband noise and far above anything a tonal stridulation produces: the encoder had replaced the band with noise of its own manufacture while leaving the waveform superficially plausible. Any measurement of modulation rate in that band would have been a measurement of the codec. No lossy audio was admitted at any stage.

A change of recorder or recording application is an instrument change and was treated as one. Where the chain changed, the two chains were co-recorded for at least five nights before the new one was used, and no night from the first five on a new chain was read as biology.

2.3 Clip selection

From each night's tape, a single five-minute clip was analysed: the final five minutes of the recording, falling between 30 and 90 minutes after civil dusk. The clip was selected by position in the tape and not by its contents, so that the selection cannot have favoured nights with a clearer signal. Selecting the last five minutes also places every clip at a comparable stage of the evening's thermal decline.

2.4 Rate measurement

Rate was measured from the amplitude-modulation spectrum of the carrier band. The clip was band-pass filtered to 9–12 kHz, the analytic envelope taken, and the power spectrum of that envelope computed by Welch's method over thirteen overlapping windows spanning the clip. The echeme repetition rate was identified as the fundamental of the envelope spectrum between 2 and 40 Hz.

Estimating the fundamental by taking the largest peak is unreliable here, because a periodic envelope with sharp onsets puts substantial power into its harmonics and the second or third harmonic is frequently the tallest. The fundamental was therefore estimated by harmonic-product scoring: for each candidate frequency, the mean log power at the candidate and its first three harmonics was computed, and the lowest candidate scoring within 15 % of the maximum was accepted. A synthetic two-syllable song constructed at a known 6.10 Hz returns 18.33 Hz — the third harmonic — under peak-picking, and 6.10 Hz under harmonic-product scoring.

The same code, with the same parameters, was applied to every clip in the season and to every archive recording in §3.7. No clip was measured by hand and no parameter was tuned per clip.

2.5 Temperature

Air temperature was recorded by an Ecowitt weather station in the same garden, in a shielded enclosure approximately 12 m from the recording position and 1.5 m above ground, logging every five minutes. Each clip was paired with the station reading nearest to the clip's own clock time; the maximum pairing offset is 2.5 minutes.

Relative humidity was logged on the same schedule and is used in §3.5.

This is a screen temperature, not a body temperature. Heath and Josephson (1970) showed those can differ by 5–15 °C in a singing katydid, with the gradient largest in the cold. The relation reported here is therefore a calibration against a quantity that an observer can measure, which is what a thermometer requires, and not a measurement of the thermal physiology of the animal. §4.4 returns to the consequences.

2.6 Acceptance criteria

A night was accepted only if all of the following held.

- **Band signal-to-noise ratio ≥ 10 dB**, computed as the 9–12 kHz band power against the median of the spectral floor outside the band.
- **Band minus floor $\geq +6$ dB**. A negative value was treated as an instrument alarm before it was treated as biology; on two occasions it correctly identified a recording-chain fault rather than a silent garden.
- **Halves agree within 2 %**. The clip was split in two and measured independently; a disagreement larger than 2 % indicates either two singers at different temperatures or a drifting estimate, and the night was rejected.
- **Subharmonic check**. The candidate rate was tested against half its value to confirm the estimator had not latched onto a period-doubled envelope.
- **Window consistency**. At least 10 of the 13 analysis windows returned a rate within 2 % of the accepted value.

Nights failing any criterion were excluded without further examination. Six distinct failure modes were encountered over the season and are described in Appendix A.

2.7 Terminology

Terminology follows Ragge and Reynolds (1998): a *hemisyllable* is the sound of one half-stroke of the tegmina, a *syllable* the sound of one complete opening-and-closing cycle, an *echeme* a first-order group of syllables, and an *echeme-sequence* a group of echemes. In *T. viridissima* as recorded here, the song consists of echemes of two syllables repeated without pause, and the quantity measured in §2.4 is the *echeme repetition rate*. This is not the syllable rate, which is approximately twice it, nor a "pulse rate", a term this paper avoids because it has been used in the literature for all three.

The distinction matters for comparison with published figures. Barataud (2025), whose French terminology describes this species as singing *strophes* of variable length composed of *phrases* of two monosyllabic *cycles*, reports rates as echeme rates; several other sources report syllable rates, and the factor of two between them accounts for at least one apparent disagreement in the literature.

2.8 Statistics

Five functional forms were fitted: linear, quadratic, exponential in temperature (the Q_{10} form), Arrhenius (exponential in reciprocal absolute temperature), and the Schoolfield et al. (1981) formulation with a low-temperature deactivation term. Their full formulation carries both low- and high-temperature inactivation terms; only the low-temperature term is used here, because the data stop at 28.3 °C and a high-temperature term would be unconstrained.

All five were fitted in rate space by least squares and compared on common residuals in hertz by AIC. This matters: fitting the exponential forms in log space, as is conventional for an Arrhenius plot, weights the cold nights more heavily and does not produce residuals comparable with a least-squares linear or quadratic fit. Both estimates of the activation energy are reported in §3.2; they agree to about 3 %, which is itself worth recording.

Confidence intervals on the activation energy come from the covariance of the non-linear fit. The confidence interval on the linear zero-crossing comes from 5000 bootstrap resamples of the thirty-seven nights.

Model choice was additionally tested out of sample by the split-half prediction test Walker (1975a) used: each form is fitted on a random half of the nights and used to predict the other half, over 2000 random splits, and the form with the smaller prediction error wins the split. This was run in Walker's two-way form (linear against exponential) and in a three-way form admitting a quadratic.

Analysis code and the complete dataset are deposited (§Declarations); every figure quoted in §3.2 and §3.3 is reproduced by running `verify_models.py` in that deposit.

3. Results

3.1 The modulated band is not an artefact

Four independent properties of the 9–12 kHz band establish that it carries a biological signal rather than an instrumental one.

The modulation depth is large: envelope power at the fundamental exceeds the median envelope power by a factor of 14 to 77, depending on the night. The modulation is confined to the band — filtering to 12–15 kHz or to 6–9 kHz recovers no comparable periodicity. The rate varies by a factor of 2.89 over the season, which no fixed instrumental periodicity would do. And it varies with temperature, which is the subject of the rest of this section.

The fourth of these is the strongest, and the contrast with a non-biological source is instructive. A candidate second singer recorded at another site during the same season produced a strongly

modulated band at a comparable level, and was shown not to be an insect precisely because its rate did not move: 12.500 ± 0.010 Hz across 3 °C of overnight cooling, which is 50 Hz divided by four. A mains-locked device is ruled out by the stability that would otherwise recommend it.

3.2 Rate against temperature

Over thirty-seven nights spanning 14.6–28.3 °C, echeme repetition rate ranged from 5.67 to 16.38 Hz, a factor of 2.89. Rate and temperature correlate at $r = 0.9863$ ($p = 5.4 \times 10^{-29}$; Fig. 1a).

Plotted as $\ln$ rate against reciprocal absolute temperature (Fig. 2), the data are straight to the eye; the Arrhenius fit leaves residual scatter of 0.482 Hz. Divided by the local slope of 0.765 Hz/°C, this is equivalent to **0.63 °C**: the precision with which a night's temperature can be recovered from its song rate at this site.

The fitted coefficients are:

Quantity	Value
Linear slope	0.765 Hz/°C
Linear intercept	−5.565 Hz
Linear zero-crossing	7.28 °C (bootstrap 95 % CI 6.3–8.0)
Q ₁₀	2.02 (rate space); 2.08 (log space)
Activation energy E _a	51.2 ± 1.4 kJ/mol (rate space, 95 % CI 48.5–53.9)
	52.7 ± 1.7 kJ/mol (log space, 95 % CI 49.3–56.1)

The two estimates of E_a differ by 3 %, which is the price of the error model and smaller than the difference between most published values for the same species. The value quoted elsewhere in this paper is the rate-space estimate, 51.2 kJ/mol, since it is the one comparable with the model selection of §3.3.

The activation energy is conditional on the Arrhenius form being the right one. Section 3.3 shows that it is not quite, and E_a should be read as a summary coefficient over 14.6–28.3 °C rather than as the barrier height of a single rate-limiting step.

Two nights are poorly fitted and have no explanation. On 7 August the rate was 9.58 Hz at 17.5 °C, 1.80 Hz above the fitted curve and the largest residual of the season; on 23 August a comparable temperature gave a rate 22 % lower. Band quality was good on both nights (+20.4 dB and +16.1 dB) and both passed every acceptance criterion. Two singers of different size, or two different individuals, is the obvious explanation and is untested.

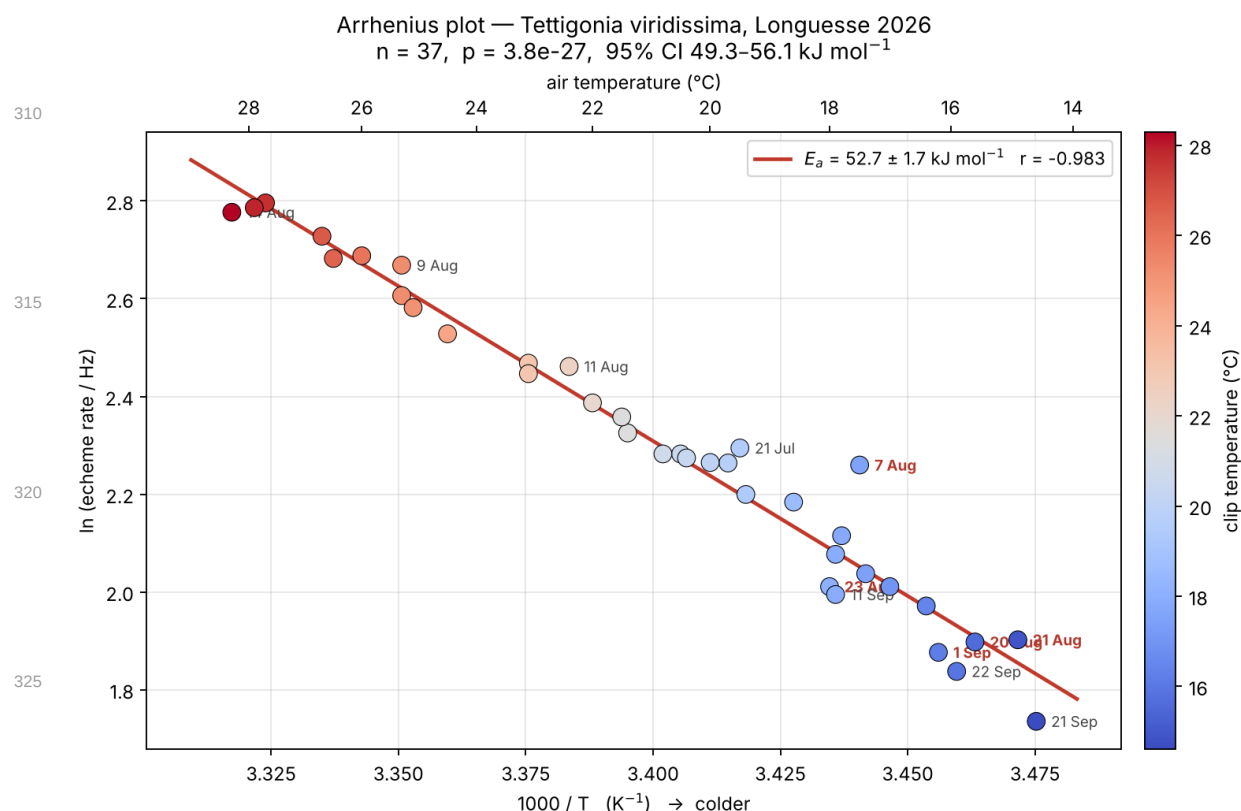


Figure 2. Arrhenius plot. Natural logarithm of echeme rate against reciprocal absolute temperature, points coloured by temperature, with the fitted line and its 95 % confidence interval on E_a . Over this 13.7 °C window 1/T varies by only 4.6 %, so the Arrhenius and Q_{10} forms are numerically almost indistinguishable: E_a is well determined *given* the model, and the model itself is not tested by this plot. The p-value shown is for the correlation of $\ln$ rate against 1/T and is therefore not the same quantity as the Pearson p quoted for rate against temperature in §3.2.

3.3 The shape of the relation

This is where the data bear on Walker's question, and the answer has two parts that must be kept separate.

Fitting all five forms in rate space and comparing on common residuals (the three fitted curves are shown in Fig. 1a):

Model	k	RMS (Hz)	AIC	Δ AIC
Quadratic	3	0.4627	-51.04	0.00
Arrhenius	2	0.4821	-49.99	+1.05
Sharpe-Schoolfield	4	0.4597	-49.51	+1.53
Q_{10} (exponential in T)	2	0.4930	-48.33	+2.70
Linear	2	0.5070	-46.26	+4.78

The quadratic is preferred, the straight line is the worst of the five, and the two forms in ordinary use sit between them. The Sharpe-Schoolfield fit places its low-temperature deactivation midpoint at 10.0 °C, below the sampled range, and buys its slightly lower RMS with two extra parameters.

First part: Walker's test does not separate linear from exponential here either. Run in his two-way form over 2000 random splits, the linear model won 996 and the exponential 1004, with mean out-of-sample prediction errors of 0.552 and 0.551 Hz respectively. That is a dead

heat, and it corroborates his central point rather than contradicting it: over a range of this width, with scatter of this size, the two forms are not distinguishable by prediction. Any Q_{10} quoted from such a range — including the one in §3.2 — is poorly determined as a mechanistic quantity.

Second part: admitting a quadratic resolves it. In the three-way test, the quadratic won 1261 splits of 2000 against 408 for the exponential and 331 for the linear, with mean prediction error 0.517 Hz against 0.551 and 0.552. The curvature therefore survives out-of-sample validation and is not an artefact of AIC rewarding a third parameter.

The cold end is where the forms separate and where the evidence is directional. Fitting an exponential to the thirty nights at or above 17.4 °C and extrapolating below that range, **all seven colder nights fall below the extrapolation**, by 0.02 to 0.91 Hz:

T (°C)	Observed (Hz)	Predicted (Hz)	Residual (Hz)
14.6	5.67	6.58	−0.91
14.9	6.70	6.72	−0.02
15.6	6.67	7.05	−0.38
15.9	6.28	7.19	−0.91
16.2	6.53	7.34	−0.81
16.4	7.18	7.44	−0.26
17.0	7.47	7.75	−0.28

Seven of seven on the same side is not proof, but the signs are systematic rather than scattered. Equally, those same nights fall above a straight line extrapolated from the warm nights: below about 17 °C the observations lie *between* the two conventional forms, and neither is right there (Fig. 1b).

One independent measurement does not agree with this, and it should be stated rather than left out. Barataud's (2025) reference recording of the species at 13 °C gives an echeme rate of 6.09 Hz. That is *above* the exponential extrapolated from the warm nights here, not below it — the opposite side from all seven of my own cold nights (Fig. 1). It is a single recording of a different population at a site I have not seen, with a temperature I did not measure, so it cannot settle anything; but it is the only independent point available below the sampled range, and it points the other way. The cold-end result of this section should be read with that in mind. If the roll-off is real it is not large enough for one recording from elsewhere to confirm, and the measurement that would settle it is the one described at the end of this section.

The reading consistent with all of this is that the relation is **convex but sub-exponential**: the rate falls somewhat faster in the cold than a single-barrier Arrhenius process predicts, while remaining far above a straight line. This is a refinement of Walker's result, not a contradiction of it. He established that these rates are not exponential over field ranges, and that a straight line predicts them at least as well; the thirty-seven nights here agree with the first half of that and add that a form between the two does better still.

The linear zero-crossing deserves comment because an earlier version of this work treated it as an absurdity. Extrapolated to zero rate, the straight line reaches zero at 7.28 °C (bootstrap 95 % CI 6.3–8.0). Walker found the regression lines of his ten *Orchelimum* species converging at 10.9 ± 1.9 °C, and seven species of electric fish converging at 4.0 ± 1.8 °C. The value found here sits at the edge of his katydid spread and well within the range his two taxa jointly describe. It is an instance of a known regularity, not an impossibility, and the convergence

Walker documented remains unexplained.

A caution on the whole of this section: the cold end rests on seven nights spanning 2.4 °C. The curvature is detectable and survives out-of-sample validation. Its form is not resolved. The measurement that would resolve it is a night near 12 °C, where the candidate forms differ by about 1.7 Hz — some three and a half times the residual scatter. The garden reaches 12 °C on most nights in late September, at around 01:00–02:00, roughly two and a half hours after the chorus has stopped.

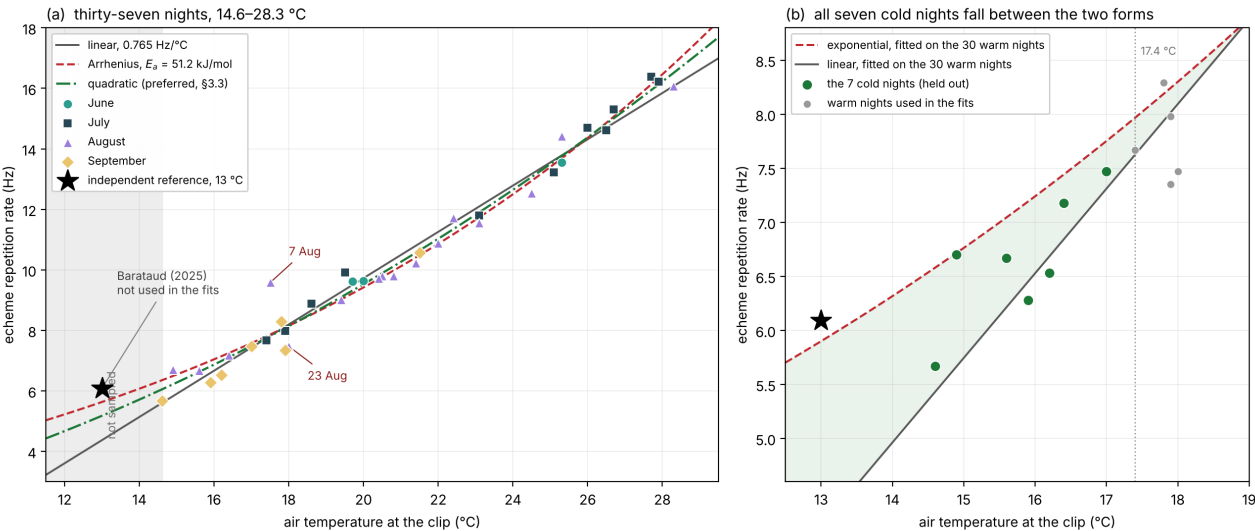


Figure 1. Echeme repetition rate against air temperature. (a) All thirty-seven nights, coloured by month, with the three candidate forms discussed in §3.3: linear (0.765 Hz/°C), Arrhenius ($E_a = 51.2$ kJ/mol) and the preferred quadratic. The shaded region below 14.6 °C was not sampled. The two nights labelled are the unexplained outliers of §3.2. (b) The cold end, with both forms fitted on the thirty nights at or above 17.4 °C and extrapolated below it, so that the seven colder nights are held out of the fit being tested. Every one falls below the exponential and above the straight line; the shaded wedge is the region between them. The star in both panels is an independent recording of the species at 13 °C (Barataud 2025), used in no fit. It lies above the extrapolated exponential — the opposite side from the seven cold nights — and is discussed in §3.3.

3.4 The internal structure of the echeme

The song is built of echemes of two syllables. The syllable count per echeme was constant at two across the full 12 °C range sampled: what changes with temperature is the timing, not the structure.

Measuring the two intervals separately shows them responding differently:

Interval	Slope	r	Apparent E_a
Between echemes	−4.90 ms/°C	−0.983	55.5 kJ/mol
Within echeme (syllable to syllable)	−1.42 ms/°C	−0.751	36.1 kJ/mol

The two apparent activation energies differ by a factor of about 1.5, and the between-echeme interval is both the more temperature-sensitive and the more tightly determined. The echeme repetition rate of §3.2 is therefore a composite of two processes with mismatched thermal sensitivities, and its E_a of 51.2 kJ/mol is a weighted average of 55.5 and 36.1, dominated by the longer interval. This is, as far as I can establish, not previously reported in this species, and it has a methodological consequence: a published activation energy for a stridulation rate is a property of whichever interval dominates the quantity measured, so figures derived from syllable rates and from echeme rates are not interchangeable even after correcting the factor of two.

I should record how this was found, because it bears on how much weight it can carry. The grouping was audible before any analysis looked for it: played at quarter speed, the song is plainly in pairs, and the measurement followed the hearing rather than the reverse.

Schul (1998) found that *T. viridissima* females do not require the double-pulse structure to recognise the song: a single long pulse lasting as long as the two pulses plus their gap was attractive, provided the merged pulse met a minimum duration and the gap between echemes fell between a minimum and a maximum. If recognition depends on the echeme as a unit and on the interval between echemes, but not on the internal split, then selection would act on the between-echeme interval and need not constrain the within-echeme one. That would be consistent with the tighter correlation and greater sensitivity observed for the former. This is a hypothesis offered for testing and not a result; distinguishing it from the simpler possibility that the within-echeme interval is just harder to measure would require within- individual recordings that this dataset does not contain.

3.5 Four negative results

No seasonal acclimation. Fitting each month separately gives predicted rates at 22 °C of 11.04, 11.08 and 11.11 Hz for June, July and August. An analysis of variance on the residuals grouped by month gives $F = 0.04$, $p = 0.963$. Over three months, with the chorus ageing and the season turning, the temperature-rate relation did not shift detectably.

No humidity effect. Residuals from the fitted curve against relative humidity give $r = +0.129$, $p = 0.51$ — not significant, and of the sign opposite to the one usually supposed. Walker (1975b) reported the same negative result for *Atlanticus*.

Carrier frequency constant. The dominant carrier was $10\,668 \pm 108$ Hz across the season, a coefficient of variation of 1.0 %, with no detectable trend against temperature. The carrier is set by the resonant properties of the tegmina; the rate is set by the nervous system driving them. That these behave differently is expected, and it is a useful internal control: an instrumental drift that moved the rate would be very likely to move the carrier too.

No period doubling. No night showed the echeme structure dropping to one syllable or extending to three, and the subharmonic check of §2.6 never fired on an accepted night.

3.6 Species identification

The singer was identified from its song. No specimen was collected and the animal was never seen.

The acoustic case is as follows. The carrier here, $10\,668 \pm 108$ Hz, compares with 10 069 Hz measured on an uncompressed reference recording of *T. viridissima*. Syllables per echeme here average 2.1 against 2.0–2.3 in the reference material. The between- and within-echeme intervals here range over 63.4–93.6 ms and 29.7–41.5 ms against 77.6 ms and 39.6 ms in the reference at a comparable temperature. The two plausible local confusions are excluded on structure rather than on frequency: *Pholidoptera griseoptera* produces echemes of a few syllables in short sequences (Ragge & Reynolds 1998), and *Metrioptera* species echemes of 5–15 syllables at 1.7–6 echemes per second (Buzzetti et al. 2006), neither of which resembles a continuous repetition of two-syllable echemes at 5–16 Hz.

The identification rests on **two independent specialist determinations**, not on one opinion confirmed by a second. Julien Barataud — author of the acoustic identification key for France, Belgium, Luxembourg and Switzerland (Barataud 2025), and the recordist of the reference sequences against which the comparison above was made — judged the stridulation characteristic of *T. viridissima* with little room for confusion, working from the song plate and the audio. The team at the Office pour les insectes et leur environnement (OPIE) reached the

same conclusion separately, working from the audio. Neither was aware of the other's assessment. Both correspondents have seen and approved the wording used here (pers. comm., 21 September 2026).

What this establishes and what it does not should be stated plainly. Two specialists who work with these songs, proceeding independently, identified the species from the recordings. That is an acoustic determination, not a voucher: there is no specimen, and the limitations section does not stop saying so.

The season ended intermittently rather than abruptly. The nights of 20, 21 and 22 September all yielded measurable choruses; 24 September was silent. No cessation date is claimed from a single silent night.

3.7 An independent test on archive recordings

The single-site limitation is the weakest feature of this design, so the fitted curve was tested against recordings nobody made for this purpose.

The xeno-canto archive holds 663 recordings of *T. viridissima*. Of these, 474 carry a temperature in their metadata, 352 of those are nocturnal and uncompressed, and **178 were accepted**: 22 recordists, 14 countries, 54 recording sessions, 13.5–32.0 °C. The measurement code was not modified in any respect.

The acceptance rule had to differ from §2.6, and it is worth saying how. The nightly criteria rely on a five-minute clip of known provenance: the split-half agreement and the band-minus-floor threshold both assume a recording made to a fixed protocol. Archive recordings are of unknown length, gain and distance, so two criteria were used that need none of that: the harmonic-product score of the fundamental had to reach 12, and a second, independent estimate of the rate taken from the raw modulation spectrum had to agree with it to within 10 %. The second is the stricter of the two and is the archive analogue of the subharmonic check. Both flags are columns in the deposited results file, so the 178 can be recovered from the 352 measured recordings exactly.

Within the Longuesse temperature range, the Longuesse curve predicts these recordings with a mean residual of **+0.79 Hz**. The relation reproduces. Its coefficient does not: refitting on the archive recordings alone gives $Q_{10} = 1.72$ against 2.02 here, and the difference persists when the archive set is restricted to the Longuesse window, so it is not an artefact of the wider range.

The archive data also bear on §3.3, in the direction one would expect from a blurred predictor. Above 18 °C, a straight line beats the Arrhenius form on the archive session means by 9.6 AIC. And both ends of the archive range fall below an exponential fitted to its middle: –2.22 Hz below 14.6 °C and –1.12 Hz above 28.3 °C.

Read as a thermometer rather than as a physiological relation, the numbers are these. At Longuesse, where the curve was calibrated, precision is **0.65 °C**. Applied without local calibration to the 152 archive recordings that fall inside the Longuesse calibration range of 14.6–28.3 °C, the curve shows bias **+1.10 °C**, scatter **2.51 °C**, and median absolute error **1.64 °C**. The restriction matters and is stated rather than assumed: asking how well a thermometer reads outside the range it was calibrated over is a different question, and §3.3 has already shown the curve to be wrong at both ends. Over all 178, including the 26 outside that range, the bias falls to +0.58 °C and the scatter rises to 2.90 °C — a better average bought with a worse spread, which is what extrapolating in both directions produces. Broken down by recordist, within the calibration range:

Recordist	n	Mean error (°C)
Barataud	18	−0.3
Lastukhin	13	0.0
Mroczko	12	+0.5
Fontana	5	+0.7
Odé	83	+1.7

For four of five recordists the uncalibrated curve is accurate to about half a degree.

The aggregate error is dominated by one recordist contributing nearly half the recordings, whose temperatures are systematically warm relative to the curve. Without knowing how each recordist measured temperature — thermometer at the microphone, a reading from a phone, a nearby station, an estimate written up afterwards — the two readings of this cannot be separated: either that recordist's animals sang slow, or their temperatures were recorded differently.

Two interpretations of the shallower archive coefficient are likewise inseparable with these data. The relation may genuinely be flatter when measured across populations, sites and microhabitats; Walker (1962) catalogued the sources of intraspecific variation in cricket calling songs, and a coefficient pooled over 14 countries is exposed to most of them. Or it may be the same relation measured through a noisier predictor: error in the temperature axis attenuates a fitted slope toward zero, and archive temperatures are certainly measured less carefully than a five-minute log twelve metres from the microphone. I think attenuation the more likely of the two, because the within-recordist errors are small for four of five recordists while the pooled slope is shallow — which is the signature of between-recordist inconsistency rather than of a different biological coefficient. I cannot demonstrate it here.

4. Discussion

4.1 The coefficient

The fitted activation energy, 51.2 ± 1.4 kJ/mol over 14.6–28.3 °C, is mid-range for an enzyme-limited biological rate and carries no surprise in itself. Its interest lies in two comparisons.

The first is with Walker's slopes. His ten *Orchelimum* species gave linear slopes from 0.9 to 5.1 wingstrokes per second per degree — a spread of more than fivefold in absolute rate — while their regression lines nonetheless converged on a common zero-crossing. In other words, the species differ greatly in how fast they sing and much less in how their singing scales with temperature. The 0.765 Hz/°C and 7.28 °C zero-crossing reported here are another point in that pattern, and the archive refit (Q_{10} 1.72 against 2.02) suggests that even within one species the coefficient varies more than the pattern does.

The second comparison is with Dolbear, and it is sharp enough to deserve its own section.

Section 3.4 complicates the whole exercise, and the complication should be stated rather than tidied away. Since the measured rate is a composite of two intervals with apparent activation energies of 55.5 and 36.1 kJ/mol, a single E_a for "stridulation rate" is a weighted average whose weights depend on which interval dominates the quantity measured. Comparing published values across studies therefore requires knowing whether each measured a syllable rate, an echeme rate or a wingstroke rate — and the three are not related by a constant factor, since the intervals that compose them scale differently.

4.2 Dolbear

Dolbear's note is a single page and contains two measurements. It is possible, 129 years later, to check it.

His published line (Fig. 3a) is $f = 0.120 T - 0.533$ Hz, implying a Q_{10} of 1.95 over 15–25 °C. His two underlying measurements, treated as a two-point Arrhenius fit, give **$Q_{10} = 2.07$ and $E_a = 53.3$ kJ/mol** — against 2.02 and 51.2 kJ/mol found here. The agreement is to 2 % and 4 % (Fig. 3b), across two families of Orthoptera, two continents and more than a century. The absolute rates differ by a factor of 5.2 (1.87 Hz against 9.73 Hz at 20 °C); the temperature coefficient does not differ meaningfully at all.

Two further observations follow, neither flattering to the rule of thumb.

Dolbear's two points span 5.6 °C. Over that interval a linear and an exponential function are indistinguishable at any plausible measurement precision, so his choice of a linear law carries no mechanistic information. He was not wrong; he simply had no way to be right on purpose, and the subsequent century of treating his linearity as a finding about insects has mistaken a consequence of his design for a result.

And the familiar rule — count the chirps in a fixed interval and add a constant — agrees with his line by arithmetic rather than by corroboration: the two share an intercept by construction. Dolbear asserted 40 chirps per minute at 50 °F. His own two measurements imply 53. He appears to have rounded a number he had not measured, and the rounding has been reproduced ever since.

Dolbear's cricket and the Longuesse chorus: the same thermal law

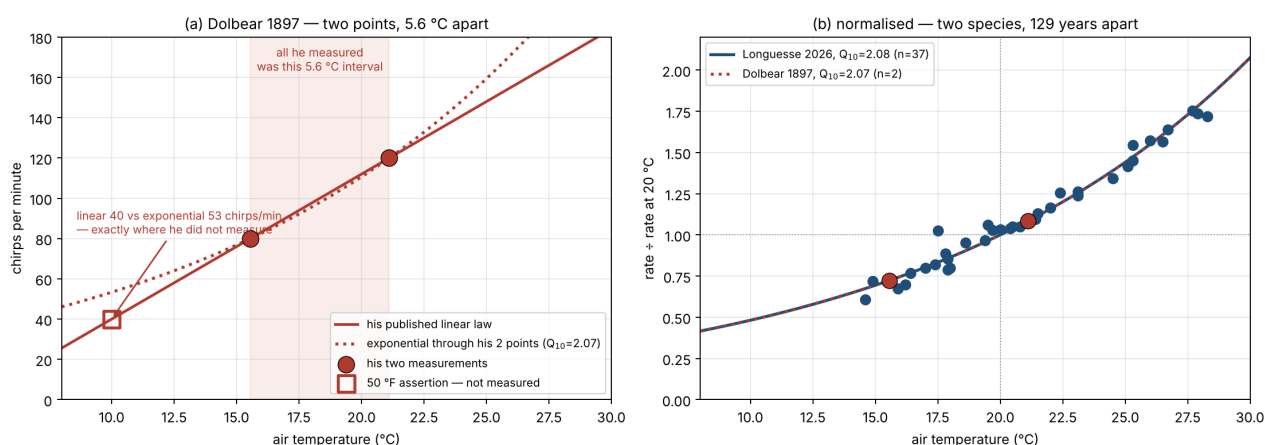


Figure 3. Dolbear's cricket and the Longuesse chorus. (a) Dolbear (1897) reported two rates, 5.6 °C apart, and asserted a third at 50 °F that he did not measure; his published linear law and an exponential through the same two points are indistinguishable over the interval he measured, and diverge only outside it. (b) The two datasets normalised to their own rate at 20 °C. The absolute rates differ by a factor of 5.2; the temperature coefficients agree to 2 %, across two families of Orthoptera and 129 years.

4.3 What the thirty-seven nights settle, and what they do not

They settle that the relation is tight: $r = 0.986$, scatter equivalent to 0.63 °C, over a 2.89-fold range of rate.

They settle, against the assumption implicit in every Q_{10} quoted for this kind of measurement, that the exponential is not the right form at the cold end. All seven nights below 17.4 °C fall below the exponential extrapolated from the warmer thirty, and those same nights fall above the extrapolated straight line. A quadratic beats both out of sample, in 1261 of 2000 splits.

They do not settle the form of the departure. Seven nights spanning 2.4 °C can show that curvature exists; they cannot distinguish a quadratic from a Sharpe-Schoolfield deactivation from any other convex function, and the AIC margin between those two is 1.5, which is nothing. The Sharpe-Schoolfield fit places its deactivation midpoint at 10.0 °C, below everything observed, which is a way of saying the data do not constrain it.

They do not settle whether the coefficient is a property of the species. The archive test says it is not, or not only: Q_{10} 1.72 across 22 recordists against 2.02 at one site. Whether that is biology or measurement error in the temperature axis remains open, for the reasons given in §3.7.

And they say nothing about Walker's convergence, which is the most striking unexplained regularity in this literature. Ten katydid species, seven electric fish species, and the dataset reported here all extrapolate to zero rate in a narrow band of temperature, having nothing obvious in common that would require it.

4.4 Limitations

Identification is acoustic. Two independent specialists identified the species from the recordings, which is strong evidence and is not a voucher specimen. Nothing was collected and nothing was seen.

One site, one season, one chorus. Individual singers were never separated or counted. If the dominant singer changed over the season — and across three months it almost certainly did — then the relation reported is a property of the local population and the local microclimate, not of an individual animal. The two unexplained outliers of §3.2 are the visible trace of this.

Screen temperature is not body temperature. Heath and Josephson (1970) measured thoracic excesses of 5–15 °C in a singing katydid, largest in the cold. If the same holds here, then part of the cold-end curvature in §3.3 could be a thermal gradient that widens as the night cools rather than a property of the underlying rate process. The two cannot be separated without measuring body temperature, and the thermometric claim of this paper — that song rate predicts the temperature an observer can measure — is unaffected either way. The physiological claim is not.

The cold end is thin. Seven nights over 2.4 °C, as discussed.

The year was exceptional. 2026 ran about 3.6 °C above the local long-term mean for the recording period. A warm summer samples the warm end densely and the cold end hardly at all, which is precisely the wrong distribution for the question of §3.3.

The rate estimator could in principle be biased rather than noisy. It is the same code on every clip, which protects against per-clip tuning but not against a systematic error. The synthetic-signal test of §2.4 and the carrier constancy of §3.5 are the available checks; neither is conclusive.

4.5 Archives, and who can hear the singer

The singer in this study was never heard by the recordist. Its carrier at 10.7 kHz lies above the comfortable range of an adult ear of my age, and the song became audible to me only when played back at quarter speed. The chorus was discovered in a spectrogram.

This is not a new observation and should not be presented as one. Newson et al. (2017) noted the same for the Speckled Bush-cricket in the Norfolk Bat Survey material, and gave it as the reason the species is overlooked by observers working by ear. The general point — that surveys conducted by ear are biased against high-frequency singers, and that the bias grows with the observer's age — follows directly, and the narrow version of it is all that should be claimed. Insect decline is documented with traps, not with ears: Hallmann et al. (2017) found more than

715 75 % decline in flying insect biomass over 27 years in protected areas, and nothing in this paper bears on that figure.

What this paper adds to Newson et al.'s point is the second record. They showed that archives collected for bats contain identifiable bush-crickets, including this species at two new sites. Section 3.7 suggests those same recordings may also carry temperature, at a median absolute error of about 1.6 °C uncalibrated and about half a degree for a recordist who measured temperature consistently. For an archive spanning years, that is a dataset nobody has yet read.

Three practical conditions would have to hold. The recordings must be uncompressed, or at least uncompressed in the band of interest — §2.2 shows what a perceptual codec does to 9–12 kHz. The species must be identified, since §3.7 shows the coefficient is not even constant within one species, let alone between them. And the temperature must have been recorded somewhere, by somebody, in a way that can be reconstructed. The third is the binding constraint, and the per-recordist table of §3.7 is the argument for it: the difference between a 0.5 °C error and a 1.7 °C error appears to be how the temperature was measured, not how the insect sang.

Equipment for this work was a smartphone, a consumer weather station and free software.

4.6 Outlook

Three measurements would resolve most of what §4.3 leaves open.

A night near 12 °C. The candidate functional forms differ by about 1.7 Hz there, roughly three and a half times the residual scatter. The obstacle is that the chorus stops some two and a half hours before the garden reaches that temperature, so the measurement requires either a colder site, a later season, or the patience to record through many nights for a few usable ones.

Body temperature in vegetation. A fine thermocouple in the singing perch, or a thermal camera, would separate the two readings of the cold-end curvature offered in §4.4.

A recordist who writes down the temperature at the microphone. This is the cheapest of the three by a wide margin and the one with the largest return. Section 3.7 shows that a single consistent recordist delivers about 0.5 °C; a handful of recordists doing so deliberately, across sites and latitudes, would convert an archive from a test set into a calibration set, and would answer the between-population question that one garden cannot.

5. Conclusions

- Over thirty-seven nights in one garden, the echeme repetition rate of *Tettigonia viridissima* predicts air temperature with residual scatter of 0.63 °C across 14.6–28.3 °C ($r = 0.986$).
- The relation is convex but sub-exponential. Both conventional forms are disfavoured: all seven nights below 17.4 °C fall below an exponential extrapolated from the warmer thirty, and above the corresponding straight line. A quadratic wins 1261 of 2000 out-of-sample splits. This refines Walker's (1975a) finding of approximate linearity rather than contradicting it; his own split-half test cannot separate linear from exponential in these data either.
- The measured rate is a composite. The between-echeme and within-echeme intervals carry apparent activation energies of 55.5 and 36.1 kJ/mol, so a single activation energy for "stridulation rate" is a weighted average whose value depends on which interval dominates the quantity measured.
- Dolbear's (1897) two measurements imply $Q_{10} = 2.07$ and $E_a = 53.3$ kJ/mol, agreeing with the values found here to 2 % and 4 % across two families and 129 years. His linear law, however,

carries no mechanistic information over the 5.6 °C his two points span, and the chirp-counting rule derived from it uses a constant he asserted rather than measured.

- Tested on 178 archive recordings by 22 recordists in 14 countries, the relation reproduces but its coefficient does not. As a thermometer the curve gives 0.65 °C where calibrated and a median 1.64 °C where not — but for four of five recordists, about half a degree with no local calibration at all.
- Existing passive-acoustic archives may therefore hold a temperature record alongside the biological one they were collected for, at a precision set by how carefully the recordist measured temperature rather than by anything about the insect.

Declarations

Species identification. The species was identified acoustically and independently by Julien Barataud and by the team at the Office pour les insectes et leur environnement (OPIE), both pers. comm., 21 September 2026, both of whom have approved the wording used here. No specimen was collected.

Ethics. No animals were handled, collected or disturbed. All recordings were made passively from a fixed position in the author's own garden.

Data and code availability. The complete dataset — thirty-seven nights of paired rate and temperature measurements, the archive test results, and all analysis code — is deposited at Zenodo under doi:10.5281/zenodo.22847684, CC BY 4.0. That is the concept DOI and always resolves to the latest version; this paper was prepared against version 1.1.0 (doi:10.5281/zenodo.23315104), which is the version to cite for exact reproduction. Every statistic in §3.2 and §3.3 is reproduced by running `verify_models.py` in that deposit.

Competing interests. None.

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Use of artificial intelligence. A large language model (Claude, Anthropic) was used as an assistant throughout this work: for writing and debugging the analysis code, for statistical advice, for verifying bibliographic details, and for drafting the text of this manuscript, which the author then revised. All measurements, all decisions about what to measure and what to accept, and all interpretation are the author's, who takes full responsibility for the content.

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Appendix A. Failure modes encountered

Six distinct ways the measurement failed over the season. Each is given with the symptom, the cause and the check that now catches it, because a reader attempting this at another site will meet the same ones.

A.1 Lossy audio. A clip recorded through an application that defaulted to HE-AAC returned a plausible rate from a band the encoder had synthesised (spectral flatness 0.93 in 9-12 kHz). Caught by refusing any non-WAV input.

A.2 Harmonic latching. Peak-picking in the envelope spectrum returned the second or third harmonic on clips with sharp syllable onsets; a synthetic 6.10 Hz song returned 18.33 Hz. Caught by harmonic-product scoring (§2.4).

A.3 Instrument change read as biology. A change of recording application shifted the apparent band level by several decibels. Caught by the rule that a chain change requires five co-recorded nights.

A.4 Negative band-minus-floor. Twice the band fell below the spectral floor. Both were recording-chain faults, not silent gardens. Now treated as an instrument alarm before biology (§2.6).

A.5 Two singers in one clip. Clips in which the two halves disagreed by more than 2 % were traced to two sources at different rates. Caught by the split-half criterion (§2.6).

A.6 A column-shifted temperature export. A weather-station export placed dew point where air temperature was expected, giving 9.1 °C for a night that was 12.1 °C. Caught now by a sanity range check and by reading the header rather than the column position.

A seventh case is worth recording although it is not a failure of this pipeline. A strongly modulated band at another site, initially taken for a second insect, proved to be a mains-locked electrical device: its rate was 12.500 ± 0.010 Hz across 3 °C of overnight cooling, which is 50 Hz divided by four. The diagnostic was the absence of temperature dependence — the very property that makes an insect useful as a thermometer, read backwards.

Appendix B. Dataset

The thirty-seven nights are in `thermometry_dataset.csv` in the Zenodo deposit (doi:10.5281/zenodo.22847684), one row per night: date, air temperature, echeme repetition rate, the two quality diagnostics (peak-over-median and band-minus-floor), and the prediction and residual of each of the three fitted forms. Carrier frequency is not a column: it was measured on the 28 archived clips rather than on all 37 nights, and the season figure quoted in §3.5 is $10\,668 \pm 108$ Hz.

The archive test results are in `xenocanto_results.csv` in the same deposit, one row per usable recording: xeno-canto identifier, temperature, measured rate, the score of the harmonic-product estimator, predicted rate and residual under each form, recordist, country and hour.