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# Temperatures in Common Kingfisher *Alcedo atthis* nesting holes indicate the timing of breeding phases

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**Abstract.** In recent years, temperature data loggers have been used to collect breeding details including the duration of incubation breaks, detect the exact start of incubation, and record unsuccessful breeding in various types of bird nests. Nevertheless, the majority of conventional techniques are inapplicable in subterranean settings. This study presents the results of using a temperature data logger to monitor breeding phases and the transitions between them in the natural nest holes of the Common Kingfisher *Alcedo atthis*. The first sensor was placed inside an occupied nest chamber (during egg laying or incubation) beside the clutch, while the second sensor was placed in a reference hole near the nest at the same depth and height as the occupied nest hole. The temperature inside the nest chamber and the reference hole was measured continuously at one-minute intervals. Measurements were taken during various time periods, from egg laying/incubation to the successful fledging of chicks or their death. The temperature curves clearly indicate the laying of the eggs, the start of incubation, successful fledging, or the death of chicks in the nest chamber, and even other fine details such as diurnal fluctuations or levels of thermal stability. It was not always possible to determine exactly when the chicks hatched from the temperature data, as incubated eggs and freshly hatched chicks have similar temperature demands and receive similar heat from the brooding parent.

**Key words:** temperature in nest, chicks feeding, Common Kingfisher, *Alcedo atthis*, egg laying, hatching, incubation, fledging, nest chamber

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## INTRODUCTION

The basic method for obtaining biological data is direct observation of breeding progress (Normant 1995). However, this approach often lacks exact and detailed data, is time-consuming, and can cause disturbance, e.g., frequent nest inspections can lead to premature fledging (Michaud & Leonard 2000, McCarty 2001, Pietz et al. 2012). Advances in technology allow the continuous collection of data using a variety of sophisticated methods. For example, cameras are effective for monitoring nest attendance (Hoover et al. 2004, Bulla et al. 2016, Croston et al. 2018, Khamcha et al. 2018, Guillette & Healy 2019) and the rate of predation (Weidinger 2006). Nevertheless, these methods often require an external power sup-

ply, cameras can be conspicuous to predators, and processing video data is time-consuming (Weidinger 2006, Dallmann et al. 2016). A number of alternative methods, such as telemetric eggs, are used to detect fine details of the incubation process (Stetten et al. 1990, Manlove & Hepp 2000, Hoover et al. 2004, Loos & Rohwer 2004, De Marchi et al. 2008, Clauser & McRae 2017).

Incubation can also be studied using complex methods that make use of data loggers and transponder systems that record the identity of the parents at the nest and their contributions to care of the eggs/hatchlings. The system consists of a small Radio Frequency Identification (RFID) or Passive Integrated Transponder device (PIT) tag attached to the tail or leg of each parent, an antenna positioned under the nest, and a nearby

recording device (Kosztolanyi & Szekely 2002, Gibbons & Andrews 2004, Zangmeister et al. 2009). A combination of these methods can provide comprehensive information about breeding behaviour, as seen in the case of waders (Bulla et al. 2016).

In recent years, small temperature loggers have been used to monitor breeding progress, allowing nest occupancy to be determined by changes in nest temperature (e.g. Hartman & Oring 2006, Schneider & McWilliams 2007, Sutti & Strong 2014, Croston et al. 2018, 2020, Hoppe et al. 2018). Temperature loggers are most commonly used to detect the start of incubation (Ruiz-De-Castañeda et al. 2012) and nest attendance (Cooper & Phillips 2002, Schneider & McWilliams 2007, Bueno-Enciso et al. 2017, Croston et al. 2020, Sullivan et al. 2020), but they can also be used to determine the date of fledging (Dubiec & Mazgajski 2023) or nest fate (Hartman & Oring 2006). These temperature loggers can provide high-resolution nest temperature data without the need to place bulky equipment inside the nests (Croston et al. 2018). This monitoring method has been used in different types of open nests. Schneider & McWilliams (2007) tested this method with the Piping Plover *Charadrius melodus*. Hoppe et al. (2018) used temperature loggers to determine nest attendance in the female Greater Prairie-chicken *Tympanuchus cupido*, while Croston et al. (2020) did so in the Mallard Duck *Anas platyrhynchos* and Gadwall *Mareca strepera*. Temperature loggers have been used in a range of bird species with different types of nests or in nest boxes (Ruiz-De-Castañeda et al. 2012, Bueno-Enciso et al. 2017), but their use in “naturally closed” nests, such as nest holes, and in tree holes, is much less common. Lill & Fell (2007) used temperature loggers to study the microclimate in the nest holes of the Rainbow Bee-eater *Merops ornatus*, Kulaszewicz & Jakubas (2018) in the burrows of the Little Auk *Alle alle*, a colonial high-Arctic seabird, and Sudyka et al. (2023) in the nest boxes and natural cavities used by several species of cavity-nesting birds in a temperate deciduous forest. De Marchi et al. (2008) used temperature data loggers to monitor the incubation behaviour of the Crab Plover *Dromas ardeola*, a shorebird that breeds in self-dug burrows (up to 2 metres long), while Zangmeister et al. (2009) studied the burrows of Leach’s Storm-Petrel *Oceanodroma leucorhoa*. Dubiec & Mazgajski (2023) employed temperature data loggers to identify the date and time of fledging in Great Tit *Parus major* young. Hamas

(1981) used different methods in his study of the thermoregulation of chicks in the nests of the Belted Kingfisher *Megaceryle alcyon* and found relatively high temperatures in their burrows.

The above-mentioned methods (i.e. cameras, telemetric eggs, RFID, PIT) are effective for open nests, nest boxes, or accessible cavities, while their application is limited in deep underground environments. Cameras can also be problematic due to their infrared light, which directly affects temperature. Temperature data loggers are most commonly used to sample the microclimate of a particular breeding phase, and less commonly to monitor the entire breeding process. Due to the relatively constant microclimate inside “closed nests”, the question of clearly identifying the individual breeding phases based on temperature data remains problematic especially in nest located in burrows.

The Common Kingfisher *Alcedo atthis* is one such species that is strongly endangered in the Czech Republic, according to the Act No. 114/1992 and Regulation No. 395/1992. It digs a nest hole that is 40–70 cm long into the steep banks of watercourses and reservoirs, as well as in the meanders of streams. Nest holes lack substantial insulation structures and are primarily influenced by the relatively stable temperature of the surrounding soil. The nest consists of a corridor and a nest chamber where the female typically lays 6–7 eggs on a thin layer of crushed regurgitated pellets (undigested prey remains, mostly fish bones, since fish dominated the diet at most localities; cf. Čech & Čech 2011, 2015). Incubation begins after the last egg is laid and lasts 18–21 days. Both parental birds participate in incubation, and hatching difference is usually no more than a day. Parents continue to warm the chicks for only 5–7 days after hatching. Both parents feed the chicks until they leave the nest hole, but the female may leave all care of the ongoing brood to the male when they are as young as 10 days old and start a new breeding attempt in another nest hole. In our study area, chicks predominantly left the nest hole at 23–25 days of age (Čech 2007, Hadravová 2019, Čech & Čech 2017, 2022). The primary aim of this study was to monitor the temperature in nest of the Common Kingfisher at 1-minute intervals and to determine whether it is possible to derive information from the temperature data regarding the breeding phases: a) egg-laying, b) the start of incubation, c) the hatching of the nestlings, and d) the fledging of the chicks.

## MATERIAL AND METHODS

### Study area and selection of the nest hole for temperature measurement

The study was carried out in the Greater Prague district, the Czech Republic, on the Radotínský stream (length 22.8 km, average annual discharge 0.17 m<sup>3</sup>/s), Botič stream (length 34.5 km, average annual discharge 0.53 m<sup>3</sup>/s), and Rokytká stream (length 37.5 km, average annual discharge 0.50 m<sup>3</sup>/s; Vlček et al. 1984).

On the three streams mentioned above, five nest holes (six broods) were experimentally monitored during a three-year period (Fig. 1) — two nest holes on the Radotínský stream (including one brood in 2018 and two consecutive breeding attempts of full length in 2020), two nest holes in the same nest wall on the Botič stream (one brood in 2018 and another in 2019), and one nest hole on the Rokytká stream (one brood in 2019). All of these nest holes are among those monitored annually in the Prague district (for details, see Table 1) as part of an extensive population study (26–41 breeding events/year).

Monitored nests should have been high enough above the water level to prevent the data logger from being washed away during rainy periods, it had to be no longer than 65 cm (the optimum length), and it had to be straight (the

nest chamber extending in a direct line from the entrance). The presence of vegetation around the nest hole was necessary to conceal the data logger units. In regard to the implementation of the research in the urban environment of the capital city of Prague, another important parameter was the location of the nest hole in a less disturbed area (further away from busy roads and not in places where dogs go to bathe, etc.), to ensure that breeding would not be disturbed and the temperature data loggers would not be at risk of theft or destruction.

### Temperature measurement

A temperature data logger with two external probes (Comet logger S0121, declared accuracy  $\pm 0.2$  °C from -50 to +100 °C, resolution 0.1 °C) was used. The external probes, which are 20 mm in length and 6 mm in diameter, are connected by a 2 m long shielded PVC cable (P1000TR160/E, cable diameter 3.5 mm, measuring range -30 to +80 °C, tolerance  $\pm (0.3 + 0.005 \cdot |t|)$  °C). Our own accuracy test showed identical or slightly shifted ( $\pm 0.1$  °C) parallel curves in a range from 10 to 40 °C. The measured values are very realistic in relative terms. Ambient air temperatures were recorded using a CEM DT-171 data logger (temperature accuracy  $\pm 1\%$  from -10 to +40 °C). According to the meteorological convention,

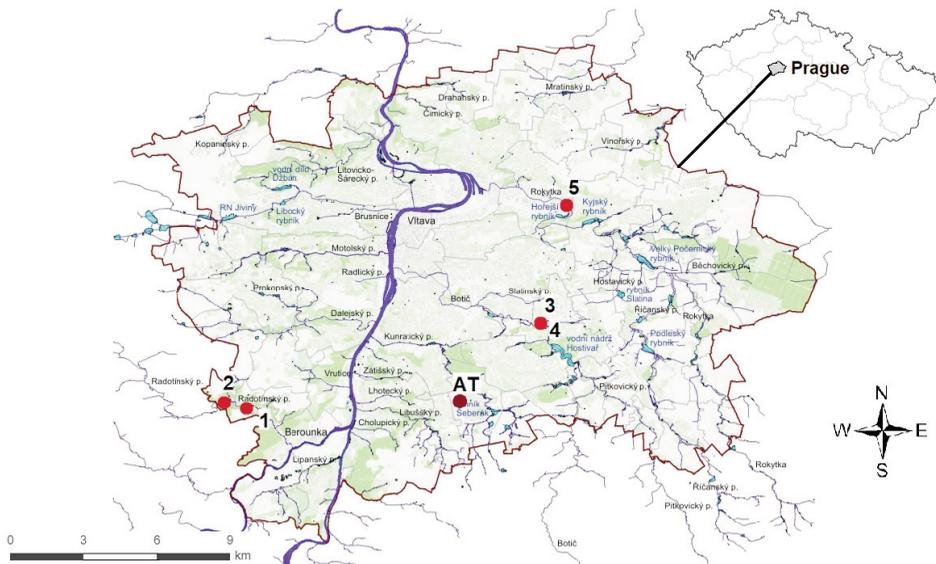


Fig. 1. A map of the Prague district showing the locations of Common Kingfisher nests where temperature was continuously measured using temperature data loggers. Red points with numbers indicate the locations of kingfisher nests: 1 — on the Radotínský stream in 2018, 2 — on the Radotínský stream in 2020 (two consecutive breeding attempts were successfully carried out in a single nest), 3 — on the Botič stream in 2018, 4 — on the Botič stream in 2019, 5 — on the Rokytká stream in 2019. The brown point marked as AT indicates the location of the temperature data logger used for measuring of the ambient air temperature.

Table 1. Parameters of individual Common Kingfisher nest burrows, where temperature was continuously measured using temperature data loggers (Greater Prague district, Czech Republic). \* — numbers correspond to the nests shown in Fig. 1.

Location	No*	Breeding season	GPS coordinates of the nest	altitude (m a.s.l.)	orientation of the nest wall	material in which the burrow is dug	the height of the nest entrance above the water level	the length of the burrow, chamber included
Radošínský stream	1	2018	49°59'51.699"N, 14°19'35.110"E	257	south-east	clay	105 cm	68 cm
	2	2020, 2 broods	49°59'48.332"N, 14°18'18.762"E	267	south-east	clay	86 cm	39 cm
Botič stream	3	2018	50°3'3.689"N, 14°31'15.127"E	228	south	clay loam	136 cm	75 cm
	4	2019	50°3'3.693"N, 14°31'15.085"E	228	south	clay loam	159 cm	59 cm
Rokytká stream	5	2019	50°6'27.503"N, 14°31'18.140"E	199	south-east	clay loam	87 cm	60 cm

the data logger was placed in the shade at a height of 2 m above the ground in Prague (50°0'47.845"N, 14°28'28.565"E). So, all study nesting holes were situated within a radius of <10 km off the ambient temperature measurement location (Fig. 1).

The choice of measurement interval was based on the memory capacity of the temperature data logger to ensure that all temperature changes during the breeding event were recorded with acceptable field effort. The temperature in the nest chamber did not change quickly, and the measurement interval was set to 1 minute, which meant that data had to be downloaded approximately every 10 days. At each data download, the position of the sensor and the breeding phase were checked using a special mini-camera (Mini PAL camera 700TVL FPV with wide-angle lens 1.8 mm 1/4 CMOS) connected to an LCD monitor (9-inches headrest TFT LCD monitor). The entire inspection took no more than 2 minutes to minimize the stress of parental birds and the brood. During the data download and inspection of the nesting holes, the nesting process was not disturbed in any way. During incubation and brooding, if a parent was present, the parent either continued to sit on the eggs/chicks or briefly retreated to the rear of the nest chamber, without leaving the nest hole after the inspection. During nestling period, an inspection was conducted after the chicks had been fed and the parent had left the nest hole.

The temperature data logger unit was concealed in a plastic cover and attached to vegetation (most often the roots of trees or bushes), all thoroughly covered by the surrounding vegetation (Fig. 2). The probe was placed inside an occupied nest chamber (during egg laying or incubation) next to the clutch, so that it lay freely on the nest substrate and did not touch the wall of the chamber (Fig. 2D). The cable of the temperature probe was fed through the centre of the corridor of the nest hole — a groove was made in which the cable was placed, and everything was covered with the surrounding material. The mini-camera was an essential tool in the entire installation, which took no more than 15 minutes. The second sensor was placed in a nearby reference hole (about 50 cm away in the same nest wall) at the same depth and height as the occupied nest hole.

### Data processing

Temperature data from the nest chamber and a parallel "soil" hole were downloaded using

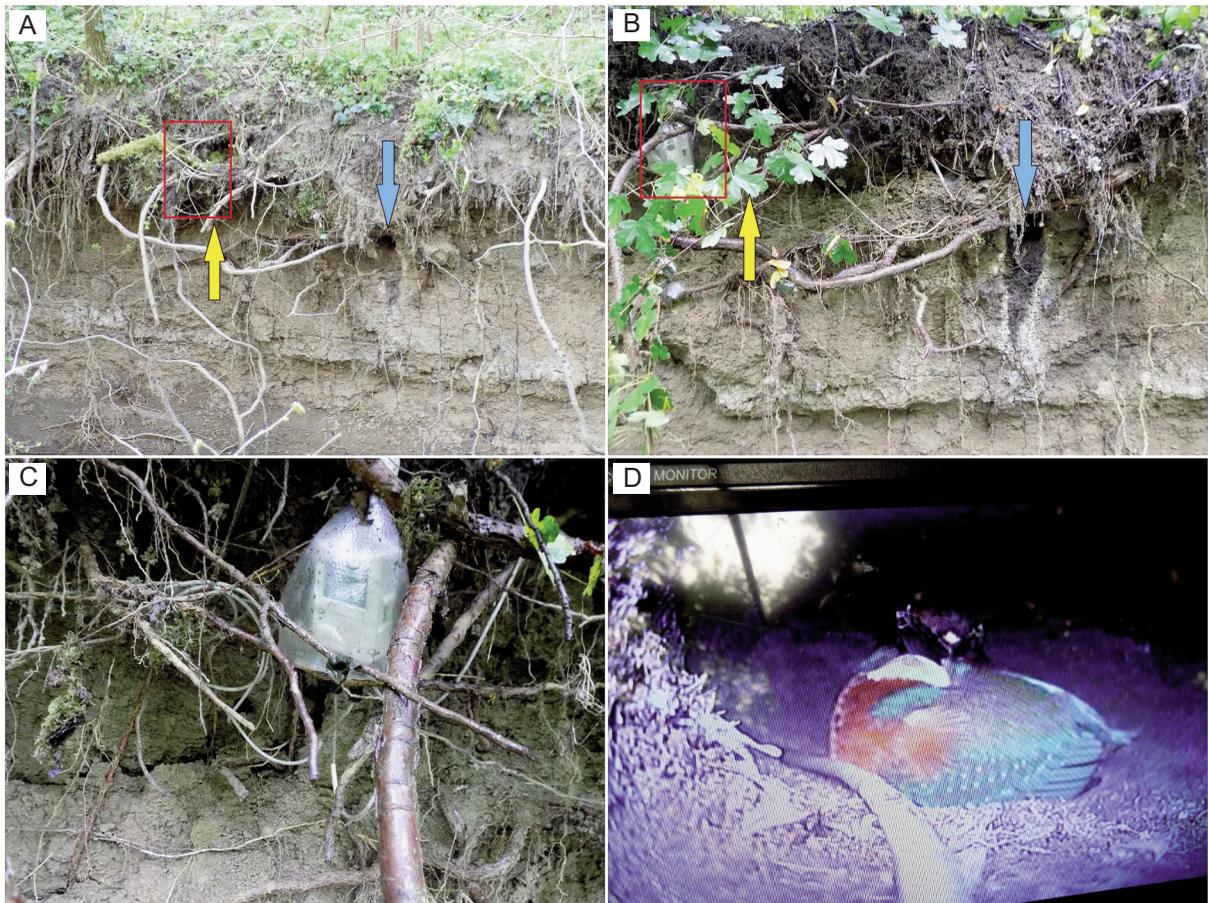


Fig. 2. Installation of the temperature data logger in the nest hole of the Common Kingfisher: A — the temperature data logger after installation (hidden in the surrounding vegetation), B — installation of the temperature data logger prior to concealing it in the surrounding vegetation, C — the temperature data logger hidden in the cut-off part of a PET bottle suspended from a tree root, D — placement of the temperature sensor in the nest chamber (an undisturbed male kingfisher still heating the eggs during a brief check with the mini-camera). The blue arrow indicates an occupied nest hole, the yellow arrow indicates the location of the handmade hole with the second temperature sensor, and the red frame indicates the data logger in the cut-off part of a PET bottle.

the manufacturer's COMET VISION version 2.1 program. Ambient air temperature data were downloaded using software from the manufacturer Weather Datalogger Inc. The data were processed using Rx64 3.1.2 statistical software (R Development Core Team 2017) and Excel 2019. The data were analysed using a two-sample Wilcoxon test to compare the temperature differences during incubation and nestling period. Paired Wilcoxon test was used to compare the temperatures during egg laying between day and night, as well as to compare the temperatures when both chicks and parent were present (during the first 5–7 days after hatching) to when the chicks were alone in the nest chamber.

Based on the knowledge of the duration of the individual rearing phases (laying, incubation,

nestling period; Čech 2007, Hadravová 2019), and according to the assumed date and field observations, the transitions between these phases were approximated on the temperature curve. Subsequently, these segments of the temperature curve were analysed. Deciles are robust measures of dispersion for fluctuating data with unclear statistical distributions. They effectively limit outliers, and the percentiles faithfully express the relative degree of temperature variation in the graphs. The 1st and 9th deciles of the half-day data were used to reduce the extreme values ("peaks"). Preliminary graphic evaluations indicated noticeable differences between days and nights, especially in some breeding phases, so the data series were split into daytime and nighttime (days comprise from 906 to 1,035 data lines and

nights that are however shorter in summer and securely delimited by the nautical twilight from 305 to 453 data lines). If the deciles D1 and D9 were very close to each other, there was little variation in temperature and *vice versa*. To correct the data for background soil temperatures, the data were adjusted by calculating the difference between the measured temperature in the occupied nest chamber and the ambient soil temperature in the man-made parallel hole. Deciles were calculated from this temperature difference. The information obtained from the individual visual checks of the nest hole (Appendix 1) was used to verify the accuracy of the localized transitions of the breeding phases on the temperature curve.

Nesting observations were conducted from early spring to summer (April 16–July 30). During this period, the length of day and night changed significantly. From observations of the species, we know that their activity begins very early at dawn (Čech & Čech 2024). Astronomical dawn and dusk were used to clearly separate nighttime recordings, while civil twilight (dawn and dusk) was used for the period of daylight. Values were obtained from the Astronomical Applications Department US Naval Observatory (2024): daytime is defined as the period from the end of dawn to the beginning of dusk, and nighttime is defined as the period from the beginning of dusk to the end of dawn.

## RESULTS

The kingfisher nest temperature was recorded for a total of 227 days (or 376,860 minutes) across three streams (Botič, Radotínský, and Rokytka) from five nest holes and six broods over the course of three years. In two instances, it was feasible to install temperature sensors at the onset of the egg-laying phase (Fig. 3B, D, Fig. 5A, B). The longest continuous measurement was conducted in 2020 on the Radotínský stream. The sensors were installed on the day the last egg of the 1<sup>st</sup> breeding event was laid, and the measurements persisted until the fledging of the 2<sup>nd</sup> breeding event (a total of 138,912 minutes, including two days of nest chamber cleaning between the 1<sup>st</sup> and 2<sup>nd</sup> breeding events; Appendix 2). For details see Table 2.

In all cases, nest walls are situated beneath the riparian vegetation, shielded from direct sunlight. Soil temperatures gradually increase in spring as the weather warms, ranging from 13 to 21 °C.

Diurnal fluctuations do not manifest in the soil, however, several days of inclement weather are characterized by a slight temperature decrease (Fig. 3, 4). A temperature sensor located in a nest hole records temperature change relatively accurately, although the absolute values vary depending on the sensor's exact position, which cannot be precisely standardized.

The raw data show relatively high short-term stability but also contain brief extremes (Fig. 3, 4),

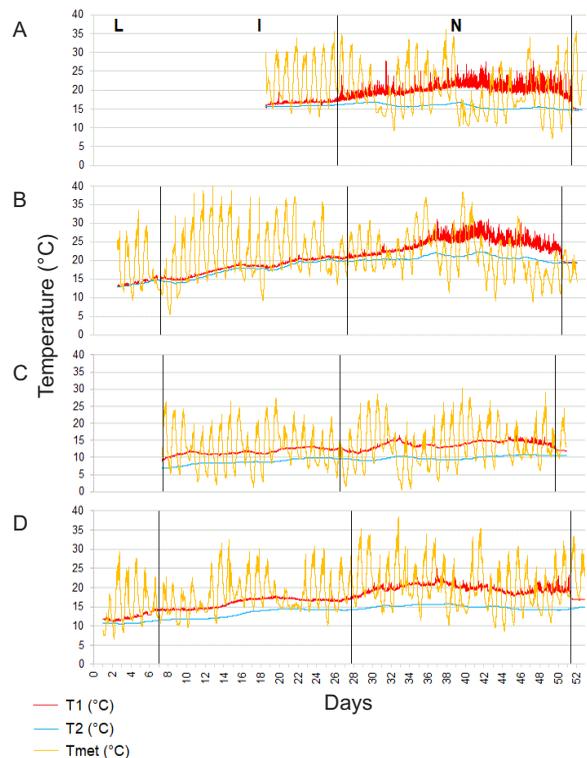


Fig. 3. The course of temperature in the active nest hole of the Common Kingfisher from egg laying or incubation to fledging: A — the nest on the Radotínský stream in 2018 (from June 1 to July 5; incubation NA; nestling period 25 days; 7 chicks fledged), B — the nest on the Rokytka stream in 2019 (from May 24 to July 11; egg laying NA; incubation 21 days; nestling period 24 days; 7 chicks fledged), C — the nest on the Radotínský stream in 2020 (the 1<sup>st</sup> breeding event from April 16 to May 28; egg laying NA; incubation 20 days; nestling period 24 days; 4 chicks fledged), D — the nest on the Radotínský stream in 2020 (the 2<sup>nd</sup> breeding event from May 30 to July 28; egg laying 7 days; incubation 20 days; nestling period 25 days; 7 chicks fledged). Vertical lines separate different phases of breeding (the length of breeding phases may vary among breeding events or seasons): L — egg laying (from the laying of the first egg, if available, to the laying of the last egg), I — incubation (from the time the last egg is laid and the female stayed during night until the chicks hatch, based on the expected date and field observations), N — nestling period phase (the period when the chicks are present in the nest chamber). (T1 — temperature in the occupied nest hole, T2 — ambient soil temperature, Tmet — ambient air temperature).

Table 2. Temperature values (°C; minimum, maximum, and mean in bold) for each breeding phase of individual Common Kingfisher nests at the Radotínský, Botič, and Rokytka streams, where temperature measurements, along with parallel measurements ambient soil temperature and ambient air temperature, were taken. \* — unsuccessful breeding attempts.

Location	study period (minutes of recording)	number of chicks	egg laying			egg incubation			nestling period				
			min.	max.	mean	min.	max.	mean	min.	max.	mean		
Radotínský stream	June 1–July 5 2018 (48,915)	7	no data			15.3	19.4	<b>16.6</b>	16.8	27.9	<b>20.3</b>		
			occupied nest hole			15.6	16.0	<b>15.8</b>	14.6	16.7	<b>15.7</b>		
			ambient air temperature			12.8	35.7	<b>22.7</b>	7.1	36.2	<b>19.3</b>		
Botič stream *	June 18–July 18 2018 (43,287)	7	no data			17.6	27.9	<b>19.1</b>	17.4	32.1	<b>22.4</b>		
			occupied nest hole			15.2	18.4	<b>16.9</b>	15.1	17.5	<b>16.0</b>		
			ambient air temperature			10.5	36.2	<b>18.6</b>	7.1	35.8	<b>19.9</b>		
Rokytka stream	May 24–July 11 2019 (69,002)	7	12.8	16.2	<b>14.2</b>	14.6	21.5	<b>18.3</b>	20.5	31.8	<b>24.4</b>		
			occupied nest hole			12.8	14.6	<b>13.8</b>	13.9	20.5	<b>17.5</b>	22.2	<b>20.7</b>
			ambient air temperature			9.2	33.7	<b>17.4</b>	5.4	40.0	<b>22.2</b>	8.8	38.3
Botič stream *	July 3–July 30 2019 (38,372)	4	no data			19.0	28.8	<b>24.4</b>	breeding failed				
			occupied nest hole			17.1	20.4	<b>18.1</b>	breeding failed				
			ambient air temperature			8.8	32.0	<b>18.0</b>	breeding failed				
Radotínský stream, 1 <sup>st</sup> brood	April 16–May 28 2020 (60,954)	4	no data			8.6	14.0	<b>11.7</b>	11.1	16.9	<b>13.8</b>		
			occupied nest hole			7.0	10.2	<b>8.7</b>	9.1	10.8	<b>9.9</b>		
			ambient air temperature			1.3	27.5	<b>12.9</b>	0.5	30.4	<b>13.3</b>		
Radotínský stream, 2 <sup>nd</sup> brood	May 30–July 20 2020 (76,156)	7	11.2	14.6	<b>12.2</b>	13.9	18.0	<b>15.9</b>	16.8	25.1	<b>19.6</b>		
			occupied nest hole			10.5	11.4	<b>10.8</b>	14.4	13.2	14.1	15.7	<b>14.9</b>
			ambient air temperature			6.5	29.5	<b>15.6</b>	9.7	32.6	<b>18.0</b>	8.5	38.5

\*unsuccessful breeding event.

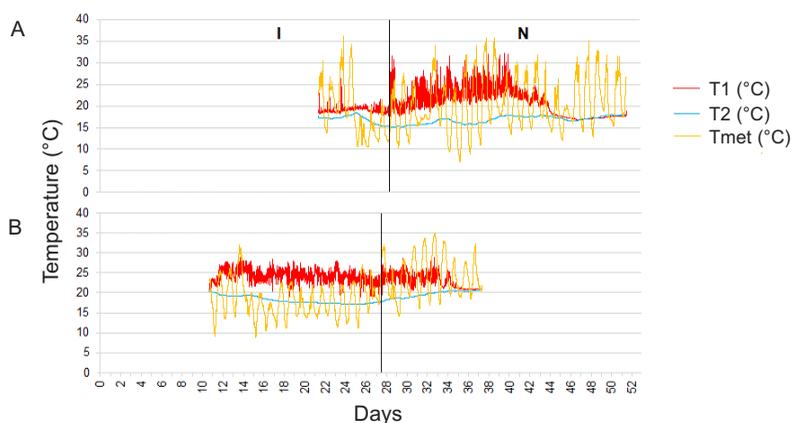


Fig. 4. The course of temperature in the active nest hole of the Common Kingfisher from incubation to the chicks' death: A — the nest on the Botič stream in 2018 (from June 18 to July 18; 7 chicks), B — the nest on the Botič stream in 2019 (from July 3 to July 30; 4 chicks). Vertical lines separate different phases of breeding (the length of breeding phases may vary among breeding events or seasons): I — incubation (from the time the last egg is laid and female stayed during night until the chicks hatch, based on the expected date and field observations), N — nestling period phase (the period when the chicks are present in the nest chamber). (T1 — temperature in the occupied nest hole, T2 — ambient soil temperature, Tmet — ambient air temperature).

likely due to random events such as the piston effect when the parents enter the nest or random movements of the chicks. The temperature curves (Fig. 3) demonstrated a gradual increase in temperature during the breeding event. During incubation, only one parent provides heat, however, in the second half of the breeding event, particularly in its pre-final stages, thermal heat is generated not only by the incubating parent but also by the increasing body mass of the growing chicks, which are still not fully feather-isolated (usually up to the age of 16–18 days). The female leaves the nest hole 5–7 days after hatching and participates in food provisioning. From this point on, we observe larger and more rapid temperature fluctuations, which are associated with changes in the position of the chicks and frequent visits from the parents during food provisioning, alternated with shorter periods of warming.

Ambient soil temperature or control temperature measurements taken at a similar position near the nest hole serve to represent the natural background. Temperature differences between the nest hole and the ambient soil temperature reflect the warming caused by the nesting pair and the growing chicks. Such series help to compensate for the influence of changes in soil temperature.

The results clearly show that, as expected, there was a temperature difference between the egg-laying phase and the incubation phase. Figures 5A and 5B demonstrate that the distance between deciles D1 and D9 was greater during the

day but almost overlapped at night during the egg-laying phase. This suggests that the female was only present in the nest chamber during the day, indicating that egg laying occurred during the daytime (the temperature in the nest chamber was significantly higher during the day than at night –  $V = 2037566$ ,  $p < 0.01$ ). After the last egg had been laid, the parent was present in the nest chamber both day and night, as evidenced by the distance between deciles D1 and D9, i.e. the distance between them was smaller and more constant (Fig. 5A, B).

The hatching of nestlings was indicated by a “jump” in the temperature curve (specifically on the Radotínský and Botič streams in 2018; Fig. 3A, Fig. 4A). This increase was also evident from the distance between deciles (Fig. 6A, E). The aforementioned temperature increase was not very noticeable in the other measurements conducted and even exhibited an opposite tendency.

There was a statistically significant difference in temperature differences (calculated from the difference between the temperature in the occupied nest chamber and the control temperature of the soil) when the parents and chicks were present (first 5 days after hatching — median 2.8 °C) compared to when the chicks were alone in the nest chamber (6–10 days after hatching — median 4.2 °C;  $W_n = 28798, 28791 = 647333467$ ,  $p < 0.01$ ). The temperature during incubation (median 2.8 °C) was lower than during nestling period (median 4.4 °C;  $W_n = 129252, 153112 = 4501860161$ ,  $p < 0.01$ ).

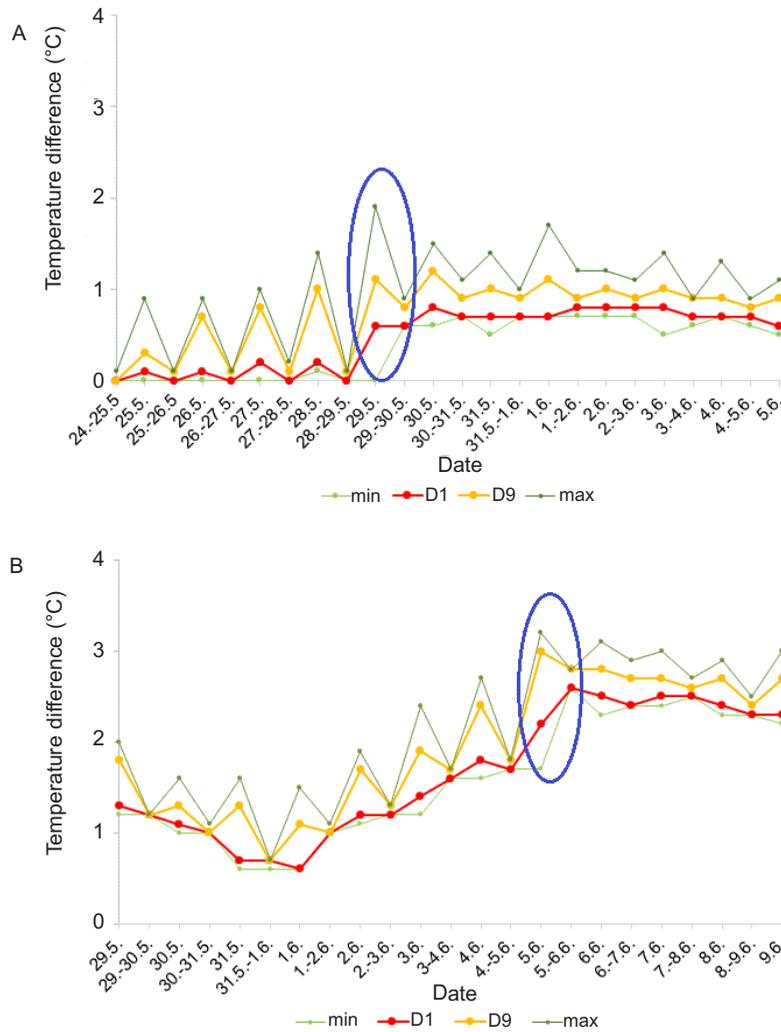


Fig. 5. Temperature difference during egg laying in the occupied nest hole of the Common Kingfisher. A — the nest on the Rokytka stream in 2019 (from May 25 to May 29 – egg laying from the 2nd egg), B — the nest on the Radotínský stream in 2020 (2nd breeding event; from May 30 to June 5); expressed using deciles calculated for separate day and night data fractions. The blue lines indicate the start of incubation. D1 — 1st decile, D9 — 9th decile, min. — minimum day/night temperature, max. — maximum day/night temperature).

For all successful breeding events, a rapid decrease in temperature was evident in the graphs during fledging (Fig. 3). At night, the empty nest chamber is indicated by the overlap of deciles D1 and D9 (Fig. 7A–D).

The unsuccessful breeding event on the Botič stream in 2018 and 2019, during which the chicks slowly died in the nest hole, consistently manifested in the same way on the temperature curve, a gradual decline in temperature as the bodies of the chicks reduced their activity and cooled down; Fig. 4A, B). The gradual death of the chicks is evident in the decile graph, with deciles D1 and D9 gradually approaching each other (Fig. 7E, F).

## DISCUSSION

This study tested a method for monitoring the breeding process of the soil cavity-nesting Common Kingfisher making use of temperature sensors placed in occupied nest holes. The data provided information on the presence in the nest chamber during egg laying, and the occurrence of brood failure, with similar findings to the monitoring of other nest types (Hartman & Oring 2006, Schneider & McWilliams 2007, Sutti & Strong 2014). Temperature data from the kingfisher nest chambers also provided information on the last egg laid and the subsequent start of incubation.

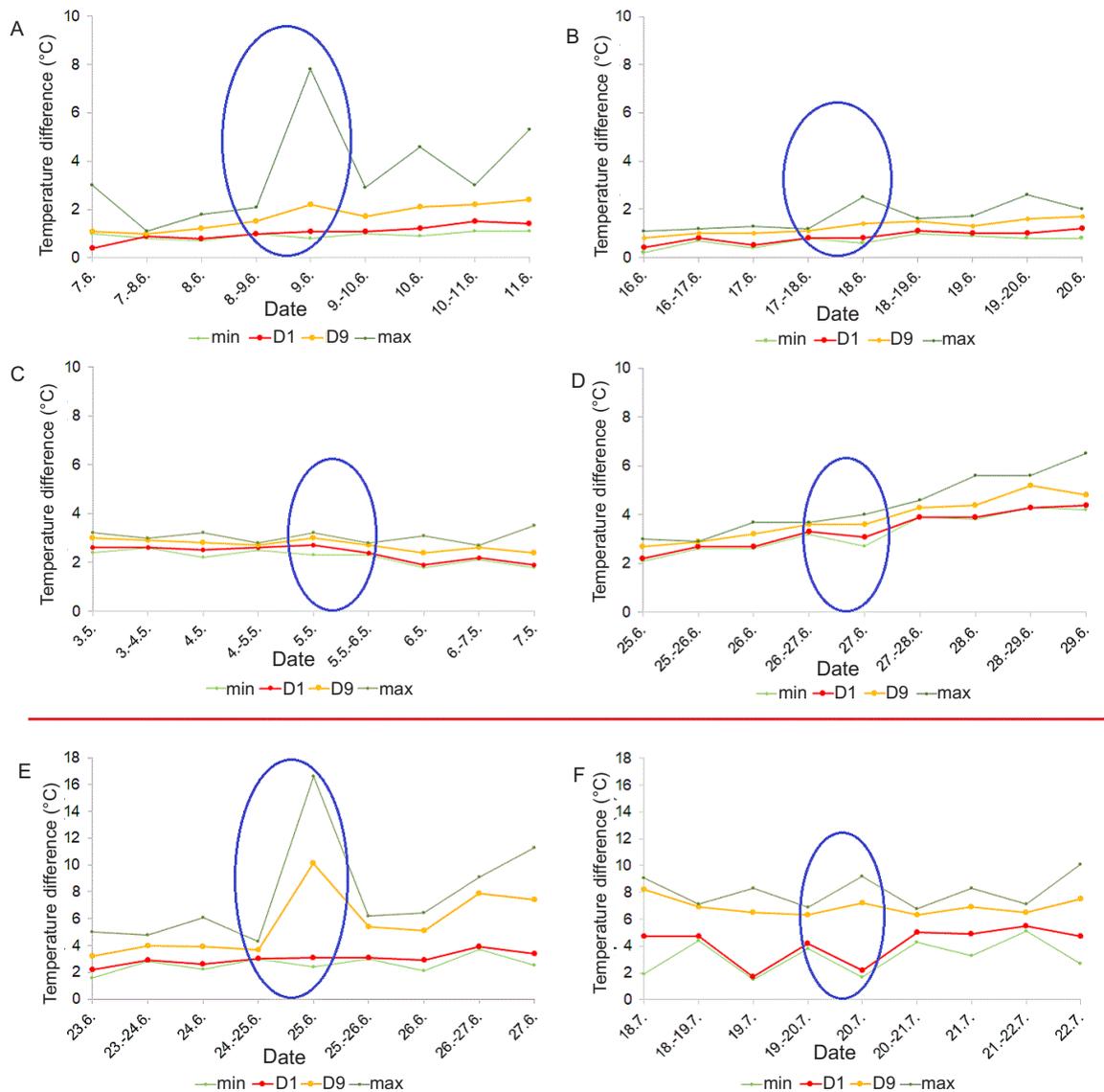


Fig. 6. Transition between the incubation and nestling period phases (hatching) of the Common Kingfisher recorded by the temperature data: A — the nest on the Radotínský stream in 2018, B — the nest on the Rokytka stream in 2019, C — the nest on the Radotínský stream in 2020 (1st breeding event), D — the nest on the Radotínský stream in 2020 (2nd breeding event), E — the nest on the Botič stream in 2018, F — the nest on the Botič stream in 2019, expressed using deciles calculated for separate day and night data fractions. D1 — 1st decile, D9 — 9th decile, min. — minimum day/night temperature, max. — maximum day/night temperature. The blue lines indicate when the chicks hatched, and the red line separates unsuccessful breeding events (shows in the two graphs below the line).

The incubation phase began when either the female or male parent was present in the nest chamber both during the day and at night. In contrast, during the egg-laying phase, the female was only present during the day (Fig. 5A, B).

Temperature data loggers are frequently used in open bird nests to monitor nest attendance, as demonstrated in the studies by Schneider & McWilliams (2007) or Hoppe et al. (2018). The

duration of the periods when neither kingfisher parent was present in the nest chamber during incubation could not be determined from the temperature curve, likely due to the rapid exchange of parents in response to the low temperature in the nest hole. The incubating bird leaves the nest only when the second bird signals in front of the nest wall that it is ready to take over parental care (M. Čech, pers. observation). Conversely, the

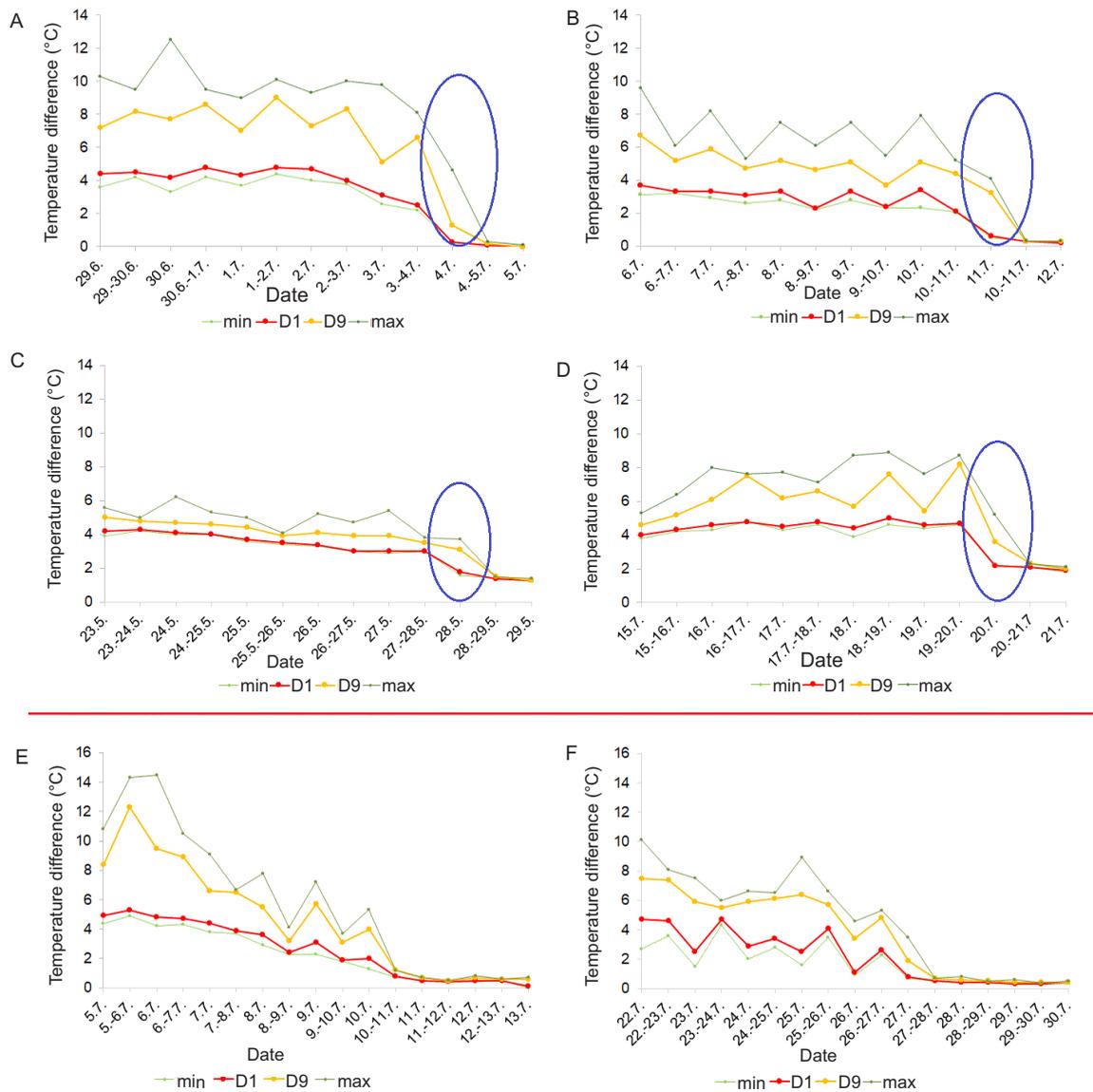


Fig. 7. Fledging of the chicks of the Common Kingfisher recorded by temperature data: A — the nest on the Radoťinský stream in 2018, B — the nest on the Rokytká stream in 2019, C — the nest on the Radoťinský stream in 2020 (the 1st breeding event), and D — the nest on the Radoťinský stream in 2020 (the 2nd breeding event); or dying of the chicks, E — the nest on the Botič stream in 2018, F — the nest on the Botič stream in 2019, expressed using deciles calculated for separate day and night data fractions. D1 — 1st decile, D9 — 9th decile, min. — minimum day/night temperature, max. — maximum day/night temperature. The blue lines indicate when the chicks fledged, the red line separates the unsuccessful breeding events (shows in the two graphs below the line).

presence or absence of the parents in the nest chamber during the egg-laying phase could be determined (the presence of the female during the day and an empty nest at night; cf. Fig. 5A, B).

Dubiec & Mazgajski (2023) used nest temperature profiles to assess the timing of fledging in the Great Tit broods. In concordance, the temperature curve allowed for the determination of the day when the kingfisher chicks left the nest chamber. This was indicated by both a rapid temperature

drop (Fig. 3) and the deciles overlapping the following night after the chick fledged (Fig. 7A–D). Hartman & Oring (2006) obtained information on when a nest failed from the temperature data of Long-Billed Curlew *Numenius americanus* nests, as did Sutti & Strong (2014) from the temperature data of different bird species. Temperatures recorded in the kingfisher nest also indicated that the nest had failed. Both observed breeding failures occurred during the nestling period phase,

and in both cases, the chicks died slowly, as evidenced by the gradual decrease in temperature in the nest chamber (Fig. 4A, B) and the gradual approach of the deciles (Fig. 7E, F). It is important to note that the dead chicks were, to some extent, preserved in the nest chamber and their decomposition partly increased the temperature again (A. Hadravová, pers. observation).

It was assumed that estimating the hatching date from the temperature data collected from the kingfisher nest chamber would not be possible. The reason for this assumption was that during the hatching phase and for the subsequent 5–7 days, a parent continued to warm the chicks in the same way as the eggs. As a result, the temperature in the nest chamber was likely not significantly affected by the small warm bodies of the chicks, since, like the eggs, the chicks are well insulated by the incubating parent. Likely for this reason, the hatching stage of chicks is often excluded from studies that utilize temperature loggers to collect data on the various phases of a breeding event (Hartman & Oring 2006, Schneider & McWilliams 2007, Ruiz-De-Castañeda et al. 2012, Bueno-Enciso et al. 2017, Croston et al. 2020, Sullivan et al. 2020). Sutti & Strong (2014) even argue that the hatching date cannot be accurately determined from temperature data alone, and that nest inspections around the predicted hatching time are necessary to estimate this date accurately. Therefore, it was surprising to find that on the Radoťský and Botič streams in 2018 (Fig. 6A, E), it was possible to estimate the hatching date of the chicks from the temperature curves, given the knowledge of their approximate hatching date.

The young hatch without down feathers and the development of juvenile plumage is slow. Feathers do not fully cover the body even at the age of 14 days. Even later, their insulating ability is limited. Growing feathers are enclosed in sheaths that unfurl very late in comparison to other species. The growing bodies of the chicks radiate metabolic heat, which affects the temperature of the nest chamber, from the age of 15 days the feathers are gradually released from the sheaths and the chicks start to be well insulated (Čech 2007). Broods of the Common Kingfisher are relatively large (mostly 6 or 7 chicks). Chicks form a permanently huddling cluster that produces fluctuating metabolic heat. Compared to the Belted Kingfisher (Hamás 1981), the young of the Common Kingfisher are three times smaller, which may explain the lower temperatures observed in their burrow.

In some cases, the clear increase in temperature (Fig. 3A, 4A) corresponds with the hatching of the chicks. At the same time, the deciles diverge as a result of larger fluctuations caused by increased care for the newly hatched chicks (Fig. 6A, E). The temperature curves in other cases do not show observable changes or even exhibit an opposite tendency (Fig. 6F). The transition from eggs to chicks is generally not a clear event; it can last for a few hours or even a day, and the behaviour of nesting birds may vary when they still have a few unhatched eggs. Newly hatched chicks are not fed immediately, and their thermal needs are similar to those of the eggs. It is not excluded that a detailed analysis may yield some results, as increased activity in the incubating bird is expected.

Stephenson et al. (2021) discovered that the use of temperature data loggers (iButton type) to obtain information on the progress of the breeding event or the entire breeding season is a gentler method than directly inspecting nests and is a safe approach that does not adversely affect breeding progress. On the other hand, some studies (e.g. Cooper & Phillips 2002, Weidinger 2006, Sutti & Strong 2014, Croston et al. 2018) acknowledge that interpreting information from temperature curves alone is somewhat burdened by a degree of uncertainty. Therefore, they suggest that for accurate interpretation, it would be advisable to have access to camera recording or information obtained from direct inspections of the nest where temperature measurements were taken. Installing a camera in the natural nest of kingfishers would be problematic, as it is too invasive, technically demanding, and likely to disrupt natural breeding behaviour (also barely allowed since the kingfisher is a highly protected, umbrella species of freshwater ecosystems according to both Czech and EU directives). Even the installation of a camera trap would not be feasible, as all of the nest holes where temperature measurements were taken were located in an urban environment. Placing another device near the nest hole could attract human attention, potentially disrupting the breeding process, or possibly leading to the theft or destruction of the camera trap.

While measuring the temperature in the kingfisher nest chambers, the position of the sensors were regularly checked to prevent them from becoming buried in the nest sediment, which could significantly affect the measured temperature. These checks also provided information about the phase of the breeding event (Appendix 1), aiding in the interpretation of the results.

The most commonly used type of temperature logger to documenting incubation behaviour and monitoring the breeding progress of birds by recording temperature fluctuations in nests is the iButton, which is a wireless temperature logger (Cooper & Phillips 2002, Hartman & Oring 2006, Schneider & McWilliams 2007, Croston et al. 2018, 2020). However, this type of data logger would not be suitable for collecting temperature data from a kingfisher nest hole. Handling the temperature sensor in a closed nest hole would be problematic, as would securing the sensor in the chamber to avoid possible burial in the nest sediment.

## CONCLUSIONS

The temperature data from an active natural nest of the Common Kingfisher indicate specific thermal conditions compared to standard nests. The relatively stable and low soil temperatures affect all breeding progress. Temperature data can be effectively used to monitor breeding phases (with the exception of hatching) and even assess breeding success in all suitable cases. However, for accurate interpretation, it is advisable to obtain additional information through direct inspection of the nest hole or via camera recording. The breeding phases and the transitions between them produce characteristic patterns. Egg-laying occurs during the day, resulting in rapid temperature changes due to the presence of the female in the nest chamber. The onset of incubation is associated with increased temperatures in the nest chamber both day and night, as the parental bird is permanently present. There is a noticeable difference between the presence of a parental bird during incubation, the parental heating of freshly hatched chicks, and the presence of grown chicks alone. The fledging of the chicks is indicated on the temperature curve by a rapid drop, and during the subsequent night, there is no temperature fluctuation in the nest chamber. Breeding failure can also be inferred from temperature trends; for instance, if the chicks die slowly in the nest chamber, the temperature will gradually decrease to the background temperature before the expected date of fledging. However, determining the exact timing of when the chicks have hatched based solely on temperature curves is not always possible, but a short nest inspection in time of expected hatching can help assess it. Further measurements are needed to clarify this phenomenon. Thus, from temperature data, we can precisely determine the

particular lengths of incubation and nestling period, or at least the total length of incubation from its start to the chicks leaving the nest. Deciles are a suitable and simple statistical method for processing largely fluctuating temperature data, as they effectively limit outliers. The percentile ranges respond to the degree of temperature change at different stages of reproduction.

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## STRESZCZENIE

### [Zmiany temperatury w norach lęgowych zimorodka wskazują na przebieg poszczególnych faz lęgu]

Dane dotyczące biologii lęgowej ptaków, takie jak wzorzec wysiadywania, czy długość okresu pisklęcego, mogą być zbieranie przy wykorzystaniu różnych urządzeń, w tym m.in. kamer oraz znaczników umożliwiających identyfikację za pomocą fal radiowych. Jednak użycie takich urządzeń w gniazdach zlokalizowanych w norach ziemnych napotyka trudności. W ostatnich latach coraz powszechniej wykorzystuje się do zbierania danych dotyczących różnych aspektów biologii lęgowej ptaków rejestratory temperatury. Praca prezentuje wyniki badań dotyczących zastosowania rejestratorów temperatury do monitorowania poszczególnych faz lęgu w naturalnych gniazdach zimorodka.

Prace prowadzono w gniazdach znajdujących się na brzegach trzech strumieni w okolicach Pragi

w Czechach (Fig. 1). Badaniami objęto 6 lęgów w pięciu norach (Tab. 1, Apendyks 1), w tym dwa następujące po sobie lęgi w tej samej norze (Apendyks 2). Wykorzystano rejestratory temperatury z dwoma czujnikami: jeden umieszczono wewnątrz komory gniazdowej (podczas składania jaj lub wysiadywania) obok gniazda, natomiast drugi — w pustej norze, zlokalizowanej ok. 50 cm od nory gniazdowej, na tej samej głębokości i wysokości, co czujnik w norze gniazdowej (Fig. 2). Temperatura wewnątrz komory gniazdowej i nory referencyjnej była mierzona w sposób ciągły w odstępach jednonminutowych. Pomiaru trwały

od złożenia jaj/wysiadywania aż do pomyślnego wylotu podlotów lub straty lęgu (Tab. 2, Fig. 3).

Profile temperaturowe pozwoliły na wyróżnienie etapu składania jaj, rozpoczęcie wysiadywania, terminu wylotu młodych z gniazda, a także terminu śmierci piskląt w komorze gniazdowej (Fig. 3–7). Na podstawie danych temperaturowych nie zawsze było jednak możliwe dokładne wyznaczenie, kiedy wykluły się pisklęta, ponieważ przez pewien czas po wykluciu pisklęta zimorodka, podobnie, jak wysiadywane jaja, są ogrzewane przez rodziców.

Appendix 1. Overview of the results of inspections of occupied Common Kingfisher nests conducted with a special mini-camera (streams in the Greater Prague district, Czech Republic). \* — unsuccessful breeding attempts.

Location of nest, breeding season (study period)	date of control	result of inspecting the nesting chamber
Radotínský stream, 2018 (June 1–July 5)	June 1	7 eggs
	June 6	the male was warming 7 eggs
	June 15	7 nestlings about 5 or 6 days old
	June 25	7 chicks about 14 or 15 days
	July 3	7 chicks about 22 or 23 days
	July 4	empty nest chamber
Botič stream 2018 (June 18–July 18) *	June 18	7 eggs
	June 27	7 nestlings about 1 or 2 days old, the female was warming the nestlings
	July 6	7 chicks about 9 or 10 days
	July 13	7 chick deaths at 11 or 12 days of age
Rokytká stream 2019 (May 24–July 11)	May 24	2 eggs
	May 31	the male was warming 7 eggs
	June 10	the male was warming 7 eggs
	June 20	7 nestlings about 1 or 2 days old, the female was warming the nestlings
	July 3	7 chicks about 15 or 16 days
	July 11	empty nest chamber
Botič stream 2019 (July 3–July 30) *	July 3	7 eggs
	July 11	the female was warming 6 eggs
	July 19	the female was warming 6 eggs
	July 30	4 chick deaths at 3 or 4 days of age
Radotínský stream 2020 (April 16–May 28)	April 16	6 eggs
	April 25	the female was warming 7 eggs
	May 4	the male was warming 6 nestlings about 1 or 2 days old and 1 egg
	May 12	4 chicks about 9 or 10 days old
	May 22	4 chicks about 18 or 19 days old
	June 1	2 eggs (the second breeding event)
	June 1	2 eggs
Radotínský stream 2020 (June 1–July 27)	June 10	the female was warming 7 eggs
	June 19	7 eggs
	June 30	7 nestlings about 3 or 4 day old
	July 10	7 chicks about 14 or 15 days old
	July 20	empty nest chamber

Appendix 2. The temperature course in the active nest hole of the Common Kingfisher from the incubation of the 1st breeding event to the fledgling of the chicks at the end of the 2nd breeding event on the Radotinský stream in 2020 (from April 16 to July 21). Vertical lines separate different phases of breeding: I1 — incubation of the 1st clutch, I2 — incubation of the 2nd clutch, N1 — nestling period phase of the 1st clutch and N2 — nestling period phase of the 2nd clutch, L2 indicates egg laying of the 2nd brood. Egg laying is defined as the period from the laying of the first egg (if available) to the laying of the last egg, incubation as the period of egg heating (from the time the last egg is laid and female stayed during night until the chicks hatch, based on the expected date and field observations) and nestling period is defined by the presence of chicks in the nest chamber (from hatching to the last chick fledging, i.e. leaving the nest). The empty nest hole is defined from the time the last chick leaves the nest hole. T1 — temperature in the occupied nest hole, T2 — ambient soil temperature, Tmet — ambient air temperature.

