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The effect of local weather conditions and nest box location on the reproduction of the Common Kestrel (*Falco tinnunculus*) in the farmland of eastern Poland

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Artificial nests like nest boxes are commonly used to improve the reproductive output and population status of wild birds and advance our understanding of their evolutionary ecology. To investigate how the location of nest boxes and local weather conditions affect Common Kestrel reproduction (number of fledglings), 319 broods from 173 nest boxes in east-central Poland were examined. Of the six meteorological parameters analysed, only mean temperature and maximum temperature were selected as the best model. Mean daily temperature had a positive effect but maximum temperature a negative one on Common Kestrel reproduction. The first egg laying date was negatively correlated with the number of fledglings. Contrary to the assumption that trees should offer a superior microclimate in the canopy, nest boxes placed on utility poles have the same numbers of fledglings. The area of the main habitat type is not decisive in Common Kestrel productivity either. These findings may be helpful for ongoing conservation programmes and confirm that utility poles should be the preferred form of deployment of nest boxes as they are easier to monitor and maintain.

1. Introduction

Many bird species use man-made structures for nesting, their primary advantage being that they often provide nesting sites in areas where natural ones are not available (Lambrechts *et al.* 2012, Mainwaring 2015, Le Roux *et al.* 2016). Artificial nests like nest boxes are commonly used to improve the reproductive output and population status of bird species with nest-site limited populations (Golawski *et al.* 2003, Klein *et al.* 2007, Smallwood *et al.* 2009, Rodríguez *et al.* 2011, Libois *et al.* 2012, Schaub *et al.* 2016, Carstens *et al.* 2019) and to improve our understanding of the functional and evolutionary ecology of wild, cavity-nesting birds (Lambrechts *et al.* 2012).

Nest boxes offer shelter against extreme weather (Lambrechts *et al.* 2012). However, weather conditions not only impact breeding

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performance directly, but also bring forward the timing of breeding (Carrillo & González-Dávila 2010a, Sumasgutner *et al.* 2020). This could have an influence on factors benefitting birds' reproduction, e.g. higher parental provisioning rates and lower ectoparasite abundance in nests (McDonald *et al.* 2004, Martínez-de la Puente *et al.* 2009). The positioning of nest boxes is also important, as the different compass directions in which they face will expose them to different sets of weather conditions (Butler *et al.* 2009). Generally, studies of falcons confirm that reproductive parameters are to a large extent affected by weather (Dawson & Bortolotii 2000, Rodríguez & Bustamante 2003, Carlzon *et al.* 2018). Nevertheless, if conservation programmes are to be effective, the influence of both nest box location and local weather conditions should be analysed (see Valkama & Korpimäki 1999).

For secondary hole-nesting raptors, the probability that a nest box is occupied and the expression of avian life-history traits of the nest box's occupants depend on aspects of nest box design, location and maintenance procedures (Lambrechts *et al.* 2012). Artificial structures are frequently used by falcons that do not build their own nests, thus benefitting their reproductive parameters (Bortolotti 1994, Fargallo *et al.* 2001). Common Kestrel *Falco tinnunculus* breeding in nest boxes in an open landscape produced more fledglings than its conspecifics breeding in other sites like holes in buildings, pylons and trees (Valkama & Korpimäki 1999, Fargallo *et al.* 2001, Charter *et al.* 2007a). The preference of Common Kestrels for artificial nests is associated with the lower predation rate by Pine Martens *Martes martes,* Goshawks *Accipiter gentilis* and rodents, reduced nest site competition with Long-eared Owls *Asio otus*, and shorter distances from the nest to foraging areas (Valkama & Korpimäki 1999, Fargallo *et al.* 2001). On the other hand, Starlings *Sturnus vulgaris* in North America have been found to usurp nest boxes during the American Kestrel's egg-laying stage, thereby reducing the nesting success of these raptors (Rohrbaugh & Yahner 1997). Nonetheless, nest boxes seem to be safer than natural sites. Despite the higher intensity of nestling infestations in nest boxes, they are less often predated (Fargallo *et al.* 2001). As a consequence, the installation of nest boxes has led to local increases in the breeding populations of different falcon species and this form of conservation management is often applied in farmland and urban areas (Bux *et al.* 2008, Smallwood & Collopy 2009, Altwegg *et al.* 2014, Costantini & Dell'Omo 2020).

The aim of this research was to investigate how the deployment of nest boxes and local weather conditions affect Common Kestrel reproduction. We hypothesised that the number of fledglings would depend on the nest box site, the time of egg laying, temperature, precipitation and wind speed. We also anticipated that numbers of fledglings would be higher in nest boxes attached to trees rather than utility poles, as the tree canopy would offer a superior microclimate (Valkama & Korpimäki 1999). On the other hand, nest boxes located on utility poles are more exposed to temperature and rainfall, which could affect the number of fledglings (see Costantini *et al.* 2010a, Kreiderits 2016). Knowledge of the impact of these factors may be useful when implementing conservation measures for the Common Kestrel in farmland (see Lambrechts *et al.* 2012).

2. Material and methods

2.1. Study area

The research was carried out within a radius of ca 50 km around the town of Siedlce (east-central Poland; 52°12'N, 22°17'E). This region has a preponderance of arable land (46.9%), with meadows and pastureland having a 14.7% coverage, and orchards, mainly apple trees, occupying 2.6% of the land. Woodlands cover 24.8% of the region and built-up areas 5.7%. The populations of the towns (Siedlce, Węgrów, Sokołów Podlaski) range from 12 800 to 78 000. The remaining 5.3% consists of water bodies and wasteland (Statistical Yearbook 2015). The area has a temperate transitional climate (Degirmendzic *et al.* 2004).

2.2. Data collection

The study was carried out during ten breeding seasons from 2010 to 2019. During this period, 173 nest boxes were visited and 319 breeding pairs of Common Kestrel investigated. The birds nested in the same type of nest box (30 cm wide × 40 long × 30 cm high), constructed from 2 cm thick pine boards and half-open to one side. The roof was secured with a metal sheet or roofing felt, and all the walls were coated with an impregnating agent. Nest boxes were hung at the same height on trees and on utility poles, between 6 and 7 m above the ground. Data were gathered from 194 nests (93 boxes) deployed on utility poles and from 125 nests (80 boxes) on trees. The mean number of nests monitored each year was 31.9 (SD = 19.46). During the breeding season each nest box was inspected at least twice: once in May and then again on the day of the last inspection, depending on the age of the fledglings and the possibility of counting them, since their number was key to this study. If, during the second inspection, the fledglings were too small to be counted, a third inspection was undertaken. The size of the fledged brood was taken to be the number of nestlings in successful nests in the fourth week (Kreiderits *et al.* 2016). To eliminate the year effect (Costantini *et al.* 2010b), the data were standardised against the first egg date (FED) in the population in each year. For all clutches, the first egg date was established by backdating from the day the chicks left the nest, assuming 30 days for incubation (starting with the 3rd egg), and the hatching day was based on a 30-day period for the nestling stage. The dominant habitat (meadows or arable land) within a 1 km radius of the boxes was determined using QGIS software. In the open areas of Europe, Kestrels are known to forage within a few km of the nest, but the mostly do so no farther away than 1000 m (Korpimäki *et al.* 1996, Norrdahl & Korpimäki 2002). The meteorological data were obtained from the weather station in Siedlce (52°25’ N, 22°26’ E), which is representative of the whole study area. The mean annual temperature during the study period varied from 15.8 to 19.3 °C. Six meteorological parameters were calculated for the nestling-rearing period: three temperature parameters (mean, maximum and minimum), two precipitation parameters (total and day numbers) and wind speed (Table 1). The mean temperature (Tmean) was calculated from the mean daily temperature for all the days in the chick-rearing period. The minimum (Tmin) and maximum temperatures (Tmax) were the lowest and highest temperatures recorded in that given period. The total precipitation (PPsum) was the total amount of precipitation that fell in a 30-day period, while the number of days with precipitation (PPdays) was the total number of days when rain fell. The mean wind speed (Wspeed) was the average of the mean daily wind speeds in a given period.

2.3. Statistical analyses

A General Linear Mixed Model (GLMM) with identity link function and normal error distribution was used to test the hypothesis stated in the introduction. The number of 4-week old

Table 1. Factors for analysing reproduction of Common Kestrel (*Falco tinnunculus*) breeding in nest boxes in eastern Poland.

Code	Description
FED	Standardised first egg laying date
Location	Category of nest box location: utility pole and tree
Habitat	Category of habitat: meadow and arable land
Tmean	mean temperature (°C), range 12.8–21.7
Tmin	minimum temperature (°C), range (–2.4)–9.4
Tmax	maximum temperature (°C), range 26.3–33.7
PPsum	total precipitation (mm), range 15.5–223.0
PPdays	number of days with precipitation (N), range 6–23
Wspeed	mean wind speed (km/h), range 6.8–11.1

Table 2. Results of three models describing the influence of habitat factors on the numbers of Common Kestrel *Falco tinnunculus* fledglings in eastern Poland. Degrees of freedom (*df*), model log-likelihood (LL), corrected AIC criterion (AIC_c), difference between the model and the best model in the data set (Δ AICc) and weight for the model (AIC_cwt) are shown.

Model (fixed effects)	*df*	LL	AIC_c	ΔAIC_c	AIC_cwt
Intercept+FED+Tmean+Tmax	6	–476.933	966.1	0.00	0.081
Intercept+FED+Tmean+Tmax+Habitat	7	–476.374	967.1	0.97	0.049
Intercept+FED+Tmean+Tmax+PPsum	7	–476.635	967.6	1.50	0.038
Intercept+FED+Tmean+Tmax+Site	7	–476.843	968.0	1.91	0.031
Intercept+FED+Tmean+Tmax+Tmin	7	–476.872	968.1	1.97	0.030

nestlings was treated as a dependent variable. Six weather parameters, the first egg laying date, habitat category and nest box location category were independent variables. Nest box identity was introduced as a random factor to account for within-subject consistency in the response. The models were constructed using the lmer function in the lme4 package for R (Bates *et al.* 2015). Model selection was performed using the information-theoretic approach (AIC) proposed by Burnham and Anderson (2002). All possible combinations of the global model were analysed using the dredge function in the MuMln package for R (Bartoń 2016). Only the models with Δ AIC ≤ 2 are discussed, because they are treated as being equally supported (Burnham & Anderson 2002). Multiple competing models were assessed with regard to their fit to the data using AIC as the leading criterion, and the models with the lowest AIC were selected as the best fitting models. All data were analysed in the R environment (R Core Team 2019). The values reported are the mean ± 1 SE. Only those results with a probability of $\alpha \leq 0.05$ are assumed to be statistically significant.

3. Results

During the ten years of the study, we found from 1 to 7 fledglings in the nest boxes (mean = 4.5, *SD* = 1.15, *N* = 319). The FED period ranged from 21 days in 2013 to 58 in 2019. Five models based on Akaike's information criterion achieved a value of Δ AIC ≤ 2. These models contained seven predictors, but three of these were the same in all the models (Table 2). The first model thus included the FED, the mean and maximum temperatures and was selected as the best model. The four other weather parameters, i.e. total precipitation, number of days with precipitation, wind speed and minimum temperature, and also the habitat and location categories were excluded from the subsequent analysis.

The GLMM model showed that all three selected factors affected the reproduction of Common Kestrel (Table 3). Both the first egg date and the maximum temperature negatively influenced the number of fledglings. On the other hand, the mean daily temperature had a positive effect on Common Kestrel reproduction (Table 3).

4. Discussion

Our study showed that the first egg laying date and two weather factors but not the location or habitat type affected the reproduction of Common Kestrel. The first egg laying date tends to be negatively correlated with fledging success in birds: as the breeding season advances, environmental conditions deteriorate (Tolonen & Korpimäki 1995, Golawski & Meissner 2008). However, in a Mediterranean population of Common Kestrel, the timing of breeding was correlated with the amount of rainfall and temperature during the laying period (Costantini *et al.* 2010a). This relationship was explained by the birds exhibiting a certain plasticity, enabling them to adapt their laying time to environmental conditions: this was manifested by delayed egg-laying in rainier and colder breeding seasons. Variation in the mean laying date among breeding seasons suggests

Table 3. Estimated model coefficients for the best GLMM model of factors affecting the numbers of Common Kestrel *Falco tinnunculus* fledglings in eastern Poland.

Fixed effects	Estimate	Standard Error	*t* value	*P* value
Intercept	6.771	0.981	6.902	<0.001
First egg laying date	–0.023	0.005	–5.006	<0.001
Tmean	0.146	0.058	2.513	0.013
Tmax	–0.143	0.046	–3.090	0.002
Random effects	Variance	Standard deviation		
Nest box	0.043	0.206		
Residual	1.123	1.060		

that this species is sensitive to weather conditions (Carrillo & González-Dávila 2010a). Studies of different Common Kestrel populations across the Western Palearctic showed that it bred earlier where winter and spring temperatures were higher (Carrillo & González-Dávila 2010b).

Despite our assumption that trees should offer a superior microclimate in the canopy, nest boxes placed on utility poles had the same numbers of fledglings. The microclimate at breeding sites has been found to be a crucial factor for breeding success in many birds (e.g. Dawson *et al.* 2005; Ardia *et al.* 2006). Thus, microclimatic conditions during offspring development can variously affect hatchling mass, nestling growth, body condition and immunity; in extreme cases, heat stress and dehydration can lead to mortality (Murphy 1985; Bull 2003). However, we found a negative effect of maximum temperature on the number of fledglings, possibly because they are sensitive to high temperatures, which also may reduce food availability due, for example, to drought. This weather factor appeared to affect the broods in both locations to a similar extent; the tree canopy did not significantly improve conditions. Relationships between temperature and breeding parameters were found in American Kestrel: hatching success was lower in south-facing boxes, which were warmer than west-facing ones (Butler *et al.* 2009). However, a Finnish study of Common Kestrel did not corroborate these differences in the number of fledglings with respect to orientation (Valkama & Korpimäki 1999). It should be emphasised that in the cooler climate of Finland, high temperatures may have a different effect on Common Kestrel reproduction than in Poland. Be that as it may, air temperatures in recent years have been rising quite distinctly (Ballester *et al.* 2010), so their effect on falcon nestlings 20 years ago may well have been different to what is happening now. Mean daily temperature seems to be conducive to greater breeding success in Common Kestrel: this could be related to the availability of prey, especially insects. *Orthopterans* are a very important component of the Common Kestrel diet (Gropalli 1992) as their development and activity are strongly dependent on temperature (Lactin & Johnson 1998, Maeno & Tanaka 2010). On the other hand, the costs of thermoregulation in cold weather may also increase food demands and affect reproductive parameters (see Carrillo & González-Dávila 2005). In general, therefore, higher temperatures may be very beneficial for falcon reproduction (Jenkins 2000, Rodríguez & Bustamante 2003).

In the present study, rainfall and wind were not important weather parameters. However, in most falcon species studied, precipitation does have a negative influence (Dawson & Bortolotii 2000, Charter *et al.* 2007b, Kreiderits *et al.* 2016). Such an adverse effect of rainfall on the number of fledglings has also been reported in shrikes *Laniidae*, whose diet is similar to that of Common Kestrel (Golawski 2006, Collister & Wilson 2007). Precipitation reduces the activity of the potential victims of birds, especially insects (Yosef 2000). A positive relationship between the total annual rainfall and Lesser Kestrel reproduction was found in Spain, which was expected, because rainfall is the main factor limiting productivity in Mediterranean climates (Rodríguez & Bustamante 2003). A warmer and rainier spring also enhanced fledgling success in an Italian population of Common Kestrel (Costantini *et al.* 2010a). Geographically related conditions could be the main explanation for the differences in breeding effort here (Carrillo & González-Dávila 2010b).

Nest boxes dedicated to kestrels and deployed on trees are often taken over by other bird species like owls (Golawski *et al.* unpublished data). Moreover, this type of location is exposed to higher predation pressure on the part of Pine Martens (Valkama & Korpimäki 1999). Utility poles therefore appear to be a safer location than trees. Assuming further that both locations had the same reproductive parameters and that nest boxes on utility poles are easier to monitor and maintain, the latter should be the preferred form of location in conservation programmes. Moreover, where habitat types form a large mosaic, as in eastern Poland, the surface area of the main habitat type will not be a decisive factor affecting kestrel productivity. Most of the feeding grounds will probably contain the necessary environmental components ensuring food abundance (see Golawski & Meissner 2008).

In conclusion, our study showed that the number of Common Kestrel fledglings in nest boxes attached to utility poles was the same as in those deployed on trees. Also, there was no clear link with the nest box location, weather factors and the dominant habitat type. These findings may be very useful in ongoing conservation programmes because nest boxes on utility poles are easier to monitor and maintain and may be safer than nest boxes on trees.

Sääolosuhteiden ja pesäpöntön sijainnin vaikutus tuulihaukan lisääntymiseen Puolassa

Keinopesiä, kuten pesäpönttöjä, käytetään usein parantamaan lintujen lisääntymismenestystä, ja ne mahdollistavat lajin ekologian ja evoluution tutkimisen. Tutkimme, miten pesäpönttöjen sijainti ja paikalliset sääolosuhteet vaikuttavat tuulihaukan lisääntymismenestykseen (poikastuotto) Puolassa. Tutkimuksen otoskoko oli 173 pesäpönttöä ja 319 poikuetta. Analysoimme kuutta meteorologista parametriä, joista keskimääräinen ja maksimilämpötila valikoituivat parhaaseen tilastomalliin: päivän keskilämpötilalla oli positiivinen vaikutus tuulihaukan pesintään, kun taas maksimilämpötilan vaikutus oli päinvastainen. Muninnan aloitus korreloi positiivisesti poikastuoton kanssa. Oletimme, että puiden latvustossa sijaitsevissa pöntöissä mikroilmasto olisi suotuisampi pesinnän kannalta kuin sähköpylvääseen kiinnitetyssä pöntössä, mutta pesimämenestys ei eronnut näissä kahdessa ryhmässä. Tulokset auttavat lajin suojelussa, ja muun muassa varmistavat että lajin populaatioseurannassa voidaan suosia sähköpylväisiin kiinnitettyjä keinopesiä, jotka helpottavat seurantaa.

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