Journal: **Frontiers in Ecology and Evolution**

Home range sizes of Tengmalm's owl offspring during the post-fledging dependence period in Central and North Europe

Simona Stehlíková Sovadinová[1]*¶, Marek Kouba[1,2¶], Michal Ševčík[1,3], Filip Tulis[1,3], Tomáš Bušina[1], Erkki Korpimäki[4]

[1]Department of Ethology and Companion Animal Science, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Prague, Czechia.

[2]Department of Game Management and Wildlife Biology, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czechia.

[3]Department of Ecology and Environmental Sciences, Faculty of Natural Sciences and Informatics, Constantine the Philosopher University in Nitra, Nitra, Slovakia.

[4]Section of Ecology, Department of Biology, University of Turku, Turku, Finland.

[¶]These authors contributed equally to this work.

*Corresponding author: s.stehlikova.s@gmail.com

ORCID – Simona Stehlíková Sovadinová: 0009-0008-9431-5156; Marek Kouba: 0000-0003-2262-5733; Erkki Korpimäki: 0000-0001-7596-1955; Michal Ševčík: 0000-0003-4533-9887; Filip Tulis: 0000-0003-2673-5630; Tomáš Bušina: 0000-0003-0301-5171

STATISTICAL ANALYSIS

Home range estimation

Considering the distance between the two study sites (Czechia and Finland), it was necessary to use an equivalent (equal-area) map projection to calculate the area to compare the sizes of home ranges (HR). We used the ETRS89-LAEA Europe coordinate reference system (EPSG code: 3035), which is suitable for generalising data, statistical mapping and analytical work whenever an accurate area representation in Europe is required (Peifer 2011).

Given that no universal home range estimator or model exists (Powell and Mitchell 2012), we estimated the HRs of each individual using five different methods: Minimum Convex Polygon (MCP), Kernel Density Estimation (KDE) with least squares cross-validation (h_{LSCV}) bandwidth selection from *adehabitatHR* package, IID bi-variate Gaussian Kernel Density Estimation model (IID KDE), Ornstein–Uhlenbeck Foraging (OUF AKDE) and weighted Ornstein–Uhlenbeck Foraging (weighted OUF AKDE) from *ctmm* package (for graphic representation see Figure S1 below). The last two methods account for autocorrelation in data, which minimises bias that can affect home range estimates if measured points depend on each other (Silva et al. 2021). Typically, the shorter the interval separating two observed locations, the more autocorrelated they will be (Noonan et al. 2019; Borger et al. 2020). However, due to the coarser frequency of data acquisition (once per day/night) and variograms of randomly selected individuals, our data did not indicate that autocorrelation need to be considered.

While LSCV-KDE estimates seemed to undersmooth the estimates, a known problem of this method, especially for birds (Mitchell et al. 2019), autocorrelation methods considerably overestimated home range sizes. Although all methods differed in their estimated HR magnitudes (ordered by mean magnitude estimate: LSCV-KDE < MCP < IID KDE < OUF AKDE < weighted OUF AKDE), all were very strongly positively correlated ($r > 0.9$, $p < 0.001$; except for LSCV-KDE with $r > 0.7$, $p < 0.001$), therefore, we performed the principal component analysis (PCA) to create a weighted linear combination of all models (HR estimation methods) and reduce dimensionality to one. The preliminary analysis used the first principal component (PC), which explained 98.8% of the total variation, as the dependent variable. More importantly, due to the high positive correlation of the first PC axis with all HR sizes ($r > 0.9$, $p < 0.001$; and $r > 0.6$, $p < 0.001$ for LSCV), a change in PC could be interpreted as a change in HR size. The PC was log-transformed to meet the linear mixed model assumptions. Since the log-transformation cannot be applied to negative values (and zero), we used the standard procedure mathematical operation that first rescales PC by subtracting the minimum value of a PC (in R: log1p(PC – min(PC))).

However, because preliminary test results for the first PC variable and individual Minimum Convex Polygon (MCP) and IID bi-variate Gaussian Kernel Density Estimation (IID KDE) methods were nearly identical, we decided to present within the main manuscript the latter two methods and results for clarity reasons only.

Model selection

Model selection is an essential part of any statistical analysis and central to the pursuit of science. Nevertheless, statisticians have no general consensus on what method to use (Kadane and Lazar 2004; Stephens et al. 2005; Lewis et al. 2011; Hooten and Hobbs 2015).

To find the best model/s, we decided to use two of the most popular approaches: model selection based on Likelihood-Ratio Tests (LRT) and based on Information-Theoretic Criteria (ITC) (Hegyi and Laczi 2015). We agree with several authors' critiques against mixing the LTR and ITC approach (i.e., ranking the candidate models with ITC and testing first "the best" model against the rest of the models; Anderson and Burnham 2002). Therefore, we applied both approaches independently to compare both results and find consensus/disagreement between selected models.

For LTR, to mitigate the central issue of parameter estimation bias of stepwise modelling (Whittingham et al. 2006) and even increase estimation accuracy, we used an altered SRPE (Stepwise Reintroduction for Parameter Estimation) version (Hegyi and Garamszegi 2011; Hegyi and Laczi 2015). The method includes adding removed terms individually for the final model and checking their fitting and effect sizes.

For ITC, we ranked all possible models by their second-order Akaike's information criterion (AICc), as described in the Material and Methods section of the main manuscript.

Because both procedures converge on the same final models, we decided to present only the results of the ITC approach within the main manuscript.

REFERENCES

Anderson, D., and K. Burnham. 2002. Model selection and multi-model inference. Second. NY: Springer-Verlag 63(2020):10.

Borger, L., J. S. Horne, J. Fieberg, J. L. Rachlow, J. M. Calabrese, and C. H. Fleming. 2020. Animal Home Ranges, Population Ecology in Practice. Wiley-Blackwell.

Hegyi, G., and L. Z. Garamszegi. 2011. Using information theory as a substitute for stepwise regression in ecology and behavior. Behavioral Ecology and Sociobiology 65:69–76.

Hegyi, G., and M. Laczi. 2015. Using full models, stepwise regression and model selection in ecological data sets: Monte Carlo simulations. In: Annales Zoologici Fennici. p 257–279.

Hooten, M. B., and N. T. Hobbs. 2015. A guide to Bayesian model selection for ecologists. Ecological Monographs 85(1):3–28. doi: 10.1890/14-0661.1.

Kadane, J. B., and N. A. Lazar. 2004. Methods and Criteria for Model Selection. Journal of the American Statistical Association 99(465):279–290. doi: 10.1198/016214504000000269.

Lewis, F., A. Butler, and L. Gilbert. 2011. A unified approach to model selection using the likelihood ratio test. Methods in Ecology and Evolution 2(2):155–162. doi: 10.1111/j.2041-210X.2010.00063.x.

Mitchell, L. J., P. C. L. White, and K. E. Arnold. 2019. The trade-off between fix rate and tracking duration on estimates of home range size and habitat selection for small vertebrates. PloS one 14(7):e0219357.

Noonan, M. J., M. A. Tucker, C. H. Fleming, T. S. Akre, S. C. Alberts, A. H. Ali, J. Altmann, P. C. Antunes, J. L. Belant, and D. Beyer. 2019. A comprehensive analysis of autocorrelation and bias in home range estimation. Ecological Monographs 89(2):e01344.

Peifer, H. 2011. About the EEA reference grid. European Environment Agency.

Powell, R. A., and M. S. Mitchell. 2012. What is a home range? Journal of Mammalogy 93(4):948–958. doi: 10.1644/11-mamm-s-177.1.

Silva, I., C. H. Fleming, M. J. Noonan, J. Alston, C. Folta, W. F. Fagan, and J. M. Calabrese. 2021. Autocorrelation-informed home range estimation: A review and practical guide. Methods in Ecology and Evolution 13(3):534–544.

Stephens, P. A., S. W. Buskirk, G. D. Hayward, and C. M. Del Rio. 2005. Information theory and hypothesis testing: a call for pluralism. Journal of Applied Ecology 42(1):4–12. doi: 10.1111/j.1365-2664.2005.01002.x.

Whittingham, M. J., P. A. Stephens, R. B. Bradbury, and R. P. Freckleton. 2006. Why do we still use stepwise modelling in ecology and behaviour? Journal of Animal Ecology 75(5):1182–1189. doi: 10.1111/j.1365-2656.2006.01141.x.

TABLES

Table S1. Basic breeding and radiotracking data of monitored nests and individuals. Basic breeding and radiotracking data of the studied nests and individuals during the six study years within the two study areas. The ranges and mean numbers (± standard deviations) of nests, clutch sizes, hatchlings, fledglings, radio-tracked fledglings, and dispersed individuals, and sums of dispersed individuals, nestling sex ratios, dates of nesting, hatching, fledging, and dispersal, duration of the nestling period, numbers of nocturnal activity, diurnal roosting and pooled radiotelemetry locations, sizes of individual and siblings night, diurnal and overall home ranges established by 95% IID Kernel Density Estimation (IID KDE) and 100% Minimum Convex Polygon (MCP) methods, and spring prey abundance determined by snap-trapping in the two study areas and listed as the number of trapped individuals per 100 trap-nights recorded during the six breeding seasons are listed.

	range	**mean ± SD**	**range**	**mean ± SD**	**range**	**mean ± SD**	**range**	**mean ± SD**	**range**	**mean ± SD**	**range**	**mean ± SD**
Year	2010		2011		2012		2015		2019		2021	
Country (study area)	Czechia (Ore Mts.)		Czechia (Ore Mts.)		Czechia (Ore Mts.)		Czechia (Ore Mts.)		Finland (Kauhava)		Finland (Kauhava)	
No. of involved nests	6		5		2		6		10		14	
Clutch size	6 - 8	7.2 ± 0.9	3 - 5	4.2 ± 0.7	6	6.0 ± 0.0	4 - 7	5.5 ± 1.1	4 - 7	5.6 ± 1.0	5 - 7	6.2 ± 0.9
No. of hatchlings	5 - 8	6.7 ± 1.4	3 - 5	3.6 ± 0.8	5 - 6	5.5 ± 0.5	2 - 7	4.8 ± 1.6	4 - 7	5.3 ± 1.0	3 - 7	6.0 ± 1.2
No. of fledglings	3 - 8	5.8 ± 1.7	1 - 4	2.0 ± 1.1	5	5.0 ± 0.0	2 - 7	4.5 ± 1.5	1 - 4	2.1 ± 1.0	1 - 6	2.8 ± 1.6
Sex of fledglings (F : M)	12 : 23		4 : 6		7 : 3		18 : 12		4 : 17		21 : 18	
No. of radio-tracked fledglings	29*		10		10		29**		21		39	
No. of dispersed fledglings	2 - 6	3.7 ± 1.4	0 - 2	1.2 ± 0.7	5	5.0 ± 0.0	0 - 5	3.0 ± 1.8	0 - 2	0.4 ± 0.7	0 - 5	2.1 ± 1.8
Sum of dispersed individuals	22		6		10		20		4		29	
Date of nesting (± days)	25 March - 1 April	29 March ± 3	15 March - 7 April	30 March ± 9	13 March	13 March ± 0	21 March - 16 April	29 March ± 9	19 March - 4 April	26 March ± 4	19 March - 3 May	8 April ± 15
Date of hatching (± days)	23 April - 10 May	1 May ± 5	12 April - 7 May	26 April ± 8	10 April - 20 April	14 April ± 3	20 April - 22 May	30 April ± 9	16 April - 2 May	24 April ± 3	17 April - 4 June	11 May ± 15
Date of fledging (± days)	23 May - 15 June	2 June ± 5	14 May - 10 June	30 May ± 9	11 May - 20 May	16 May ± 3	18 May - 22 July	31 May ± 9	22 May - 2 June	27 May ± 3	19 May - 5 July	11 June ± 14
Date of dispersal (± days)	5 July - 30 July	17 July ± 6	11 July - 3 August	24 July ± 9	1 July - 11 July	7 July ± 3	6 July - 2 August	22 July ± 7	16 July - 22 July	18 July ± 2	3 July - 11 August	20 July ± 11
Duration of nestling period (days)	28 - 36	32 ± 2	27 - 38	34 ± 3	30 - 33	32 ± 1	28 - 35	31± 2	29 - 39	33 ± 3	19 - 40	31 ± 3
No. of night locations	32 - 46	40 ± 4	49 - 59	53 ± 3	44 - 54	49 ± 3	-		39 - 44	41 ± 2	28 - 41	34 ± 4

Individual night IID KDE 95% (ha)	7.4 - 130.1	52.5 ± 33.2	13.6 - 130.2	95.3 ± 41.2	26.7 - 103.4	54.4 ± 28.4	-		72.6 - 135.1	93.2 ± 24.6	8.0 - 215.5	64.7 ± 52.1
Individual night MCP 100% (ha)	5.3 - 61.1	30.2 ± 16.1	11.8 - 75.9	52.8 ± 21.3	14.4 - 69.4	36.9 ± 18.9	-		42.0 - 81.2	56.4 ± 14.8	4.8 - 135.1	35.5 ± 30.6
Siblings night MCP 100% (ha)	10.2 - 73.0	46.5 ± 20.8	11.8 - 78.9	51.7 ± 27.2	31.9 - 80.0	55.9 ± 24.1	-		42.0 - 81.2	59.0 ± 16.4	5.2 - 157.0	48.9 ± 49.2
No. of daytime locations	-		-		46 - 57	52 ± 3	40 - 58	50 ± 6	25 - 32	29 ± 3	29 - 44	36 ± 4
Individual daytime IID KDE 95% (ha)	-		-		22.8 - 96.6	43.6 ± 27.2	1.9 - 79.2	30.1 ± 26.3	70.6 - 141.6	114.7 ± 27.4	3.7 - 233.3	61.5 ± 52.8
Individual daytime MCP 100% (ha)	-		-		10.3 - 65.7	25.2 ± 19.9	1.4 - 35.6	15.3 ± 10.1	31.9 - 71.0	55.3 ± 15.1	2.0 - 139.2	31.9 ± 30.9
Siblings daytime MCP 100% (ha)	-		-		16.9 - 74.5	45.7 ± 28.8	4.7 - 38.9	20.8 ± 11.9	31.9 - 72.2	56.6 ± 17.7	4.0 - 141.4	43.5 ± 45.4
No. of all locations	-		-		90 - 111	101 ± 5	-		66 - 76	70 ± 4	57 - 84	70 ± 8
Individual overall IID KDE 95% (ha)	-		-		23.4 - 96.2	49.2 ± 27.0	-		67.8 - 134.3	100.4 ± 23.6	6.5 - 208.5	59.3 ± 48.2
Individual overall MCP 100% (ha)	-		-		14.9 - 82.8	40.3 ± 22.9	-		43.3 - 84.7	66.8 ± 15.4	5.4 - 147.1	39.2 ± 32.6
Siblings overall MCP 100% (ha)	-		-		32.0 - 91.6	61.8 ± 29.8	-		43.3 - 84.7	68.4 ± 18.0	6.6 - 161.6	52.8 ± 51.1
Prey abundance (spring)	10.19		0.55		4.87		2.50		0.42		7.80	

*Six other individuals from five involved nests fledged before tagging with a radio transmitter.

**One other individual fledged before tagging with a radio transmitter.

Table S2. A priori hypotheses for the three tested models / dependent variables "a, b, c". Final multiple a priori hypotheses based on the remaining biologically relevant variables after testing for collinearity and pre-analysis (see the main manuscript) evaluated to determine which model/s is/are the best in explaining the (a) fledglings' home range size based on nocturnal locations, (b) fledglings' home range size based on diurnal locations, and (c) fledglings' home range size based on pooled nocturnal and diurnal locations recorded throughout the post-fledging dependence period.

Model No.	Models (a, b, c) – Fledglings' home range size based on nocturnal (a), diurnal (b) and pooled (c) locations recorded throughout the post-fledging dependence period – a priori hypotheses
1	nest box ID
2	duration of stay on the nest nest box ID
3	duration of PFDP nest box ID
4	duration of stay on the nest duration of PFDP nest box ID
5	locality nest box ID
6	duration of stay on the nest locality nest box ID
7	duration of PFDP locality nest box ID
8	duration of stay on the nest duration of PFDP locality nest box ID
9	No. of fledglings nest box ID
10	duration of stay on the nest No. of fledglings nest box ID
11	duration of PFDP No. of fledglings nest box ID
12	duration of stay on the nest duration of PFDP No. of fledglings nest box ID
13	locality No. of fledglings nest box ID
14	duration of stay on the nest locality No. of fledglings nest box ID
15	duration of PFDP locality No. of fledglings nest box ID
16	duration of stay on the nest duration of PFDP locality No. of fledglings nest box ID
17	order of hatching nest box ID
18	duration of stay on the nest order of hatching nest box ID
19	duration of PFDP order of hatching nest box ID
20	duration of stay on the nest duration of PFDP order of hatching nest box ID
21	locality order of hatching nest box ID
22	duration of stay on the nest locality order of hatching nest box ID
23	duration of PFDP locality order of hatching nest box ID

24 duration of stay on the nest duration of PFDP locality order of hatching nest box ID
25 No. of fledglings order of hatching nest box ID
26 duration of stay on the nest No. of fledglings order of hatching nest box ID
27 duration of PFDP No. of fledglings order of hatching nest box ID
28 duration of stay on the nest duration of PFDP No. of fledglings order of hatching nest box ID
29 locality No. of fledglings order of hatching nest box ID
30 duration of stay on the nest locality No. of fledglings order of hatching nest box ID
31 duration of PFDP locality No. of fledglings order of hatching nest box ID
32 duration of stay on the nest duration of PFDP locality No. of fledglings order of hatching nest box ID
33 locality*duration of PFDP nest box ID
34 locality*order of hatching nest box ID
35 locality*duration of stay on the nest nest box ID
36 locality*No. of fledglings nest box ID
37 duration of PFDP*order of hatching nest box ID
38 duration of PFDP*duration of stay on the nest nest box ID
39 duration of PFDP*No. of fledglings nest box ID
40 order of hatching*duration of stay on the nest nest box ID
41 order of hatching*No. of fledglings nest box ID
42 duration of stay on the nest*No. of fledglings nest box ID

Biological explanations:

nest box ID - used as random effect only, but expected to be important because the fledged sibling groups always keep together throughout the post-fledging dependence period; thus, similar size of home range within siblings can be expected

duration of stay on the nest - the longer individuals stay on the nest, the better fledging condition can be expected, and fledglings in better condition can be expected to have larger home ranges of nocturnal activity because they can afford to invest more energy in exploration

duration of PFDP - the longer individuals stay in the natal area (having a longer post-fledging dependence period), the larger home ranges might be expected because they will move overall further from the nest throughout this period

No. of fledglings - the more fledged siblings will be present at a given nest, the smaller home ranges can be expected because, for the male parent, it will be harder to move with the whole sibling group in a specific direction

order of hatching - individuals who hatch later are the younger / youngest, and in their case, they can be expected to reach independence last; thus, larger home ranges might be expected in their case because they will move overall further from the nest compared to earlier hatched ones

locality - we did not expect to find differences in fledglings' home range sizes between the two study localities (i.e., between the Ore Mts. in Czechia and Kauhava region in Finland)

Table S3. Composition of the best models. Composition (applied fixed effects) of the five best fitting models sorted according to fitting statistics, AICc (the smaller, the better), ΔAICc, AICc weights, and AICc odds for the six modelled dependent variables (models a, b, c).

Models (a)	**AICc**	**Delta AICc**	**AICc weights**	**AICc Odds**
Model (a1) - Fledglings' home range size of nocturnal activity throughout the PFDP calculated by IID Kernel Density Estimation*				
1) duration of stay on the nest, duration of PFDP, order of hatching, nest box ID	269.49	0	0.36	1
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	270.16	0.67	0.26	1.4
3) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	271.8	2.31	0.11	3.18
4) duration of stay on the nest, duration of PFDP, No. of fledglings, order of hatching, nest box ID	271.84	2.35	0.11	3.24
5) duration of PFDP, order of hatching, nest box ID	273.41	3.92	0.05	7.1
Model (a2) - Fledglings' home range size of nocturnal activity throughout the PFDP calculated by Minimum Convex Polygon*				
1) duration of stay on the nest, duration of PFDP, order of hatching, nest box ID	236.46	0	0.2	1
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	236.59	0.13	0.19	1.07
3) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	238.2	1.74	0.08	2.39
4) duration of PFDP, order of hatching, nest box ID	238.46	2.01	0.07	2.73
5) duration of PFDP, locality, order of hatching, nest box ID	238.49	2.03	0.07	2.76

Models (b)	**AICc**	**Delta AICc**	**AICc weights**	**AICc Odds**
Model (b1) - Fledglings' home range size of diurnal roosting throughout the PFDP calculated by IID Kernel Density Estimation*				
1) duration of PFDP, locality, order of hatching, nest box ID	254.27	0	0.24	1
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	255.21	0.94	0.15	1.6
3) duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	255.56	1.29	0.13	1.91
4) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	255.62	1.35	0.12	1.96
5) locality, order of hatching, nest box ID	257.51	3.24	0.05	5.06
Model (b2) - Fledglings' home range size of diurnal roosting throughout the PFDP calculated by Minimum Convex Polygon*				

1) duration of PFDP, locality, order of hatching, nest box ID	223.11	0	0.35	1
2) duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	224.74	1.63	0.15	2.26
3) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	224.87	1.76	0.14	2.41
4) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	225.93	2.82	0.09	4.09
5) duration of PFDP, order of hatching, nest box ID	227.52	4.41	0.04	9.06

Models (c)	**AICc**	**Delta AICc**	**AICc weights**	**AICc Odds**
Model (c1) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the PFDP calculated by IID Kernel Density Estimation*				
1) duration of stay on the nest, duration of PFDP, order of hatching, nest box ID	171.08	0	0.4	1
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	171.44	0.36	0.33	1.2
3) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	173.42	2.33	0.12	3.21
4) duration of stay on the nest, duration of PFDP, No. of fledglings, order of hatching, nest box ID	173.9	2.81	0.1	4.08
5) duration of PFDP, order of hatching, nest box ID	178.24	7.15	0.01	35.71
Model (c2) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the PFDP calculated by Minimum Convex Polygon*				
1) duration of stay on the nest, duration of PFDP, order of hatching, nest box ID	150.53	0	0.41	1
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	150.96	0.42	0.33	1.23
3) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	152.91	2.38	0.12	3.28
4) duration of stay on the nest, duration of PFDP, No. of fledglings, order of hatching, nest box ID	153.34	2.8	0.1	4.06
5) duration of stay on the nest, duration of PFDP, nest box ID	158.42	7.88	0.01	51.5

*All six dependent variables tested were square-root transformed before the analyses.

Table S4. Comparison of the best models. Comparison of the five best models to the Null model (AICc and relative information loss) for the six modelled dependent variables (models a, b, c) with values of the expanded information criteria sorted by AICc (from the lowest to the highest value) and its rank (the number in parentheses correspond to a rank within the criterion).

Models (a)	**AICc (rank)**	**AIC (rank)**	**HQIC (rank)**
Model (a1) - Fledglings' home range size of nocturnal activity throughout the post-fledging dependence period calculated by IID Kernel Density Estimation*			
1) duration of stay on the nest, duration of PFDP, order of hatching, nest box ID	269.49 (1)	268.18 (1)	274.18 (1)
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	270.16 (2)	268.39 (2)	275.39 (2)
3) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	271.80 (3)	269.48 (3)	277.48 (4)
4) duration of stay on the nest, duration of PFDP, No. of fledglings, order of hatching, nest box ID	271.84 (4)	270.07 (4)	277.07 (3)
5) duration of PFDP, order of hatching, nest box ID	273.41 (5)	272.49 (5)	277.49 (5)
Null model	282.95	282.59	285.59
Relative information loss to the best model (No. 1)	0.001	7E-4	0.003
Model (a2) - Fledglings' home range size of nocturnal activity throughout the post-fledging dependence period calculated by Minimum Convex Polygon*			
1) duration of stay on the nest, duration of PFDP, order of hatching, nest box ID	236.46 (1)	235.15 (2)	241.15 (1)
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	236.59 (2)	234.82 (1)	241.82 (2)
3) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	238.20 (3)	235.88 (3)	243.88 (8)
4) duration of PFDP, order of hatching, nest box ID	238.46 (4)	237.54 (6)	242.54 (3)
5) duration of PFDP, locality, order of hatching, nest box ID	238.49 (5)	237.18 (5)	243.18 (4)
Null model	248.52	248.16	251.16
Relative information loss to the best model (No. 1)	0.002	0.001	0.007

Models (b)	**AICc (rank)**	**AIC (rank)**	**HQIC (rank)**
Model (b1) - Fledglings' home range size of diurnal roosting throughout the post-fledging dependence period calculated by IID Kernel Density Estimation*			
1) duration of PFDP, locality, order of hatching, nest box ID	254.27 (1)	252.77 (1)	258.77 (1)
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	255.21 (2)	253.17 (3)	260.17 (2)
3) duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	255.56 (3)	253.52 (4)	260.52 (3)
4) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	255.62 (4)	252.95 (2)	260.95 (4)
5) locality, order of hatching, nest box ID	257.51 (5)	256.45 (5)	261.45 (5)
Null model	260.62	260.21	263.21
Relative information loss to the best model (No. 1)	0.04	0.02	0.1

Model (b2) - Fledglings' home range size of diurnal roosting throughout the post-fledging dependence period calculated by Minimum Convex Polygon*			
1) duration of PFDP, locality, order of hatching, nest box ID	223.11 (1)	221.61 (1)	227.61 (1)
2) duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	224.74 (2)	222.71 (2)	229.71 (2)
3) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	224.87 (3)	222.83 (3)	229.83 (3)
4) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	225.93 (4)	223.27 (4)	231.27 (4)
5) duration of PFDP, order of hatching, nest box ID	227.52 (5)	226.47 (5)	231.47 (5)
Null model	229.95	229.55	232.55
Relative information loss to the best model (No. 1)	0.03	0.02	0.08

Models (c)	**AICc (rank)**	**AIC (rank)**	**HQIC (rank)**
Model (c1) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the post-fledging dependence period calculated by IID Kernel Density Estimation*			
1) duration of stay on the nest, duration of PFDP, order of hatching, nest box ID	171.08 (1)	168.75 (2)	174.75 (1)
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	171.44 (2)	168.24 (1)	175.24 (2)
3) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	173.42 (3)	169.18 (3)	177.18 (3)
4) duration of stay on the nest, duration of PFDP, No. of fledglings, order of hatching, nest box ID	173.90 (4)	170.70 (4)	177.70 (4)
5) duration of PFDP, order of hatching, nest box ID	178.24 (5)	176.61 (6)	181.61 (5)
Null model	181.12	180.5	183.5
Relative information loss to the best model (No. 1)	0.007	0.002	0.01
Model (c2) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the post-fledging dependence period calculated by Minimum Convex Polygon*			
1) duration of stay on the nest, duration of PFDP, order of hatching, nest box ID	150.53 (1)	148.20 (2)	154.20 (1)
2) duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID	150.96 (2)	147.76 (1)	154.76 (2)
3) duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID	152.91 (3)	148.67 (3)	156.67 (3)
4) duration of stay on the nest, duration of PFDP, No. of fledglings, order of hatching, nest box ID	153.34 (4)	150.14 (4)	157.14 (4)
5) duration of stay on the nest, duration of PFDP, nest box ID	158.42 (5)	156.80 (5)	161.80 (5)
Null model	164.39	163.77	166.77
Relative information loss to the best model (No. 1)	9E-4	3E-4	0.002

*All six tested dependent variables (models a, b, c) were square-root transformed before the analyses.

Table S5. Model information. Estimate (β), standard error (SE), and 95% confidence interval (CI) of the fixed factors in the best models of the six modelled dependent variables (models a, b, c).

Models (a)	Model No.	Effect	Estimate	SE	95% CI	
Model (a1) - Fledglings' home range size of nocturnal activity throughout the post-fledging dependence period calculated by IID Kernel Density Estimation*	1)	**duration of stay on the nest**	**0.21**	**0.08**	**0.05**	**0.38**
		duration of PFDP	**0.13**	**0.03**	**0.07**	**0.20**
		order of hatching	**0.22**	**0.06**	**0.09**	**0.35**
	2)	**duration of stay on the nest**	**0.21**	**0.08**	**0.05**	**0.37**
		duration of PFDP	**0.15**	**0.03**	**0.08**	**0.21**
		locality	-1.53	1.12	-3.79	0.75
		order of hatching	**0.23**	**0.07**	**0.10**	**0.36**
Model (a2) - Fledglings' home range size of nocturnal activity throughout the post-fledging dependence period calculated by Minimum Convex Polygon*	1)	**duration of stay on the nest**	**0.14**	**0.07**	**0.01**	**0.27**
		duration of PFDP	**0.12**	**0.03**	**0.06**	**0.17**
		order of hatching	**0.12**	**0.05**	**0.02**	**0.23**
	2)	**duration of stay on the nest**	**0.14**	**0.07**	**0.01**	**0.27**
		duration of PFDP	**0.13**	**0.03**	**0.07**	**0.18**
		locality	-1.27	0.81	-2.91	0.38
		order of hatching	**0.14**	**0.05**	**0.03**	**0.25**
	3)	**duration of stay on the nest**	**0.16**	**0.07**	**0.02**	**0.29**
		duration of PFDP	**0.13**	**0.03**	**0.08**	**0.19**
		locality	-1.60	0.87	-3.36	0.16
		No. of fledglings	0.21	0.22	-0.23	0.66
		order of hatching	**0.13**	**0.05**	**0.02**	**0.24**

Models (b)	Model No.	Effect	Estimate	SE	95% CI	
Model (b1) - Fledglings' home range size of diurnal roosting throughout the post-fledging dependence period calculated by IID Kernel Density Estimation*	1)	**duration of PFDP**	**0.11**	**0.04**	**0.02**	**0.20**
		locality	**-4.01**	**1.50**	**-7.05**	**-0.95**
		order of hatching	**0.32**	**0.10**	**0.12**	**0.52**
	2)	duration of stay on the nest	0.12	0.10	-0.07	0.32
		duration of PFDP	**0.12**	**0.04**	**0.03**	**0.21**

		locality	**-3.91**	**1.51**	**-6.98**	**-0.83**
		order of hatching	**0.34**	**0.10**	**0.14**	**0.53**
	3)	**duration of PFDP**	**0.11**	**0.04**	**0.02**	**0.20**
		locality	**-4.83**	**1.63**	**-8.13**	**-1.50**
		No. of fledglings	0.50	0.44	-0.40	1.39
		order of hatching	**0.31**	**0.10**	**0.11**	**0.51**
	4)	duration of stay on the nest	0.16	0.10	-0.04	0.36
		duration of PFDP	**0.13**	**0.04**	**0.04**	**0.22**
		locality	**-5.01**	**1.61**	**-8.30**	**-1.72**
		No. of fledglings	0.69	0.45	-0.23	1.61
		order of hatching	**0.33**	**0.10**	**0.13**	**0.52**
Model (b2) - Fledglings' home range size of diurnal roosting throughout the post-fledging dependence period calculated by Minimum Convex Polygon*	1)	**duration of PFDP**	**0.11**	**0.04**	**0.04**	**0.18**
		locality	**-3.02**	**1.08**	**-5.22**	**-0.83**
		order of hatching	**0.25**	**0.08**	**0.09**	**0.41**
	2)	**duration of PFDP**	**0.11**	**0.04**	**0.04**	**0.18**
		locality	**-3.51**	**1.18**	**-5.91**	**-1.12**
		No. of fledglings	0.30	0.31	-0.34	0.94
		order of hatching	**0.24**	**0.08**	**0.08**	**0.40**
	3)	duration of stay on the nest	0.07	0.08	-0.09	0.23
		duration of PFDP	**0.12**	**0.04**	**0.04**	**0.19**
		locality	**-2.96**	**1.09**	**-5.18**	**-0.74**
		order of hatching	**0.26**	**0.08**	**0.09**	**0.42**

Models (c)	**Model No.**	**Effect**	**Estimate**	**SE**	**95% CI**	
Model (c1) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the post-fledging dependence period calculated by IID Kernel Density Estimation*	1)	**duration of stay on the nest**	**0.35**	**0.10**	**0.14**	**0.55**
		duration of PFDP	**0.26**	**0.05**	**0.14**	**0.38**
		order of hatching	**0.46**	**0.11**	**0.23**	**0.68**
	2)	**duration of stay on the nest**	**0.35**	**0.09**	**0.15**	**0.55**
		duration of PFDP	**0.28**	**0.06**	**0.16**	**0.40**
		locality	-4.01	2.47	-9.22	1.04

		order of hatching	**0.49**	**0.11**	**0.26**	**0.71**
Model (c2) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the post-fledging dependence period calculated by Minimum Convex Polygon*	1)	**duration of stay on the nest**	**0.30**	**0.07**	**0.14**	**0.46**
		duration of PFDP	**0.26**	**0.04**	**0.16**	**0.35**
		order of hatching	**0.34**	**0.08**	**0.15**	**0.51**
	2)	**duration of stay on the nest**	**0.30**	**0.07**	**0.14**	**0.45**
		duration of PFDP	**0.27**	**0.04**	**0.18**	**0.36**
		locality	-3.23	2.02	-7.53	0.90
		order of hatching	**0.36**	**0.08**	**0.18**	**0.53**

*All six tested dependent variables (models a, b, c) were square-root transformed before the analyses.

Variables with 95% CI that do not cross zero are shown in bold text (significant effects).

Table S6. Variable importance. A sum of AICc weights (relative importance) of the fixed factors in the best models of the six modelled dependent variables (models a, b, c).

	Variable importance					
	Models (a)		**Models (b)**		**Models (c)**	
Effect	**Model (a1) - Fledglings' home range size of nocturnal activity throughout the PFDP calculated by IID Kernel Density Estimation***	**Model (a2) - Fledglings' home range size of nocturnal activity throughout the PFDP calculated by Minimum Convex Polygon***	**Model (b1) - Fledglings' home range size of diurnal roosting throughout the PFDP calculated by IID Kernel Density Estimation***	**Model (b2) - Fledglings' home range size of diurnal roosting throughout the PFDP calculated by Minimum Convex Polygon***	**Model (c1) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the PFDP calculated by IID Kernel Density Estimation***	**Model (c2) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the PFDP calculated by Minimum Convex Polygon***
duration of PFDP	**1.00**	**1.00**	**0.78**	**0.90**	**0.99**	**1.00**
order of hatching	**0.98**	**0.79**	**0.92**	**0.91**	**0.98**	**0.98**
duration of stay on the nest	**0.87**	**0.71**	0.4	0.31	**0.96**	**0.98**
locality	0.44	0.48	**0.82**	**0.86**	0.47	0.47
No. of fledglings	0.26	0.27	0.36	0.31	0.23	0.23

*All six dependent variables tested were square-root transformed before the analyses.

Variables with values > 0.7 are shown in bold text (significant effects).

Table S7. Set of the best models (a). The five best candidate models for the dependent variable fledglings' home range size of nocturnal activity throughout the post-fledging dependence period calculated by IID Kernel Density Estimation (model a1) and fledglings' home range size of nocturnal activity throughout the post-fledging dependence period calculated by Minimum Convex Polygon (model a2) according to the values of the three information criteria (AICc, AIC, HQIC) used, including delta values, Akaike weights, and Odds sorted by AICc (from the lowest to the highest value), are listed.

Model No.	Model (a1) - Fledglings' home range size of nocturnal activity throughout the post-fledging dependence period calculated by IID Kernel Density Estimation*
1	duration of stay on the nest, duration of PFDP, order of hatching, nest box ID
2	duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID
3	duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID
4	duration of stay on the nest, duration of PFDP, No. of fledglings, order of hatching, nest box ID
5	duration of PFDP, order of hatching, nest box ID

Model No.	AICc	Delta AICc	AICc weights wi	AICc Odds	AIC	Delta AIC	AIC weights wi	AIC Odds	HQIC	Delta HQIC	HQIC weights wi	HQIC Odds
1	269.49	0	0.36	1	268.18	0	0.31	1	274.18	0	0.4	1
2	270.16	0.67	0.26	1.4	268.39	0.21	0.28	1.11	275.39	1.21	0.22	1.83
3	271.8	2.31	0.11	3.18	269.48	1.3	0.16	1.92	277.48	3.3	0.08	5.21
4	271.84	2.35	0.11	3.24	270.07	1.89	0.12	2.57	277.07	2.89	0.09	4.24
5	273.41	3.92	0.05	7.1	272.49	4.31	0.04	8.63	277.49	3.31	0.08	5.23

Model No.	Model (a2) - Fledglings' home range size of nocturnal activity throughout the post-fledging dependence period calculated by Minimum Convex Polygon*
1	duration of stay on the nest, duration of PFDP, order of hatching, nest box ID
2	duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID
3	duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID
4	duration of PFDP, order of hatching, nest box ID
5	duration of PFDP, locality, order of hatching, nest box ID

Model No.	AICc	Delta AICc	AICc weights wi	AICc Odds	AIC	Delta AIC	AIC weights wi	AIC Odds	HQIC	Delta HQIC	HQIC weights wi	HQIC Odds
1	236.46	0	0.2	1	235.15	0.33	0.18	1.18	241.15	0	0.2	1
2	236.59	0.13	0.19	1.07	234.82	0	0.22	1	241.82	0.67	0.14	1.4
3	238.2	1.74	0.08	2.39	235.88	1.06	0.13	1.7	243.88	2.73	0.05	3.92
4	238.46	2.01	0.07	2.73	237.54	2.73	0.06	3.91	242.54	1.39	0.1	2.01
5	238.49	2.03	0.07	2.76	237.18	2.36	0.07	3.26	243.18	2.03	0.07	2.76

*Both dependent variables (models a1 and a2) tested were square-root transformed before the analyses.

Table S8. Set of the best models (b). The five best candidate models for the dependent variable fledglings' home range size of diurnal roosting throughout the post-fledging dependence period calculated by IID Kernel Density Estimation (model b1) and fledglings' home range size of diurnal roosting throughout the post-fledging dependence period calculated by Minimum Convex Polygon (model b2) according to the values of the three information criteria (AICc, AIC, HQIC) used, including delta values, Akaike weights, and Odds sorted by AICc (from the lowest to the highest value), are listed.

Model No.	Model (b1) - Fledglings' home range size of diurnal roosting throughout the post-fledging dependence period calculated by IID Kernel Density Estimation*
1	duration of PFDP, locality, order of hatching, nest box ID
2	duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID
3	duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID
4	duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID
5	locality, order of hatching, nest box ID

Model No.	AICc	Delta AICc	AICc weights wi	AICc Odds	AIC	Delta AIC	AIC weights wi	AIC Odds	HQIC	Delta HQIC	HQIC weights wi	HQIC Odds
1	254.27	0	0.24	1	252.77	0	0.21	1	258.77	0	0.24	1
2	255.21	0.94	0.15	1.6	253.17	0.4	0.17	1.22	260.17	1.4	0.12	2.02
3	255.56	1.29	0.13	1.91	253.52	0.76	0.14	1.46	260.52	1.76	0.1	2.41
4	255.62	1.35	0.12	1.96	252.95	0.18	0.19	1.1	260.95	2.18	0.08	2.98
5	257.51	3.24	0.05	5.06	256.45	3.69	0.03	6.32	261.45	2.69	0.06	3.83

Model No.	Model (b2) - Fledglings' home range size of diurnal roosting throughout the post-fledging dependence period calculated by Minimum Convex Polygon*
1	duration of PFDP, locality, order of hatching, nest box ID
2	duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID
3	duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID
4	duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID
5	duration of PFDP, order of hatching, nest box ID

Model No.	AICc	Delta AICc	AICc weights wi	AICc Odds	AIC	Delta AIC	AIC weights wi	AIC Odds	HQIC	Delta HQIC	HQIC weights wi	HQIC Odds
1	223.11	0	0.35	1	221.61	0	0.31	1	227.61	0	0.35	1
2	224.74	1.63	0.15	2.26	222.71	1.09	0.18	1.73	229.71	2.09	0.12	2.85
3	224.87	1.76	0.14	2.41	222.83	1.22	0.17	1.84	229.83	2.22	0.12	3.03
4	225.93	2.82	0.09	4.09	223.27	1.65	0.14	2.28	231.27	3.65	0.06	6.21
5	227.52	4.41	0.04	9.06	226.47	4.85	0.03	11.33	231.47	3.85	0.05	6.87

*Both dependent variables (models b1 and b2) tested were square-root transformed before the analyses.

Table S9. Set of the best models (c). The five best candidate models for the dependent variable fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the post-fledging dependence period calculated by IID Kernel Density Estimation (model c1) and fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the post-fledging dependence period calculated by Minimum Convex Polygon (model c2) according to the values of the three information criteria (AICc, AIC, HQIC) used, including delta values, Akaike weights, and Odds sorted by AICc (from the lowest to the highest value), are listed.

Model No.	Model (c1) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the post-fledging dependence period calculated by IID Kernel Density Estimation*
1	duration of stay on the nest, duration of PFDP, order of hatching, nest box ID
2	duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID
3	duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID
4	duration of stay on the nest, duration of PFDP, No. of fledglings, order of hatching, nest box ID
5	duration of PFDP, order of hatching, nest box ID

Model No.	AICc	Delta AICc	AICc weights wi	AICc Odds	AIC	Delta AIC	AIC weights wi	AIC Odds	HQIC	Delta HQIC	HQIC weights wi	HQIC Odds
1	171.08	0	0.4	1	168.75	0.51	0.28	1.29	174.75	0	0.41	1
2	171.44	0.36	0.33	1.2	168.24	0	0.36	1	175.24	0.49	0.32	1.28
3	173.42	2.33	0.12	3.21	169.18	0.94	0.23	1.6	177.18	2.43	0.12	3.37
4	173.9	2.81	0.1	4.08	170.7	2.45	0.11	3.41	177.7	2.94	0.09	4.36
5	178.24	7.15	0.01	35.71	176.61	8.37	0.01	65.67	181.61	6.86	0.01	30.92

Model No.	Model (c2) - Fledglings' home range size of pooled nocturnal activity and diurnal roosting throughout the post-fledging dependence period calculated by Minimum Convex Polygon*
1	duration of stay on the nest, duration of PFDP, order of hatching, nest box ID
2	duration of stay on the nest, duration of PFDP, locality, order of hatching, nest box ID
3	duration of stay on the nest, duration of PFDP, locality, No. of fledglings, order of hatching, nest box ID
4	duration of PFDP, order of hatching, nest box ID
5	duration of PFDP, locality, order of hatching, nest box ID

Model No.	AICc	Delta AICc	AICc weights wi	AICc Odds	AIC	Delta AIC	AIC weights wi	AIC Odds	HQIC	Delta HQIC	HQIC weights wi	HQIC Odds
1	150.53	0	0.41	1	148.2	0.45	0.29	1.25	154.2	0	0.42	1
2	150.96	0.42	0.33	1.23	147.76	0	0.36	1	154.76	0.55	0.32	1.32
3	152.91	2.38	0.12	3.28	148.67	0.92	0.23	1.58	156.67	2.47	0.12	3.44
4	153.34	2.8	0.1	4.06	150.14	2.38	0.11	3.29	157.14	2.94	0.1	4.34
5	158.42	7.88	0.01	51.5	156.8	9.04	0	91.84	161.8	7.59	0.01	44.59

*Both dependent variables (models c1 and c2) tested were square-root transformed before the analyses.

FIGURES

Figure S1. Visual comparison of the five methods used for home range calculations. Estimated nocturnal activity (A, C) and diurnal roosting (B, D) home ranges using Minimum Convex Polygon (MCP), Kernel Density Estimation (KDE) with least squares cross-validation (h_{LSCV}) bandwidth selection, IID bi-variate Gaussian Kernel Density Estimation model (IID KDE), weighted Ornstein–Uhlenbeck Foraging (weighted OUF AKDE) and Ornstein–Uhlenbeck Foraging (OUF AKDE; this method displayed almost identical sizes and shapes to weighted OUF AKDE and therefore not shown in the four map panels) methods for one selected fledgling from both Czechia (A, B) and Finland (C, D).