Effect of long-term temperature changes at non-breeding grounds on phenological shifts in spring migration timing of male and female blackcaps on the southern Baltic coast

Supplementary Materials: Figures S1-S2 and Tables S1-S23

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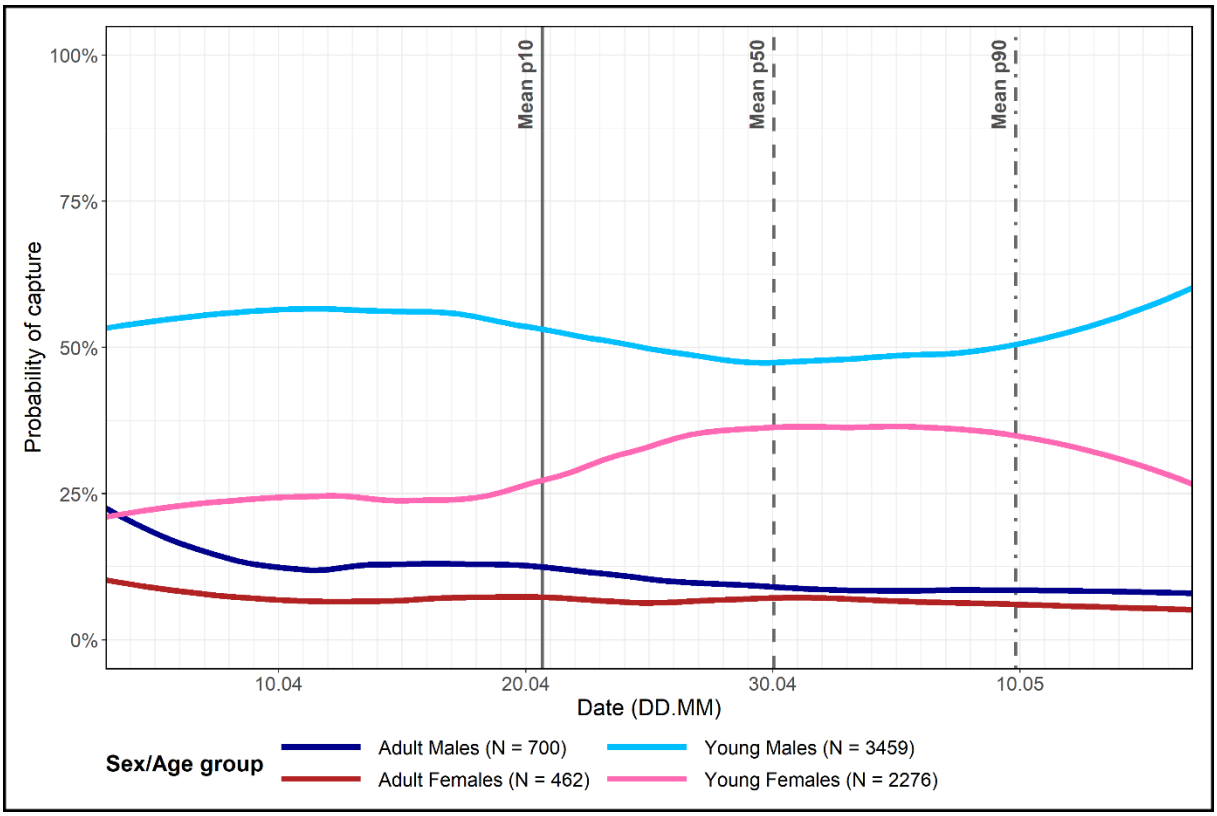


Figure S1. Daily capture probability of adult and young (second-calendar-year birds) male and female Eurasian blackcaps during spring migration at Bukowo-Kopań. Coloured smoothed (LOESS) curves show proportions of each sex/age group changing over the season. Vertical lines indicate the mean dates of the first (p10, solid line), median (p50, dashed line), and last (p90, dot-dash line) phases of passage calculated for all these age/sex groups combined.

(a)

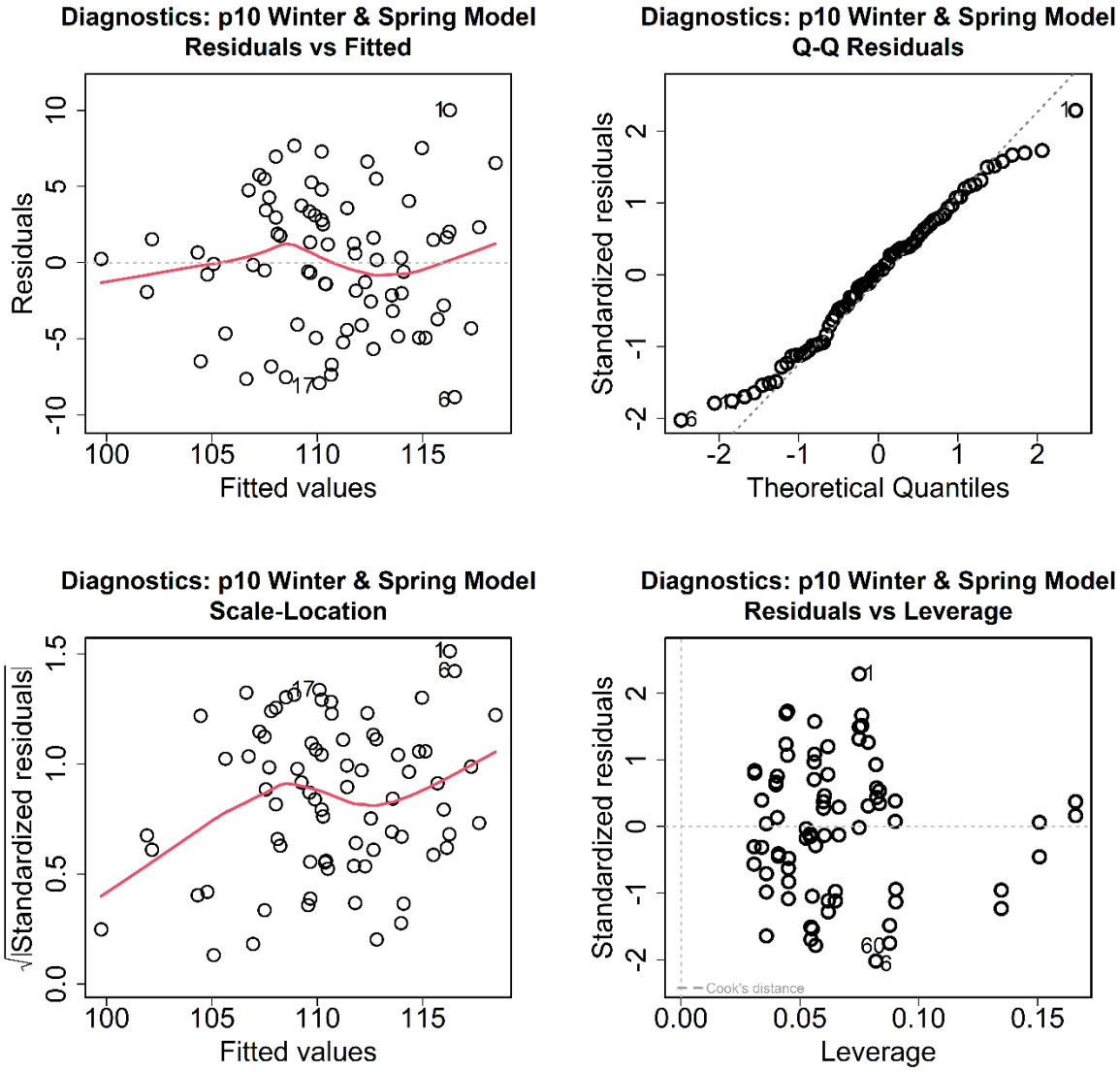


Figure S2. Diagnostic plots for the final best "winter and spring" linear regression models for the dates of the first (p10), median (p50), and last (p90) phases of spring migration. The plots present residuals versus fitted values, normal Q-Q plots, scale location plots, and residuals versus leverage to assess regression assumptions, including linearity, normality of residuals, and identification of highly influential data points (Cook's distance). (a) Diagnostic plots for the best model for p10; (b) Diagnostic plots for the best model for p50; (c) Diagnostic plots for the best model for p90.

(b)

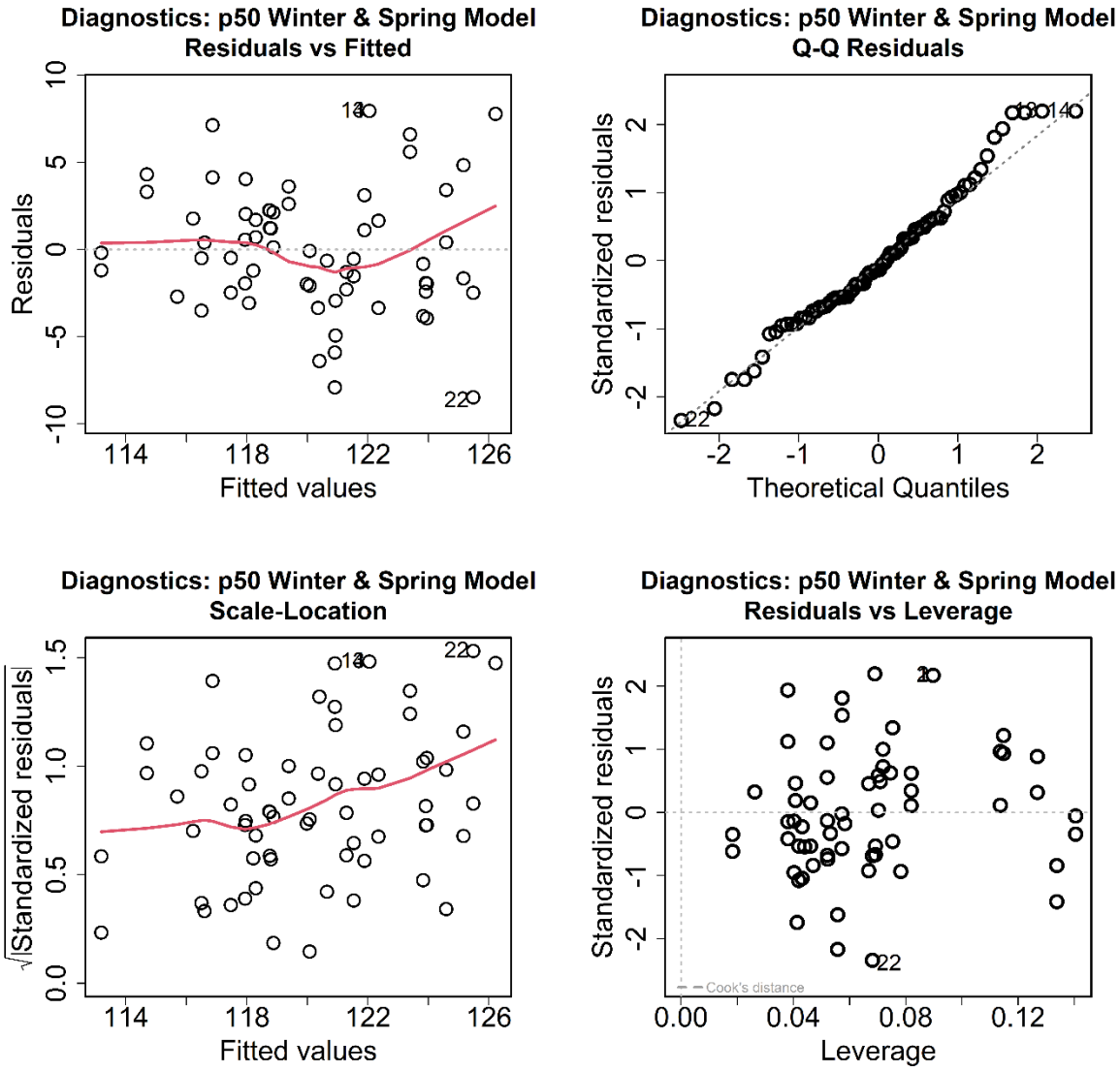


Figure S2. Continued

(c)

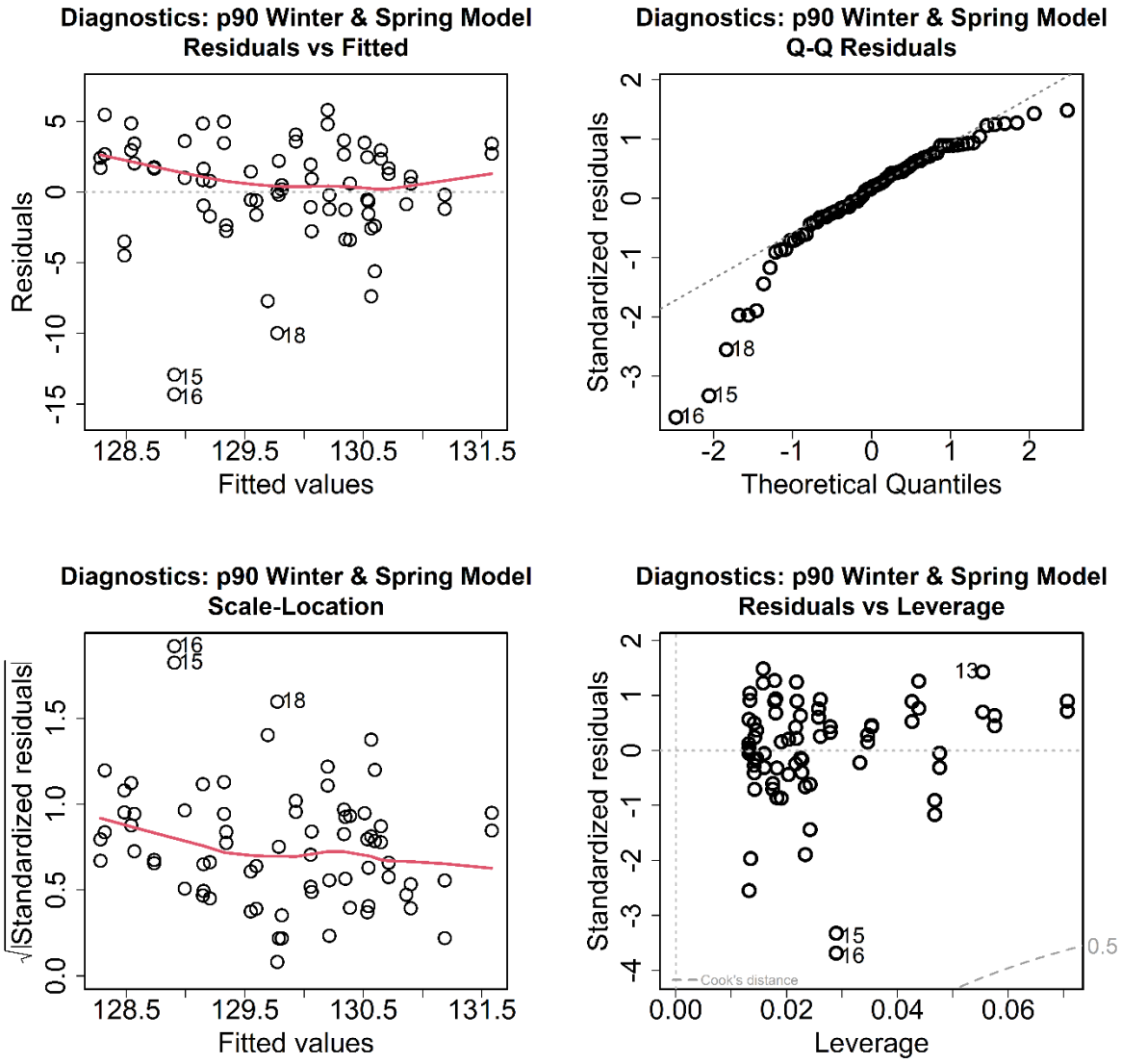


Figure S2. Continued

Table S1. Numbers of captured males, females, and all Eurasian blackcaps (Sylvia atricapilla) caught, and of the nets used during each spring migration season (26 March–16 May) at Bukowo-Kopań in subsequent years of the period 1982–2025. Grey fields – seasons which were excluded from analyses, because the station did not operate or fewer than 5 birds of one sex were caught. Total for analyses (bold font) indicates the numbers of individuals considered in the models.

Year	Females	Males	Total	N nets
1982	44	54	98	57
1983	34	46	80	57
1984	8	13	21	57
1985	5	8	13	42
1986	13	11	24	51
1987	3	5	8	50
1988	15	20	35	45
1989	3	8	11	45
1990	4	4	8	45
1991	6	22	28	45
1992	3	12	15	45
1993	8	11	19	37
1994	23	35	58	47
1995	17	18	35	47
1996	32	32	64	47
1997	47	62	109	47
1998	48	71	119	47
1999	56	77	133	47
2000	38	81	119	47
2001	72	110	182	47
2002	43	91	134	57
2003	54	88	142	51
2004	68	94	162	46
2005	124	154	278	50
2006	133	162	295	50
2007	89	119	208	50
2008	59	91	150	54
2009	124	143	267	50
2010	149	143	292	46
2011	0	0	0	0
2012	105	175	280	35
2013	162	273	435	44
2014	77	140	217	41
2015	73	119	192	48
2016	151	230	381	51
2017	77	126	203	52
2018	123	258	381	52
2019	128	225	353	53
2020	0	0	0	0
2021	156	196	352	46
2022	119	180	299	57
2023	145	165	310	47
2024	148	298	446	48
2025	139	204	343	61
Grand total	2925	4374	7299	
Total for analyses	**2912**	**4345**	**7257**	

Table S2. Pearson's correlation coefficients between the winter and spring temperature variables in 1982–2025. Bold values indicate statistically significant correlations, after Benjamini-Hochberg correction for multiple comparisons with an accepted 5% level of false positives. Abbreviations of the temperature variables as in Table 1.

Variables	TCE_SPR	TWM_WIN	TWM_SPR	TEM_WIN	TEM_SPR	TWA_WIN	TWA_SPR	TEA_WIN	TEA_SPR
TCE_WIN	**0.58**	**0.47**	**0.40**	0.18	**0.45**	-0.08	**0.36**	-0.15	**0.52**
TCE_SPR		0.24	**0.50**	0.12	**0.38**	0.10	**0.35**	0.09	**0.43**
TWM_WIN			**0.33**	**0.55**	**0.32**	**0.34**	**0.47**	0.08	**0.52**
TWM_SPR				**0.45**	**0.45**	**0.46**	**0.64**	**0.48**	**0.56**
TEM_WIN					**0.55**	**0.59**	**0.62**	**0.65**	**0.63**
TEM_SPR						**0.25**	**0.52**	**0.43**	**0.61**
TWA_WIN							**0.62**	**0.71**	**0.59**
TWA_SPR								**0.50**	**0.82**
TEA_WIN									**0.51**

Table S3. Linear regression parameters for the long-term trends in the mean tri-monthly temperatures during winter and spring in the five studied regions across the full period (1982–2025) and two sub-periods (1982–2004 and 2005–2025) (Figure 2). The table presents the intercept (a), slope coefficient (β), standard error (SE), t-value (t), significance level (p), R^2 and Adjusted R^2. 'Change in period' is the estimated total shift in temperature (°C) during the analysed period, calculated by multiplying the slope coefficient β by the number of years. A positive β value indicates an increase in temperature over time. Abbreviations of the temperature variables are provided in Table 1.

Period	Temperature variable	a	β	SE	t	p	R^2	Adj R^2	No of years	Change in period
1982-2025	TCE_WIN	-103.15	0.05	0.02	3.17	**0.0030**	0.20	0.18	44	2.3
	TWM_WIN	-48.17	0.03	0.01	2.68	**0.0107**	0.15	0.13		1.3
	TEM_WIN	-86.26	0.05	0.01	4.32	**0.0001**	0.32	0.30		2.1
	TWA_WIN	-39.01	0.03	0.01	4.66	**<0.0001**	0.35	0.34		1.4
	TEA_WIN	-69.45	0.05	0.01	4.87	**<0.0001**	0.37	0.36		2.0
	TCE_SPR	-65.78	0.04	0.01	3.75	**0.0006**	0.26	0.24		1.6
	TWM_SPR	-79.31	0.05	0.01	6.93	**<0.0001**	0.55	0.53		2.1
	TEM_SPR	-74.70	0.05	0.01	5.07	**<0.0001**	0.39	0.38		2.0
	TWA_SPR	-32.52	0.03	0.01	6.16	**<0.0001**	0.49	0.47		1.4
	TEA_SPR	-61.52	0.05	0.00	9.90	**<0.0001**	0.71	0.70		2.0
1982-2004	TCE_WIN	-121.29	0.06	0.05	1.33	0.1994	0.08	0.03	23	1.4
	TWM_WIN	-63.64	0.04	0.03	1.37	0.1847	0.08	0.04		0.8
	TEM_WIN	-54.82	0.03	0.03	1.19	0.2489	0.06	0.02		0.7
	TWA_WIN	-56.67	0.04	0.02	2.39	**0.0262**	0.21	0.18		0.9
	TEA_WIN	-43.62	0.03	0.03	1.30	0.2067	0.08	0.03		0.8
	TCE_SPR	-124.63	0.07	0.02	2.93	**0.0080**	0.29	0.26		1.5
	TWM_SPR	-121.16	0.07	0.02	3.67	**0.0014**	0.39	0.36		1.6
	TEM_SPR	-58.42	0.04	0.02	1.59	0.1268	0.11	0.07		0.9
	TWA_SPR	-4.97	0.02	0.01	1.41	0.1745	0.09	0.04		0.4
	TEA_SPR	-45.04	0.04	0.01	3.21	**0.0042**	0.33	0.30		0.8
2005-2025	TCE_WIN	-199.49	0.10	0.05	2.19	**0.0430**	0.22	0.17	21	2.1
	TWM_WIN	-179.60	0.09	0.03	3.03	**0.0075**	0.35	0.31		2.0
	TEM_WIN	-112.71	0.06	0.04	1.63	0.1215	0.14	0.08		1.3
	TWA_WIN	-7.57	0.02	0.02	0.72	0.4791	0.03	-0.03		0.3
	TEA_WIN	8.72	0.01	0.03	0.28	0.7826	0.01	-0.05		0.2
	TCE_SPR	-61.93	0.04	0.03	1.03	0.3180	0.06	0.00		0.7
	TWM_SPR	-39.02	0.03	0.02	1.43	0.1696	0.11	0.06		0.6
	TEM_SPR	-40.21	0.03	0.03	1.02	0.3207	0.06	0.00		0.6
	TWA_SPR	-52.70	0.04	0.02	2.49	**0.0234**	0.27	0.22		0.9
	TEA_SPR	-70.89	0.05	0.01	3.35	**0.0038**	0.40	0.36		1.0

Table S4. Model selection for the linear regression models for the regional temperature variables, used as response variables to test for changes in temperature trends between the two study periods. The explanatory variables in the full models included year number (YearN), study period (PeriodN), and their interaction. The table presents the coefficient estimates for the intercept and the explanatory variables selected in each model, followed by the model statistics: degrees of freedom (df), log-likelihood (logLik), Akaike Information Criterion corrected for small sample sizes (AICc), the difference in AICc relative to the best model (delta), and the Akaike weight (weight). The table presents the set of models with delta AICc < 2. Parameters of the best models are presented in more detail in Table S5.

Temperature variable	(Intercept)	PeriodN	YearN	PeriodN:YearN	df	AICc	delta	weight
TCE_WIN	**0.47**		**0.05**		**3**	**149.48**	**0.00**	**0.69**
	0.25	-0.75	0.08		4	151.07	1.58	0.31
TWM_WIN	**7.91**	**-0.94**	**0.06**		**4**	**111.35**	**0.00**	**0.41**
	8.20	-2.36	0.04	0.06	5	111.80	0.45	0.33
	8.18		0.03		3	112.32	0.96	0.26
TEM_WIN	**7.71**		**0.05**		**3**	**115.23**	**0.00**	**1.00**
TWA_WIN	**23.63**		**0.03**		**3**	**74.64**	**0.00**	**1.00**
TEA_WIN	**22.72**	**1.20**			**3**	**102.32**	**0.00**	**0.43**
	22.25		0.05		3	103.09	0.77	0.29
	22.45	0.70	0.02		4	103.20	0.88	0.28
TCE_SPR	**8.02**		**0.04**		**3**	**106.77**	**0.00**	**0.67**
	7.88	-0.48	0.05		4	108.22	1.45	0.33
TWM_SPR	**14.91**		**0.05**		**3**	**75.71**	**0.00**	**1.00**
TEM_SPR	**16.34**		**0.05**		**3**	**99.09**	**0.00**	**0.71**
	16.44	0.35	0.03		4	100.91	1.82	0.29
TWA_SPR	**29.38**		**0.03**		**3**	**50.21**	**0.00**	**1.00**
TEA_SPR	**27.63**		**0.05**		**3**	**41.09**	**0.00**	**1.00**

Table S5. Parameters of the best linear regression models for the regional temperature variables used as response variables, selected based on the lowest AICc (Table S4). The table presents the coefficient estimate (Estimate), its standard error (SE), t-value (t), significance level (p), and Variance Inflation Factor (VIF) for the intercept and explanatory variables selected in the best models, as well as the R^2 and Adjusted R^2 (Adj R^2) for the entire model.

Temperature variable	Explanatory variable	Estimate	SE	t	p	VIF	R^2	Adj R^2
TCE_WIN	(Intercept)	0.47	0.42	1.12	0.2676		20.00%	18.00%
	YearN	0.05	0.02	3.17	**0.0030**			
TWM_WIN	(Intercept)	7.91	0.30	26.25	**<0.0001**		21.80%	17.80%
	PeriodN	-0.94	0.52	-1.82	0.0769	3.88		
	YearN	0.06	0.02	2.96	**0.0052**	3.88		
TEM_WIN	(Intercept)	7.71	0.28	27.69	**<0.0001**		31.80%	30.10%
	YearN	0.05	0.01	4.32	**0.0001**			
TWA_WIN	(Intercept)	23.63	0.17	137.57	**<0.0001**		35.20%	33.60%
	YearN	0.03	0.01	4.66	**<0.0001**			
TEA_WIN	(Intercept)	22.72	0.16	140.68	**<0.0001**		38.30%	36.80%
	PeriodN	1.20	0.24	4.99	**<0.0001**			
TCE_SPR	(Intercept)	8.02	0.25	31.86	**<0.0001**		26.00%	24.10%
	YearN	0.04	0.01	3.75	**0.0006**			
TWM_SPR	(Intercept)	14.91	0.17	85.69	**<0.0001**		54.50%	53.40%
	YearN	0.05	0.01	6.93	**<0.0001**			
TEM_SPR	(Intercept)	16.34	0.23	71.10	**<0.0001**		39.10%	37.60%
	YearN	0.05	0.01	5.07	**<0.0001**			
TWA_SPR	(Intercept)	29.38	0.13	228.84	**<0.0001**		48.70%	47.40%
	YearN	0.03	0.01	6.16	**<0.0001**			
TEA_SPR	(Intercept)	27.63	0.12	239.89	**<0.0001**		71.00%	70.30%
	YearN	0.05	0.00	9.90	**<0.0001**			

Table S6. Linear regression parameters for the long-term trends in the dates for the first (p10), median (p50), and last (p90) phases of spring migration of the Eurasian blackcaps at Bukowo-Kopań in the entire study period (1982–2025) and two sub-periods (1982–2004 and 2005–2025) (Figure 3). The table presents the intercept (a), slope coefficient (β), standard error (SE), t-value (t), significance level (p), R^2 and Adjusted R^2. 'Change in period' is the estimated total shift in arrival timing (in days) during the analysed period, calculated by multiplying the slope coefficient by the number of years. A negative β value indicates an advance in the date of the analysed percentile over time.

Percentile	Period	Sex	a	β	SE	t	p	R^2	Adj R^2	No of years	Change in period
p10	1982-2025	Males	114.46	-0.21	0.07	-3.01	**0.0050**	20.10%	17.80%	44	-9.19
		Females	116.39	-0.20	0.07	-2.96	**0.0050**	19.50%	17.30%		-8.74
	1982-2004	Males	116.07	-0.32	0.17	-1.90	0.0750	17.50%	12.70%	23	-7.41
		Females	117.18	-0.26	0.15	-1.76	0.0970	15.40%	10.40%		-6.08
	2005-2025	Males	106.31	0.03	0.21	0.13	0.8990	0.10%	-5.80%	21	0.56
		Females	114.42	-0.14	0.22	-0.63	0.5340	2.30%	-3.40%		-2.92
p50	1982-2025	Males	124.82	-0.21	0.05	-3.90	**<0.0001**	29.70%	27.80%	44	-9.25
		Females	124.04	-0.17	0.06	-2.96	**0.0050**	19.50%	17.30%		-7.32
	1982-2004	Males	127.61	-0.45	0.15	-2.98	**0.0080**	34.30%	30.50%	23	-10.27
		Females	126.97	-0.42	0.16	-2.63	**0.0180**	28.90%	24.70%		-9.69
	2005-2025	Males	118.78	-0.03	0.12	-0.21	0.8330	0.30%	-5.60%	21	-0.55
		Females	119.14	-0.01	0.12	-0.11	0.9180	0.10%	-5.80%		-0.27
p90	1982-2025	Males	130.31	0.00	0.05	-0.01	0.9900	0.00%	-2.80%	44	-0.03
		Females	128.53	0.04	0.06	0.63	0.5340	1.10%	-1.70%		1.56
	1982-2004	Males	132.00	-0.15	0.15	-1.00	0.3340	5.50%	-0.10%	23	-3.46
		Females	130.65	-0.17	0.17	-1.04	0.3110	6.00%	0.50%		-3.99
	2005-2025	Males	128.15	0.07	0.09	0.76	0.4580	3.30%	-2.40%	21	1.47
		Females	129.96	0.01	0.12	0.07	0.9430	0.00%	-5.80%		0.19

Table S7. Model selection for the linear regression models for the dates of the first (p10), median (p50), and last (p90) phases of spring passage, used as response variables to test for changes in protandry. The explanatory variables in the full models included sex (SexN), year number (YearN), study period (PeriodN), and their interactions. The table presents the coefficient estimates for the intercept and the explanatory variables selected in each model, followed by the model statistics: degrees of freedom (df), log-likelihood (logLik), Akaike Information Criterion corrected for small sample sizes (AICc), the difference in AICc relative to the best model (delta), and the Akaike weight (weight). The table presents the set of models with delta AICc < 2. Parameters of the best models are presented in more detail in Table S8.

Percentile	(Intercept)	PeriodN	SexN	YearN	PeriodN:SexN	PeriodN:YearN	SexN:YearN	df	AICc	delta	weight
p10	**114.34**		**2.17**	**-0.20**				**4**	**472.75**	**0.00**	**0.63**
	115.43			-0.20				3	473.84	1.09	0.37
p50	**127.29**	**-8.33**		**-0.43**		**0.41**		**5**	**432.74**	**0.00**	**1.00**
p90	**129.83**							**2**	**429.60**	**0.00**	**0.25**
	129.26	1.13						3	430.23	0.63	0.18
	130.30		-0.95					3	430.68	1.08	0.15
	130.21	2.70		-0.07				4	431.27	1.67	0.11
	131.33	-2.27		-0.16		0.20		5	431.35	1.75	0.11
	129.74	1.13	-0.95					4	431.35	1.75	0.11
	129.42			0.02				3	431.54	1.94	0.10

Table S8. Parameters of the best linear regression models for the dates of the first (p10), median (p50), and last (p90) phases of spring migration used as response variables, selected based on the lowest AICc (Table S7). The table presents the coefficient estimate (Estimate), its standard error (SE), t-value (t), significance level (p), and Variance Inflation Factor (VIF) for the intercept and explanatory variables selected in the best models, as well as the R^2 and Adjusted R^2 for the entire model.

Percentile	Explanatory variable	Estimate	SE	t	p	VIF	R^2	Adj R^2
p10	(Intercept)	114.34	1.41	81.34	**<0.0001**		23%	20%
	SexN	2.17	1.20	1.81	0.0750	1.00		
	YearN	-0.20	0.05	-4.24	**0.0001**	1.00		
p50	(Intercept)	127.29	1.34	95.07	**<0.0001**		34%	31%
	PeriodN	-8.33	3.85	-2.16	**0.0337**	17.66		
	YearN	-0.43	0.09	-4.71	**<0.0001**	6.32		
	PeriodN:YearN	0.41	0.14	2.98	**0.0040**	28.45		
p90	(Intercept)	129.83	0.46	282.86	**<0.0001**		0%	0%

Table S9. Model selection for the "winter" models of relationships including the TWA temperature variable (without TEA) between dates of the first (p10), median (p50), and last (p90) phases of spring migration of the Eurasian blackcap at Bukowo-Kopań and winter large-scale temperature variables, excluding the winter TEA variable, in 1982–2025. The candidate explanatory variables are listed in the table heading. The table presents the coefficient estimates for the intercept and the explanatory variables selected in each model, followed by the model statistics: degrees of freedom (df), Akaike Information Criterion corrected for small sample sizes (AICc), the difference in AICc relative to the best model (delta AICc), and the Akaike weight (weight). The table presents the set of models with delta AICc < 2. Bold digits indicate variables selected for the best partial "winter" model. Parameters of this best model are presented in more detail in Table S10. Abbreviations of the temperature variables are provided in Table 1.

Percentile	(Intercept)	SexN	TCE_WIN	TEM_WIN	TWA_WIN	TWM_WIN	YearSt	SexN:TCE_WIN	SexN:TEM_WIN	SexN:TWA_WIN	SexN:TWM_WIN	SexN:YearSt	df	AICc	delta	weight
p10	**109.77**	**2.17**	**-2.36**	**-1.56**		**1.33**	**-1.18**						**7**	**467.95**	**0.00**	**0.15**
	109.66	2.17	-1.88				-1.69						5	468.00	0.05	0.15
	109.74	2.17	-2.86	-2.10		1.38							6	468.02	0.07	0.15
	109.73	2.17	-1.89	-0.90			-1.23						6	468.75	0.80	0.10
	109.69	2.17	-2.40	-1.45									5	469.01	1.06	0.09
	110.75		-1.88				-1.69						4	469.34	1.40	0.08
	110.85		-2.36	-1.56		1.33	-1.18						6	469.39	1.44	0.07
	109.66	2.17	-2.11			0.66	-1.82						6	469.40	1.45	0.07
	110.82		-2.86	-2.10		1.38							5	469.41	1.46	0.07
	109.79	2.17	-1.96	-1.78	0.73	1.25	-1.64						8	469.74	1.79	0.06
p50	**120.13**		**-1.68**			**1.44**	**-2.14**						**5**	**431.38**	**0.00**	**0.53**
	120.13		-1.33		0.59	1.30	-2.59						6	432.94	1.56	0.24
	120.17		-1.76	-0.53		1.67	-1.92						6	433.04	1.67	0.23
p90	**129.82**					**0.88**							**3**	**428.30**	**0.00**	**0.28**
	129.74			0.78									3	429.21	0.91	0.18
	130.29	-0.95				0.88							4	429.39	1.09	0.16
	129.83												2	429.60	1.31	0.15
	129.78			0.41		0.66							4	430.02	1.72	0.12
	129.81		-0.34			1.03							4	430.12	1.82	0.11

Table S10. Parameters of the best "winter" linear regression models including the TWA temperature variable (without TEA) for the dates of the first (p10), median (p50), and last (p90) phases of spring migration and winter regional temperatures in 1982–2025. The best models had the lowest AICc (Table S9). The table presents the coefficient estimate (estimate), standard error (std.error), t-value (statistic), significance level (p), and Variance Inflation Factor (VIF) for the intercept and explanatory variables selected by the best model, as well as the R^2 and Adjusted R^2 for the entire model. Abbreviations of the temperature variables are provided in Table 1.

Percentile	Explanatory Variable	Estimate	SE	t	p	VIF	R^2	Adj R^2
p10	(Intercept)	109.77	0.81	136.28	**<0.0001**		33.80%	29.00%
	SexN	2.17	1.13	1.91	0.0599	1.00		
	TCE_WIN	-2.36	0.75	-3.15	**0.0024**	1.55		
	TEM_WIN	-1.56	0.81	-1.92	0.0595	1.76		
	TWM_WIN	1.33	0.76	1.74	0.0856	1.67		
	YearSt	-1.18	0.77	-1.53	0.1304	1.75		
p50	(Intercept)	120.13	0.46	263.76	**<0.0001**		34.90%	32.10%
	TCE_WIN	-1.68	0.59	-2.85	**0.0057**	1.51		
	TWM_WIN	1.44	0.54	2.66	**0.0096**	1.31		
	YearSt	-2.14	0.55	-3.86	**0.0002**	1.41		
p90	(Intercept)	129.82	0.45	287.43	**<0.0001**		4.50%	3.20%
	TWM_WIN	0.88	0.47	1.86	0.0667			

Table S11. Model selection for the "winter" models of relationships including the TEA temperature variable (without TWA) between dates of the first (p10), median (p50), and last (p90) phases of spring migration of the Eurasian blackcap at Bukowo-Kopań and winter large-scale temperature variables, excluding the winter TWA variable, in 1982–2025. The candidate explanatory variables are listed in the table heading. The table presents the coefficient estimates for the intercept and the explanatory variables selected in each model, followed by the model statistics: degrees of freedom (df), Akaike Information Criterion corrected for small sample sizes (AICc), the difference in AICc relative to the best model (delta AICc), and the Akaike weight (weight). The table presents the set of models with delta AICc < 2. Bold digits indicate variables selected for the best partial "winter" model. Parameters of this best model are presented in more detail in Table S12. Abbreviations of the temperature variables are provided in Table 1.

Percentile	(Intercept)	SexN	TCE_WIN	TEA_WIN	TEM_WIN	TWM_WIN	YearSt	SexN:TCE_WIN	SexN:TEA_WIN	SexN:TEM_WIN	SexN:TWM_WIN	SexN:YearSt	df	AICc	delta	weight
p10	**109.80**	**2.17**	**-2.99**	**-1.84**									**5**	**465.32**	**0.00**	**0.68**
	110.89		-2.99	-1.84									4	466.79	1.47	0.32
p50	**120.13**		**-1.68**			**1.44**	**-2.14**						**5**	**431.38**	**0.00**	**0.70**
	120.17		-1.76		-0.53	1.67	-1.92						6	433.04	1.67	0.30
p90	**129.82**					**0.88**							**3**	**428.30**	**0.00**	**0.25**
	129.74				0.78								3	429.21	0.91	0.16
	130.29	-0.95				0.88							4	429.39	1.09	0.15
	129.83												2	429.60	1.31	0.13
	129.78				0.41	0.66							4	430.02	1.72	0.11
	129.77			0.32		0.89							4	430.10	1.80	0.10
	129.81		-0.34			1.03							4	430.12	1.82	0.10

Table S12. Parameters of the best "winter" linear regression models including the TEA temperature variable (without TWA) for the dates of the first (p10), median (p50), and last (p90) phases of spring migration and winter regional temperatures in 1982–2025. The best models had the lowest AICc (Table S11). The table presents the coefficient estimate (Estimate), standard error (SE), t-value (t), significance level (p), and Variance Inflation Factor (VIF) for the intercept and explanatory variables selected by the best model, as well as the R^2 and Adjusted R^2 for the entire model. Abbreviations of the temperature variables are provided in Table 1.

Percentile	Explanatory variable	Estimate	SE	t	p	VIF	R^2	Adj R^2
p10	(Intercept)	109.80	0.81	136.05	**<0.0001**		31.90%	29.00%
	SexN	2.17	1.13	1.91	0.0598	1.00		
	TCE_WIN	-2.99	0.61	-4.95	**<0.0001**	1.02		
	TEA_WIN	-1.84	0.62	-2.96	**0.0041**	1.02		
p50	(Intercept)	120.13	0.46	263.76	**<0.0001**		34.90%	32.10%
	TCE_WIN	-1.68	0.59	-2.85	**0.0057**	1.51		
	TWM_WIN	1.44	0.54	2.66	**0.0096**	1.31		
	YearSt	-2.14	0.55	-3.86	**0.0002**	1.41		
p90	(Intercept)	129.82	0.45	287.43	**<0.0001**		4.50%	3.20%
	TWM_WIN	0.88	0.47	1.86	0.0667			

Table S13. Model selection for the "spring" models of relationships including the TWA temperature variable (without TEA) between dates of the first (p10), median (p50), and last (p90) phases of spring migration of the Eurasian blackcap at Bukowo-Kopań and spring large-scale temperature variables, excluding the spring TEA variable, in 1982–2025. The candidate explanatory variables are listed in the table heading. The table presents the coefficient estimates for the intercept and the explanatory variables selected in each model, followed by the model statistics: degrees of freedom (df), Akaike Information Criterion corrected for small sample sizes (AICc), the difference in AICc relative to the best model (delta AICc), and the Akaike weight (weight). The table presents the set of models with delta AICc < 2. Bold digits indicate variables selected for the best partial "spring" model. Parameters of this best model are presented in more detail in Table S14. Abbreviations of the temperature variables are provided in Table 1.

Percentile	(Intercept)	SexN	TCE_SPR	TEM_SPR	TWA_SPR	TWM_SPR	YearSt	SexN:TCE_SPR	SexN:TEM_SPR	SexN:TWA_SPR	SexN:TWM_SPR	SexN:YearSt	df	AICc	delta	weight
	109.82	**2.17**	**-1.85**	**-1.85**	**-1.23**								**6**	**453.76**	**0.00**	**0.29**
	109.81	2.17	-2.22	-1.96	-1.67	1.04							7	453.86	0.10	0.27
p10	109.84	2.17	-2.13	-2.54									5	454.54	0.77	0.19
	109.80	2.17	-2.08	-2.10	-1.56		0.81						7	455.25	1.49	0.14
	109.81	2.18	-2.22	-1.85	-1.23			0.74					7	455.71	1.95	0.11
	120.15		**-2.38**	**-1.37**									**4**	**425.45**	**0.00**	**0.31**
	120.14		-2.07	-1.13		-0.69							5	426.06	0.62	0.22
p50	120.15		-2.11	-0.99			-0.71						5	426.51	1.06	0.18
	120.08		-2.11				-1.29						4	426.86	1.41	0.15
	120.14		-2.27	-1.09	-0.51								5	426.99	1.55	0.14
	129.83												**2**	**429.60**	**0.00**	**0.41**
p90	130.30	-0.95											3	430.68	1.08	0.24
	129.78			0.40									3	431.12	1.52	0.19
	129.81						0.22						3	431.54	1.94	0.16

Table S14. Parameters of the best "spring" linear regression models including the TWA temperature variable (without TEA) for the dates of the first (p10), median (p50), and last (p90) phases of spring migration and spring regional temperatures in 1982–2025. The best models had the lowest AICc (Table S13). The table presents the coefficient estimate (Estimate), standard error (SE), t-value (t), significance level (p), and Variance Inflation Factor (VIF) for the intercept and explanatory variables selected by the best model, as well as the R^2 and Adjusted R^2 for the entire model. Abbreviations of the temperature variables are provided in Table 1.

Percentile	Explanatory variable	Estimate	SE	t	p	VIF	R^2	Adj R^2
p10	(Intercept)	109.82	0.74	148.24	**<0.0001**			
	SexN	2.17	1.04	2.08	**0.0411**	1.00		
	TCE_SPR	-1.85	0.61	-3.03	**0.0034**	1.23	43.30%	40.10%
	TEM_SPR	-1.85	0.72	-2.56	**0.0125**	1.62		
	TWA_SPR	-1.23	0.71	-1.73	0.0881	1.71		
p50	(Intercept)	120.15	0.44	270.38	**<0.0001**			
	TCE_SPR	-2.38	0.50	-4.81	**<0.0001**	1.14	37.90%	36.20%
	TEM_SPR	-1.37	0.51	-2.67	**0.0094**	1.14		
p90	(Intercept)	129.83	0.46	282.86	**<0.0001**		0.00%	0.00%

Table S15. Model selection for the "spring" models of relationships including the TEA temperature variable (without TWA) between dates of the first (p10), median (p50), and last (p90) phases of spring migration of the Eurasian blackcap at Bukowo-Kopań and spring large-scale temperature variables, excluding the spring TWA variable, in 1982–2025. The candidate explanatory variables are listed in the table heading. The table presents the coefficient estimates for the intercept and the explanatory variables selected in each model, followed by the model statistics: degrees of freedom (df), Akaike Information Criterion corrected for small sample sizes (AICc), the difference in AICc relative to the best model (delta AICc), and the Akaike weight (weight). The table presents the set of models with delta AICc < 2. Bold digits indicate variables selected for the best partial "spring" model. Parameters of this best model are presented in more detail in Table S16. Abbreviations of the temperature variables are provided in Table 1.

Percentile	(Intercept)	SexN	TCE_SPR	TEA_SPR	TEM_SPR	TWM_SPR	YearSt	SexN:TCE_SPR	SexN:TEA_SPR	SexN:TEM_SPR	SexN:TWM_SPR	SexN:YearSt	df	AICc	delta	weight
p10	**109.87**	**2.17**	**-1.77**	**-1.27**	**-1.76**								**6**	**454.17**	**0.00**	**0.27**
	109.88	2.17	-2.06	-2.24	-1.96		1.47						7	454.31	0.15	0.25
	109.84	2.17	-2.13		-2.54								5	454.54	0.37	0.23
	109.88	2.17	-2.04	-1.45	-1.88	0.69							7	455.45	1.28	0.14
	109.87	2.18	-2.14	-1.27	-1.76			0.74					7	456.12	1.95	0.10
p50	**120.12**		**-2.17**	**1.58**	**-1.41**		**-1.71**						**6**	**425.32**	**0.00**	**0.25**
	120.15		-2.38		-1.37								4	425.45	0.12	0.23
	120.14		-2.07		-1.13	-0.69							5	426.06	0.74	0.17
	120.15		-2.11		-0.99		-0.71						5	426.51	1.19	0.14
	120.08		-2.11				-1.29						4	426.86	1.53	0.12
	120.13		-2.51	0.45	-1.64								5	427.25	1.93	0.09
p90	**129.83**												**2**	**429.60**	**0.00**	**0.34**
	130.30	-0.95											3	430.68	1.08	0.20
	129.79			0.45									3	430.88	1.27	0.18
	129.78				0.40								3	431.12	1.52	0.16
	129.81						0.22						3	431.54	1.94	0.13

Table S16. Parameters of the best "spring" linear regression models including the TEA temperature variable (without TWA) for the dates of the first (p10), median (p50), and last (p90) phases) of spring migration and spring regional temperatures in 1982–2025. The best models had the lowest AICc (Table S15). The table presents the coefficient estimate (Estimate), standard error (SE), t-value (t), significance level (p), and Variance Inflation Factor (VIF) for the intercept and explanatory variables selected by the best model, as well as the R^2 and Adjusted R^2 for the entire model. Abbreviations of the temperature variables are provided in Table 1.

Percentile	Explanatory variable	Estimate	SE	t	p	VIF	R^2	Adj R^2
p10	(Intercept)	109.87	0.74	147.89	**<0.0001**		43.00%	39.80%
	SexN	2.17	1.04	2.08	**0.0416**	1.00		
	TCE_SPR	-1.77	0.63	-2.82	**0.0063**	1.30		
	TEA_SPR	-1.27	0.79	-1.61	0.1114	2.11		
	TEM_SPR	-1.76	0.78	-2.27	**0.0264**	1.85		
p50	(Intercept)	120.12	0.44	274.90	**<0.0001**		41.70%	38.40%
	TCE_SPR	-2.17	0.55	-3.98	**0.0002**	1.43		
	TEA_SPR	1.58	0.86	1.84	0.0697	3.62		
	TEM_SPR	-1.41	0.65	-2.17	**0.0334**	1.91		
	YearSt	-1.71	0.84	-2.03	**0.0460**	3.59		
p90	(Intercept)	129.83	0.46	282.86	**<0.0001**		0.00%	0.00%

Table S17. Model selection for the "winter and spring" models of relationships between the dates of the first (p10), median (p50), and last (p90) phase and the temperature variables selected in the best partial "winter" model including the TWA variable (Table S10) and the best partial "spring" model including the TEA variable (Table S16) in 1982–2025. The candidate explanatory variables are listed in the table heading. The table presents the coefficient estimates for the intercept and the explanatory variables selected in each model, followed by the model statistics: degrees of freedom (df), Akaike Information Criterion corrected for small sample sizes (AICc), the difference in AICc relative to the best model (delta AICc), and the Akaike weight (weight). The table presents the set of models with delta AICc < 2. Bold digits indicate variables selected for the final best "winter and spring" model. Parameters of this best model are presented in more detail in Table S18. Abbreviations of the temperature variables are provided in Table 1.

Percentile	(Intercept)	SexN	TCE_SPR	TCE_WIN	TEA_SPR	TEM_SPR	TEM_WIN	TWM_WIN	YearSt	df	AICc	delta	weight
	109.87	**2.17**	**-1.77**		**-1.27**	**-1.76**				**6**	**454.17**	**0.00**	**0.21**
	109.88	2.17	-2.06		-2.24	-1.96			1.47	7	454.31	0.15	0.19
	109.84	2.17	-2.13			-2.54				5	454.54	0.37	0.17
p10	109.90	2.17	-1.72		-1.67	-1.73		0.71		7	455.25	1.08	0.12
	109.91	2.17	-2.02		-2.70	-1.94		0.75	1.52	8	455.27	1.10	0.12
	109.81	2.17	-1.70	-0.86		-2.33				6	455.37	1.20	0.11
	109.85	2.17	-1.59	-0.49	-1.06	-1.77				7	456.16	1.99	0.08
	120.18		**-2.08**			**-1.12**		**0.99**	**-1.02**	**6**	**424.60**	**0.00**	**0.12**
	120.17		-2.46			-1.61		0.81		5	424.79	0.19	0.11
	120.11		-1.67	-1.08	1.55	-1.39		1.00	-1.81	8	424.92	0.32	0.11
	120.14		-2.05	-0.85		-1.49		1.08		6	425.22	0.63	0.09
	120.12		-2.17		1.58	-1.41			-1.71	6	425.32	0.72	0.09
p50	120.16		-1.74	-0.78		-1.04		1.22	-0.96	7	425.39	0.80	0.08
	120.15		-2.13		1.11	-1.39		0.77	-1.65	7	425.42	0.82	0.08
	120.15		-2.38			-1.37				4	425.45	0.85	0.08
	120.09		-2.09					0.90	-1.65	5	425.77	1.17	0.07
	120.07		-1.69	-0.89				1.17	-1.52	6	426.07	1.47	0.06
	120.09		-1.86	-0.77	1.99	-1.42			-1.83	7	426.20	1.60	0.06
	120.15		-2.11			-0.99			-0.71	5	426.51	1.91	0.05
	129.82							**0.88**		**3**	**428.30**	**0.00**	**0.48**
p90	130.29	-0.95						0.88		4	429.39	1.09	0.28
	129.83									2	429.60	1.31	0.25

Table S18. Parameters of the best "winter and spring" linear regression models for the dates of the first (p10), median (p50), and last (p90) and the temperature variables selected in the best partial "winter" model including the TWA variable and the best partial "spring" model including the TEA variable in 1982–2025. The best models had the lowest AICc (Table S17). The table presents the coefficient estimate (estimate), standard error (SE), t-value (t), significance level (p), and Variance Inflation Factor (VIF) for the intercept and explanatory variables selected by the best model, as well as the R^2 and Adjusted R^2 for the entire model. Abbreviations of the temperature variables are provided in Table 1.

Percentile	Explanatory variable	Estimate	SE	t	p	VIF	R^2	Adj R^2
p10	(Intercept)	109.87	0.74	147.89	**<0.0001**		43.00%	39.80%
	SexN	2.17	1.04	2.08	**0.0416**	1.00		
	TCE_SPR	-1.77	0.63	-2.82	**0.0063**	1.30		
	TEA_SPR	-1.27	0.79	-1.61	0.1114	2.11		
	TEM_SPR	-1.76	0.78	-2.27	**0.0264**	1.85		
p50	(Intercept)	120.18	0.43	276.39	**<0.0001**		42.20%	39.00%
	TCE_SPR	-2.08	0.54	-3.83	**0.0003**	1.43		
	TEM_SPR	-1.12	0.61	-1.84	0.0702	1.69		
	TWM_WIN	0.99	0.49	2.03	**0.0466**	1.19		
	YearSt	-1.02	0.66	-1.56	0.1239	2.22		
p90	(Intercept)	129.82	0.45	287.43	**<0.0001**		4.50%	3.20%
	TWM_WIN	0.88	0.47	1.86	0.0667			

Table S19. Simple linear regression parameters for the relationships between the dates of the first (p10), median (p50), and last (p90) phases of spring migration of male and female Eurasian blackcaps and the key temperature variables selected by the "winter and spring" models in 1982–2025 (Figure 4). The table presents the intercept (a), slope coefficient (β), standard error (SE), t-value (t), significance level (p), Adjusted R^2 (Adj R^2).

Percentile	Variable	Sex	a	β	SE	t	p	Adj R^2
p10	TCE_SPR	Males	109.52	-3.35	0.86	-3.89	**<0.0001**	27.6%
		Females	111.71	-2.62	0.89	-2.94	**0.0060**	17.2%
	TEM_SPR	Males	109.96	-3.17	0.92	-3.44	**0.0010**	22.7%
		Females	112.16	-3.43	0.85	-4.05	**<0.0001**	29.4%
	TEA_SPR	Males	109.87	-3.09	0.87	-3.55	**0.0010**	23.9%
		Females	112.06	-3.40	0.79	-4.29	**<0.0001**	32.0%
p50	TCE_SPR	Males	119.85	-3.21	0.66	-4.85	**<0.0001**	37.9%
		Females	120.11	-2.48	0.72	-3.45	**0.0010**	22.8%
	TEM_SPR	Males	120.18	-2.32	0.79	-2.95	**0.0060**	17.2%
		Females	120.41	-2.13	0.78	-2.72	**0.0100**	14.8%
	TWM_WIN	Males	119.91	-0.13	0.84	-0.16	0.8750	-2.7%
		Females	120.16	-0.16	0.82	-0.19	0.8510	-2.7%
p90	TWM_WIN	Males	130.29	0.87	0.61	1.42	0.1640	2.7%
		Females	129.35	0.89	0.73	1.22	0.2300	1.3%

Table S20. Diagnostic tests for the final best "winter and spring" linear regression models for the dates of the first (p10), median (p50), and last (p90) of spring migration. The table presents the multiple coefficient of determination (R^2), adjusted R^2, (Adj R^2) the ratio of Adj R^2 to R^2, predictive R^2 (Pred R^2) calculated based on the Predicted Residual Error Sum of Squares (PRESS) to evaluate model overfitting, and the Durbin-Watson statistics (DW) along with its p-value (DW_p) to assess first-order autocorrelation in the residuals.

Percentile	R^2	Adj R^2	R^2/Adj R^2	Pred R^2	PRESS	DW	DW p	Adj R^2-Pred R^2
p10	43.00%	39.80%	0.925	0.347	1686.2	1.251	**<0.0001**	0.0510
p50	42.20%	39.00%	0.923	0.335	1148.2	1.211	**<0.0001**	0.0550
p90	4.50%	3.20%	0.711	-0.007	1209	1.234	**<0.0001**	0.0390

Table S21. Model selection for the linear regression models testing the interaction between the key temperature variables and the study period (PeriodN) on the dates of the first (p10), median (p50), and last (p90). The table presents the set of models with delta AICc < 2. Parameters of this best model are presented in more detail in Table S22. Abbreviations of the temperature variables are provided in Table 1.

Percentile	Temperature Variable	(Intercept)	PeriodN	TCE_SPR	TEM_SPR	TEA_SPR	TWM_WIN	PeriodN:TCE_SPR	PeriodN:TEM_SPR	PeriodN:TEA_SPR	PeriodN:TWM_WIN	df	AICc	delta	weight
p10	TCE_SPR	**111.92**	**-2.60**	**-2.44**								**4**	**467.57**	**0.00**	**1.00**
	TEM_SPR	**111.06**			**-3.30**							**3**	**466.16**	**0.00**	**0.67**
		111.65	-1.29		-2.88							4	467.56	1.40	0.33
	TEA_SPR	**110.97**				**-3.25**						**3**	**464.33**	**0.00**	**1.00**
p50	TCE_SPR	**120.05**	**-1.26**	**-4.33**				**2.97**				**5**	**423.80**	**0.00**	**1.00**
	TEM_SPR	**120.29**			**-2.22**							**3**	**444.13**	**0.00**	**0.45**
		121.03	-1.60		-1.70							4	444.65	0.52	0.34
		120.64	-1.63		-2.62				1.55			5	445.62	1.49	0.21
	TWM_WIN	**121.76**	**-3.46**									**3**	**448.69**	**0.00**	**1.00**
p90	TWM_WIN	**129.82**					**0.88**					**3**	**428.30**	**0.00**	**0.41**
		129.83										2	429.60	1.31	0.22
		129.39	0.85				0.80					4	429.64	1.34	0.21
		129.26	1.13									3	430.23	1.94	0.16

Table S22. Parameters of the best linear regression models testing the interaction between the key temperature variables and the study period (PeriodN) on the dates of the first (p10), median (p50), and last (p90). The best models were selected based on the lowest AICc (Table S21). The table presents the coefficient estimate (Estimate), standard error (SE), t-value (t), significance level (p), and Variance Inflation Factor (VIF) for the intercept and explanatory variables, as well as the R^2 and Adjusted R^2 for the entire model.

Percentile	Temperature variable	Explanatory variable	Estimate	SE	t	p	VIF	R^2	Adj R^2
p10	TCE_SPR	(Intercept)	111.92	0.86	129.82	**<0.0001**		27.70%	25.70%
		PeriodN	-2.60	1.26	-2.06	**0.0434**	1.19		
		TCE_SPR	-2.44	0.67	-3.65	**0.0005**	1.19		
	TEM_SPR	(Intercept)	111.06	0.58	190.15	**<0.0001**		26.90%	25.90%
		TEM_SPR	-3.30	0.63	-5.22	**<0.0001**			
	TEA_SPR	(Intercept)	110.97	0.57	192.99	**<0.0001**		28.60%	27.70%
		TEA_SPR	-3.25	0.60	-5.45	**<0.0001**			
p50	TCE_SPR	(Intercept)	120.05	0.69	174.64	**<0.0001**		41.00%	38.60%
		PeriodN	-1.26	0.95	-1.33	0.1886	1.20		
		TCE_SPR	-4.33	0.80	-5.42	**<0.0001**	3.07		
		PeriodN:TCE_SPR	2.97	1.02	2.91	**0.0048**	2.76		
	TEM_SPR	(Intercept)	120.29	0.51	238.08	**<0.0001**		18.20%	17.10%
		TEM_SPR	-2.22	0.55	-4.06	**0.0001**			
	TWM_WIN	(Intercept)	121.76	0.73	166.71	**<0.0001**		13.20%	12.00%
		PeriodN	-3.46	1.03	-3.35	**0.0013**			
p90	TWM_WIN	(Intercept)	129.82	0.45	287.43	**<0.0001**		4.50%	3.20%
		TWM_WIN	0.88	0.47	1.86	0.0667			

Table S23. Simple linear regression parameters for the relationships between the dates of the first (p10), median (p50), and last (p90) of spring migration of male and female Eurasian blackcaps and the key temperature variables, partitioned by the two sub-periods: 1982–2004 and 2005–2025 (Figure 5). The table presents the intercept (a), slope coefficient (β), standard error (SE), t-value (t), significance level (p), R^2 and Adjusted R^2.

Percentile	Temperature variable	Period	a	β	SE	t	p	R^2	Adj R^2
p10	TCE_SPR	1982-2004	111.81	-2.73	1.03	-2.64	**0.0120**	16.20%	13.90%
		2005-2025	109.26	-2.25	0.90	-2.52	**0.0160**	15.00%	12.60%
	TEM_SPR	1982-2004	111.62	-2.97	1.20	-2.47	**0.0180**	14.50%	12.10%
		2005-2025	110.32	-2.82	1.07	-2.64	**0.0120**	16.20%	13.90%
	TEA_SPR	1982-2004	111.14	-2.90	1.33	-2.19	**0.0350**	11.80%	9.30%
		2005-2025	111.26	-3.58	1.16	-3.09	**0.0040**	20.90%	18.70%
p50	TCE_SPR	1982-2004	120.05	-4.33	0.94	-4.60	**<0.0001**	37.00%	35.20%
		2005-2025	118.79	-1.37	0.50	-2.76	**0.0090**	17.40%	15.10%
	TEM_SPR	1982-2004	120.64	-2.62	1.29	-2.03	**0.0500**	10.20%	7.70%
		2005-2025	119.01	-1.07	0.63	-1.69	0.1000	7.40%	4.80%
	TWM_WIN	1982-2004	121.73	-0.23	1.09	-0.21	0.8330	0.10%	-2.60%
		2005-2025	118.22	0.45	0.50	0.91	0.3680	2.30%	-0.50%
p90	TWM_WIN	1982-2004	129.38	0.73	0.96	0.76	0.4530	1.60%	-1.20%
		2005-2025	130.24	0.84	0.42	1.99	0.0540	9.90%	7.40%