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Supplementary material

Appendix 1

Table A1 The different categories that describe the state of the nest, in bold those nest stages that give information that is used to calculate the laydate of the nest.

Categories	Nest stage	Description
Nest building phase (R)	R9	nest (box) unoccupied
	R0	nest (box) in place, no nest building recorded
	R1	nest being build (no more info)
	R2	nest building just started
	R3	nest halfway done
	R4	nest almost ready
	R5	nest ready, no eggs
Egg phase (M)	**M0**	nest with eggs, unknown amount
	M1	number of eggs recorded, no more info
	M2	eggs cold
	M3	eggs warm
	M4	incubation just started
	M5	incubation halfway
	M6	incubation for long time
	M7	eggs hatching
	M8	eggs remain unhatched
	M9	adult at nest, egg stage not checked
Nestling phase (P)	**P0**	adult at nest, number of nestlings not counted
	P1	eggs and nestlings counted, no more info
	P2	nestlings just hatched
	P3	nestlings small, naked or 'fluffy'
	P4	nestlings halfway nestling stage
	P5	nestlings ringed
	P6	nestlings close to fledging
	P7	nestlings fledged normally
	P8	nestlings out of nest, not able to fly
	P9	nestlings out of nest, in flying condition
Adult on the nest (E)	E1	one adult on nest
	E2	two adults on nest
Destroyed/failed nests (T)	T0	eggs or young (no more info)
	T1	only eggs
	T2	already nestlings
Final check (J)	J0	nest empty, egg/nestling fate unknown, but not destroyed
	J1	part of the alive nestlings still in nest
	J2	eggs and or dead young left in otherwise successful nest

Table A2. Species breeding parameters used for the calculation of the laying date estimates for all species used in the study, in alphabetical order. These are values taken from von Haartman (1969) and Ferguson-Lees *et al*. (2011). And life-history groups of species, as used in the models: Migration group (Resdidents (RES), Short distance migrants (SDM) and Long distance migrants (LDM)), Diet (Omnivorous (O), Insectivorous (I)), Habitat (open and forest).

Species	Egg laying interval (days)	Incubation period (days)	Nestling period (days)	Migration group	Diet	Habitat
Carduelis chloris	1	13	15	RES	O	open
Certhia familiaris	1	14	15	RES	I	forest
Ficedula hypoleuca	1	13	16	LDM	I	forest
Fringilla coelebs	1	13	14	SDM	O	forest
Hirundo rustica	1	15	23	LDM	I	open
Larus canus	2	26	35*	SDM	O	open
Chroicocephalus ridibundus	2	25	35*	SDM	O	open
Motacilla alba	1	13	15	SDM	I	open
Muscicapa striata	1	13	13	LDM	I	forest
Numenius arquata	2	29	35*	SDM	O	open
Periparus ater	1	14	19	RES	O	forest
Cyanistes caeruleus	1	14	19	RES	O	forest
Lophophanes cristatus	1	14	22	RES	O	forest
Parus major	1	14	21	RES	O	forest
Phoenicurus phoenicurus	1	14	14	LDM	I	forest
Phyloscopus trochilus	1	14	15	LDM	I	forest
Pica pica	1	21	26	RES	O	open
Saxicola rubetra	1	13	17	LDM	I	open
Sterna hirundo	1.5	22	26*	LDM	O	open
Sturnus vulgaris	1	13	21	SDM	O	open
Sylvia borin	1	12	10	LDM	I	forest
Sylvia communis	1	12	11	LDM	I	open
Turdus iliacus	1	13	14	SDM	O	forest
Turdus merula	1	14	14	SDM	O	forest
Turdus pilaris	1	14	15	SDM	O	open
Vanellus vanellus	1.5	27	36*	SDM	O	open

* Precocial species (time in the nest up to a few days)

Supplementary information A3

26 rules from which laydate estimates (LD_est) can be calculated with accompanying accuracy level, based on nest stages as found by the observers. Laydate estimates are based one or a combination of two nest stages. All observations on a nest-card are used to estimate laydates. After all observations on a nest-card are used, the laydate with the best accuracy level is selected as the best laydate estimate of the nest-card. In case multiple laydate estimates with the same accuracy level occur, the one with the lowest rule number is chosen.

The 26 rules use a combination of data from the nest-cards and breeding biological parameters specific to each species:

t_egg – interval time between laying of eggs (in days)

inc – incubation period (days)

nest – nestling period (days)

Nest stages 'EA' and 'CA' are created when the observer indicates the age of the eggs (EA) or nestlings (CA).

Rule 1: given nest stage is 'M1', 'M2', 'M3', 'M4' or 'EA', and the following nest stage (can be the same) is 'M', 'EA', 'CA', 'P' or 'T' and ('NE' or 'NEY') is larger than the earlier recorded, THEN:
LD_est = day1 - (NE - 1) * t_egg
accu = 5
where:
DAY1 is the date of the earlier nest stage
NE the number of eggs in the nest at DAY1

Rule 2: given the age of the eggs (egg_age) is known then stage is 'EA'
LD_est = day1 - egg_age - (NE - 1) * t_egg
accu = 4
DAY1 is the date of the nest stage
NE the number of eggs in the nest at DAY1

Rule 3: given nest is empty (nest stage='R1', 'R2', 'R3', 'R4', 'R5' or 'R9') and within 10 days from the observation there are eggs in the nest (M0-9 & EA)
Dif3 = ((DAY2 - (NE - 1) * t_egg) - day1) / 2
LD_est = day1 + Dif3
where:
DAY1 is the date of the empty nest stage
DAY2 is the date of the nest stage with eggs
NE is the number of eggs on DAY2

Rule 4: When the nest stage is 2 or more times in a row one of these: 'M1', 'M2', 'M3', 'M4', 'M5', 'M6', 'M7','M8', 'EA'
Dif4 = inc - (day2 - day1)
When Dif4 is between 0 and -4 then Dif4 will be set to 0. When Dif4 is lower than -4 this rule is not valid.
LD_est = day1 - (NE - 1) * t_egg - Dif4 / 2
where:
DAY1 is the date of the first occurrence
DAY2 the date of the last occurrence
NE is the number of eggs on the first occurrence.

Rule 5: given nest stage is (M1-M7 & EA) and subsequent nest stage is (P0-P7) where date is 'DAY2'
dif5 = day2 - day1
LD_est = day1 - (NE - 1) * t_egg - inc + dif5 / 2
where:
DAY1 is date of the last M-stage (where NE is known)
NE is number of eggs on first nest stage
DAY2 is the date of the first P-stage

Rule 6: When the nest stage is 2 or more times in a row one of these: 'P1', 'P2', 'P3', 'P4', 'P5', 'P6', 'P7', 'CA'
Dif6 = nest - (day2 - day1)
LD_est = day1 - (NEY - 1) * t_egg - inc - Dif6 / 2
where:
DAY1 is the date of the earliest occurrence
DAY2 the date of the last occurrence
NEY is the total number of eggs and young on the first occurrence

Rule7*: given nest stage is (M1-M7 or EA) and later the nest stage is (P0-P7 or CA),
Dif7 = inc + nest - (day2 - day1)
LD_est = day1 - (NE - 1) * t_egg - Dif7 / 2
where:
DAY1 is the date of the earliest 'M' stage
DAY2 is the date of the last 'P' stage
NE is the number of eggs at DAY1

Rule8: given nest stage is 'M7'
LD_est = day1 - (NE - 1) * t_egg - inc
accu = 4
where:
DAY1 is the date
NE is the clutchsize at DAY1

Rule9*: given nest stage is 'P2'
LD_est = day1 - (NEY- 1) * t_egg - inc - nest / 10
accu = 4 (when NEY is only nestlings) accu = 3 (when NEY is eggs + nestlings)
where:
DAY1 is the date
NEY is the broodsize (total eggs+young) at DAY1

Rule 10: given the age of the nestlings ('N_AGE') is known, nest stage is 'CA'
LD_est = day1 - (NEY - 1) * t_egg - inc - N_AGE
accu = 4 (when NEY is only nestlings) accu = 3 (when NEY is eggs + nestlings)
where:

DAY1 is the date
NEY is the broodsize at DAY1

Rule 11: given nest stage is 'M4'
LD_est = day1 - (ne - 1) * t_egg - inc / 4
accu = 3
where:DAY1 is the date
NE is the clutch size at DAY1

Rule 12*: given nest stage is 'P3'
LD_est = day1 - (ney - 1) * t_egg - inc - nest / 5
accu = 4 (when NEY is only nestlings) accu = 3 (when NEY is eggs + nestlings)
where:
DAY1 is the date
NEY is the broodsize (total eggs+young) at DAY1

Rule 13*: given nest stage is 'P7'
LD_est = day1 - (ney - 1) * t_egg - inc - nest
accu = 3
where:
DAY1 is the date
NEY is the broodsize (total eggs+young) at DAY1

Rule 14: given nest stage is 'M5', date is DAY1 and clutch size is NE then:
LD_est = day1 - (ne - 1) * t_egg - inc / 2
accu = 3
where:
DAY1 is the date
NE is the broodsize at DAY1

Rule 15*: given nest stage is 'P4'
LD_est = day1 - (ney - 1) * t_egg - inc - nest / 2
accu = 3
where:
DAY1 is the date
NEY is the broodsize (total eggs+young) at DAY1

Rule 16*: given nest stage is 'P6' or 'P8'
LD_est = day1 - (ney - 1) * t_egg - inc - nest
accu = 3
where:
DAY1 is the date
NEY is the broodsize (total eggs+young) at DAY1

Rule 17*: given nest stage is 'P5'
LD_est = day1 - (ney - 1) * t_egg - inc - 0.6 * nest
accu = 2
where:
DAY1 is the date
NEY is the broodsize (total eggs+young) at DAY1

Rule 18: given nest stage is 'M6'

LD_est = day1 - (ne - 1) * t_egg - 0.75 * inc
accu = 2
where:
DAY1 is the date
NE is the broodsize at DAY1

Rule 19: given nest stage is 'M3'
LD_est = day1 - (ne - 1) * t_egg - inc / 3
accu = 1
where:
DAY1 is the date
NE is the broodsize at DAY1

Rule 20*: given nest stage is 'P1'
LD_est = day1 - (ney - 1) * t_egg - inc - nest / 2
accu = 1
where:
DAY1 is the date
NEY is the broodsize (total eggs+young) at DAY1

Rule 21: Given nest stage is "M1" or "M2"
LD_est = day1 - (ne - 1) * t_egg - inc / 2
accu = 1
where:
DAY1 is the date
NE is the broodsize (number of eggs) at DAY1

Rule 22: given nest stage is 'M1' or 'M2' and the subsequent nest stage is also 'M1' or 'M2',
day = (day1 - day2) / 2
LD_est = day2 - day - (ne - 1) * t_egg - inc / 2
accu = 1
where:
DAY1 is the date of the first M1 or M2
Day2 is the date of the last M1 or M2 (with ne > 0)
NE is the clutch-size on the last M1 or M2

Rule 23: given nest stage is 'M9'
LD_est = day1 - (cs - 1) * t_egg - inc / 2
accu = 1
where:
DAY1 is the date

Rule 24*: given nest stage is 'P0'
LD_est = day1 - (cs - 1) * t_egg - inc - nest / 2
accu = 1
where:
DAY1 is the date

Rule 25: given nest stage is 'M0'
LD_est = day1 - (cs - 1) * t_egg - inc / 2
accu = 1
where:

DAY1 is the date

Rule 26*: given nest stage is 'P9'
LD_est = day1 - (ney - 1) * t_egg - inc - 1.05 * nest
accu = 1
where:
DAY1 is the date
NEY is the broodsize (total eggs+young) at DAY1

*To calculate laydate estimates for precocial species some of the rules indicated with * were adjusted, due to their very short stay in the nest after egg hatching. These adaptations are not presented here.

For rules 3 - 7 the accuracy level of the LD_est is dependent on the number of days between observations. Each of these rules has a so called 'Dif' score which can be translated into an accuracy level (1 - 5) see table below.

Dif	Accuracy level	Corresponding interval around estimated laydate (days)
≥ 8	accu 1	± 10
5-7	accu 2	± 5
3	accu 3	± 3
2	accu 4	± 2
0 – 1	accu 5	± 1
-	accu 6*	± 0

* accu = 6 is given on nest-card cases where an exact laydate has been reported by the observer

Table A4 The total number of laydate estimates with a particular accuracy level for the 26 species.

Species	LD acc. exact	LD acc. ±1 days	LD acc. ±2 days	LD acc. ±3 days	LD acc. ±5 days	LD acc. ±10 days	Total LD-estimates
Carduelis chloris	0	253	159	239	141	346	1,138
Certhia familiaris	0	464	247	335	202	319	1,567
Ficedula hypoleuca	2,568	12,818	4,207	4,813	3,177	5,136	32,719
Fringilla coelebs	0	756	362	612	318	1,675	3,723
Hirundo rustica	0	325	226	341	175	427	1,494
Larus canus	0	369	344	357	262	2,295	3,627
Chroicocephalus ridibundus	0	245	171	300	233	1,794	2,743
Motacilla alba	0	450	393	646	432	1,073	2,994
Muscicapa striata	0	1,253	419	689	384	1,183	3,928
Numenius arquata	0	353	359	211	61	764	1,748
Periparus ater	38	608	303	537	294	347	2,127
Cyanistes caeruleus	95	1,478	807	1,199	702	667	4,948
Lophophanes cristatus	6	126	209	308	197	300	1,146
Parus major	1,041	5,074	2,437	3,472	2,338	4,486	18,848
Phoenicurus phoenicurus	41	764	380	288	218	480	2,171
Phyloscopus trochilus	0	428	429	783	381	1,084	3,105
Pica pica	0	395	218	414	389	816	2,232
Saxicola rubetra	0	61	354	359	405	373	1,552
Sterna hirundo	0	267	213	434	238	1,735	2,887
Sturnus vulgaris	0	1,272	730	745	1,109	1,427	5,283
Sylvia borin	0	521	512	438	156	565	2,192
Sylvia communis	0	189	426	289	126	151	1,181
Turdus iliacus	0	2,119	1,718	2,183	1,472	3,845	11,337
Turdus merula	0	267	305	400	158	524	1,654
Turdus pilaris	0	2,260	1,253	1,907	1,567	3,125	10,112
Vanellus vanellus	0	381	313	389	131	1,393	2,607
ALL DATA	**3,789**	**33,496**	**17,494**	**22,688**	**15,266**	**36,330**	**129,063**

Table A5 Coefficients of spring temperature (°C) and spring precipitation (mm) for migration strategy groups and for each species separate. LMMs per migration group and per species had the same fixed effect structure as the most parsimonious model of the analysis of the whole data set (table 1). The random effects structure for migration groups was the same as for the whole data analysis, analyses per species contained the random variables, 'year' (factor) and 'location block'. Weights were applied according to the accuracy level of the laydate calculation from the nest-cards. Coefficients were derived from linear mixed effects models fit with REML. Coefficients between brackets are non-significant ($p > 0.05$).

Common name Scientific name	Laydates estimated	Population mean laydate (day of year)	Laydate change / °C in spring temp	Laydate change / mm sum spring precipitation
Resident species (RES)	32006	130 ± 4.19	- 3.18 ± 0.29	0.62 ± 0.14
Greenfinch *Carduelis chloris*	1138	135 ± 5.07	(- 3.67 ± 1.94)	(- 1.48 ± 1.22)
Eurasian treecreeper *Certhia familiaris*	1567	137 ± 3.60	- 3.17 ± 0.99	(1.25 ± 0.65)
Blue tit *Cyanistes caeruleus*	4948	136 ± 2.04	- 3.16 ± 0.57	(0.55 ± 0.32)
Great tit *Parus major*	18848	136 ± 1.38	- 3.61 ± 0.38	0.68 ± 0.19
Crested tit *Lophophanes cristatus*	1146	116 ± 2.26	- 2.88 ± 0.76	0.88 ± 0.41
Coal tit *Periparus ater*	2127	132 ± 3.45	(-1.53 ± 1.15)	(0.06 ± 0.61)
Black-billed magpie *Pica pica*	2232	121 ± 1.54	- 2.42 ± 0.55	0.88 ± 0.33
Short Distance Migrants (SDM)	45828	134 ± 2.82	- 1.85 ± 0.21	(- 0.10 ± 0.10)
Blackbird *Turdus merula*	1654	143 ± 2.83	(- 1.69 ± 1.22)	(- 0.31 ± 0.74)
Fieldfare *Turdus pilaris*	10112	135 ± 1.69	- 2.03 ± 0.46	- 1.06 ± 0.21
Redwing *Turdus iliacus*	11337	139 ± 1.68	(- 0.03 ± 0.52)	(- 0.19 ± 0.26)
European starling *Sturnus vulgaris*	5283	126 ± 1.45	- 2.55 ± 0.44	0.65 ± 0.19
White wagtail *Motacilla alba*	2994	145 ± 1.43	- 3.26 ± 0.58	(0.38 ± 0.38)
Chaffinch *Fringilla coelebs*	3723	140 ± 1.93	- 2.59 ± 0.64	(0.22 ± 0.33)
Common gull *Larus canus*	3627	135 ± 1.73	- 4.09 ± 0.57	1.62 ± 0.30

Black-headed gull *Chroicocephalus ridibundus*	2743	140 ± 4.46	- 6.34 ± 1.13	- 1.84 ± 0.37
Curlew *Numenius arquata*	1748	124 ± 1.33	- 2.21 ± 0.50	(0.46 ± 0.30)
Northern lapwing *Vanellus vanellus*	2607	119 ± 2.34	- 3.12 ± 0.83	(- 0.47 ± 0.38)
Long Distance Migrants (LDM)	51229	156 ± 2.46	- 1.25 ± 0.13	(0.05 ± 0.06)
Pied flycatcher *Ficedula hypoleuca*	32719	150 ± 1.12	- 1.35 ± 0.16	(0.07 ± 0.06)
Barn swallow *Hirundo rustica*	1494	167 ± 2.16	(- 0.20 ± 0.74)	(0.57 ± 0.51)
Spotted flycatcher *Muscicapa striata*	3928	161 ± 1.27	- 2.38 ± 0.42	0.65 ± 0.23
Common redstart *Phoenicurus phoenicurus*	2171	150 ± 1.68	(- 0.83 ± 0.54)	- 0.64 ± 0.31
Willow warbler *Phyloscopus trochilus*	3105	155 ± 1.46	- 2.19 ± 0.44	(- 0.22 ± 0.25)
Winchat *Saxicola rubetra*	1552	148 ± 1.64	- 1.56 ± 0.62	(- 0.43 ± 0.33)
Garden warbler *Sylvia borin*	2192	166 ± 0.67	(- 0.54 ± 0.62)	(- 0.62 ± 0.40)
Whitethroat *Sylvia communis*	1181	156 ± 2.21	- 2.74 ± 0.82	(- 0.35 ± 0.59)
Common tern *Sterna hirundo*	2887	146 ± 2.31	- 1.58 ± 0.76	1.82 ± 0.38

Table A5 Coefficients of change in time for each species separate from nest-card data. From the nest-card data LMMs per species had as fixed effect structure: mean spring temperature, spring precipitation sum, latitude, longitude, year and year^2. The random effects structure for contained the random variables, 'year' (factor) and 'location block'. Weights were applied according to the accuracy level of the laydate calculation from the nest-cards. Coefficients were derived from linear mixed effects models fit with REML. The last two columns are from the nestling ringing data (1973-2012) where change over time is derived from a linear regression with nestling ringing date as response and time (years) as predictor variable. Between brackets are the standard errors. Coefficients in bold are significant ($p< 0.05$), only significant 2nd order polynomials are given.

	Nest card data			Nestling ringing data	
Species	change in time (SE) (days / year)	2nd order polynomial of time (t)	number of nest-cards	change in time (SE) (days / year)	number of nestlings
Carduelis chloris	**- 0.23 (0.06)**	$0.65 * t - 0,017 * t^2$	1,138	-0.14 (0.08)	5,770
Certhia familiaris	**- 0.14 (0.04)**		1,567	**-0.20 (0.06)**	30,639
Ficedula hypoleuca	**- 0.07 (0.004)**	$0.11 * t - 0.003 * t^2$	32,719	**-0.11 (0.04)**	381,664
Fringilla coelebs	0.01 (0.02)	$0.47 * t - 0,010 * t^2$	3,723	0.01 (0.07)	6,404
Hirundo rustica	- 0.02 (0.04)		1,494	**-0.10 (0.04)**	74,853
Larus canus	**- 0.09 (0.02)**	$0.19 * t - 0.006 * t^2$	3,627	**-0.23 (0.04)**	21,962
Chroicocephalus ridibundus	**- 0.26 (0.02)**		2,743	-0.05 (0.09)	32,123
Motacilla alba	0.001 (0.01)		2,994	-0.08 (0.04)	22,424
Muscicapa striata	0.01 (0.01)		3,928	-0.03 (0.05)	21,292
Numenius arquata	- 0.02 (0.02)		1,748		
Periparus ater	**- 0.11 (0.03)**	$0.18 * t - 0.005 * t^2$	2,127	**-0.25 (0.06)**	58,030
Cyanistes caeruleus	**- 0.17 (0.02)**	$0.09 * t - 0.004 * t^2$	4,948	**-0.19 (0.05)**	224,596
Lophophanes cristatus	**- 0.17 (0.03)**		1,146	**-0.33 (0.06)**	14,122
Parus major	**- 0.13 (0.01)**	$0.09 * t - 0.004 * t^2$	18,848	**-0.20 (0.05)**	366,014
Phoenicurus phoenicurus	- 0.01 (0.02)	$0.28 * t - 0.006 * t^2$	2,171	**-0.11 (0.04)**	43,920
Phyloscopus trochilus	- 0.03 (0.02)	$0.10 * t - 0.003 * t^2$	3,105	**-0.08 (0.03)**	23,428
Pica pica	**- 0.10 (0.03)**	$- 0,32 * t + 0.005 * t^2$	2,232	0.12 (0.07)	15,359
Saxicola rubetra	0.02 (0.02)	$0.21 * t - 0.005 * t^2$	1,552	-0.08 (0.04)	26,300
Sterna hirundo	**- 0.06 (0.02)**	$0.47 * t - 0.010 * t^2$	2,887	-0.03 (0.04)	17,332
Sturnus vulgaris	**- 0.16 (0.01)**	$0.22 * t - 0.008 * t^2$	5,283	**-0.32 (0.04)**	86,789
Sylvia borin	- 0.02 (0.02)		2,192	-0.06 (0.04)	7,307
Sylvia communis	- 0.06 (0.03)	$0.28 * t - 0.006 * t^2$	1,181	**-0.17 (0.05)**	6,104
Turdus iliacus	**0.04 (0.01)**	$0.49 * t - 0.009 * t^2$	11,337	**-0.15 (0.05)**	59,232
Turdus merula	0.03 (0.04)		1,654	0.02 (0.06)	6,808
Turdus pilaris	**- 0.09 (0.01)**	$0.32 * t - 0.008 * t^2$	10,112	**-0.18 (0.05)**	58,389
Vanellus vanellus	0.01 (0.02)	$0.39 * t - 0.007 * t^2$	2,607		

Fig. A1 A spline correlogram of the 'Pearson' residuals from the most parsimonious model of a random subset of 2500 data points to check whether there is spatial auto-correlation. The distance is in meters ranging here from 0 – 100.000 (= 100km). No spatial auto-correlation detected.

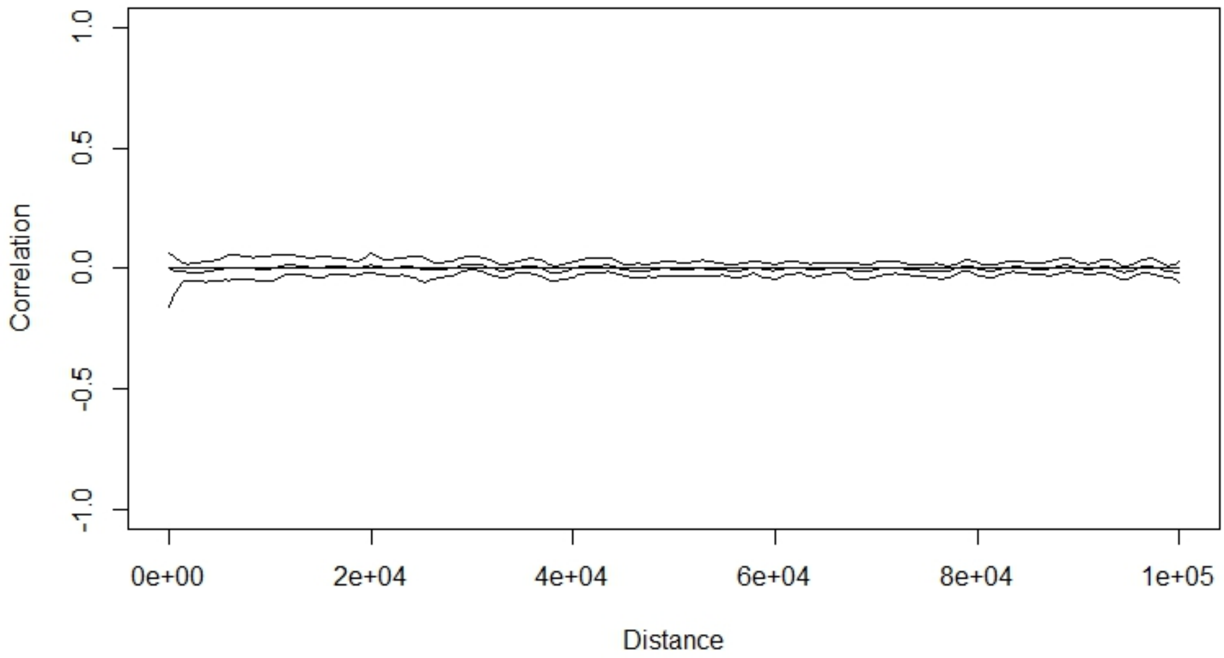

Fig. A2 The relationship between the log of body weight (x-axis) for 26 bird species and the breeding phenological response (advance) to an increase in mean spring temperature (y-axis). The red dashed line indicates the (non-significant) linear trend. Labels next to the dots indicate the species. Species are abbreviated such capital letter is the genus name, followed by three first letters of the species name (e.g. Turdus merula = Tmer).