CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	Climate change leads to differential shifts in the timing of annual cycle stages in a migratory bird
Authors	Tomotani, Barbara M.;van der Jeugd, Henk;Gienapp, Phillip;de la Hera, Iván;Pilzecker, Jos;Teichmann, Corry;Visser, Marcel E.
Publication date	2018
Original Citation	Tomotani, B. M., van der Jeugd, H., Gienapp, P., de la Hera, I., Pilzecker, J., Teichmann, C. and Visser, M. E. (2018) 'Climate change leads to differential shifts in the timing of annual cycle stages in a migratory bird', Global Change Biology, 24(2), pp. 823-835. doi: 10.1111/gcb.14006
Type of publication	Article (peer-reviewed)
Link to publisher's version	https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.14006 - 10.1111/gcb.14006
Rights	© 2017, the Authors. Global Change Biology Published by John Wiley & Sons Ltd. This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited. - https://creativecommons.org/licenses/by/4.0/
Download date	2026-11-09 20:07:53
Item downloaded from	https://hdl.handle.net/10468/6481

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Supporting information

Tomotani BM, van der Jeugd H, Gienapp P, de la Hera I, Pilzecker J, Teichmann C, Visser ME. Climate change leads to differential shifts in the timing of annual cycle stages in a migratory bird. Global Change Biology.

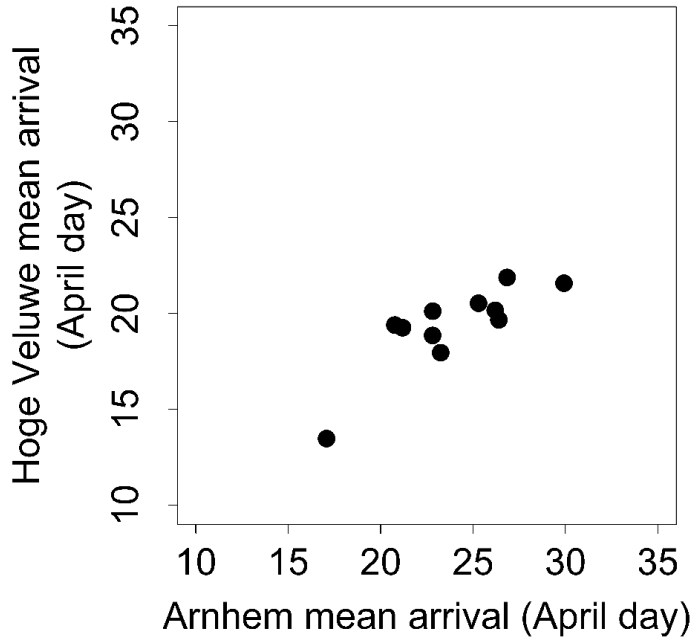


Figure S1: Correlation between mean arrival dates collected at the Hoge Veluwe and by the Arnhem group. Correlation coefficient: 0.83, 95% CI [0.45, 0.95]; R-squared (adjusted): 0.65; slope: 0.52 ±0.12; intercept: 6.73 ±2.87; *p*-value <0.01. This slope and the intercept were used to estimate the arrival date of the males in the Hoge Veluwe National Park before 2005.

Table S1: Model results for the multiple regression analyses testing the different rate of stage shifts (including annual means of arrival, laying, and moult onset dates). Statistics are given for each term at the point of the exclusion of the term from the model. Estimates and standard errors are presented only for significant terms or main terms in the presence of significant interactions.

Date (all stages)	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Stage : Centred Year^2			5	146	0.97	1.38	0.23
Stage : Centred Year			5	152	1.00	6.74	**<0.01***
Centred Year^2			1	151	0.97	2.40	0.12
Stage (Arrival observed) : Centred Year	-0.32	0.28					
Stage (Arrival calculated) : Centred Year	-0.03	0.05					
Stage (Arrival female) : Centred Year	-0.30	0.05					
Stage (Egg-laying) : Centred Year	-0.30	0.05					
Stage (Hatching) : Centred Year	-0.30	0.05					
Stage (Moult) : Centred Year	-1.11	0.29					
Stage (Arrival observed)	23.32	3.56					
Stage (Arrival calculated)	19.74	0.48					
Stage (Arrival female)	31.29	0.48					
Stage (Egg-laying)	38.93	0.48					
Stage (Hatching)	57.64	0.48					
Stage (Moult)	87.50	3.84					
Date (Arrival and Egg-laying)	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Stage : Centred Year^2			3	132	0.96	1.86	0.14
Stage : Centred Year			3	136	0.96	8.12	**<0.01***
Centred Year^2			1	135	0.96	2.23	0.14
Stage (Arrival calculated) : Centred Year	-0.03	0.05					
Stage (Arrival female) : Centred Year	-0.30	0.05					
Stage (Egg-laying) : Centred Year	-0.30	0.05					
Stage (Hatching) : Centred Year	-0.30	0.05					
Stage (Arrival calculated)	19.74	0.49					
Stage (Arrival female)	31.29	0.49					
Stage (Egg-laying)	38.93	0.49					
Stage (Hatching)	57.64	0.49					

Table S2: Model results for the simple and multiple regression analyses testing the trends of different annual cycle stages in relation to the linear and quadratic year term. Analyses were performed with the complete dataset (from 1980 until 2015) when data was available and with a subset of the dataset (from 2005 to 2015). Statistics are given for each term at the point of the exclusion of the term from the model.

	1980 to 2015							2005 to 2015						
1) Male arrival (observed)								**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2								0.07	0.07	1	8	0.13	1.01	0.34
Year								-0.32	0.20	1	9	0.13	2.51	0.15
2) Male arrival (calculated)	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**							
Year^2	-0.01	0.003	1	33	0.10	4.41	**0.04***							
Year	25.30	12.06												
Year (without quadratic)	-0.03	0.03	1	34	0.01	1.30	0.26							
3) Female Arrival	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2	0.01	0.01	1	33	0.46	1.78	0.19	0.02	0.10	1	8	-0.20	0.03	0.87
Year	-0.30	0.06	1	34	0.45	29.55	**<0.01***	0.16	0.27	1	9	-0.07	0.38	0.55
4) Laying date	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2	0.01	0.005	1	33	0.60	2.93	0.10	0.11	0.07	1	8	0.17	2.98	0.12
Year	-0.30	0.04	1	34	0.58	48.80	**<0.01***	0.19	0.20	1	9	-0.01	0.89	0.37
5) Hatching date	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2	0.01	0.01	1	33	0.45	0.93	0.34	0.10	0.08	1	8	0.11	1.52	0.25
Year	-0.30	0.05	1	34	0.45	29.72	**<0.01***	0.30	0.24	1	9	0.06	1.66	0.23
6) Departure NL								**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year								-2.10	0.05	1	3	1.00	1452.00	**0.02***

Table S2 (cont.)

	1980 to 2015							2005 to 2015						
7) Arrival Africa								**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year								4.49	5.24	1	3	-0.15	0.74	0.55
8) Moult onset - males								**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2								0.12	0.13	1	6	0.58	0.75	0.42
Year								-1.41	0.39	1	7	0.60	12.90	**0.01***
9) Interval fledge and moult – males								**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2								-0.04	0.09	1	6	0.74	0.22	0.66
Year								-1.38	0.26	1	7	0.77	27.87	**<0.01***
10) Interval arrival and laying - males (observed)								**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2								0.04	0.07	1	8	0.32	0.33	0.58
Year								0.51	0.20	1	9	0.37	6.82	**0.03***
11) Interval arrival and laying – females	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**							
Year^2	0.005	0.002	1	33	0.07	3.46	0.07							
Year	0.04	0.02	1	34	0.03	2.27	0.14							
12a) Interval arrival and laying - males (calculated)	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**							
Year^2	0.01	0.01	1	33	0.53	7.86	**<0.01***							
Year	-56.64	20.10												
Year (without quadratic)	-0.27	0.05	1	34	0.43	27.64	**<0.01***							
12b) Interval arrival and laying before 2008	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**							
Year	-0.42	0.07	1	26	0.57	37.11	**<0.01***							
12c) Interval arrival and laying after 2008	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**							
Year	0.60	0.20	1	6	0.54	9.08	**0.02***							

Table S3: Log-likelihood used in the model selection of all models for each annual cycle stage analysed. Models differ in the length of the temperature window (in days) for African and Dutch temperatures prior to the event or in the position of the window (lag in days) for the African temperature (with a fixed window of 20 days). Values in bold correspond to the best model fit.

Period evaluated for temperatures without lag (days)	Lag for African temperatures (days), period = 20 days	Model Log Likelihood				
		Male arrival (observed)	Male arrival (calculated)	Female arrival	Egg laying (NL temperatures)	Moult (NL temperatures)
5.00	20.00	-15.60	-92.76	-91.10	-96.07	-15.31
5.00	40.00	**-13.18**	-92.48	-89.93		
5.00	60.00	-16.49	-92.62	-91.77		
5.00	80.00	-16.24	-92.82	-91.28		
10.00	20.00	-16.48	-92.27	-89.11	-91.05	-15.30
10.00	40.00	-14.57	-91.62	-87.75		
10.00	60.00	-16.61	-92.47	-89.65		
10.00	80.00	-15.68	-92.57	-89.29		
15.00	20.00	-16.40	-92.27	-88.74	-88.74	-15.21
15.00	40.00	-14.73	**-91.41**	**-87.47**		
15.00	60.00	-16.57	-92.22	-89.50		
15.00	80.00	-15.62	-92.46	-88.77		
20.00	20.00	-16.71	-93.40	-91.52	-85.25	-15.28
20.00	40.00	-14.27	-91.98	-90.27		
20.00	60.00	-16.93	-93.72	-92.25		
20.00	80.00	-15.87	-93.92	-91.39		
25.00	20.00	-15.71	-94.01	-92.53	**-84.47**	-14.66
25.00	40.00	-15.47	-92.83	-91.39		
25.00	60.00	-16.68	-94.13	-93.01		
25.00	80.00	-14.05	-94.36	-92.33		
30.00	20.00	-15.74	-93.96	-93.04	-84.57	**-14.04**
30.00	40.00	-15.12	-93.09	-92.04		
30.00	60.00	-16.71	-94.21	-93.30		
30.00	80.00	-14.05	-94.41	-92.77		

Table S4: Model results for the effects of temperatures on the timing of stages analysed with proportional hazard models. Statistics are given for each term at the point of exclusion of the term from the model. *p*-values are significant at an adjusted significance level of x, where x = 0.05/number of tests.

1) Male arrival (observed)	**Coefficient**	**s.e.**	**Sample size**	**Events**	**χ^2**	***p*-value**
Day-length : Temperature NL	0.01	0.02	543	11	0.55	0.46
Day-length : Temperature Africa (lag)	-0.01	0.01	543	11	0.35	0.55
Temperature Netherlands (10 days period, no lag)	0.16	0.11	543	11	2.07	0.15
Temperature Ivory Coast (20 days period, 80 days lag)	-0.77	0.50	543	11	2.42	0.12
Temperature Ivory Coast (10 days period, no lag)	0.90	0.49	543	11	3.26	0.07
2) Male arrival (calculated)	**Coefficient**	**s.e.**	**Sample size**	**Events**	**χ^2**	***p*-value**
Day-length : Temperature NL	0.004	0.02	1795	36	0.05	0.82
Day-length : Temperature Africa (lag)	-0.001	0.01	1795	36	0.05	0.82
Temperature Netherlands (15 days period, no lag)	0.25	0.10	1795	36	6.25	0.01
Temperature Ivory Coast (20 days period, 40 days lag)	0.21	0.29	1795	36	0.55	0.46
Temperature Ivory Coast (15 days period, no lag)	0.76	0.50	1795	36	1.73	0.19
3) Female arrival	**Coefficient**	**s.e.**	**Sample size**	**Events**	**χ^2**	***p*-value**
Day-length : Temperature NL	-0.01	0.01	2208	36	3.25	0.07
Day-length : Temperature Africa (lag)	0.004	0.01	2208	36	0.55	0.46
Temperature Netherlands (5 days period, no lag)	0.23	0.07	2208	36	10.26	**<0.01***
Temperature Ivory Coast (20 days period, 80 days lag)	0.33	0.22	2208	36	2.20	0.14
Temperature Ivory Coast (5 days period, no lag)	-0.18	0.38	2208	36	0.24	0.63
4a) Egg laying (without year trend)	**Coefficient**	**s.e.**	**Sample size**	**Events**	**χ^2**	***p*-value**
Day-length : Temperature NL	0.001	0.01	1046	36	0.00	0.95
Temperature Netherlands (25 days period, no lag)	0.58	0.12	1046	36	25.89	**<0.01***
4b) Egg laying (with year trend)	**Coefficient**	**s.e.**	**Sample size**	**Events**	**χ^2**	***p*-value**
Day-length : Temperature NL	-0.01	0.01	1046	36	0.52	0.47
Temperature Netherlands (25 days period, no lag)	0.57	0.14	1046	36	19.59	**<0.01***
Year	0.10	0.02	1046	36	19.73	**<0.01***
5) Male moult	**Coefficient**	**s.e.**	**Sample size**	**Events**	**χ^2**	***p*-value**
Day-length : Temperature NL	-0.08	0.06	842	9	1.85	0.17
Temperature Netherlands (30 days period, no lag)	-0.26	0.31	842	9	0.73	0.39

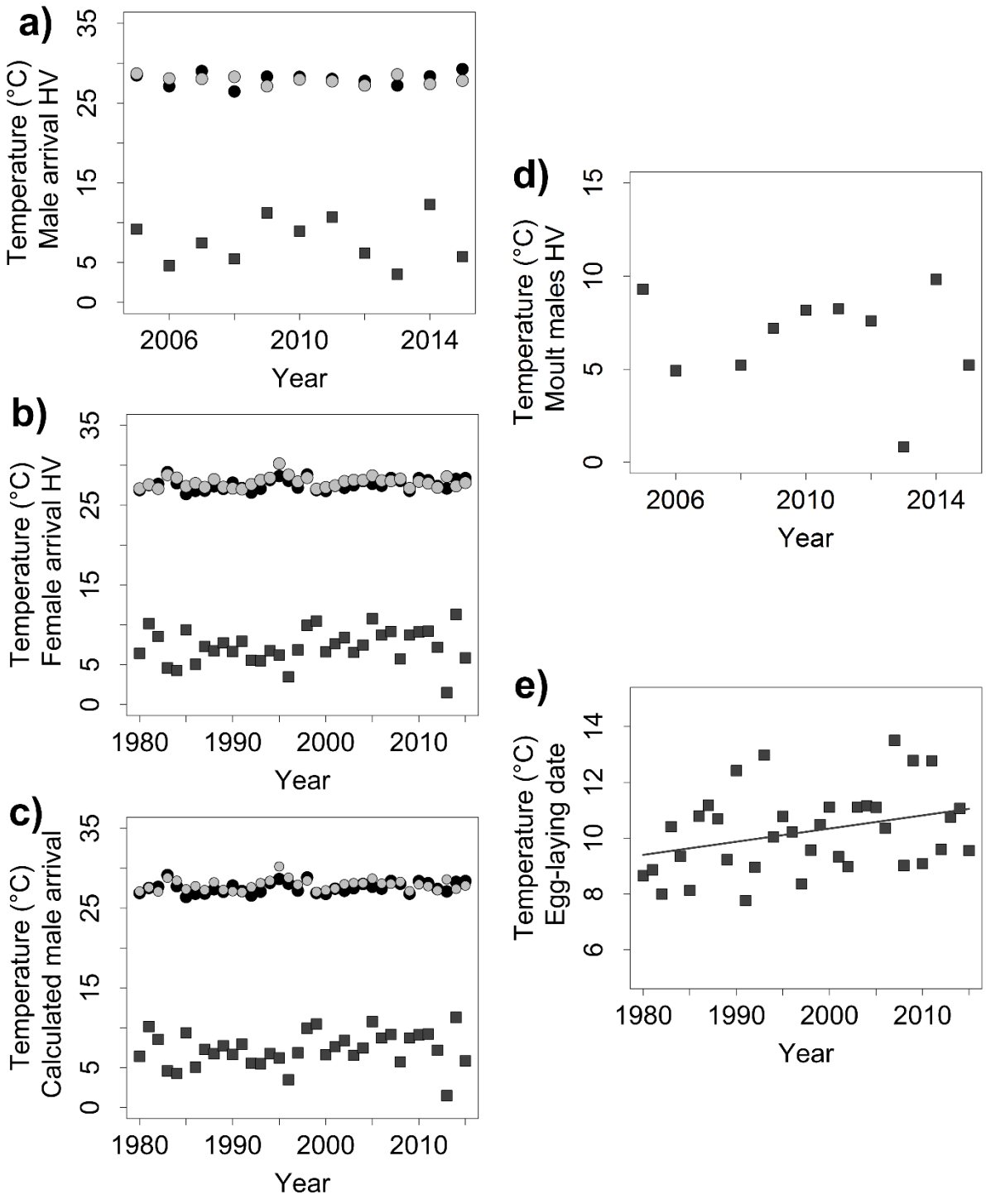


Figure S2: Trends of the temperatures extracted from the best model for **a)** Male arrival, short dataset (observed); **b)** Female arrival; **c)** Male arrival, long dataset (calculated); **d)** Male moult; **e)** Egg-laying date. Black squares: Dutch temperatures; dark circles: African temperatures without lag; grey circles: lagged African temperatures. Solid lines represent model prediction (of significant terms only).

Table S5: Model results for the simple and multiple regression analyses testing the trends of different temperatures (extracted from the best models) in relation to the linear and quadratic year terms. Analyses were performed with the average temperatures of each year. Statistics are given for each term at the point of exclusion of the term from the model.

1) Males arrival (observed)	**Explanatory variables**	**Estimates**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
a) Temperature Netherlands	Year^2	-0.05	0.11	1	8	-0.22	0.20	0.67
	Year	0.02	0.29	1	9	-0.11	0.01	0.94
b) Temperature Africa	Year^2	0.03	0.03	1	8	-0.04	1.18	0.31
	Year	0.05	0.08	1	9	-0.06	0.42	0.53
c) Temperature Africa lag	Year^2	0.02	0.02	1	8	0.13	1.54	0.25
	Year	-0.06	0.05	1	9	0.08	1.83	0.21
2) Males arrival (calculated)	**Explanatory variables**	**Estimates**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
a) Temperature Netherlands	Year^2	-0.0004	0.004	1	33	-0.04	0.01	0.91
	Year	0.03	0.03	1	34	-0.01	0.81	0.38
b) Temperature Africa	Year^2	0.001	0.001	1	33	0.02	0.37	0.55
	Year	0.02	0.01	1	34	0.01	2.27	0.14
c) Temperature Africa lag	Year^2	-0.002	0.001	1	33	0.01	1.92	0.18
	Year	0.01	0.01	1	34	-0.02	0.36	0.55
3) Females arrival	**Explanatory variables**	**Estimates**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
a) Temperature Netherlands	Year^2	-0.0004	0.004	1	33	-0.04	0.01	0.91
	Year	0.03	0.03	1	34	-0.01	0.81	0.38
b) Temperature Africa	Year^2	0.001	0.001	1	33	0.02	0.37	0.55
	Year	0.02	0.01	1	34	0.01	2.27	0.14
c) Temperature Africa lag	Year^2	-0.002	0.001	1	33	0.01	1.92	0.18
	Year	0.01	0.01	1	34	-0.02	0.36	0.55
4) Egg laying	**Explanatory variables**	**Estimates**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Temperature Netherlands	Year^2	-0.002	0.002	1	33	0.08	0.86	0.36
	Year	0.05	0.02	1	34	0.09	4.41	**0.04***
5) Males moult	**Explanatory variables**	**Estimates**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Temperature Netherlands	Year^2	0.001	0.10	1	7	-0.25	0.0001	0.99
	Year	-0.12	0.28	1	8	-0.10	0.20	0.67

Table S6: Model results for the simple and multiple regression analyses testing effects of the linear and quadratic year and intervals (arrival and breeding, breeding and moult) on clutch size and proportion of fledged chicks that recruited. Statistics are given for each term at the point of exclusion of the term from the model.

Clutch size and year	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2	-0.001	0.0005	1	33	0.40	9.50	**< 0.01***
Year	5.76	1.86					
Year (without quadratic)	0.02	0.005	1	34	0.25	12.55	**< 0.01***
Clutch size before 2008	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year	0.03	0.01	1	26	0.38	17.43	**< 0.01***
Clutch size after 2008	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year	-0.10	0.05	1	6	0.36	4.90	0.07
Clutch size and arrival/breeding	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2	-0.001	0.0005	1	33	0.40	9.50	**< 0.01***
Year	5.76	1.86					
(Difference calculated arrival and breeding)^2	-0.002	0.002	1	31	0.44	0.88	0.35
Difference calculated arrival and breeding	-0.03	0.02	1	32	0.44	3.54	0.07
Clutch size and breeding/moult	**Estimate**	**s.e.**	**ndf**	**ddf**	**R^2 (adjusted)**	***F*-test**	***p*-value**
Year^2	-0.02	0.01	1	5	0.38	5.66	0.06
Year	-0.03	0.03	1	8	0.01	1.08	0.33
(Difference moult males and breeding)^2	-0.01	0.005	1	4	0.47	1.86	0.24
Difference moult males and breeding	0.05	0.85	1	6	-0.09	0.37	0.57
Proportion of fledged chicks that recruited and year	**Estimate**	**s.e.**	**ndf**	**sample size**		**χ^2**	***p*-value**
Year^2	0.001	0.0002	1	33		10.49	**< 0.01***
Year	-3.86	0.74					
Year (without quadratic)	0.02	0.004	1	34		32.02	**< 0.01***
Proportion of fledged chicks that recruited and arrival/breeding	**Estimate**	**s.e.**	**ndf**	**sample size**		**χ^2**	***p*-value**
Year^2	0.002	0.0005	1	33		15.98	**< 0.01***
Year	-7.27	1.82					
(Difference calculated arrival and breeding)^2	-0.001	0.002	1	33		0.15	0.69
Difference calculated arrival and breeding	-0.04	0.01	1	33		6.99	**0.01***
Difference calculated arrival and breeding (alone)	-0.04	0.01	1	33		25.44	**< 0.01***
Proportion of fledged chicks that recruited and breeding/moult	**Estimate**	**s.e.**	**ndf**	**sample size**		**χ^2**	***p*-value**
Year^2	-0.03	0.03	1	8		1.18	0.28
Year	0.12	0.05	1	8		5.31	**0.02***
(Difference moult males and breeding)^2	-0.02	0.01	1	8		5.40	**0.02***
Difference moult males and breeding	0.25	0.10					
Difference moult males and breeding (alone)	-0.01	0.02	1	8		0.43	0.51

Table S6 (cont.)

Proportion of fledged chicks that recruited and laying date	Estimate	s.e.	ndf	sample size	χ^2	*p*-value
Year^2	0.001	0.0004	1	33	12.12	**< 0.01***
Year	-5.89	1.68				
(Laying date)^2	0.001	0.002	1	33	0.33	0.56
Laying date	-0.03	0.02	1	33	4.04	**0.04***
Laying date (alone)	-0.05	0.01	1	33	31.23	**< 0.01***