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Supplementary material

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Appendix 1. Are first arrival or onset of breeding related to population density?

We explored the possibility that the first arrival or onset of breeding are related to population density (e.g., Dunn and Winkler 1999, Tryjanowski and Sparks 2001, Miller-Rushing et al. 2008, Lindén 2011), which might confound the results found. Over the past decades, the breeding populations of the Pied Flycatcher (50% increase in 38 years) and the Great Tit (population doubled in 37 years) and the northern populations of the Common Redstart (population doubled in 35 years) in Finland have significantly increased, while no long-term trend has been found of the Southern populations of the Common Redstart (see population trajectories in Väisänen and Lehikoinen 2013). To address these questions, we added the annual breeding population size index (Väisänen and Lehikoinen 2013) of each species as the fifth explanatory variable in the multiple regressions. Nationwide estimates for the Pied Flycatcher and the Great Tit were used, but for the Common Redstart, the population trajectories differed between Southern and Northern Finland; we therefore used the population trajectory of Southern Finland in our analyses. These models were fitted for data of years for which population index data was available (1975-2010 for the Pied Flycatcher, 1979-2010 for the Common Redstart, and 1976-2010 for the Great Tit). We found that population size was not an important explanatory variable of the arrival or onset of breeding for any of the studied species (Table A1). Because the inclusion of population size to analyses would have reduced the number of years, this variable was omitted from the final analyses.

Table A1. The model averaged parameter values and relative variable importance (Burnham and Anderson 2002) of models describing the timing of arrival and onset of breeding, including the population size index (PopSize) of each species. The larger the relative variable importance, the more important the variable is relative to the other variables considered.

Response	Explanatory variables	n	Model averaged parameter value	Estimated unconditional SE	Relative variable importance
PF arrival	$T_{AprilBalt}$	34	-3.28	0.76	1.00
	NAO	34	0.90	0.41	0.78
	$T_{AprilLoc}$	34	0.58	0.65	0.28
	$T_{MarchBalt}$	34	-0.34	0.48	0.27
	PopSize	34	-0.03	0.04	0.24
CR arrival	$T_{AprilBalt}$	30	-1.90	0.65	0.96
	$T_{AprilLoc}$	30	0.41	0.60	0.28
	PopSize	30	0.02	0.03	0.26
	NAO	30	0.18	0.35	0.22
	$T_{MarchBalt}$	30	-0.13	0.39	0.21
PF onset	T_{MayLoc}	34	-1.45	0.29	1.00
	NAO	34	-0.25	0.22	0.35
	$T_{AprilLoc}$	34	-0.31	0.27	0.34
	Arrival	34	0.05	0.08	0.25
	PopSize	34	0.00	0.02	0.21
CR onset	T_{MayLoc}	23	-0.99	0.45	0.72
	NAO	23	-0.51	0.31	0.50
	Arrival	23	0.18	0.17	0.27
	PopSize	23	0.04	0.04	0.27
	$T_{AprilLoc}$	23	-0.20	0.43	0.19
GT onset	$T_{midApril–mid\text{-}MayLocal}$	35	-1.69	0.31	1.00
	$T_{mid\text{-}March–mid\text{-}AprilLocal}$	35	-0.86	0.33	0.90
	PopSize	35	0.04	0.02	0.50
	NAO	35	0.15	0.29	0.24

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Appendix 2. Long-term changes in meteorological datasets

We fitted linear regressions to find out if there are long-term changes (1973-2010) in the meteorological time-series studied. Residuals of each regression were tested for autocorrelation using Ljung–Box tests; however, no significant autocorrelations were found (in all cases, $p > 0.05$).

There was no long-term change in the local mean temperatures of March during our study period (linear regression; slope = -0.004, SE ± 0.040, t = -0.1, p = 0.93), or between mid-March to mid-April (slope = 0.012, SE ± 0.025, t = 0.5, p = 0.64), but the mean temperatures of April (slope = 0.050, SE ± 0.025, t = 2.0, p = 0.0497, R^2 adj. = 0.08; Fig. A1A; 1.9ºC increase between 1973 and 2010) and the mean temperatures between mid-April and mid-May (slope = 0.060, SE ± 0.027, t = 2.2, p = 0.031, R^2 adj. = 0.10) have been rising significantly. We found no long-term trend in May temperatures (slope = 0.009, SE ± 0.025, t = 0.35, p = 0.73).

There was no long-term change in the mean March (linear regression; slope = 0.022, SE ± 0.031, t = 0.7, p = 0.49) or May (linear regression; slope = 0.023, SE ± 0.018, t = 1.3, p = 0.20) temperatures over the Baltic area during our study period, but the mean temperatures of April were rising significantly (slope = 0.079, SE ± 0.015, t = 5.3, $p < 0.001$, R^2 adj. = 0.42; Fig. A1B) by 2.9ºC between 1973 and 2010. There was also no long-term change in the winter NAO index values (linear regression; slope = -0.031, SE ± 0.031, t = -1.0, p = 0.33) during our study period.

There were no long-term changes in the thermal sum that accumulated between 1 March until 31 May (i.e., until the typical onset of breeding for Pied Flycatcher and Common Redstart) with temperature thresholds 0ºC (slope = 1.53, SE ± 0.96, t = 1.6, p = 0.12), 2.5 (slope = 0.99, SE ± 0.82, t = 1.2, p = 0.23), 5 (slope = 0.48, SE ± 0.67, t = 0.7, p = 0.48) or 7.5ºC (slope = 0.05, SE ± 0.52, t = 0.1, p = 0.93). However, we found an increasing pattern in the thermal sum that accumulated between 1 March until 15 May (the typical onset of breeding for Great Tit) with temperature threshold 0ºC (slope = 1.81, SE ± 0.75, t = 2.4, p = 0.022), and 2.5 (slope = 1.28, SE ± 0.58, t = 2.2, p = 0.034), but the increasing trend was only suggestive with threshold 5 (slope =

0.78, SE ± 0.40, t = 2.0, p = 0.059) and not significant with threshold 7.5ºC (slope = 0.39, SE ± 0.23, t = 1.7, p = 0.10).

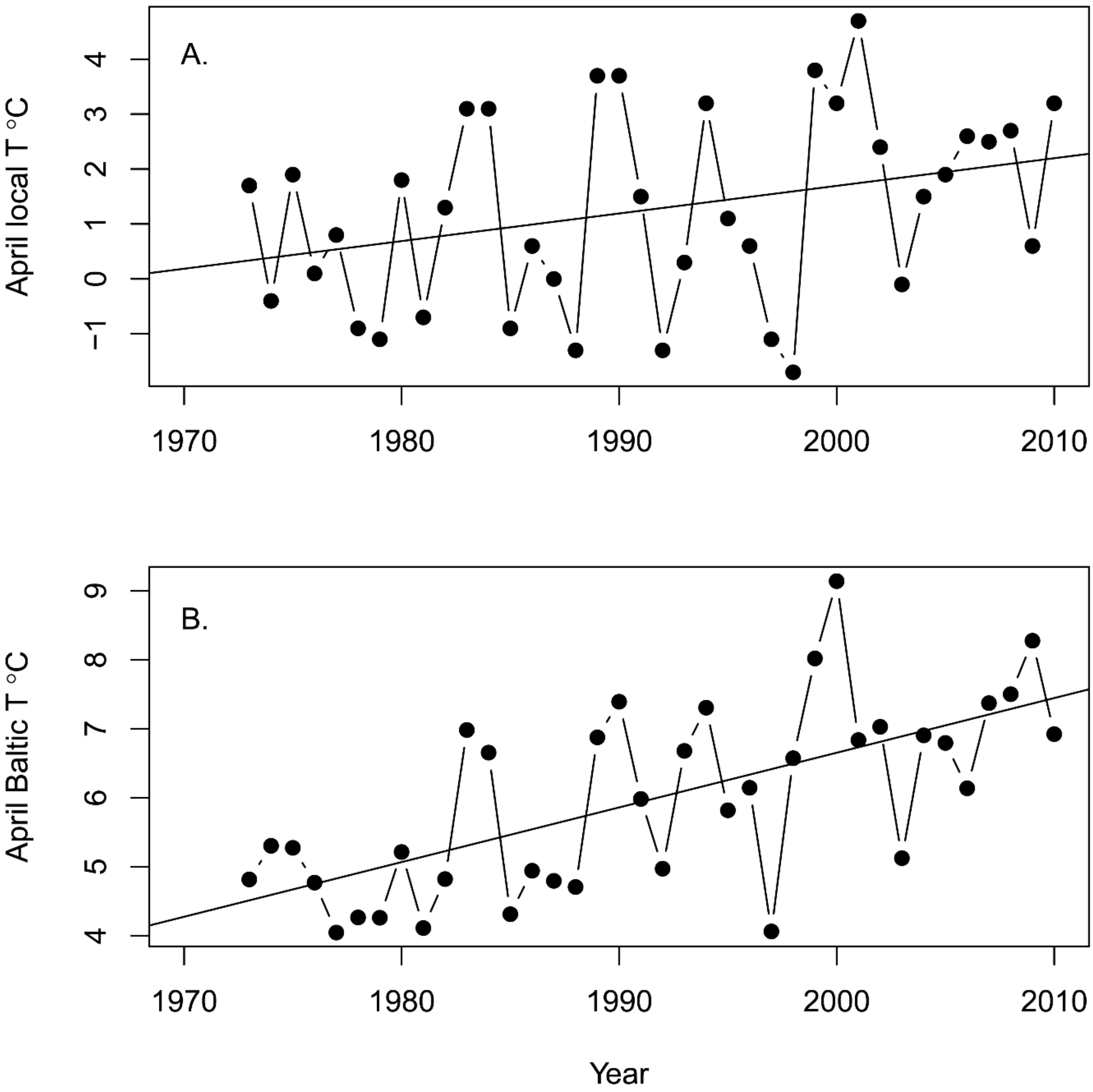

Fig. A1. Long-term trends in (A.) local mean temperatures of April and (B.) mean temperatures of April in the Baltic region. Linear regression lines are overlaid.

Appendix 3. Phenology of spring flying insects

As a proxy for phenological timing of insects, we used data on the spring phenology of moths flying approximately at the time of onset of breeding. To study the correlation between insect phenology and the Great Tit onset of breeding (ranging from 4 May to 22 May), we selected all moth species with ≥ 100 records in the data and median of observations between 4 May and 22 May (for adult overwintering species only observations before mid-summer were included, and species which were not observed each year were excluded). The nine moth species ("spring moths") were: *Cerastis rubricosa* (Noctuidae), *Cleora cinctaria* (Geometridae; all observations after mid-summer removed to exclude observations of 2nd generations), *Conistra vaccinii* (Noctuidae; all observations after mid-summer removed to exclude observations of fall flying individuals), *Eupithecia lanceata* (Geometridae), *Lycia hirtaria* (Geometridae), *Odontosia sieversii* (Notodontidae), *Orthosia gothica* (Noctuidae), *Orthosia incerta* (Noctuidae) and *Trichopteryx carpinata* (Geometridae). To study the correlation between insect phenology and onset of breeding for the Pied Flycatcher or the Common Redstart (ranging from 24 May to 9 June), we selected all moth species with ≥ 100 records in the data and median of observations between 24 May and 9 June (using the same criteria as above). The seven moth species ("late spring moths") were: *Aethalura punctulata* (Geometridae; all observations after June removed to exclude observations of 2nd generations), *Ectropis crepuscularia* (Geometridae; all observations after June removed), *Hydriomena ruberata* (Geometridae), *Lampropteryx suffumata* (Geometridae; all observations after June removed), *Odontosia carmelita* (Notodontidae), *Selenia dentaria* (Geometridae; all observations after June removed) and *Selenia tetralunaria* (Geometridae; all observations after mid-July removed).

Table A2. Locations, covered years and total captured moth individuals of the ten light traps providing data to estimate the phenology of moths (data by the Finnish Moth Monitoring Scheme "Nocturna", coordinated by the Finnish environmental administration; Leinonen et al. 2016). The light traps were emptied approximately weekly throughout the flight period of macro-moths in the region. Data includes species belonging to superfamilies Lasiocampoidea, Bombycoidea, Geometroidea, Noctuoidea and Hepialoidea.

Trap no	Latitude	Longitude	Years	Captures
701	62.56	29.82	1993–2000, 2003–2004	25378
702	62.56	29.82	1993–2008	51820
703	62.77	30.97	1993–1997, 2004–2010	46788
704	62.77	30.97	1993–1997	3453
705	62.23	30.35	1993–2001, 2010	33635
706	62.24	30.35	1993–2006	66167
707	62.98	29.75	1993–2001	26767
708	62.98	29.76	1993–2003	40995
709	62.58	31.17	1998–2001	8844
710	62.86	30.40	1998–2010	73864

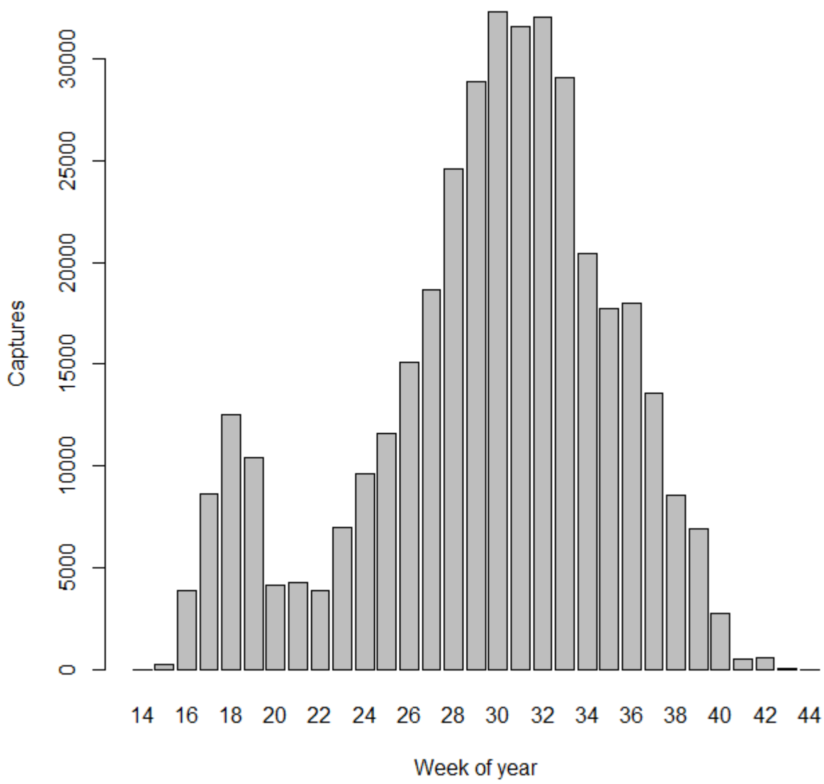

Fig. A2. Seasonal pattern of captured moth individuals of the ten light traps providing data to estimate the phenology of moths (data by the Finnish Moth Monitoring Scheme "Nocturna", coordinated by the Finnish environmental administration; Leinonen et al. 2016).

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Appendix 4. Long-term patterns in onset of breeding

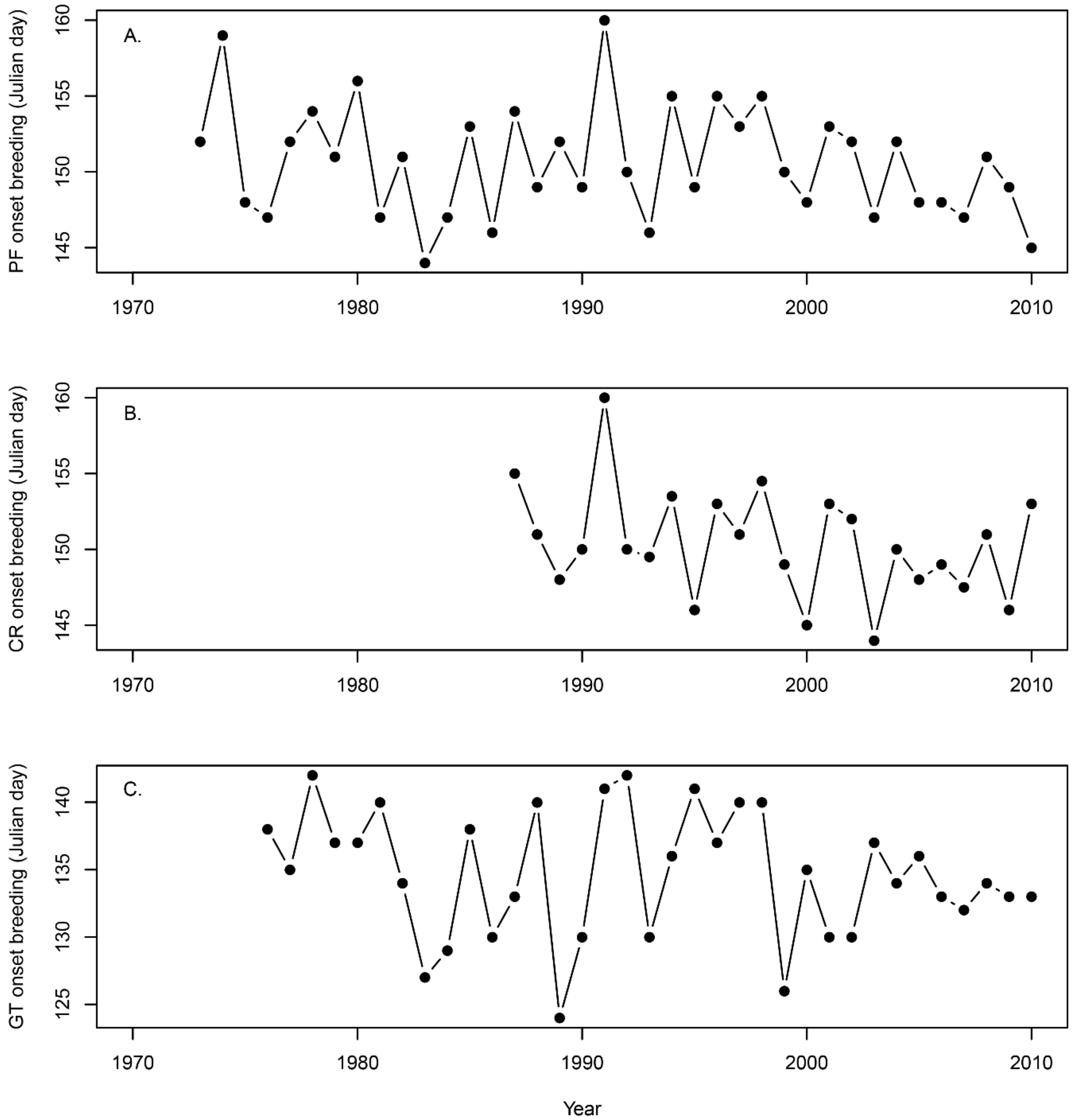

Fig. A3. Long-term patterns in onset of breeding for (A.) the Pied Flycatcher, (B.) the Common Redstart and (C.) the Great Tit.