Supplementary Information

2. Model 2. Model used to estimate the overall response in the magnitude of synchrony change.
3. Model 3. Model used to estimate the relationship between temperature change and change in phenology across interactions (i.e. covariate models).
4. Model 4. Model used to estimate the relationship between temperature change and change in synchrony across interactions (i.e. covariate models).

Appendix S.1. Additional background information

A. ADDITIONAL BACKGROUND

It is commonly thought that warming will lead to changes in synchrony (1-3). These changes are expected to be prevalent because (i) temperature is an important phenological cue for many taxonomic groups (4), (ii) the temperature sensitivity of phenology of interacting species can differ (5,6) and, (iii) global temperatures have increased on average by 0.85°C since 1880 (7). Indeed, there is evidence from single-systems, as well as from reviews (8,9), that many interacting species are shifting their phenologies at different rates, leading to changes in synchrony (10-13). To date, however, there have been no quantitative assessments of shifts across studies for species that directly interact—leaving open the question of how prevalent and large such shifts may be. Indeed, another set of studies that span observational evidence, theoretical considerations, and small-scale experiments suggest that maintenance of synchrony in the context of environmental change could be common (14-19). There are examples from directly interacting species that show synchrony has been sustained (20-21). Others show that the degree of changes in synchrony can vary across populations (22-24) or has been less than expected (25,26). These examples question whether shifts toward asynchrony should be widespread (14,27,28).

From an evolutionary-perspective, it is not clear that species interactions should necessarily move towards asynchrony during environmental change. Species in different types of interactions are likely to have evolved different types of responses to environmental cues making it difficult to make predictions about the likelihood of asynchrony based on more general associations (14, 29). For example, we should expect differences in the strength of natural selection on synchrony between specialized interactions and less closely interacting species. There is likely to be strong selection on processes governing phenological synchrony among pairs of closely interacting species (30, 31). Maintenance of synchrony in consumer-resource interactions could be a result of selection pressures from shifts in the timing of resource availability to minimize changes in synchrony (28,32). For mutualistic interactions, there should be strong selection for the two to use the same cues, or at least cues that have historically been strongly correlated (29, 33). For non-trophic interactions (e.g. competition), interacting species are likely to be influenced by shared environmental factors (14). In other systems, asynchrony might be more adaptive than synchrony making it difficult to anticipate how synchrony will change (31,34).

In many systems, there is limited knowledge about the relative importance of environmental cues controlling phenology for both partners in an interaction (20, 35), making it difficult to predict how they will respond to changing environmental conditions. Moreover, phenological responses are a function of both organismal mechanisms (e.g., environmental cues) and environmental mechanisms (e.g., degree, seasonality of temperature change). For example, even if interacting taxa respond to different cues or respond to the same cues but at different rates, their responses may still be in the same direction and of a similar magnitude, thereby maintaining their phenological synchrony over a range of abiotic conditions, given the complexity and multidimensional nature of how cues are changing with climate change (e.g., interannual variation vs. long-term directional change, a change in one cue but not another; 20). In conclusion, it is difficult to predict the prevalence and magnitude of shifts in synchrony *a* *priori* and an analysis that directly compares the phenological responses of interacting species is needed.

B. REFERENCES ASSOCIATED WITH ADDITIONAL BACKGROUND

1. Harrington R, Woiwod I, Sparks T (1999) Climate change and trophic interactions. *Trends Ecol Evol* 14:146-150.
2. Stenseth NC, Mysterud A (2002) Climate, changing phenology, and other life history traits: nonlinearity and match–mismatch to the environment. *Proc Natl Acad Sci USA* 99:13379-13381.
3. Visser ME, Both C, Lambrechts MM (2004) Global climate change leads to mistimed avian reproduction. *Adv Ecol Res* 35:89-110.
4. Pau S, et al. (2011) Predicting phenology by integrating ecology, evolution and climate science. *Glob. Change Biol* 17:3633-3643.
5. Thackeray SJ, et al. (2016) Phenological sensitivity to climate across taxa and trophic levels. *Nature* 535:241-245.
6. Kharouba HM, Vellend M (2015) Flowering time of butterfly nectar food plants is more sensitive to temperature than the timing of butterfly adult flight. *J Anim Ecol* 84:1311-1321.
7. Stocker TF, et al. (IPCC, 2013) *Climate Change 2013: The Physical Science Basis* 1535 pp.
8. Visser ME, Both C (2005). Shifts in phenology due to global climate change: the need for a yardstick. *Philos. Trans. R. Soc. London B* 272:2561-2569.
9. Donnelly A, Caffarra A, O'Neill BF (2011) A review of climate-driven mismatches between interdependent phenophases in terrestrial and aquatic ecosystems. *Int. J. Biometeorol.* 55:805-817.
10. Post E, Forchhammer MC (2008) Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. *Philos. Trans. R. Soc. London B* 363: 2367-2373.
11. McKinney AM, et al. (2012) Asynchronous changes in phenology of migrating Broad‐tailed Hummingbirds and their early‐season nectar resources. *Ecology* 93:1987-1993.
12. Mayor SJ, et al. (2017) Increasing phenological asynchrony between spring green-up and arrival of migratory birds. *Sci Rep-UK* 7.
13. Ross MV, Alisauskas RT, Douglas DC, Kellett DK (2017) Decadal declines in avian herbivore reproduction: density‐dependent nutrition and phenological mismatch in the arctic. *Ecology* 98:1869-1883.
14. Ovaskainen O, et al. (2013) Community-level phenological response to climate change. *Proc. Natl. Acad. Sci. USA* 110:13434-13439.
15. Aebischer NJ, Coulson JC, Colebrookl JM (1990) Parallel long-term trends across four marine trophic levels and weather. *Nature* 347:753-755.
16. Seebens H, Einsle U, Straile D (2009) Copepod life cycle adaptations and success in response to phytoplankton spring bloom phenology. *Glob Change Biol* 15:1394–1404.
17. Bartomeus I, et al. (2011) Climate-associated phenological advances in bee pollinators and bee-pollinated plants. *Proc Natl Acad Sci USA* 108:20645–20649.
18. Rafferty NE, Ives AR (2011) Effects of experimental shifts in flowering phenology on plant–pollinator interactions. *Ecol Lett* 14:69-74.
19. Johansson J, Kristensen NP, Nilsson JÅ, Jonzén N (2015) The eco‐evolutionary consequences of interspecific phenological asynchrony–a theoretical perspective. *Oikos* 124:102-112.

20. Iler AM, et al. (2013) Maintenance of temporal synchrony between syrphid flies and floral resources despite differential phenological responses to climate. *Glob. Change Biol.* 19:2348-2359.
21. Gustine D, et al. (2017) Advancing the match-mismatch framework for large herbivores in the Arctic: Evaluating the evidence for a trophic mismatch in caribou. *PLOS ONE* 12:p.e0171807.
22. Visser ME, Van Noordwijk AJ, Tinbergen JM, Lessells CM (1998) Warmer springs lead to mistimed reproduction in great tits (*Parus major*). *Philos. Trans. R. Soc. London B* 265:1867-1870.
23. Bauer Z, et al. (2010) Changing climate and the phenological response of great tit and collared flycatcher populations in floodplain forest ecosystems in Central Europe. *Int. J. Biometeorol*. 54:99-111.
24. Charmantier A, et al. (2008) Adaptive Phenotypic Plasticity in Response to Climate Change in a Wild Bird Population. *Science* 320:800-803.
25. Hua F, et al. (2016) Community‐wide changes in intertaxonomic temporal co‐occurrence resulting from phenological shifts. *Glob Change Biol* 22:1746-1754.
26. Mortensen LO, et al. (2016) Analysis of trophic interactions reveals highly plastic response to climate change in a tri-trophic high-Arctic ecosystem. *Polar Biol* 39:1467-1478.
27. Bolmgren K, Eriksson O (2015). Are mismatches the norm? Timing of flowering, fruiting, dispersal and germination and their fitness effects in *Frangula alnus* (Rhamnaceae). *Oikos* 124:639-648.
28. Bewick S, Cantrell RS, Cosner C, Fagan WF (2016) How resource phenology affects consumer population dynamics. *Am. Nat* 187:151-166.
29. Forrest JR, Thomson JD (2011). An examination of synchrony between insect emergence and flowering in Rocky Mountain meadows. *Ecol Monogr* 81:469-491.
30. van Asch M, Visser ME (2007) Phenology of forest caterpillars and their host trees: the importance of synchrony. *Annu Rev Entomol* 52:37-55.
31. Johansson J, Jonzén N (2012) Game theory sheds new light on ecological responses to current climate change when phenology is historically mismatched. *Ecol Lett* 15:881-888.
32. Nussey DH, Postma E, Gienapp P, Visser ME (2005) Selection on heritable phenotypic plasticity in a wild bird population. *Science* 310:304-306.
33. Danforth BN (1999) Emergence dynamics and bet hedging in a desert bee, Perdita portalis. *Philos. Trans. R. Soc. London B* 266:1985-1994.
34. Singer MC, Parmesan C (2010) Phenological asynchrony between herbivorous insects and their hosts: signal of climate change or pre-existing adaptive strategy? *Philos. Trans. R. Soc. London B* 365:3161-3176.
35. Hegland SJ, Nielsen A, Lázaro A, Bjerknes AL, Totland Ø (2009) How does climate warming affect plant‐pollinator interactions? *Ecol Lett* 12:184-195.

Appendix S.2. Additional information for methods

A. DATA

a) Phenological data

i) Database construction. We searched Web of Science using the search string: phenolog* AND mismatch* OR synchron* AND interact*, and then further refined by 'ecology' to identify studies in peer-reviewed journals that recorded phenology for interacting species prior to August 2015, netting 188 studies. To be selected, phenological data had to be associated with a treatment, site or year. In addition, authors had to be explicit that the two species interacted (e.g. specifying type of interaction). However, the author's definition of 'interacting species' and the degree to which two species interacted (i.e. interaction strength) likely varied across studies. Studies that considered assemblies of species (e.g. communities) or comparisons across taxonomic groups were not included (n=9). Given that only rarely was enough detail provided to be able to quantify the strength of the interaction (10/54 interactions), we were unable to use a quantitative approach to define the strength of interaction (and thus unable to assess whether synchrony change varies with strength of interaction). Only one of the interactions was explicitly described as specialized. All of the other interactions were 'diffuse' in some way: many interactions consisted of data for a consumer and a group of resources (e.g. genus) or data for a single consumer and resource but either the consumer or resource was paired across multiple interactions. To ensure a reasonable sample size and to include studies across different major biomes, we included interactions that were resolved to the genus-level and below. Given that the majority of taxa in this study were species (n=61; 69%), we use the term 'species' throughout the paper to represent both species and genus.

We excluded time-series that (1) were shorter than 5 years in length; (2) did not measure phenology as day of year (e.g. proportion of individuals observed by a particular date); or (3) did not measure phenology directly (e.g. used derived measures of phenology, such as NDVI). Although none of the authors mentioned it explicitly, we assumed that authors corrected for leap years because the majority of the studies represented original empirical collections. We do note that not correcting for leap years could introduce bias into estimates of phenological shifts (1).

To avoid using the same data set more than once, we further reduced the database. In cases where two studies had tracked the same interaction in the same location for completely overlapping years (n=2), we randomly chose one study. When the studies only partially overlapped in time (n=2) or when the same interaction was considered by multiple studies (i.e. non-unique interactions; n=2), we chose the study with the longer time series.

When multiple phenological events per species were recorded in a given study, we prioritized maximizing the number of years with data for both species and when possible we chose first date because it was the most common metric across studies. When multiple sites were included in a given study (n=4 studies), we took the median day of year across sites.

In total, we were able to identify 54 unique pair-wise species interactions among 27 studies (Table S8) with time-series phenological data that spanned 1951 to 2013. Our dataset includes 88 species that span a wide range of taxonomic groups from aquatic and terrestrial ecosystems across four continents (Figure S1). The mean study length was 21.7 years (sd=8.4) and mean first year of study was 1984 (sd=9.4).

ii) Data structure

Our final database included some species that were replicated across time and/or space. These cases differed from the interactions described above because aspects of these interactions were unique (other species, location or time-series). There were repeating species that occurred both within (i.e. where a single species was in multiple interactions) and across studies. For those species found in more than one study, the time-series length (e.g. *Parus major*: 1985-2005 (2) vs. 1961-2006 (3)) and/or location (e.g. *Parus major*: Netherlands (2) vs. Wytham, UK (3)) would vary between studies. Repeating species were included as independent data points (but see statistical analysis section for decisions related to pseudoreplication); i.e. each unique species-location-time series combination was included. However, the number of repeating species constituted a small proportion of the overall number of species (within studies: 15/88; across studies: 8/88; Table S8).

b) Temperature data

i) Database construction

For those studies that considered temperature as a main phenological cue for at least one of the interacting species, we included temperature data for those years with phenological data for both species. We excluded studies i) that measured temperature as a function of the day of year (e.g. when a certain temperature was reached) to isolate the effect of temperature from time; ii) found temperature was not a predictor of phenology for either taxon (n=2); iii) measured temperature as a cumulative sum across days; iv) where nutrients have been shown to explain phenology of one of the interacting species (n=3).

Since our goal was to link temperature change to synchrony change, temperature change was estimated for an interaction (rather than a species). Therefore, decisions about which temperature variable to use were made at the interaction level. For example, if one species had first day of ice break as the best predictor and March temperature was the best predictor for the other species, change in March temperature was estimated. If temperature was not mentioned as a predictor for a species in an interaction, temperature data for the other species was used for both species in the interaction. For more details on which temperature metrics were used, see Table S1. The mean number of years with temperature data available and with phenological data for both partners of the interaction was 20.65 (8.56SD) years.

ii) Data structure

After construction of our temperature database we identified two types of non-independence (see discussion about the issue in the analysis section). First, there were several studies with temperature data that came from the same weather station location (Air: 2 studies; Water: 2 studies; Table S2). However, different temperature metrics were used for the species at these locations. Second, there were three studies with temperature data from multiple sites (2-3 sites/study; Table S3). For these studies, we took the mean temperature across sites. In the end, there were 18 unique datasets (i.e. independent measure of temperature) from 13 studies.

B. STATISTICAL ANALYSIS

(Note that these descriptions of our statistical methods supplement those in the main text so both sections should be read together)

i) Overall approach

The analysis was divided into four sections. First, we estimated phenological shift (days/decade) across species. Next, we estimated synchrony change (days/decade) using those estimates of phenological shift. Third, we estimated temperature change (°C/decade) and phenological sensitivity to temperature (days/°C) across species. Finally, we examined whether temperature change could predict phenological and synchrony change.

All statistical analyses were conducted in the R 3.3.2 environment (4) using the *rstan* package (version 2.14.1). Stan provides efficient MCMC sampling via a No-U-Turn Hamiltonian Monte Carlo approach (5,6). Posterior distributions of model parameters were estimated from 3000 samples from each of four independent Markov chains. The number of iterations varied by model (range=6000-14000) but convergence was always achieved. Convergence of the four chains and sufficient sampling of posterior distributions were confirmed by: visual inspection of parameter traces, ensuring a scale reduction factor ($\hat{R}$) below 1.01, and an effective size (n_{eff}) of at least 10% the number of iterations (6).

We used three approaches to test our models. First, to ensure models were specified properly we checked that our models could return known parameters generated from simulated data. Second, we assessed overall model fit using posterior predictive checks (estimated global parameters from the hierarchical models were compared against parameters estimated from simple linear models). Finally, we validated our estimates of synchrony change with the estimates from a sample of original studies (see Appendix S3).

Given significant warming trends in recent decades and the detection of non-stationarities in both temperature data and recent ecological responses to climate change (7-12), we used a hinge model (Figure S2). There is no consensus on a breakpoint for temperature change: the estimates vary for different places and are dependent on data and methods (13-15). Breakpoints range from 1976 to 1984 with much of the change noted in the early 1980s. We used 1981 as the inflection point to reflect the major change in temperature observed in the early 1980s. To test the robustness of our estimates of synchrony change (the key analysis of the paper), we also used an inflection point of 1976 and the results were similar (Appendix S3).

We used a two-level hierarchical model for all analyses. We were unable to include study as a hierarchical level because we did not have a reasonable number of repeating species across studies (i.e. the species that did repeat across studies only did so across a small number of studies (2-3)). Therefore the model would not have been able to properly partition variance between species and studies. Additionally, we did not have very strong prior to inform the model where to partition the variance.

To account for potential study differences (e.g. methodology), we took two approaches. First, by pooling slopes or intercepts across species, the models weighted species based on the variance and length of time-series, thus accounting for this major methodological difference across studies. Secondly, we directly evaluated the strength of the relationship between synchrony change and three main factors that differed across studies: frequency of phenological observation (daily or weekly), first year of study, and length of study (see Appendix S3 for analysis).

ii) Covariate models

To estimate the relationship between temperature change and synchrony change, we fit synchrony change as a function of temperature change. To do so, we took the same steps as the covariate model for phenology but with one modification. In order to obtain one estimate of temperature change for interactions where different temperature metrics were provided for each species in an interaction (n=8), we used the temperature data for the resource. We tested the robustness of our results by choosing the consumer in the relationship and the results were similar (β =0.2 days/°C (-0.2, 0.5)). The slope of the relationship slightly differed (β =0.2 (-0.2, 0.5) vs. β =-0.1 (-0.5, 0.2)) because temperature change was estimated on a different number of species (resource: 21 vs. consumer=18): there were some consumers common to multiple interactions.

b) Null models

We constructed three different null models. Two were used to establish a baseline for changes in synchrony by estimating the amount of natural variation among interactions before recent climate change began and one was used to explore the effect of time series length on estimates of phenological change.

i) Synchrony null model- modeled estimates of synchrony change from simulated data using pre-recent climate change data:

Our workflow to simulate synchrony change based on phenological change estimated before significant climate change was as follows:

1. We estimated phenological change on the 'pre-recent climate change' datasets following methods described in the main text.
2. We calculated *observed* synchrony change for this subset of interactions (n=22) using our estimates obtained in step 1 and following methods described in the main text.
3. Next we simulated data for each pair of interacting species:
    a. For the first species in each pair (sppA), we sampled the posterior distributions for slope and intercept (obtained in step 1) to predict the date for a given year (ypred). To determine the years and length of time series, we randomly chose a pre-recent climate change dataset. We then sampled new dates from a normal distribution of the required length. This distribution was constructed using the mean of ypred and a randomly sampled estimate of variation from the posterior distribution of the pre-recent climate change datasets.
    b. For the second species in each pair (sppB), we sampled an estimate of synchrony change from the observed distribution (step 2) and used the difference between slope for sppA (step 3a) and synchrony change to calculate the slope for sppB. To predict dates for sppB, we sampled an intercept and estimate of variation from sppA (step 1). We used the same years and length of time series as sppA. We followed the same approach as step3a to simulate new dates for sppB.
4. We then estimated phenological change across all years on this simulated data for all species following methods described in the main text.
5. Finally, we calculated *simulated* synchrony change for all interactions following methods described in the main text.
6. Steps 3-5 were repeated five times.
7. One null model was then randomly chosen and results from this model were reported.

This approach is likely to capture any phenological change that actually occurred from 1951-1981, though our estimates of synchrony change are simulated based on estimates of phenological change and not raw data. To explore another null model option, we also simulated synchrony change directly from the raw data from the pre-recent climate change data. This model predicted smaller synchrony change but also likely underestimates potential phenological change from 1951-1981.

ii) Synchrony null model- estimates of synchrony change from raw pre-recent climate change data

We estimated synchrony change for 1951-1981 using the 'pre-recent climate change 'datasets (n=16 interactions). To estimate changes in phenology, we used a non-hinge model as described in the main text. Then to estimate the change in synchrony, we followed the steps we outlined in the main text for the synchrony models.

iii) Time series length null model

To explore the effect of time series length on estimates of phenological change without significant climate change occurring:

1. We estimated phenological change on the pre-recent climate change datasets following methods described in the main text.
2. We then simulated data for all species based on X=5 to 40 (by 5 year increments) years of data.
3. For each species, we followed the same approach as used to estimate phenologcial change for sppA as described above (Appendix S2.B.b.i.3.a). Briefly, we sampled the posterior distributions for slope and intercept created in step 1 (Appendix S2.B.b.iii.1) to predict the date in a given year (ypred). To determine the years of the time series, we randomly chose X number of years from the full dataset (1951-2013).
4. We estimated phenological change on this simulated data for all species following methods described in the main text for each time series increment.

C. REFERENCES ASSOCIATED WITH METHODS

1. Sagarin R (2001) Phenology: False estimates of the advance of spring. *Nature* 414:600-600.
2. Both C, Van Asch M, Bijlsma RG, Van Den Burg AB, Visser ME (2009) Climate change and unequal phenological changes across four trophic levels: constraints or adaptations? *J Anim. Ecol.* 78:73-83.
3. Charmantier, A. *et al*. Adaptive Phenotypic Plasticity in Response to Climate Change in a Wild Bird Population. *Science.* ***320***, 800-803 (2008).
4. R Development Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, (2016).
5. Gelman, A. et al. Bayesian Data Analysis. 3rd ed. CRC Press, New York. (2014)
6. Gelman, A. & Hill, J. Data analysis using regression and multilevel/hierarchical models. Cambridge University Press, UK. (2007)
7. Booth, B.B., Dunstone, N.J., Halloran, P.R., Andrews, T. & Bellouin, N. Aerosols implicated as a prime driver of twentieth-century North Atlantic climate variability. *Nature* **484**, 228-232 (2012).
8. Wolkovich, E.M., Cook, B.I., McLauchlan, K.K. & Davies, T.J. Temporal ecology in the Anthropocene. *Ecol. Lett.* **17**, 1365-1379 (2014).
9. Cook, B.I. & Wolkovich, E.M. Climate change decouples drought from early wine grape harvests in France. *Nature Climate Change* **6**, 715-719 (2016).
10. Navarro, J.A., et al. Amplification of Arctic warming by past air pollution reductions in Europe. *Nature Geoscience* **9**, 277-281 (2016).

11. Medhaug, I., Stolpe, M.B., Fischer, E.M. & Knutti, R. Reconciling controversies about the 'global warming hiatus'. *Nature* **545**, 41-47 (2017).
12. Risbey, J.S. & Lewandowsky, S. Climate science: The 'pause' unpacked. *Nature* **545**, 37-39 (2017).
13. Seidel, D. J. & J. R. Lanzante. An assessment of three alternatives to linear trends for characterizing global atmospheric temperature changes. *J. Geophys. Res.* **109**, D14108 (2004).
14. Solomon, S. et al. Climate Change 2007: The physical Science Basis (IPCC, 2007).
15. Cahill, N., Rahmstorf, S. & Parnell, A.C. Change points of global temperature. *Environmental Research Letters* **10**, p.084002 (2015).

Figure S1. Map of all studies (n=27) included in the analysis.

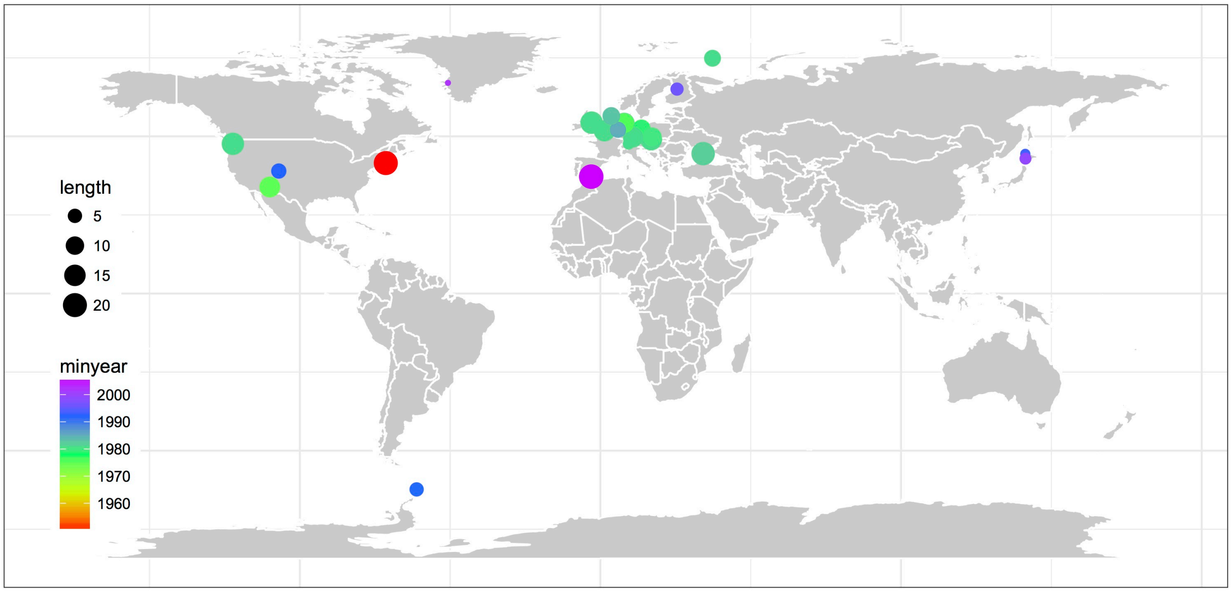

Figure S2. Estimating phenological change (days/year) using a hinge model and linear model for two interactions. (a) *Daphnia spp*. (in red) and *Perca fluviatillis* (in green) over the years 1969 to 2008 and (b) *Operophtera brumata* (in red) and *Parus major* (in green) over the years 1961 to 2008. Solid lines represent hinge model and dashed lines represent linear model. The dotted vertical line represents the inflection point of 1981 at year 0.

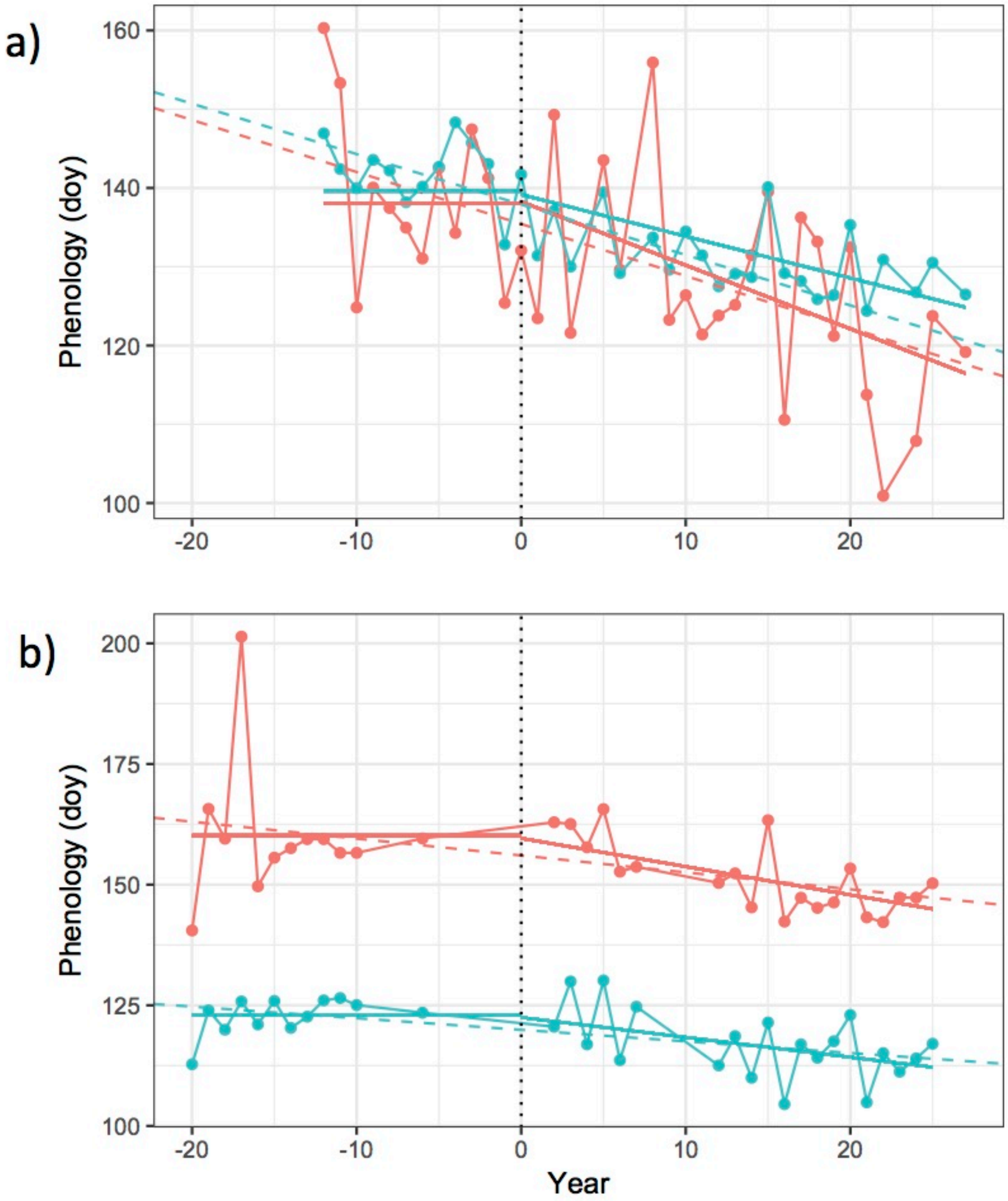

Figure S3. Phenological sensitivity to temperature (a) and temperature change across datasets (b). Raw data are shown as points in (a) and as time-series in (b). Colours represent different species in (a) and unique time-series in (b). Coloured lines in (a) represent estimates of temperature sensitivity for each species with the global slope in black (-4.78 days/°C) and 95% credible intervals in grey. For (b), the solid line represents the global slope (0.077 days/year) with 95% credible intervals in grey and the dotted vertical line represents the inflection point of 1981 at year 0.

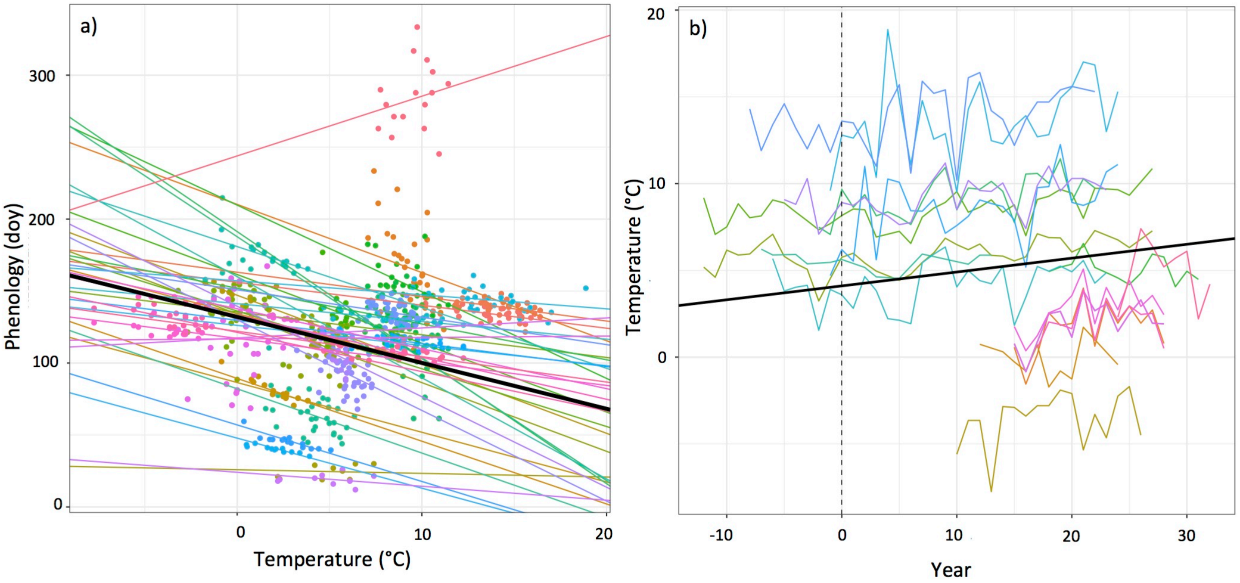

Table S1. List of species interactions for which temperature change and sensitivity were estimated (n=13 studies; 37 species). Bibliographic information for studies is in Appendix S3.

Type of temperature	Study reference	First species	Second species	Ecosystem type	Temperature metric
air	24	*Engraulis japonicus*	*Cerorhinca monocerata*	Aquatic	Mean temperature in March
water	21	*Phytoplankton spp.*	*Daphnia spp.*	Aquatic	Monthly mean for April-May
		Daphnia spp.	*Perca fluviatillis*	Aquatic	Monthly mean for April-May
water	19	*Phytoplankton spp.*	*Cyclops vicinus*	Aquatic	April temperature (measured monthly)
water	25	*Diatom spp.*	*Copepod spp.*	Aquatic	Monthly mean for January to March
water	18	*Copepod spp.*	*Pleurobrachia pileus*	Aquatic	Monthly mean for April-June
		Pleurobrachia pileus	*Beroe gracilis*	Aquatic	Monthly mean for April-June
air	22	*Epirrita autumnata*	*Poecile montanus*	terrestrial	Monthly mean for March-May
air	15	*Pygoscelis adeliae*	*Pygoscelis antarcticus*	terrestrial	Mean temperature in October
		Pygoscelis adeliae	*Pygoscelis papua*	terrestrial	Mean temperature in October
		Pygoscelis antarcticus	*Pygoscelis papua*	terrestrial	Mean temperature in October
air	14	*Bombus spp.*	*Corydalis ambigua*	terrestrial	Mean temperature in April
air	1	*Ficedula albicollis*	*Glis glis*	terrestrial	Mean temperature in May
		Parus caeruleus	*Glis glis*	terrestrial	Mean temperature in May
		Parus major	*Glis glis*	terrestrial	Mean temperature in May
		Sitta europaea	*Glis glis*	terrestrial	Mean temperature in May
air	17	*Acrocephalus arundinaceus*	*Acrocephalus scirpaceus*	terrestrial	Mean temperature in May
water	2	*Diatom spp.*	*Daphnia spp.*	aquatic	Monthly mean for March-May

		Diatom spp.	*Thermocyclops oithonoides*		Monthly mean for March-May
air	23	*Caterpillar spp.*	*Parus major*	terrestrial	Monthly mean for March- May
		Caterpillar spp.	*Parus caeruleus*	terrestrial	Monthly mean for March- May
air	3	*Pica pica*	*Clamator glandarius*	terrestrial	Mean temperature in February

Table S2. List of studies with temperature data that came from the same weather station location. Bibliographic information for studies is in Appendix S3.

Environment	Site	Study reference
Air	Oulu, Finland	22
		23
Water	Helgoland Roads, North Sea	25
		18

Table S3. List of studies with temperature data across multiple sites. Bibliographic information for studies is in Appendix S4.

Study reference	Number of sites
15	2
21	2
14	3

Appendix S3. Additional analyses

Proof of concept: Comparisons of our approach with original studies

To show that our approach was able to recapture estimates of phenological shift and general changes in synchrony, we included a brief comparison of our findings and the results from the original studies (Table S4 and Table S5).

Insensitivity of results to alternative inflection points

To test the robustness of our synchrony change results, we also used an inflection point of 1976 in our hinge model. As described in more detail in the main text, to estimate changes in synchrony over time, we used a two-level hierarchical hinge model for those species with greater than 4 years of data before 1976. Synchrony was estimated as described in the main text.

Results were near identical with 1976 as our inflection point (vs. 1981). Overall synchrony change was 0.51 days/decade (95% CI: -2.2, 1.1, n=54) and the magnitude of change 6.06 days/decade (95%CI: 5.2, 6.9, n=54).

Influence of methodological differences of studies on results

To evaluate the influence of key methodological differences across studies, we estimated the relationship between synchrony change and each of: first year of study, length of time series and frequency of phenological observation (daily, weekly), using linear models (n=54). Additionally, we evaluated the effect of time series length and first year of study on the magnitude of synchrony change and temperature, as well as the influence of two early and short studies from the 1950s on our estimate of the magnitude of synchrony change. Since there is a strong negative relationship between time series length and first year of study across the dataset (r=-0.55, r=-0.86 if you exclude the time series from the 1950s), we consider the influence of these factors individually.

Overall, we did not find any strong or consistent relationships between time series length, first year of study and our key response variables. While we did find a negative relationship between first year of study and the magnitude of synchrony change, this relationship was entirely driven by the two early studies from the 1950s (Figure S4, Table S6). Without the outliers, synchrony has shifted in magnitude by 5.9 days/decade (95%CI: 5.1, 6.8). Since the estimate of synchrony change is near identical with (6.1 days/decade; 95% CI: 5.2,7.0) and without those two outliers, the results in the main text are based on the full dataset. Finally, synchrony change was not influenced by the estimated effect of frequency of observation (overall synchrony change: -0.33 days/6-day change in frequency, 95% CI: -0.7,0.01; magnitude of synchrony change: 0.06 days/6-day change in frequency, 95% CI: -0.2, 0.3).

To evaluate the potential influence of latitudinal patterns in time series length and the first year of study, we evaluated latitudinal variation in synchrony change, first year of study and length of time series. We found that studies conducted at higher latitudes started more recently (Figure S4, Table S7). However, we did not find any latitudinal pattern in synchrony change (Table S7).

Influence of changes in population size on results

Given that phenology was typically measured as the first date of occurrence in our database, we measured the sensitivity of our results to sampling frequency (see previous subsection for more details) and potential changes in population size on our estimates of synchrony change (described here).

To evaluate the potential changes in population size on our estimates of synchrony change, we excluded studies that (1) explicitly mentioned they detected directional changes in population estimates (i.e., abundance or density) over time and (2) had used first dates of occurrences. Four studies consisting of 7 pair-wise interactions in total met these criteria. In these studies, species experienced either positive or negative changes in population size over time. Temporal increases in population size can lead to spurious trends towards earlier dates whereas temporal decreases in population size can lead to biases towards later dates (1)[1].

We found no evidence that such shifts, however, influenced our results. With these interactions excluded, the estimates of synchrony change were similar to the estimates presented in the main text. The magnitude of synchrony change was 6.0 days/decade (95%CI: 5.1 to 7.0) and the overall estimate of synchrony change (including both direction and magnitude) was 0.56 days/decade (95%CI: -2.3 to 1.2). Similar to the results presented in the main text, there was variation across interactions in the direction of shifts in synchrony: 55% (26/47) of the interacting species are shifting closer together, whereas 45% (21/47) of the interacting species are shifting further apart. Therefore, we believe that the use of first dates of occurrences in some of our studies did not impact our main conclusions.

---

[1] Miller-Rushing AJ, Høye TT, Inouye DW, Post E (2010) The effects of phenological mismatches on demography. *Philos. Trans. R. Soc. London B* 365*:*3177-3186.

Figure S4. Relationship between (a) the magnitude of synchrony change and first year of study (β=-0.15 days/decade per year (0.06SE)) and (b) first year of study and latitude (β=0.41 year/degree of latitude (0.15SE)). Shown is the predicted slope with a 95% confidence interval.

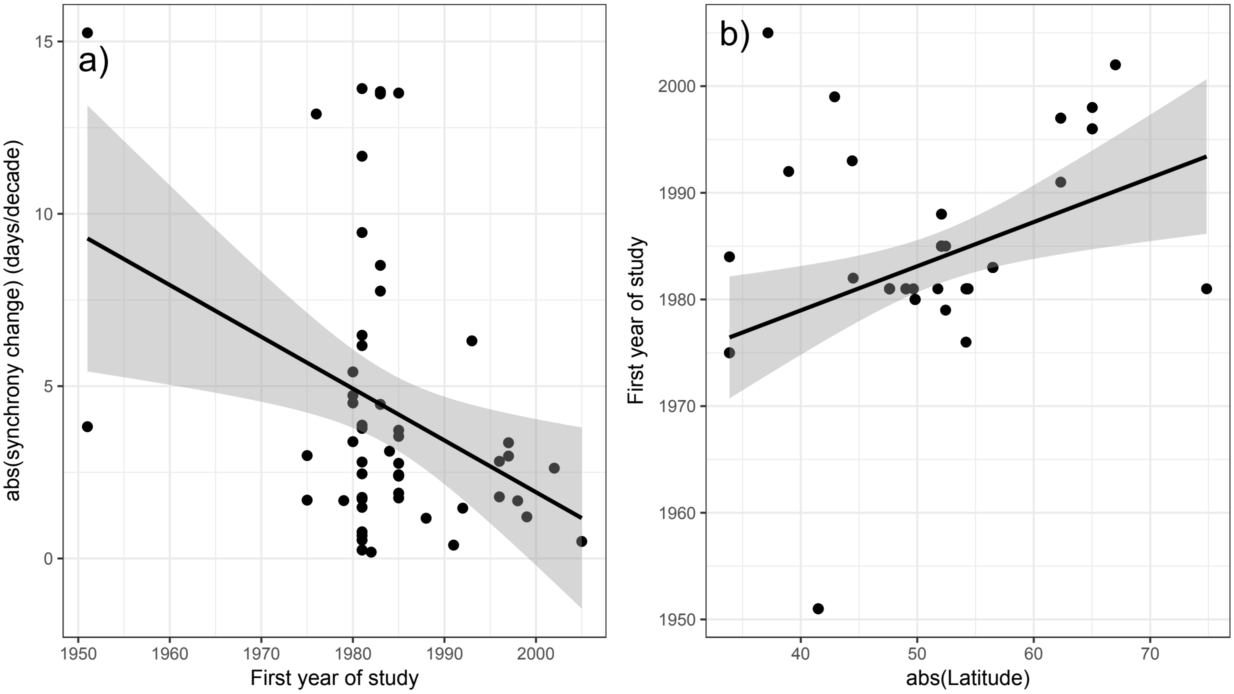

Table S4. A comparison of some phenological shift estimates between our paper and original studies. The Bayesian model we used adjusts estimates based on time-series length and variance of original data. All estimates are days per decade. Bibliographic information for studies is in Appendix S4.

Study reference (location)	Species	Time series	Standard deviation of phenological event dates	Stan estimate (95% credible interval)	Linear model estimate (SE)	Original study
5 (Netherlands)	*Parus major*[*]	1985-2005	4.41	-3.8 (-10.8, 3.2)	-3.7 (1.4)	-3.6
	Parus major[§]	1985-2004	4.37	-3.4 (-10.7, 3.7)	-3.1 (1.6)	-3.6
7 (UK)	*Parus major*	1961-2007	6.57	-4.3 (-8.5, -0.2)	-4.4 (1.0)	-3.0
4 (Czeck Republic)	*Parus major*	1961-2007	6.28	-3.1 (-7.7, 1.5)	-2.9 (1.3)	-1.7

[*] Interaction between *Parus major* and caterpillar

[§] Interaction between *Parus major* and *Accipiter nisus*

Table S5. A comparison of some synchrony change estimates between our paper and original studies. We chose studies that included a concluding statement about synchrony changes and paraphrased the wording. We note that direct comparisons of magnitude of synchrony change between our estimates and the original estimates are challenging because studies took different approaches in calculating synchrony changes. Moreover, we specifically did not evaluate whether synchrony changes for individual interactions were significant. Bibliographic information for studies is in Appendix S4.

Study reference	Interaction	Study conclusions	Our estimate of synchrony change (95%CI)
5	*Parus major*-caterpillar	Interval between events got closer by 3.8 days/decade	Events are closer by 2.4 days/decade (2.2, 2.6)
7	*Parus major*-caterpillar	No change in synchrony ($p>0.05$)	Events are closer by 1.8 days/year (1.7, 1.9)
4	*Parus major*-caterpillar	No change is synchrony ($p>0.05$)	Events are closer by 0.81 days/decade (0.68, 0.93)
23	*Parus major*-caterpillar	No change in synchrony*	Events are closer by 2.0 days/decade (1.8, 2.3)
21	*Daphnia*-phytoplankton	Decrease in number of days between events (convergence)	Events are closer by 1.9 days/decade (1.8, 2.0)

*Study compared overlap of events each year. For 8/16 years, there was a good match between events. No formal statistics were provided.

Table S6. Relationship between synchrony and temperature change, and methodological differences across studies. Synchrony and temperature change were estimated in days/year and °C/year, respectively. Values in bold are slope estimates where the 95% credible interval does not include zero.

Response	Predictor	Intercept (95%CI)	Slope coefficient (95%CI)	Sigma (95%CI)
Synchrony change	First year of study (n=54)	-0.1 (-0.3, 0.07)	0.02 (-1.3e-05, 0.03)	0.6 (0.5, 0.7)
	First year of study-without outliers (n=52)	-0.05 (-0.3, 0.1)	0.01 (-0.02, 0.03)	0.6 (0.5, 0.7)
	Length of time series (n=54)	-0.2 (-0.6, 0.3)	0.004 (-0.02, 0.03)	0.62 (0.5, 0.8)
Magnitude of synchrony change	First year of study (n=54)	0.5 (0.4, 0.6)	**-0.01 (-0.03, -0.003)**	0.4 (0.3, 0.5)
	First year of study-without two outliers (n=52)	0.5 (0.4, 0.6)	-0.01 (-0.03, 0.002)	0.4 (0.3, 0.5)
	Length of time series (n=54)	0.4 (0.06, 0.7)	0.002 (-0.01, 0.02)	0.4 (0.35, 0.5)
Magnitude of temperature change	First year of study (n=54)	0.1 (-0.1, 0.4)	-0.00001 (-1e-04, 9e-05)	0.003 (0.002, 0.004)
	Length of time series (n=54)	0.08 (0.075, 0.081)	3.2e-06 (-1.2e-04, 1.3e-04)	3.2e-03 (2.5e-03, 4.1e-03)

Table S7. Relationship between first year of study, length of time series, synchrony change and latitude of study. Synchrony change was estimated in days/year and the absolute value of latitude was taken. Values in bold are slope estimates where the 95% credible interval does not include zero.

Response	Predictor	Intercept (95%CI)	Slope coefficient (95%CI)	Sigma (95%CI)
First year of study (n=54)	abs(latitude)	-18.7 (-34.4, -3.8)	**0.42 (0.13, 0.72)**	9.04 (7.5, 11.03)
First year of study - Without two outliers (n=52)	abs(latitude)	-8.1 (-20.1, 3.8)	**0.23 (0.002, 0.46)**	6.9 (5.7, 8.4)
Length of time series (n=54)	abs(latitude)	25.39 (10.7, 40.0)	-0.07 (-0.35, 0.21)	8.61 (7.15, 10.5)
Synchrony change (n=54)	abs(latitude)	-0.39 (-1.5, 0.7)	0.01 (-0.01, 0.03)	0.62 (0.51, 0.75)
Magnitude of synchrony change (n=54)	abs(latitude)	0.35 (-0.38, 1.07)	0.002 (-0.01, 0.02)	0.42 (0.35, 0.52)

Appendix S4. Study and species information

Table S8. Data-series characteristics for interacting species in the phenology and synchrony change analyses. Bibliographic information for studies is in Appendix S4.

Study reference	Consumer	Resource	Interaction type	Habitat	First year of study	Number of years
8	*Mnemiopsis leidyi*	*Acartia tonsa*	predation	aquatic	1951	6
12	*Tortrix viridana*	*Quercus spp.*	herbivory	terrestrial	1982	7
16	*Selasphorus platycercus*	*Castilleja tenuiflora*	pollination	terrestrial	1984	19
	Selasphorus platycercus	*Delphinium nuttallianum*	pollination	terrestrial	1975	30
	Selasphorus platycercus	*Erythronium grandiflorum*	pollination	terrestrial	1975	28
22	*Poecile montanus*	*Epirrita autumnata*	herbivory	terrestrial	1996	14
24	*Cerorhinca monocerata*	*Engraulis japonicus*	predation	aquatic	1993	11
15	*Pygoscelis antarcticus*	*Pygoscelis adeliae*	competition	terrestrial	1997	10
	Pygoscelis papua	*Pygoscelis adeliae*	competition	terrestrial	1991	17
	Pygoscelis papua	*Pygoscelis antarcticus*	competition	terrestrial	1997	10
21	*Daphnia spp.*	*Phytoplankton spp.*	herbivory	aquatic	1969	37
	Perca fluviatillis	*Daphnia spp.*	predation	aquatic	1969	36
14	*Corydalis ambigua*	*Bombus spp.*	pollination	terrestrial	1999	14
4	*Parus major*	*Caterpillar spp.*	predation	terrestrial	1961	36
	Ficedula albicollis	*Caterpillar spp.*	predation	terrestrial	1962	34
	Caterpillar spp.	*Quercus robur*	herbivory	terrestrial	1961	34
7	*Parus major*	*Operophtera brumata*	predation	terrestrial	1961	32
26	*Daphnia pulicaria*	*Diatom spp.*	herbivory	aquatic	1977	25
13	*Rangifer tarandus*	*Plant spp.*	herbivory	terrestrial	2002	10
2	*Daphnia spp.*	*Diatom spp.*	herbivory	aquatic	1979	25
	Thermocyclops oithonoides	*Diatom spp.*	herbivory	aquatic	1985	16
10	*Daphnia hyalina-galeata*	*Asterionella spp.*	herbivory	aquatic	1956	26
11	*Syrphid spp.*	*Plant spp.*	pollination	terrestrial	1992	19
19	*Cyclops vicinus*	*Phytoplankton spp.*	herbivory	aquatic	1974	14
20	*Mnemiopsis leidyi*	*Acartia hudsonica*	predation	aquatic	1951	8
25	*Copepod spp.*	*Diatom spp.*	herbivory	aquatic	1975	30
27	*Daphnia spp.*	*Diatom spp.*	herbivory	aquatic	1976	27
	Keratella cochlearis	*Diatom spp.*	herbivory	aquatic	1963	32
	Leptodiaptomus	*Diatom spp.*	herbivory	aquatic	1964	37

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1	*Glis glis*	*Ficedula albicollis*	predation	terrestrial	1980	26
	Glis glis	*Parus caeruleus*	predation	terrestrial	1980	26
	Glis glis	*Parus major*	predation	terrestrial	1980	26
	Glis glis	*Sitta europaea*	predation	terrestrial	1980	26
9	*Rissa tridactyla*	*Guillemots spp.*	competition	terrestrial	1973	23
17	*Acrocephalus scirpaceus*	*Acrocephalus arundinaceus*	competition	terrestrial	1973	29
18	*Pleurobrachia pileus*	*Copepod spp.*	predation	aquatic	1976	27
	Beroe gracilis	*Pleurobrachia pileus*	predation	aquatic	1976	27
5	*Accipiter nisus*	*Ficedula hypoleuca*	predation	terrestrial	1985	16
	Accipiter nisus	*Parus ater*	predation	terrestrial	1985	16
	Accipiter nisus	*Parus caeruleus*	predation	terrestrial	1985	16
	Accipiter nisus	*Parus major*	predation	terrestrial	1985	16
	Ficedula hypoleuca	*Caterpillar spp.*	predation	terrestrial	1985	19
	Parus ater	*Caterpillar spp.*	predation	terrestrial	1985	20
	Parus caeruleus	*Caterpillar spp.*	predation	terrestrial	1985	20
	Parus major	*Caterpillar spp.*	predation	terrestrial	1985	20
	Caterpillar spp.	*Quercus robur*	herbivory	terrestrial	1988	17
23	*Parus major*	*Caterpillar spp.*	herbivory	terrestrial	1996	16
	Parus caeruleus	*Caterpillar spp.*	herbivory	terrestrial	1998	14
3	*Clamator glandarius*	*Pica pica*	parasitism	terrestrial	2005	9
6	*Alca torda*	*Ammodytes marinus*	predation	aquatic	1983	24
	Fratercula arctica	*Ammodytes marinus*	predation	aquatic	1983	24
	Phalacrocorax aristotelis	*Ammodytes marinus*	predation	aquatic	1983	24
	Rissa tridactyla	*Ammodytes marinus*	predation	aquatic	1983	24
	Uria aalge	*Ammodytes marinus*	predation	aquatic	1983	24

Bibliographic information for studies used in analyses.

1. Adamík, P., Král, M. Climate- and resource-driven long-term changes in dormice populations negatively affect hole-nesting songbirds. *J. Zool.* ***275***, 209-215 (2008).
2. Adrian, R., Wilhelm, S., Gerten, D. Life-history traits of lake plankton species may govern their phenological response to climate warming. *Glob. Change Biol.* ***12***, 652-661 (2006).
3. Avilés, J., Molina-Morales, M., Martinez, J. Climatic effects and phenological mismatch in cuckoo-host interactions: a role for host phenotypic plasticity in laying date? *Oikos.* ***123***, 993-1002 (2014).
4. Bauer, Z. *et al*. Changing climate and the phenological response of great tit and collared flycatcher populations in floodplain forest ecosystems in Central Europe. *Int. J. Biometeorol.* ***54***, 99-111 (2010).
5. Both, C., van Asch, M., Bijlsma, R., van den Burg, A., Vissier, M. Climate change and unequal phenological changes across four trophic levels: constraints or adaptions? *J. Anim. Ecol.* ***78***, 73-83 (2009).
6. Burthe, S. *et al.* Phenological trends and trophic mismatch across multiple levels of a North Sea pelagic food web. *Mar. Ecol. Prog. Ser.* ***454***, 119-133 (2012).
7. Charmantier, A. *et al*. Adaptive Phenotypic Plasticity in Response to Climate Change in a Wild Bird Population. *Science.* ***320***, 800-803 (2008).
8. Costello, J., Sullivan B, Gifford D. A physical-biological interaction underlying variable phenological responses to climate change by coastal zooplankton. *J. Plankton Res.* ***28***, 1099-1105 (2006).
9. Durant, J. M., Krasnov, K. V., Nikolaeva, N. K., Stenseth, N. C. Within and between species competition in a seabird community: statistical exploration and modeling of time-series data. *Oecologia.* ***169***, 685-694 (2012).
10. George, D. The effect of nutrient enrichment and changes in the weather on the abundance of *Daphnia* in Esthwaite Water, Cumbria. *Freshwater Biol.* ***57***, 360-372 (2012).
11. Iler, A. M. *et al*. Maintenance of temporal synchrony between syrphid flies and floral resources despite differential phenological responses to climate. *Glob. Change Biol.* ***19***, 2348-2359 (2013).
12. Ivashov, A. V., Boyko, G. E., Simchuk, A. P. The role of host plant phenology in the development of the oak leafroller moth, *Tortrix viridana* L. (Lepidoptera: Tortricidae). *Forest Ecol. Manag.* ***157***, 7-14 (2002).
13. Kerby, J. T., Post, E. Advancing plant phenology and reduced herbivore production in a terrestrial system associated with sea ice decline. *Nat. Commun.* ***4***, 1-6 (2013).
14. Kudo G., Ida, T. Early onset of spring increases the phenological mismatch between plants and pollinators. *J. Ecol.* ***94***, 2311-2320 (2013).
15. Lynch, H. J., Fagan, W. F., Naveen, R., Trivelpiece, S. G., Trivelpiece, W. Z. Differential advancement of breeding phenology in response to climate may alter staggered breeding among sympatric pygoscelid penguins. *Mar. Ecol. Prog. Ser.* ***454***, 135-145 (2012).
16. McKinney, A. *et al*. Asynchronous changes in phenology of migrating Broad-tailed Hummingbirds and their early-season nectar resources. *Ecol. Appl.* ***93***, 1987-1993 (2012).
17. Schaefer, T., Ledebur, G., Beier, J., Leisler, B. Reproductive responses of two related coexisting songbird species to environmental changes: global warming, competition, and population sizes. *J. Ornithol.* ***147***, 47-56 (2006).

18. Schlüter, M. *et al*. Phenological shifts of three interacting zooplankton groups in relation to climate change. *Global Change Biol.* ***16***, 3144-3153 (2010).
19. Seebens, H., Einsle, U., Straile, D. Copepod life cycle adaptations and success in response to phytoplankton spring bloom phenology. *Glob. Change Biol.* ***15***, 1394-1404 (2009).
20. Sullivan, B., Costello, D., Van Keuren, D. Seasonality of the copepods *Antarctica hudsonica* and *Acartia tonsa* in Narragansett Bay, RI, USA during a period of climate change. *Estuar. Cost. Shelf Sci*. ***73***, 259-267 (2007).
21. Thackeray, S. J. et al. Food web de-synchronization in England's largest lake: an assessment based on multiple phenological metrics. *Glob. Change Biol.* ***19***, 3568-3580 (2013).
22. Vatka, E., Orell, M., Rytkönen, S. Warming climate advances breeding and improves synchrony of food demand and food availability in a boreal passerine. *Glob. Change Biol.* ***17***, 3002-3009 (2011).
23. Vatka, E., Rythkönen, S., Orell, M. Does the temporal mismatch hypothesis match in boreal populations? *Oecologia.* ***176***, 595-605 (2014).
24. Watanuki, Y., Ito, M., Deguchi, T., Minobe, S. Climate-forced seasonal mismatch between the hatching of rhinoceros auklets and the availability of anchovy. *Mar. Ecol. Prog. Ser.* ***393***, 259-271 (2009).
25. Wiltshire, K. *et al*. Resilience of North Sea phytoplankton spring bloom dynamics: An analysis of long-term data at Helgoland Roads. *Limnol. Oceanogr.* ***53***, 1294-1302 (2008).
26. Winder, M., Schindler, D. E. Climate change uncouples trophic interactions in an aquatic ecosystem. *Ecology*. ***85***, 2100-2106 (2004).
27. Winder, M., Schindler, D. E. Climate effects on the phenology of lake processes. *Glob. Change Biol.* ***10***, 1844-1856 (2004).

Appendix S5. Stan code

Model 1. Model used to estimate change in phenology, synchrony and temperature, and temperature sensitivity. We used default priors on all parameters (i.e. unconstrained priors: uniform(-∞,∞), except parameters declared with a lower bound of zero which were given the prior: uniform(0,∞)).

```
//Two-level partially pooling slope model

data{
 int<lower=0> N;                    //Level 1: Number of observations
 int<lower=0> Nspp;                 //Level 2: Number of groups (ex: species)
 int species[N];           //Grouping factor identity (e.g. species)

 vector[N] x;
 real y[N];
}

parameters{
 real mu_b;                         //overall slope
 real<lower=0> sigma_y;             //measurement error, noise etc. (overall sd)

 real a[Nspp];             //the intercept for each group
 real b[Nspp];             //the slope for each group
 real<lower=0> sigma_b;             //variation of slope among groups; [sd of random effects]
}

transformed parameters{
 real ypred[N];

for (i in 1:N){
          ypred[i]=a[species[i]]+b[species[i]]*x[i];
 }
}

model{
 b~normal(mu_b, sigma_b);
 y~normal(ypred, sigma_y);
}
```

Model 2. Model used to estimate the overall response in the magnitude of synchrony change. We used default priors on all parameters (i.e. unconstrained priors: uniform(-∞,∞), except parameters declared with a lower bound of zero which were given the prior: uniform(0,∞)).

```
//Two-level intercepts only model with truncated distribution

data{
 int<lower=0> N;          //Level 1: Number of observations
 int<lower=0> Nint;       //Level 2: Number of groups (e.g. interactions)
 int species[N];          //Grouping factor identity

 real y[N];
}

parameters{
 real<lower=0> mu_a;               //overall intercept
 real<lower=0> sigma_y;            //measurement error, noise etc. (overall sd)
 real<lower=0> a[Nint];            //the intercept for each interaction
 real<lower=0> sigma_a;            //variation of intercepts among interactions;
}

transformed parameters{
 real ypred[N];

for (i in 1:N){
          ypred[i]<-a[species[i]];
 }
}

model{
 a~normal(mu_a, sigma_a);
 y~normal(ypred, sigma_y);
}
```

Model 3. Model used to estimate the relationship between temperature change and change in phenology across interactions (i.e. covariate models). We used default priors on all parameters (i.e. unconstrained priors: uniform(-∞,∞), except parameters declared with a lower bound of zero which were given the prior: uniform(0,∞)).

```
//Two-level partially pooling intercept model where slopes do not vary

data{
 int<lower=0> N;           //Level 1: Number of observations
 int<lower=0> Nspp;    //Level 2: Number of groups
 int species[N];             // Grouping factor identity

 vector[N] x;
 real y[N];
}

parameters{
 real mu_a;                    //overall intercept
 real mu_b;                    //overall slope
 real<lower=0> sigma_y;          //measurement error, noise etc. (overall sd)
 real a[Nspp];               //the intercept for each group
 real<lower=0> sigma_a;          //variation of intercept among groups;
}

transformed parameters{
 //Individual mean
 real ypred[N];

//Individual mean
for (i in 1:N){
          ypred[i]<-a[species[i]]+mu_b*x[i];
 }
}

model{
 a~normal(mu_a, sigma_a);
 y~normal(ypred, sigma_y);
}
```

Model 4. Model used to estimate the relationship between temperature change and change in synchrony across interactions (i.e. covariate models). We used default priors on all parameters (i.e. unconstrained priors: uniform(-∞,∞), except parameters declared with a lower bound of zero which were given the prior: uniform(0,∞)).

```
//Two-level partially pooling intercept model where slopes do not vary

data{
 int<lower=0> N;          //Level 1: Number of observations
 int<lower=0> Nspp;       //Level 2: Grouping factor
 int species[N];          //Grouping factor identity

 vector[N] x;
 real y[N];
}

parameters{
 real<lower=0> mu_a;  //overall intercept
 real mu_b;           //overall slope
 real<lower=0> sigma_y;          //measurement error, noise etc. (overall sd)
 real<lower=0> a[Nspp];          //the intercept for each group
 real<lower=0> sigma_a;          //variation of intercept among groups; [sd]
}

transformed parameters{
 real ypred[N];

for (i in 1:N){
          ypred[i]<-a[species[i]]+mu_b*x[i];
 }
}

model{
 a~normal(mu_a, sigma_a);
 y~normal(ypred, sigma_y);
}
```