Appendix S1 Long-term phenological data sets (>10 years in length) ending before 1990. These were not used in the present study but could provide useful baseline data for future studies.

Country	Taxa	No. of species	Years	Phenophases	Reference
Australia	Plant	49	1864-1885	Flowering, leafing, fruiting, harvest	Chambers & Keatley 2010
Australia	Plant	4	1940-1962	Flowering	Keatley et al. 2002
Australia	Aves	1	1975-1986	Laying dates	Olsen & Olsen 1989
New Zealand	Plant	1	1965-1988	Seed fall dates (monthly)	Allen & Platt 1990
New Zealand	Plant	7	1970-1989?	Flowering	Atkins & Morgan 1990
New Zealand	Aves	1	1943-1953	Arrival dates	Cunningham 1953
New Zealand	Aves	1	1970-1986	Laying dates	Flux 1987
New Zealand	Aves	1	1971-1982	Laying, fledging dates	Imber 1987
New Zealand	Aves	1	1936-1954	Laying dates	Richdale 1957
New Zealand	Aves	1	1954-1964	Laying, hatching dates	Williams 1967
Antarctica	Aves	1	1962-1975	Arrival, laying dates	Ainley et al. 1983
Sub-Antarctic	Mammalia	1	1950-1959	Peak haul out dates	Hindell & Burton 1988
Sub-Antarctic	Mammalia	1	1949-1979	First, last sighting	Rounsevell & Eberhard 1980

Ainley D, Russell J, Jenouvrier S, Woehler E, Lyver POB, Fraser WR, *et al.* (2010) Antarctic penguin response to habitat change as Earth's troposphere reaches 2° C above preindustrial levels. Ecol Monogr 80: 49-66.

Allen RB, Platt K (1990) Annual seedfall variation in *Nothofagus solandri* (Fagaceae), Canterbury, New Zealand. Oikos 57: 199-206.

Atkins T, Morgan E (1989) Modelling the effects of possible climate change scenarios on the phenology of New Zealand fruit crops. II International Symposium on Computer Modelling in Fruit Research and Orchard Management.

Chambers LE, Keatley MR (2010) Phenology and climate - early Australian botanical records. Aust J Bot 58: 473-484.

Cunningham JM (1953) The dates of arrival of the Shining-bronze Cuckoo in New Zealand in 1952. Notornis 5: 192-195.

Flux JEC (1987) Drift in laying dates of starlings *Sturnus vulgaris*. Ornis Scand 18: 146-148.

Hindell MA, Burton HR (1988) Seasonal haul-out patterns of the southern elephant seal (*Mirounga leonina* L.), at Macquarie Island. Journal of Mammalogy 69: 81-88.

Imber M (1987) Breeding ecology and conservation of the black petrel (*Procellaria parkinsoni*). Notornis 34: 19-39.

Keatley MR, Fletcher TD, Hudson IL, Ades PK (2002) Phenological studies in Australia: potential application in historical and future climate analysis. Int J Clim 22: 1769-1780.

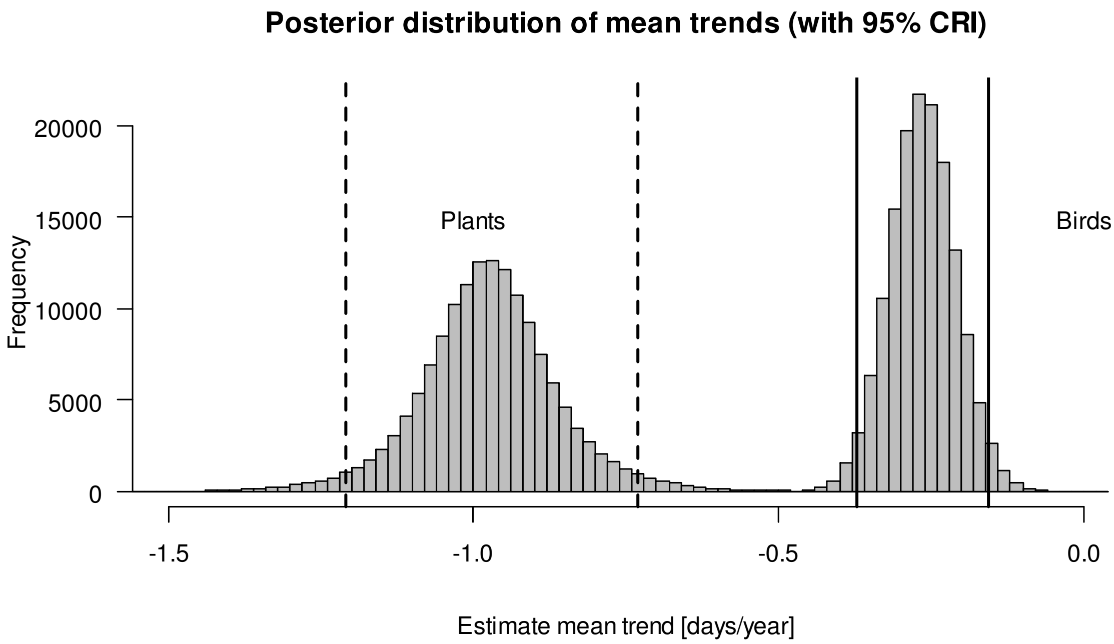
Olsen P, Olsen J (1989) Breeding of the Peregrine Falcon *Falco peregrinus*. II. Weather, Nest Quality and the Timing of Egg Laying. Emu 89: 1-5.

Rounsevell D, Eberhard I (1980) Leopard Seals, *Hyrurga leptonyx* (Pinnipedia), at Macquarie Island from 1949 to 1979. Wildl Res 7: 403-415.

Williams G (1967) The breeding biology of California quail in New Zealand. Proc N Z Ecol Soc 14: 88-99.

Appendix S2. WinBUGS code used to estimate mean trends in phenology across plants and birds together with a plot of the posterior distribution for means and 95% credible intervals. We used non-informative priors N(0, 10^6) for the means and U(0, 100) for the standard errors, and ran three chains of length 1.2 million of which the first 200000 samples were discarded as burn-in and inference was drawn from the rest of the chains after thinning by a factor of 20. The model converged according to the R-hat statistic which was below 1.01 for all parameters, and we also visually inspected the chains.

```
model {

# The data are mean trends per year for each time series ('trend.estimate')
#        and their standar errors ('se.estimate')
# Plants: phylum = 1; birds: phylum = 0
# The parameter 'beta' measures the difference between plants and birds
# time.spand is the logarithm of the length of the time series in years, rescaled to mean = 0
and unit sd
# beta.ts is the effect of time span on phenology trend

# Priors
mu.birds ~ dnorm(0, 0.0000001)         # mean trend for birds
beta ~ dnorm(0, 0.0000001)         # difference in trend between plants and birds
beta.ts ~ dnorm(0, 0.0000001)       # coefficient for time span
tau.series <- pow(sd.series, -2)
sd.series ~ dunif(0, 100)      # Among series heterogeneity
tau.species <- pow(sd.species, -2)
sd.species ~ dunif(0,100)

# Likelihood
for (i in 1:nspecies)  # for each of the n species
  {
   spp[i] ~ dnorm(0, tau.species)  # random species effect
  }
for (i in 1:n){
  trend.estimate[i] ~ dnorm(mu[i], tau.error[i])
  mu[i] ~ dnorm(mu.a[i], tau.series)
  mu.a[i] <- mu.birds + beta * phylum[i] + beta.ts * time.span[i] + spp[species[i]]
  tau.error[i] <- pow(se.estimate[i], -2)
}

# Derived quantities
mu.plants <- mu.birds + beta         # mean trend for plants

} # end model
```



Posterior distribution of mean trends (with 95% CRI)
Plants
Birds
Frequency
20000
15000
10000
5000
0
-1.5
-1.0
-0.5
0.0
Estimate mean trend [days/year]

Appendix S3. Papers with long-term (at least 10 years) phenological data used in the analyses.

Alencar JC (1994) Fenologia de cinco espécies arbóreas tropicais de Sapotaceae correlacionada a variáveis climáticas na Reserva Ducke, Manus, AM. *Acta Amazon*, 24, 161-182.

Alencar JC, Almeida RA,Fernandes N (1979) Fenologia de espécies florestais em floresta tropical úmida de terra firme na Amazônia Central. *Acta Amazon*, 9, 163-198.

Allen RB, Mason NWH, Richardson SJ, Platt KH (2011a) Synchronicity, periodicity and bimodality in inter-annual tree seed production along an elevation gradient. *Oikos*, 121, 367-376.

Allen WJ, Helps FW, Molles LE (2011b) Factors affecting breeding success of the Flea Bay white-flippered penguin (*Eudyptula minor albosignata*) colony. *N Z J Ecol*, 35, 199-208.

Altwegg R, Broms K, Erni B, Barnard P, Midgley GF, Underhill LG (2012) Novel methods reveal shifts in migration phenology of barn swallows in South Africa. *Proc R Soc B*, 279, 1485-1490.

Armstrong DP, Davidson RS, Dimond WJ, Perrott JK, Castro I, Ewen JG*, et al.* (2002) Population dynamics of reintroduced forest birds on New Zealand islands. *J Biogeogr*, 29, 609-621.

Barbraud C, Weimerskirch H (2006) Antarctic birds breed later in response to climate change. *PNAS*, 103, 6248-6251.

Barlow ML, Dowding JE (2002) Breeding biology of Caspian terns (*Sterna caspia*) at a colony near Invercargill, New Zealand. *Notornis*, 49, 76-90.

Baylis AMM, Zuur AF, Brickle P, Pistorius PA (2012) Climate as a driver of population variability in breeding Gentoo Penguins *Pygoscelis papua* at the Falkland Islands. *Ibis*, 154, 30-41.

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Boersma PD, Rebstock GA (2009) Intraclutch egg-size dimorphism in Magellanic Penguins (*Spheniscus* magellanicus): adaptation, constraint, or noise? *The Auk,* 126, 335-340.

Bull CM, Burzacott D (2006) Changes in climate and in the timing of pairing of the Australian lizard, *Tiliqua rugosa*: a 15-year study. *J. Zool*, 256, 383-387.

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Chambers LE (2005) Migration dates at Eyre Bird Observatory: links with climate change? *Clim Res*, 29, 157-165.

Chambers LE (2008) Trends in timing of migration of south-western Australian birds and their relationship to climate. *Emu*, 108, 1-14.

Chambers LE (2010) Altered timing of avian movements in a peri-urban environment and its relationship to climate. *Emu*, 110, 48-53.

Chambers LE, Gibbs H, Weston MA, Ehmke GC (2008) Spatial and temporal variation in the breeding of Masked Lapwings (*Vanellus miles*) in Australia. *Emu*, 108, 115-124.

Chambers LE, Beaumont LJ, Hudson IL (*accepted*) Continental scale analysis of bird migration timing: influences of climate and life history traits - a generalised mixture model clustering and discriminant approach. *International Journal of Biometeorology.*

Crawford R, Dyer B, Cooper J, Underhill L (2006) Breeding numbers and success of Eudyptes penguins at Marion Island, and the influence of mass and time of arrival of adults. *CCAMLR Science*, 13, 175-190.

Cullen J, Chambers L, Coutin P, Dann P (2009) Predicting onset and success of breeding in little penguins *Eudyptula minor* from ocean temperatures. *Mar Ecol Prog Ser*, 378, 269-278.

Darbyshire R, Webb L, Goodwin I, Barlow EWR (*in press*) Evaluation of recent trends in Australian pome fruit spring phenology. *Int J Biometeorol*, DOI 10.1007/s00484-012-0567-1

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Dunlop J, Surman C (2012) The role of foraging ecology in the contrasting responses of two dark terns to a changing ocean climate. *Mar Ornithol*, 40, 105-110.

Durant JM, Crawford RJM, Wolfaardt AC, Agenbag K, Visagie J, Upfold L*, et al.* (2010) Influence of feeding conditions on breeding of African penguins- importance of adequate local food supplies. *Mar Ecol Prog Ser*, 420, 263-271.

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Appendix S4. Assessing the impact of the length of the data series on the likelihood of detecting a significant trend towards earlier or later phenologies.

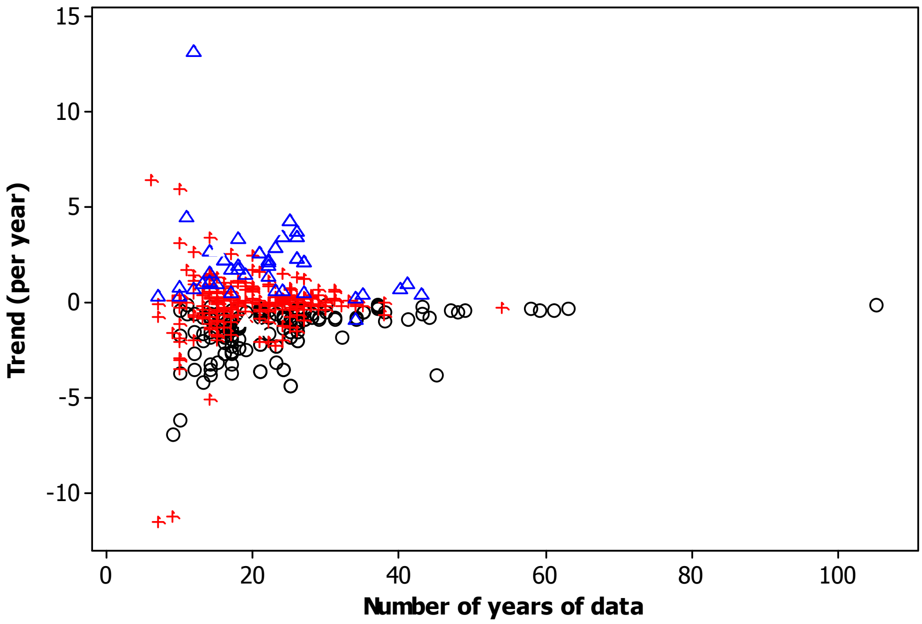


Figure 1. Strength of trend (days per year) versus number of years used to calculate the trend (triangles significantly earlier, circles significantly later, + non-significant trends).

There was no impact of the length of the data series or the year in which the data series commenced on the likelihood of detecting an earlier or later trend over time (Sections S4.1 and S4.2, respectively). However the length of the data series clearly influenced the magnitude of the trend observed (Figure 1; Section S4.3), with the start year having only a marginal effect. In general, the magnitude of the phenological trend was greater for shorter data series and for those that started more recently.

All analyses were conducted using the Minitab Statistical Software (Release 14, Minitab Inc., www.minitab.com)

S4.1 Ordinal Logistic Regression: Influence of number of years of data on significance of trend

Here we use ordinal logistic regression to perform a logistic regression on an ordinal response variable, representing the significance and direction of the phenological trend. This technique is designed to deal with ordinal variables, i.e. categorical variables that have three or more possible levels with a natural ordering, in our case earlier, no change and later. Iterative-reweighted least squares algorithm is used to obtain maximum likelihood estimates of the parameters. The values labelled Const(1) and Const(2) are estimated intercepts for the logits of the cumulative probabilities of 'earlier', and for 'no change', respectively. Because the cumulative probability for the last response value is 1, there is not need to estimate an intercept for 'later'.

Link Function: Logit $g(\chi) = \log_e(\chi / (1 - \chi))$

where χ is the cumulative probability up to and including the relevant category of the response.

Response Information:

Variable: SIGN, defined as -1 for significantly earlier trends, 1 for significantly later trends and 0 for non-significant trends.

Value	Count
-1 (Earlier)	157
0 (No change)	315
1 (Later)	66
Total	538

NOTE: 538 cases were used; 670 cases contained missing values

Logistic Regression Table:

Predictor	Coefficient	SE Coeff.	Z	P-value	Odds Ratio	95% CI
Const(1)	-1.2408	0.2120	-5.85	<0.001		
Const(2)	1.6261	0.2218	7.33	<0.001		
No. years of data	0.0163	0.0085	1.92	0.055	1.02	(1.00, 1.03)

Log-Likelihood = -498.759
Test that all slopes are zero: G = 3.402, DF = 1, P-Value = 0.065

Goodness-of-Fit Tests

Method	Chi-square	df	P-value
Pearson	136.90	93	0.002
Deviance	136.58	93	0.002

Measures of Association: (Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	40585	50.3	Somers' D	0.06
Discordant	35927	44.6	Goodman-Kruskal Gamma	0.06
Ties	4095	5.1	Kendall's Tau-a	0.03
Total	80607	100.0		

S4.2 Ordinal Logistic Regression: Influence of number of years of data and start year

See S4.1 for analysis details and variable definitions.

Link Function: Logit

Response Information: Variable: SIGN

Value	Count
-1 (Earlier)	156
0 (No change)	315
1 (Later)	66
Total	537

NOTE: 537 cases were used; 671 cases contained missing values

Logistic Regression Table

Predictor	Coefficient	SE Coeff.	Z	P-value	Odds Ratio	95% CI
Const(1)	-6.0351	12.1757	-0.50	0.620		
Const(2)	-3.1622	12.1727	-0.26	0.795		
No. years of data	0.0185	0.0095	1.95	0.052	1.02	(1.00, 1.04)
Start year	0.0024	0.0061	0.39	0.695	1.00	(0.99, 1.01)

Log-Likelihood = -497.323
Test that all slopes are zero: G = 3.805, DF = 2, P-Value = 0.149

Goodness-of-Fit Tests

Method	Chi-square	df	P-value
Pearson	629.172	530	0.002
Deviance	621.278	530	0.004

Measures of Association: (Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	41979	52.3	Somers' D	0.08
Discordant	35808	44.6	Goodman-Kruskal Gamma	0.08
Ties	2439	3.0	Kendall's Tau-a	0.04
Total	80226	100.0		

S4.3 Regression: Magnitude of trend and years of data

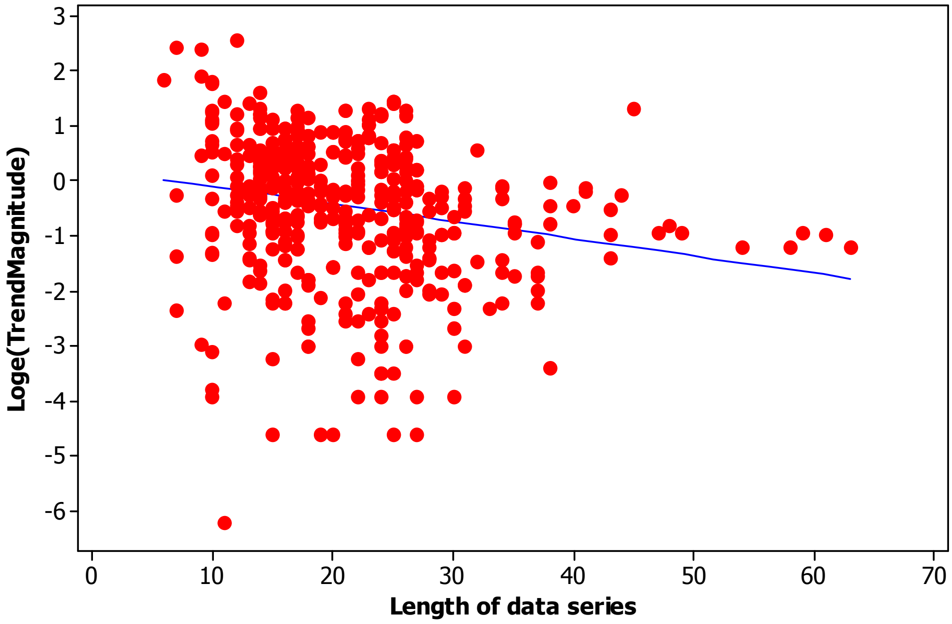
All trends (significant or not) were transformed to positive values only and natural logarithm taken. The data series of length 105 years is an outlier and was removed.

The regression equation is
Loge(TrendMagnitude) = 0.2239 - 0.03160 (No.Yrs of Data)

S = 1.27115   R-Sq = 4.2%   R-Sq(adj) = 4.0%

Analysis of Variance

Source	df	SS	MS	F	P-value
Regression	1	32.875	32.876	20.35	<0.001
Error	462	746.511	1.616		
Total	463	779.386			



Including year the observations started:

The regression equation is
Loge(TrendMagnitude) = - 17.1 - 0.0270 (No. yrs data) + 0.00873 (Start yr)

463 cases used, 745 cases contain missing values

Predictor	Coefficient	SE Coef.	T	P-value
Constant	-17.107	8.281	-2.07	0.039
No. yrs data	-0.027	0.007	-3.63	<0.001
Start year	0.009	0.004	2.10	0.037

S = 1.26410   R-Sq = 5.3%   R-Sq(adj) = 4.9%

Appendix S5. Breakdown of number of observations by family and species, based on the full data set (1208 times series).

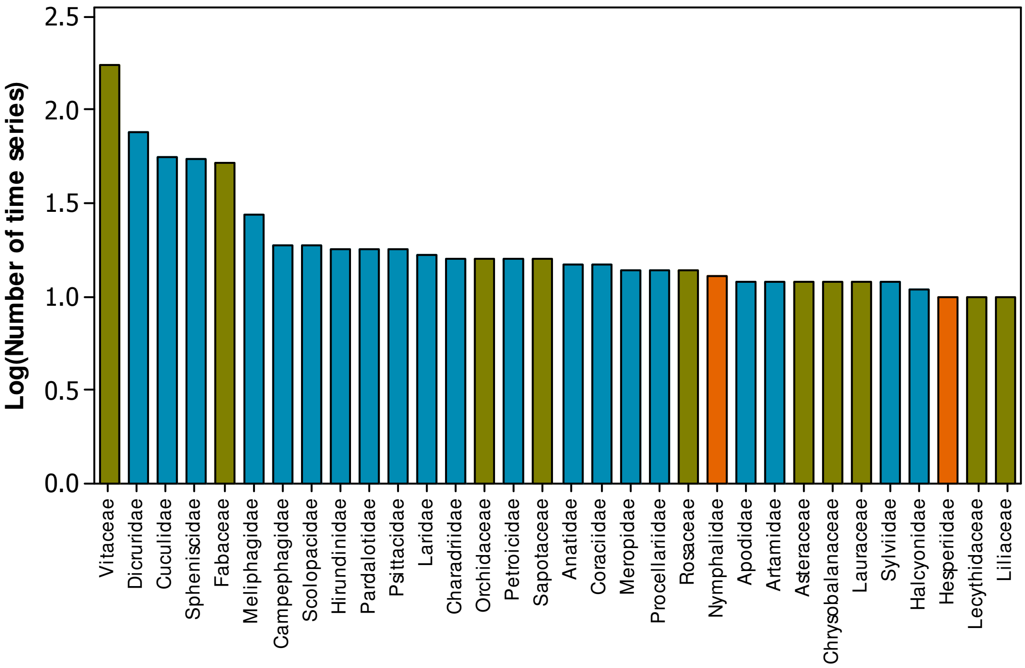


Figure S5.1. Number of observations for each family (restricted to those with at least 10 observations). Plant species represented by green bars, birds by blue bars and arthropods by orange bars.

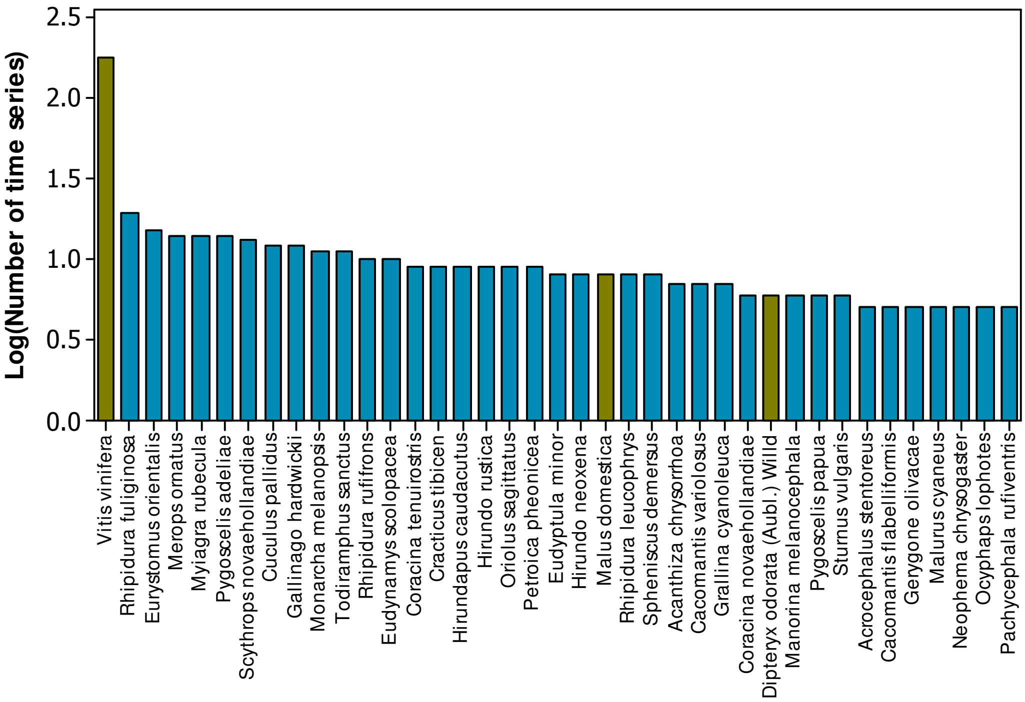


Figure S5.2. Number of observations for each species (restricted to those with at least 5 observations). Plant species represented by green bars and birds by blue bars.

Appendix S6 Summary of datasets and their trends using details of the phenophase

Table S6.1. Breakdown of long-term phenological data sets (>10 years in length) by phenophase. Number of datasets covers all datasets that have the same type of phenophase observed. Mean trends are only calculated if at least 5 datasets in this category, S.E. is the standard error of the mean trend estimate and N is the number of datasets in this category that reported a trend estimate.

Taxa	Phenophase	Details of phenophase	Number of datasets	Mean trend (S.E.; N)
Arthropoda	Migration	First arrival date	2	-
	Emergence	First emergence date	1	-
		First flight date	157	0.243 (0.180; 25)
		First sighting date	1	-
Aves	Breeding	Age at first breeding	2	-
		First laying date	20	-1.693 (0.635; 5)
		First laying date & mean laying date	3	-
		Mean first laying date	1	-
		Mean laying date	13	- (-; 4)
		Median laying date	3	-
		Modal egg date	1	-
		Laying date	21	- (-; 3)
		Last laying date	3	-
		Timing of nesting	3	-
		Mean breeding timing	4	-
		Timing of breeding	1	-
		Incubation date	1	-
		Number of pairs incubating	1	-
		Hatching date	83	0.125 (0.101; 77)
		Creching date	1	-
		First chick banding date	1	-
		Mean chick banding date	1	-
		Fledging date	2	-
		Fledging departure date	2	-
		Mean fledging date	2	-
		Timing of fledging	1	-
		Season length	1	-
	Migration	Arrival date	3	-
		Arrival date: females	2	-
		Arrival date: males	2	-
		Arrival: proportion of checklist	3	-
		First arrival date	200	-0.305 (0.106; 179)
		Last departure date	131	0.061 (0.176; 120)

		Departure: proportion of checklist	3	-
		Departure: female	1	-
		Departure: male	1	-
		Peak abundance date	27	0.038 (0.755; 27)
		Season length	9	
	Moult	Moult peak date	3	-
Mammalia	Breeding	Birth date	1	-
	Haulout	Date maximum number adults	1	-
	Migration	Abundance timing	2	-
Phytoplankton	Biomass		1	-
Plant	Harvest	Date of designated maturity	74	-1.262 (0.108; 74)
		Harvest commenced	45	-1.285 (0.085; 45)
	Maturity	Date of designated maturity	45	-1.404 (0.089; 45)
		Duration linear increase in total	3	-
		Onset linear increase in total	3	-
		Threshold time for maximum conc.	3	-
		Time when berries reach 12 Be	3	-
	Flowering	Bloom date	4	-
		First flowering date	23	- (-; 1)
		Flowering commenced	69	-0.284 (0.455; 17)
		Flowering	5	-0.810 (0.144; 5)
		Full bloom	7	-0.091 (0.061; 7)
		Full flowering	1	-
		Peak flowering	3	-
		Peak % trees	85	- (-; 3)
		Years to first flower	1	-
		(unspecified)	11	
	Budding	Green tip	1	-
	Fruiting	Peak % trees	85	- (-; 0)
	Seeding	Mast seeding	4	-
		Seed fall	2	-
	Pollen	Season start	1	-
		Season end	1	-
		Season length	1	-
Reptilia	Breeding	End of pairing	1	-
		Start of pairing	1	-
		Timing of oviposition	1	-

Table S6.2. Statistics related to type of phenophase. Codes: F first date; L last date; M mean, median or peak date; O other definition of timing or insufficient detail provided in source paper to correctly identify. Mean trends are only calculated if at least 5 datasets in this category, S.E. is the standard error of the mean trend estimate.

Taxa	Phenophase	Phenophase Code	Number of datasets with trends reported	Mean trend (S.E.)
Arthropoda	Migration	F	1	-
	Emergence	F	26	0.228 (0.174)
Aves	Breeding	F	6	-1.453 (0.571)
		L	2	-
		M	11	-0.355 (0.241)
		O	81	0.111 (0.096)
	Migration	F	179	-0.305 (0.106)
		L	120	0.061 (0.176)
		M	27	0.038 (0.755)
		O	10	0.350 (0.516)
Plant	Harvest	F	45	-1.285 (0.085)
		O	74	-1.262 (0.108)
	Maturity	O	45	-1.404 (0.089)
	Flowering	F	18	-0.307 (0.429)
		M	11	-0.143 (0.077)
		O	9	-0.519 (0.138)
	Budding	O	1	-
	Pollen	F	1	-
		L	1	-
		O	1	-
Reptilia	Breeding	F	1	-
		L	1	-