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The responses of species to climate over two centuries: an analysis of the Marsham phenological record, 1736–1947

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Summary

1 The Marsham phenological data have been 'rediscovered' several times. This unique data set, spanning two centuries, consists of first dates of observation, or 'indications of spring', for 27 phenological events which relate to over 20 species of plants and animals.
2 This paper extends the 1926 appraisal of the data from 1736 to 1925 by adding the 22 years up to 1947, when publication of the record ceased.
3 The Marsham data are examined in relation to Manley's central England monthly temperature data and Craddock's annual rainfall data and are further examined for unexplained trends over time.
4 Most of the phenological variables were significantly related to climatic variables or changed through time.
5 An appraisal of the historical response of flora and fauna to climate was made and allowed us to predict changes in species performance due to climate change in the future. If commonly used climate scenarios are accurate we predict that most or all of the indications of spring noted in the Marsham record will occur earlier in the calendar year.

Keywords: phenology, climate change, temperature, indications of spring

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Introduction

Ecologists and policy makers are currently concerned how species will be affected by predicted changes in climate. Considerable research effort is presently directed at determining which, if any, aspects of climate control the performance of both flora and fauna. The performance of individuals, in terms of their survival and the number of offspring produced, will ultimately affect both species' abundance and their distributional limits.

Many of the current studies aimed at predicting future distribution are weakened by having to assume that the current distributions of species are both correlated with and in equilibrium with the current climate. For most species, constraints on dispersal will cause a time-lag between the climate becoming suitable for establishment and their actual appearance (Davis 1989). In order to predict future responses of species to a changed climate we need first to discover how plants have responded to climate in the past. Much useful information on population behaviour could have been gained from long term monitoring. Unfortunately very few monitoring schemes on plants or animals have been of sufficient duration to show long term trends due to climate. There are, however, large datasets, in the form of phenological records, which can provide us with information indicating how some aspects of species performance have reacted annually to climate over a considerable time-span.

Collecting phenological data has been a pastime amongst many literate country dwellers for several centuries, for example Gilbert White (White 1789). During the 19th century, this activity took on a scientific flavour, and a phenological committee of the Royal Meteorological Society was formed to collate and report phenological data sent in by observers throughout Britain. This was an extension of the network of climatic recorders which was also co-ordinated by the Royal Meteorological Society. Contacts were made with scientific organisations in other countries who were encouraged to collect similar data (Clarke 1936). Much emphasis was placed on phenological data at that time (Margary 1927), and a cursory inspection of the *Quarterly Journal of the Royal Meteorological Society* reveals how much effort was expended in producing each annual report. Annual reports of the phenological committee commenced in 1875 but were sadly discontinued in 1948 because the Society felt it was no longer the most suitable body to bear the responsibility of such a report. The expense of producing the report may have further influenced the Society's decision.

Margary (1926) reported the rediscovery of a unique set of phenological records dating back to 1736 which had been kept by five generations of the same family. Records of the first dates of observations, or indications of spring, for 27 phenological events had been taken in the Marsham family estates, a few miles to the north of Norwich, Norfolk. Observations were first recorded by Robert Marsham, FRS, a contemporary and correspondent of Gilbert White (Marsham & Bell 1896). Robert Marsham communicated his results to the Royal Society in 1789 (Marsham 1789) and further discussion appeared in 1875 (Southwell 1875) and 1901 (Southwell 1901) but in the quarter century until Margary's paper had again lapsed into obscurity. The Marsham observations (recorded by a further two generations of the family) were then included in the annual *Phenological Report* for a further 22 years.

Nearly two centuries of data collected in the same locality in Norfolk gave us a unique chance to examine how the dates of appearance of a small group of common species of plants and animals in the spring have varied with the climate. This dataset can be compared to another recently used by other authors (Fitter *et al.* 1995). The latter dataset was unique because of the large number of species recorded and in that they were recorded throughout the year; it was, however, much shorter (1954–89). Researchers investigating the effects of climate on species often have to rely on a snapshot in time and also have to look at responses over a range of locations. It is our belief that the study by Fitter *et al.* (1995) together with our study of the Marsham phenological record can provide a means of gaining confidence in predicting species response under a wide range of conditions.

Materials and methods

MARSHAM DATA

The data from 1736–1925 have been previously documented (Margary 1926). We have used these data but have omitted those figures that he created by interpolation to fill gaps in the record. Data from 22 additional years, collected by Rev. A. F. Marsham and Miss M. A. Marsham, have been abstracted from the relevant *Quarterly Journal of the Royal Meteorological Society* volumes (Appendix 1). The Marsham data are not complete over the whole period; few records were kept between 1736 and 1745 and there is a total absence of records for the years 1811–34 and 1841–44. A small number of records prior to 1777 were taken elsewhere in south-eastern England: as these records are few and occur only in counties in the south-east of England we have included them in our analysis. Some data values are extreme outliers and may be the result of typographical errors or due to errors in another step of the process of converting the original date records into print. No attempt was made to correct or remove these data as we have no way of telling if they truly are errors. Where errata were noted and published in the Phenological Report we have included the corrections. The 27 phenological events that were recorded came from a wide variety of taxa and are all common species of the British countryside (Table 1). We have used the scientific names of species where possible but in some cases it is impossible to tell from the records exactly which species was recorded. Both scientific names and English names appear in Table 1. The 'churn owl' refers to *Caprimulgus europaeus* (nightjar) and 'Ring dove' referred to any pigeon prior to 1915, the record being restricted to turtle dove only after 1915. We have therefore omitted ring dove from any analysis in this paper. The 'yellow butterfly' has been confirmed as the male brimstone, *Gonepteryx rhamni* (Margary 1926) which over-winters as an adult and is renowned for fitful appearances on any warm day. No records of *Caprimulgus europaeus* have been taken since 1904 and the last nightingale (*Luscinia megarhynchos*) was heard in 1915. Margary (1926) stated that the same methods were carefully followed by successive generations of observers; leafing referring to the date when leaves were of a recognisable shape and flowering when the centre of blossom was visible. All dates were corrected by Margary to the modern calendar and refer to the day number after 31 December.

TEMPERATURE DATA

To cover the length of the Marsham series, the central England mean monthly air temperature data of Manley (1974) have been utilised. Although less than ideal, these data have been shown to correlate well (although at a higher mean) with data from Edinburgh (Duncan 1991). We have assumed that a similar relationship would exist with Norfolk data and that Manley's data can be considered to be a reasonable approximation to the temperature where the Marsham records were taken.

RAINFALL DATA

The only dataset we have that covers the length of the Marsham series is the annual rainfall data published by Craddock (1976). Unfortunately, Craddock's data for East Anglia are not complete for the full time span considered. We have therefore used the average data which are expressed as a percentage of 'normal' rainfall.

Table 1 Recorded phenological variables, number of recorded years (n), mean dates and extreme dates (all in days with reference to 31 December). Scientific names are given where possible to specific level. Generic names followed by the specific name in parentheses indicate that this is the probable species but we are uncertain

Variable	n	Mean	Min.	Max.
Flowering records				
Galanthus nivalis – Snowdrop	168	17	−17	72
Anemone nemorosa – Wood anemone	143	84	44	115
Crataegus monogyna – Hawthorn	165	131	105	160
Brassica (*rapa*?) – Turnip	140	98	−6	136
Leafing records				
Hawthorn	174	69	19	116
Acer pseudoplatanus – Sycamore	164	92	29	124
Betula (*pendula*?) – Birch	164	95	61	127
Ulmus (*procera*?) – Elm (common)	137	94	40	127
Sorbus aucuparia – Mountain ash	154	96	64	122
Quercus spp. – Oak	167	114	84	140
Fagus sylvatica – Beech	167	111	74	132
Aesculus hippocastanum – Horse chestnut	162	94	62	122
Castanea sativa – Chestnut	144	109	74	138
Carpinus betulus – Hornbeam	149	98	39	127
Fraxinus excelsior – Ash	147	119	86	147
Tilia spp. – Lime	156	103	63	132
Acer (*campestre*?) – Maple	104	109	71	140
Migratory birds				
Hirundo rustica – Swallow	179	110	93	135
Cuculus canorus – Cuckoo	180	114	102	127
Luscinia megarhynchos – Nightingale	118	116	92	143
Caprimulgus europaeus – Churn Owl calls	68	145	117	190
Other birds				
Turdus turdus – Thrush singing	153	26	−42	80
'Ringdoves' coo	136	72	−7	151
Corvus frugilegus – Rooks build	169	62	33	86
Young rooks	165	103	82	131
Other records				
Gonepteryx rhamni – Yellow butterfly	150	78	14	123
Frogs & toads croak	162	85	53	151

ANALYSIS

Because of the potential lack of independence between successive annual observations, the data were first examined for evidence of autocorrelation. If autocorrelation existed, a first order autoregressive term was included in the regression as the initial term. Stepwise regression techniques were then employed. Potentially, the regression equations included monthly temperatures from May of the preceding year to April of the recorded year and annual rainfall data of the recorded and preceding year as 14 independent variables. A year index (1 = 1700, 247 = 1947) was included as a 15th independent variable. Temperature records for months following the mean date of the records were not included in the stepwise approach. Where appropriate, quadratic effects were examined to allow for curvature in the response. To maintain parsimony, a 1% cut-off significance was adopted in the stepwise model building stage. Residuals from fitted models were examined as a check of the adequacy of the models using methods suggested by Draper & Smith (1981). Where autocorrelation in the residuals was identified a first order autoregressive term was added as the final term in the model and residuals were further examined for independence. Correlation coefficients have been calculated in some instances, but these should be examined with caution since these only measure linear association and may not reveal other forms of relationship.

Results

Twenty-four of the 27 phenological events were recorded in more than 130 years (Table 1). Only *Acer campestre* (104 years), *Luscinia megarhynchos* (118 years) and *Caprimulgus europaeus* (68 years) were recorded in fewer than 130 years.

Correlations of the phenological records with temperature, rainfall, and the year index showed some interesting results (Table 2). The weather of the year preceding that of the recorded year seems to have had little influence on plant and animal response, whilst correlations with early spring weather and the year index were much more apparent (Table 2). There was some indication of linear trend in the climate data; especially a general warming during November and January (Table 3). Regression of the phenological records on the year index, to examine for trend, sug-

Table 2 Correlations between phenological events and Manley's central England monthly temperature data for the months preceding mean observed date, Craddock's annual rainfall of the preceding year (RainA) and recorded year (RainB), and a year index (Year, 1 = 1700). Correlations were not calculated (represented by .) for the months which were later than the mean first date of observation

	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	RainA	RainB	Year
Flowering																			
Snowdrop	0.07	−0.01	−0.01	0.04	−0.09	−0.26	−0.07	0.05	0.17	0.13	−0.03	−0.27	−0.34	.	.	.	0.04	−0.01	0.01
Wood anemone	−0.10	−0.10	−0.12	0.02	0.03	0.12	0.18	0.13	0.16	−0.02	−0.10	−0.25	−0.37	−0.57	−0.52	.	−0.12	−0.06	−0.44
Hawthorn	0.07	0.04	−0.03	−0.13	−0.17	0.00	0.10	−0.10	0.00	0.04	0.08	−0.02	−0.10	−0.39	−0.52	−0.57	0.05	0.02	−0.10
Turnip	0.20	0.06	0.06	0.03	−0.10	0.02	0.14	0.10	0.05	0.10	0.19	−0.16	−0.30	−0.37	−0.27	−0.22	−0.06	−0.05	0.26
Leafing																			
Hawthorn	0.03	0.06	−0.07	0.03	0.00	0.02	0.14	0.09	0.25	0.14	0.19	−0.20	−0.49	−0.61	−0.42	.	−0.09	−0.20	−0.08
Sycamore	−0.06	−0.05	−0.10	−0.10	−0.16	0.00	0.05	0.05	0.15	0.10	−0.04	−0.14	−0.24	−0.50	−0.62	−0.25	−0.06	−0.10	−0.21
Birch	0.09	0.04	−0.01	0.01	−0.08	−0.04	0.06	0.09	0.15	0.19	0.15	0.02	−0.12	−0.47	−0.57	−0.20	0.02	−0.04	0.25
Elm	0.12	−0.03	−0.03	0.07	−0.21	−0.02	−0.03	−0.13	0.05	0.13	0.16	−0.08	−0.17	−0.41	−0.48	−0.15	−0.03	−0.10	0.26
Mountain ash	0.07	−0.04	−0.06	−0.04	−0.12	−0.05	0.11	−0.01	0.14	0.18	0.18	−0.06	−0.16	−0.58	−0.70	−0.33	−0.01	−0.16	0.08
Oak	−0.07	−0.08	−0.13	−0.03	−0.06	0.03	0.15	0.04	0.11	0.02	−0.13	−0.22	−0.27	−0.50	−0.65	−0.59	0.01	−0.01	−0.31
Beech	−0.07	−0.11	−0.15	−0.12	−0.03	−0.12	0.01	−0.12	0.08	−0.02	−0.15	−0.06	−0.17	−0.33	−0.49	−0.55	0.06	−0.06	−0.36
Horse chestnut	0.02	−0.05	−0.08	−0.13	−0.15	−0.05	0.02	0.02	0.14	0.12	0.09	−0.14	−0.20	−0.44	−0.66	−0.24	−0.04	−0.10	0.05
Chestnut	0.01	0.06	−0.01	0.02	0.04	0.12	0.17	0.04	0.06	0.02	0.00	−0.04	−0.26	−0.51	−0.62	−0.42	−0.05	−0.03	−0.21
Hornbeam	0.07	−0.10	0.04	−0.07	−0.14	−0.12	0.01	−0.05	0.18	0.09	0.07	−0.09	−0.23	−0.44	−0.49	−0.22	0.02	−0.09	0.20
Ash	−0.05	−0.10	−0.06	−0.04	−0.10	0.01	0.11	−0.10	0.00	0.06	0.13	−0.04	−0.18	−0.36	−0.40	−0.47	−0.01	0.03	0.01
Lime	0.00	0.04	−0.05	0.02	−0.06	0.03	0.06	−0.06	0.11	0.09	0.11	−0.01	−0.10	−0.51	−0.61	−0.40	0.07	−0.03	−0.15
Maple	0.05	−0.02	0.14	0.11	−0.13	0.08	0.06	0.02	0.11	0.25	0.12	0.02	−0.09	−0.37	−0.43	−0.38	0.01	0.08	0.22
Migratory Birds																			
Swallow	0.11	0.04	0.15	−0.06	−0.07	−0.15	0.01	0.09	0.07	0.08	0.09	0.04	0.06	0.09	−0.01	−0.26	0.03	0.05	0.46
Cuckoo	−0.02	−0.14	−0.15	−0.15	−0.11	−0.05	0.05	0.03	−0.01	−0.17	−0.04	−0.12	−0.12	−0.11	−0.22	−0.40	0.05	0.02	−0.34
Nightingale	−0.08	−0.04	0.08	0.02	0.13	0.10	0.04	0.16	−0.17	0.12	0.08	−0.09	−0.06	−0.01	0.06	−0.18	−0.09	0.07	−0.24
Nightjar	0.13	0.03	−0.17	0.02	0.10	−0.08	−0.17	−0.12	−0.25	−0.07	0.16	0.10	−0.04	−0.07	−0.13	0.02	0.12	0.09	−0.22
Other birds																			
Thrush	0.01	0.00	−0.03	−0.02	0.01	0.19	0.02	0.05	0.04	−0.01	−0.08	−0.28	−0.40	.	.	.	0.02	−0.20	−0.26
Rooks build	−0.03	0.15	0.14	0.01	0.13	0.10	0.11	0.13	0.20	0.12	0.05	0.13	−0.05	−0.21	−0.05	.	0.01	−0.04	0.06
Young rooks	0.06	0.10	0.16	0.00	0.06	−0.06	−0.02	0.04	0.06	0.08	0.13	0.14	0.06	−0.28	−0.22	−0.04	0.10	−0.08	0.33
Other animals																			
Yellow butterfly	0.05	0.13	0.20	−0.06	−0.09	−0.04	−0.08	−0.23	−0.16	0.05	0.11	0.14	0.10	−0.20	−0.14	.	0.01	0.01	0.36
Frogs croak	0.12	0.14	0.19	0.08	−0.04	−0.02	0.18	−0.01	0.14	0.24	0.12	0.13	−0.09	−0.20	−0.24	.	0.03	−0.02	0.26

Table 3 Correlations between climatic variables and time (year index), $n = 184$

Variable	r
Temperatures	
January	0.209
February	0.098
March	0.160
April	0.098
May	−0.025
June	−0.124
July	−0.056
August	−0.074
September	−0.067
October	0.127
November	0.202
December	0.131
Annual rainfall	0.048

gested the changes shown in Table 4. These display a range of reaction to the environment over two centuries, and some trends are much more significant than others, for example *Anemone nemorosa* flowered 0.10 days $year^{-1}$ earlier from 1736 to 1947 and *Hirundo rustica* arrived 0.05 days $year^{-1}$ later. These trends (Table 4) should be treated with caution as they have not been adjusted for changes in the climate.

The results of regression modelling including all 15 climatic and temporal independent variables are presented in Table 5. There were negative effects of early spring temperature on a number of species. In some cases, monthly temperatures from the preceding year were included in the models. Variables from the previous year were generally of less importance than the early spring temperatures. The effects of the year index were still very evident and the estimated trend per year, after elimination of climatic effects, has been added as a final column to Table 4 for comparison.

Discussion

PHENOLOGICAL DATA

Phenological data have received much criticism in the past. It is argued that the recording of first dates can be seriously influenced by a rogue event or individual (Williams 1949). There have been suggestions that such data are most valid when, in the case of trees, the same tree is recorded year after year. This, of

Table 4 Crude per annum trend effects in the observed data, where trend effects were significant. The final column lists the trend estimated from the final regression model. Note caution expressed in the text about these results and especially those regarding the ring dove record

Variable	Trend/year	R^2 (%)	F	P	Trend†
Flowering records					
Snowdrop	.		$F_{1,166} = 0.02$	ns	.
Wood anemone	−0.103	19.0	$F_{1,141} = 32.99$	***	−0.064
Hawthorn	.		$F_{1,163} = 1.65$	ns	.
Turnip	+0.097	6.5	$F_{1,138} = 9.57$	**	+0.165
Leafing records					
Hawthorn	.		$F_{1,172} = 1.21$	ns	.
Sycamore	−0.046	4.4	$F_{1,162} = 7.40$	**	.
Birch	+0.052	6.1	$F_{1,162} = 10.44$	***	+0.074
Elm (common)	+0.061	7.0	$F_{1,135} = 10.20$	**	+0.066
Mountain ash	.		$F_{1,152} = 0.98$	ns	+0.032
Oak	−0.053	9.7	$F_{1,165} = 17.72$	***	−0.032
Beech	−0.048	12.8	$F_{1,165} = 24.29$	***	−0.029
Horse chestnut	.		$F_{1,160} = 0.36$	ns	+0.032
Chestnut	−0.041	4.4	$F_{1,142} = 6.60$	*	.
Hornbeam	+0.051	3.9	$F_{1,147} = 5.96$	*	+0.074
Ash	.		$F_{1,145} = 0.00$	ns	.
Lime	.		$F_{1,154} = 3.55$	ns	.
Maple	+0.045	5.0	$F_{1,102} = 5.35$	*	.
Migratory birds					
Swallow	+0.050	21.1	$F_{1,177} = 47.76$	***	+0.052
Cuckoo	−0.028	11.9	$F_{1,178} = 24.07$	***	−0.019
Nightingale	−0.043	5.7	$F_{1,116} = 7.01$	**	.
Churn Owl	.		$F_{1,66} = 3.32$	ns	.
Other birds					
Thrush singing	−0.084	6.8	$F_{1,151} = 11.05$	***	.
Rooks build	.		$F_{1,167} = 0.71$	ns	.
Young rooks	+0.040	10.7	$F_{1,163} = 19.52$	***	+0.043
Other records					
Yellow butterfly	+0.139	13.3	$F_{1,148} = 22.64$	***	+0.142
Frogs & toads croak	+0.070	6.8	$F_{1,160} = 11.75$	***	+0.092

† Trend after fitting final model, see Table 5.

Table 5 Fitted regression models from stepwise regression of climatic variables and trend. Estimated coefficients are negative unless indicated as positive (+). Parameters are listed in the order they entered the model. MarT is March temperature; AprT is April temperature, OctTP is October temperature in the preceding year etc.; RainP is the total rainfall in the preceding calendar year; Year is the year index (1700 = 1), AR1 indicates the inclusion of a first order autoregressive term. All models were significant at $P = 0.001$ except 'rooks build' which was significant at $P = 0.01$

Variable	Model terms	R^2(%)
Flowering records		
Snowdrop	AR1(+), JanT, JunTP, DecTP	25.6
Wood anemone	AR1(+), FebT, Year, MarT, RainP, JanT	64.6
Hawthorn	AR1(+), AprT, MarT	49.9
Turnip	FebT, Year(+), JanT, MarT, AugTP(+)	37.2
Leafing records		
Hawthorn	FebT, JanT, SepTP(+), MarT, OctTP(+), AR1(+)	57.6
Sycamore	AR1(+), MarT, FebT	45.5
Birch	AR1(+), MarT, Year(+), FebT, AugTP(+)	58.9
Elm (common)	AR1(+), FebT, MarT, Year(+)	44.6
Mountain ash	MarT, FebT, Year(+), AprT, OctTP(+)	65.4
Oak	MarT, AprT, Year, FebT, AugTP(+)	73.1
Beech	AR1(+), AprT, JunT, MarT, Year	51.2
Horse chestnut	MarT, FebT, Year(+), AugTP(+)	52.0
Chestnut	MarT, AprT, FebT, JunTP(+), AR1(+)	57.5
Hornbeam	AR1(+), MarT, FebT, Year(+), JanT, SepTP(+)	53.7
Ash	AR1(+), AprT, MarT, FebT	42.8
Lime	MarT, AprT, FebT	50.4
Maple	AR1(+), FebT, AprT	34.0
Migratory birds		
Swallow	AR1(+), Year(+), AprT	33.2
Cuckoo	AR1(+), AprT, Year	27.4
Nightingale	AR1(+)	16.7
Churn Owl calls	AR1(+)	26.0
Other birds		
Thrush singing	AR1(+), JanT	14.3
Rooks build	FebT	4.5
Young rooks	AR1(+), FebT, Year(+)	32.3
Other records		
Yellow butterfly	Year(+), FebT	18.0
Frogs & toads	Year(+), MarT, JulTP(+), AprT	22.5

course, is only possible in long-lived individuals. Other suggestions recommend the recording of all individuals and summarising, for example, the mean first date of observation.

First dates of observation data are strictly left-censored; the actual date being no later than that recorded, whilst they could of course have been present at an earlier date. This situation is likely to be more serious for fauna, when individuals may be present for several days before being observed or heard. However, first dates of observation require relatively little effort to record, and, if their limitations are recognised, provide valuable information, especially if recorded over many years or in a wide variety of geographical and environmental locations.

CLIMATE DATA

Our results (Table 3) agreed with those of Dyer (1976) who noted a positive trend, after analysis of the complete set of Manley's data, from October through to April inclusive, but not in the summer months. Manley (1944) reported a similar increase in winter temperatures in data from Stockholm, and Parker (1988) noted systematic changes in temperature and rainfall but over a slightly different time scale. We did not detect any systematic changes to rainfall over the period 1736–1947.

REGRESSION MODELS

Some species showed particularly significant responses, e.g. the leafing date of *Quercus* ($R^2 = 73.1\%$), leafing date of *Sorbus aucuparia* ($R^2 = 65.4\%$) and flowering date of *Anemone nemorosa* ($R^2 = 64.6\%$). The absence of monthly rainfall figures may partly explain the lower value of R^2 in some of the models. *Fraxinus excelsior* (Foggo & Speight 1993), *Betula* and *Fagus sylvatica* (G. Peterken personal communication), for example, are strongly affected by drought and monthly rainfall data may have detected a response of these species in the following year. Particularly severe weather conditions, e.g. drought, or critical temperatures, may affect the performance of long-lived species for many years afterwards and for short-lived species may cause large fluctuations in the size and number of populations (e.g. Waite 1984). Extreme weather events therefore may have an impact on any study which attempts to look for long term trends in species performance. The unprecedented length of the Marsham dataset damps down the effects of extreme weather in our models but cannot remove them completely. The length of the Marsham dataset will also enable us to determine the duration of the effects caused by extreme weather conditions in a future investigation.

Fitter *et al.* (1995) have shown the importance of February temperatures and positive associations with temperatures in the previous autumn for spring flowering plants. Both of these observations are also apparent from our analysis of the Marsham data (Table 5).

Although highly significant, the models explaining the appearance of migratory birds were less impressive than the models relating the phenological events of plants to climate (Table 5). This possibly reflects the problems with recording the 'first date' for birds. Migratory birds would also be affected by weather conditions along their migratory routes which are outside the geographic area represented by the Manley or Craddock datasets. This point is demonstrated by the early appearance of *Hirundo rustica* in 1745 which was the coldest winter on record in this country (the mean temperatures of December 1744, January and February 1745 were all below 0°C). As a colleague of ours pointed out 'swallows have no access to detailed weather forecasts for conditions at the end of their migration route when they set out'.

PREDICTIVE MODELS

The success of the regression models (Table 5) gave us the opportunity to suggest how climate change may affect the observed species. We fitted the IS92a climate scenario (Houghton *et al.* 1992) to the regression models summarised in Table 5. The IS92a scenario predicts that for the south east of England by 2100 there will be a 3.5°C rise in the temperatures of December, January and February, a 3°C rise in the temperatures of June, July and August and a 10% increase in annual precipitation. Making the assumption that the relationship between climate and phenology has not altered over the last 50 years we have multiplied the regression coefficients for December, January and February by 3.5. We have assumed that the other 9 months will rise by 3°C and have multiplied the regression coefficients for those months by 3. The one significant regression coefficient for rainfall was multiplied by 10 (the rainfall variable is based on percentile units). The results of adding these climate changes to the regression equations indicated that a dramatic change in the response of species is possible (Table 6). Many of the records of species appearance will occur two to three weeks earlier than present. These findings are in accord with Margary (1926) who suggested a mean 2°F – 5-day relationship (3.5°C – 16 days) and Fitter *et al.* (1995) who suggest a mean 1°C – 4 day relationship (3.5°C – 14 days). Experimental work in temperature controlled environments has suggested a 14–30 day advancement of bud-burst in *Quercus robur* when young trees are grown in 3°C elevated temperatures (A. Buse personal communication)

Table 6 Estimated effects on day of first observation caused by a 3.5°C rise in winter temperature a 3°C rise in the temperature of spring, summer and autumn and a 10% increase in rainfall on the species observed by the Marsham family. These estimates are additional to any unidentified trends (. = no estimate)

Variable	Net effect
Flowering records	
Snowdrop	−25
Wood anemone	−23
Hawthorn	−20
Turnip	−24
Leafing records	
Hawthorn	−18
Sycamore	−21
Birch	−13
Elm (common)	−21
Mountain ash	−20
Oak	−22
Beech	−15
Horse chestnut	−13
Chestnut	−19
Hornbeam	−18
Ash	−20
Lime	−24
Maple	−15
Migratory birds	
Swallow	−5
Cuckoo	−4
Nightingale	.
Churn Owl calls	.
Other birds	
Thrush singing	−12
Rooks build	−3
Young rooks	−4
Other records	
Yellow butterfly	−9
Frogs & toads croak	−9

In this paper we have demonstrated how phenological records can give us some indication of how species respond to climate over a period of more than 200 years. In this time there has been a rise in temperature and species have responded to this and other unexplained factors, some by coming into leaf earlier (e.g. *Quercus*), flowering earlier (e.g. *Anemone nemorosa*) or appearing earlier (e.g. *Cuculus canorus*) and others by coming into leaf later (e.g. *Betula*), flowering later (e.g. *Brassica rapa*) or arriving later (e.g. *Hirundo rustica*). We have predicted that climate change will cause the earlier appearance of most of the phenological events observed by the Marsham family, but these may be modified by underlying and undefined trends over time. How the earlier leafing, flowering and arrival of animals will affect our perception of spring is difficult to gauge. The slow rate of change and annual variation will probably mean that the changes will probably go unnoticed by a single human generation. The consequences of future climate change on the population biology of the species described by the Marsham family await investigation.

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Appendix 1

The Marsham phenological record for the years post Margary (1926). No additional records on the nightingale or 'churn owl' were taken. The Royal Meteorological Society ceased publication of its Phenological Report in 1948

Year	sn	wa	ha	tu	hw	sy	bi	el	mo	oa	be	hc	ch	ho	as	li	ma	sw	cu	th	rd	rb	ry	yb	fr
1926	23	66	115	95	47	63	80	69	73	94	99	80	83	94	99	63	94	103	105	7	138	52	104	55	62
1927	27	69	125	105	61	61	94	81	82	103	109	86	99	84	105	83	94	113	111	12	125	58	106	81	122
1928	23	63	131	106	19	78	80	94	88	104	104	88	94	101	112	88	103	111	116	16	120	65	101	64	100
1929	32	88	138	118	86	90	102	88	104	109	107	92	112	109	121	114	133	109	108	21	127	63	102	68	*
1930	16	85	132	118	61	92	115	91	103	113	114	98	111	111	113	107	122	113	114	18	133	61	107	87	124
1931	19	68	143	118	81	93	113	119	105	119	117	99	110	111	127	103	137	113	115	26	151	69	110	86	126
1932	12	93	143	127	31	80	123	101	110	120	118	101	120	111	123	111	*	105	113	19	123	72	115	113	*
1933	29	71	120	110	64	78	97	86	88	98	102	88	99	95	112	90	*	109	113	6	124	68	108	72	*
1934	15	84	136	115	80	101	110	98	103	114	106	100	114	107	126	106	136	121	107	12	132	72	119	68	106
1935	17	71	124	129	73	76	98	86	97	106	108	84	107	104	119	100	131	122	112	16	127	66	114	85	121
1936	16	88	131	116	79	86	98	87	94	115	114	90	87	109	126	99	138	120	116	25	133	74	113	82	82
1937	18	85	138	113	72	92	108	101	100	114	111	102	117	117	123	104	140	135	112	6	133	69	111	78	104
1938	20	67	106	85	53	29	87	73	81	84	94	80	81	84	86	88	*	113	118	2	*	66	107	73	76
1939	20	68	129	116	69	67	100	80	97	104	106	96	108	100	115	100	120	114	113	11	129	61	112	92	91
1940	52	84	136	121	87	93	116	105	107	115	114	94	120	115	125	104	125	115	110	54	123	78	127	84	111
1941	25	85	*	122	92	98	127	106	118	131	112	107	129	121	138	119	134	120	112	46	124	71	124	87	128
1942	47	91	132	119	97	99	111	113	108	120	110	100	119	111	140	110	110	118	112	61	130	75	113	90	93
1943	21	72	118	100	74	86	100	86	91	104	103	91	95	101	110	93	103	109	108	20	119	60	111	75	85
1944	20	73	130	104	84	88	104	87	100	114	106	100	113	107	123	103	114	109	106	10	130	78	*	30	88
1945	34	72	108	88	69	69	92	87	81	100	96	81	96	89	130	83	102	124	107	30	130	53	97	50	72
1946	14	79	116	104	79	80	111	84	96	104	99	102	105	97	117	95	109	107	104	8	127	83	114	83	79
1947	72	90	135	116	102	103	116	111	111	116	110	103	107	115	133	111	120	117	106	16	130	68	131	101	87

sn, snowdrop; wa, wood anemone; ha, hawthorn flowering; tu, turnip; hw, hawthorn leafing; sy, sycamore; bi, birch; el, elm; mo, mountain ash; oa, oak; be, beech; hc, horse chestnut; ch, chestnut; ho, hornbeam; as, ash; li, lime; ma, maple; sw, swallow; cu, cuckoo; th, thrush; rd, ring dove; rb, rooks build; ry, rook young; yb, yellow butterfly; fr, frogs or toads croak.

* indicates no observation for the phenological event was made.

We believe the value for sycamore in 1938 could be a misprint in the original data.