SCOTTISH
NATURAL
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COMMISSIONED REPORT

Commissioned Report No. 167

Natural Heritage Trends of Scotland: phenological indicators of climate change

(ROAME No. F01NB01)

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SCOTTISH NATURAL HERITAGE

COMMISSIONED REPORT Summary

Natural Heritage Trends of Scotland: phenological indicators of climate change

Commissioned Report No. 167 (ROAME No. F01NB01)
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Background

Global mean temperatures are rising and are predicted to continue rising during the current century. There is, according to the Intergovernmental Panel on Climate Change (IPCC), a discernible human influence on the level of warming.

Much of the evidence for climate impacts summarised by the IPCC comes from phenological studies, ie observed dates on which biological events, such as flowering or migration, occur. The purpose of this report is to review evidence for phenological change in Scotland in terrestrial, freshwater and marine environments.

Main findings

- We have managed to access a surprisingly large amount of data on phenology within Scotland, but predominantly from terrestrial studies with less information available for freshwater and marine environments.
- Data on the phenology of nesting and migrating birds, on aphids, moths, butterflies, flowering plants and marine plankton have been assessed.
- Here we report change on all data available, whether statistically significant or not, as an unbiased assessment of change or the lack of it.
- Of over 500 spring/summer phenology series in the terrestrial environment, 74% show some evidence of advance and 25% of the total were significantly earlier. Only 3% of the total were significantly later.
- Changes in phenology, typically an advance in event dates, were widespread reflecting increases in air, water and sea temperatures. Many species not yet demonstrating changes in phenology show the potential to do so as temperatures continue to rise. Temperature was more influential on phenology than either sunshine or rainfall.
- Within species groups, there is ample evidence for differential change amongst species that may ultimately affect competition between them.
- Some groups, eg (appearance of) aphids, appear more responsive to warming than others, eg (nesting of) birds. Mean advances varied from one day/decade earlier (nesting birds) to almost five days/decade earlier (aphids). There is thus potential for the de-synchronisation of food chains unless adaptation takes place.
- It is unlikely that this report has detected all sources of phenological data in Scotland, and it is hoped that its publication will encourage the identification of additional datasets.

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1 INTRODUCTION

This report was commissioned by Scottish Natural Heritage (SNH) to identify and summarise climate-related signals of phenological change in Scottish terrestrial (land-based), freshwater and marine environments.

Phenology, the study of annually recurring life cycle events such as the timing of migrations and flowering, is a particularly sensitive indicator of climate change.

The Intergovernmental Panel on Climate Change has recognised that much of the evidence for climate change impacts comes from phenological studies. Such studies have been mainly restricted to western Europe and North America, but to date few reports have focussed exclusively on Scottish phenology. It is important to know, on issues of synchrony and adaptation, about species which are not changing as much as others and hence this report summarises all data available.

The work was undertaken by the Centre for Ecology and Hydrology as the main contractor with a large number of contributors (see list).

1.1 Climate

The emphasis in this report is a review of whether the phenology of Scottish biota is changing. However, it was felt important to include an opening section on the changing climate of Scotland. This section has only accessed data sources that were readily available, rather than being exhaustive and definitive. To do the latter would be a considerable task beyond the scope of the current report.

1.1.1 Terrestrial measurements

The UK Meteorological Office (www.met-office.gov.uk) regularly updates an All Scotland series of monthly mean temperature, monthly rainfall and monthly sunshine. The former two series originate in 1914 and the latter in 1929.

A wider range of meteorological variables is available from the met station in the Royal Botanic Garden Edinburgh (RBGE) and we had ready access to the data from 1976–2003.

Over the duration of the All Scotland series, trends in all monthly temperatures have been positive (ie warming) but only that of August has been statistically significant, whilst four other months have been marginal. Changes in rainfall and sunshine have been less clear (Table A1, Appendix A).

Over the shorter time scale and more recent period (1976–2003) for which both All-Scotland and RBGE data were both available there is considerable evidence for warming in the months at the beginning of the year (Table 1.1). This can be seen in Figure 1.1. More recent changes in rainfall (Table A2, Appendix A) and sunshine (Table A3) are less clear, particularly for rainfall. There does seem to be a tendency for increased sunshine from September to March with stronger trends in Edinburgh than Scotland as a whole.

Table 1.1 RBGE and All Scotland 1976–2003. Monthly mean air temperatures (°C). Trend and SE give, respectively, an indication of per annum change and the confidence associated with that change. Significant trends ($p<0.05$) are shown in bold, marginal significance ($p<0.1$) marked by an asterisk

	RBGE mean air temperature			All Scotland mean air temperature		
	Mean	**Trend ***	**SE**	**Mean**	**Trend ***	**SE**
January	3.8	**0.078**	0.034	2.3	**0.076**	0.032
February	4.2	**0.084**	0.040	2.6	0.069	0.035 *
March	5.9	0.052	0.027 *	4.0	**0.056**	0.026
April	7.7	**0.048**	0.022	5.9	0.044	0.023 *
May	10.5	0.037	0.020 *	8.8	0.031	0.022
June	13.3	0.005	0.020	11.2	0.006	0.022
July	15.1	–0.005	0.017	13.2	0.014	0.024
August	15.0	0.027	0.022	13.0	0.040	0.027
September	12.8	0.025	0.018	10.8	**0.041**	0.016
October	9.7	–0.007	0.036	7.9	–0.007	0.031
November	6.6	0.040	0.030	5.0	0.044	0.027
December	4.3	0.013	0.036	3.0	0.012	0.033

* *Note:* A positive trend valve represents a mean annual increase; a negative valve represents a mean annual decrease across the survey period.

Changes in dry bulb, wet bulb, maximum, minimum, grass, 10cm soil, 20cm soil and 30cm soil temperatures at RBGE (Tables A4–A7, Appendix A) broadly follow the pattern for mean air temperature with more pronounced warming in the winter and early months of the year.

1.1.2 River/Lake (Loch) temperatures

Data on river temperatures on a large number of catchments are available on the SEPA website. For brevity, we abstracted data on 15 rivers; five from each of the three regions. In addition, data from a relative short time frame were obtained for eight Scottish rivers (Stinchar, Lower Cylde, Allt a'Mharcaidh, Spey at Fochabers, Tweed at Galafoot, Eden (Fife), Cree and Ewe) and five lakes (Lochs Lomond, Katrine, Davan, Kinord and Dee) from the Environmental Change Network (ECN). A significant increase in river temperature was apparent in the early months of the year (Table 1.2) confirming the findings of Langan *et al.* (2001) and as was seen for air temperatures. Figure 1.2 displays changes in annual mean river temperature from these SEPA sites and from ECN sites together with the ECN lake data. There is broad agreement between SEPA and ECN river temperatures in common years ($r=0.70$, $p<0.05$). The short series of lake temperatures rise at an apparently much faster rate and merit further enquiry.

Table 1.2 Quarterly mean river temperatures (°C) for 15 rivers across Scotland 1975–2003 and an indication of trend over time. Significant trends are shown in bold

Quarter	Mean	Trend	SE
JFM	7.2	**0.045**	**0.018**
AMJ	14.8	–0.019	0.024
JJA	11.1	0.008	0.021
OND	4.3	0.026	0.015

Figure 1.1 Changes in temperature of the All Scotland series for January–March (black line) and annual (grey line) 1976–2003. Both show a significant increase (p<0.01 in both cases)

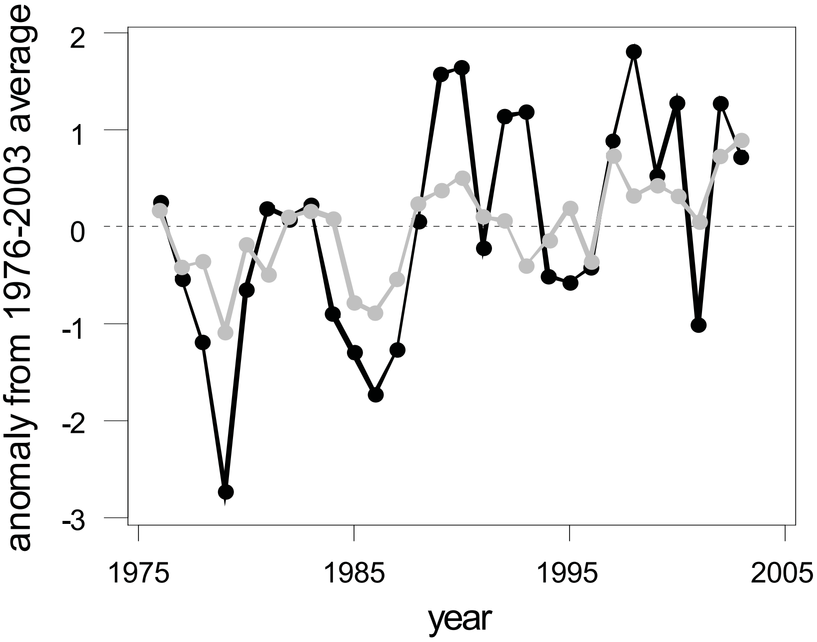
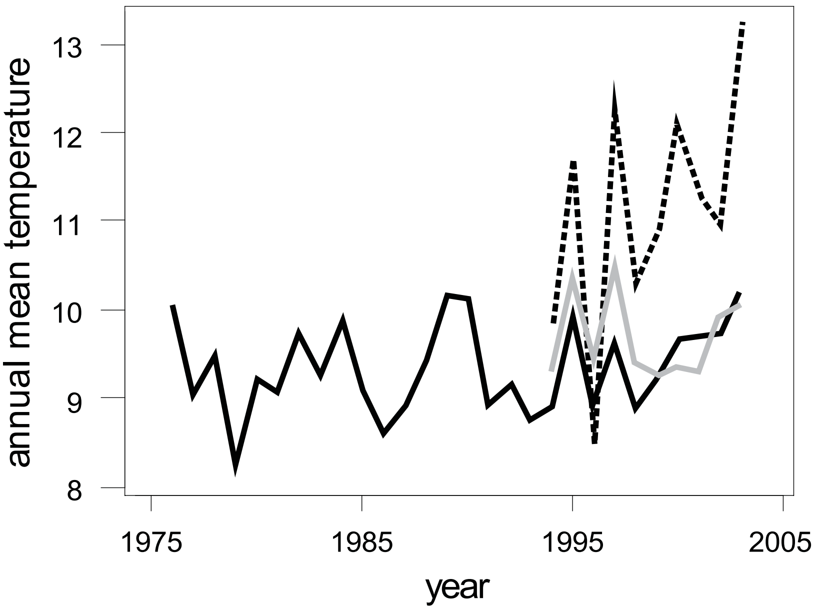


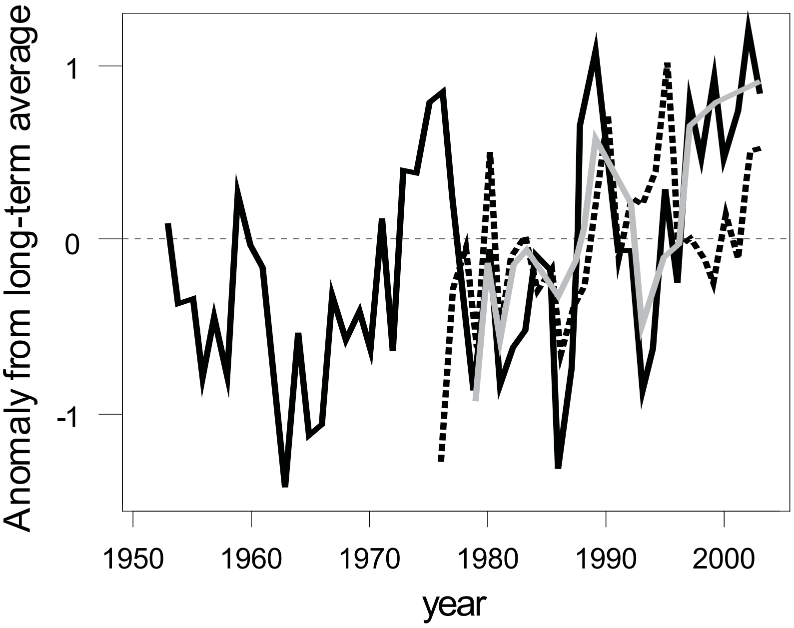
Figure 1.2 Annual mean river temperature (°C) from 15 SEPA sites (solid black line), ECN rivers (grey line) and ECN lakes (dotted line). None of these changes is statistically significant (p>0.05) although that for lakes comes close (p=0.08) even though based on only 10 years of data



1.1.3 Marine temperatures

The Scottish Executive report, on their web site, sea surface temperatures for Millport (western Scotland), Peterhead (eastern Scotland) and Fair Isle (northern Scotland). Figure 1.3 displays the anomalies (differences) from the long term annual average at each site. The per annum change in °C over the entire Millport series was 0.021±0.005, $p<0.001$ but was more rapid after 1979 (0.063±0.015, $p<0.001$). Trends at Peterhead were 0.051±0.011 ($p<0.001$) and at Fair Isle were 0.022±0.011 ($p<0.05$).

Figure 1.3 Change in annual mean coastal sea temperature (°C) at Millport (solid black line), Peterhead (solid grey line) and Fair Isle (dotted line). Data are temperature anomalies from long-term averages (Millport 1971–2000, Peterhead 1976–2000, Fair Isle 1979–1999). Trends in temperature at the three sites were all significant ($p<0.001$, $p<0.001$ and $p<0.05$ respectively)



2 METHODOLOGY

2.1 Data sources

The sources of data are described in each of the sections.

2.2 Analysis

Statistical analysis of phenology varies between sections. In some cases, data were not available but a summary of phenological change was. In such cases, we could only use the information that was presented. In all cases, the method of analysis is described.

Where data were available, the standard approach used here was to convert data into summary date measures and convert these into day numbers post December 31 (so that January 1 = day 1, February 1 = day 32 etc, with adjustment for leap years). Where data existed in a single scheme from several sites they were typically averaged to produce a mean date for each year and each species. These mean dates were then regressed against the year in which they were recorded. Where some measure of recording effort was available (eg the number of traps contributing to the calculated date) weighted regression was used. This places more emphasis on data collected with greater sampling effort and gives less emphasis to possibly erratic values arising from low sampling effort. The regression approach produces a linear estimate of change over the entire series which can be compared between species. Even if the series is not linear, this approach estimates an average change over the entire series. In most of these analyses the trend slope (hereinafter "**trend**" in days/year) is presented with its standard error. As a rule of thumb, trends approximately double the size of their standard error are statistically significant, ie the trend is unlikely to occur by chance. Where significant trends existed these are usually emboldened for ease of identification. Negative trends indicate an advance in the phenological measure and vice-versa, so that, for example, a trend of –0.2 days/annum indicates that the event is getting earlier by 0.2 days per year, ie by two days per decade.

Alternative methods of analysis are possible; that used here is generally considered to be robust and was used to enable a comparison in a simple and consistent way. The use of simple trends such as those calculated here is widespread in the phenological literature and in reports by groups such as the IPCC (Intergovernmental Panel on Climate Change).

Unless otherwise specified, the phenological variable was correlated, using the Pearson coefficient, with the three monthly mean temperatures up to and including mean date (denoted T_{-2}, T_{-1} and T_0), ie the two previous months and the current month. This was repeated for rainfall and sunshine using the Met Office's All Scotland series. Initially, more months were looked at, but the three months leading up to mean date are typically sufficient for our purposes. In practice, as will be shown later, temperature was far more important than rainfall and sunshine and only correlations with temperature are presented. If temperature (or rainfall or sunshine) was having no overall effect we would expect to see equal numbers of negative (indicating an advance in dates) and positive (indicating a delay) correlations and the number of significant correlations would be about 5% of the total number calculated. It should be borne in mind that correlations measure *linear* association, although are reasonably reliable in detecting monotonic patterns.

Finally to give an impression of the expected response of the phenological variable to temperature a multiple regression of date on the three individual months' temperatures leading up to the mean date was used and the resulting coefficients summed to produce an estimate of change in the phenological variable for a

1°C rise in temperature over the three months (hereinafter described as "**response**"). The emphasis here is on estimating response to actual and potential warming rather than on significance testing. However, lack of response would typically produce values randomly around zero.

We would expect that the temperature responsive species identified by this method were the species that changed more during recording, ie that there was a positive correlation between trend and response. Departures from this hypothesis could suggest a number of other factors influencing the phenology. One of these might be a changing population of the species where first observation might appear earlier as a consequence of a growing population, and vice versa. This potential problem (eg Tryjanowski *et al.*, 2005) is likely to be less of a problem when fixed protocols have been used, and particularly for the static plant species. It should not affect mean observations (as opposed to first observations) as these should be unaffected by sample size. Another reason for a mismatch between trend and response is that the climate may not have warmed in the months critical for that species.

2.3 Caveats

The data presented in this report inevitably cover different time periods, though the majority end in recent years, ie 2001–2005. The decision was taken to analyse all possible data rather than reduce all data to a common set of years. The latter course of action would have reduced the chances of detecting significant trends and would have reduced the accuracy of measuring temperature responses. Shorter phenological series will have experienced a more rapid period of temperature increase and their trends may be greater than would be the case if they extended further back in time. Consequently, trends based on different sets of year should be compared with caution. However, the responses to temperature should not be affected.

We only examine climatic responses in this report and concentrate on a few climatic variables. This may ignore subtle effects (for example, of soil temperatures) but was necessary to cope with the volume of data generated. There may be other influences on phenology (for example, eutrophication and CO_2) but temperature has previously been shown to be the dominant factor in many phenological systems.

2.4 Presentation of results

Trends and responses are summarised as outlined in the analysis section above. Because of limited space, a few example graphs have been produced in each section rather than swamping the report.

2.5 Missing data sets

Whilst a great many phenological datasets were accessed in this study, it can not claim to have been exhaustive. The publication of a report such as this will inevitably bring to light further unknown data sets, and encourage others to computerise records which may currently exist in log books and record sheets.

Particularly important would be information from the freshwater and marine environments. Because of its economic importance in Scotland a large amount of data on salmon exists. A previous SNH contract with Fisheries Research Services considered trends in Atlantic salmon numbers (Eatherley *et al.*, 2005); this indicated that the timing of migration was dependent on a range of factors, including weather-dependent water flow (eg rainfall and snowmelt), and therefore the data were not useful for this assessment. Data on seals and cetaceans undoubtedly exist and will come to light, hopefully, in the near future.

3 TERRESTRIAL PHENOLOGY

In this chapter we examine data on bird nesting and migration, observation dates of aphids, moths and butterflies and first flowering dates. All of these measures have been shown in the literature to exhibit some degree of response to climate and trends in phenology. More data exist than presented here, for example from other bird observatories, but we selected data sets that were available in the time available. Analyses of these data are not exhaustive, but rather are a rapid assessment of change.

3.1 British Trust for Ornithology nest record scheme

3.1.1 Data

The Nest Record Scheme (NRS) of the British Trust for Ornithology (BTO) is a long-term network of volunteers collecting information on nesting and nest productivity in birds (Crick *et al.*, 2003). For this report we consider data on mean first egg laying dates in Scotland for the 38-year period 1966–2003. Twelve species provided more than 380 nest records and a further 14 provided more than 190 nest records. One of the latter category (sand martin) only had six years of data and has been omitted. These records have been summarised to provide mean first egg date for each species in each year and it is these values that were subsequently analysed.

3.1.2 Results

An analysis of trends using weighted regression (with weights equal to the number of records in each year) has been carried out and is summarised in Table 3.1 below. Eighteen of the 25 species had a negative regression coefficient (Trend) of which five had got significantly earlier. The blue tit trend was marginally significant ($p<0.1$). Song thrush appears to be nesting significantly later. The average trend was –0.11 days indicating an average advance in nesting of 1.1 days/decade or by four days over the entire study period. For example, Figure 3.1 displays advancing egg laying dates for the dipper and great tit.

In comparison with All Scotland temperature, rainfall and sunshine for the months January to June, there were 34 significant correlations with temperature, 10 with rainfall and 15 with sunshine. Temperature therefore seems to the strongest correlate. In Table 3.2 are summarised the correlations of mean first egg date with monthly temperatures. For each species the comparison is made with the month of mean egg laying date and the two preceding months. Of the 75 tabulated correlations, 60 are negative (17 significant) and 15 positive (one significant). Multiple weighted regression with these three monthly temperatures was then carried out to determine the response to a 1°C increase in temperature over the three month period by summing the three regression coefficients. The responses range from –7.5 days/°C to +2 days/°C and average –2.4 days/°C. The response is positively correlated with trends ($r=0.40$, $p<0.05$). Resident species nested on average 20 days earlier than migrants but there was no significant difference (ANOVA) in trend or response.

Table 3.1 Total numbers of nest records (nn), numbers of years of records (ny), mean first egg date and trend (days/year) determined by regression on year. Significant trends are emboldened, species are ordered by magnitude of trend

			First egg date		
Species	**nn**	**ny**	**Mean**	**Trend**	**SE**
Greenfinch	304	36	138.4	**–0.44**	**0.17**
Great tit	282	25	128.2	**–0.39**	**0.13**
Oyster catcher	515	38	129.4	**–0.32**	**0.11**
Redstart	730	33	140.9	**–0.31**	**0.08**
Dipper	583	36	104.5	**–0.25**	**0.10**
Wheatear	313	24	139.3	–0.22	0.14
Ring ouzel	382	32	131.0	–0.20	0.17
Robin	202	38	126.5	–0.19	0.15
Tree sparrow	546	32	149.6	–0.15	0.15
Meadow pipit	410	36	137.4	–0.13	0.11
Blue tit	360	37	125.5	–0.13	0.08
Dunnock	246	38	128.1	–0.13	0.15
Tawny owl	218	29	86.2	–0.13	0.18
Stonechat	219	27	125.2	–0.10	0.20
Spotted flycatcher	290	37	158.4	–0.09	0.11
Willow warbler	434	38	143.4	–0.08	0.05
Swallow	622	37	172.2	–0.03	0.16
Linnet	351	35	141.0	–0.01	0.19
Chaffinch	482	38	133.6	0.00	0.10
Whinchat	253	34	148.3	0.00	0.08
Blackbird	380	38	123.1	0.01	0.12
Starling	260	37	119.7	0.04	0.10
Grey wagtail	351	37	128.3	0.12	0.13
Pied wagtail	605	38	140.6	0.13	0.10
Song thrush	823	38	121.4	**0.35**	**0.13**

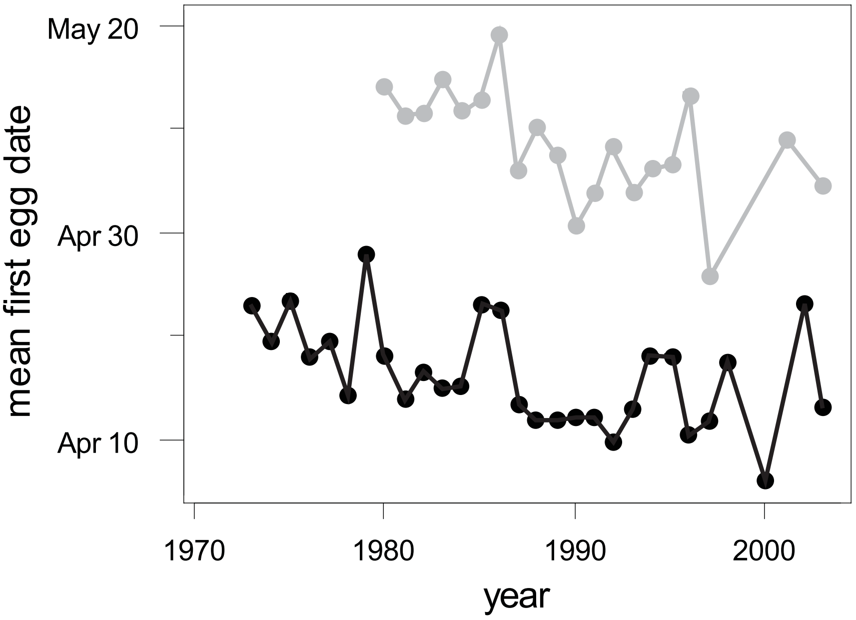
Table 3.2 The correlations of mean first egg date with monthly temperatures for the mean month (T_0) and two preceding months (T_{-1} and T_{-2}) and the response (Resp) of the species to a 1°C increase in these months. Significant correlations are emboldened, species order as Table 3.1

Species	T_{-2}	T_{-1}	T_0	**Resp**
Greenfinch	**–0.34**	**–0.50**	–0.02	–7.5
Great tit	**–0.51**	**–0.50**	–0.30	–3.3
Oyster catcher	–0.22	–0.18	**–0.38**	–2.6
Redstart	–0.31	–0.01	**–0.39**	–2.1
Dipper	0.11	–0.14	0.23	–2.0
Wheatear	–0.01	–0.25	–0.31	–2.6
Ring ouzel	**0.43**	0.03	0.23	0.9
Robin	–0.31	–0.03	–0.28	–4.4
Tree sparrow	–0.16	0.08	0.16	–1.9
Meadow pipit	–0.13	–0.10	**–0.34**	–1.9
Blue tit	**–0.34**	**–0.69**	–0.27	–4.1
Dunnock	**–0.40**	–0.01	–0.28	–3.9
Tawny owl	–0.08	–0.19	–0.16	–1.3
Stonechat	0.10	–0.09	–0.14	2.0
Spotted flycatcher	–0.06	–0.17	–0.12	–3.5
Willow warbler	**–0.40**	–0.20	**–0.38**	–2.7
Swallow	–0.22	–0.12	0.13	–2.6
Linnet	–0.05	–0.23	–0.15	–4.4
Chaffinch	–0.15	–0.19	–0.21	–4.5
Whinchat	–0.05	–0.17	**–0.40**	–2.6
Blackbird	**–0.39**	**–0.33**	–0.10	–4.7
Starling	–0.23	–0.14	–0.02	0.1
Grey wagtail	0.02	0.18	**–0.35**	–0.2
Pied wagtail	0.08	–0.04	**–0.39**	–2.2
Song thrush	0.19	0.08	0.31	0.9

An example of phenological change is shown in Figure 3.1.

Some of the species, for example dipper and grey wagtail, may be reasonably considered as freshwater rather than terrestrial species.

Figure 3.1 Changes in mean first egg dates for dipper (black line) and great tit (grey line), significant at $p<0.05$ and $p<0.01$ respectively. Means based on <5 records have been omitted from this graph



3.2 Scottish Bird Report hirundine (swallow family) migration dates

3.2.1 Data

Data were abstracted from the Scottish Bird Report for the years 1968–2000 by Angela Turner (University of Nottingham). First seen and last seen dates for swallow, house martin and sand martin were summarised.

3.2.2 Results

A significant advance in first arrival was detected for all three species (Table 3.3). There was no significant trend in departure dates, although all three coefficients were positive suggesting later departure.

The advantage of temperature over rainfall or sunshine as a predictor of migration phenology was less clear cut than in other series. Arrivals were significantly negatively correlated with either current month's temperature or with that of the previous month. The pattern was less clear for departures, although a significant positive correlation (warmer = later departure) was calculated for house martin and the temperature of the month prior to the mean date (November). The duration of stay was significantly longer in all three species.

The response to temperature suggests an advance in spring arrival and a delay in autumn departure are both associated with rising temperatures. These data are taken from an all-Scotland report and it must be borne in mind that some of the tabulated trends may be influenced by recorder effort if a growing number of observers is contributing to the report.

Table 3.3 Trends (days/year) in first seen and last seen records of three hirundines 1968–2000, correlations with monthly temperatures for the mean month (T_0) and two preceding months (T_{-1} and T_{-2}) and the response of the species to a 1°C increase in these months. Significant results are emboldened.

	Arrival or departure date						
	Mean	**Trend**	**SE**	**T_{-2}**	**T_{-1}**	**T_0**	**Response days/°C**
Swallow first seen	87.2	**–0.732**	**0.138**	–0.17	**–0.51**	**–0.66**	–5.8
House martin first seen	94.0	**–0.787**	**0.150**	**–0.35**	**–0.38**	–0.15	–4.8
Sand martin first seen	81.7	**–0.702**	**0.130**	–0.26	–0.33	**–0.63**	–5.3
Swallow last seen	329.9	0.382	0.204	0.15	0.02	0.34	6.6
House martin last seen	353.0	0.113	0.188	–0.23	**0.41**	0.23	3.2
Sand martin last seen	348.9	0.225	0.263	–0.17	0.33	0.32	5.1

3.3 Deeside bird records

3.3.1 Data

The data used are an extension of those reported by Jenkins & Watson (2000) to include the years 1974–2005. All observations of first song and arrival were recorded near Aboyne by David Jenkins. Species with less than 10 years of records were omitted leaving 39 species for analysis.

3.3.2 Results

Table 3.4 summarises trends in the bird species. Of the 39 species, 32 had negative trends (13 significant) and seven positive trends (none significant). The average trend was –0.41 days/year equating to an average advance of over four days/decade or 13 days over the entire study period. Early bird events were associated with a greater advance in phenology (Figure 3.2).

Temperature again dominated significant correlations with climate variables; there were 23 significant correlations with temperature, 13 with rainfall and eight with sunshine. Table 3.5 summarises the correlations with three monthly temperatures. Eighty three of the correlations were negative (19 significant) and 33 positive (four significant). The response to temperature ranged from −14 days/°C to +14 days/°C although it should be noted that the extreme values were often associate with shorter, and thus less reliable, series (Figure 3.3). For 29 of the 39 species the response was negative and the all species average was –2.5 days/°C.

For the 25 non migrant events the mean date was day 43.4, the mean trend –0.528, and the mean response –3.4 days/°C. For the 14 migrant events the mean date was day 122.6, mean trend was –0.206 and mean response −1.1 days/°C. Of these, only the difference in dates is statistically significant, although the others are significant when the short time series (<20 years) are removed.

There is a significant correlation between trend and response ($r=0.35$, $p<0.05$).

Figure 3.4 shows the changing phenology for a migratory (sand martin) and non-migratory (grey wagtail) species. The change in sand martin phenology is very evident from a large number of other UK locations.

Table 3.4 Numbers of years of records (n) and trend (days/year) over time for first song or arrival of 39 bird species. Significant trends are emboldened, species ordered by magnitude of trend

	First song or arrival date			
Species	**n**	**Mean**	**Trend**	**SE**
Pied wagtail	17	26.6	**–3.54**	**0.62**
Blackcap	16	129.6	**–2.01**	**0.46**
Greenfinch	22	30.4	**–1.64**	**0.31**
Lapwing	25	44.9	**–1.20**	**0.41**
Wren	22	15.8	–1.09	0.53
Dunnock	21	36.9	–1.08	0.53
Grey wagtail	19	71.3	**–1.04**	**0.17**
Robin	26	12.5	**–0.97**	**0.18**
Song thrush	26	40.8	**–0.93**	**0.40**
Chaffinch	31	36.0	**–0.89**	**0.20**
Blue tit	26	7.8	**–0.89**	**0.23**
Mistle thrush	25	20.0	**–0.77**	**0.30**
Great tit	28	11.0	**–0.75**	**0.15**
Oystercatcher	27	50.6	**–0.55**	**0.19**
Blackbird	23	59.0	–0.53	0.35
Sand martin	17	105.8	**–0.45**	**0.12**
Great crested grebe	14	75.4	–0.38	0.73
Goldcrest	10	49.9	–0.37	1.04
Curlew	25	61.9	–0.32	0.23
Black-headed gull	24	57.6	–0.30	0.18
Coal tit	22	5.6	–0.28	0.26
Tree pipit	23	115.2	–0.23	0.19
Swallow	25	109.3	–0.19	0.12
Spotted flycatcher	25	133.6	–0.17	0.16
Whinchat	20	120.0	–0.15	0.18
Swift	24	134.1	–0.12	0.08
Cuckoo	26	123.5	–0.11	0.14
Willow warbler	31	110.7	–0.09	0.07
Sandpiper	25	117.1	–0.09	0.16
Redstart	23	116.0	–0.05	0.14
Redshank	18	79.9	–0.04	0.31
Sedge warbler	18	132.0	–0.04	0.26
Treecreeper	11	37.2	0.08	0.63
Yellowhammer	12	62.4	0.14	0.57
Wood warbler	22	129.8	0.24	0.22
Whitethroat	15	139.5	0.58	0.38
Green woodpecker	20	59.8	1.11	0.64
Meadow pipit	12	75.8	1.11	1.21
Stonechat	16	55.9	1.92	1.18

Table 3.5 The correlations of first song/arrival with monthly temperatures for the mean month (T_0) and two preceding months (T_{-1} and T_{-2}) and the response of the species to a 1°C increase in these months. Significant correlations are emboldened, species order as Table 3.4

Species	T_{-2}	T_{-1}	T_0	**Response days/°C**
Pied wagtail	–0.21	0.14	–0.03	–0.7
Blackcap	–0.09	–0.48	–0.21	–9.3
Greenfinch	–0.26	–0.24	–0.43	–9.2
Lapwing	0.06	–0.35	–0.38	–3.1
Wren	–0.26	0.02	–0.02	–2.9
Dunnock	**–0.53**	–0.43	**–0.57**	–13.6
Grey wagtail	–0.37	–0.20	–0.41	–3.6
Robin	–0.27	–0.07	–0.39	–5.0
Song thrush	0.10	–0.40	**–0.52**	–5.6
Chaffinch	–0.12	**–0.42**	–0.22	–4.0
Blue tit	**–0.41**	–0.07	–0.32	–5.8
Mistle thrush	–0.17	–0.20	**–0.55**	–7.0
Great tit	–0.37	–0.12	0.03	–2.6
Oystercatcher	–0.31	**–0.53**	**–0.61**	–6.5
Blackbird	**–0.42**	–0.25	**–0.51**	–9.6
Sand martin	–0.40	–0.48	**–0.65**	–5.5
Great crested grebe	0.32	–0.11	**0.62**	8.4
Goldcrest	0.54	–0.24	–0.45	14.6
Curlew	**–0.41**	**–0.63**	**–0.46**	–6.0
Black-headed gull	0.00	**–0.63**	**–0.44**	–4.0
Coal tit	0.07	–0.09	–0.36	–1.6
Tree pipit	0.09	–0.38	**–0.56**	–5.6
Swallow	0.17	–0.19	–0.05	–0.7
Spotted flycatcher	–0.26	–0.18	0.08	–1.4
Whinchat	0.41	–0.22	0.14	1.4
Swift	–0.02	–0.22	–0.03	–0.7
Cuckoo	0.11	–0.19	–0.14	–1.2
Willow warbler	–0.04	0.09	**–0.50**	–1.3
Sandpiper	0.28	0.07	0.08	1.2
Redstart	0.07	0.12	–0.07	0.2
Redshank	–0.39	–0.09	–0.15	–1.4
Sedge warbler	**0.51**	–0.23	0.07	0.3
Treecreeper	**–0.65**	–0.28	–0.59	–14.6
Yellowhammer	–0.17	–0.59	–0.15	–6.5
Wood warbler	0.36	0.33	0.18	6.0
Whitethroat	**0.60**	–0.26	0.13	1.4
Green woodpecker	–0.35	0.02	–0.07	–7.5
Meadow pipit	0.29	0.54	–0.22	4.9
Stonechat	–0.03	**0.56**	0.16	9.1

Figure 3.2 Early bird events were associated with greater phenological advance (r=0.34, p<0.05)

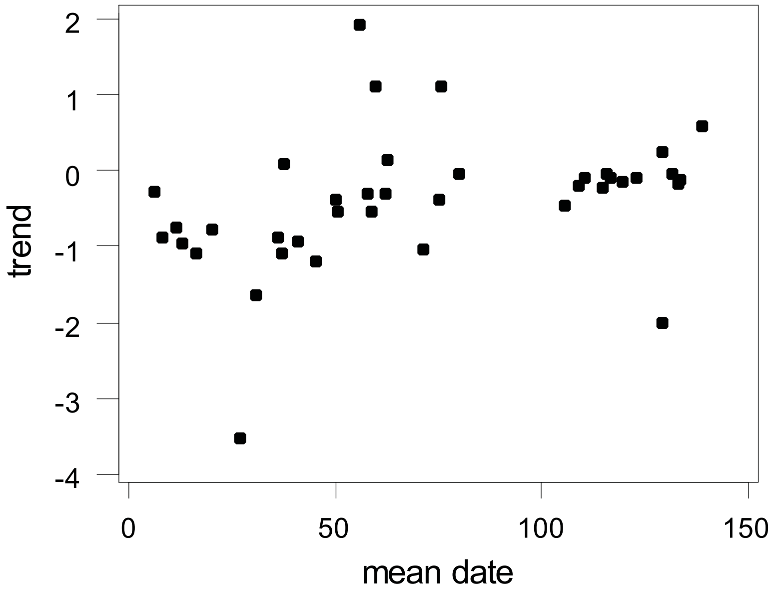


Figure 3.3 The relationship between response and length of series. Greater variability in response was associated with short series of data

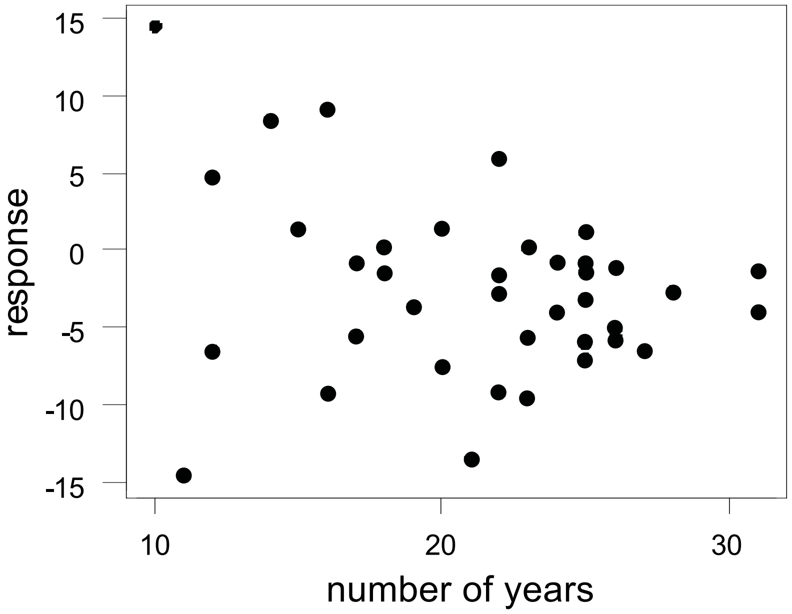
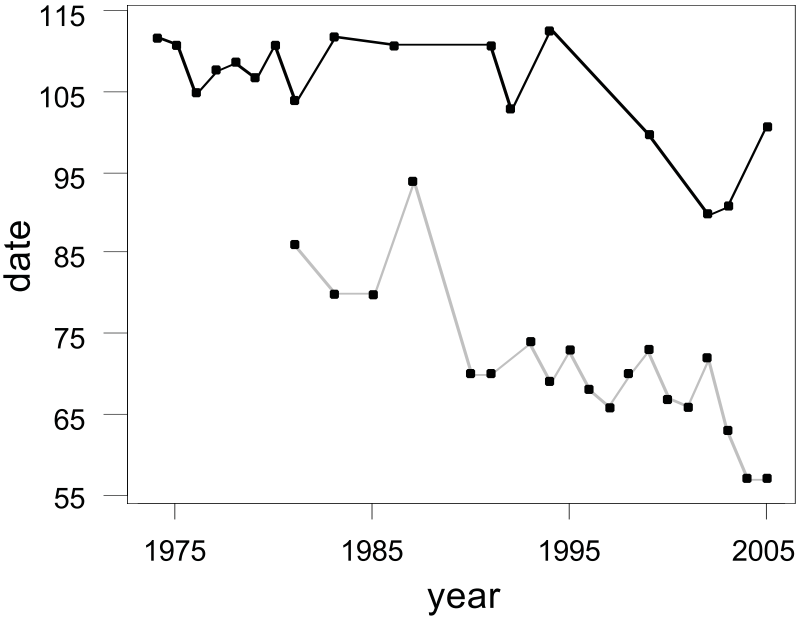


Figure 3.4 Two species showing a phenological advance: the change in mean date for grey wagtail (grey) and sand martin (black), significant at $p<0.01$ and $p<0.001$ respectively



3.4 North Ronaldsay Bird Observatory

3.4.1 Data

Observations of birds have been made at the North Ronaldsay Bird Observatory (NRBO) for the 20-year period 1985–2004. Bird numbers are logged daily and from these the first and last observations in a year can be calculated. We have made a very elementary investigation of the nine million records collected in this period. We have focussed on the summer visitors and passage birds (82 species) and winter visitors and passage birds (29 species). Only the first and last birds in each year have been summarised. Time prevented the calculation of mean passage date in spring and autumn, or a measure of spread or symmetry (skewness) in the seasonal patterns. Time also prevented (at this stage at least) the calculation of correlations with temperature. We have omitted birds with less than 100 observations overall. Trends in dates were calculated by regression with numbers of observations as a weighting factor. Shortage of time has meant that the huge potential from this data set has not been realised. It is recommended that further work be undertaken on this data set.

3.4.2 Results

3.4.2.1 Summer bird species

A summary of trends in first and last birds is given in Table 3.6. Trends in first date varied from –5.7 days/year to +14.3 days/year and averaged –0.34 days/year (earlier by over three days/decade) or an average advance of nearly seven days over the study period.

Fifty three species (13 significant) had a negative trend in first arrival and 29 (one significant) a positive trend. Earlier species tended to have a greater trend towards earlier observation (Figure 3.5).

Table 3.6 A summary of the arrival and departure dates of 82 summer bird species from North Ronaldsay 1985–2004. "m" and "L" indicate initial designations for marine and long distance migrants respectively. Significant trends (days/year) in arrival and departure birds are emboldened, species ordered by trend in first arrival date

			Spring arrival			**Autumn departure**		
		Species	**Mean**	**Trend**	**SE**	**Mean**	**Trend**	**SE**
		Little grebe	183.1	–5.71	3.14	271.5	**–6.00**	**2.79**
m	L	Pintail	72.0	**–5.64**	**1.47**	310.2	**3.88**	**1.00**
		Common redpoll	90.1	–4.65	2.90	310.6	2.06	1.31
		Greenfinch	129.6	–4.14	3.51	287.1	–1.50	2.39
		Lapland bunting	134.2	–4.12	2.35	303.1	0.46	1.07
	L	Greenshank	130.4	**–3.87**	**1.18**	258.3	–0.09	0.80
		Chaffinch	64.7	**–3.73**	**1.07**	314.9	–0.15	0.61
m		Black-headed gull	47.8	**–3.63**	**0.94**	321.7	1.16	0.84
	L	Black-tailed godwit	118.2	**–3.57**	**1.07**	264.9	0.12	0.75
m	L	Scaup	164.9	–3.28	2.47	269.1	**4.09**	**1.76**
m		Shelduck	32.1	–3.21	0.95	275.4	–0.84	3.01
m	L	Pomarine skua	216.5	–3.06	2.88	293.1	–0.81	1.20
	L	Black redstart	88.8	**–2.64**	**0.96**	295.4	**4.37**	**1.81**
		Collared dove	98.5	**–2.63**	**0.82**	246.9	–0.16	1.54
m	L	Leach's petrel	195.5	–2.54	1.85	259.0	1.36	1.14
m	L	Little gull	154.6	–2.27	1.31	250.1	–2.55	1.32
	L	Chiffchaff	83.8	–1.86	1.00	326.9	0.93	0.84
	L	Bluethroat	152.5	–1.72	1.44	249.4	–1.50	1.45
		Long-eared owl	88.7	–1.67	3.60	301.6	1.01	1.55
		Stonechat	76.5	**–1.62**	**0.61**	236.1	5.37	2.93
m	L	Great skua	93.0	–1.30	0.94	298.4	–0.64	0.46
m	L	Manx shearwater	134.6	–1.08	1.05	287.9	–0.50	0.38
m	L	Storm petrel	173.2	–1.08	0.99	276.5	–1.07	1.07
m	L	Lesser black-backed gull	77.4	–1.05	1.00	274.5	–0.63	0.57
		Mistle thrush	95.4	–0.98	2.25	280.8	–0.34	1.26
		Carrion crow	92.7	**–0.95**	**0.43**	215.8	**–5.79**	**2.38**
	L	Common redstart	127.4	–0.92	0.74	288.5	–0.63	0.65
		Pied wagtail	67.8	–0.90	0.69	293.8	0.04	0.26
	L	Sand martin	118.0	**–0.80**	**0.26**	249.4	1.59	1.32
	L	Whinchat	127.5	–0.76	0.43	291.7	–0.50	0.63
		Wood pigeon	80.8	–0.75	1.27	297.1	2.27	1.11
	L	Swallow	108.4	**–0.72**	**0.32**	290.5	0.87	0.50
	L	Blackcap	116.0	–0.45	1.15	320.2	0.63	0.80
m	L	Arctic tern	117.3	**–0.43**	**0.11**	279.9	**–1.34**	**0.55**
	L	Lesser whitethroat	137.6	–0.41	1.27	293.4	–0.67	0.41
	L	Willow warbler	108.8	–0.41	0.46	290.3	–0.89	0.56
	L	House martin	125.2	–0.41	0.42	253.1	–2.45	1.66
		White wagtail	95.7	–0.36	0.89	255.9	–0.64	2.38
		Sparrowhawk	88.4	–0.35	1.26	282.6	–1.10	1.71
		Dunnock	93.4	–0.34	0.84	295.7	1.74	1.46

Table 3.6 *(continued)*

			Spring arrival			Autumn departure		
		Species	**Mean**	**Trend**	**SE**	**Mean**	**Trend**	**SE**
m	L	Common tern	146.3	–0.33	0.59	231.5	**2.43**	**1.12**
		Short-eared owl	101.9	–0.33	1.16	273.7	–0.85	1.14
	L	Sedge warbler	131.8	–0.30	0.25	231.8	2.92	1.49
	L	Wheatear	91.8	–0.29	0.19	305.0	0.15	0.52
	L	Yellow-browed warbler	265.9	–0.26	0.23	286.4	–0.25	0.39
m	L	Sandwich tern	88.1	–0.22	0.24	257.8	–0.41	0.50
		Common rosefinch	159.7	–0.12	0.99	267.3	0.42	0.71
	L	Spotted flycatcher	137.6	–0.11	0.27	266.7	–1.45	1.03
		Little bunting	272.6	–0.07	0.42	284.6	–1.40	0.80
m	L	Arctic skua	108.6	–0.07	0.51	285.8	–0.22	0.78
	L	Blue-headed wagtail	154.0	–0.06	2.74	256.8	1.04	1.22
	L	Ring ouzel	107.1	–0.02	0.41	298.1	0.74	0.51
	L	Swift	143.7	–0.01	0.33	258.2	–0.78	0.72
	L	Red-backed shrike	146.4	0.03	0.40	231.5	–0.59	1.22
		Rook	76.4	0.07	0.49	230.5	3.93	3.74
	L	Common sandpiper	126.9	0.14	0.39	253.7	1.20	0.89
		Goldcrest	85.3	0.15	0.38	307.7	0.08	0.30
	L	Whitethroat	129.0	0.20	0.57	266.0	–0.94	0.70
		Jackdaw	98.9	0.24	0.74	175.6	**–9.62**	**2.66**
	L	Barred warbler	234.5	0.45	0.83	282.5	–0.24	0.40
		Brambling	89.5	0.47	0.96	319.1	0.71	0.62
	L	Garden warbler	143.1	0.48	0.66	294.8	–0.33	0.44
	L	Corncrake	148.4	0.53	0.80	236.0	–1.64	1.08
	L	Icterine warbler	192.3	0.58	2.46	241.1	–2.02	1.10
m	L	Common scoter	130.4	0.65	2.79	281.8	**–3.50**	**1.66**
m	L	Puffin	93.6	0.73	0.86	287.1	**–2.90**	**1.02**
	L	Reed warbler	177.5	0.81	1.96	271.1	–1.31	0.95
	L	Turtle dove	147.7	0.88	1.01	271.0	1.85	1.36
		Siskin	99.9	0.95	1.76	299.2	**–2.30**	**1.08**
		Linnet	71.5	0.98	1.52	314.5	**–2.32**	**1.07**
m	L	Sooty shearwater	207.8	1.25	1.00	301.9	**–1.93**	**0.84**
		Alba wagtail	136.3	1.34	3.84	287.9	0.53	0.95
	L	Pied flycatcher	138.6	1.44	1.36	276.4	**–1.11**	**0.40**
	L	Wood warbler	155.6	1.45	1.32	258.3	0.43	0.55
	L	Red-breasted flycatcher	233.2	1.79	2.32	283.1	–0.05	0.42
		Bullfinch	241.7	1.95	1.98	255.4	4.61	2.12
	L	Wryneck	165.6	1.98	2.48	252.0	–0.05	0.74
	L	Green sandpiper	157.5	3.14	1.56	236.2	–0.45	0.71
	L	Tree pipit	130.0	3.22	1.90	278.6	1.14	0.95
		Common crossbill	164.9	**3.83**	**0.99**	224.3	**–3.56**	**1.09**
		Yellowhammer	198.3	10.09	4.84	269.9	0.33	1.64
m	L	Little auk	143.7	14.29	7.66	319.8	–0.55	1.17

Figure 3.5 Greater advance in spring arrival date was evident in earlier species (r=0.27, p<0.05)

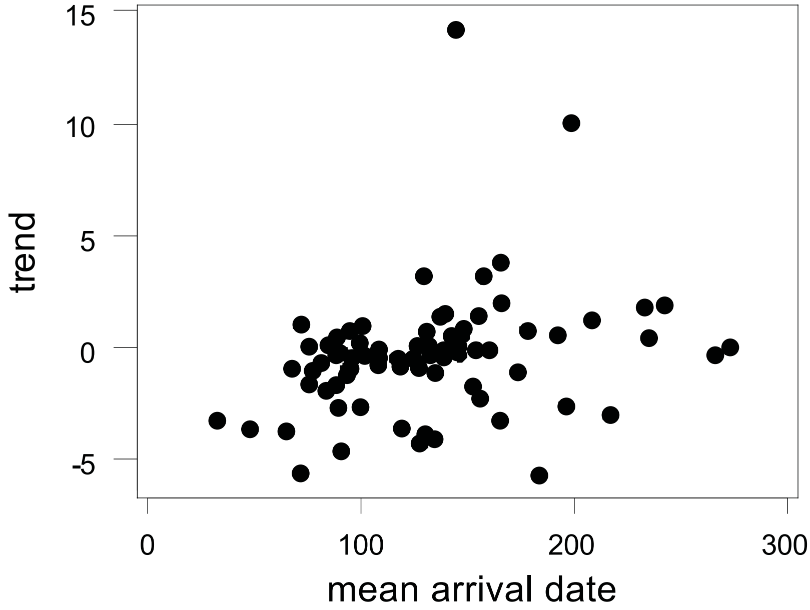
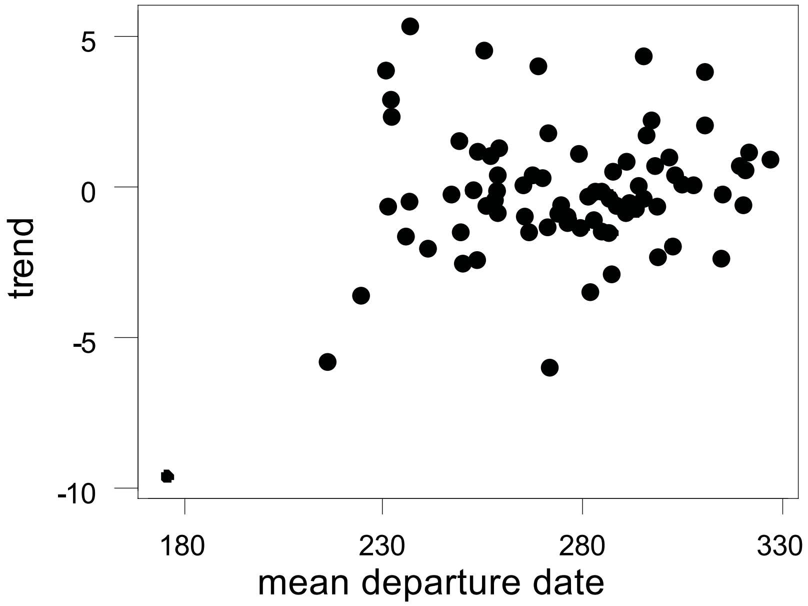


Figure 3.6 Greater advance may also be apparent in species departing earlier in autumn (r=0.24, P=0.027)



Trends in last date varied from –9.6 days/year to +5.4 days/year and averaged –0.21 days/year (over two days per decade) or an average advance of four days over the study period. Forty nine species (11 significant) had a negative trend in last date and 33 species (four significant) a positive trend.

Short distance migrants (30 species) had a mean first day of day 111.9, a trend in first day of –0.673, a mean last day of day 276.7 and a trend in last day of –0.305. Long distance migrants (52 species) had a mean first day of day 140.7, a trend in first day of –0.152 (earlier by one and a half days/decade), a mean last day of day 274.5 and a trend in last day of –0.101 (earlier by one day/decade). Only mean first date was significantly different (tested using ANOVA) between the two groups.

Marine species (19 species) had a mean first date of day 126.2, a mean trend in first date of –0.646 (earlier by six days/decade), a mean last date of 282.1 and mean trend in last date of –0.251 (earlier by over two days per decade). The remaining species (63 species) had a mean first date of day 131.4, a mean trend in first date of –0.251 (earlier by over two days/decade), a mean last date of day 273.2 and a mean trend in last date of –0.193 (earlier by nearly two days/decade). None of these were significantly different (tested using ANOVA).

Table 3.7 summarises correlation with air temperatures for the three months up to and including the month of the mean date. 162 (65%) of possible correlations with arrival date were negative (17 significantly negative, one significantly positive) whilst exactly 50% for departure dates (six significantly negative, eight significantly positive). Responses to temperature varied greatly and averaged –3.0 days/°C for arrival and –1.1 days/°C for departure.

3.4.2.2 Winter bird species

In addition to the summer migrants, dates of spring and autumn passage (ie departure and arrival) are also available for 29 wintering bird species. Table 3.8 summarises dates and trends in these variables. Trends to later spring departure were evident for 20 species (four significant) and earlier departure for nine species (one significant). The overall mean value was for delayed departure by 0.43 days/year (later by four days/decade). In autumn arrivals the opposite was true with 20 earlier species (three significant) and nine delayed species (none significant). The average trend was for earlier arrival by –0.34 days/year (earlier by three days/decade).

Table 3.7 The correlations of arrival and departure dates with monthly temperatures for the mean month (T_0) and two preceding months (T_{-1} and T_{-2}) and the response of the species to a 1°C increase in these months. Significant correlations are emboldened, species order as Table 3.6

	Spring arrival				**Autumn departure**			
Species	T_{-2}	T_{-1}	T_0	**Response days/°C**	T_{-2}	T_{-1}	T_0	**Response days/°C**
Little grebe	–0.41	–0.45	0.06	–52.9	0.14	–0.11	–0.20	–1.9
Pintail	–0.25	–0.41	–0.37	–18.8	0.36	0.00	0.26	18.2
Common redpoll	0.19	–0.02	0.09	6.0	–0.17	0.16	**0.53**	6.8
Greenfinch	0.12	0.11	0.36	38.8	0.26	–0.13	0.36	–0.5
Lapland bunting	–0.03	–0.18	0.08	–7.0	–0.01	–0.32	–0.28	–11.1
Greenshank	–0.30	–0.34	–0.06	–12.7	0.14	0.40	0.21	6.5
Chaffinch	–0.32	–0.24	–0.17	–8.4	0.23	0.11	0.23	6.9
Black-headed gull	0.18	**–0.53**	–0.39	–9.5	0.37	–0.11	0.18	9.1
Black-tailed godwit	–0.36	–0.27	–0.29	–18.8	–0.11	–0.25	–0.16	–4.6
Scaup	0.11	0.38	0.02	38.2	**0.58**	**0.60**	0.47	43.5
Shelduck	0.24	**–0.45**	–0.39	–6.1	0.06	–0.31	–0.13	–32.2
Pomarine skua	–0.07	0.05	0.06	–1.6	**–0.46**	–0.11	–0.23	–5.6
Black redstart	0.14	–0.05	–0.04	0.4	**0.60**	0.39	–0.15	22.0
Collared dove	–0.12	–0.29	**–0.53**	–14.1	**0.53**	0.30	0.22	29.2
Leach's petrel	0.14	0.07	–0.35	–8.5	0.02	–0.13	0.13	5.8
Little gull	–0.26	0.08	–0.14	–12.9	0.25	0.04	–0.30	–6.4
Chiffchaff	–0.20	–0.18	–0.23	–6.7	0.33	–0.30	0.00	3.6
Bluethroat	**–0.59**	0.03	0.09	–19.7	0.22	–0.08	–0.09	12.1
Long-eared owl	–0.19	–0.28	–0.36	–19.2	–0.06	0.05	–0.18	–4.4
Stonechat	–0.25	–0.12	–0.36	–6.6	0.25	–0.25	0.32	15.2
Great skua	0.05	0.08	–0.36	–5.7	–0.18	–0.19	0.11	–1.7
Manx shearwater	–0.34	–0.22	–0.08	–10.9	0.09	–0.10	–0.18	–2.3
Storm petrel	–0.19	–0.08	–0.15	–7.9	0.09	–0.25	–0.38	–10.9
Lesser black-backed gull	–0.31	–0.23	–0.07	–5.9	0.00	0.02	0.21	2.0
Mistle thrush	0.19	0.43	–0.06	14.6	0.13	0.06	0.09	7.1
Carrion crow	–0.31	0.02	–0.11	–2.1	–0.22	–0.22	–0.38	–37.8
Common redstart	0.15	–0.08	–0.09	–3.8	–0.02	–0.07	–0.14	–2.7
Pied wagtail	–0.43	–0.18	–0.14	–5.7	0.27	0.16	–0.08	0.8
Sand martin	–0.27	0.12	–0.29	–2.6	–0.10	–0.01	0.11	1.5
Whinchat	**–0.55**	0.04	–0.36	–3.9	0.09	0.14	–0.03	1.8
Wood pigeon	–0.14	–0.11	–0.18	–4.6	0.34	0.08	–0.31	–4.8
Swallow	–0.37	–0.19	–0.36	–4.3	0.22	0.14	–0.26	–0.3
Blackcap	–0.39	0.09	–0.13	–4.7	0.13	–0.07	–0.12	0.4
Arctic tern	–0.23	–0.41	–0.42	–2.4	0.11	–0.41	0.13	–5.7
Lesser whitethroat	0.24	0.03	0.00	2.3	–0.16	–0.29	–0.34	–5.9
Willow warbler	**–0.45**	–0.41	–0.42	–6.1	–0.19	–0.15	0.04	–1.7
House martin	0.18	–0.15	0.29	2.0	–0.27	–0.15	–0.32	–28.0
White wagtail	–0.05	–0.12	–0.32	–9.8	0.36	–0.16	–0.35	–2.5

Table 3.7 *(continued)*

	Spring arrival				Autumn departure			
Species	**T_{-2}**	**T_{-1}**	**T_0**	**Response days/°C**	**T_{-2}**	**T_{-1}**	**T_0**	**Response days/°C**
Sparrowhawk	–0.20	**–0.46**	–0.35	–9.5	0.29	–0.05	–0.04	–4.0
Dunnock	–0.17	0.13	0.06	1.8	0.11	0.17	–0.16	3.3
Common tern	–0.42	–0.26	0.20	–3.7	0.37	–0.16	–0.14	10.7
Short-eared owl	–0.09	0.00	0.08	1.0	0.13	**0.45**	0.06	–2.2
Sedge warbler	–0.34	–0.36	–0.16	–4.4	0.36	–0.27	0.32	4.8
Wheatear	**–0.59**	–0.38	**–0.45**	–3.7	0.00	0.04	0.08	1.1
Yellow-browed warbler	–0.24	0.11	0.16	–0.8	0.25	0.00	–0.18	–1.5
Sandwich tern	**–0.45**	–0.22	–0.31	–2.6	0.18	0.34	0.19	5.1
Common rosefinch	–0.11	0.10	–0.30	–5.2	0.17	0.10	0.04	6.9
Spotted flycatcher	–0.27	–0.27	–0.20	–4.0	**–0.51**	–0.09	–0.17	–25.2
Little bunting	–0.15	0.02	0.35	3.4	–0.23	–0.12	–0.34	–6.2
Arctic skua	–0.20	0.14	–0.04	0.0	–0.05	–0.20	–0.28	–6.7
Blue-headed wagtail	–0.29	0.14	–0.12	–9.3	–0.16	0.08	0.11	–3.2
Ring ouzel	**–0.54**	–0.06	0.20	–0.1	0.34	0.12	**0.60**	7.1
Swift	0.20	–0.05	0.10	0.8	0.13	0.24	0.38	9.9
Red-backed shrike	–0.30	–0.16	0.28	3.0	0.34	–0.14	0.28	13.2
Rook	–0.34	–0.11	–0.28	–3.9	–0.22	–0.11	–0.02	–36.0
Common sandpiper	–0.38	–0.38	–0.13	–5.9	–0.13	0.32	0.22	–1.7
Goldcrest	–0.26	**–0.46**	**–0.45**	–3.7	–0.09	–0.24	**0.45**	0.2
Whitethroat	0.01	0.00	–0.28	–3.1	0.17	0.26	0.26	11.4
Jackdaw	–0.32	**–0.51**	–0.17	–13.6	–0.08	–0.32	0.01	–28.9
Barred warbler	**–0.52**	0.12	0.11	–8.4	–0.06	–0.19	0.21	–0.9
Brambling	–0.15	–0.19	0.20	0.3	–0.16	–0.28	0.40	–1.7
Garden warbler	–0.36	–0.14	0.31	2.8	0.16	–0.26	0.20	–1.6
Corncrake	–0.11	0.09	–0.41	–10.8	0.14	**–0.64**	–0.08	–23.6
Icterine warbler	–0.43	–0.23	**0.54**	4.9	0.10	–0.01	–0.20	4.0
Common scoter	0.04	–0.07	–0.21	–20.3	–0.05	0.02	0.00	1.4
Puffin	0.14	–0.22	–0.30	–11.5	–0.24	–0.08	–0.11	–3.2
Reed warbler	–0.12	0.17	–0.36	–3.3	**–0.55**	–0.37	–0.27	–29.8
Turtle dove	–0.14	–0.10	0.42	9.7	–0.19	0.01	–0.10	–14.3
Siskin	0.21	0.14	–0.06	2.2	0.11	**–0.50**	0.14	–7.6
Linnet	–0.30	–0.25	–0.18	–9.7	0.01	–0.23	–0.13	–6.0
Sooty shearwater	0.12	0.27	–0.04	7.4	–0.18	–0.17	0.08	–2.5
Alba wagtail	0.43	0.46	–0.05	28.6	–0.22	–0.29	–0.07	–5.0
Pied flycatcher	–0.30	–0.33	0.13	–5.7	–0.29	–0.41	0.00	–4.7
Wood warbler	–0.08	0.26	–0.25	–2.9	–0.19	0.04	0.20	–0.6
Red-breasted flycatcher	**–0.52**	0.44	0.27	–2.9	–0.09	–0.20	0.25	–0.9
Bullfinch	0.28	–0.12	0.25	15.8	–0.15	0.27	0.36	13.1
Wryneck	–0.43	–0.03	–0.19	–26.1	**–0.50**	–0.28	–0.04	–15.0
Green sandpiper	–0.04	0.13	0.12	7.4	0.06	0.12	–0.07	7.1
Tree pipit	0.10	–0.25	0.07	–4.0	0.09	–0.08	–0.30	–5.1
Common crossbill	–0.13	–0.25	0.07	–13.8	–0.12	0.11	0.20	–0.7
Yellowhammer	0.09	0.30	–0.04	37.6	0.10	–0.12	0.13	27.5
Little auk	0.21	0.07	0.05	21.6	0.08	0.11	–0.07	2.2

Table 3.8 Mean dates of spring departure and autumn arrival of 29 wintering bird species 1985–2004, together with estimates of trend (days/year). Significant trends are emboldened, species ordered by trend in spring departure

	Spring departure			**Autumn arrival**		
Species	**Mean**	**Trend**	**SE**	**Mean**	**Trend**	**SE**
Fieldfare	145.9	−1.14	0.61	236.4	−0.54	0.86
Robin	143.2	**−0.98**	0.35	253.0	0.51	0.49
Goldeneye	135.7	−0.97	0.69	274.8	0.85	0.81
Glaucous gull	118.8	−0.67	1.61	280.2	0.90	1.29
Long-tailed duck	145.7	−0.67	0.87	264.2	0.07	1.14
Grey plover	117.8	−0.49	1.82	244.2	−0.19	0.86
Ruff	135.7	−0.18	0.75	217.4	−0.57	0.54
Purple sandpiper	150.7	−0.18	0.20	190.5	−0.23	0.21
Song thrush	154.2	−0.17	0.70	231.0	0.30	1.23
Woodcock	113.9	0.10	1.18	280.3	−1.05	0.61
Pink-footed goose	131.5	0.29	2.14	261.3	−0.02	0.16
Snow bunting	139.8	0.31	0.61	256.9	0.12	0.14
Red-breasted merganser	154.4	0.36	0.55	230.2	−0.72	1.42
Redwing	145.0	0.41	0.56	255.6	−1.26	0.71
Whimbrel	169.2	0.47	0.38	189.6	−0.12	0.25
Sanderling	174.1	**0.73**	0.32	191.8	−1.04	0.52
Curlew sandpiper	155.1	0.73	0.46	234.7	**−2.17**	0.40
Dunlin	172.5	**0.76**	0.34	190.8	−0.93	0.53
Turnstone	176.6	**0.82**	0.30	184.5	−0.13	0.14
Greylag goose	151.1	0.84	0.65	239.9	−1.48	1.11
Knot	163.0	0.94	0.46	199.1	**−1.31**	0.50
Jack snipe	100.8	1.02	1.93	260.8	0.31	0.37
Little stint	154.1	1.12	1.15	244.9	0.73	0.51
Grey heron	144.6	1.14	0.94	195.2	**−1.29**	0.55
White-fronted goose	93.8	1.21	3.96	305.9	1.41	1.79
Hen harrier	106.9	1.22	1.62	266.3	−1.44	1.02
Whooper swan	127.3	1.51	1.01	263.0	−0.30	1.06
Bar-tailed godwit	160.3	**1.59**	0.48	193.7	−0.51	0.47
Barnacle goose	134.9	2.30	1.37	269.9	−0.42	1.01

Table 3.9 summarises correlations with temperatures. For spring departures the ratio of negative to positive correlations was 35:51 (0:5 significant) and the response averaged +3.0 days/°C. For autumn arrivals the relevant figures are 62:24 (8:0 significant) and a mean response of −3.3 days/°C. The overall impression is one for later departure and earlier arrival.

Table 3.9 The correlations of spring departure and autumn arrival with monthly temperatures for the mean month (T_0) and two preceding months (T_{-1} and T_{-2}) and the response (Resp) of the species to a 1°C increase in these months. Significant correlations are emboldened, species order as Table 3.8

	Spring departure				**Autumn arrival**			
Species	**T_{-2}**	**T_{-1}**	**T_0**	**Resp**	**T_{-2}**	**T_{-1}**	**T_0**	**Resp**
Fieldfare	0.05	–0.26	–0.23	–8.0	–0.19	0.16	–0.21	–0.7
Robin	–0.20	–0.27	–0.38	–7.2	–0.11	–0.07	0.26	3.2
Goldeneye	–0.15	0.02	0.08	1.4	0.32	0.06	0.21	4.2
Glaucous gull	0.27	–0.26	–0.21	–2.5	–0.03	–0.01	0.13	2.4
Long-tailed duck	–0.23	–0.03	–0.04	–2.4	–0.16	–0.16	–0.01	–3.3
Grey plover	–0.03	0.10	–0.23	–3.0	–0.05	–0.14	0.25	8.1
Ruff	0.41	0.27	0.15	8.0	–0.06	0.16	–0.10	1.7
Purple sandpiper	0.10	–0.24	–0.04	–1.3	–0.27	–0.37	0.11	–2.3
Song thrush	0.15	0.07	–0.18	1.7	0.17	**–0.47**	–0.14	–11.7
Woodcock	0.01	–0.06	–0.08	–2.4	–0.07	–0.41	0.25	–4.5
Pink-footed goose	0.32	–0.17	**0.69**	18.7	–0.18	–0.15	–0.14	–1.5
Snow bunting	0.11	–0.31	0.28	0.3	0.37	0.26	0.29	2.4
Red-breasted merganser	0.13	0.26	0.11	5.9	–0.07	**–0.52**	–0.16	–25.5
Redwing	0.01	0.28	–0.03	3.4	0.29	–0.21	–0.21	3.8
Whimbrel	0.11	–0.04	–0.21	–0.5	–0.13	–0.23	–0.31	–4.3
Sanderling	0.44	0.25	0.09	6.2	–0.24	**–0.48**	–0.03	–9.7
Curlew sandpiper	0.32	0.59	0.27	14.3	**–0.46**	–0.30	**–0.58**	–14.3
Dunlin	0.44	0.32	0.18	7.6	–0.10	–0.29	–0.20	–8.6
Turnstone	**0.45**	0.21	0.00	5.3	–0.06	0.00	–0.31	–1.5
Greylag goose	**0.51**	0.40	0.20	11.4	0.00	**–0.63**	**–0.45**	–23.0
Knot	0.21	–0.12	–0.28	–1.0	–0.16	–0.07	–0.18	–6.1
Jack snipe	–0.50	0.02	0.19	–0.9	–0.08	–0.07	0.26	2.9
Little stint	0.24	0.49	–0.47	5.3	–0.07	0.24	0.12	–0.8
Grey heron	0.40	**0.46**	–0.02	11.9	–0.31	**–0.55**	–0.04	–12.8
White-fronted goose	–0.66	–0.36	0.59	–2.9	0.28	–0.12	0.19	21.1
Hen harrier	0.05	0.08	–0.07	0.2	0.00	–0.18	–0.12	–1.5
Whooper swan	0.03	0.23	–0.05	4.6	–0.04	–0.03	–0.10	–4.4
Bar-tailed godwit	**0.47**	–0.04	0.26	7.8	–0.18	0.06	–0.25	–4.7
Barnacle goose	–0.07	0.19	–0.09	3.7	–0.20	0.10	0.17	–3.1

3.5 Fair Isle Bird Observatory

3.5.1 Data

The Fair Isle Bird Observatory (FIBO) was established in 1948 and dates of bird migration were recorded from this period. For this study we have concentrated on the more readily accessible first arrival dates in spring for the period 1970–2004. After eliminating some rarer species for which estimates of arrival date may be strongly influenced by low population, and records where no spring migration was observed, a total of 43 species remained. As with the NRBO data there is huge potential in the dataset for a more thorough analysis.

3.5.2 Results

A summary of results is shown in Table 3.10. Trends in first date varied from –0.7 days/year to +0.4 days/year and averaged –0.13 days/year (over one day/decade earlier) or an average advance of 4.5 days over the study period. 32 species (11 significant) had a negative trend in first arrival and 11 (one significant) a positive trend. There was no overall relationship between trend and mean first arrival date (r=0.22, P=0.15).

There were too few short distance migrants to undertake a comparison of short and long distance species.

In a comparison with All Scotland temperature over the three months up to and including mean arrival date of each species, there were 79 negative correlations (three significant) and 50 positive correlations (three significant). Whilst there were more negative correlations the overall level of significant correlations is no more than would be expected by chance and hence these correlations have not been tabulated. Ratios for negative to positive correlations for rainfall and sunshine were close to 50:50 with few significant results. The response to temperatures of the three months is shown in Table 3.10 and varies from −8.3 to +8.3 days/°C with a mean of –0.5 days/°C (five days earlier per decade).

The low level of correlation with temperature compared to other examined data sets might suggest that All Scotland temperature data would be inappropriate for a remote island like Fair Isle.

Figure 3.7 displays the opposing trends in spring arrival date for two species: arctic tern and turtle dove. The latter species was the only species to be significantly later and is undergoing a "rapid decline" in population which may, at least in part, account for its later observation.

Figure 3.7 Changes in mean first appearance date of the arctic tern (solid line) and turtle dove (dotted line) at Fair Isle, significant at p<0.001 and p<0.01 respectively

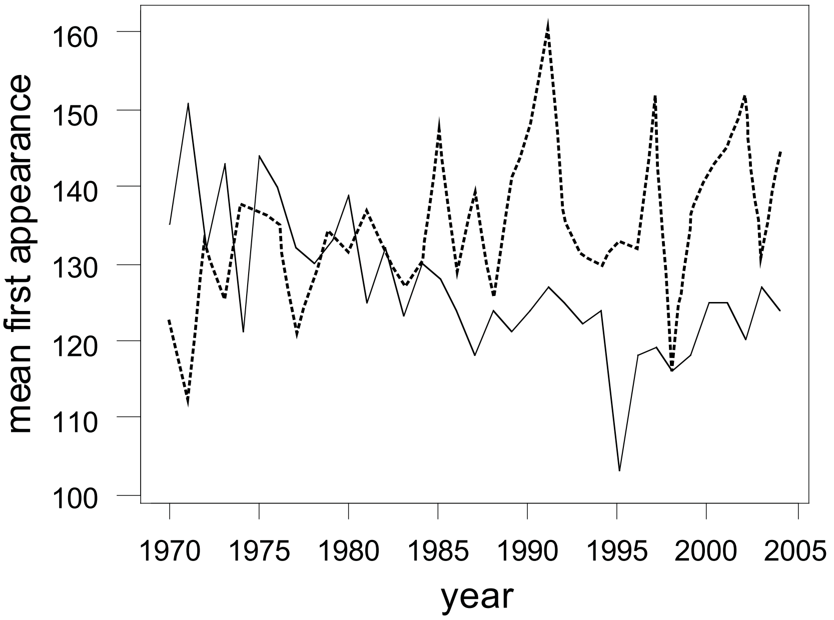


Table 3.10 A summary of the 43 species from Fair Isle 1970–2004. The numbers of years of records (n), mean arrival date and trend (days/year) over time (with standard error) are given together with the predicted response to a 1°C increase in temperature. Significant trends are emboldened, species ordered by magnitude of trend

		Arrival date			
Species	**n**	**Mean**	**Trend**	**SE**	**Response days/°C**
Pied wagtail	35	74.5	**–0.74**	**0.18**	–6.4
Subalpine warbler	26	137.5	**–0.63**	**0.28**	–8.3
Arctic tern	35	126.9	**–0.61**	**0.11**	–2.4
Sand martin	35	118.0	**–0.52**	**0.16**	–3.6
Blackcap	35	116.0	–0.45	0.24	–0.2
Grasshopper warbler	33	119.5	**–0.39**	**0.15**	–2.4
Great skua	35	88.5	**–0.36**	**0.15**	0.5
Common tern	35	127.3	**–0.34**	**0.09**	–0.9
House martin	35	122.0	**–0.32**	**0.15**	–0.1
Sedge warbler	35	124.5	**–0.30**	**0.14**	–0.5
Common rosefinch	32	144.1	–0.28	0.19	1.3
Swallow	35	109.8	**–0.27**	**0.11**	–3.0
Reed warbler	32	145.8	–0.27	0.21	–3.8
Icterine warbler	29	148.4	–0.22	0.11	–1.4
Common sandpiper	34	117.3	–0.21	0.13	–0.5
Marsh warbler	32	153.8	–0.18	0.19	–4.9
Northern wheatear	35	88.5	–0.16	0.11	–2.3
Whimbrel	34	111.4	**–0.16**	**0.06**	–1.3
Tree pipit	35	116.6	–0.16	0.08	–1.8
Swift	35	138.6	–0.14	0.13	–1.7
Bluethroat	35	131.2	–0.13	0.12	–0.9
Lesser black-backed gull	35	82.8	–0.13	0.25	–3.3
Arctic skua	35	104.9	–0.12	0.07	–1.0
Whitethroat	35	126.1	–0.10	0.13	–0.6
Ring ouzel	35	98.9	–0.08	0.15	–0.2
Pied flycatcher	35	125.9	–0.04	0.11	0.6
Goldcrest	35	84.6	–0.03	0.26	–5.1
Red backed shrike	35	137.0	–0.02	0.15	–0.2
Osprey	29	138.3	–0.01	0.26	–0.7
Lesser whitethroat	35	124.9	–0.01	0.12	–0.6
Whinchat	35	120.7	–0.01	0.12	0.1
Wryneck	33	125.2	0.00	0.15	0.9
Cuckoo	35	132.2	0.00	0.18	–0.2
Sandwich tern	29	143.0	0.02	0.44	3.3
Common redstart	35	118.4	0.04	0.12	–0.4
Green sandpiper	34	116.7	0.08	0.19	1.6
White wagtail	35	90.7	0.11	0.23	2.8
Quail	28	140.8	0.12	0.26	2.9
Spotted flycatcher	35	131.2	0.17	0.09	0.5
Yellow wagtail (flava)	28	133.6	0.23	0.26	5.0
Yellow wagtail (thunbergi)	31	138.5	0.29	0.18	2.3
Yellow wagtail (flavissima)	32	126.6	0.30	0.23	8.3
Turtle dove	35	134.7	**0.44**	**0.15**	5.3

3.6 Aphids

3.6.1 Data

The data are from the four Scottish suction traps (Ayr, Dundee, East Craigs, Elgin) operated by the Scottish Agricultural Science Agency at Edinburgh in collaboration with the Rothamsted Insect Survey (www.rothamsted.bbsrc.ac.uk/insect-survey). For each year, the mean first capture date was calculated. Species categories were reduced to those 46 present in at least three quarters of the traps in the years 1971–2004. Data on first capture were obtained for each group in each year. Regression was weighted by the number of traps contributing to the mean date in each year.

3.6.2 Results

Table 3.11 summarises mean dates and trends. Forty three of the trends were negative , ie towards earlier capture. Of these 20 were statistically significant. None of the three positive trends was significant. The mean trend was –0.47 days/annum (nearly five days/decade earlier) equating to a mean advance of 16 days over the 34-year period of recording.

Examining first capture date with three months of All Scotland climate data revealed 44 significant correlations with temperature, six with rainfall and eight with sunshine. Table 3.12 summarises the correlations with temperature and the response to a 1°C warming over the three months. 128 of the correlations were negative (44 significant) compared to only 10 positive correlations (none significant). All but one species had a negative response to temperature. The average response to temperature was 12.5 days/°C.

Figure 3.8 shows, as an example of an advancing species, the trend in first capture date of *Ceruraphis eriophori* and Figure 3.9 demonstrates that a greater response was evident in the earlier species (r=0.45, P=0.002).

Table 3.11 Mean first capture dates and trends (days/year) of 46 aphid groups in Scotland 1971–2004. Significant trends are emboldened, species ordered by magnitude of trend

	Capture date		
Name	**Mean**	**Trend**	**SE**
Ceruraphis eriophori	186.4	**–1.32**	**0.51**
Aulacorthum solani	171.5	–1.01	0.56
Rhopalosiphum maidis	190.5	**–0.95**	**0.44**
Macrosiphum rosae	168.2	**–0.94**	**0.26**
Metopolophium fasciatum + dirhodum	154.4	**–0.93**	**0.34**
Aphis fabae + sambuci + spp.	160.6	**–0.78**	**0.31**
Anoecia corni + spp.	217.0	**–0.76**	**0.37**
Eriosoma (Schizoneura) patchiae	206.3	–0.74	0.56
Myzus ascalonicus	137.8	–0.74	0.45
Hyadaphis foeniculi	178.5	**–0.72**	**0.31**
Rhopalosiphum insertum	149.5	**–0.70**	**0.29**
Myzus cerasi	169.7	**–0.68**	**0.33**
Thecabius affinis	190.4	–0.65	0.36
Macrosiphum euphorbiae	152.3	**–0.64**	**0.31**
Euceraphis punctipennis	141.1	**–0.64**	**0.31**
Cavariella theobaldi	169.0	**–0.63**	**0.29**
Myzus ornatus	156.9	–0.61	0.49
Cavariella aegopodii	148.0	**–0.61**	**0.26**
Betulaphis quadrituberculata	166.7	–0.60	0.44
Brachycaudus helichrysi	142.0	**–0.58**	**0.25**
Metopolophium festucae s.lat.	150.9	–0.51	0.37
Acyrthosiphon pisum	169.2	–0.50	0.26
Rhopalosiphum insertum male	247.2	**–0.50**	**0.16**
Hyalopterus pruni	172.8	**–0.49**	**0.23**
Sitobion fragariae	164.5	–0.46	0.32
Capitophorus similis	166.7	–0.46	0.28
Sitobion avenae	157.5	–0.45	0.30
Rhopalosiphum padi male	221.9	**–0.45**	**0.21**
Cavariella pastinaceae	167.0	–0.44	0.28
Elatobium abietinum	134.4	**–0.44**	**0.18**
Drepanosiphum platanoidis	133.7	**–0.43**	**0.18**
Myzus persicae	172.9	–0.42	0.40
Rhopalosiphum padi	144.2	–0.42	0.26
Hyperomyzus lactucae	169.7	–0.37	0.35
Microlophium carnosum	171.3	–0.37	0.45
Ceruraphis eriophori male	282.4	**–0.31**	**0.14**
Drepanosiphum platanoidis male	271.4	–0.17	0.28
Eriosoma (Schizoneura) ulmi	171.4	–0.15	0.22
Adelgidae	156.5	–0.13	0.17
Brachycaudus helichrysi male	250.2	–0.08	0.17
Phyllaphis fagi	152.6	–0.08	0.28
Pemphigus + Parathecabius	195.1	–0.05	0.32
Capitophorus hippophaes	186.1	–0.03	0.46
Cavariella archangelicae	170.4	0.29	0.38
Cryptomyzus galeopsidis	171.3	0.36	0.35
Nasonovia ribisnigri	185.2	0.62	0.43

Table 3.12 Correlations of first capture date with temperature two months (T_{-2}), one month (T_{-1}) and in month (T_0) of mean date, those in bold are statistically significant. Response indicates the predicted change in dates for a 1°C rise in temperature over the same three month period, species order as Table 3.11

Species	**T_{-2}**	**T_{-1}**	**T_0**	**Response days/°C**
Ceruraphis eriophori	–0.14	–0.32	–0.16	–17.8
Aulacorthum solani	–0.14	**–0.58**	–0.19	–24.7
Rhopalosiphum maidis	–0.30	–0.02	0.21	–1.2
Macrosiphum rosae	**–0.38**	**–0.51**	–0.15	–14.4
Metopolophium fasciatum + dirhodum	–0.30	**–0.65**	–0.28	–21.2
Aphis fabae + sambuci + spp.	**–0.37**	**–0.74**	–0.22	–20.1
Anoecia corni + spp.	–0.08	–0.21	**–0.50**	–8.5
Eriosoma (Schizoneura) patchiae	–0.02	–0.05	**–0.44**	–21.5
Myzus ascalonicus	–0.30	–0.33	**–0.42**	–20.6
Hyadaphis foeniculi	–0.27	**–0.61**	–0.17	–20.7
Rhopalosiphum insertum	–0.30	**–0.35**	**–0.51**	–14.2
Myzus cerasi	–0.28	**–0.46**	**–0.42**	–18.5
Thecabius affinis	–0.19	**–0.34**	0.10	–9.6
Macrosiphum euphorbiae	–0.32	**–0.66**	–0.19	–17.4
Euceraphis punctipennis	–0.23	**–0.53**	–0.34	–14.7
Cavariella theobaldi	–0.12	**–0.38**	–0.33	–11.7
Myzus ornatus	–0.19	**–0.43**	–0.22	–19.3
Cavariella aegopodii	**–0.54**	–0.33	**–0.46**	–14.4
Betulaphis quadrituberculata	–0.19	–0.28	–0.12	–13.1
Brachycaudus helichrysi	**–0.45**	**–0.38**	**–0.64**	–15.4
Metopolophium festucae s.lat.	–0.21	**–0.36**	**–0.47**	–16.0
Acyrthosiphon pisum	–0.24	**–0.47**	–0.19	–10.9
Rhopalosiphum insertum male	0.10	–0.28	**–0.51**	–4.5
Hyalopterus pruni	–0.39	**–0.58**	**–0.31**	–14.3
Sitobion fragariae	–0.31	**–0.56**	–0.27	–17.3
Capitophorus similis	–0.25	–0.10	0.25	–8.8
Sitobion avenae	–0.30	**–0.52**	–0.27	–15.5
Rhopalosiphum padi male	–0.18	–0.30	**–0.48**	–6.2
Cavariella pastinaceae	–0.28	–0.20	–0.18	–10.3
Elatobium abietinum	**–0.51**	**–0.40**	**–0.57**	–11.0
Drepanosiphum platanoidis	–0.26	**–0.57**	–0.23	–8.4
Myzus persicae	–0.12	**–0.46**	–0.24	–15.3
Rhopalosiphum padi	**–0.35**	–0.22	**–0.52**	–11.7
Hyperomyzus lactucae	–0.32	**–0.37**	–0.05	–11.5
Microlophium carnosum	–0.29	–0.23	0.07	–14.3
Ceruraphis eriophori male	–0.19	**–0.53**	0.13	–5.0
Drepanosiphum platanoidis male	0.04	–0.09	0.04	2.4
Eriosoma (Schizoneura) ulmi	–0.34	–0.11	0.01	–4.0
Adelgidae	**–0.44**	**–0.61**	–0.23	–10.1
Brachycaudus helichrysi male	–0.20	–0.08	–0.22	–4.5
Phyllaphis fagi	–0.18	–0.28	–0.09	–7.5
Pemphigus + Parathecabius	–0.12	–0.20	–0.21	–12.2
Capitophorus hippophaes	–0.01	–0.20	–0.05	–8.7
Cavariella archangelicae	–0.07	–0.10	0.00	–4.7
Cryptomyzus galeopsidis	–0.08	–0.04	–0.10	–10.5
Nasonovia ribisnigri	–0.32	–0.19	–0.05	–15.5

Figure 3.8 Mean first catch dates of *Ceruraphis eriophori* in Scotland 1971–2004 have got earlier ($p<0.05$)

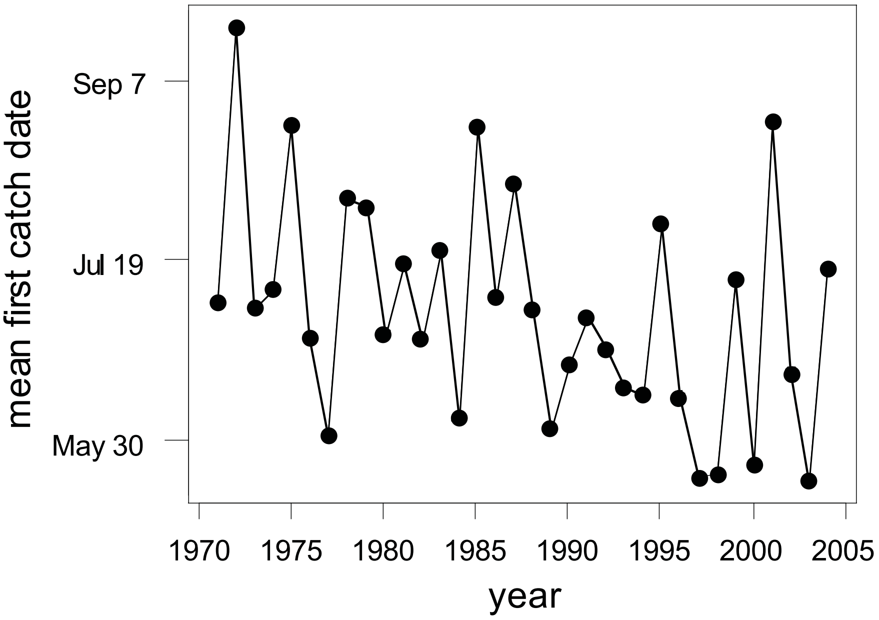
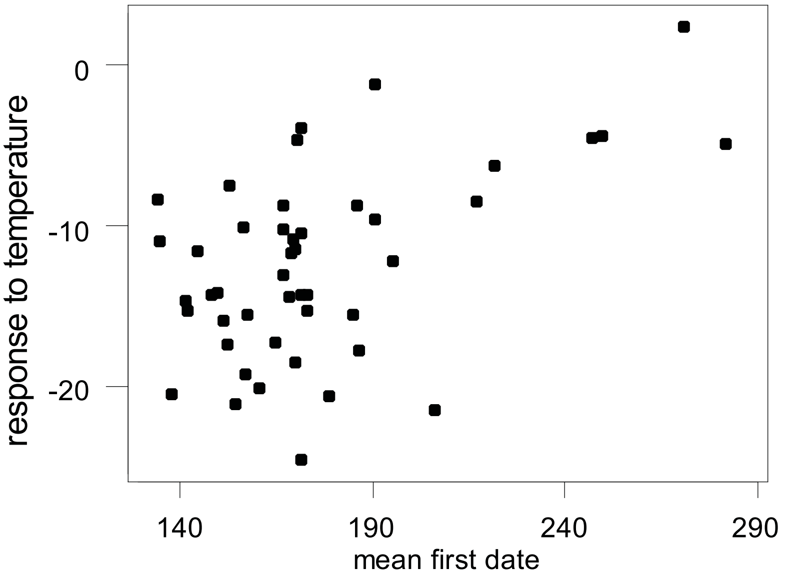


Figure 3.9 Early aphid species showed greater phenological advance in Scotland 1971–2004 ($r=0.45$, $P=0.002$)



3.7 Moths

3.7.1 Data

Information from Scotland for 22 species of moths was obtained from Rothamsted Research. The species were selected by Ian Woiwod and covered 31 years from 1973–2003. These have been summarised across trapping sites to provide a mean first date (ie the average date first caught) and a mean mean date (ie the average catch date). Regressions for trend were weighted by numbers of traps contributing to the mean. Only mean first date was considered for double brooded species (garden carpet and dark marbled carpet) as the mean mean date would be misleading.

3.7.2 Results

The large majority of both first date (17 out of 22) and mean date (16 out of 20) trends were negative, ie earlier, and eight and three correlations were significantly earlier for first date and mean date respectively (Table 3.13). One first date and one mean date were significantly later. The average trends were –0.112 days/year (one day/decade earlier) and –0.086 days/year (nearly one day/decade earlier) equating to an average advance of c.3 days. If the strange positive response for garden carpet (Figure 3.10) is omitted the average trend for first dates increases to –0.170 days/year (nearly two days/decade earlier), or an advance of five days over the study period.

Mean first dates and mean dates were highly correlated ($r=0.99$, $p<0.001$). Whilst dates and trends were correlated for mean capture ($r=0.70$, $p=0.001$, Figure 3.11), this was only true for first dates if garden carpet was omitted ($r= 0.51$, $p<0.05$). Thus trends to earliness were more pronounced in earlier species.

In comparisons of first dates with three months of temperature, rainfall and sunshine data there were 38 significant correlations with temperature, eight with rainfall and eight with sunshine. The comparative figures for mean date were 42 significant correlations with temperature, seven with rainfall and 14 with sunshine. Again the dominance of temperature in explaining phenology is demonstrated and in Table 3.14 only correlations with temperature are shown.

Of 66 possible significant correlations with first date in Table 3.14, 65 are negative of which 38 are significant. The respective figures for mean date are 58 negative correlations (out of a possible 60) of which 42 are significant. The mean responses are 6.3 and 5.1 day advance /degree warming for first and mean dates respectively.

Trends in mean first date for garden carpet (getting later) and common quaker (getting earlier) are shown in Figure 3.10.

Trends and responses were correlated for first date ($r=0.74$, $p<0.001$) but not for mean date ($r=0.18$, $p>0.05$).

Table 3.13 Mean dates of first and mean capture 1971–2003 and a summary of evidence for trends through time. Trends (days/year) in bold are statistically significant, species ordered by magnitude of trend in first date

		First date			**Mean date**		
Scientific name	**English name**	**Mean**	**Trend**	**SE**	**Mean**	**Trend**	**SE**
Orthosia cerasi	Common quaker	92.8	**–0.49**	**0.16**	108.4	**–0.36**	**0.12**
Chloroclysta truncata	Common marbled carpet	181.0	**–0.45**	**0.16**	218.8	–0.17	0.10
Orthosia gothica	Hebrew character	84.7	**–0.45**	**0.20**	110.1	**–0.37**	**0.11**
Hydriomena furcata	July highflyer	205.9	**–0.37**	**0.11**	229.9	–0.09	0.10
Chloroclysta citrata	Dark marbled carpet	211.0	**–0.35**	**0.11**			
Campaea margaritata	Light emerald	184.3	**–0.29**	**0.10**	199.6	–0.05	0.08
Colostygia pectinataria	Green carpet	175.2	**–0.26**	**0.12**	197.4	–0.12	0.09
Idaea biselata	Small fan-footed wave	199.4	**–0.26**	**0.10**	214.7	–0.19	0.11
Diarsia rubi	Small square-spot	178.1	–0.21	0.11	199.3	–0.04	0.08
Hypena proboscidalis	The snout	190.0	–0.18	0.13	208.5	–0.12	0.11
Eulithis populata	Northern spinach	203.1	–0.18	0.12	219.2	–0.06	0.12
Xanthorhoe montanata	Silver-ground carpet	161.3	–0.17	0.11	181.4	–0.09	0.11
Noctua pronuba	Large yellow underwing	204.2	–0.16	0.12	226.4	–0.06	0.11
Rusina ferruginea	Brown rustic	159.2	–0.05	0.12	175.1	–0.01	0.11
Cerapteryx graminis	Antler moth	199.1	–0.04	0.11	216.7	**–0.15**	**0.06**
Spilosoma lubricipeda	White ermine	148.9	–0.02	0.14	169.6	–0.14	0.15
Apamea monoglypha	Dark arches	193.9	–0.02	0.12	213.6	–0.04	0.12
Diarsia mendica	Ingrailed clay	187.0	0.01	0.09	202.9	0.13	0.09
Mythimna impura	Smoky wainscot	192.7	0.09	0.10	208.6	0.03	0.10
Hydraecia micacea	Rosy rustic	229.5	0.12	0.17	251.5	0.02	0.14
Xestia xanthographa	Square-spot rustic	218.5	0.15	0.07	234.9	**0.14**	**0.06**
Xanthorhoe fluctuata	Garden carpet	158.8	**1.11**	**0.23**			

Table 3.14 Correlations of first and mean capture dates with temperature two months (T_{-2}), one month (T_{-1}) and in month (T_0) of mean date, those in bold are statistically significant. "Resp" indicates the predicted change in dates for a 1°C rise in temperature over the same three month period, species order as Table 3.13

	First date				**Mean date**			
	T_{-2}	**T_{-1}**	**T_0**	**Resp**	**T_{-2}**	**T_{-1}**	**T_0**	**Resp**
Common quaker	**–0.60**	**–0.65**	–0.24	–7.1	**–0.61**	**–0.46**	**–0.69**	–6.7
Common marbled carpet	**–0.45**	**–0.48**	–0.22	–9.2	–0.15	0.06	0.16	–0.1
Hebrew character	**–0.74**	**–0.59**	**–0.56**	–7.6	**–0.66**	**–0.49**	**–0.65**	–6.2
July highflyer	**–0.42**	**–0.50**	**–0.47**	–8.9	**–0.38**	**–0.50**	**–0.61**	–4.9
Dark marbled carpet	–0.25	–0.12	–0.32	–4.3				
Light emerald	**–0.70**	**–0.41**	–0.15	–6.9	**–0.68**	–0.23	**–0.39**	–5.1
Green carpet	**–0.38**	**–0.46**	–0.31	–5.9	**–0.44**	–0.05	**–0.42**	–3.9
Small fan-footed wave	**–0.50**	**–0.44**	–0.31	–6.9	**–0.52**	–0.28	**–0.46**	–5.5
Small square-spot	**–0.48**	**–0.49**	**–0.47**	–7.3	**–0.37**	–0.31	–0.18	–3.5
The snout	**–0.44**	**–0.51**	–0.33	–8.2	**–0.52**	**–0.36**	**–0.48**	–7.2
Northern spinach	**–0.51**	–0.33	**–0.37**	–7.9	–0.32	–0.24	–0.34	–4.2
Silver-ground carpet	**–0.57**	**–0.66**	–0.27	–7.3	**–0.50**	**–0.37**	**–0.71**	–6.9
Large yellow underwing	**–0.47**	–0.20	**–0.39**	–6.8	–0.27	**–0.59**	**–0.46**	–4.5
Brown rustic	**–0.49**	**–0.60**	–0.29	–6.6	**–0.55**	**–0.39**	**–0.57**	–6.8
Antler moth	–0.30	**–0.38**	**–0.40**	–6.2	–0.31	**–0.43**	**–0.43**	–2.5
White ermine	–0.35	**–0.53**	**–0.53**	–7.1	**–0.58**	–0.32	**–0.63**	–9.2
Dark arches	–0.27	–0.14	**–0.41**	–4.8	**–0.38**	**–0.62**	**–0.75**	–6.4
Ingrailed clay	–0.35	**–0.53**	–0.23	–4.7	–0.30	**–0.46**	**–0.51**	–5.5
Smoky wainscot	–0.31	**–0.49**	–0.25	–5.1	–0.21	**–0.66**	**–0.43**	–6.1
Rosy rustic	–0.32	**–0.56**	**–0.66**	–7.8	**–0.58**	–0.15	**–0.78**	–4.7
Square-spot rustic	–0.12	–0.29	–0.22	–1.5	–0.10	**–0.53**	**–0.46**	–2.0
Garden carpet	0.17	–0.15	–0.03	–0.5				

Figure 3.10 Trends in mean first date of garden carpet (black line) and common quaker (grey line). Both trends are statistically significant (p<0.001 and p<0.01 respectively)

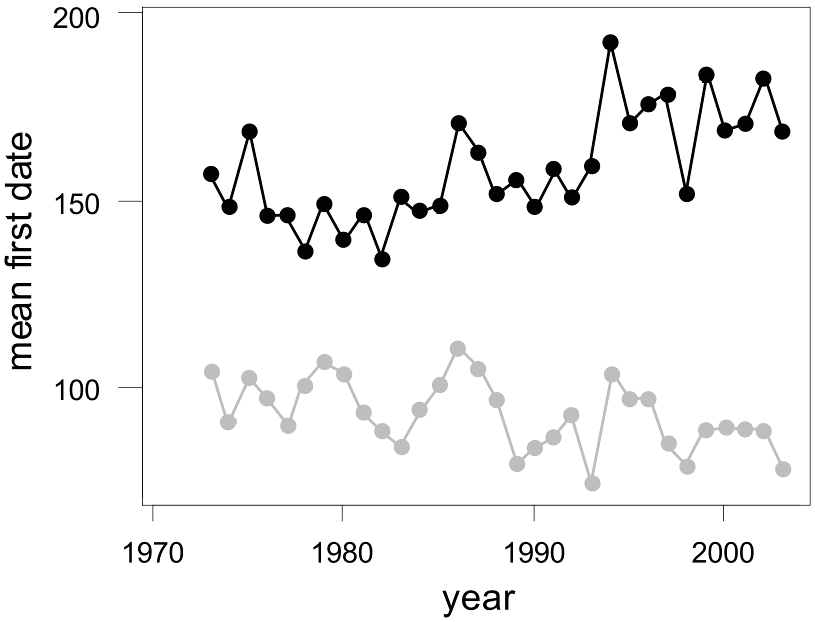
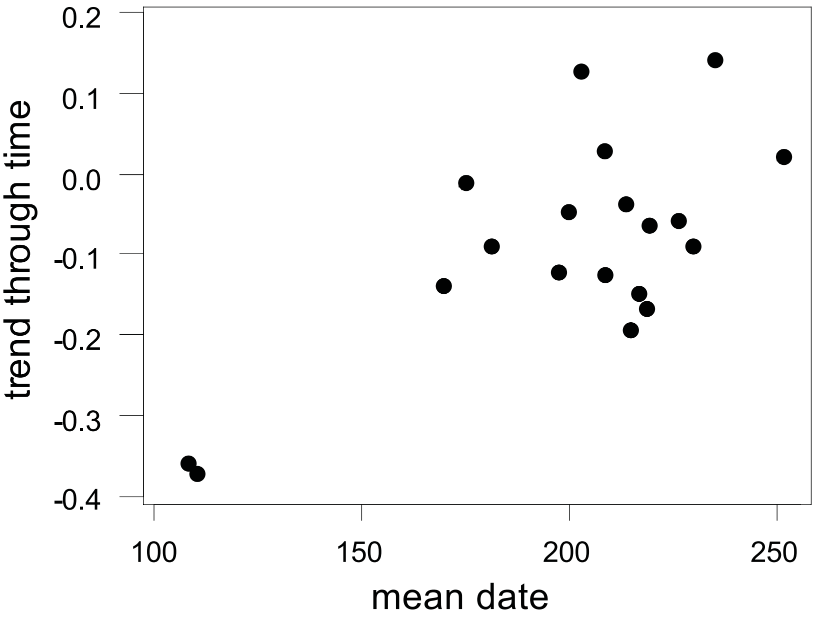


Figure 3.11 Trends in mean date are related to the timing of the species (r=0.70, p=0.001)



3.8 Butterflies

3.8.1 Data

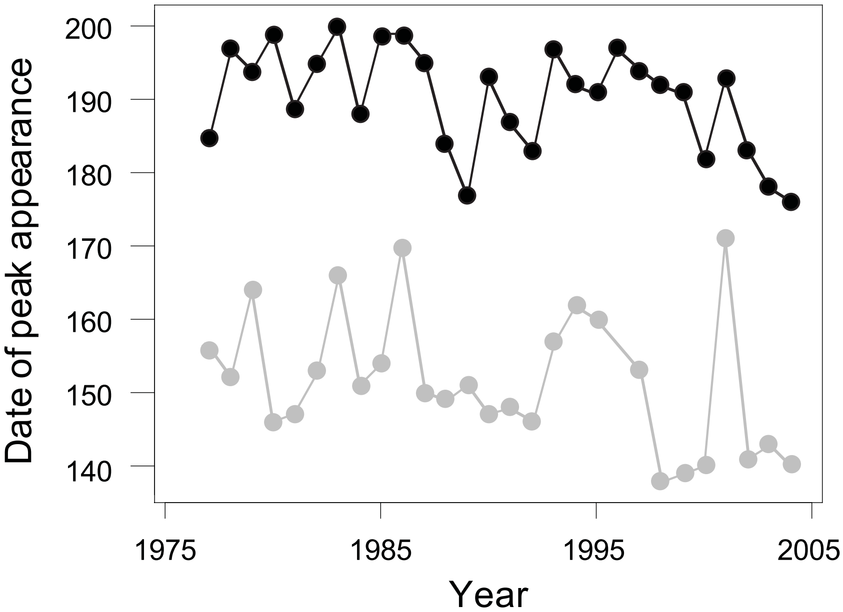
Information from Scotland on all butterfly species recorded under the Butterfly Monitoring Scheme for the 28 years 1977–2004 was obtained. For multivoltine (more than one brood per year) species with distinct flight periods the broods are considered separately. Mean first observation and mean peak observation were calculated. Table 3.15 lists the 30 series of data considered.

3.8.2 Results

Table 3.15 lists trends in first and peak appearance dates. There were 24 advances in first appearance date (five significant) and six delays (none significant). The average trend was an advance of 0.272 days/annum (just less than three days/decade earlier) equating to 7.6 days over the 38-year period. For peak appearance dates, advances were apparent in 26 species (nine significant) and delays in four (none significant). The average trend in peak appearance date was an advance of 0.350 days/annum (three and a half days per decade earlier) equating to a 9.8 day advance over the 38-year period. Figure 3.12 shows trends in peak appearance date of the small heath and orange tip.

In a comparison with the three months up to and including the date of first appearance there were 26 significant correlations with All Scotland temperature, three with rainfall and 14 with sunshine. The equivalent figures for peak appearance were 29 significant correlations with temperature, four with rainfall and 14 with sunshine. Table 3.16 lists correlations with temperatures of each of these three months and the response to a 1°C increase in temperature over the three month period. Out of a possible 90 correlations for first appearance, 73 were negative (26 significant) and 17 positive (one significant). The equivalent figures for peak appearance were 74 negative (29 significant) and 16 positive (one significant).

Figure 3.12 Changes in the peak appearance dates of two advancing butterflies species in Scotland 1977–2004; small heath (black line) and orange tip (grey line), both p<0.01



Responses to temperature (Table 3.16) varied considerably but were predominantly negative (28 out of 30 for both first and peak appearance). The response of the migrant painted lady was unusual; being large and positive. Even including this species the mean response of butterflies to warming was a 5.4 days advance in first date and a 5.1 day advance in peak date for each 1°C rise in temperature.

Whilst the four "northern" species (large heath, mountain ringlet, northern brown argus, Scotch argus) appeared to have changed their peak appearance less (mean±se, –0.17±0.10) than the remainder (–0.38±0.07 n–26) the difference was not statistically different.

Table 3.15 Mean first and peak observation dates (expressed in days after December 31) for butterfly species in Scotland 1977–2004. Trends (days/year) in dates, together with their standard errors (SE) are presented. Trends in bold are statistically significant, species order by magnitude of trend in first date

	First date			**Peak date**		
English name	**Mean**	**Trend**	**SE**	**Mean**	**Trend**	**SE**
Red admiral	214.6	**–1.42**	**0.66**	243.9	–0.37	0.27
Pearl-bordered fritillary	153.5	**–0.91**	**0.41**	164.2	**–1.21**	**0.38**
Northern brown argus	188.5	**–0.64**	**0.26**	197.1	–0.40	0.27
Painted lady	210.2	–0.62	0.68	223.8	0.11	0.51
Small white (Brood 1)	145.7	–0.59	0.32	157.2	**–0.89**	**0.26**
Peacock (Autumn)	227.8	–0.52	0.39	239.4	–0.33	0.34
Orange tip	141.4	**–0.52**	**0.22**	151.6	**–0.55**	**0.18**
Large white (Brood 1)	159.2	–0.51	0.29	167.8	**–0.62**	**0.23**
Dingy skipper (Brood 1)	148.7	–0.48	0.58	152.4	–0.74	0.54
Large white (Brood 2)	212.6	–0.47	0.26	225.4	–0.39	0.20
Green-veined white (Brood 2)	203.6	**–0.42**	**0.16**	223.3	**–0.25**	**0.12**
Peacock (Spring)	109.6	–0.41	0.60	126.9	**–0.88**	**0.38**
Small heath	168.8	–0.37	0.20	190.4	**–0.48**	**0.15**
Small white (Brood 2)	212.5	–0.36	0.28	230.5	–0.37	0.20
Small pearl-bordered fritillary (Brood 1)	174.0	–0.34	0.17	183.8	–0.29	0.16
Green-veined white (Brood 1)	131.3	–0.34	0.18	153.1	–0.30	0.16
Large heath	186.1	–0.31	0.30	195.0	–0.24	0.29
Meadow brown	191.1	–0.18	0.15	208.5	–0.22	0.14
Green hairstreak	133.3	–0.16	0.24	141.0	–0.28	0.24
Marsh fritillary	158.4	–0.15	0.43	166.0	–0.08	0.27
Small copper (Brood 1)	147.0	–0.15	0.18	159.3	–0.33	0.18
Ringlet	181.6	–0.13	0.17	197.4	**–0.31**	**0.12**
Grayling	201.3	–0.06	0.15	217.2	**–0.32**	**0.11**
Common blue (Brood 1)	180.3	0.00	0.19	186.8	0.04	0.21
Scotch argus	210.9	0.02	0.10	223.9	–0.08	0.09
Small copper (Brood 2)	217.8	0.06	0.19	235.9	–0.22	0.14
Mountain ringlet	185.6	0.07	0.45	193.9	0.04	0.35
Dark green fritillary	192.4	0.09	0.17	207.1	–0.15	0.15
Small tortoiseshell	143.1	0.63	0.39	200.8	0.44	0.31
Speckled wood	151.0	1.05	1.07	216.6	–0.80	0.42

Table 3.16 Correlations of mean first and peak appearance date with temperature two months (T_{-2}), one month (T_{-1}) and in month (T_0) of mean date, those in bold are statistically significant. "Resp" indicates the predicted change in dates for a 1°C rise in temperature over the same three month period, species order as Table 3.15

	First date				**Peak date**			
English name	T_{-2}	T_{-1}	T_0	**Resp**	T_{-2}	T_{-1}	T_0	**Resp**
Red admiral	–0.29	–0.19	**–0.39**	–20.3	–0.18	–0.26	**–0.44**	–6.9
Pearl-bordered fritillary	**–0.43**	–0.29	–0.06	–12.0	–0.36	–0.37	–0.15	–14.3
Northern brown argus	–0.39	–0.42	0.19	–7.3	0.03	**–0.68**	0.01	–6.6
Painted lady	0.15	–0.03	**0.59**	29.9	0.13	**0.56**	0.32	25.9
Small white (Brood 1)	–0.31	**–0.61**	–0.35	–13.1	**–0.62**	–0.30	–0.31	–12.3
Peacock (Autumn)	–0.02	**–0.52**	**–0.65**	–8.9	–0.16	**–0.57**	**–0.67**	–9.1
Orange tip	**–0.44**	**–0.46**	–0.36	–9.3	**–0.51**	**–0.53**	**–0.53**	–9.6
Large white (Brood 1)	**–0.53**	–0.23	0.13	–5.0	**–0.60**	–0.34	0.24	–4.8
Dingy skipper (Brood 1)	0.36	–0.57	**–0.64**	–10.8	–0.63	–0.60	0.09	–13.9
Large white (Brood 2)	–0.24	0.05	–0.25	–8.1	0.01	–0.13	–0.38	–2.4
Green-veined white (Brood 2)	**–0.49**	–0.29	–0.18	–7.5	–0.33	–0.26	–0.49	–4.3
Peacock (Spring)	–0.19	**–0.59**	0.13	–6.4	**–0.78**	–0.13	–0.42	–8.1
Small heath	–0.05	**–0.58**	–0.08	–5.1	**–0.46**	–0.37	–0.23	–7.7
Small white (Brood 2)	–0.19	–0.34	–0.34	–11.1	–0.30	**–0.42**	–0.34	–7.4
Small pearl-bordered fritillary (Brood 1)	–0.24	**–0.57**	**–0.41**	–7.3	**–0.65**	**–0.48**	0.13	–6.4
Green-veined white (Brood 1)	–0.29	**–0.70**	**–0.43**	–9.0	**–0.64**	**–0.57**	–0.26	–8.2
Large heath	–0.31	**–0.44**	0.18	–4.9	–0.19	–0.18	0.16	–1.7
Meadow brown	–0.37	**–0.54**	–0.06	–5.9	**–0.44**	**–0.53**	–0.32	–8.2
Green hairstreak	–0.15	**–0.47**	–0.20	–5.0	–0.12	**–0.47**	–0.40	–6.2
Marsh fritillary	0.34	**–0.56**	0.11	–0.2	0.07	–0.34	0.02	–1.2
Small copper (Brood 1)	–0.01	–0.30	–0.31	–4.1	–0.36	**–0.67**	–0.23	–8.0
Ringlet	**–0.52**	–0.33	–0.31	–6.5	**–0.53**	**–0.44**	–0.29	–7.1
Grayling	**–0.54**	–0.35	0.13	–4.6	–0.33	–0.10	–0.35	–3.0
Common blue (Brood 1)	–0.11	**–0.42**	–0.31	–5.3	–0.20	–0.22	–0.01	–3.7
Scotch argus	–0.16	–0.21	**–0.41**	–4.0	–0.23	**–0.46**	**–0.42**	–3.4
Small copper (Brood 2)	**–0.45**	0.25	0.24	–2.5	**–0.53**	–0.24	–0.36	–6.6
Mountain ringlet	–0.18	–0.07	–0.05	–4.1	–0.17	–0.23	0.00	–3.2
Dark green fritillary	–0.32	**–0.38**	0.18	–4.1	–0.30	**–0.46**	–0.10	–7.6
Small tortoiseshell	0.02	–0.14	–0.09	–3.4	0.08	0.14	**0.45**	10.3
Speckled wood	0.27	–0.09	0.20	4.2	**–0.52**	–0.12	–0.43	–8.5

3.9 Fred Last's flowering records

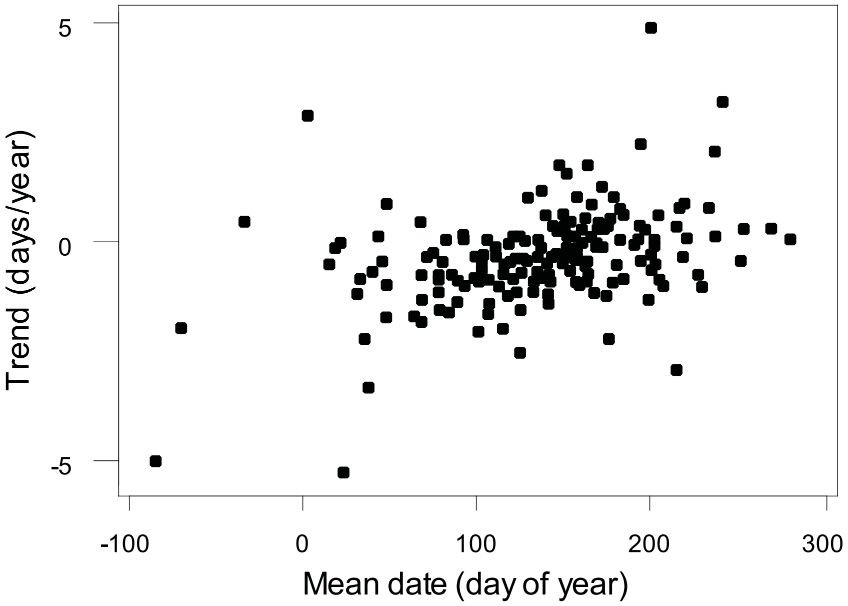
3.9.1 Data

Fred Last has been making observations of the flowering of plants in his garden in East Lothian since 1978. The results up to 2001 were summarised in a SNH report (Roberts, Last & Kempton, 2004) and it is these data that are summarised here.

3.9.2 Results

Table B9 of the SNH report summarises trends in 208 species and designates them as native or non-native. 141 species show a negative trend (35 significant) and 67 a positive trend (10 significant). The 165 non-native species have an identical trend as the 65 native species (both –0.328 days/annum or three days/decade earlier). Trend was greatest in the earlier flowering species (r=0.40, p<0.001; Figure 3.13).

Figure 3.13 The relationship between trend and mean flowering date of 208 species recorded in East Lothian 1978–2001 (r=0.40, p<0.001). Early species had greater phenological advance



3.10 Long-term records from the UK phenology network database

3.10.1 Data

The UK Phenology Network, in addition to collecting current phenology, has sought to attract long term data sets from past observers. Whilst such recorders are fewer in number than in England, Table 3.17 summarises some longer term records (>10 years) from individuals in Scotland. These have been broadly divided into plant, bird, and other records.

3.10.2 Results

The mean trend in plant records is –0.299 days/year (three days/decade earlier), in spring bird measures –0.182 days/year (nearly two days/decade earlier, Table 3.17). Of the 37 spring measures, 26 have negative trends (seven significant) and 11 have positive trends (none significant).

Figure 3.14 shows trends in snowdrop flowering dates at the three sites; only the loner series at Aberfeldy shows a significant advance.

Figure 3.15 shows trends in two frogspawn records together with a record from Cumbria. Whilst all three sites display a significant correlation with temperature, none have yet shown a significant advance in spawning date.

Figure 3.16 shows trends in four first lawn cutting records. Whilst all four have a negative trend, only that for Kilmarnock is significant.

Examining these records against three months of All Scotland climate data produces 32 significant correlations with temperature, nine with rainfall and five with sunshine. Table 3.18 displays the correlations with temperature over three months and the response to a 1°C increase in temperature. Of the spring events there are 91 negative correlations (32 significant) and 20 positive correlations (three significant). The overall temperature response in spring events is –4.3 days/°C.

Table 3.17 Trends (days/year) in long term UKPN records from Scotland, variable numbers of years (n). Mean dates (expressed in days after December 31) are presented together with trends and their standard errors (SE). Trends in bold are statistically significant, species ordered by magnitude of trend within division

			Date			
Species	**Event**		**n**	**Mean**	**Trend**	**SE**
Plant species						
Snowdrop	first flower	Abernethy	12	47.3	−1.07	0.87
Daffodil	first flower	Skye	24	63.9	**–0.97**	**0.37**
Daffodil	first flower	Abernethy	12	99.8	–0.96	0.68
Snowdrop	first flower	Skye	23	30.8	–0.48	0.43
Hawthorn	first leaf	Kilmarnock	15	104.5	–0.35	0.42
Dog rose	first flower	Aberfeldy	21	156.0	**–0.32**	**0.14**
Snowdrop	first flower	Aberfeldy	38	17.3	**–0.28**	**0.13**
Lesser celandine	first flower	Skye	21	78.8	–0.26	0.43
Larch	first leaf	Aberfeldy	27	74.4	–0.25	0.16
Beech	first leaf	Aberfeldy	24	112.9	–0.18	0.12
Daffodil	first flower	Aberfeldy	23	72.4	0.00	0.23
Bluebell	first flower	Skye	23	119.1	0.12	0.31
Violet	first flower	Skye	21	111.5	0.14	0.25
Primrose	first flower	Skye	23	83.0	1.02	0.64

Table 3.17 *(continued)*

			Date			
Species	**Event**		**n**	**Mean**	**Trend**	**SE**
Bird species						
Swallow	first seen	Kilmarnock	13	122.3	**–1.10**	**0.28**
Young eider	first seen	Skye	18	161.6	**–0.98**	**0.39**
Young chaffinch	first seen	Skye	23	160.4	**–0.95**	**0.27**
Swallow	first seen	Skye	20	127.6	–0.87	0.48
Swift	last seen	Glasgow	11	228.6	–0.74	0.51
Young tit	first seen	Skye	19	167.6	–0.74	0.36
Cuckoo	first heard	Skye	24	118.3	–0.32	0.17
Swallow	first seen	Dumfries	20	110.9	–0.21	0.18
Willow warbler	first seen	Aberfeldy	21	116.3	–0.13	0.10
Young robin	first seen	Skye	21	153.7	–0.13	0.51
Swallow	first seen	Aberfeldy	46	112.3	–0.10	0.07
Cuckoo	first heard	Aberfeldy	46	118.8	–0.02	0.06
Swift	first seen	Aberfeldy	42	133.5	0.20	0.16
Sandpiper	first seen	Aberfeldy	18	111.5	0.53	0.38
Wheatear	first seen	Aberfeldy	19	97.2	0.57	0.29
Swift	first seen	Glasgow	12	133.0	0.64	0.35
Wheatear	first seen	Skye	23	105.0	0.68	0.45
Bumblebee						
Bumblebee	first seen	Abernethy	13	95.2	–0.87	0.61
Frog						
Frogspawn	first seen	Syke	23	52.1	–0.18	0.30
Frogspawn	first seen	Abernethy	12	72.9	–0.02	0.38
Lawn						
Lawn	first cut	Abernethy	10	129.6	–1.67	1.79
Lawn	first cut	Kilmarnock	17	97.9	**–1.43**	**0.56**
Lawn	first cut	Kirkcaldy	20	80.0	–0.63	0.36
Lawn	first cut	Edinburgh	15	51.8	–0.33	1.11
Lawn	last cut	Kirkcaldy	20	218.6	1.50	0.53
Observations on snow						
Snow on cuillins	Skye		22	295.4	0.38	0.54
First snow	Skye		14	370.4	0.58	0.80
First ice	Skye		19	323.6	1.33	0.73

Table 3.18 Correlations of long term UKPN records with temperature two months (T_{-2}), one month (T_{-1}) and in month (T_0) of mean date, those in bold are statistically significant. Response indicates the predicted change in dates for a 1°C rise in temperature over the same three month period, species order as Table 3.17

Species	**Event**		**T_{-2}**	**T_{-1}**	**T_0**	**Response days/°C**
Plant species						
Daffodil	first flower	Skye	**–0.70**	**–0.63**	**–0.52**	–10.2
Daffodil	first flower	Abernethy	**–0.83**	–0.50	–0.33	–11.1
Snowdrop	first flower	Skye	–0.31	–0.26	**–0.55**	–9.7
Hawthorn	first leaf	Kilmarnock	**–0.71**	–0.34	–0.26	–4.1
Dog rose	first flower	Aberfeldy	–0.42	**–0.79**	–0.32	–8.2
Snowdrop	first flower	Aberfeldy	**–0.38**	**–0.39**	**–0.44**	–10.8
Lesser celandine	first flower	Skye	–0.36	**–0.49**	**–0.47**	–7.3
Larch	first leaf	Aberfeldy	–0.37	**–0.61**	–0.20	–4.7
Beech	first leaf	Aberfeldy	**–0.75**	**–0.49**	**–0.79**	–5.9
Daffodil	first flower	Aberfeldy	**–0.42**	**–0.61**	–0.30	–6.1
Bluebell	first flower	Skye	**–0.54**	–0.39	–0.35	–6.7
Violet	first flower	Skye	–0.26	**–0.48**	–0.34	–5.1
Primrose	first flower	Skye	–0.36	–0.32	–0.09	–5.7
Bird species						
Swallow	first seen	Kilmarnock	–0.29	–0.01	–0.17	–2.4
Young eider	first seen	Skye	–0.14	–0.09	0.11	–2.6
Young chaffinch	first seen	Skye	–0.39	–0.05	–0.12	–4.9
Swallow	first seen	Skye	–0.32	0.25	0.04	2.0
Swift	last seen	Glasgow	–0.42	–0.53	–0.47	–5.0
Young tit	first seen	Skye	–0.24	–0.26	0.16	–3.1
Cuckoo	first heard	Skye	–0.14	0.10	–0.27	–1.0
Swallow	first seen	Dumfries	–0.08	–0.13	–0.42	–2.4
Willow warbler	first seen	Aberfeldy	–0.03	–0.14	–0.29	–1.3
Young robin	first seen	Skye	–0.16	–0.20	–0.01	–4.4
Swallow	first seen	Aberfeldy	–0.03	0.00	–0.24	–1.4
Cuckoo	first heard	Aberfeldy	–0.12	–0.03	–0.19	–0.9
Swift	first seen	Aberfeldy	0.20	0.01	0.03	1.5
Sandpiper	first seen	Aberfeldy	**0.64**	0.12	**0.49**	11.3
Wheatear	first seen	Aberfeldy	0.24	0.03	0.34	3.5
Swift	first seen	Glasgow	0.57	**0.76**	0.05	3.9
Wheatear	first seen	Skye	–0.40	–0.29	–0.31	–7.7
Bumblebee						
Bumblebee	first seen	Abernethy	**–0.70**	**–0.77**	**–0.58**	–12.4

Table 3.18 *(continued)*

Species	**Event**		**T_{-2}**	**T_{-1}**	**T_0**	**Response days/°C**
Frog						
Frogspawn	first seen	Skye	–0.37	**–0.56**	**–0.62**	–7.4
Frogspawn	first seen	Abernethy	**–0.69**	–0.58	–0.47	–5.5
Lawn						
Lawn	first cut	Abernethy	–0.03	0.28	–0.14	4.7
Lawn	first cut	Kilmarnock	**–0.71**	**–0.50**	–0.40	–12.6
Lawn	first cut	Kirkcaldy	**–0.51**	**–0.54**	–0.44	–5.2
Lawn	first cut	Edinburgh	**–0.74**	0.36	–0.31	–5.1
Lawn	last cut	Kirkcaldy	**0.49**	0.28	**0.46**	7.6
Observation on snow						
Snow on cuillins		Skye	0.23	0.11	**0.58**	11.1
First snow		Skye	0.03	**0.75**	0.21	0.2
First ice		Skye	–0.06	0.15	0.15	3.4

Figure 3.14 Snowdrop first flowering dates at Aberfeldy (black line), Abernethy (grey line) and Skye (dotted line). Only that at Aberfeldy is statistically significant ($p<0.05$)

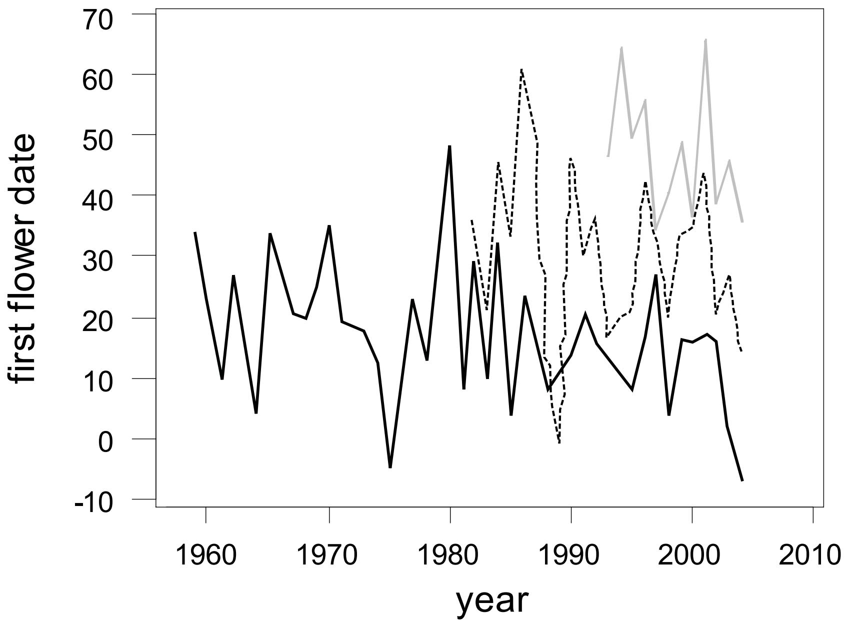


Figure 3.15 First frogspawn records from Skye (black line), Aberfeldy (grey line) and Grange-over-sands, Cumbria (dotted line). None of these relationships is statistically significant

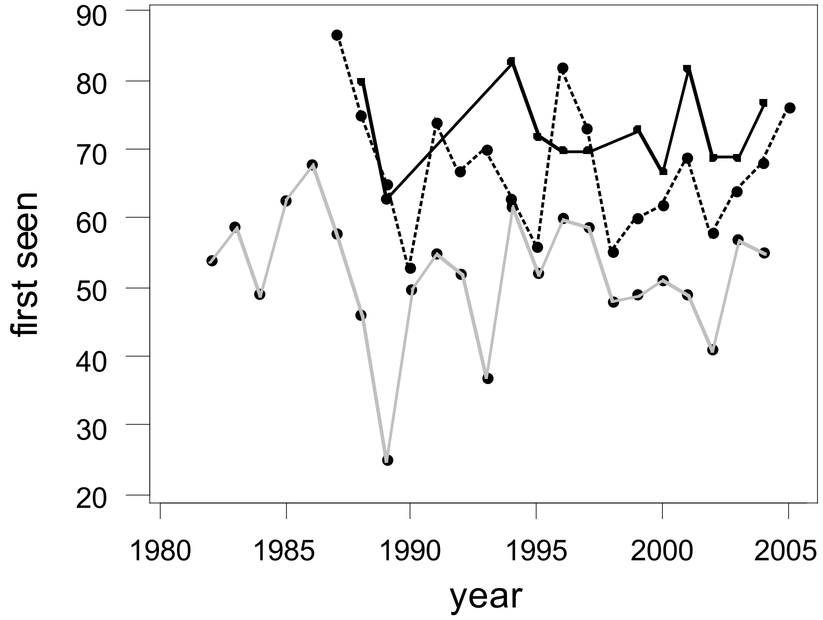
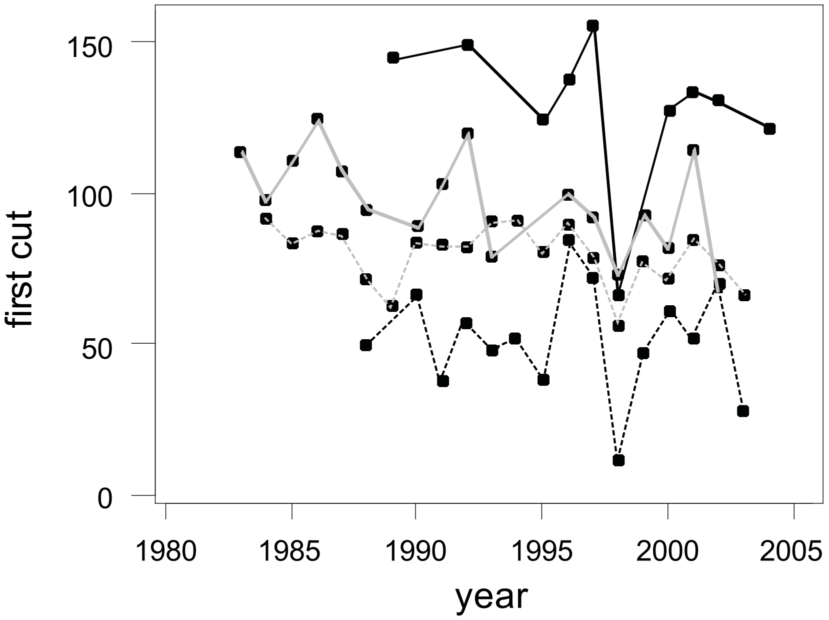


Figure 3.16 First lawn cutting dates at Abernethy (black line), Kilmarnock (grey line), Edinburgh (black dotted line) and Kirkcaldy (grey dotted line). Only that at Kilmarnock is statistically significant ($p<0.05$)



3.11 Terrestrial summary

We failed to find long term phenological data on some characteristically Scottish species such as capercaillie, grouse or ptarmigan. Data on fungi, recorded at monthly intervals by Roy Watling, were not considered to be adequate to detect any phenological shifts.

Table 3.19 summarises trends in spring migration arrival for those bird species that were recorded in more than one of data sources. The average trend across species is –0.11 (1.1 days earlier/decade). About two thirds of the species have a negative mean trend. Trends in mean arrival date of some species are particularly consistent, eg sand martin where four out of four trends were statistically significant. In contrast, none out of four wheatear series revealed a significant trend. Table 3.19 also summarises the consistency of the mean trend calculated. For several species the mean is far enough away from zero to show some consistency in patterns, for example common tern. Nine of the negative mean trends are more than two standard errors (SEs) from zero whilst this is true for only one, turtle dove, of the positive trends.

Table 3.20 and Figure 3.17 summarise the terrestrial sections of this report. It is clear that there have been trends in phenology right across the groups that have been investigated. The strongest trends appear to be in lawn cutting records and Scottish Bird Report arrivals. However, both of these are based on relatively few series of data. The strongest trend in the larger data sets include aphid first catch dates advancing by nearly five days a decade on average. In contrast bird nesting has only changed by 1.1 days/decade.

Of the potential responses to temperature, the insects appear to show a more consistent responsiveness than the other groups and that of aphids is particularly strong. There are obviously differences between potential advance in phenology and realised advance and a number of potential factors may influence this (see, for example, Tryjanowski *et al.* (2005)). These may include rapid changes in population size and observer effort. Changes in population size might be expected to have more influence on observability (and hence recorded date) for migrant species of low population density and detectability. Observer effort will have least effect on schemes such as those reported here recording insects with a standardised protocol and most on those such as the Scottish Bird Report with a (presumed) growing number of contributors.

However, despite these shortcomings this section provides overwhelming evidence that many phenological events from a wide range of taxa are responsive to temperature and that many events are already becoming earlier. With continued warming over the coming century these (spring events) are likely to become even earlier and those events where a trend is currently equivocal will experience sufficient warming to cause a statistically significant change in phenology. Detection of such effects will be eased by the growing length of the phenological series considered and the emergence of new data series from (semi) obscurity.

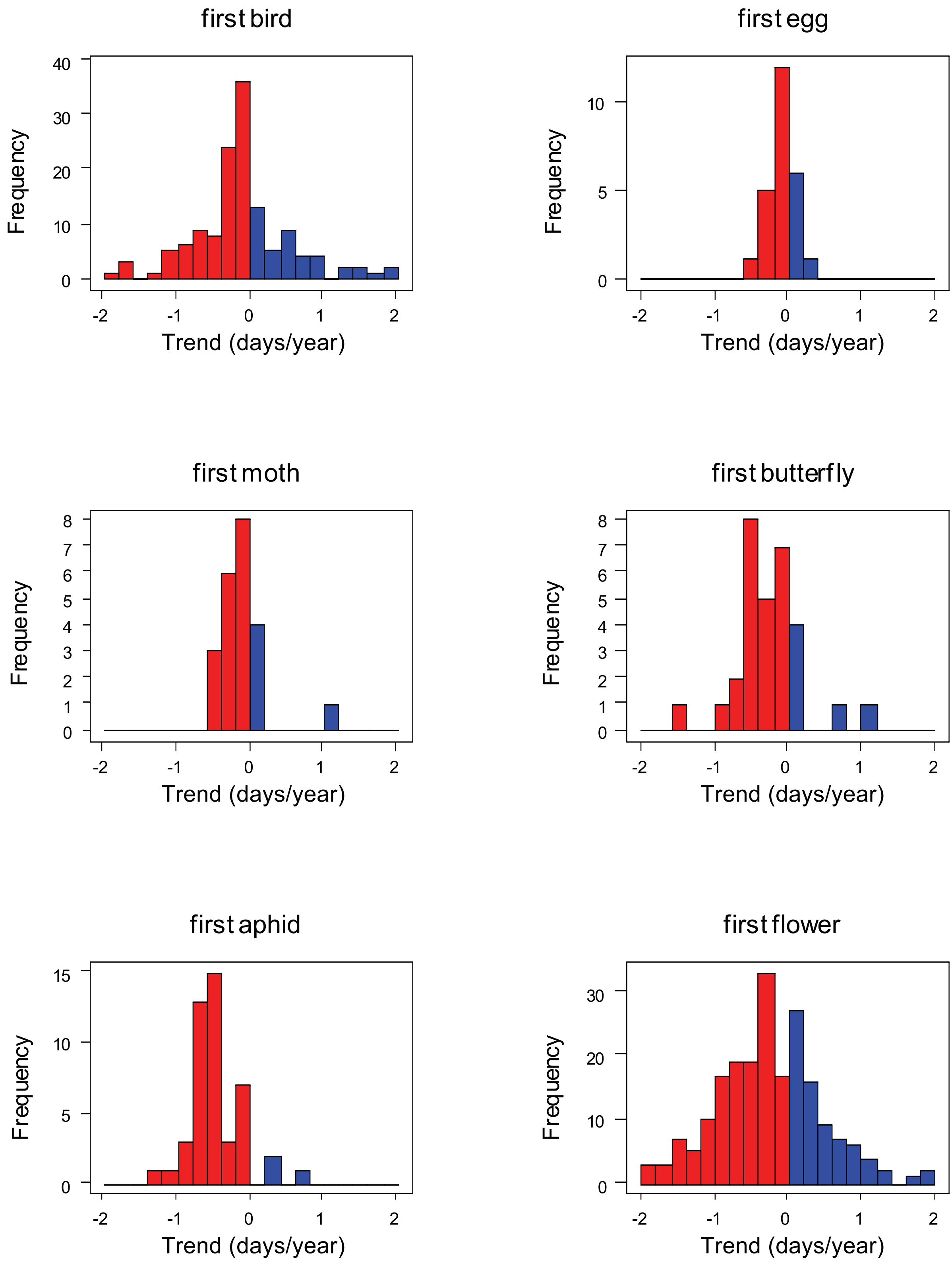
Table 3.19 A summary of spring migration arrival for species which appear in more than one of the above sections. The number of series (n), the number significant trends (nsig) and the mean trend (days/year)and standard error are given. Trends whose mean is twice as large as their SE are emboldened, species ordered by magnitude of mean trend

			Spring arrival	
	n	**nsig**	**Mean trend**	**SE**
Pied wagtail	3	2	–1.73	0.91
Blackcap	3	1	–0.97	0.52
Bluethroat	2	0	–0.93	0.79
Great skua	2	1	–0.83	0.47
Sand martin	4	4	**–0.62**	0.08
Lesser black-backed gull	2	0	–0.59	0.46
Arctic tern	2	2	**–0.52**	0.09
Swallow	8	4	**–0.52**	0.13
House martin	3	2	**–0.50**	0.14
Common redstart	2	0	–0.44	0.48
Common tern	2	1	**–0.33**	0.00
Whinchat	3	0	–0.30	0.23
Lesser whitethroat	2	0	–0.21	0.20
Sedge warbler	3	1	**–0.21**	0.09
Willow warbler	3	0	**–0.21**	0.10
Common rosefinch	2	0	**–0.20**	0.08
White wagtail	2	0	–0.12	0.23
Cuckoo	4	0	–0.11	0.07
Sandwich tern	2	0	–0.10	0.12
Arctic skua	2	0	**–0.09**	0.03
Goldcrest	3	0	–0.09	0.15
Ring ouzel	2	0	–0.05	0.03
Spotted flycatcher	3	0	–0.04	0.11
Red backed shrike	2	0	0.01	0.03
Common sandpiper	4	0	0.09	0.16
Swift	5	0	0.11	0.15
Icterine warbler	2	0	0.18	0.40
Wheatear	4	0	0.20	0.25
Whitethroat	3	0	0.22	0.20
Reed warbler	2	0	0.27	0.54
Turtle dove	2	1	**0.66**	0.22
Pied flycatcher	2	0	0.70	0.74
Tree pipit	3	0	0.95	1.14
Wryneck	2	0	0.99	0.99
Green sandpiper	2	0	1.61	1.53

Table 3.20 A summary of the phenological trends and responses in the terrestrial sections of this report

		Section	**No of series**	**Trend days/ decade**	**Response days/°C**
Bird nesting	First egg	5.1	25	−1.1	−2.4
Scottish bird report	spring arrivals	5.2	3	−7.4	−5.3
Scottish bird report	autumn departures	5.2	3	2.4	5.0
Deeside bird records	spring bird arrivals	5.3	39	−4.1	−2.5
North Ronaldsay	spring bird arrivals	5.4	82	−3.4	−3.0
North Ronaldsay	autumn bird departures	5.4	82	−2.1	−1.1
North Ronaldsay	spring bird departures	5.4	29	4.3	3.0
North Ronaldsay	autumn bird arrivals	5.4	29	−3.4	−3.3
Fair Isle	spring bird arrivals	5.5	43	−1.3	−0.5
Moths	first	5.6	22	−1.1	−6.3
Moths	mean	5.6	22	−0.9	−5.1
Aphids	first	5.7	46	−4.7	−12.5
Butterflies	first	5.8	30	−2.7	−5.4
Butterflies	peak	5.8	30	−3.5	−5.1
Fred Last	plant flowering	5.9	208	−3.3	Not available
UKPN	plants	5.10	14	−2.7	−7.5
UKPN	birds	5.10	16	−1.8	−0.6
UKPN	frogspawn	5.10	2	−1.0	−6.4
UKPN	lawn cutting	5.10	4	−10.1	−4.6

Figure 3.17 Summary of trends in different groupings, red = trends to earlier, blue to later. In order to get the same horizontal scale some bird and plant records may be omitted, see appropriate sections for individual trends



4 FRESHWATER PHENOLOGY

Due to a shortage of phenological data from Scottish freshwaters the emphasis in this chapter is on effects that are likely to be occurring, albeit unrecorded.

4.1 Phenological changes in Scottish lochs resulting from climate change

This section relies upon evidence from elsewhere that is considered to be relevant to Scotland.

4.1.1 Introduction on sensitivity of lakes to climate change

Lakes (lochs in Scotland) can be extremely sensitive to climate change. They are directly affected by meteorological conditions such as wind speed, air temperature, incoming radiation and precipitation. Variation in these weather factors can affect the timing of ice-on and ice-off, water temperature and strength of stratification in the lake, the retention time and nutrient load from the catchment: all of which have a direct knock-on effect on lake ecology and the timing of key events. Processes within a lake, such as the concentration of oxygen at depth, are also sensitive to climate change and secondary effects on lakes, brought about by changes in land-use as a result of climate change are likely to be important in the future.

The strength of the effect of weather on lakes, and by extension climate, can be seen by the effect of regional-scale correlations between lake response and factors such as the position of the north-wall of the Gulf Stream (George & Taylor, 1995) and the North Atlantic Oscillation (NAO; Straile *et al.*, 2003). One consequence of the sensitivity of lakes to these weather patterns is that some features, particularly those that relate to water temperature (Gronskaya *et al.*, 2001), are synchronised in lakes over a wide geographical region. For other features, however, the response of lakes to a given climate driver varies with the sensitivity of the lake in question (George *et al.*, 2004).

There is a growing body of information on the response of lakes to climate change in general and phenological change in particular. For example, Winder & Schindler (2004) review the effects of climate on lake phenology based on 40 years of data from Lake Washington, USA. Much similar work has been produced in Europe but there is little specific phenological information from Scottish lochs. There is no reason to suppose that the response of Scottish lochs will differ from other European lakes so the evidence from the latter is reviewed to highlight the kind of changes that may be expected and are probably already occurring in Scotland.

4.1.2 Evidence of phenological change from European lakes

4.1.2.1 Ice cover

A long-term trend has been reported towards later lake-freezing and earlier ice break-up for lakes around the Northern hemisphere (eg Magnusson *et al.*, 2000) including Europe (eg Livingstone, 2000). Predictions using various climate scenarios suggest that these trends will increase in the future (Blenckner *et al.*, 2002).

4.1.2.2 Phytoplankton timing

The timing of the spring phytoplankton bloom is driven particularly by weather. In ice-covered lakes, earlier ice-break causes an early improvement in the underwater light-climate and an earlier spring bloom (eg Adrian *et al.*, 1999; Weyhenmeyer *et al.*, 1999). In lakes that do not freeze, light and turbulence often control timing of the spring bloom and there has been a tendency for this to occur earlier in recent years (eg Müller-Navarra *et al.*, 1997). About 60 years of data are currently being analysed for four lakes in the English Lake District. Results show an earlier spring bloom, by the main component, the planktonic diatom *Asterionella formosa*, by between two and six days per decade depending on the lake (S.C. Maberly, *in prep.*). When attempts are made to relate this earlier timing to environmental factors, both water temperature and increasing winter concentrations of phosphate, the main limiting nutrient, are statistically significant. A modelling study using the lake model PROTECH confirmed that both increasing water temperature and nutrient availability led to an earlier growth of *A. formosa* (J.A Elliott & S.C. Maberly, *in prep.*). This result suggests that care needs to be exercised in the attribution of environmental change to effects of climate.

A second phytoplankton-related phenological phenomenon is the 'clear-water phase': the time after the spring bloom when the spring phytoplankton have declined and before the summer phytoplankton has started to grow. This typically results in high water transparency (eg deeper visibility) and is caused by a variety of environmental factors including an increase in zooplankton grazing pressure. Numerous papers document an earlier clear water phase in response to climate change and in particular warmer spring water temperature (eg Straile, 2000; Straile *et al.*, 2003).

4.1.2.3 Macrophytes

There is little information on the effect of climate change on macrophyte phenology. Kankaala *et al.* (2000) showed, however, in a controlled environment experiment in Finland, that warming air-temperature by 2–3°C led to an earlier growth of emergent, shoreline vegetation. This is likely to be a general phenomenon. Timing of submerged macrophytes may also be influenced by water temperature, but the underwater light climate is likely also to be an important factor.

4.1.2.4 Zooplankton

The timing of zooplankton growth appears to be very sensitive to climate effects. Part of the weather-related effect is mediated by changes in the quantity and quality of food (George *et al.*, 1990). There is also a direct effect of water temperature on zooplankton phenology through its effect on egg development and growth rate. Evidence exists from a number of lakes to show an earlier zooplankton peak in early summer in relation to warmer water (eg Straile, 2000; Gerten & Adrian, 2000; Weyhenmeyer, 2001).

4.1.2.5 Macroinvertebrates

There appear to be relatively few studies of the effect of climate on macroinvertebrate phenology. Elliott (1996) showed, using a combination of long-term observation and laboratory experimentation, that the date of pupation and emergence of adult alder flies (*Sialis lutaria*) occurred earlier with warmer water temperature.

4.1.2.6 Fish

Effects on fish may occur through direct effects of lake conditions and possibly via indirect effects caused by changed timing of other components of the lake, particularly sources of food. Direct effects include the timing of emergence of sea trout fry in a Lake District stream, which was strongly correlated with the NAO and driven largely by water temperature in early spring (Elliott *et al.*, 2000). These two facts suggest that timing of fry emergence may be coherent over a wide area of Europe and that emergence may take place earlier as early spring water temperatures increase. Work on perch (*Perca fluviatilis*) in Windermere between 1945 and the present has found that spawning now takes place earlier and correlates strongly with increasing water temperature in the first 15 weeks of the year (Winfield *et al.*, 2004). This is believed to result directly via the effect of water temperature on fish behaviour. Studies of 44-year datasets from Lake Peipsi in Eastern Estonia have also found an earlier spawning date for pike (*Esox lucius*) and bream (*Abramis brama*; Ahas, 1999). Further work on Lake Peipsi, and also Vortsjarv, in Estonia confirmed the response of bream but showed that the spawning time of roach (*Rutilis rutilis*) was unaffected by water temperature and had remained essentially unchanged between 1961 and 1990 (Nõges & Jarvet, 2005).

4.1.3 Conclusions and effect of climate change on implementation of the Water Framework Directive

Although for convenience, different components of lakes have been treated separately, many of these are linked. For example, in northern or high altitude lakes, a warmer early winter may produce earlier ice-break which in turn will allow an earlier phytoplankton spring bloom and an earlier zooplankton bloom. Many of the trends and year-to-year variation in lake phenology in the future will be coherent across a number of lakes, especially where they are driven by temperature. For other features, particularly those driven by rainfall and resulting hydraulic flushing, different lakes will be differentially sensitive depending on their retention time (George *et al.*, 2004). Finally, climate change will affect the ecological status of lakes and thus potentially their compliance with the EU Water Framework Directive. While phenology is less likely to affect ecological status than quantity of nutrients, there are some indications that an earlier growing season can cause an increase in lake productivity (Pettersen & Grust, 2002; Blenckner *et al.*, 2002). Some of the general issues of European lake response to climate change, including impact on the Water Framework Directive, are reviewed in Eisenreich *et al.* (2005).

4.2 Other freshwater data

Some of the species considered in the terrestrial sections of this report may be considered as freshwater because they either feed in freshwaters or part of their life cycle occurs there.

In Section 3.1 the dipper shows a trend towards earlier laying of –0.25 days/annum. In contrast the grey wagtail has not significantly changed its laying date, but has returned to Deeside earlier to breed (Section 3.2). The sand martin is also associated with riparian habitats and its return from migration has got significantly earlier (Sections 3.2, 3.3, 3.4, 3.5). In fact, sand martin is probably the most consistent bird in its trend to earlier arrival throughout the UK. Section 3.10 reports two frog spawning records. Whilst neither has got significantly earlier, they both show a temperature response and the potential to change as temperatures continue to rise. In the UK as a whole, many frogspawn series display this negative, but not consistently significant, trend to earliness.

No data were detected relating to natterjack toads in Scotland.

4.3 Salmon

Youngson *et al*. (2001) detected change in smolt timing in the Girnock burn but could not link this significantly to rising river temperature. Changes in salmon phenology appear to be affected by a range of factors that may be difficult to disentangle. These factors include survival in the marine phase, changing age distribution, fishing intensity, local weather events and probably climate. Ronald Campbell (*pers. comm.*) has more than a century of data from the Tweed and shown a shift in migration timing between spring and autumn but detecting a climate signal is difficult. Migration phenology changes have also been noted on the Tay (David Summers, *pers. comm.*) but data may not be robust enough to detect any climate signal in this. SNH have commissioned Fisheries Research Services to investigate trends from fish counters (Eatherley *et al*., 2005). However, for the reasons stated above, these were not able to reveal phenological trends.

5 MARINE PHENOLOGY

In this chapter the emphasis is on plankton data collected by the Sir Alister Hardy Foundation for Ocean Science. These have been shown to exhibit good responses to sea temperature and have been widely reported in the literature. Because of a scarcity of other marine phenology in Scottish waters we also discuss changes likely to be occurring with fish and cephalopods.

5.1 Plankton phenology

5.1.1 Introduction

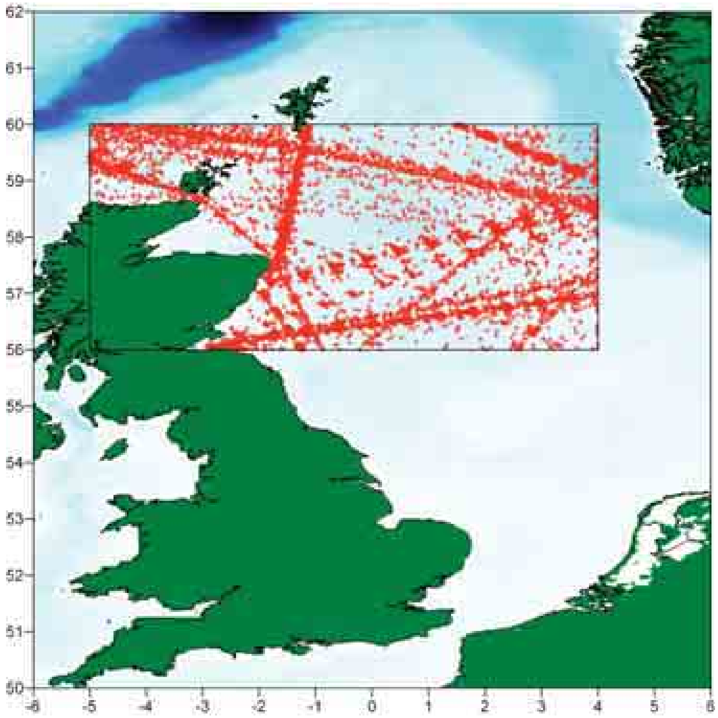
Changes in phenology may be important to ecosystem function, as the level of response to climate change may vary between different groups in a community and vary across multiple trophic levels. For example, planktonic fish larvae depend on zooplankton as a source of food and if the phenological response is different between these two groups this could potentially lead to fish larvae having very little food to feed on. The de-coupling of phenological relationships will, therefore, have important ramifications for trophic interactions, altering food-web structures and leading to eventual ecosystem-level changes. Temperate marine environments are thought to be particularly vulnerable to these changes because the recruitment success of higher trophic levels (eg fish) is highly dependent on synchronisation with pulsed planktonic production. In this report we show long-term results of eight taxa collected from the waters to the east of Scotland. These eight taxa represent four important groups (diatoms, dinoflagellates, holozooplankton and meroplankton) of the plankton (two taxa per group).

5.1.2 Methods

The Continuous Plankton Recorder (CPR) survey has been operational in the North Sea and North Atlantic for almost 70 years. As such, it provides a valuable dataset of plankton abundance, and long term changes and trends can be identified. It provides a unique long-term dataset of plankton abundance in the North Atlantic and North Sea, using 'ships of opportunity' to tow the CPR on regular routes, sampling at a depth of approximately 10m (methodology described in full in Warner and Hays 1994). Each sample represents 18km of tow and approximately 3m^3 of filtered seawater (John *et al.* 2002). The survey records over 400 taxa of plankton, composed of phytoplankton and zooplankton entities, many of which are recorded to species level. It is the only biological survey that can monitor long term changes over broad areas, such as the North Atlantic. The survey began in the North Sea in 1931, with computerised records from 1948 (for this report data were extracted from 1958). Data collected from the survey allows long term changes, as well as seasonal cycles, in the plankton community to be identified. In addition to the examination of specific planktonic entities, phytoplankton colour, an index of estimation of chlorophyll a values (Hays and Lindley 1994), can be seen to represent changes in primary production. The area chosen for this report, east of Scotland into the northern North Sea (56–60°N, 5°W–4°E), is shown in Figure 5.1, along with all the sample positions from 1958–2003 (n=14124).

The phytoplankton community can be divided into larger entities such as diatoms and dinoflagellates, and the smaller flagellates. The latter are often referred to as pico or nano plankton because of their small size, but can at times make up a large proportion of the phytoplankton community. Diatoms are characterised by having a siliceous body, comprising two valves, and being autotrophic (produce energy by photosynthesis). Dinoflagellates differ in having two flagella and a normally a cellulose body. They are usually mixotrophic (consumers), but can also photosynthesize under certain conditions. Diatoms typically 'bloom' in the spring, whilst dinoflagellates are more dominant in the latter part of the year. In this report two taxa of both diatoms and dinoflagellates are examined: *Hyalochaeta* spp. and *Pseudonitzschia seriata* (diatoms), *Ceratium fusus* and *Protoperidinium* spp. (dinoflagellates). Diatoms and dinoflagellates represent the functional group 'primary producers'.

Figure 5.1 Map of North Sea study area grid showing CPR samples (represented by dots) from 1958–2003



The most common group of organisms in the zooplankton community are the copepods (Ikeda *et al.*, 2001). These small shrimp-like crustaceans are known to reach large concentrations, and they form the main food source for higher trophic levels. In the study area the dominant copepod is *Calanus finmarchicus*, this species has been extensively researched, and has been shown to respond to hydro-climate variability (Planque and Fromentin 1996). Along with this species, a smaller Calanoid copepod taxa is examined, *Para-pseudocalanus* spp. Both these taxa represent the functional group 'holozooplankton' and are the dominant secondary consumers in the plankton.

The remaining two taxa that have been used are Echinodermata and Decapoda larvae. Echinodermata larvae are the distributive stages of starfish and sea urchins, and they remain part of the plankton until they settle on the benthos. These organisms may be over a centimetre in diameter and are supported by skeletal calcareous rods. Decapoda larvae are the initial stages of primarily benthic decapods such as crabs and lobsters. Both these taxa represent the functional group 'meroplankton'. Meroplankton are organisms that spend some of their life-cycle in the plankton, usually in their larval stages.

The aim of this study is to examine the phenological response of a number of representative plankton taxa. The timing of the seasonal peak each year (the central tendency, T) was estimated using a weighted average of each calendar month's captures (Colebrook and Robinson 1965), specifically

$$T = \frac{\sum_{i=1}^{12} M.x_m}{\sum_{i=1}^{12} x_m}$$

where x_m is the mean abundance in month M (January = 1, ..., December = 12).

5.1.3 Results

Figures 5.2 show the changes in phenology for each of the chosen taxa. Results are summarised as follows:

- *Ceratium fusus*

  Results for this dinoflagellate are shown in Figure 5.2 (start of slope = 8.01, end of slope 7.14, movement forward in weeks = 3.48, r = 0.46, p<0.001). The species seasonal peak appears to be advancing generally, with early peaks in 1980 and 2002. Seasonal peaks in the 1960s were in the 1st week in August, moving forward to the 2nd week in July in the post-90 period. Late peaks have occurred in 1958 and 1964.

- *Protoperidinium* spp.

  This dinoflagellate taxon seasonal peak has advanced: seasonal peaks in the 1960s were in the 2nd week of July, advancing to the last week in June in the post-90 period (start of slope = 7.47, end of slope 6.65, movement forward in weeks = 3.2, r = 0.37, p<0.001). Late peaks occurred in 1958 (as in *Ceratium fusus*), and 1966. This taxon had an exceptional early seasonal peak in 2002, again the same as *Ceratium fusus*.

- *Hyalochaeta* spp.

  This diatom species has remained relatively static in seasonality during the study period, although extremes of early appearance (1966, 1991 and 2001) and late appearance (1975) have occurred (start of slope = 4.65, end of slope 4.58, movement forward in weeks = 0.28, not significant).

- *Pseudonitzschia seriata*

  The diatom *Pseudonitzschia seriata* appears to have erratic seasonal peaks over the study period, with early appearances in 1966 and 1991 (same as diatom *Hyalochaeta* spp.), and also 1968 and 1989. Late peaks have occurred in 1960 and 1970 (start of slope = 5.1, end of slope 4.8, movement forward in weeks = 1.2, not significant).

- *Calanus finmarchicus*

  The copepod *Calanus finmarchicus* has moved slightly earlier in its seasonal peak, from end of June in the 1960s to beginning of June in the post–90 period. It has had early peaks in 1970 and 1994, and late peaks in 1980 and 1998 (start of slope = 6.8, end of slope 6.4, movement forward in weeks = 1.6, not significant).

- *Para-pseudocalanus* spp.

  This copepod taxon has shifted slightly earlier in peak abundance, from the beginning of July in the 1960s to mid-June in the post-90 period. A very early peak in abundance occurred in 1990, and late appearances occurred in 1966 and 1969 (start of slope = 7.2, end of slope 6.7, movement forward in weeks = 2, r = 0.28, p<0.01).

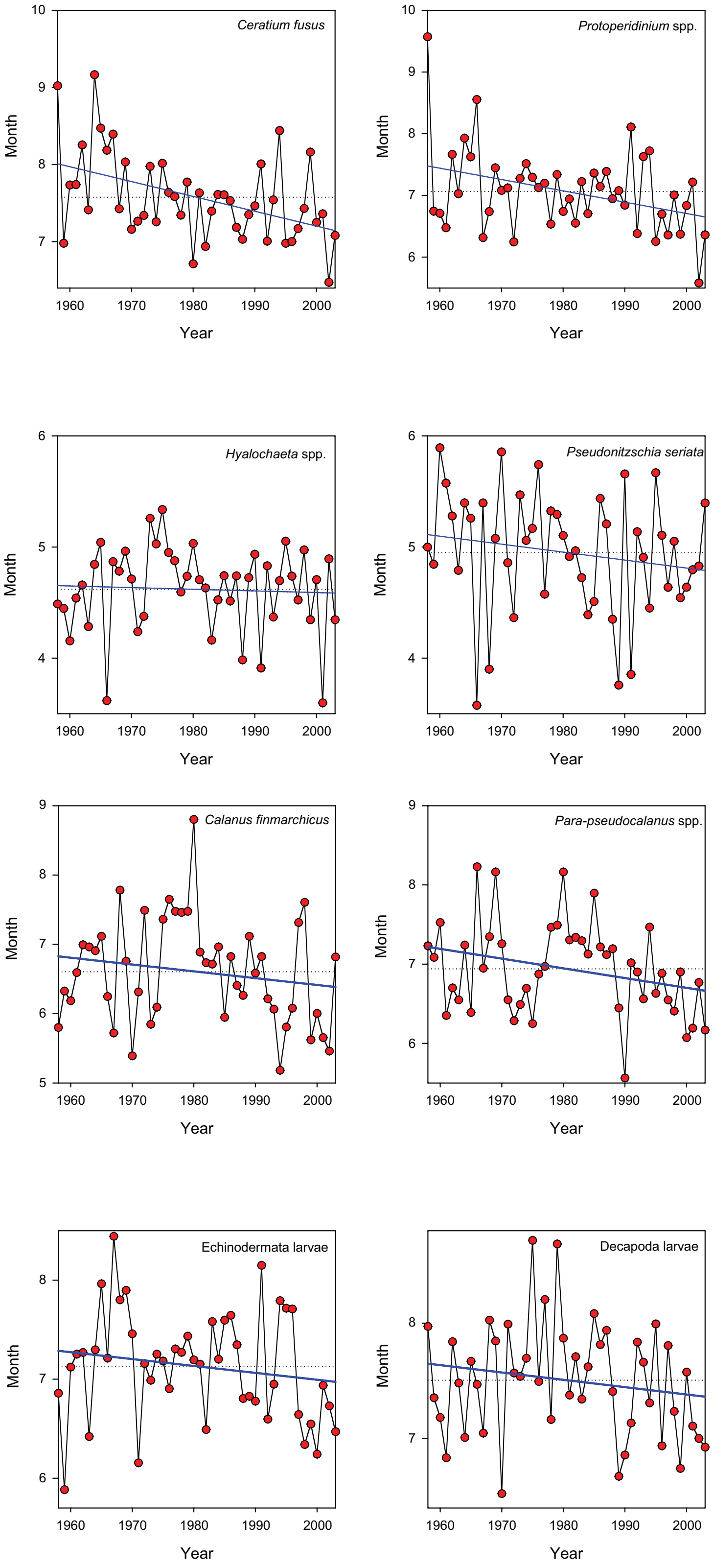
- Echinodermata larvae

  This taxon, which undoubtedly includes a number of different species, appears to have moved forward since the 1960s (from mid-July to the end of June in the post-90 period). The group has had very early peaks in 1959 and 1971, and late peaks in 1967 and 1991(start of slope = 7.3, end of slope 6.9, movement forward in weeks = 1.6, not significant).

- Decapoda larvae

  Seasonality of Decapoda larvae is highly variable in the study period, but peak abundance does seem to have shifted slightly forward. Exceptional early peaks have occurred in 1970, 1989 and 1999, whilst late appearances occurred in 1975 and 1979 (start of slope = 7.6, end of slope 7.4, movement forward in weeks = 0.8, not significant).

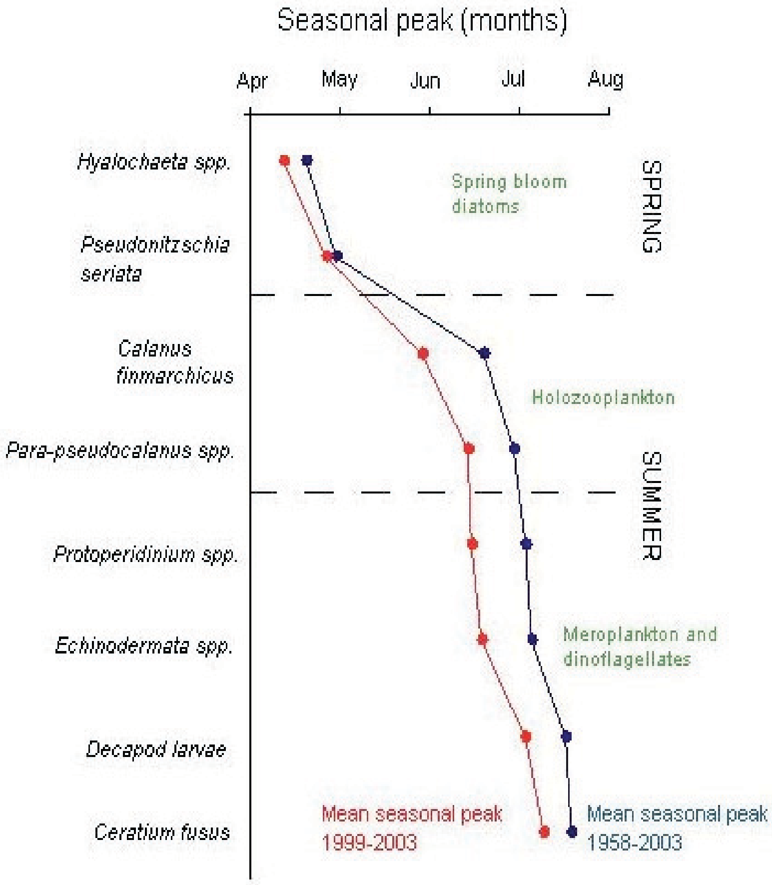
Figure 5.2 Graphs of phenology for the dinoflagellates *Ceratium fusus* and *Protoperidinium* spp., the diatoms *Hyalochaeta* spp. and *Pseudonitzscia seriata*, the copepods *Calanus finmarchicus* and *Para-pseudocalanus* spp., and Echinodermata and Decapoda larvae (1958–2003). Dotted line represents mean value, blue line represents linear trend. Trends for *Ceratium fusus*, *Protoperidinium* spp. and *Para-pseudocalanus* spp. are significant (p<0.001, p<0.001 and p<0.01 respectively)



5.1.4 Summary

This study has shown, despite a lot of inter-annual variability that the plankton taxa examined in this study are moving forward in their seasonal cycles. The taxa *C. fusus*, *Protoperidinium* spp. and *Para-pseudocalanus* spp. showed statistically significant movements forward in their seasonal cycles over the study period. The average movement forward for all taxa examined over the last 46 years equates to nearly two weeks, but more importantly the degree of movement differs between the groups examined. Figure 5.3. demonstrates the difference between the phenology of the last five years and the long-term average. The diatoms (primary producers) for example, have shown little long-term movement in the seasonal cycles while the other groups have all moved forward. This is an important finding because this may eventually lead to certain groups that are dependent on the diatoms for food, missing the main pulse of food. This may also have a knock-on effect on commercially-important fish species (Edwards & Richardson, 2004). Diatoms may have been fairly static in their phenology over the last 46 years because the levels of light and wind-mixing may play a more important role in triggering their seasonal timing rather than the physiological effects of temperature. The taxa that showed the most significant movement forward were the dinoflagellates. Both for this group showed the largest movement forward in the seasonal cycles, *C. fusus* for example, was found to have moved nearly four weeks forward over the last 46 years. If climate continues to warm at its present rate marine food-webs will become radically altered. Further work is needed to examine fully the potential consequences of phenological changes on the marine environment.

Figure 5.3 Summary figure for the eight plankton taxa (in date order) representing functional groups. Average seasonal peaks for 1958–2003 (blue line) and for the last five-years 1999–2003 (red line). Note the peaks in the recent period have all been earlier but the spring bloom diatoms have shown the least movement forward



5.2 Phenological change in Scottish waters: fish and cephalopods

Future climatic change will have a significant impact on marine ecosystems in the North Atlantic because sea-surface temperatures (SSTs) are forecasted to increase by 0.5–4.0°C over the next century (Hulme *et al.*, 2002). Given the relative importance of marine natural resources to the Scottish economy, it is important that attempts are made to predict the effects of these changes. Maintaining capture rates in commercial fisheries relies on knowledge of fish distribution, particularly the timing and location of peak abundance of different species, and how this changes with season. Integral to this is an understanding of the timing of fish movements, such as migration phenology to spawning grounds, but with respect to climate change, of principal concern is the need to understand how climate will influence such migrations. Large-scale changes in the timing of migration for spawning or foraging, that acts to shift peak population abundances of fish in time and/or space, may have important consequences for trophic (food chain) dynamics, fisheries yields of the ecosystem, and may, ultimately, have economic implications. The question is, are changes in migration phenology likely?

For aquatic ectotherms such as fish and cephalopods in particular, seasonal rises in temperature can act as an important cue in the timing of migration and for synchronizing reproduction with the seasonal increase in abundance of food (Cushing, 1990). None the less, phenological changes in the migration of marine fish as a consequence of climatic variation are poorly understood. Few studies have been completed, and none have documented the phenological effects on marine species in Scottish waters. However, appraisal of information from other regions indicates that changes in migration phenology of some commercially important fish and cephalopods in Scottish waters is likely.

Fishes may migrate earlier in years when the sea temperature is warmer compared to colder years because they have temperature-dependent gonadal development and/or so as to match indirectly their spawning time with seasonal peaks in productivity, such as zooplankton, that in turn may shift with climatic changes (Cushing, 1969; Cushing 1990). Some studies on migratory fish species provide support for the phenological change predicted for warmer years. Capelin, *Mallotus villosus*, off Newfoundland were found to have earlier spawning time when mean fish lengths were lower and SSTs were higher than average (Carscadden *et al.*, 1997). Pacific herring, *Clupea pallasi*, spawned earlier when the water was warmer because the instantaneous rate of gonad growth depended on fish mass and daily sea temperature (Ware & Tanasichuk, 1989). In contrast however, Cushing (1969) found that the variability in spawning periods of Atlantic herring (*Clupea harengus*), plaice (*Pleuronectes platessa*) and cod (*Gadus morhua*) was low, although there were indications that cod may adapt to climatic change. Other studies with weakly migratory species such as sole (*Solea solea*) in the Bristol Channel, similarly indicate no relationship between the timing of spawning and seasonal increase in temperature (Horwood, 1990). More recently, however, substantial variation in the timing of cod spawning has been reported in Newfoundland waters (Lawson & Rose, 2000), indicating observed changes for the same species may vary between different geographic regions.

Some of the clearest evidence for the effects of climate-induced sea temperature changes on migration phenology in marine species come from south-west England, a region that has been subjected to major climatic shifts, with mean annual SSTs fluctuating within a range of 1.8°C over the past century (Southward *et al.*, 2004). Interannual changes in the timing of migration of veined squid (*Loligo forbesi*) were linked to climate-forced sea bottom temperature, with migration occurring earlier in warmer years when the North Atlantic Oscillation (NAO) was more positive (Sims *et al.*, 2001). The timing of squid abundance advanced by 120–150 days in the warmest years compared with the coldest. The annual migration of squid through the English Channel represents a clear example of temperature-dependent movement, which is in turn mediated by climatic changes associated with the NAO (Sims *et al.*, 2001). Similar effects were not observed in cuttlefish (*Sepia officinalis*) which undertakes a much more local inshore-offshore migration that may be less influenced by larger scale climate-linked environmental change.

In contrast, the spawning migration of flounder (*Platichthys flesus*) from their overwintering estuarine habitat to spawning grounds at sea started earlier in cooler years (Sims *et al.*, 2004). Flounder migrated to sea some 1–2 months earlier in years that were up to 2°C cooler. They arrived on the spawning grounds over a shorter time period (2–6 days) when colder than normal conditions prevailed in the estuary, compared to their arrival in warmer years (12–15 days), indicating a more synchronous, population-level early migration when it was cold. Migration was earlier when the largest temperature differences occurred between Plymouth Sound and offshore environments, differences that were related significantly to cold, negative phases of the NAO. Therefore, flounder migration phenology appears to be driven by short-term, climate-induced changes in the thermal resources of their overwintering habitat (Sims *et al.*, 2004).

These studies indicate that climate-forced fluctuations in sea temperatures affect the timing and location of peak population abundance of fish and cephalopods, but emphasise that the specific patterns and underlying mechanisms are complex and depend to a large degree on habitats preferred by individual species in addition to life-history characteristics (eg squid compared with flounder). Phenological changes due to climate have been documented in species in the northeast Atlantic that are also present in Scottish waters. This suggests that similar changes are likely, or have, perhaps, already occurred, but have so far remained unrecorded. Species that undertake spawning migrations may be particularly vulnerable to climate-linked sea temperature changes and shifts in biotic interactions.

Regional differences in climate change, however, may influence the same species differently, which may result in different phenological patterns between different geographic areas. This is supported by community-level studies that showed that marine fish community composition in both the English Channel and Bristol Channel were strongly linked to SST, but the same species did not show congruent trends between sites (Genner *et al.*, 2004). This suggests that within a region, populations of the same species may respond differently to climatic change, possibly owing to additional local environmental determinants, interspecific ecological interactions (Schindler *et al.*, 2005) and dispersal capacity (Genner *et al.*, 2004).

5.3 Other marine data

We failed to detect long term phenological data on cetaceans or basking sharks.

Some of the bird species in the terrestrial section rely on the marine environment and could be considered in this section. Whilst these appeared to be advancing their spring migration more than other species (–0.646 days/annum c.f. –0.251 days/annum) the difference was not significant.

Further seabird data may exist within the JNCC Seabird Monitoring Programme. Analysis of the three species on the Isle of May provided evidence of climate drivers in nesting phenology (Frederiksen *et al.*, 2004) and this area justifies further investigation.

Coastal plankton has been recorded at Stonehaven since 1997 and with time will provide data complementary to the data reported above from the CPR.

The Sea Mammal Research Unit has some data on the phenology of seals. Whilst that of haul-out dates was not considered to be climate driven, seal calving dates may be. The results will be published by SMRU in the near future.

6 CONCLUSIONS

This report summarises data that were readily available during the analysis and writing phases. We recognise that it is biased towards terrestrial data, with less data available from marine and freshwater environments. In some instances we can learn from studies undertaken in England and in other European countries where we believe that similar changes will have taken place in Scotland.

Whilst we believe that this report is as comprehensive as it could have been at the time, we are certain its publication will encourage others to reveal additional data sets or analyse data sets not reported here.

6.1 Natural Heritage Trends

From the evidence gathered here there can be little doubt that the phenology of Scottish species is advancing and changing in response to a warming climate. Temperature appeared to be the major driver of change with less influence of sunshine or rainfall. It is clear that change is happening in the phenology of species towards the lower end of the food web; marine plankton, plants, aphids and probably freshwater plankton also. Because of this is will be necessary for higher life forms to also adjust their phenology. If they do not match these changes, then there may be serious consequences in terms of fitness and survival. It is interesting to note the relatively small amount of change (one day/decade on average) for nesting birds relative to that of aphids (five days/decade) which form an important part of the diet for several bird species. Further complications may arise via altered competition if species within communities change at different rates. Indeed, there was a wide range of trends and responses between species of the same taxa. Some species buck the trends (eg turtle dove) and it may well be that some changes are masked, or even influenced, by population increases or decreases and hence higher or lower chances of earlier detection.

The results of this work have been summarised into three SNH Natural Heritage Trends Notes, one each for the terrestrial, freshwater and marine environments (Appendix B).

It is recommended that these data sets be analysed more fully to extract additional useful information that will exist within them. For example, a fuller analysis could examine the total distribution of the phenology of several taxa, eg migrating birds, where records are kept throughout the season.

6.2 Selecting indicators of climate change

In choosing species to be recommended as indicators it was felt important to meet several criteria; importance within that environment, completeness of a time series, likelihood of continued recording, existing protocol for recording and so on. The three species selected all show a response to temperature, and all demonstrate an advance in recent decades. For the terrestrial environment, the green spruce aphid can cause serious damage to forestry and, with other aphid species, form an important component of the diet of many birds. The dipper is characteristic of upland streams and reliant on the freshwater environment. The dinoflagellate *Ceratium fusus*, with other phytoplankton, are the basic building blocks of the oceans and have a key role in food webs. In all three cases, data recording is co-ordinated by scientific organisations; Scottish Agricultural Sciences Agency, British Trust for Ornithology and the Sir Alister Hardy Foundation for Ocean Science respectively. Justification as to why they are appropriate for SNH to adopt as indicators is given in Appendix C.

Table 6.1 List of phenological indicators of climate change for the terrestrial, freshwater and marine environments in Scotland

	Species	**Phenological variable**	**Advance per 1°C warming**
Terrestrial	Green spruce aphid	Mean capture date	8 days
Freshwater	Dipper	First egg date	4 days
Marine	The dinoflagellate *Ceratium fusus*	Seasonal peak date	12 days

REFERENCES

Adrian, R. *et al.* (1999). Effects of ice duration on plankton succession during spring in a shallow polymictic lake. *Freshwater Biology*, **41**, 621–632.

Ahas, R. (1999). Long-term phyto-, ornitho- and ichthyophenological times-series analyses in Estonia. *International Journal of Biometeorology*, **42**, 119–123.

Blenckner, T., Omstedt, A. & Rammukainedn, M. (2002). A Swedish case study of contemporary and possible future consequences of climate change on lake function. *Aquatic Sciences*, **64**, 171–184.

Carscadden, J., Nakashima, B.S. & Frank, K.T. (1997). Effects of fish length and temperature on the timing of peak spawning in capelin (*Mallotus villosus*). Canadian *Journal of Fisheries and Aquatic Sciences*, **54**, 781–787.

Colebrook, J.M. & Robinson, G.A. (1965). Continuous Plankton Records: seasonal cycles of phytoplankton and copepods in the north-eastern Atlantic and the North Sea. *Bulletin of Marine Ecology*, **6**, 123–139.

Crick, H.Q.P., Baillie, S.R. & Leech, D.I. (2003). The UK Nest Record Scheme: its value for science and conservation. *Bird Study*, **50**, 254–270.

Cushing, D.H. (1969). The regularity of the spawning season of some fishes. *Journal du Consiel pour de l'Exploration de la Mer*, **33**, 81–92.

Cushing, D.H. (1990). Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. *Advances in Marine Biology*, **26**, 249–293.

Eatherley D.M.R. *et al.* (2005). Trends in Atlantic salmon: the role of automatic fish counter data in their recording. *Scottish Natural Heritage Commissioned Report No. 100* (ROAME No. F01NB02).

Edwards, M. & Richardson, A. (2004). Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature*, **430**, 881–884.

Eisenreich, S.J. *et al.* (2005). Climate change and the *European water dimension*. European Commission – Joint Research Centre report EUR 21553, 253pp.

Elliott, J.M. (1996). Temperature-related fluctuations in the timing of emergence and pupation of Windermere alder-flies over 30 years. *Ecological Entomology*, **21**, 241–247.

Elliott, J.M., Hurley, M.A. & Maberly, S.C. (2000). The emergence period of sea trout fry in a Lake District stream correlates with the North Atlantic Oscillation. *Journal of Fish Biology*, **56**, 208–210.

Frederiksen, M. *et al.* (2004). Scale-dependent climate signals drive breeding phenology of three seabird species. *Global Change Biology*, **10**, 1214–1221.

Genner, M.J. *et al.* (2004). Regional climatic warming drives long-term community changes of British marine fish. *Proceedings of the Royal Society of London B*, **271**, 655–661.

George, D.G. *et al.* (1990). The relative effects of enrichment and climatic change on the long-term dynamics of *Daphnia* in Esthwaite Water, Cumbria. *Freshwater Biology*, **43**, 449–461.

George, D.G., Maberly, S.C. & Hewitt, D.P. (2004). The influence of the North Atlantic Oscillation on the physics, chemistry and biology of four lakes in the English Lake District. *Freshwater Biology*, **49**, 760–774.

George, D.G. & Taylor, A.H. (1995). UK lake plankton and the Gulf stream. *Nature*, **378**, 139.

Gerten, D. & Adrian, R. (2000). Climate-driven changes in spring plankton dynamics and the sensitivity of shallow polymictic lakes to the North Atlantic Oscillation. *Limnology & Oceanography*, **45**, 1058–1066.

Gronskaya, T.P., George, D.G. & Arvola, L. (2001). The influence of long-term changes in the weather on the thermal characteristics of lakes in the UK, Finland and Russia. *Proceedings of the 9th International Conference on the Conservation and Management of Lakes*, November 11–16, 2001 Shiga, Japan, pp. 43–46.

Hays, G.C. & Lindley, J.A. (1994). Estimating chlorophyll a abundance from the 'PCI' recorded by the Continuous Plankton Recorder survey: validation with simultaneous fluorometry. *Journal of Plankton Research*, **16**, 23–34.

Horwood, J.W. (1990). The Bristol Channel sole (*Solea solea* (L.)): A fisheries case study. *Advances in Marine Biology*, **29**, 215–367.

Hulme, M. *et al.* (2002). *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report.* University of East Anglia, Norwich.

Ikeda, T. *et al.* (2001). Metabolic rates of epipelagic marine copepods as a function of body mass and temperature. *Marine Biology (Berlin)*, **139**, 587–596.

Jenkins, D. & Watson, A. (2000). Dates of first arrival and song of birds during 1974–1999 in mid-Deeside, Scotland. *Bird study*, **47**, 249–251.

John, E.H. *et al.* (2002). Continuous Plankton Records stand the test of time: evaluation of flow rates, clogging and the continuity of the CPR time-series. *Journal of Plankton Research*, **24**, 941–946.

Kankaala, P. *et al.* (2000). Response of littoral vegetation on climate warming in the boreal zone: an experimental simulation. *Aquatic Ecology*, **34**, 433–444.

Langan, S.J. *et al.* (2001). Variation in river water temperatures in an upland stream over a 30-year period. *The Science of the Total Environment*, **265**, 195–207.

Lawson, G.L. & Rose, G.A. (2000). Small-scale spatial and temporal patterns in spawning of Atlantic cod (*Gadus morhua*) in coastal Newfoundland waters. *Canadian Journal of Fisheries and Aquatic Sciences*, **57**, 1011–1024.

Livingstone, D.M. (2000). Large-scale climatic forcing detected in historical observations of lake ice break-up. *Internationale Vereinung fur Limnologie, Verhandlungen*, **27**, 2775–2783.

Magnusson, J. J. *et al.* (2000). Historical trends in lake and river ice cover in the Northern Hemisphere. *Science*, **289**, 1743–1746.

Müller-Navarra, D.C., Güss, S. & Von Storch, H. (1997). Interannual variability of seasonal succession events in a temperate lake and its relation to temperature variability. *Global Change Biology*, **3**, 429–438.

Nõges, P. & Jarvet, A. (2005). Climate driven changes in the spawning of roach (*Rutilus rutilus* (L.)) and bream (*Abramis brama* (L.)) in the Estonian part of the Narva River basin. *Boreal Environment Research*, **10**, 45–55.

Pettersen, K. & Grust, K. (2002). Seasonality of nutrients in Lake Erken – effects of weather conditions. *Internationale Vereinung fur Limnologie, Verhandlungen*, **28**, 731–734.

Planque, B. & Fromentin, J.M. (1996). *Calanus* and environment in the eastern North Atlantic. I. Spatial and temporal patterns of *C. finmarchicus* and *C. helgolandicus*. *Marine Ecology – Progress Series*, **134**, 101–109.

Roberts, A.M.I., Last, F.T. & Kempton, E. (2004). Preliminary analyses of changes in the first flowering dates of a range of plants between 1978 and 2001. *Scottish Natural Heritage Commisioned Report No. 035* (ROAME No. F01NA04).

Schindler, D.E. *et al.* (2005). Effects of changing climate on zooplankton and juvenile sockeye salmon growth in southwestern Alaska. *Ecology*, **86**, 198–209.

Sims, D.W. *et al.* (2001). Timing of squid migration reflects North Atlantic climate variability. *Proceedings of the Royal Society of London B*, **268**, 2607–2611.

Sims, D.W. *et al.* (2004). Low-temperature-driven early spawning migration of a temperate marine fish. *Journal of Animal Ecology*, **73**, 333–341.

Southward, A.J. *et al.* (2004). Long-term oceanographic and ecological research in the western English Channel. *Advances in Marine Biology*, **47**, 1–105.

Sparks, T.H. *et al.* (2005). The grass is greener (for longer). *Weather*, **60**, 121–125.

Straile, D. (2000). Meteorological forcing of plankton dynamics in a large and deep continental European lake. *Oecologia*, **122**, 44–50.

Straile, D. *et al.* (2003). The response of freshwater ecosystems to climate variability associated with the North Atlantic Oscillation. *In:* J.W. Hurrell, Y. Kushnir, G. Ottersen & M. Visbeck, eds. *The North Atlantic Oscillation: Climatic significance and environmental impact*. Geophysical Monograph Series, **134**, pp. 263–279.

Tryjanowski, P., Kuźniak, S. & Sparks, T.H. (2005). What affects the magnitude of change in first arrival dates of migrant birds? *Journal of Ornithology*, **146**, 200–205.

Ware, D.M. & Tanasichuk, R.W. (1989). Biological basis of maturation and spawning waves in Pacific herring (*Clupea harengus pallasi*). *Canadian Journal of Fisheries and Aquatic Sciences*, **46**, 1776–1784.

Warner, A.J. & Hays, G.C. (1994). Sampling by the Continuous Plankton Recorder Survey. *Progress in Oceanography*, **34**, 237–256.

Weyhenmeyer, G. (2001). Warmer winters: Are planktonic algal populations in Sweden's largest lakes affected? *Ambio*, **30**, 565–571.

Weyhenmeyer, G., Blenckner, T. & Petterson, K. (1999). Changes of the plankton spring outburst related to the North Atlantic Oscillation. *Limnology & Oeanography*, **44**, 1788–1792.

Winder, M. & Schindler, D.E. (2004). Climatic effects on the phenology of lake processes. *Global Change Biology*, **10**, 1844–1856.

Winfield, I.J. *et al.* (2004). Long-term trends in the timing of the spawning season of Eurasion perch (*Perca fluviatilis*) in the north basin of Windermere, UK. *In:* T.P. Barry & J.A. Malison, eds. Proceedings of Percis III: The 3rd Int. Percid Fish Symposium. Univ. of Wisc. Sea Grant Institute, Madison, WI, pp. 95–96.

Youngson, A. *et al.* (2001). *Declines in spring salmon: effects of climate change*. Report to the Atlantic Salmon Trust.

Appendix A Tables of meteorological variables summarised by month

Table A1 All Scotland 1914–2004. Monthly mean temperature (°C), rainfall (mm) and sunshine (hours). Trend and SE give, respectively, an indication of per annum change and the confidence associated with that change. Significant trends ($p<0.05$) are shown in bold, those marginally significant ($p<0.1$) by an asterisk. NB sunshine series from 1929 only

	Temperature			**Rainfall**			**Sunshine**		
	Mean	**Trend**	**SE**	**Mean**	**Trend**	**SE**	**Mean**	**Trend**	**SE**
January	2.3	0.002	0.006	153.5	0.108	0.213	35.0	–0.039	0.036
February	2.4	0.000	0.006	110.6	0.242	0.214	63.4	0.045	0.068
March	3.8	0.009	0.006	105.3	**0.605**	0.160	96.2	–0.104	0.095
April	5.8	0.007	0.004 *	85.2	–0.074	0.121	134.7	0.006	0.131
May	8.6	0.007	0.004 *	80.5	–0.130	0.121	172.9	0.093	0.153
June	11.2	0.004	0.004	81.9	0.117	0.112	161.8	–0.320	0.164 *
July	12.8	0.004	0.004	100.7	**–0.311**	0.127	138.7	0.209	0.165
August	12.7	**0.008**	0.004	111.2	–0.250	0.168	135.0	**0.300**	0.149
September	10.7	0.006	0.004 *	125.6	0.164	0.174	103.7	0.096	0.088
October	7.9	0.007	0.004	153.2	0.165	0.215	74.6	0.080	0.063
November	4.7	0.009	0.005 *	147.2	0.168	0.206	44.9	0.027	0.038
December	3.0	0.002	0.005	154.5	0.073	0.215	28.1	–0.005	0.030

Table A2 RBGE and All Scotland 1976–2003. Monthly mean rainfall (mm). Trend and SE give, respectively, an indication of per annum change and the confidence associated with that change. Significant trends ($p<0.05$) are shown in bold, those marginally significant ($p<0.1$) by an asterisk

	RBGE rainfall			**All Scotland rainfall**		
	Mean	**Trend**	**SE**	**Mean**	**Trend**	**SE**
January	62.5	0.310	0.652	163.5	0.794	1.371
February	45.9	0.989	0.714	125.2	**3.702**	1.463
March	52.5	**–1.080**	0.419	138.7	–1.182	0.986
April	41.8	0.964	0.516 *	80.7	**1.292**	0.627
May	47.5	0.407	0.589	74.6	0.641	0.813
June	57.6	0.324	0.833	80.9	0.819	0.631
July	56.9	0.872	0.899	88.4	0.605	0.788
August	54.5	0.238	0.757	99.8	–0.429	1.193
September	63.6	–0.605	0.853	133.3	**–2.757**	0.924
October	77.5	–0.030	0.879	165.3	–0.111	1.188
November	62.1	0.194	0.652	159.4	–0.904	1.220
December	65.1	0.056	0.641	157.9	0.240	1.373

Table A3 RBGE and All Scotland 1976–2003. Monthly mean sunshine (hours). Trend and SE give, respectively, an indication of per annum change and the confidence associated with that change. Significant trends (p<0.05) are shown in bold, those marginally significant (p<0.1) by an asterisk

	RBGE sunshine			**All Scotland sunshine**		
	Mean	**Trend**	**SE**	**Mean**	**Trend**	**SE**
January	52.7	0.162	0.287	34.6	0.073	0.156
February	75.1	**1.378**	0.450	62.6	0.094	0.315
March	109.2	**1.141**	0.535	91.4	0.672	0.426
April	138.0	0.376	0.651	132.1	–0.147	0.542
May	181.0	0.261	0.798	177.2	0.234	0.747
June	169.6	–0.362	0.709	152.8	–0.153	0.615
July	170.9	–0.528	0.872	143.9	–0.558	0.834
August	162.2	0.539	0.596	141.6	0.314	0.760
September	124.3	0.844	0.609	104.7	**0.928**	0.410
October	101.8	0.659	0.384 *	75.8	0.475	0.267 *
November	69.0	–0.060	0.297	45.2	0.089	0.204
December	44.1	0.536	0.295 *	27.2	0.223	0.131

Table A4 RBGE 1976–2003. Monthly mean dry bulb and wet bulb temperatures (°C). Trend and SE give, respectively, an indication of per annum change and the confidence associated with that change. Significant trends (p<0.05) are shown in bold, those marginally significant (p<0.1) by an asterisk

	Dry bulb temperature			**Wet bulb temperature**		
	Mean	**Trend**	**SE**	**Mean**	**Trend**	**SE**
January	3.5	**0.076**	0.036	2.8	**0.080**	0.032
February	3.8	0.078	0.041 *	2.9	0.062	0.036 *
March	5.9	0.054	0.028 *	4.5	**0.056**	0.026
April	7.9	**0.047**	0.021	6.1	**0.052**	0.018
May	10.9	0.027	0.018	8.8	**0.041**	0.017
June	13.5	0.014	0.020	11.3	0.017	0.016
July	15.2	0.012	0.018	13.3	0.033	0.019 *
August	15.2	0.031	0.022	13.3	**0.043**	0.020
September	12.9	0.028	0.018	11.3	**0.042**	0.016
October	9.6	–0.009	0.038	8.4	–0.004	0.035
November	6.2	0.040	0.034	5.3	0.050	0.031
December	4.2	0.015	0.038	3.4	0.024	0.035

Table A5 RBGE 1976–2003. Monthly mean maximum and minimum air temperatures (°C). Trend and SE give, respectively, an indication of per annum change and the confidence associated with that change. Significant trends (p<0.05) are shown in bold, those marginally significant (p<0.1) by an asterisk

	Mean maximum air temperature			Mean minimum air temperature		
	Mean	**Trend**	**SE**	**Mean**	**Trend**	**SE**
January	6.6	**0.078**	0.036	1.1	0.074	0.037 *
February	7.2	**0.100**	0.037	1.3	0.069	0.044
March	9.3	**0.064**	0.030	2.6	0.041	0.028
April	11.3	0.046	0.026 *	4.1	**0.050**	0.021
May	14.4	0.018	0.024	6.6	**0.056**	0.022
June	17.1	0.004	0.025	9.5	0.006	0.018
July	18.9	–0.011	0.026	11.4	0.005	0.016
August	18.8	0.025	0.027	11.3	0.029	0.019
September	16.2	0.041	0.020 *	9.3	0.008	0.021
October	13.0	0.002	0.034	6.5	–0.019	0.038
November	9.5	0.038	0.028	3.6	0.039	0.035
December	7.0	0.022	0.036	1.6	0.009	0.038

Table A6 RBGE 1976–2003. Monthly mean grass and 10cm soil temperatures (°C). Trend and SE give, respectively, an indication of per annum change and the confidence associated with that change. Significant trends (p<0.05) are shown in bold, those marginally significant (p<0.1) by an asterisk

	Grass temperature			10cm soil temperature		
	Mean	**Trend**	**SE**	**Mean**	**Trend**	**SE**
January	–2.6	0.076	0.043 *	2.1	0.035	0.027
February	–2.3	0.040	0.049	2.6	0.051	0.030
March	–0.8	0.023	0.035	4.2	0.028	0.023
April	0.5	**0.069**	0.029	7.0	0.028	0.020
May	3.3	**0.092**	0.024	10.9	0.009	0.017
June	6.5	–0.011	0.026	14.0	–0.027	0.020
July	8.5	0.003	0.021	15.6	–0.024	0.021
August	8.0	0.020	0.023	14.9	0.008	0.022
September	5.6	–0.020	0.030	11.9	0.014	0.017
October	2.8	–0.027	0.041	8.4	–0.016	0.029
November	–0.1	0.042	0.040	5.1	0.016	0.026
December	–2.1	0.019	0.040	3.0	0.023	0.026

Table A7 RBGE 1976–2003. Monthly mean 20cm and 30cm soil temperatures (°C). Trend and SE give, respectively, an indication of per annum change and the confidence associated with that change. Significant trends (p<0.05) are shown in bold, those marginally significant (p<0.1) by an asterisk

	20cm soil temperature			**30cm soil temperature**		
	Mean	**Trend**	**SE**	**Mean**	**Trend**	**SE**
January	2.7	0.017	0.030	3.0	0.039	0.027
February	3.1	0.065	0.034 *	3.3	**0.062**	0.028
March	4.7	0.019	0.027	5.2	0.030	0.021
April	7.4	0.026	0.018	8.0	0.027	0.017
May	11.0	0.016	0.019	11.6	0.007	0.012
June	13.9	–0.026	0.018	14.4	**–0.040**	0.014
July	15.5	–0.025	0.020	16.0	–0.036	0.018 *
August	15.2	0.006	0.022	15.8	–0.003	0.020
September	12.6	0.008	0.014	13.3	0.013	0.013
October	9.2	–0.013	0.025	9.9	0.009	0.024
November	5.8	0.010	0.024	6.4	0.022	0.024
December	3.8	0.012	0.026	4.1	0.045	0.023 *

Table A8 RBGE 1976–2003. Monthly mean cloud cover (eighths) and wind speed (m/s). Trend and SE give, respectively, an indication of per annum change and the confidence associated with that change. Significant trends (p<0.05) are shown in bold

	Cloud cover			**Wind**		
	Mean	**Trend**	**SE**	**Mean**	**Trend**	**SE**
January	5.8	–0.005	0.020	7.7	0.005	0.078
February	5.8	–0.025	0.018	8.2	0.030	0.119
March	5.7	–0.013	0.015	8.8	–0.069	0.087
April	5.9	–0.007	0.018	7.5	0.010	0.060
May	5.8	–0.008	0.018	7.2	0.051	0.057
June	6.1	0.009	0.015	7.9	–0.020	0.047
July	6.1	0.023	0.020	7.1	–0.027	0.062
August	5.8	–0.003	0.012	7.5	–0.064	0.090
September	5.7	–0.018	0.014	9.0	**–0.196**	0.057
October	5.6	0.015	0.018	8.3	–0.025	0.079
November	5.3	–0.002	0.017	7.4	**–0.124**	0.057
December	5.7	–0.003	0.018	7.3	–0.074	0.073

Appendix B Natural Heritage Trends notes

These draft Trends Notes summarise phenological change in Scotland in terrestrial, freshwater and marine environments.

SCOTTISH
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Information
NATURAL HERITAGE TRENDS

Draft – changes in the phenology of Scottish terrestrial species

The earth's climate is warming. There is already abundant evidence that this is having an impact on plant and animal species. Change has been detected in distributions, population abundance and, particularly, in phenology, the timing of life cycle events such as flowering and migration (eg Parmesan & Yohe, 2003).

Phenological change can occur across plant and animal groups (eg Peñuelas *et al.*, 2002) and is both highly responsive to temperature and easily measured.

Over the 20th century, trends in Scottish temperatures were towards warming in each calendar month, but changes in rainfall and sunshine were more mixed (Sparks *et al.*, 2006). In the last three decades, temperature trends have been much more pronounced with warming being most marked in the first few months of the year.

Given the documented responsiveness of phenology to temperature we could anticipate that warming in Scotland would lead to a change in the phenology of Scottish biota. The purpose of this note is to summarise evidence of phenological change in terrestrial species in Scotland.

Trends

Figure 1 displays trends in the major groups; those in red show some evidence of earlier activity and those in blue some evidence of later activity. The overall tendency has been towards earlier activity among all groups.

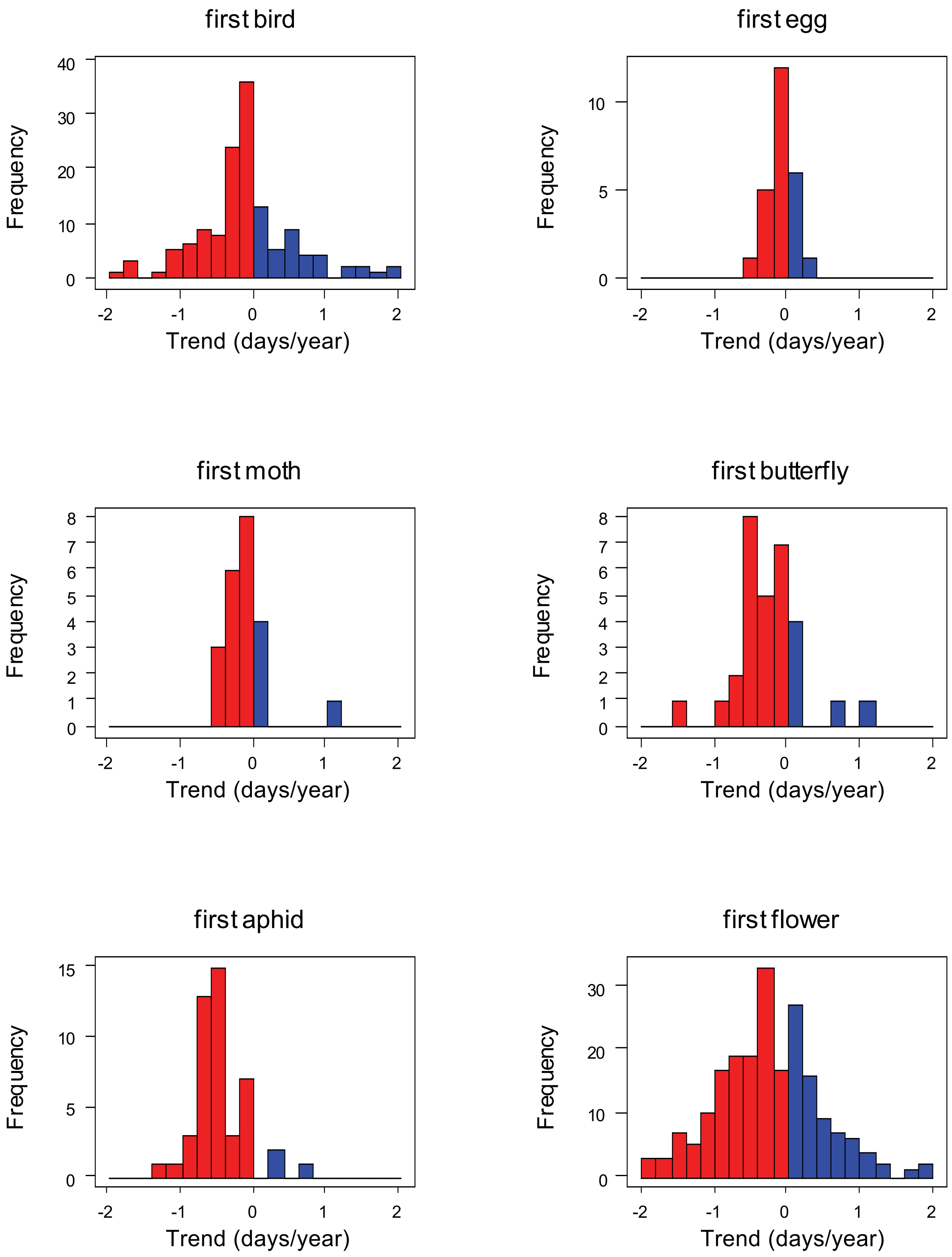
Birds

The timing of spring bird migration, incorporating data from North Ronaldsay and Fair Isle bird observatories and other sources, has advanced by an average of 0.26 days/year (2.6 days/decade). About a quarter of the examined series revealed a statistically significant advance. The average advance in egg laying in 25 bird species was 1.1 days/decade and one fifth of the series revealed a statistically significant advance. There were few examples of significant counter-trends, in which events became later.

Insects

The average advance in 22 moth species recorded from Rothamsted light traps was 1.1 days/decade. In 30 butterfly series recorded in the Butterfly Monitoring Scheme the average advance was 2.7 days/decade. The 46 aphid series recorded in suction traps operated by the Scottish Agricultural Science Agency advanced on average by 4.7 days/decade. One third of the moths, one sixth of the butterflies and nearly half of the aphids revealed a statistically significant advance. There were few examples of significant counter-trends.

Figure 1 Histograms showing trends (days/year) in major phenological groupings[1], the vertical scale represents the number of species in each band



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[1] Some extreme values omitted to ensure all graphs are to same horizontal scale

Flowers

The average advance in 219 series of flowering was 3.2 days/decade, of which one sixth revealed a statistically significant advance. There were only a small number of significant counter-trends.

The clear signal is of phenological advance associated with a period of climate warming. Species exhibit different responses to warming, partly dependent on their timing; earlier species typically show a greater response (Sparks & Menzel, 2002). There are differences between species groups; aphids have shown a particularly strong trend in recent years. The consequences of different species responding at different rates in communities or in food chains are largely unknown but could be critically important for survival. Many more species than those currently exhibiting significant trends nevertheless display a temperature responses and are therefore expected to change more as warming increases in coming decades. Climatic variables, such as sunshine and rainfall, also drive phenology but in the Scottish climate temperature is currently the most importance influence.

Sources

Data that can contribute to an examination of phenological change come from a wide variety of sources. Data on aphids, moths and butterflies derive, respectively, from the Rothamsted suction traps, Rothamsted light traps and Butterfly Monitoring Scheme. Data on bird migration timing came from the Fair Isle and North Ronaldsay Bird Observatories, from the records of David Jenkins and from other individuals. Egg laying data came from the British Trust for Ornithology's Nest Record Scheme. Trends in plant phenology were obtained from Fred Last's records with additions from other individuals contributing to the UK Phenology Network. Changes in the phenology of species are derived from different time periods but generally cover the last 20–30 years, ie during a period of more rapid warming.

The summary here is derived from Sparks *et al.* (2006).

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References

Parmesan, C. and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems, *Nature*, **421**, 37–42.

Peñuelas, J., Filella, J. and Comas, P. (2002). Changes in plant and animal life cycles from 1952–2000 in the Mediterranean region, *Global Change Biology*, **8**, 531–544.

Sparks, T.H. and Menzel, A. (2002). Observed changes in the seasons: an overview, *International Journal of Climatology*, **22**, 1715–1725.

Sparks, T.H., Collinson, N., Crick, H., Croxton, P., Edwards, M., Huber, K., Jenkins, D., Johns, D., Last, F., Maberly, S., Marquiss, M., Pickup, J., Roy, D., Sims, D., Shaw, D., Turner, A., Watson, A., Woiwod, I. and Woodbridge, K. (2006). Natural Heritage Trends of Scotland: phenological indicators of climate change. *Scottish Natural Heritage Commissioned Report No. 167 (ROAME No. F01NB01).*

This note forms part of the Natural Heritage Trends series, documenting the best information available on rates and directions of change (temporal and spatial) in terrestrial, fresh water and marine environments:

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Updated: September 2005

SCOTTISH
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Information
NATURAL HERITAGE TRENDS

Draft – changes in the phenology of Scottish freshwater species

The earth's climate is warming. There is already abundant evidence that this is having an impact on plant and animal species. Change has been detected in distributions, population abundance and in phenology, the timing of life cycle events such as flowering and migration (eg Parmesan & Yohe, 2003).

In the last 10 years, temperatures of rivers across Scotland have risen by at least 0.5°C, matching changes in air temperature (Sparks *et al.*, 2006). Change in loch or lake temperatures may be much greater.

Rising temperatures are likely to affect a range of plants, invertebrates and vertebrates that rely on freshwaters for all or part of their life cycle. The purpose of this note is to summarise evidence of phenological change in freshwater species in or around Scotland.

Trends

Plankton

There are few sources of data available for Scottish freshwater species, but we anticipate change will be similar to that occurring at other high latitudes. One of the longest freshwater series recorded concerns phytoplankton blooms in the Lake District, just to the south of the Scottish border with England. There *Asterionella formosa* has been advancing by 2–6 days/decade with a marked temperature influence. It is highly likely that change in Scotland will be comparable. Although not recorded, it is likely that changes are taking place in freshwater zooplankton, as has been detected in marine zooplankton.

Invertebrates

A study in the Lake District has revealed the changing phenology of alder flies in response to temperature, with first appearance linked to a temperature threshold (*c.*10°C Such change in invertebrates with a freshwater component to their life cycles is highly likely and relevant to Scotland.

Fish

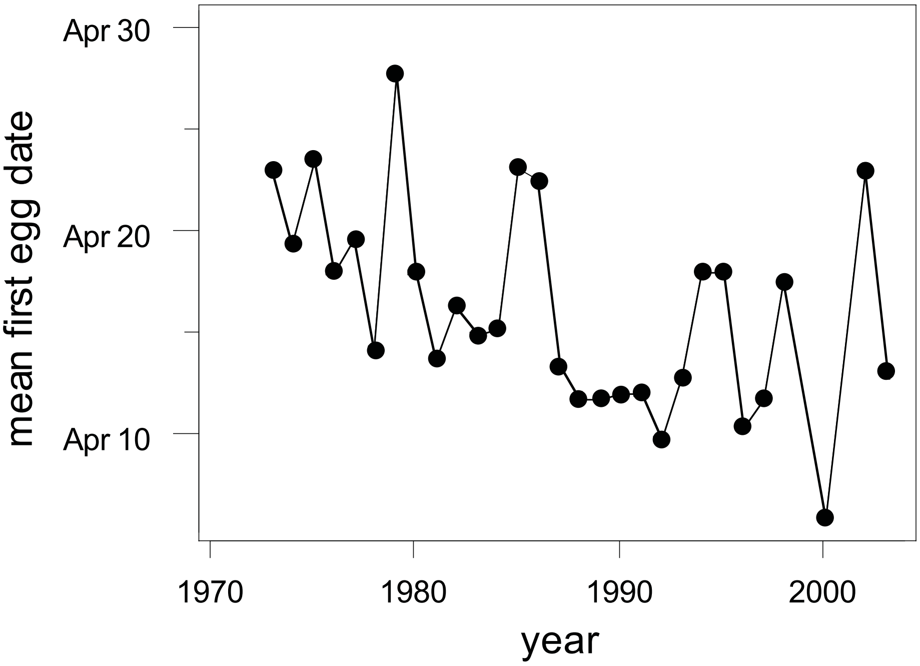
Advances in spawning and fry emergence phenology with rising temperatures have been recorded from the Lake District and from Northern European countries. Once again, similar changes in Scotland are highly likely although data do not exist. Long-term data exist on salmon, but a number of confounding factors such as population changes, age structure changes, flow conditions and fishing intensity make it hard to differentiate a temperature signal.

Birds

Several bird species are reliant on an aquatic habitat and some show clear trends. First egg dates of dipper (Figure 1), for example, have shown an advance of 2.5 days/decade. Several records on the arrival dates of sand martin have shown advances of 4–8 days/decade.

Whilst quantitative data on freshwater species in Scotland are scarce, the likelihood is that changes in phenology will be occurring. For example, frogs spawning show a response to rising temperatures although a significant change has not yet been detected.

Figure 1 Mean first egg dates of the dipper



Sources

Data on dipper first egg dates derive from the British Trust for Ornithology's Nest Record Scheme. Sand martin records come from Fair Isle and North Ronaldsay Bird Observatories, and from David Jenkins and Angela Turner. Frog spawn information came from the UK Phenology Network. Data cover various time periods from a minimum of 12–38 years.

The summary here is derived from Sparks *et al.* (2006).

Authorship

Sparks, T.H.
Centre for Ecology and Hydrology

References

Parmesan, C. and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems, *Nature*, **421**, 37–42.

Sparks, T.H., Collinson, N., Crick, H., Croxton, P., Edwards, M., Huber, K., Jenkins, D., Johns, D., Last, F., Maberly, S., Marquiss, M., Pickup, J., Roy, D., Sims, D., Shaw, D., Turner, A., Watson, A., Woiwod, I. and Woodbridge, K. (2006). Natural Heritage Trends of Scotland: phenological indicators of climate change. *Scottish Natural Heritage Commissioned Report No. 167 (ROAME No. F01NB01).*

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Contact: FREEPOST Natural Heritage Trends E-mail: trends@snh.gov.uk

Updated: September 2005

SCOTTISH NATURAL HERITAGE

Information

NATURAL HERITAGE TRENDS

Draft – changes in the phenology of Scottish marine species

The earth's climate is warming. There is already abundant evidence that this is having an impact on plant and animal species. Change has been detected in distributions, population abundance and in phenology, the timing of life cycle events such as flowering and migration (eg Parmesan & Yohe, 2003). Growing evidence suggests that the waters around the British Isles are acquiring new species as a consequence of northwards movement and changes to the marine environment are likely to be just as marked as the more easily observable effects on land.

In the last 25 years, coastal sea temperatures in Scotland have risen by 0.5–1.5°C (Sparks *et al.*, 2006). Large changes, particularly in North Sea species, have been documented (eg Reid *et al.*, 1998; Planque & Fromentin, 1996; Frederickson *et al.*, 2004).

Many marine species are cold blooded and sea temperature is critical to their distribution, activity and fecundity. The purpose of this note is to summarise evidence of phenological change in marine species around Scotland.

Trends

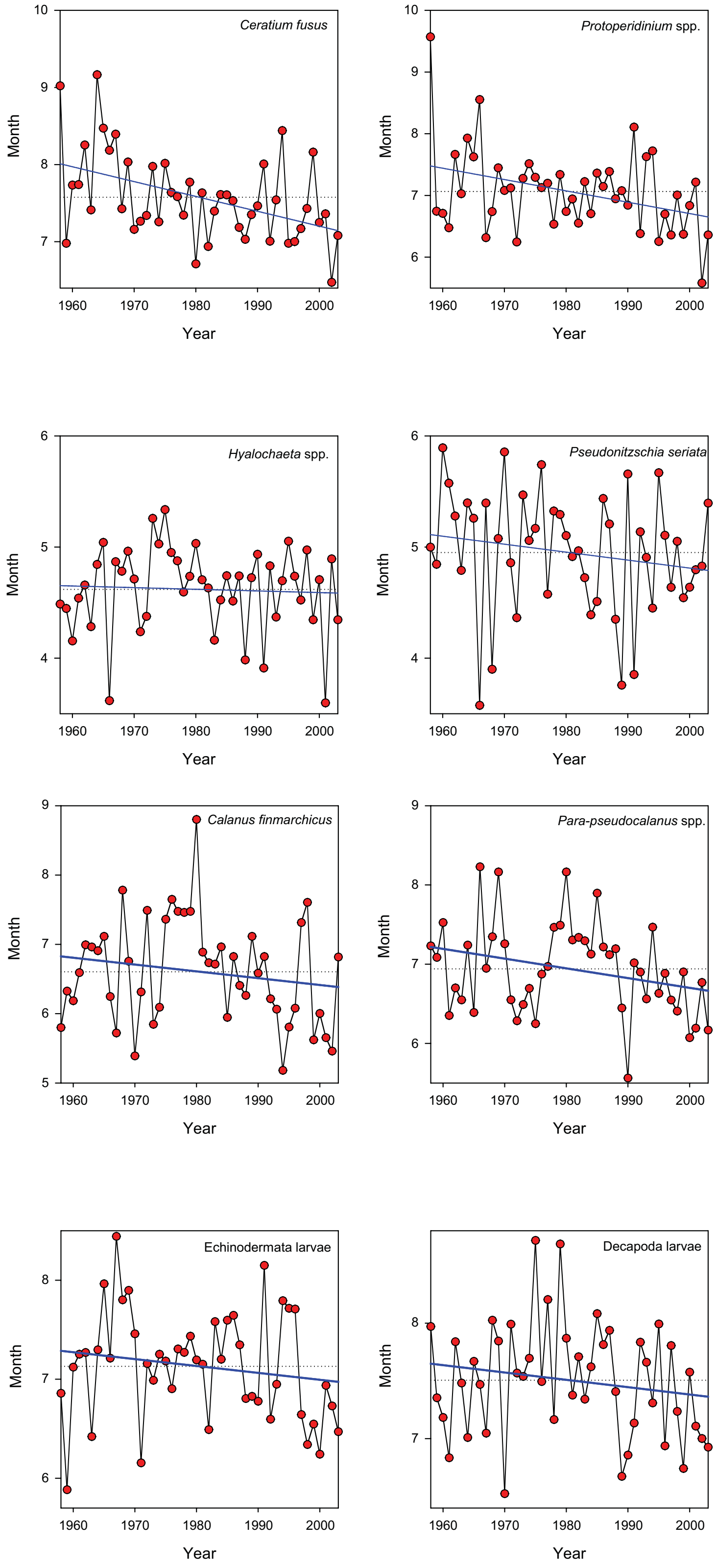
Plankton

Figure 1 displays trends in eight representative example species/groups of species; the top line shows two dinoflagellates (large phytoplankton), the next line two diatoms (also phytoplankton), followed by two copepods (small shrimp-like zooplankton) and finally the planktonic or larval stages of sea urchins/starfish and of crustaceans. The two dinoflagellates and *Para-pseudocalanus* spp. advanced their phenology significantly; *Ceratium fusus* by about four weeks. Most of the remainder show evidence of advance, to varying degrees, although not significant. Despite considerable inter-annual variability and differences between species groups, the average advance in the seasonal peak abundance for plankton taxa examined from Continuous Plankton Recorder records of the northern North Sea over the past 46 years (1958–2003) was two weeks. The rate of change appears to be steepest in recent years. Differences in trends may foretell problems with community structure or food chains (Edwards & Richardson, 2004).

Fish/cephalopods

Whilst no data derive specifically from Scottish waters it is highly likely that spawning and migration phenology will change in warming seas. Such changes are not all of the same strength or in the same direction and, once again, effects on food chains and communities may result.

Figure 1 Graphs of phenology for the dinoflagellates *Ceratium fusus* and *Protoperidinium* spp., the diatoms *Hyalochaeta* spp. and *Pseudonitzscia seriata*, the copepods *Calanus finmarchicus* and *Para-pseudocalanus* spp., and Echinodermata and Decapoda larvae (1958–2003)[2]



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[2] Dotted line represents mean value, blue line represents linear trend

Birds

Changes in spring migration phenology at North Ronaldsay of marine species have been particularly strong with an average advance over 19 species of 6.5 days/decade.

Whilst quantitative data on marine species, other than plankton, are scarce for Scottish waters the likelihood is that major changes in phenology in parts of the marine food web will have implications right up through heirarchy.

Sources

Data on plankton derive from the Continuous Plankton Recorder of the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) and examples used here cover the years 1958–2003. Data on marine bird species derive from North Ronaldsay Bird Observatory and cover the years 1985–2004.

The summary here is derived from Sparks *et al.* (2006).

Authorship

Sparks, T.H.[1] & Edwards, M.[2]
[1]*Centre for Ecology and Hydrology* and [2]*Sir Alister Hardy Foundation for Ocean Science*.

References

Edwards, M. and Richardson, A. (2004). Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature*, **430**, 881–884.

Frederiksen, M. *et al.* (2004). Scale-dependent climate signals drive breeding phenology of three seabird species. *Global Change Biology*, **10**, 1214–1221.

Parmesan, C. and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems, *Nature*, **421**, 37–42.

Planque, B. and Fromentin, J.M. (1996). *Calanus* and environment in the eastern North Atlantic. I. Spatial and temporal patterns of *C. finmarchicus* and *C. helgolandicus*. *Marine Ecology – Progress Series*, **134**, 101–109.

Reid, P.C., Edwards, M., Hunt, H.G. and Warner, A.J. (1998). Phytoplankton change in the North Atlantic. *Nature*, **391**, 546.

Sparks, T.H., Collinson, N., Crick, H., Croxton, P., Edwards, M., Huber, K., Jenkins, D., Johns, D., Last, F., Maberly, S., Marquiss, M., Pickup, J., Roy, D., Sims, D., Shaw, D., Turner, A., Watson, A., Woiwod, I., & Woodbridge, K. (2006). Natural Heritage Trends of Scotland: phenological indicators of climate change. *Scottish Natural Heritage Commissioned Report No. 167 (ROAME No. F01NB01).*

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Appendix C Natural Heritage Indicator notes

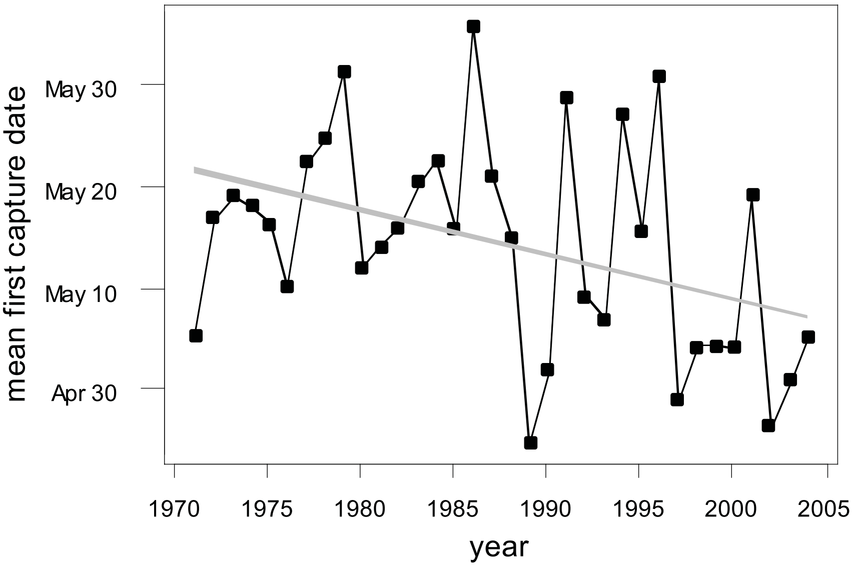
Three notes on selected indicator species are presented outlining the rationale as to why these species have been selected to be phenological indicators of climate change for Scotland.

DRAFT INDICATOR NOTE Terrestrial Phenology

Phenology is the study of the timing of natural events, ie the date on which events such as flowering or migration take place.

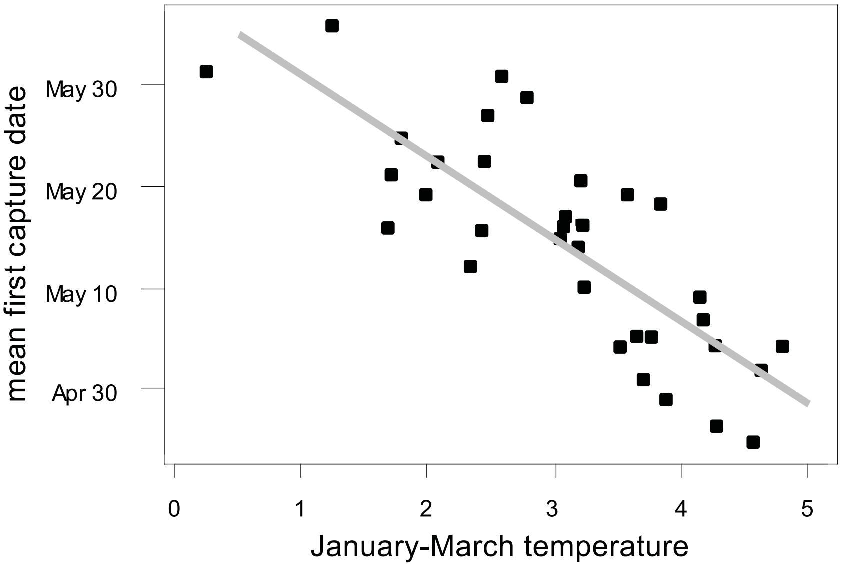
Trends

Change in mean first capture date of the green spruce aphid, 1971–2004



The green spruce aphid has advanced its mean first capture date in Scotland by 4.3 days/decade. The advance is statistically significant ($p=0.021$; $R^2=16\%$ regression weighted by number of trap sites per year). Change is more pronounced in the post 1985 period.

Relationship of mean first capture date to temperature



The relationship is statistically significant ($p<0.001$; $R^2=65\%$ regression weighted by number of trap sites per year) and suggests a 1°C increase in temperature was associated with a 8.1 day advance in mean first capture date.

Commentary

Several aphids are serious pests of agriculture, horticulture and forestry as well as being an important component of the food chain. The green spruce aphid *Elatobium abietinum* can cause serious damage to spruce trees and damage is inevitably worse after mild winters. The data used here are collected as part of a long-term national recording scheme with standardized protocols and proven ability to detect environmental change. Statistically significant earlier phenology was found in almost half of 46 species of aphid examined (Sparks *et al.*, 2006). Aphids are very responsive to temperature in both phenology and population size (eg Cannell *et al.*, 1999).

The green spruce aphid has been selected as an indicator because there has been a clear advance in its phenology (4.3 days/decade) and clear evidence that this is temperature driven; a 1°C increase in temperature has been associated with an eight day advance in mean first capture date.

Data sources

The data are from the four Scottish suction traps (Ayr, Dundee, East Craigs, Elgin) operated to a standard protocol of the Rothamsted Insect Survey. (www.rothamsted.bbsrc.ac.uk/insect-survey). For each year, the mean first capture date was calculated. Because in six years there were only captures from three sites, weighted regression was used to give greater emphasis to years based on four sites. Data were obtained from Jon Pickup at the Scottish Agricultural Science Agency, East Craigs.

Updates

Development of the indicator and future updates are dependent on SASA/Rothamsted Insect Survey and could be updated annually.

Literature and references

Cannell, M.G.R., Palutikof, J.P. and Sparks, T.H. (eds) (1999). *Indicators of Climate Change in the UK.* DETR, London.

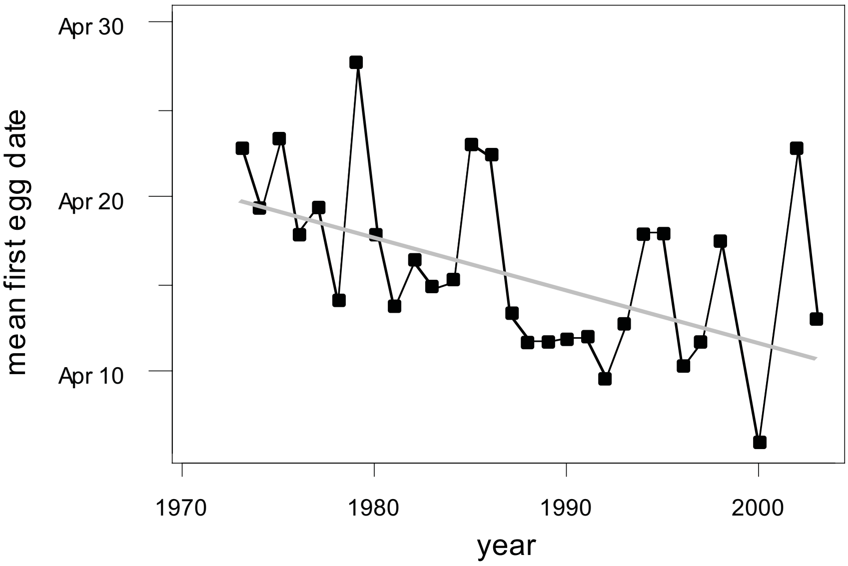
Sparks, T.H., Collinson, N., Crick, H., Croxton, P., Edwards, M., Huber, K., Jenkins, D., Johns, D., Last, F., Maberly, S., Marquiss, M., Pickup, J., Roy, D., Sims, D., Shaw, D., Turner, A., Watson, A., Woiwod, I. and Woodbridge, K. (2006). Natural Heritage Trends of Scotland: phenological indicators of climate change. *Scottish Natural Heritage Commissioned Report No. 167 (ROAME No. F01NB01).*

DRAFT INDICATOR NOTE Freshwater Phenology

Phenology is the study of the timing of natural events, ie the date on which events such as flowering or migration take place. Within Scotland phenological data on freshwater species are sparse.

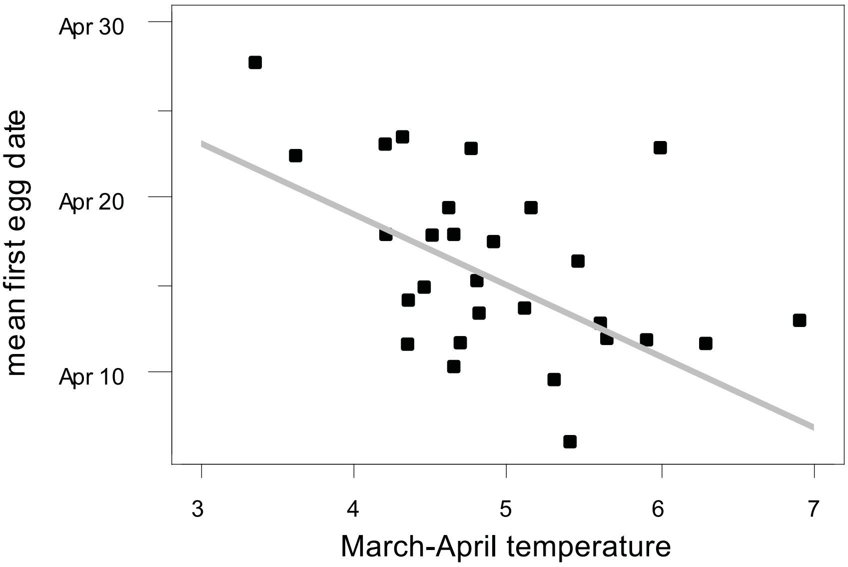
Trends

Change in mean first egg date of the dipper, 1973–2003



The dipper has advanced its mean first egg date in Scotland by 3.0 days/decade. The advance is statistically significant (p=0.007; R^2=24%, regression weighted by number of records per year). Years with less than five records omitted.

Relationship of mean first egg date to temperature



The relationship is statistically significant (p=0.001; R^2=33%, regression weighted by number of records per year) and suggests a 1°C increase in temperature was associated with a 4.1 day advance in mean first egg date. Years with less than five records omitted.

Commentary

Advances in egg laying dates in recent years are well documented and appear to be driven by temperature increases (eg Crick & Sparks, 1999). The dipper is a characteristic bird of upland streams and very dependent on the aquatic environment. The data used here are collected as part of a long-term national recording scheme with proven ability to detect environmental change. The dipper has been selected as an indicator because it has shown both responsiveness to temperature and change in recent decades (Sparks *et al.*, 2006).

There has been a clear advance in Scottish laying dates of this species by three days/decade and clear evidence that this is temperature driven; a 1°C increase in temperature has been associated with a four day advance in mean first egg date.

Data sources

The data are from the British Trust for Ornithology's Nest Record Scheme (www.bto.org; Crick *et al.*, 2003) and are restricted to records from Scotland. For each year, the mean first egg date was calculated and years with less than five records omitted from this analysis. Because of differences in numbers of records between years, weighted regression was used to give greater emphasis to years based on a larger number of records.

Updates

Development of the indicator and future updates are dependent on the British Trust for Ornithology, data could be updated annually.

Literature and references

Crick, H.Q.P., Baillie, S.R. and Leech, D.I. (2003). The UK Nest Record Scheme: its value for science and conservation. *Bird Study*, **50**, 254–270.

Crick, H.Q.P. and Sparks, T.H. (1999). Climate change related to egg-laying trends. *Nature*, **399**, 423–424.

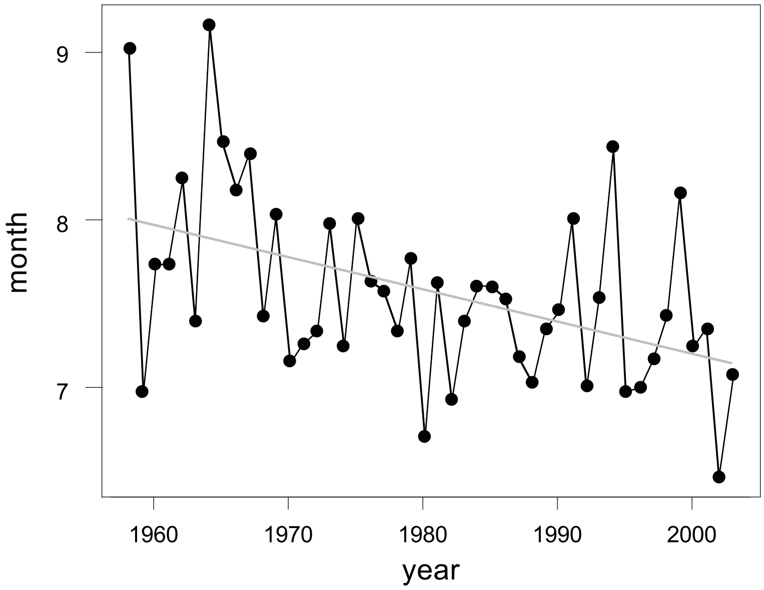
Sparks, T.H., Collinson, N., Crick, H., Croxton, P., Edwards, M., Huber, K., Jenkins, D., Johns, D., Last, F., Maberly, S., Marquiss, M., Pickup, J., Roy, D., Sims, D., Shaw, D., Turner, A., Watson, A., Woiwod, I. and Woodbridge, K. (2006). Natural Heritage Trends of Scotland: phenological indicators of climate change. *Scottish Natural Heritage Commissioned Report No. 167 (ROAME No. F01NB01).*

DRAFT INDICATOR NOTE Marine Phenology

Phenology is the study of the timing of natural events, ie the date on which events such as flowering or migration take place.

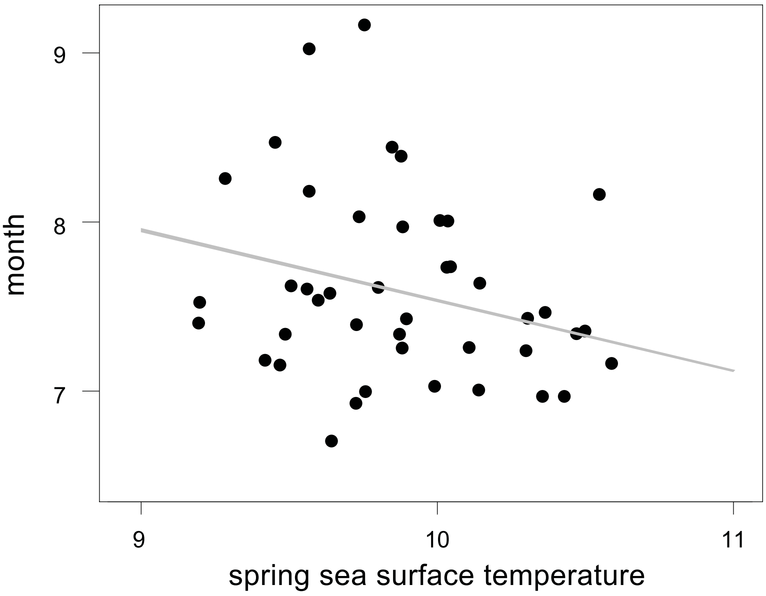
Trends

Change in the seasonal peak of the phytoplankton *Ceratium fusus*, 1958–2003



Ceratium fusus has advanced its seasonal peak off Scotland by 5.3 days/decade. The advance is statistically significant ($p<0.001$, $R^2=21\%$).

Relationship of seasonal peak to temperature



Ceratium fusus phenology is significantly correlated with spring sea surface temperatures ($p<0.05$, $R^2=10\%$,) and suggests a 1°C increase in temperature was associated with a 12 day advance in seasonal peak.

Commentary

Phytoplankton are the building blocks of the ocean and many species higher in the food chain are directly or indirectly reliant on them for survival. Much work has shown changes in distribution, abundance and phenology as a consequence of changing sea temperatures (eg Reid *et al.*, 1998; Edwards & Richardson, 2004). Not all species are changing at the same rate or in the same direction. The data used here are collected as part of a long-term recording scheme with standardized protocols and proven ability to detect environmental change.

Ceratium fusus has been selected as an indicator because it has shown a clear advance in its phenology by 5.3 days/decade (Sparks *et al.*, 2006) and is very strongly linked to spring sea surface temperatures (Edwards & Richardson, 2004).

Data sources

The data are from the Continuous Plankton Recorder of the Sir Alister Hardy Foundation for Ocean Science (www.sahfos.ac.uk). Recording follows a strict protocol, and plankton are caught in devices towed by ships on commercial routes. Data used here come from the northern North Sea (56–60°N, 5°W–4°E), and from over 14,000 samples in the period 1958–2003.

Updates

Development of the indicator and future updates are dependent on SAHFOS, data could be updated annually.

Literature and references

Edwards, M. and Richardson, A. (2004). Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature*, **430**, 881–884.

Reid, P.C., Edwards, M., Hunt, H.G. and Warner, A.J. (1998). Phytoplankton change in the North Atlantic. *Nature*, **391**, 546.

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