Met Office Hadley Centre

WOODLAND TRUST

State of the UK Climate 2016 Phenology supplement

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Cover: Oak after budburst on 15th April 2016, view southwards over the Exe Estuary, Devon. Photo: Debbie Hemming.

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Introduction

This Phenology Supplement to the State of the UK Climate 2016 report presents observations of the timing of budburst for 11 well-known tree species across the UK. The observations for 2016 are discussed relative to their longer-term (2000 to 2016) context, and simple relationships between budburst and climate are explored that highlight significant differences between species and regions.

Phenology is the study of recurring events in nature and their relationships with climate. The word derives from the Greek phaínō ‘appear’ and logos ‘reason’, emphasising the focus on observing events and understanding why they occur. Budburst is one of the most regularly observed phenological events in plants. According to Nature’s Calendar, budburst occurs when: “The colour of the new green leaves is just visible between the scales of the swollen or elongated bud” (https://www.woodlandtrust.org.uk/visiting-woods/natures-calendar/).

Phenological records, when combined with climate observations, provide long-term indicators of how plants and animals respond to seasonal variations and longer-term trends in climate, and which species are more sensitive to these changes. Budburst in particular is an important event to study as it signifies the beginning of activity in trees in spring, and it is one of the clearest phenological events to observe. Although the year-to-year timing of seasonal events can vary considerably, warmer springs are typically associated with earlier signs of spring, including budburst, and this is particularly prominent for the more temperature-sensitive species.

Executive Summary

- Phenology is the study of recurring events in nature and their relationships with climate. There is a long history of recording phenological events, stretching back at least to 1736, in the UK.
- This phenology supplement presents results on the timing of budburst for 11 well-known tree species across the UK, comparing 2016 with the average for the 2000 to 2016 period.
- Simple relationships between date of budburst and monthly climate variables (temperature, sunshine and precipitation) are described.
- In 2016 the UK average date of budburst for all 11 species was 12th April. European Larch was earliest on 2nd April, and Ash was latest on 1st May.
- Budburst in 2016 took a slow ‘phenological amble’ from south to north across the UK, at a pace of between about 1.0 and 2.5 km/hr.
- Relative to the 2000 to 2016 average, UK average budburst for all species (except Pedunculate Oak) was later in 2016 by between 1 day (Sessile Oak) and 5 days (Rowan).
- The later than average budburst of most species in 2016 was associated with cooler March and April temperatures in the UK. 2016 March temperature was 0.3°C below, and April 1.5°C below, the 2000 to 2016 average.
- The timing of UK budburst for 10 out of the 11 tree species was significantly related to March or April temperature (depending on species). A 1°C lower (or higher) temperature during these months was associated with later (or earlier) budburst of between 3 days for Alder in the South East and 6 days for Larch in the North East.
- Ash showed a significant relationship with sunshine. This was strongest in March and in the South West region.
- March to April temperatures for the 2000 to 2016 period have been on average 1.1°C warmer than the 1961 to 1990 climatological average.
- Many phenological events are closely related with climate variability and change. They are simple to observe and provide valuable records of long-term environmental change.

European Larch

Horse Chestnut

Sycamore

Alder

Silver Birch

Rowan

Field Maple

Beech

Pedunculate Oak

Sessile Oak

Ash

The value of phenology records

The practice of recording phenological events has a long history. Some ancient Greek records of the timing of spring still survive (Stillingfleet, 1762), and detailed records of the timing of cherry and peach blossom associated with ancient festivals in Japan and China can be traced back to the 8th Century (Aono and Kazui, 2008). The UK also embraced phenological study (see next section 'Brief history of phenology in the UK'), and its fundamental association with meteorology was highlighted when in 1875 the (Royal) Meteorological Society launched a national scheme to record the annual timing of plant and animal life, which persisted for over 60 years. After a 50-year gap, the current Nature's Calendar scheme run by the Woodland Trust was established.

These phenological schemes have generated, and allowed scientists to utilise, large amounts of valuable observational data, with significant contributions from members of the public and enthusiastic volunteers. Most recording is simple to undertake and generally involves easy-to-identify species. Analysis of data from the early observations was limited and often only comprised basic annual summaries. However, since the 1990s there has been a resurgence of interest in phenology, resulting from questions about whether rising temperatures associated with a changing climate are affecting our environment.

Many phenological events show a very strong relationship with temperature, particularly for plants. In the UK, long-term records, such as those collected by Jean Combes OBE since 1947, show an overall trend of budburst getting earlier. However, this trend is not always evident in shorter records because of large year-to-year variations in budburst, which are responding largely to natural climate variability. Thus, the records generated by members of the public can clearly demonstrate the effects of year-to-year variability in climate as well as longer-term trends; and these can be more readily comprehended than what appear to be slight changes in average temperature. Records can be accumulated for locations remote from a meteorological station, and if recording is compatible, can be compared with the growing database of historical records to investigate long-term environmental change.

Brief history of phenology in the UK

Robert Marsham was the first to make consistent phenological observations in the UK, recording 27 'Indicators of Spring' on his estate in Norfolk between 1736 and his death in 1797 (Sparks and Carey, 1995, Sparks and Lines, 2008). Subsequent Marsham family members continued this valuable record until 1958.

Zoffany portrait of Robert Marsham (Courtesy of Alex Sparks)

Encouraged by the Belgian polymath Adolphe Quetelet, and recognising the value of phenological records for understanding nature, the British Association for the Advancement of Science attempted to organise phenological recording from the 1840s. However, it was not until the 1870s that the (Royal) Meteorological Society successfully launched a national phenology network recording flowering dates of up to 13 plant species and appearance of specific bird and insect species. This ran between 1875 and 1948 (Clark, 1936), and at its peak about 600 observers were involved across the UK. Annual Phenological Reports were published by the Society summarising the observations, highlighting unusual phenological events and their relationships with climate during the season. Although it was providing valuable scientific insight and remained popular with its observers, retirement of the last coordinator initiated closure of the network.

After a gap of 50 years, the UK Phenology Network was resurrected in 1998 by the Centre for Ecology and Hydrology (Sparks et al, 1998), and joined by the Woodland Trust in 2000 to promote phenology to a wider and larger audience (Sparks and Smithers, 2002). This resulted in establishment of Nature's Calendar (https://www.woodlandtrust.org.uk/visiting-woods/natures-calendar/), which currently has over 4,000 active participants and whose database contains 2.7 million records covering a wide range of phenological observations.

Budburst

During 2016, the average date of budburst in the UK for all 11 tree species combined was 12th April, and this ranged from 2nd April for European Larch to 1st May for Ash (Table 1). All species showed a south to north trend, with earlier budburst typically occurring in the South East or South West regions, and later in the northern and Scottish regions. Appendix 1 describes the methods used to calculate and map these dates, and discusses uncertainties.

The UK-wide average budburst dates for all species, except Pedunculate Oak, were later (positive anomaly values in Table 1) than the 2000 to 2016 average by between 1 day for Sessile Oak to 5 days for Rowan. However, there are variations across the different regions with both earlier and later budburst dates observed in 2016. Some species showed large regional variations in the timing of budburst in 2016 relative to the 2000 to 2016 average. For example, Pedunculate Oak budburst was 7 days earlier in the South West and 7 days later in Southern Scotland, while other species showed very consistent dates across all regions, for example, Silver Birch, Rowan and Horse Chestnut.

Table 1: Regional and UK mean dates of budburst (Actual) and daily anomalies (Anom) in 2016 relative to 2000 to 2016 averages. Positive anomalies show later budburst in 2016 relative to 2000 to 2016, and negative anomalies show earlier budburst in 2016. Earliest (orange) and latest (blue) dates of budburst are highlighted. Species columns are arranged from earliest to latest budburst dates, and region rows from south to north. Dates composed of less than 5 observations are shaded grey and not included in the UK estimates.

	European Larch		Horse Chestnut		Sycamore		Alder	
	Actual	Anom	Actual	Anom	Actual	Anom	Actual	Anom
South East	25 Mar	-3	27 Mar	+1	3 Apr	+1	4 Apr	+2
South West	1 Apr	+7	26 Mar	-1	1 Apr	-2	6 Apr	-1
Central	5 Apr	+6	29 Mar	+1	4 Apr	0	12 Apr	+6
North West	4 Apr	+5	1 Apr	+2	6 Apr	+1	9 Apr	-1
North East	3 Apr	+3	3 Apr	+4	6 Apr	+1	8 Apr	-2
Northern Ireland	13 Mar	-15	27 Mar	0	6 Apr	+2	29 Mar	-7
Southern Scotland	4 Apr	+5	30 Mar	-1	10 Apr	+4	17 Apr	+3
Eastern Scotland	7 Apr	+6	7 Apr	+4	13 Apr	+6	24 Apr	+14
Northern Scotland	4 Apr	+2	5 Apr	0	20 Apr	+7	16 Apr	-1
UK mean	2 Apr	+3.9	31 Mar	+1.1	7 Apr	+2.3	12 Apr	+2.3

	Silver Birch		Rowan		Field Maple		Beech	
	Actual	Anom	Actual	Anom	Actual	Anom	Actual	Anom
South East	6 Apr	+4	8 Apr	+7	6 Apr	0	9 Apr	-2
South West	10 Apr	+5	11 Apr	+7	8 Apr	0	16 Apr	+2
Central	7 Apr	-3	9 Apr	+7	8 Apr	+1	17 Apr	+2
North West	11 Apr	+3	13 Apr	+8	10 Apr	+3	19 Apr	+1
North East	12 Apr	+4	6 Apr	0	7 Apr	-2	16 Apr	-2
Northern Ireland	7 Apr	0	28 Mar	-5	21 Apr	+10	20 Apr	-2
Southern Scotland	14 Apr	+3	10 Apr	+1	19 Apr	+9	26 Apr	+4
Eastern Scotland	13 Apr	+2	19 Apr	+11	17 Apr	+7	29 Apr	+8
Northern Scotland	10 Apr	-2	9 Apr	-3	15 Apr	+6	3 May	+8
UK mean	10 Apr	+1.9	10 Apr	+4.8	9 Apr	+1.8	20 Apr	+2.0

	Pedunculate Oak		Sessile Oak		Ash	
	Actual	Anom	Actual	Anom	Actual	Anom
South East	9 Apr	-4	10 Apr	-3	19 Apr	+2
South West	8 Apr	-7	14 Apr	-2	23 Apr	+2
Central	13 Apr	-5	18 Apr	+1	26 Apr	+4
North West	24 Apr	+4	22 Apr	+3	27 Apr	+1
North East	22 Apr	0	27 Apr	+6	22 Apr	-5
Northern Ireland	11 Apr	-10	13 May	+20	2 May	+4
Southern Scotland	3 May	+7	27 Apr	0	6 May	+4
Eastern Scotland	14 May	+15	7 May	+10	2 May	+1
Northern Scotland	11 May	+8	11 May	+12	15 May	+10
UK mean	18 Apr	-0.8	18 Apr	+1.0	1 May	+2.6

Table 2 shows estimates of the speed of northward progression of budburst during 2016 for each of the 11 tree species and the UK average. Various methods could have been used to estimate this progression, here this is based on the regional average timing and location (region centre points are used) of the earliest and latest budburst for each species, and as such they should only be used to infer broad-scale changes. These estimates suggest that the average speed of northward progression of budburst during 2016 varied from around 2.0-2.5 km/h for European Larch, Horse Chestnut, Silver Birch, to less than 1.0 km/h for Pedunculate and Sessile Oak – a slow phenological amble across the UK! Species with later budburst dates, e.g. the Oaks and Ash, tended to also show slower northward progression, taking nearly 1 month to cover all regions.

Table 2: Estimate of the average speed of northward progression of budburst for each tree species, and the UK mean, based on the timing and location of the earliest and latest regional average budburst. The number of days between the earliest and latest budbursts are noted, and the approximate distances (to nearest 50km) between these regions (region centre points used) are shown.

	UK Earliest	UK Latest	Days	Distance (km)	Speed north (km/h)
European Larch	25 Mar	7 Apr	13	650	2.1
Horse Chestnut	26 Mar	7 Apr	12	600	2.1
Sycamore	1 Apr	20 Apr	19	650	1.4
Alder	4 Apr	24 Apr	20	650	1.4
Silver Birch	6 Apr	14 Apr	8	500	2.6
Rowan	6 Apr	19 Apr	13	300	1.0
Field Maple	6 Apr	19 Apr	13	500	1.6
Beech	9 Apr	3 May	24	700	1.2
Pedunculate Oak	9 Apr	3 May	24	500	0.9
Sessile Oak	10 Apr	27 Apr	17	400	1.0
Ash	19 Apr	15 May	26	700	1.1
UK mean	5 Apr	22 Apr	17	559	1.5

The following sections compare the spatial patterns of budburst in 2016 relative to the 2000 to 2016 average for each of the 11 tree species individually.

European Larch

Figure 1 shows that budburst in 2016 was delayed in most regions (except South East) by 2 to 6 days, compared to the 2000 to 2016 average – this is a significant delay for this species.

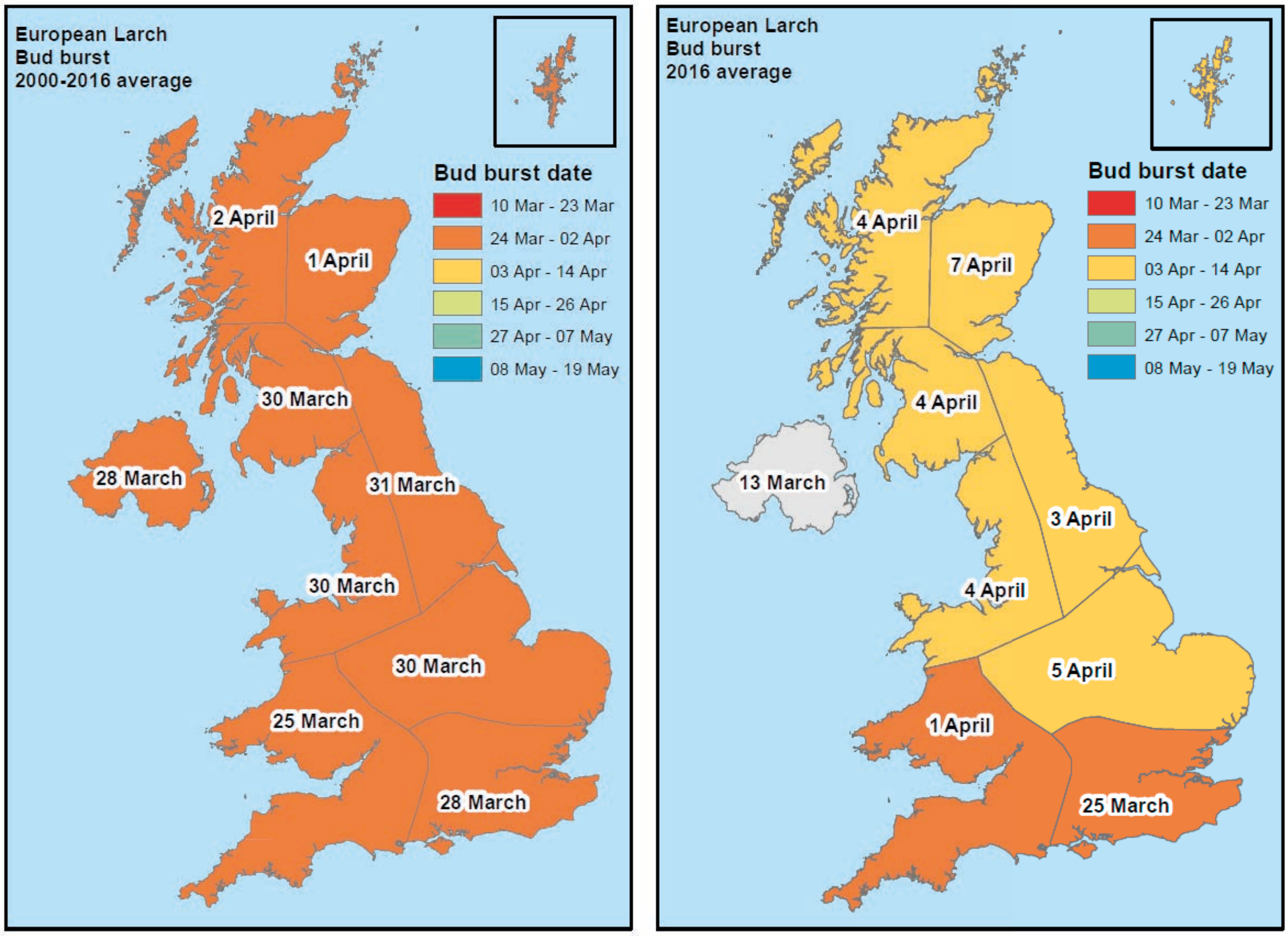


Figure 1: Mean date of budburst of European Larch in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Horse Chestnut

Figure 2 shows that the dates and locations of budburst in Horse Chestnut during 2016 were similar to the 2000 to 2016 average, apart from a small delay (average of 4 days) in the North East and Eastern Scotland regions.

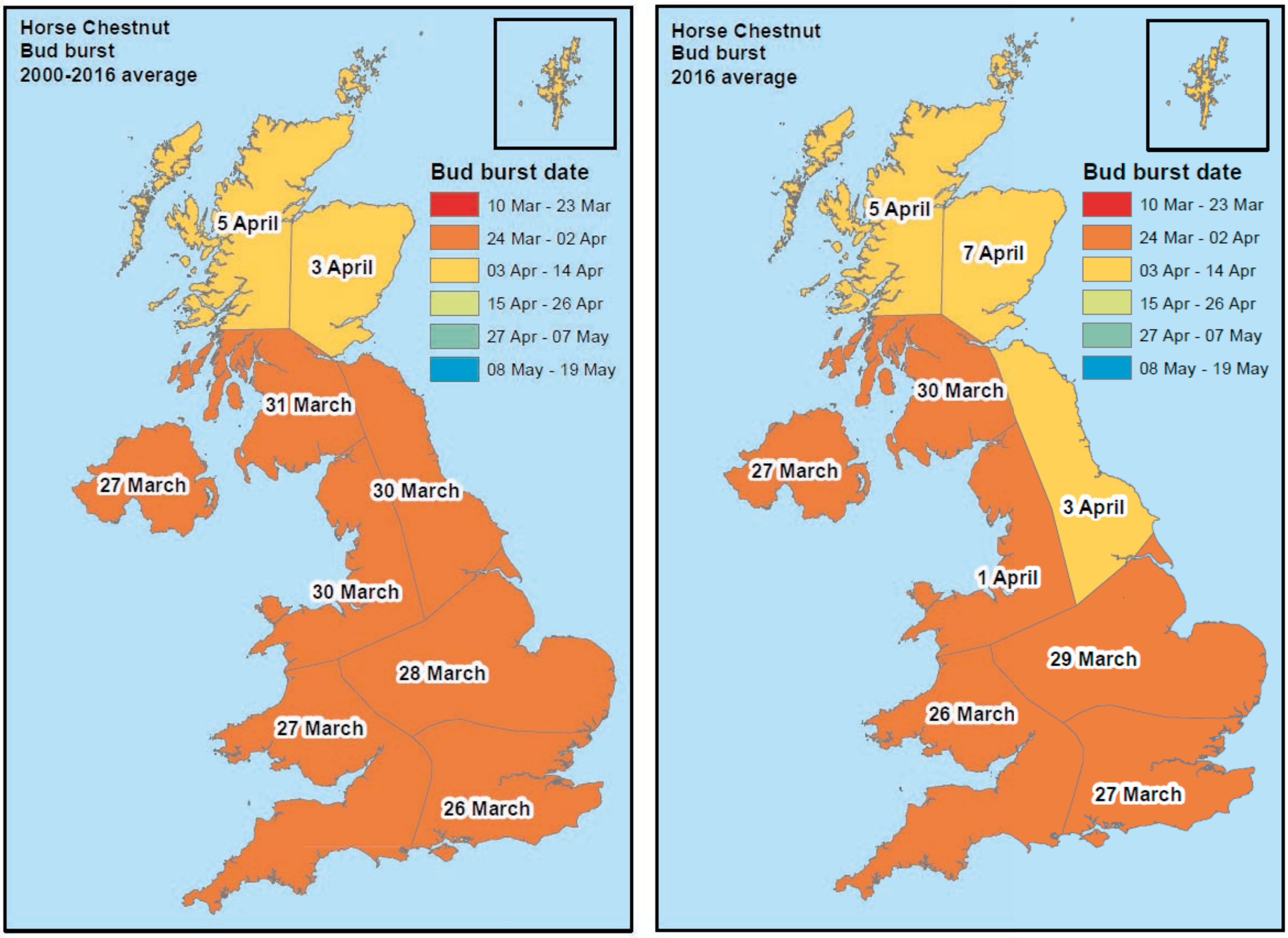


Figure 2: Mean date of budburst of Horse Chestnut in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Sycamore

Figure 3 shows that the average date of budburst for Sycamore during 2016 was within 2 days of the 2000 to 2016 average in all regions in England and Wales, but delayed by between 4 to 7 days across the Scottish regions.

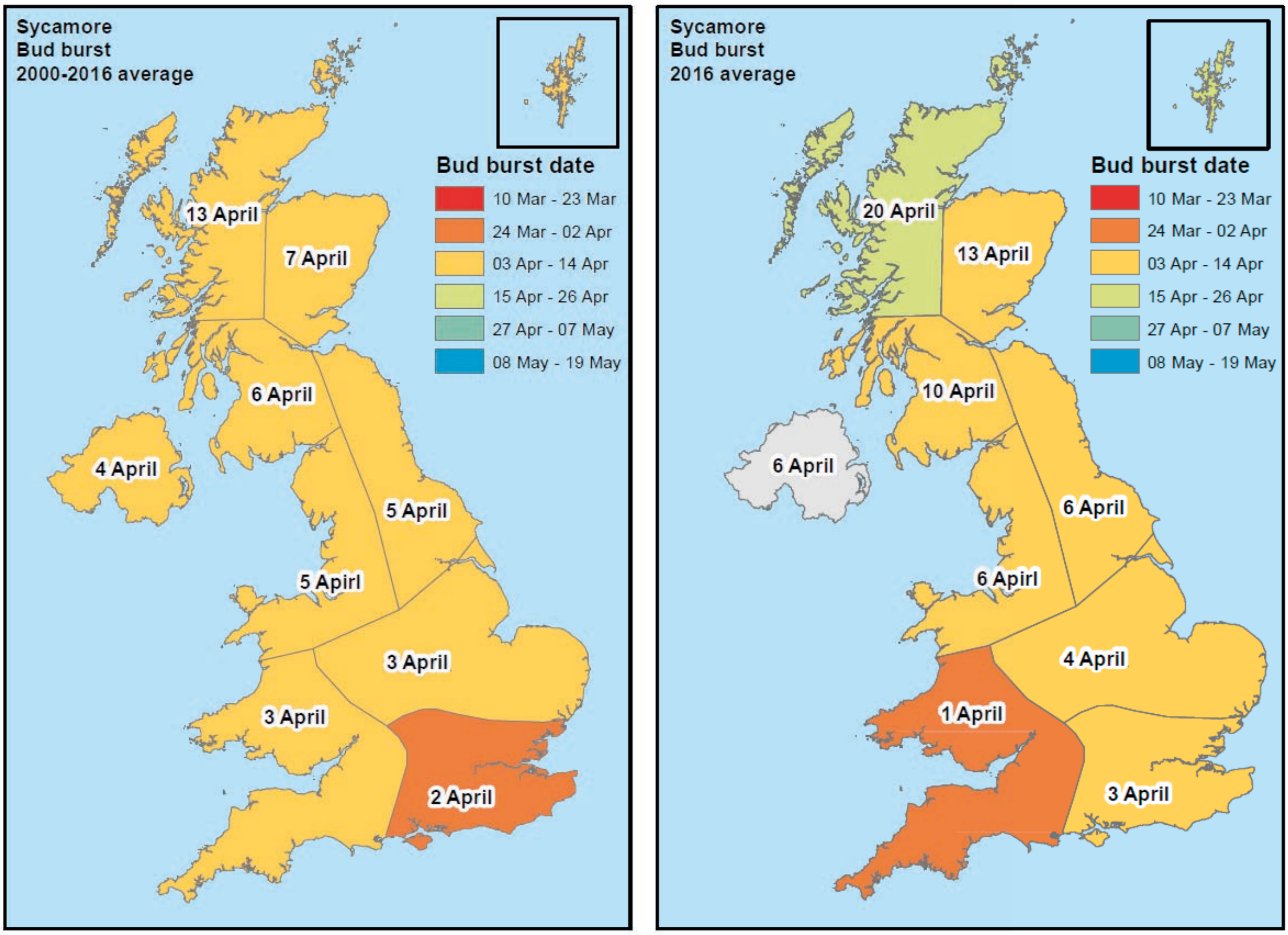


Figure 3: Mean date of budburst of Sycamore in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Alder

Figure 4 shows that the average dates of budburst for Alder during 2016 were within 2 days of the 2000 to 2016 average, except in the Central and Eastern Scotland regions where the 2016 budburst was later by 6 days and 14 days, respectively.

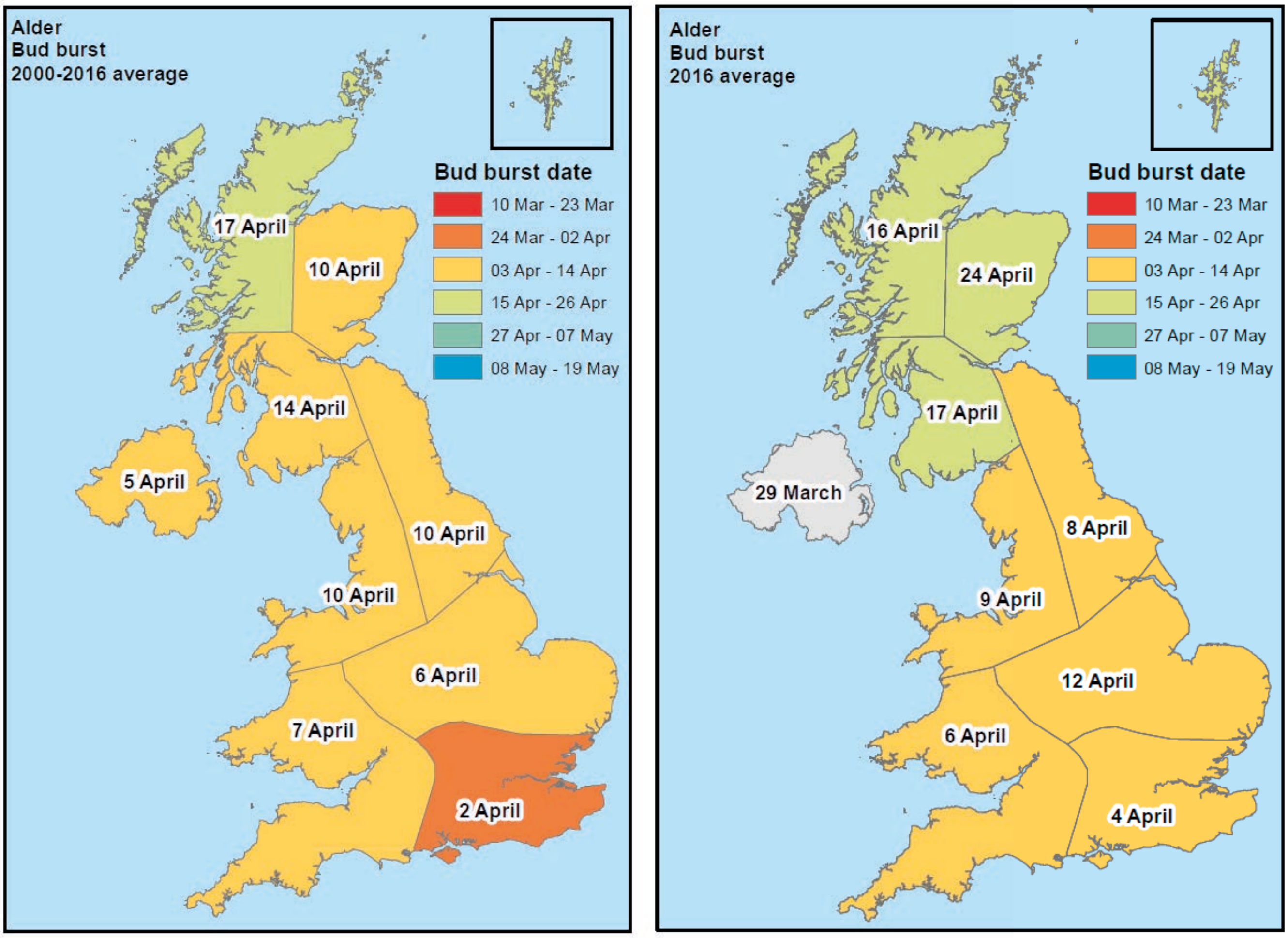


Figure 4: Mean date of budburst of Alder in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Silver Birch

Figure 5 shows that the average date of budburst for Silver Birch during 2016 was generally similar to the 2000 to 2016 average. There was a tendency for slightly later budburst in 2016, notably in the South West (5 days) and North East (4 days) regions.

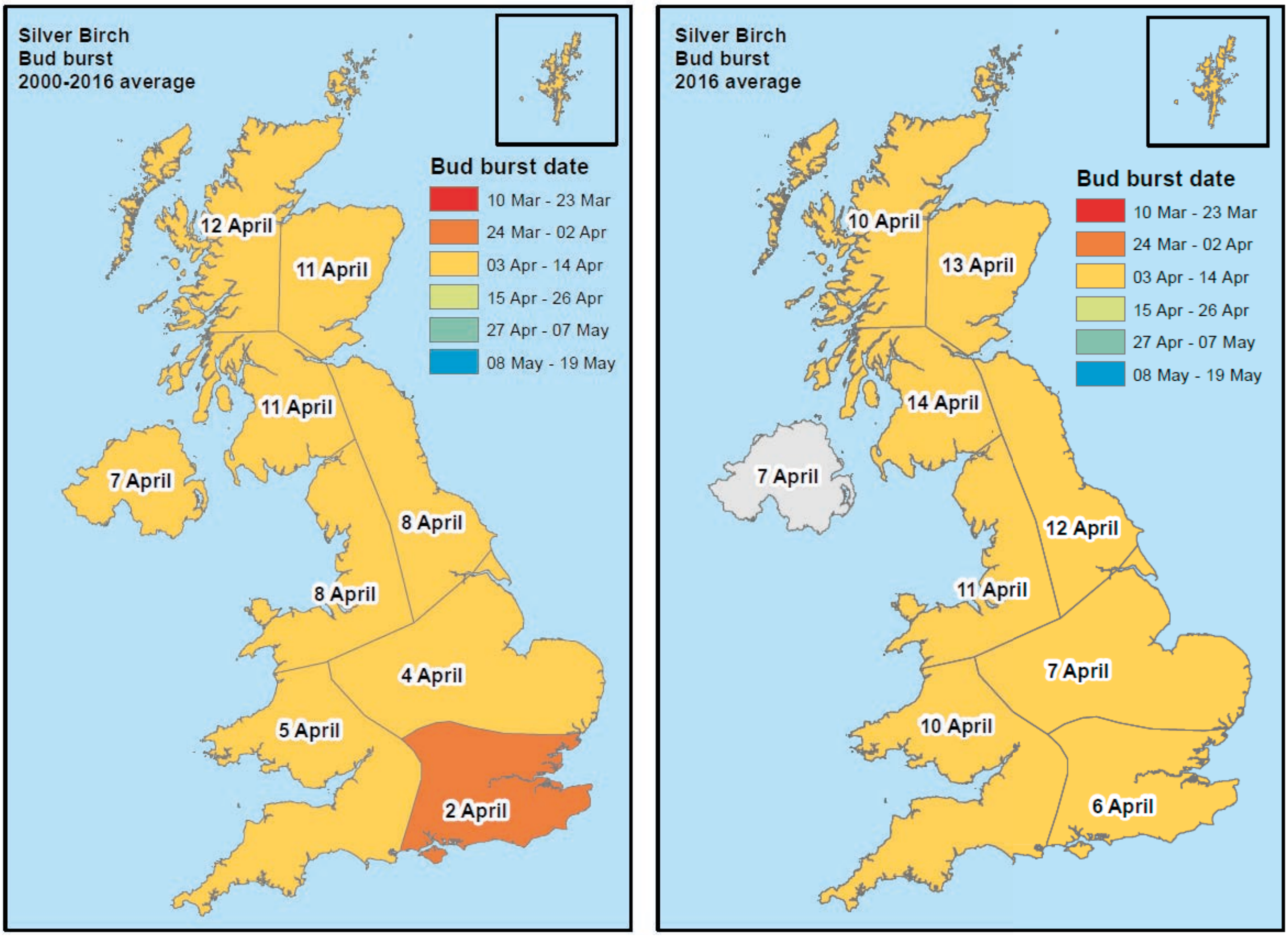


Figure 5: Mean date of budburst of Silver Birch in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Rowan

Figure 6 shows that the average date of budburst for Rowan during 2016 was generally delayed across the UK, relative to the 2000 to 2016 average. The greatest delay, of 11 days, was observed in Eastern Scotland, and in the southern regions of the South West, South East and Central the average delay was 7 days. Northern Ireland shows a relative advance in budburst in 2016, but with less than 5 observations this result is considered unreliable (grey shading in Figure 6).

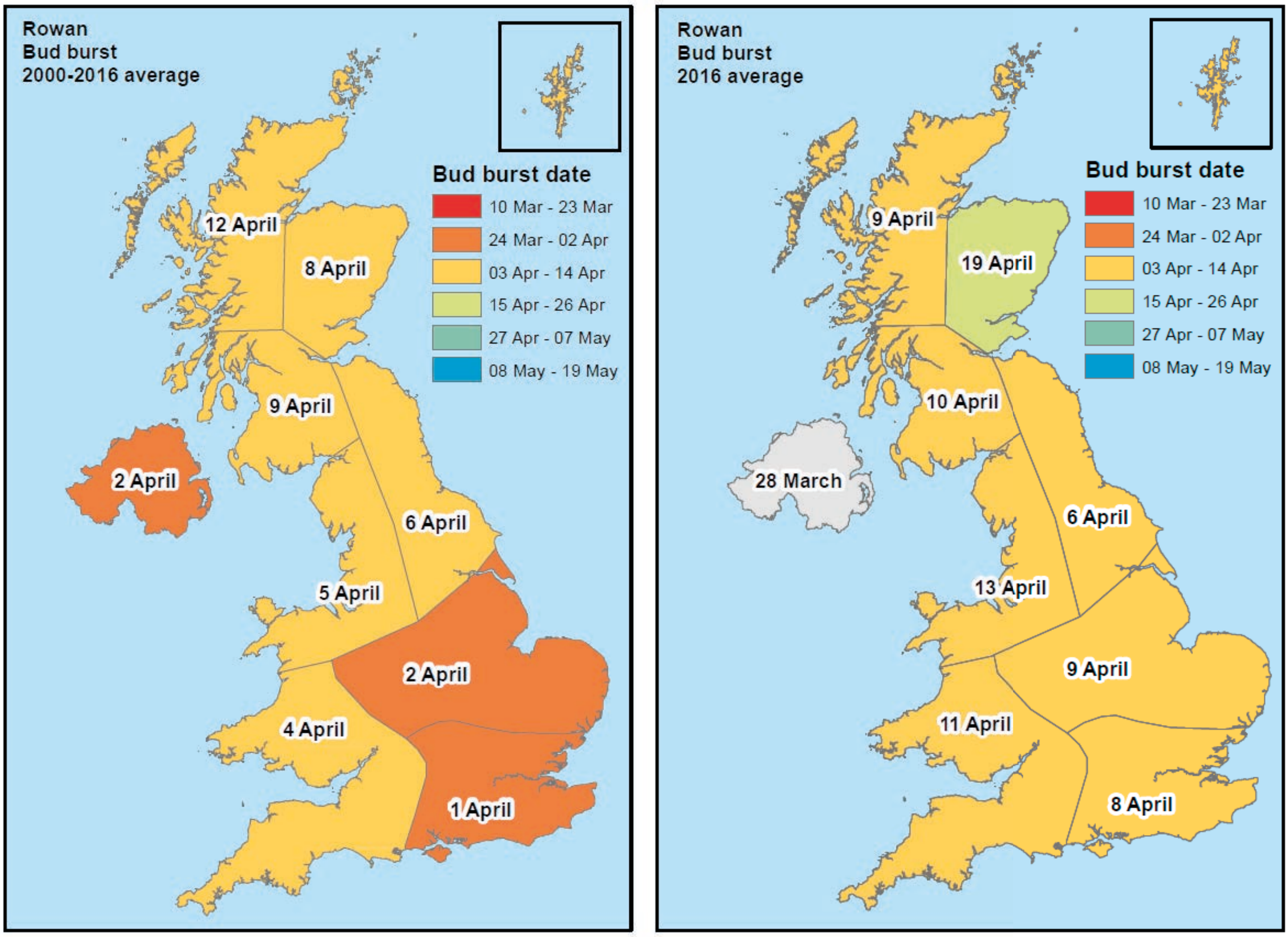


Figure 6: Mean date of budburst of Rowan in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Field Maple

Figure 7 shows that the 2000 to 2016 average dates of budburst for Field Maple are very similar across all regions of the UK, varying by only 4 days from 6th April in the South East to 10th April in Southern and Eastern Scotland. Relative to the longer-term average, in 2016, budburst was delayed by 9 days in Southern Scotland and by 3 days in the North West. Other Scottish regions and Northern Ireland had less than 5 observations for this species in 2016, so their results are considered unreliable (grey shading in Figure 7).

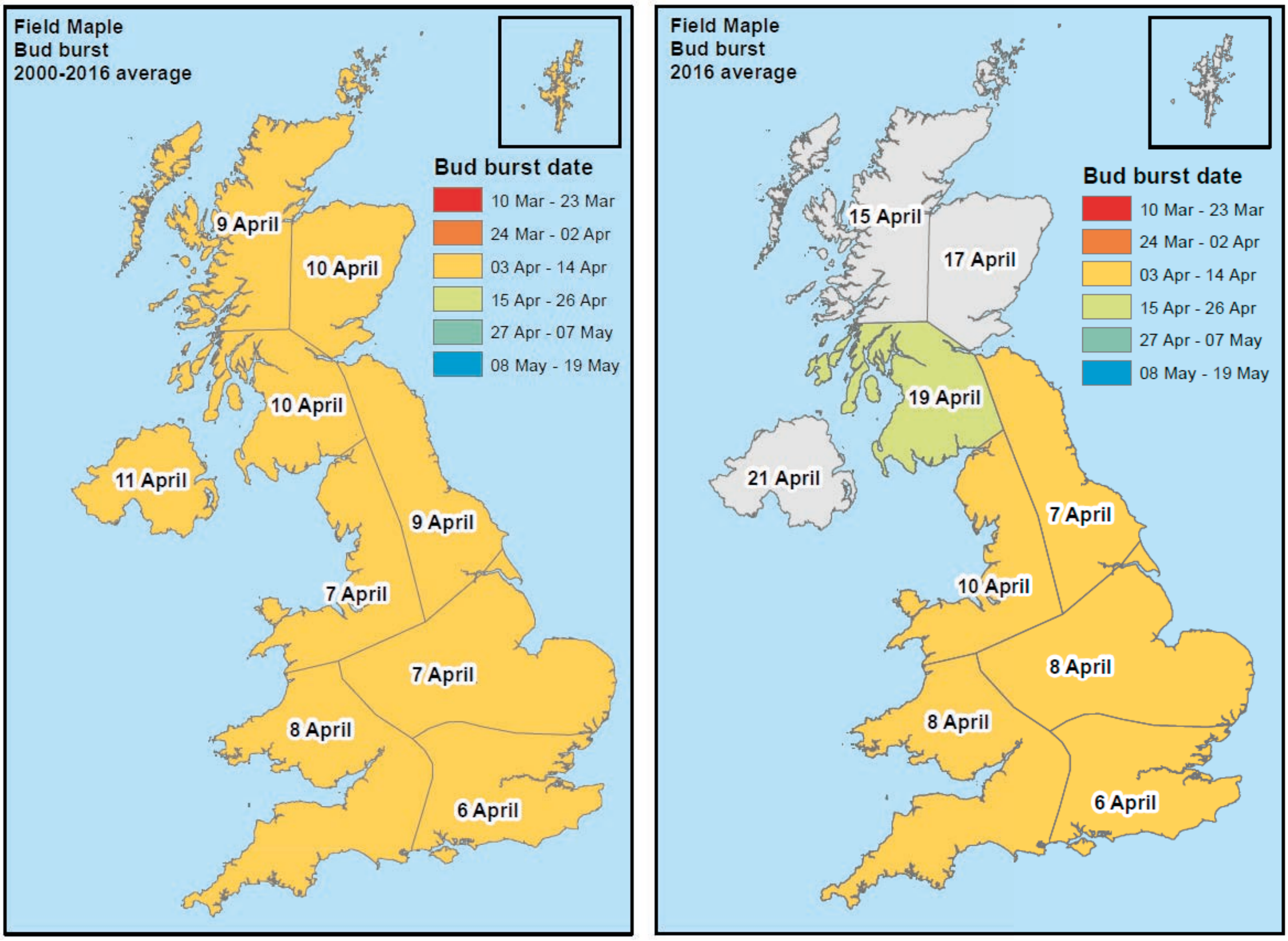


Figure 7: Mean date of budburst of Field Maple in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Beech

Figure 8 shows that the budburst dates of Beech across different regions were both delayed and advanced in 2016, depending on the region, relative to the 2000 to 2016 average. The largest delays, 8 days, were observed in Northern and Eastern Scotland, and small advances of 2 days were noted in the South East, North East and Northern Ireland regions.

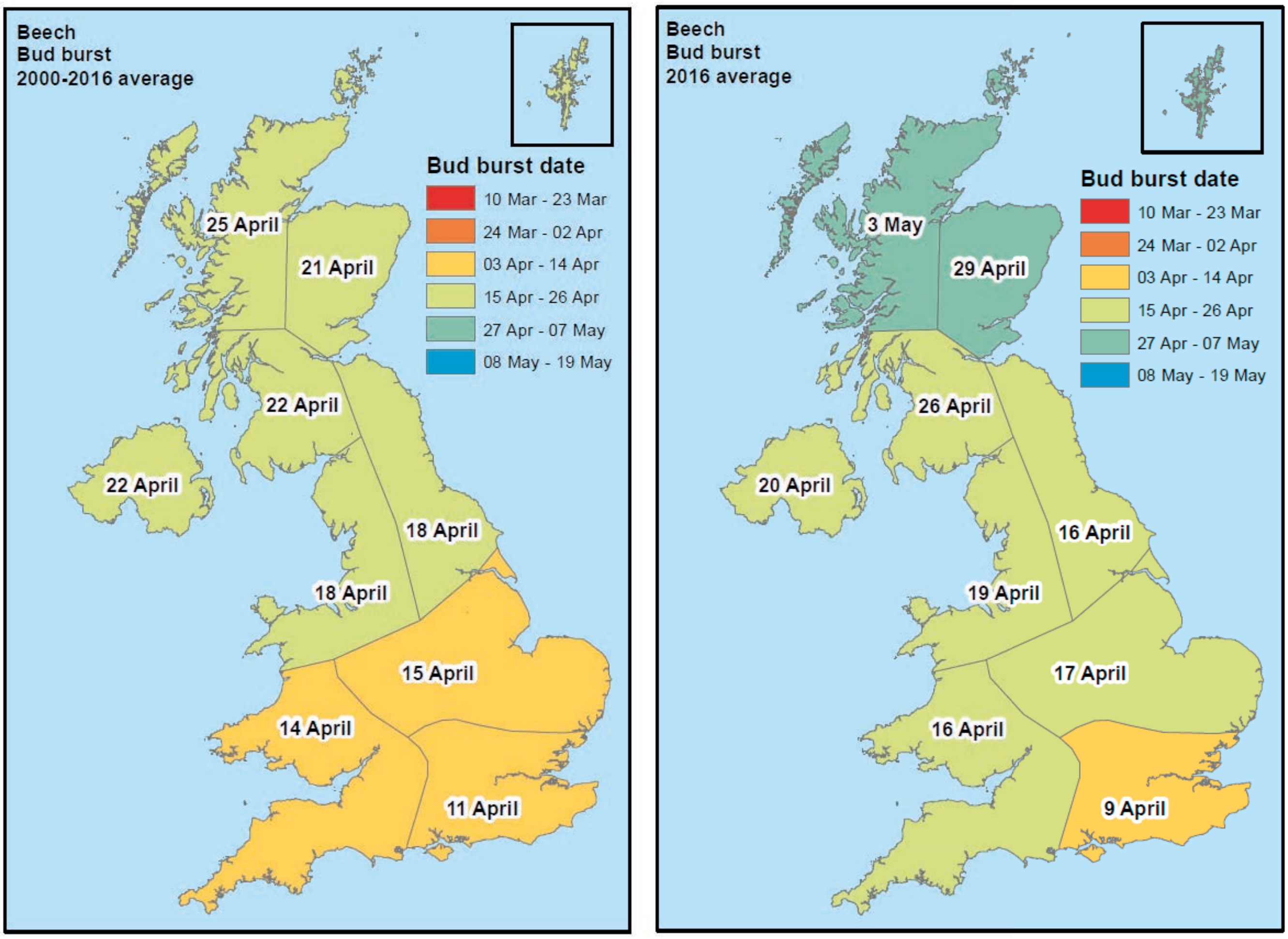


Figure 8: Mean date of budburst of Beech in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Pedunculate Oak

Figure 9 shows that the average budburst dates of Pedunculate Oak was generally advanced in 2016, relative to the 2000 to 2016 average. The average day of budburst in 2016 was earlier in the South West by 7 days, in the Central region by 5 days, and in the South East by 4 days relative to the 2000 to 2016 average. Observations for this species in Northern and Eastern Scotland and Northern Ireland were again too small to provide confidence in the results for these regions.

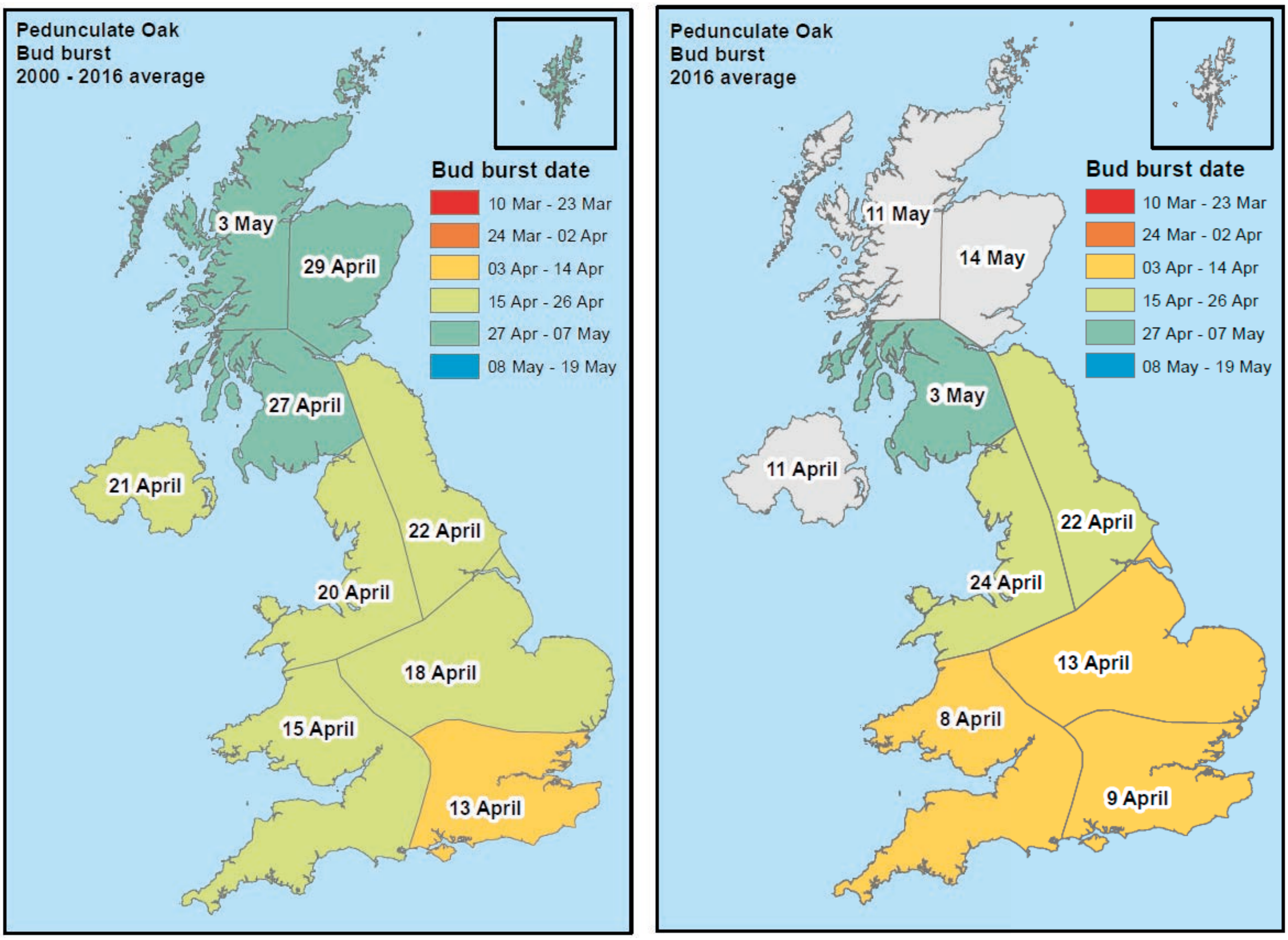
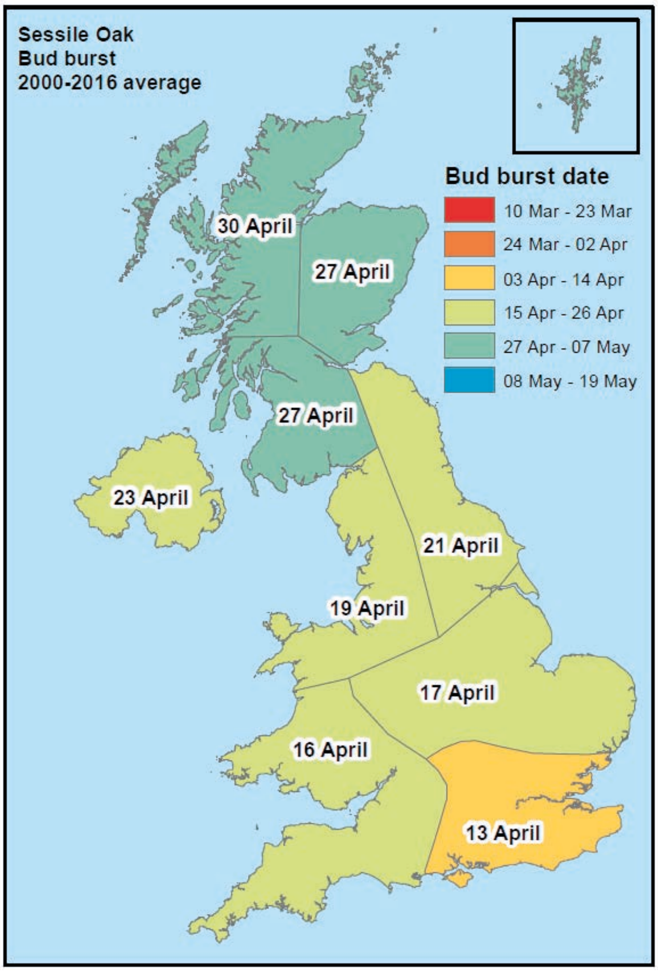


Figure 9: Mean date of budburst of Pedunculate Oak in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Sessile Oak

Figure 10 shows that the average 2016 budburst dates for Sessile Oak were both advanced and delayed, depending on the region, relative to the 2000 to 2016 average. In the South West and South East budburst was advanced by 2 days and 3 days, respectively. Whereas, the North East observed an average delay of 6 days. 2016 observations for this species in Northern and Eastern Scotland and Northern Ireland were again too small to provide confidence in the results for these regions.



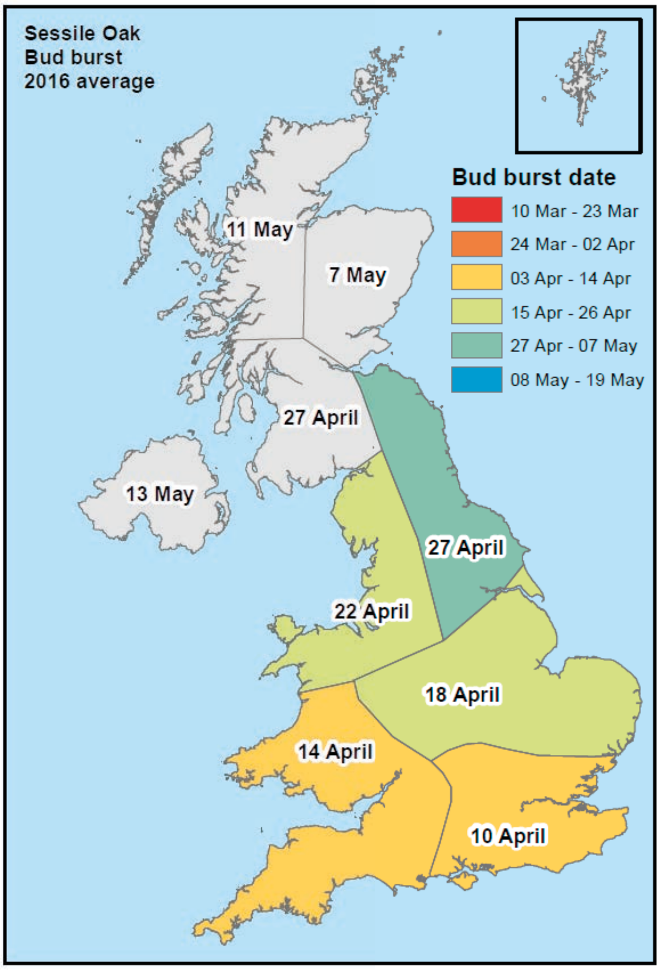
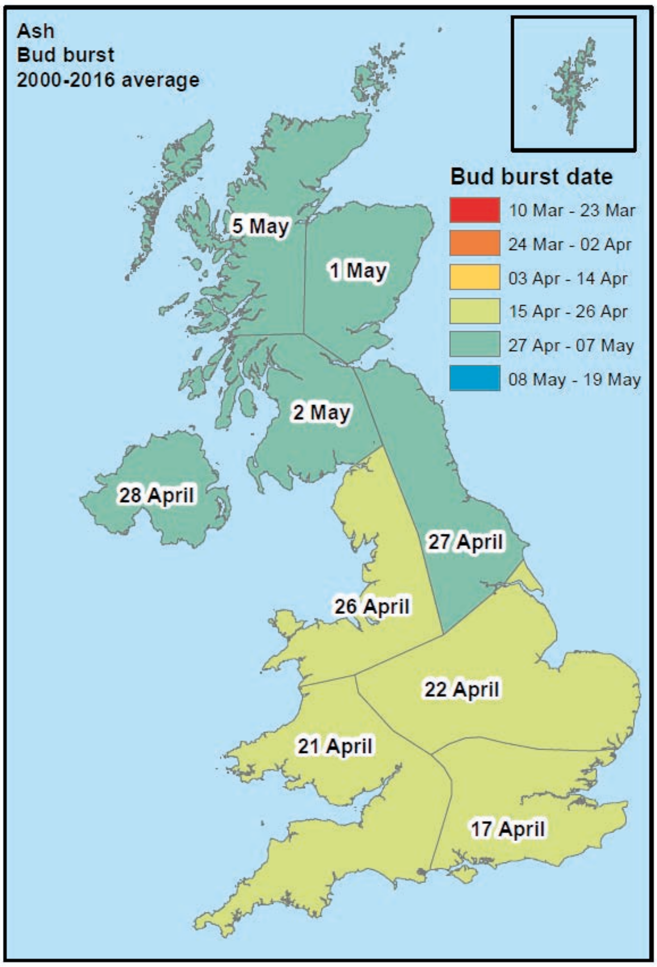


Figure 10: Mean date of budburst of Sessile Oak in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Ash

Figure 11 shows that budburst of Ash in 2016 was generally delayed relative to the 2000 to 2016 average. This delay ranged from 10 days in Northern Scotland to 2 days in the South West and South East, and 1 day in the North West. The only region which experienced an earlier budburst in 2016 was the North East (5 days on average).



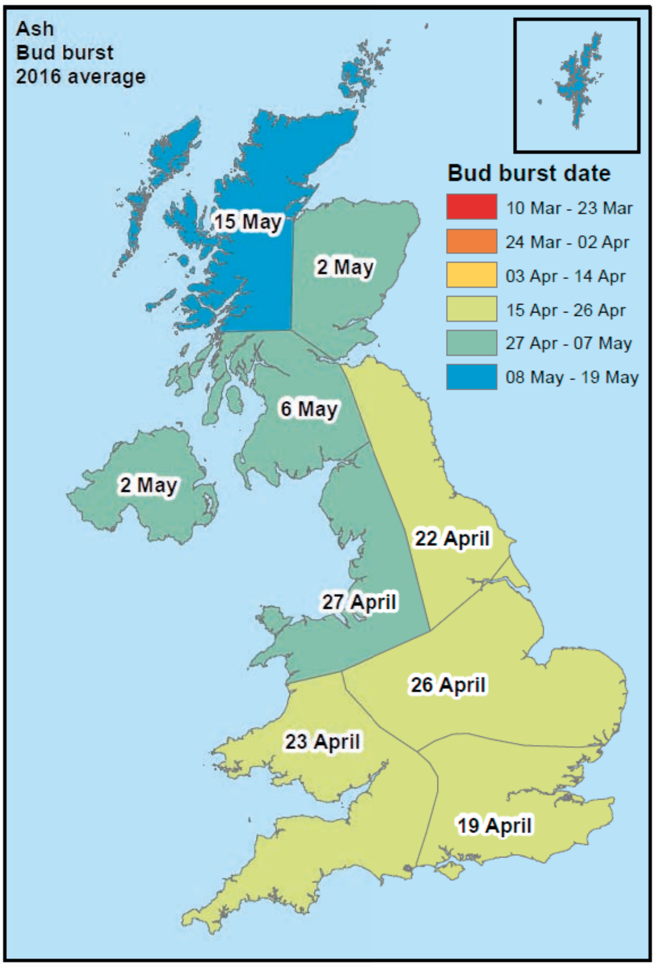


Figure 11: Mean date of budburst of Ash in each region for 2000 to 2016 average (left) and 2016 (right). The colour scale spans budburst of all species. Grey shading shows regions with less than 5 observations.

Climate and budburst

This section presents relationships between climate and budburst for those regions and metrics that exhibited the strongest associations. All the presented relationships were found to be statistically significant at the 1% level (meaning there is less than 1% chance that the result occurred by chance). The same or similar associations may also be evident for other regions but not necessarily as strong an association because other factors may also play a role. For practical reasons of brevity not all of the statistically significant linkages are presented in this report, only those that exhibited the strongest association. A brief description of the methods applied here can be found in Appendix 1, and for more details the reader is referred to Abernethy (2017).

Many studies of UK phenology have shown strong associations between climate conditions and the timing of biological events (Sparks and Carey, 1995; Sparks et al, 2000; Thackeray et al, 2016). Variations in budburst and flowering are often linked with spring temperature, although other factors, including night-time lighting, level of chilling in the preceding winter, and day length can also be important (Wesolowski and Rowinski, 2006; Thompson and Clark, 2008; Laube et al, 2014; Pletsers et al, 2015; ffrench-Constant et al, 2016). These statistical associations are supported by results from controlled climate experiments conducted on a wide range of species (Primack et al, 2015).

In 2016, a notably wet and mild winter gave way to a relatively unremarkable spring climatologically speaking. Temperature and rainfall were both close to their climatological averages. March saw temperatures rather below average across southern areas, and it was also a wet month for the south and east, but Scotland had a relatively dry month. April was cool across much of the country, with relatively late snowfalls and frosts across northern areas and wetter than average for most. Both March and April were relatively sunny months for the UK. This report assesses phenology and climate variations since 2000, and Appendix 2 contains further details to place the recent climate of 2000 to 2016 in the context of longer-term UK climate variations and trends.

Figure 12 summarises the strongest regional associations between budburst dates and the climate variables used for this study. Budburst for 10 out of the 11 species was most strongly associated with March or April temperature. A 1°C rise in temperature during these months was linked with earlier budburst of between 4 days for Alder in the South East, and 6 days for European Larch in the North East.

Ash was the only species to exhibit its strongest climate relationship with daily sunshine hours rather than temperature. This was most prominent for March sunshine in the South West region. Strong associations were also noted between precipitation and budburst for some species and regions. However, these were not as strong as for temperature or sunshine, and therefore are not highlighted in this summary.

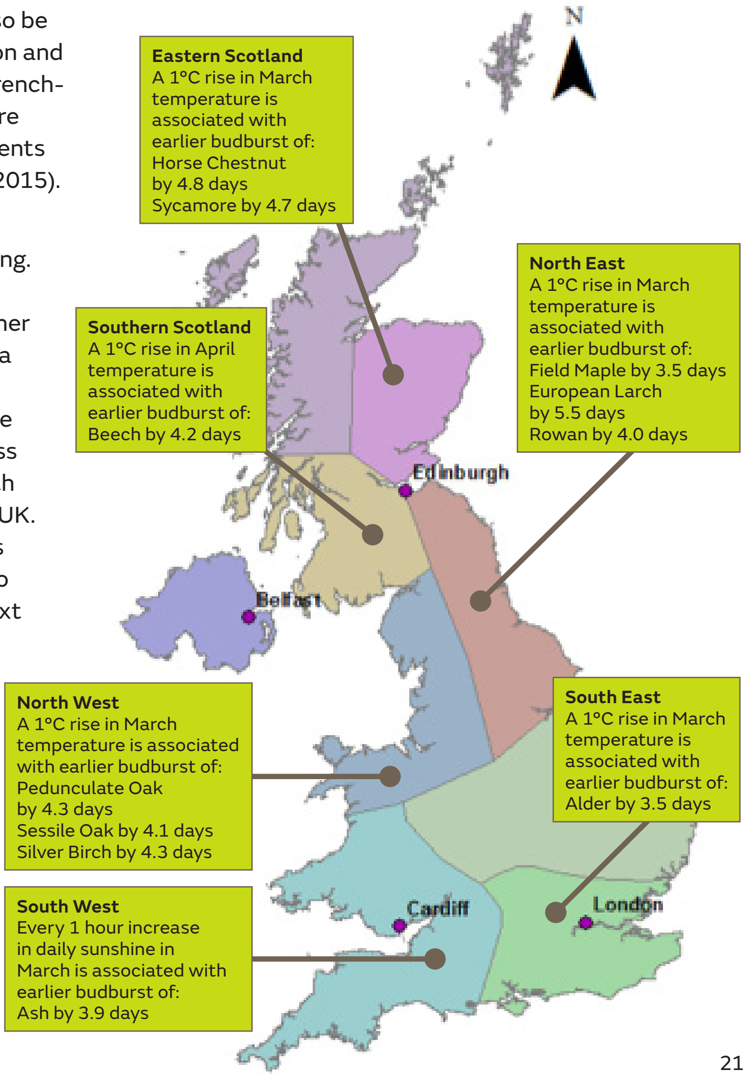


Figure 12: Summary map highlighting the strongest associations between climate variables and budburst in different UK regions for each of the 11 species studied, covering the period 2000 to 2016.

The following sections provide additional information on the strongest associations between climate and budburst for each species summarised in Figure 12. Other statistically significant associations between budburst and climate were observed, but only the strongest associations are highlighted in this report.

Alder in the South East

Alder budburst showed the strongest associations with March temperature in the South East region. The scatter plot (Figure 13) shows that a 1°C average increase in March temperature in this region was associated with 3.5 days earlier budburst of Alder.

Figure 14 shows the year-to-year variability in average date of budburst (top) from 2000 to 2016 compared with March average climate for the 3 variables in the South East. The earliest budburst was on 31st March 2012, and latest was 25th April 2001. Years with the latest budburst, e.g. 2001, 2006, 2013, were associated with the lowest March temperatures, as well as lower than average daily sunshine hours and higher precipitation.

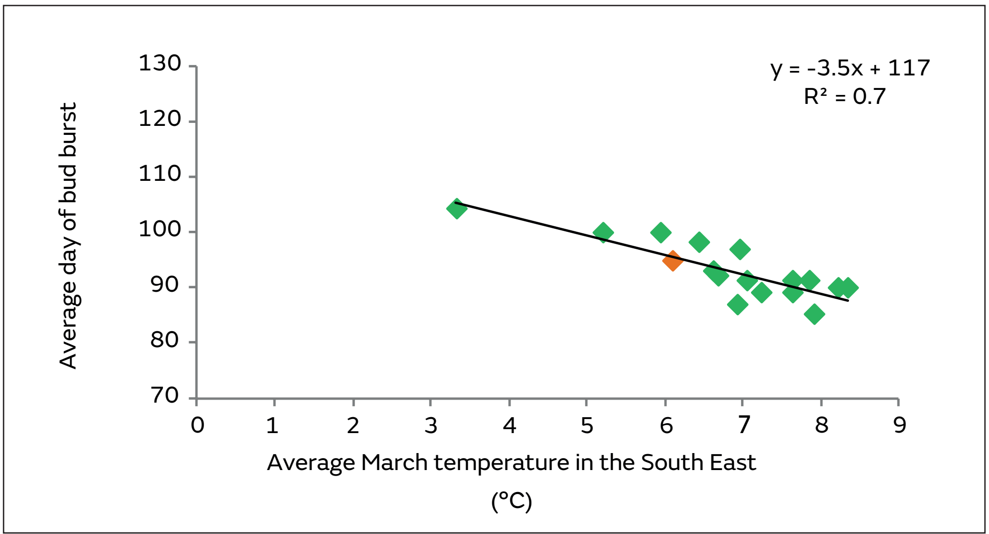


Figure 13: Relationship between Alder budburst (day of year from 1st January) and March temperature in the South East between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

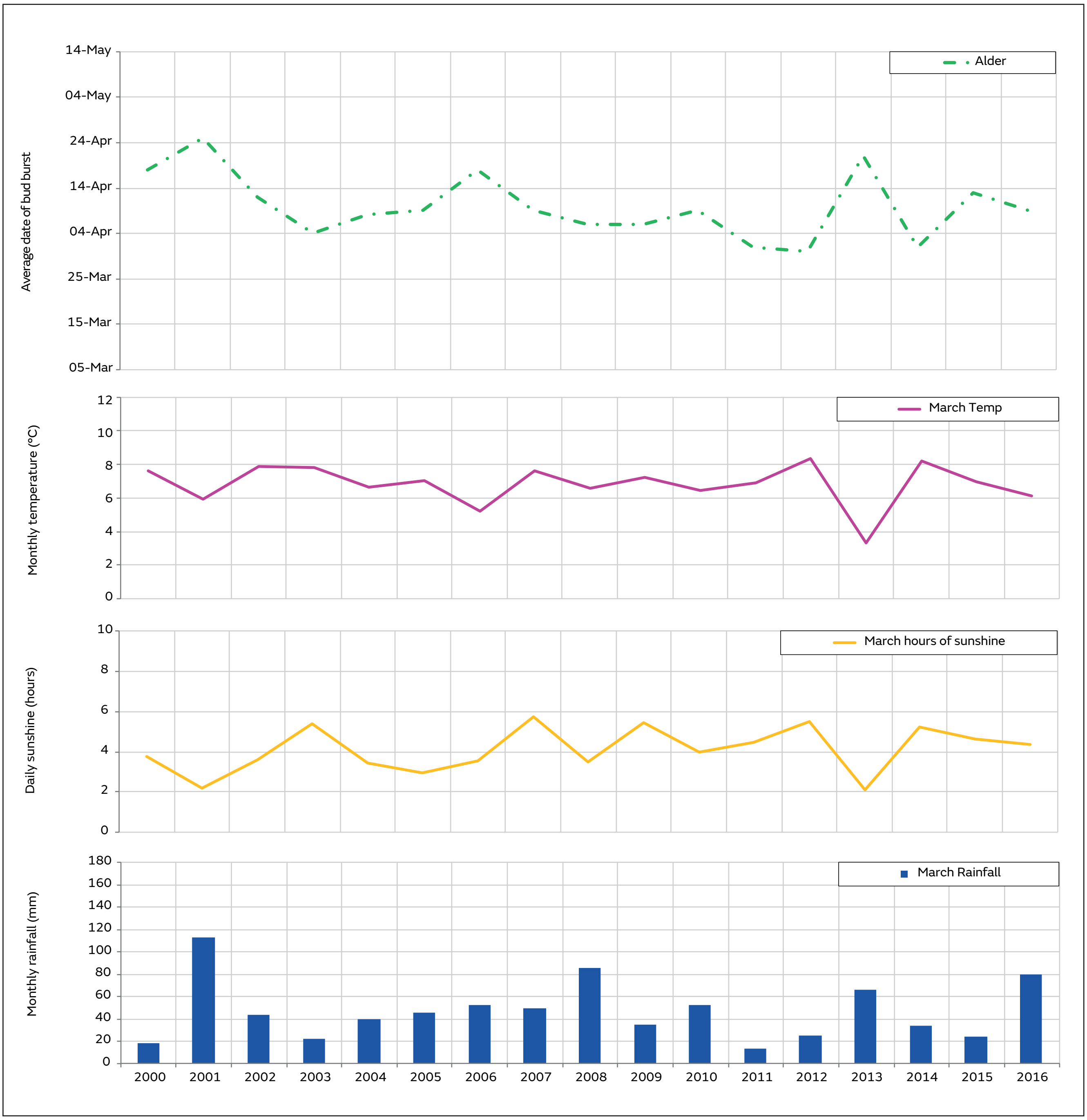


Figure 14: Time series from 2000 to 2016 for the average date of budburst of Alder (top), and the March climate variables – monthly average temperature, daily sunshine hours and monthly total precipitation in the South East.

Ash in the South West

Ash is the only species for which the timing of budburst between 2000 and 2016 was associated most strongly with daily hours of sunshine, rather than temperature. This was most prominent in the South West region. The scatter plot (Figure 15) shows that for every 1 hour increase in daily sunshine in March, Ash budburst was earlier by 3.9 days on average.

As with other species and regions, 2013 was a year of later than average budburst in Ash in the South West. This was associated with lower March temperature and fewer hours of sunshine (Figure 16). 2005 was another late year for Ash budburst in this region. This was a year of low sunshine hours during March but close to average temperature and precipitation.

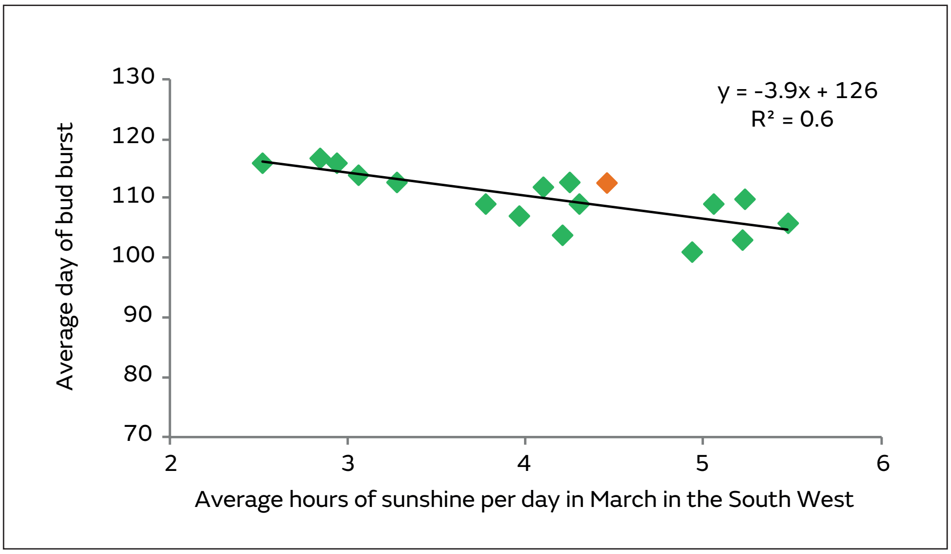


Figure 15: Relationship between Ash budburst (day of year from 1st January) and March temperature in the South East between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

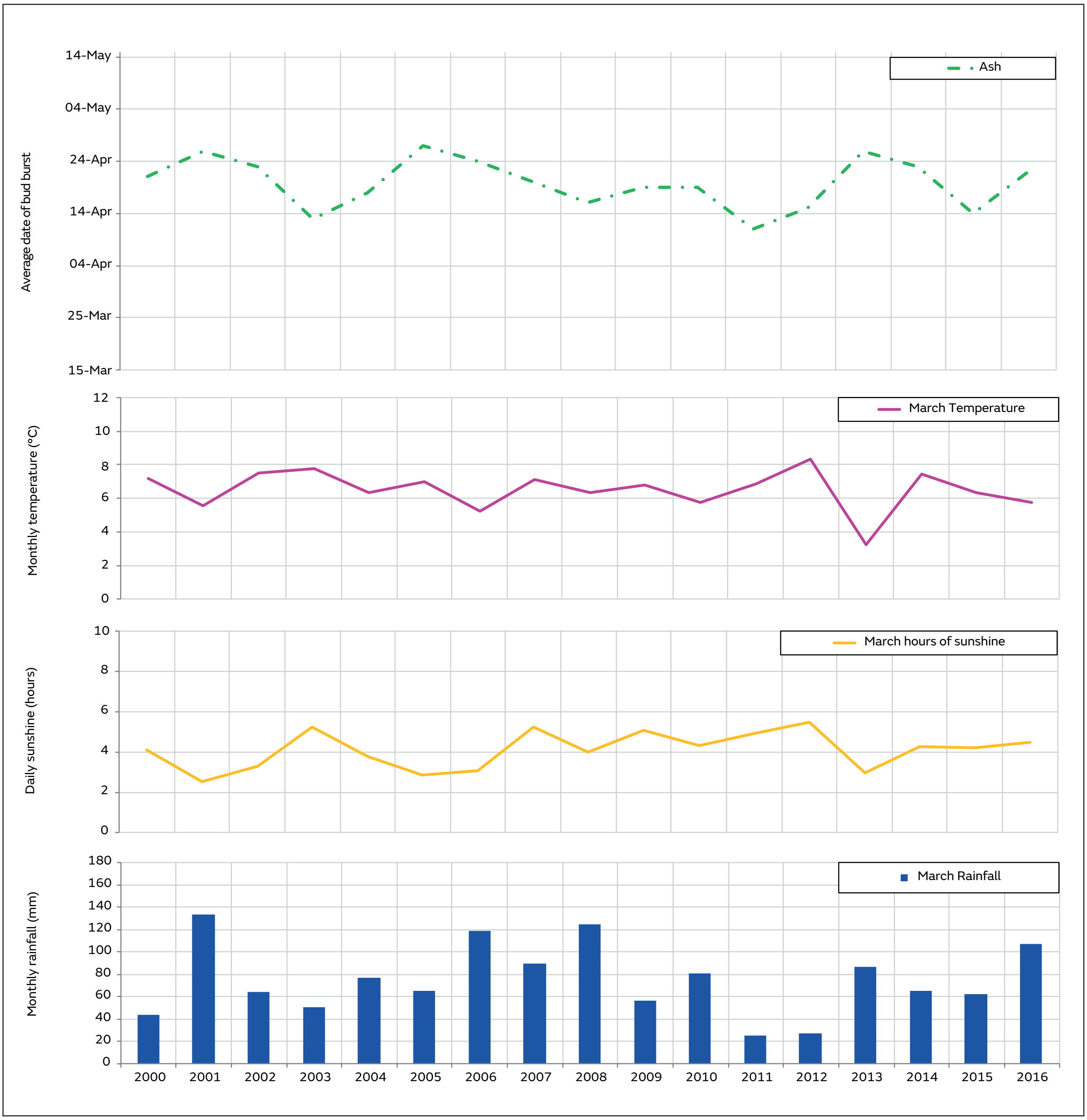


Figure 16: Time series from 2000 to 2016 for average date of budburst of Ash (top), and the March climate variables – monthly average temperature, daily sunshine hours and monthly total precipitation in the South East.

Pedunculate Oak, Sessile Oak and Silver Birch in the North West

Budburst of Pedunculate Oak, Sessile Oak and Silver Birch all showed their strongest associations with March temperature in the North West region. For every 1°C rise in March temperature in this region, budburst was earlier by just over 4 days for all three species (Figures 17 to 19).

Despite all three species showing similar year-to-year variability, budburst for Silver Birch generally occurred earlier (by 12 days on average, see Table 1) than that of Pedunculate and Sessile Oak in this region (Figure 20).

2011 was the earliest year of budburst for all three species in this region, and this coincided with a warm average March temperature of 5.7°C. In comparison, the latest budburst for all three species occurred in 2013, which experienced a relatively cool March average temperature of 1.9°C.

In 2016, budburst occurred 4 days later for Pedunculate Oak and 3 days later for both Sessile Oak and Silver Birch compared with the 2000 to 2016 average, and this was associated with a 0.5°C lower than average temperature in 2016 compared with the 2000 to 2016 average.

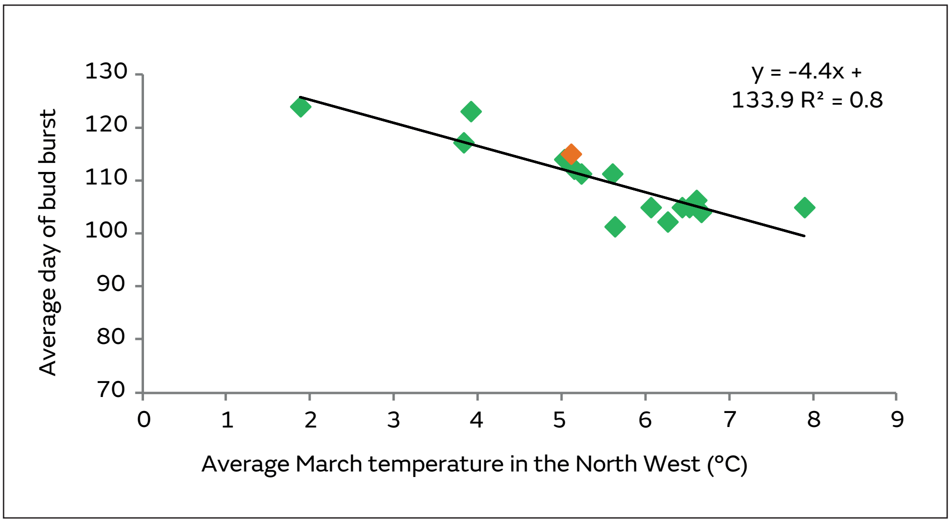


Figure 17: Relationship between Pedunculate Oak budburst (day of year from 1st January) and March temperature in the North West between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

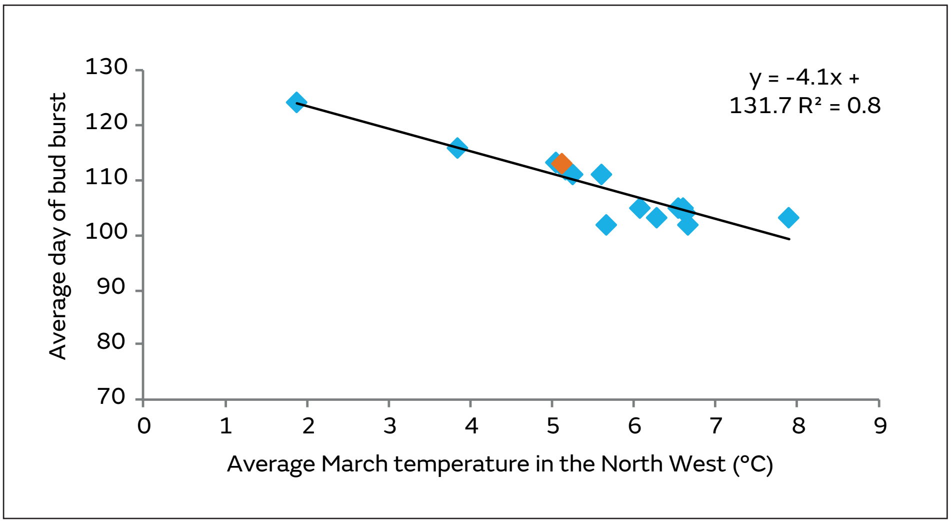


Figure 18: Relationship between Sessile Oak budburst (day of year from 1st January) and March temperature in the North West between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

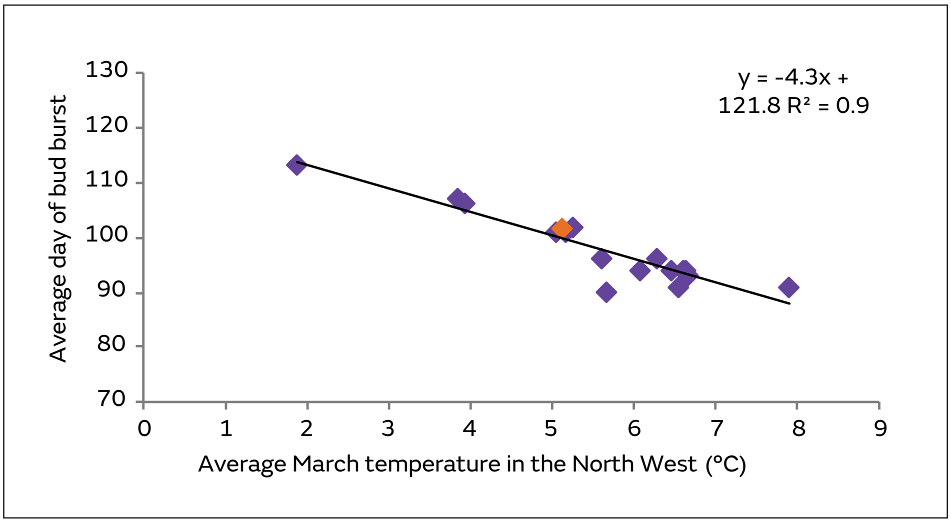


Figure 19: Relationship between Silver Birch budburst (day of year from 1st January) and March temperature in the North West between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

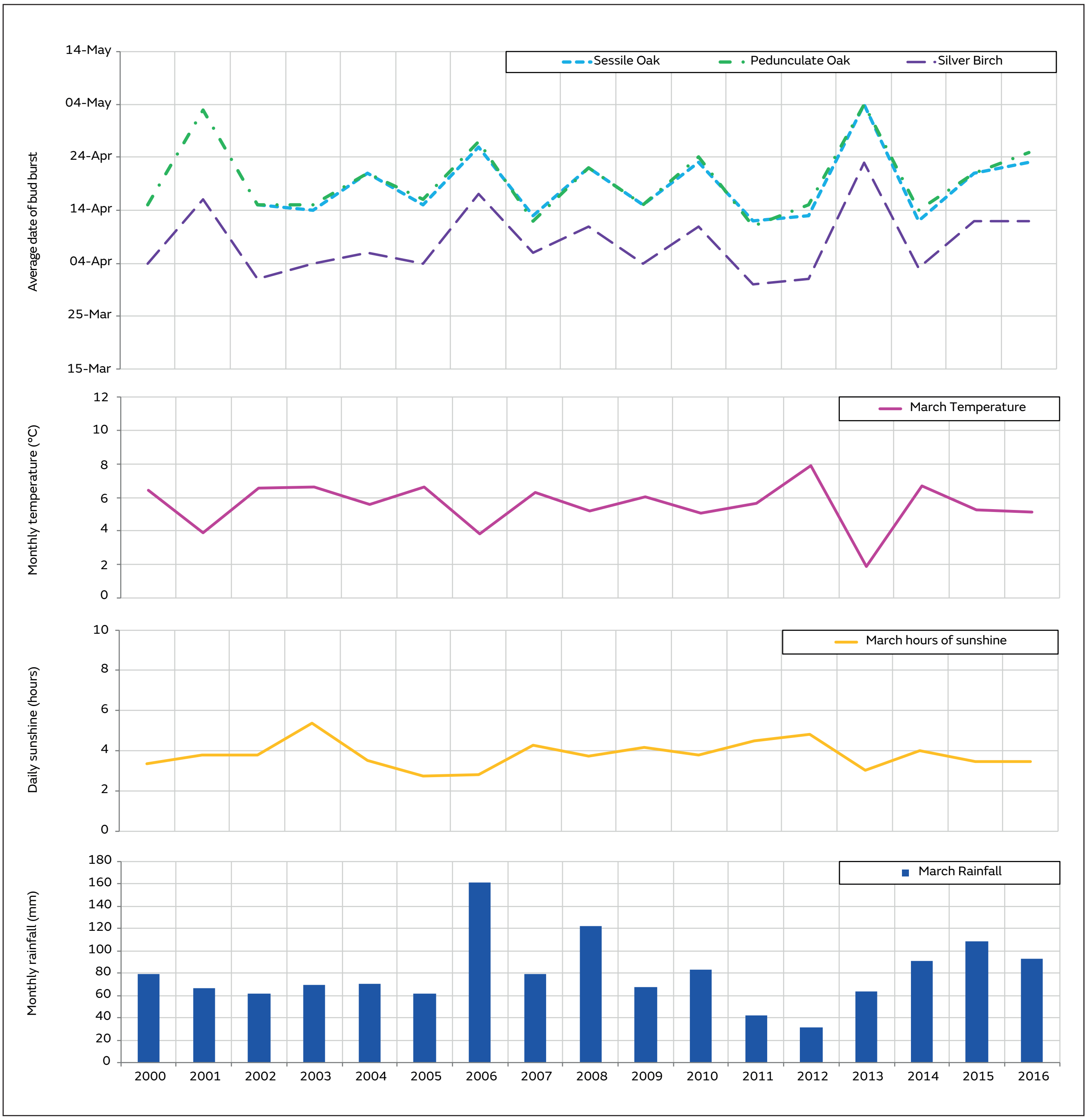


Figure 20: Time series from 2000 to 2016 for average date of budburst of Pedunculate Oak, Sessile Oak and Silver Birch (top), and the March climate variables – monthly average temperature, daily sunshine hours and monthly total precipitation in the North West.

Field Maple, European Larch and Rowan in the North East

Field Maple, European Larch and Rowan budburst were all strongly associated with March temperature, particularly in the North East region. For every 1°C rise in March average temperature, budburst occurred earlier in Field Maple by 3.5 days, European Larch by 5.5 days and Rowan by 4.0 days (Figures 21 to 23).

Time series for these three species (Figure 24) show similar year-to-year variations. 2013 experienced the latest budburst dates, between 18th and 20th April, when March average temperature and daily sunshine were both at their lowest for the 2000 to 2016 period.

2012 was a relatively early year for budburst in all three species in the North East, and this coincided with the warmest average temperature and lowest precipitation in March for the 2000 to 2016 period.

The majority of species studied in this report showed significant climate relationships with March or April temperature, with few significant associations noted between budburst and precipitation. However, for the species which did show significant precipitation relationships (Field Maple, European Larch, Rowan, Sessile Oak and Sycamore), all were located in the North East region. As one of the driest regions in the UK, with the driest season being spring, it is not surprising that the influence of precipitation on phenology is more significant here. Although the highest parts of the Pennines can receive more than 1500 mm of precipitation on average each year, these localities are unlikely to be dominated by trees (Met Office, 2016).

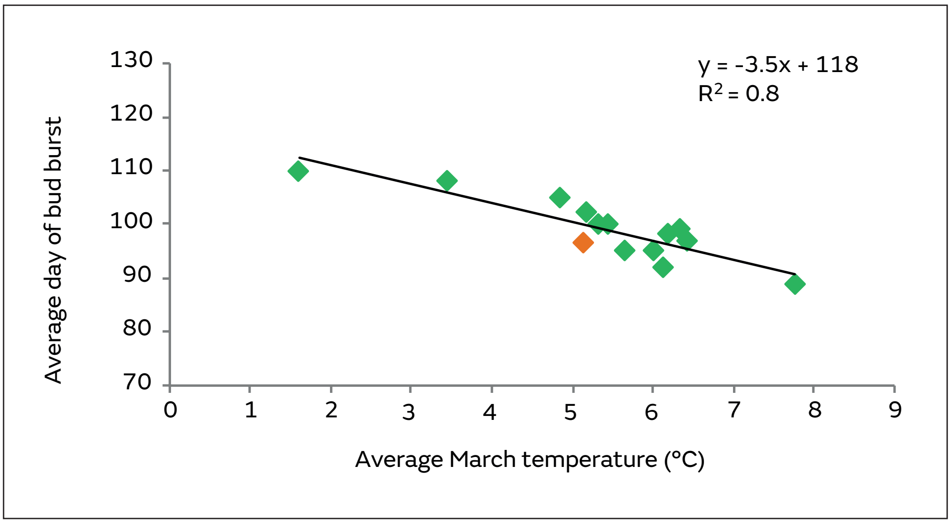


Figure 21: Relationship between Field Maple budburst (day of year from 1st January) and March temperature in the North East between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

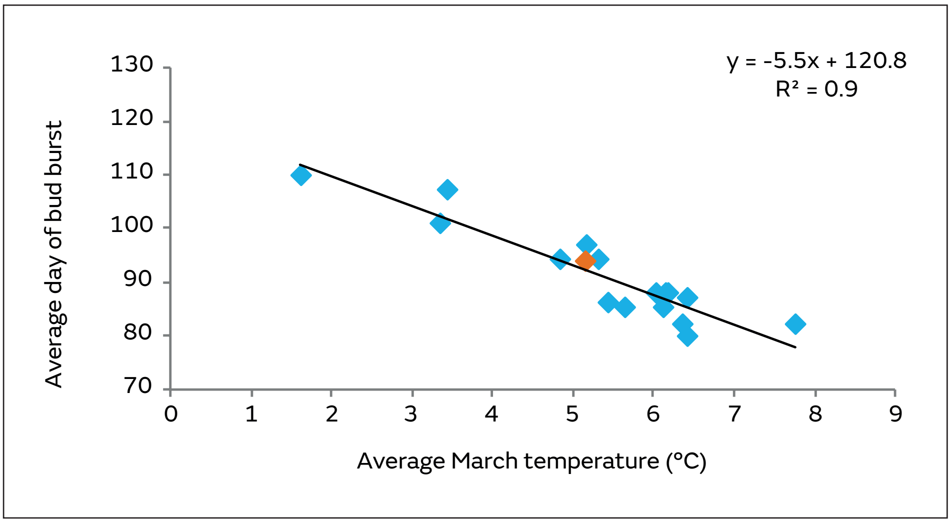


Figure 22: Relationship between Larch budburst (day of year from 1st January) and March temperature in the North East between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

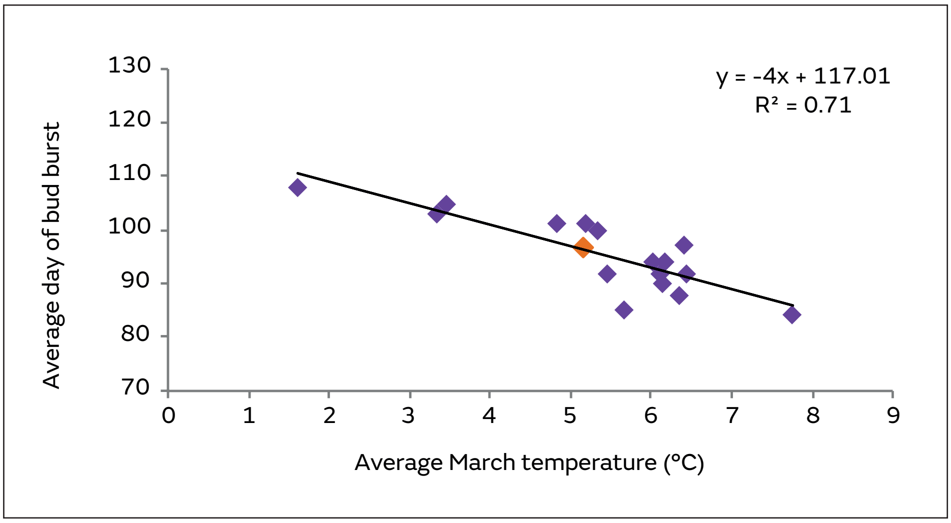


Figure 23: Relationship between Rowan budburst (day of year from 1st January) and March temperature in the North East between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

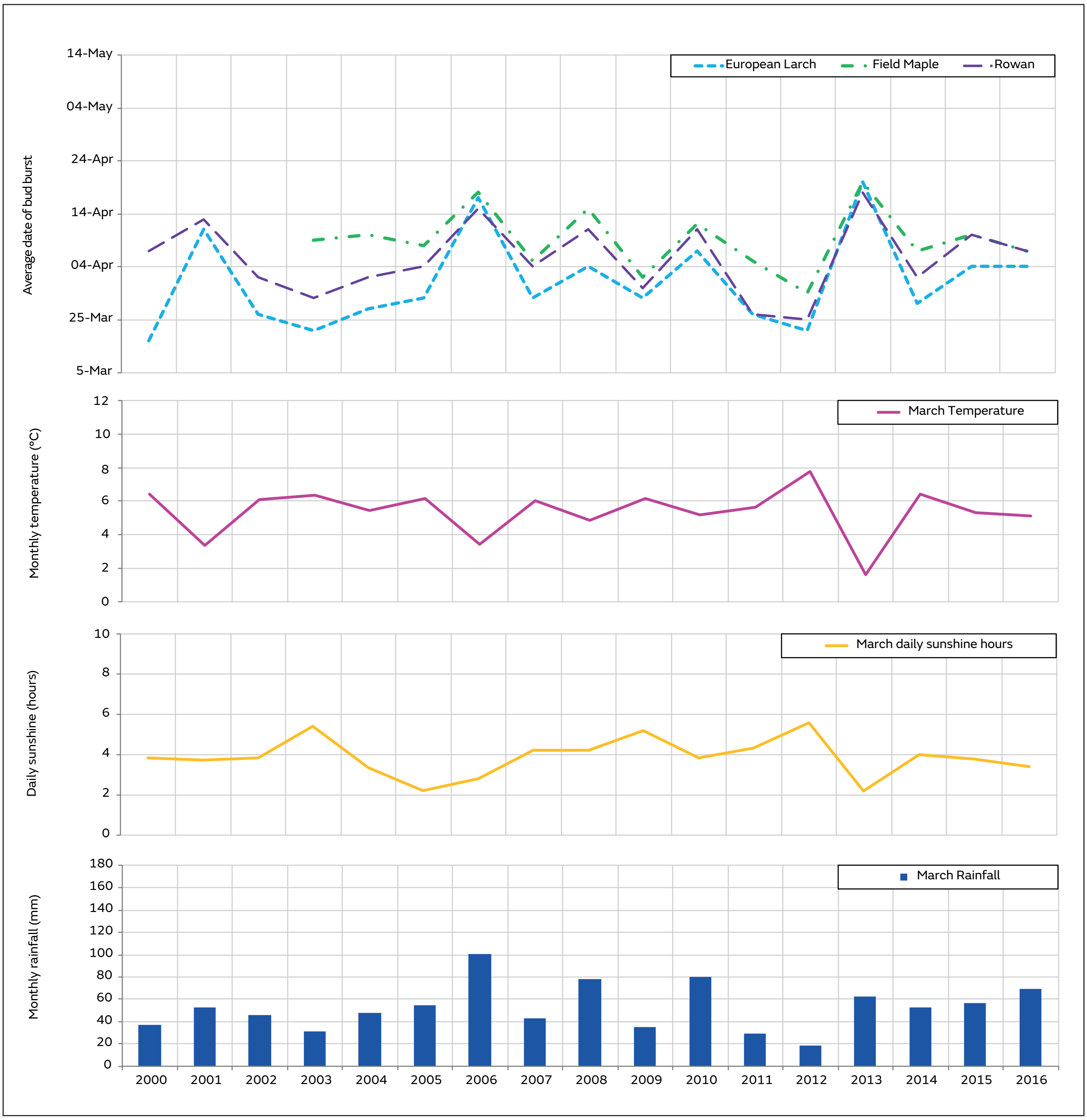


Figure 24: Time series from 2000 to 2016 for average date of budburst of Field Maple, European Larch and Rowan (top), and the March climate variables – monthly average temperature, daily sunshine hours and monthly total precipitation in the North East.

Beech in Southern Scotland

Beech budburst was most strongly associated with April temperature in Southern Scotland. For every 1°C rise in April temperature, Beech budburst was 4.2 days earlier on average (Figure 25).

The earliest budburst date for Beech in this region (12th May) occurred in 2014, when the average temperature was relatively warm (8.7°C), and the latest budburst occurred in 2001, when the average temperature was relatively cool (just under 6.0°C).

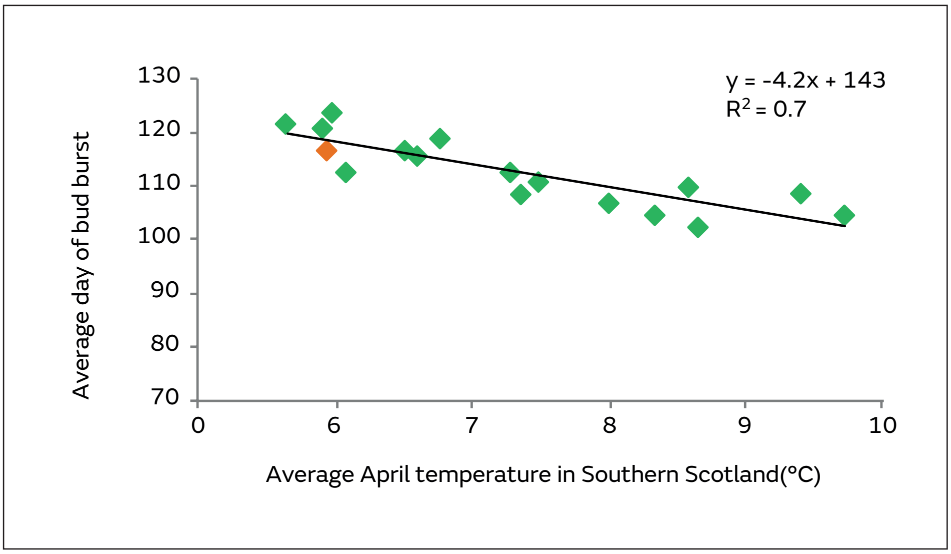


Figure 25: Relationship between Beech budburst (day of year from 1st January) and April temperature in Southern Scotland between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

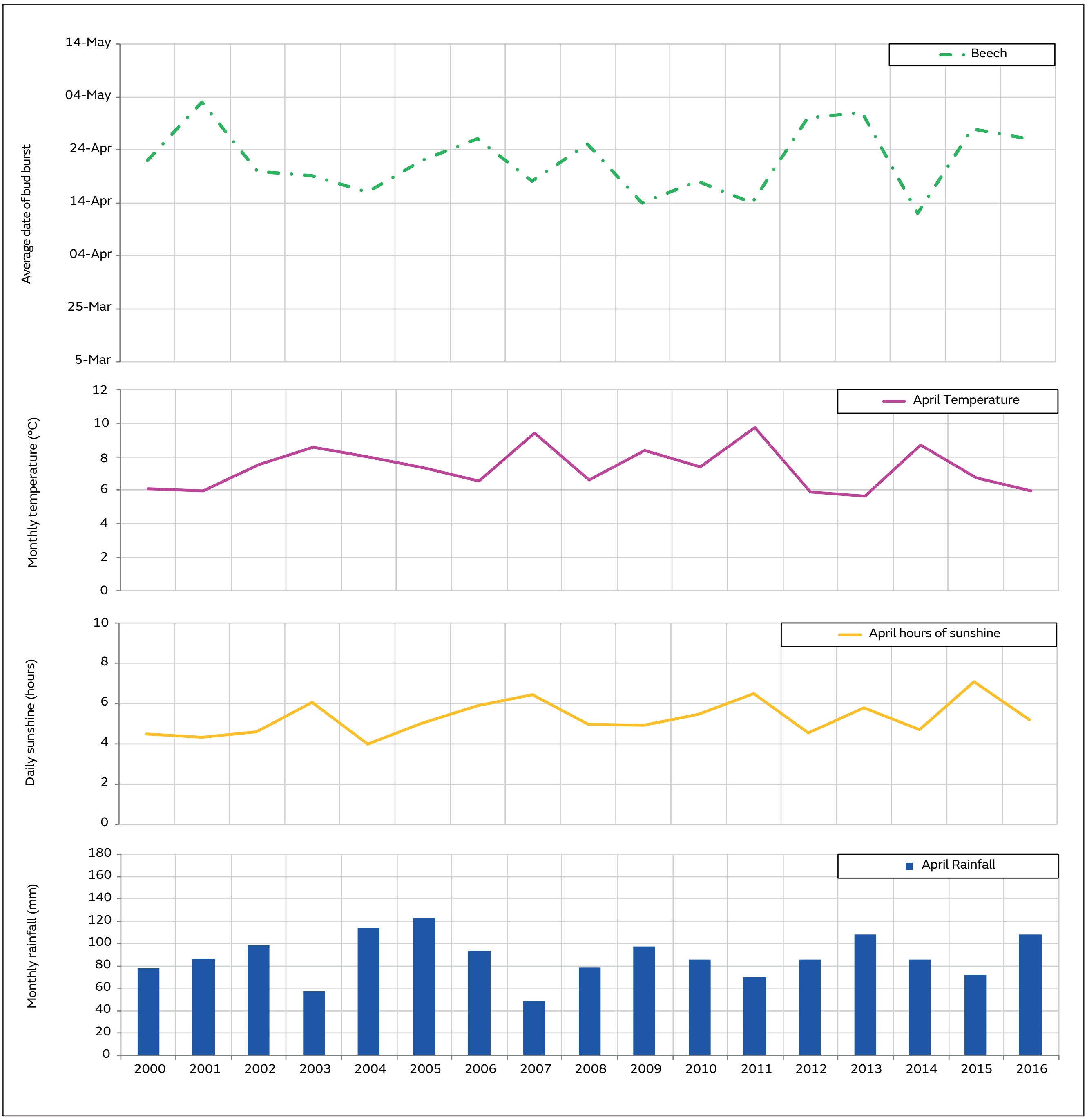


Figure 26: Time series from 2000 to 2016 for average date of budburst of Beech (top), and the April climate variables – monthly average temperature, daily sunshine hours and monthly total precipitation in the North East.

Sycamore and Horse Chestnut in Eastern Scotland

Both Sycamore and Horse Chestnut budburst showed strongest associations with March temperature in Eastern Scotland. For every 1°C rise in March temperature, budburst was on average earlier by 4.7 days for Sycamore and 4.8 days for Horse Chestnut (Figures 27 and 28).

Of the 11 species included in this study, Horse Chestnut showed the earliest regional average budburst date of 18th March in 2012. This was closely followed by European Larch on 22nd March of the same year (Figure 29). Climatologically, 2012 experienced the highest average March temperature of 7.0°C, a high daily sunshine of 4.8 hours, and the lowest average precipitation of 18.5mm, relative to the 2000 to 2016 period.

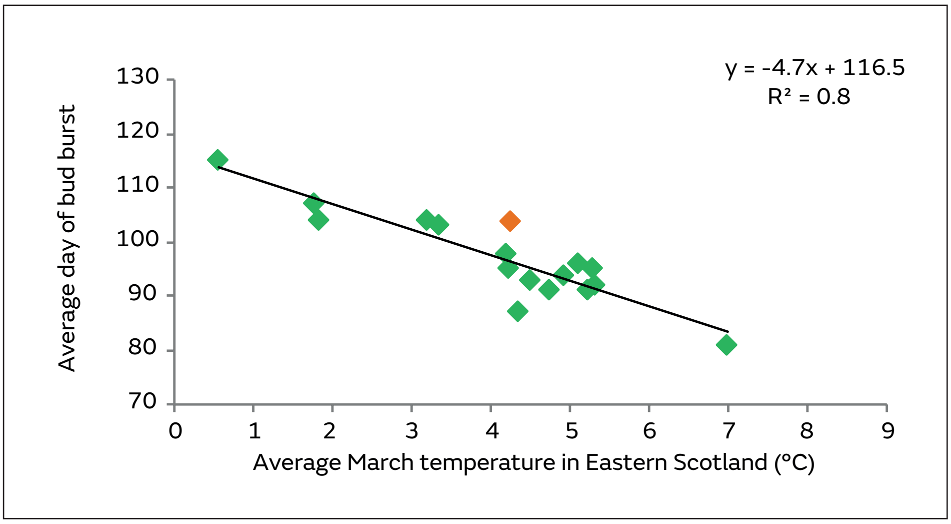


Figure 27: Relationship between Sycamore budburst (day of year from 1st January) and March temperature in Eastern Scotland between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

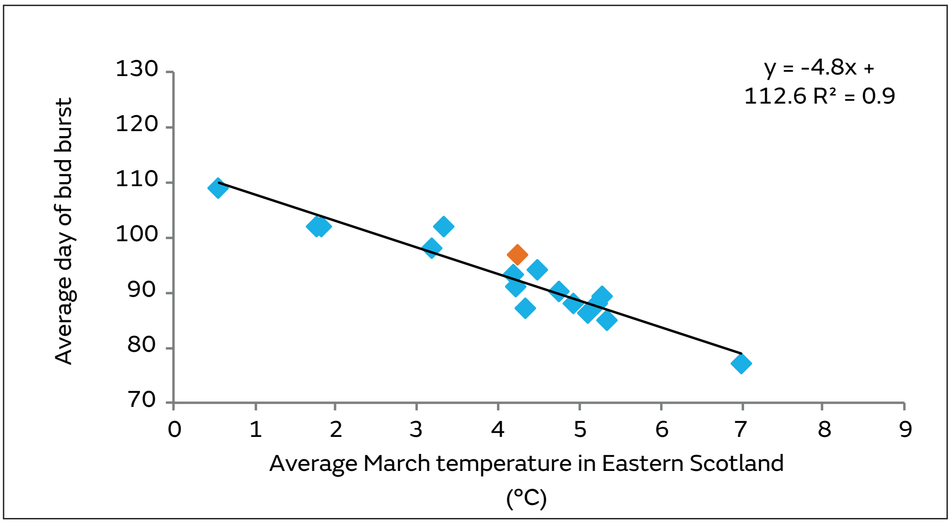


Figure 28: Relationship between Horse Chestnut budburst (day of year from 1st January) and March temperature in Eastern Scotland between 2000 and 2016. The linear regression line and its equation and goodness of fit (R^2) are shown. The orange marker on the graph shows the average day of budburst in 2016.

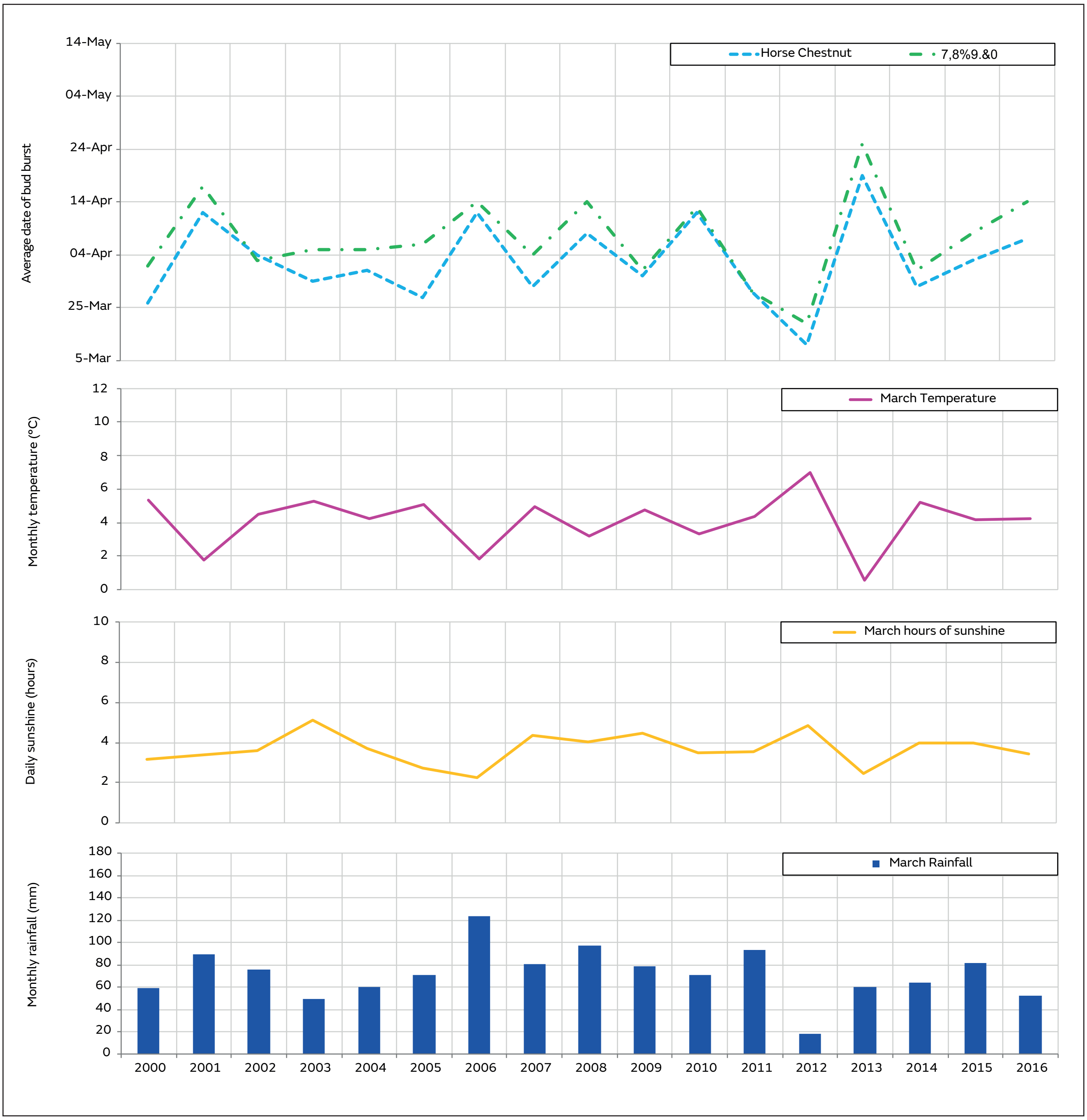


Figure 29: Time series from 2000 to 2016 for average date of budburst of Sycamore and Horse Chestnut (top), and the March climate variables – monthly average temperature, daily sunshine hours and monthly total precipitation in the Eastern Scotland.

Weather lore – "Ash before oak..."

The weather (folk)lore phrase: "Ash before oak, we're in for soak; oak before ash, we're in for a splash" means that if ash leaves appear before oak leaves in the spring, it is going to be a very rainy summer. However, if oak comes into leaf before ash, there will only be a little bit of rain in summer.

Expressions like this are well known but are they true?

The time series graph in Figure 30 shows that since 2000, budburst of oak trees has generally occurred before Ash. In fact, between 2000 and 2016 Pedunculate Oak budburst has occurred before Ash every year except 2003, 2006 and 2008, when the average day of bud burst was the same for both species, 2010, when Ash budburst occurred 3 days earlier, and 2013 when Ash budburst occurred 1 day earlier.

What does this mean in terms of climate?

As Pedunculate Oak budburst typically occurs before Ash, this would mean less rain in summer, according to the weather lore. However, there have been some very wet summers in the UK between 2000 and 2016 that coincided with Oak budburst much earlier than Ash. For example, in 2012, the average Oak budburst in UK occurred 6 days before Ash, yet there was a very high summer monthly rainfall average of 125 mm during this year.

Despite this weather lore proving untrue, phenology records such as those presented in this report are a very valuable contribution to monitoring and understanding the influence of variations in climate on aspects of nature that we can all observe. Continued long-term monitoring of phenology will prove particularly important as an indicator of environmental change as we progress through the 21st Century.

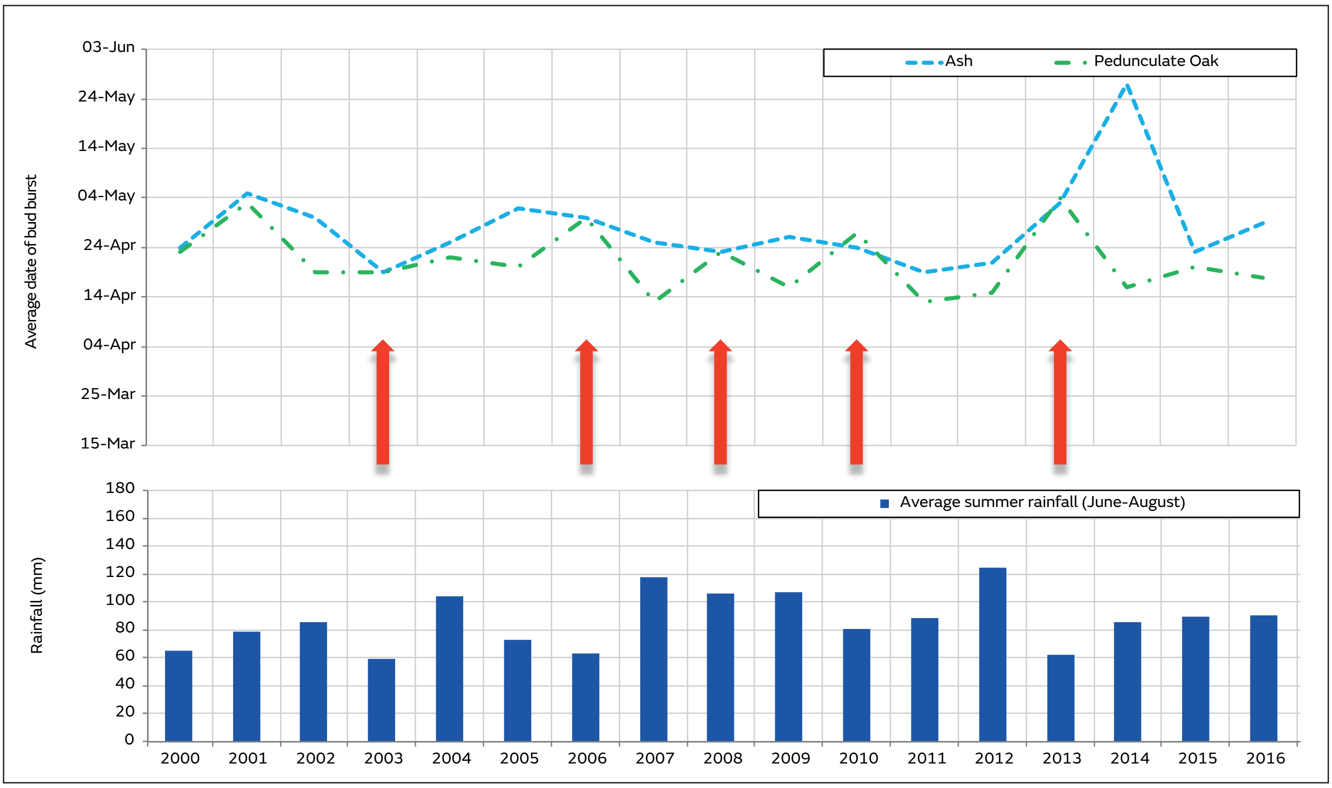


Figure 30: Time series from 2000 to 2016 for average date of budburst of Ash and Pedunculate Oak (upper), and the average summer monthly rainfall for June to August (lower). Red arrows show the years when the average date of Ash budburst across UK was before or the same as that of oak.

Appendix 1: Methods

Phenological data from the period 2000 to 2016 were obtained from the Woodland Trust (www.woodlandtrust.org.uk), who have been managing Nature's Calendar (http://naturescalendar.woodlandtrust.org.uk/) in partnership with the Centre for Ecology and Hydrology (CEH) since the year 2000. Overall, there were 122,118 budburst observations recorded during this period. The phenological data for Northern Ireland was between 2002 and 2016, due to lack of data in previous years.

Sixteen years (from 2000 to 2016) is a short time period when investigating the influence of climate variations on phenological events. This was chosen because it provided a consistently high number of recordings for each year and species studied, and was therefore considered the most robust and up-to-date phenology records to compare spatial and temporal analyses across the UK. It should be highlighted that the UK does have a number of very long phenology series that are not discussed in this report.

Figure A1 shows the 9 regions used for this study. These are the same as the Hadley Centre UK regional precipitation series (HadUKP) regions, which were based on 5 coherent precipitation regions for England and Wales (Wigley et al, 1984), and subsequently updated using the same method to include Scotland (Gregory et al, 1991).

Common and Latin names of the 11 tree species studied for this report are listed in Table A1.

Figure A1: Map of the UK showing the 9 climate regions used in this study.

Table A1: Basic information on the tree species used in this study. Source: The Woodland Trust - https://www.woodlandtrust.org.uk/visiting-woods/trees-woods-and-wildlife/british-trees/

Common Name	Scientific Name
Alder	Alnus glutinosa
Ash	Fraxinus excelsior
Beech	Fagus sylvatica
European Larch	Larix decidua
Field Maple	Acer campestre
Horse Chestnut	Aesculus hippocastanum
Pedunculate Oak	Quercus robur
Sessile Oak	Quercus petraea
Rowan	Sorbus aucuparia
Silver Birch	Betula pendula
Sycamore	Acer pseudoplatanus

The 3 climate variables that are used here to highlight significant climate associations with budburst are: Monthly average air temperature; monthly average hours of sunshine each day; monthly average precipitation. These were obtained from the Met Office National Climate Information Centre (NCIC). Data have been used from 1999 to 2016 so that previous October, November and December measurements could be included for all years.

ArcGIS mapping software was used to join budburst locations and climate data to one of 9 UK climate regions. The average day of budburst (DBB) and the monthly value for each climate variable was calculated as an areal average of all observations in each region for each year.

Linear regression analysis (Sparks and Menzel, 2002) was used to investigate simple statistical relationships between date of budburst and climate variables. Maps were created to show the average date of budburst in each region in 2016, and for the longer-term average between 2000 and 2016.

Appendix 2: Climate context

Phenological data have been analysed for the Nature's Calendar bud-burst dataset that spans the period 2000 to 2016. This datasets provides sufficient data across the UK to allow for a spatial analysis, and to infer simple year-to-year relationships between climate and budburst. It does unfortunately limit the scope for putting these recent years into longer historical context. In the State of UK Climate report, to which this is a companion report, climate data are provided that place 2016 in the context of the most recent decade (2007 to 2016) and the two reference climatology periods of 1961 to 1990 and 1981 to 2010. In this appendix, we provide some additional comparison to show how the 2000 to 2016 period compares to the reference climatology for the climate regions shown in figure A1.

Overall, the 2000 to 2016 period during March and April has been on average warmer and sunnier than the 1961 to 1990 reference climatology. This means that although budburst in 2016 was generally later than other recent years, due mainly to a relatively cooler March and April, this should be interpreted in the context of these longer-term climate trends.

Temperature

The UK mean temperature in March was 0.3°C below the 2000-2016 mean, but it is 0.6°C above the 1961 – 1990 climatology. In South and Central England during March the anomalies were 0.2 to 0.3°C above the 1961 to 1990, but for Northern Scotland the anomaly was 1.3°C. April 2016 was 1.5°C below the 2000 to 2016 average and 0.2°C below the 1961 to 1990 average.

This demonstrates that although spring 2016 was somewhat cool relative to the data period of Nature's Calendar phenology records used, due to an observed warming trend across the UK, 2016 was warmer than the longer-term reference climatology periods. More details can be found in State of the UK Climate 2016.

Table A2: March mean temperature (°C) for 2016 and averaging periods of 2000-2016 and 1961-1990

Region	1961 - 1990	2000 - 2016	2016
South East	5.8	6.8	6.1
South West	5.6	6.5	5.8
Central	5.4	6.4	5.7
North West	4.6	5.6	5.1
North East	4.3	5.4	5.1
Northern Ireland	5.2	6.0	6.1
Southern Scotland	4.0	5.1	5.2
Eastern Scotland	3.1	4.1	4.2
Northern Scotland	3.4	4.6	4.7
UK	4.7	5.6	5.3

Table A3: April mean temperature (°C) for 2016 and averaging periods of 2000-2016 and 1961-1990

Region	1961 - 1990	2000 - 2016	2016
South East	8.0	9.5	8.2
South West	7.5	8.8	7.6
Central	7.6	9.0	7.5
North West	6.7	7.9	6.5
North East	6.4	7.7	6.1
Northern Ireland	7.0	8.2	6.4
Southern Scotland	6.1	7.3	5.9
Eastern Scotland	5.1	6.3	4.6
Northern Scotland	5.2	6.6	5.1
UK	6.7	8.0	6.5

Rainfall

During March 2016, regions of South, East and Central England were wetter than average, but not exceptionally so, and Scotland was drier. The period 2000 to 2016 had on average less rainfall, at approximately 84% of the 1961 to 1990 average. For April, the 2000 to 2016 and 1961 to 1990 periods are more comparable, and April 2016 saw 116% of average rainfall.

Table A4: March rainfall (mm) for 2016 and averaging periods of 2000-2016 and 1961-1990

Region	1961 - 1990	2000 - 2016	2016
South East	57	47	80
South West	93	75	107
Central	50	40	75
North West	102	80	93
North East	66	53	69
Northern Ireland	91	82	73
Southern Scotland	125	111	86
Eastern Scotland	86	72	52
Northern Scotland	164	139	113
UK	92	77	83

Table A5: April rainfall (mm) for 2016 and averaging periods of 2000-2016 and 1961-1990

Region	1961 - 1990	2000 - 2016	2016
South East	50	50	54
South West	69	71	61
Central	49	46	63
North West	77	75	103
North East	56	59	80
Northern Ireland	67	67	81
Southern Scotland	79	88	108
Eastern Scotland	65	71	95
Northern Scotland	95	109	104
UK	67	71	78

Sunshine

For the UK overall, the 2000 to 2016 period has seen on average 6% more sunshine hours in March and 14% more in April compared to the 1961 to 1990 average. March and April 2016 saw sunshine hours that were comparable to those from the 2000 to 2016 average, and therefore sunnier than the longer-term climatological reference period.

Table A6: March sunshine (hours) for 2016 and averaging periods of 2000-2016 and 1961-1990

Region	1961 - 1990	2000 - 2016	2016
South East	112	127	134
South West	109	127	138
Central	103	123	122
North West	97	118	107
North East	99	120	106
Northern Ireland	97	113	115
Southern Scotland	94	108	110
Eastern Scotland	100	114	106
Northern Scotland	88	100	103
UK	101	117	117

Table A7: April sunshine (hours) for 2016 and averaging periods of 2000-2016 and 1961-1990

Region	1961 - 1990	2000 - 2016	2016
South East	150	187	180
South West	156	182	179
Central	137	175	179
North West	139	166	159
North East	133	163	165
Northern Ireland	146	171	151
Southern Scotland	144	164	162
Eastern Scotland	135	157	144
Northern Scotland	134	154	146
UK	142	163	161

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