

Timing of plant phenophases in Finnish Lapland in 1997–2006

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We investigated whether there were consistent changes in plant phenophases in 1997–2006 at 13 observation sites in Finnish Lapland, and whether such changes could be explained by measured climatic conditions. The phenological data were collected within the Finnish National Phenological Network organised by the Finnish Forest Research Institute (Metla). During the observation period, the effective temperature sum (ETS) increased on average by 17.7 day degrees/year, while the maximum snow depth decreased by 3.5 cm/year and the timing of snow melt advanced by 1.4 days/year. The spring phenophases advanced on average by 1–2 days/year in the case of most of the species studied, which resulted in a lengthening of their growth period. The autumn phenophases did not show any trends or relationships with respect to the studied climatic conditions, however. The mean May temperature and the date of snow melt explained best of all the onset of spring in the studied species.

Introduction

The warming of global climate is predicted to be most crucial at northern latitudes. During the 20th century, the average surface temperature has globally risen by 0.6 °C and this increase is predicted to be even more rapid during the coming decades (IPCC 2001). In Finland, the latest predictions concerning temperature elevation vary from 2 °C to 7 °C by the year 2080 (Jylhä *et al.* 2004, Ruosteenoja *et al.* 2005), and in the arctic regions the winter temperatures are predicted to elevate by 12 °C by 2050 (Mitchell *et al.* 1990, Maxwell 1992, Houghton *et al.* 1996). Thus, the impacts of climate warming may become evident in arctic ecosystems sooner than elsewhere (e.g.

Walker *et al.* 1995, Overpeck *et al.* 1997, Arctic Climate Impact Assessment (ACIA) 2005, Aerts *et al.* 2006).

Northern plants have developed a growth rhythm that recurs annually due to the seasonal changes in their environment. Plants can, therefore, be used as biological indicators of changing environmental conditions (Menzel 2002, Dose and Menzel 2004). Especially long observation series help to predict the timing of phenophases (Häkkinen 1999, Menzel 2002) and, consequently, environmental monitoring is becoming an increasingly important issue when predicting the impacts of climate change on the environment. In regions where vascular plants grow near their northern distribution limits, even

minor changes in climate can change the timing of plant growth and reproduction.

Phenology is a field of science investigating the timing of biological events (Lieth 1974). The annual cycle of plants includes an active period, autumn dormancy, and winter dormancy. The initiation of the active period is influenced mostly by temperature (e.g. Sarvas 1972, Heikinheimo and Lappalainen 1997). The photoperiod may also have a major influence on spring phenophases (Linkosalo 2000b). At the end of their active period, forest trees begin to prepare for the dormancy (Sarvas 1972, 1974). The factors involved are mainly air temperature and light signal (Häkkinen 1999).

Many recent monitoring studies have demonstrated that the timing of spring phenophases has advanced due to the elevation of spring temperatures (e.g. Menzel 2000, Braslavská *et al.* 2004, Grisule and Malina 2005, Dai *et al.* 2005, Menzel *et al.* 2006b). The same conclusion was drawn in experimental manipulation studies carried out at thirteen research sites located in arctic ecosystems (Arft *et al.* 1999).

We investigated whether consistent changes occurred in plant phenophases in Finnish Lapland during the last ten years. We also studied whether these changes, if they occurred, were connected to environmental factors, such as the effective temperature sum, the mean May temperature, the thickness of the maximum snow cover, and the timing of snow melt. We monitored five tree species and two dwarf shrubs at 13 observation sites during the 10-year period from 1997 to 2006. We hypothesised that especially spring phenophases would have advanced due to increased spring temperatures, thereby leading to the lengthening of the growth period. This is the first study to summarise long-term phenological patterns of several species from data collected within the Finnish National Phenological Network.

Material and methods

The research was carried out at 13 observation sites across Finnish Lapland in 1997–2006. The observation sites belong to the Finnish National Phenological Network launched by the Finn-

ish Forest Research Institute (Metla) in 1995 (Poikolainen *et al.* 1996) (Fig. 1 and Table 1). At each observation site, five tree individuals in mature (41–80 years) and planted tree stands were randomly selected for long-term observations (Kubin *et al.* 2007) (Table 2). One criterion was that the selected tree individuals had to be healthy, normal in size, and naturally established. In addition, the selected trees had to be part of a stand growing on a mesic or relatively dry forest, dominated by *Vaccinium myrtillus* or *V. vitis-idaea*. Furthermore, the selected trees were required to be representative of the average local environment, meaning that the timing of the phenophases should not to be exceptionally early or late relative to the surroundings. The distance between the selected tree individuals varied from site to site. Two dwarf shrub species were observed on five study plots each 1 m² in size and approximately 10 m apart.

Depending on the species, two to four phenophases were recorded annually while monitoring the same tree individuals or study plots (Table 2). The vegetative phenophases related to foliage growth were recorded in the case of *Betula pendula*, *Betula pubescens* and *Populus tremula*, while the reproductive phenophases related to the flowering and ripening of berries were recorded in *Prunus padus*, *Vaccinium myrtillus* and *Vaccinium vitis-idaea*. In *Sorbus aucuparia*, both vegetative and reproductive phenophases were recorded. All observers were given uniform instructions (Kubin *et al.* 2007). The observations were made twice a week applying visual estimations of phenophases. The bud burst phase was determined as the date on which the leaves were still very small but fully extruded from the bud, and when the leaf petiole was not yet visible. The phase when the leaves were full-sized was recorded when the leaves no longer increased in size. The criterion applied in all the phenophases was the threshold value of 50%. For the observation of leaf colouring, for example, this meant that 50% of leaves of a certain species per observation site had turned yellow by the observation date. The variation in the timing of phenophases amongst individual trees or study plots of the dwarf shrubs was not recorded.

Daily data on mean temperatures from the beginning of March to the end of October, maxi-

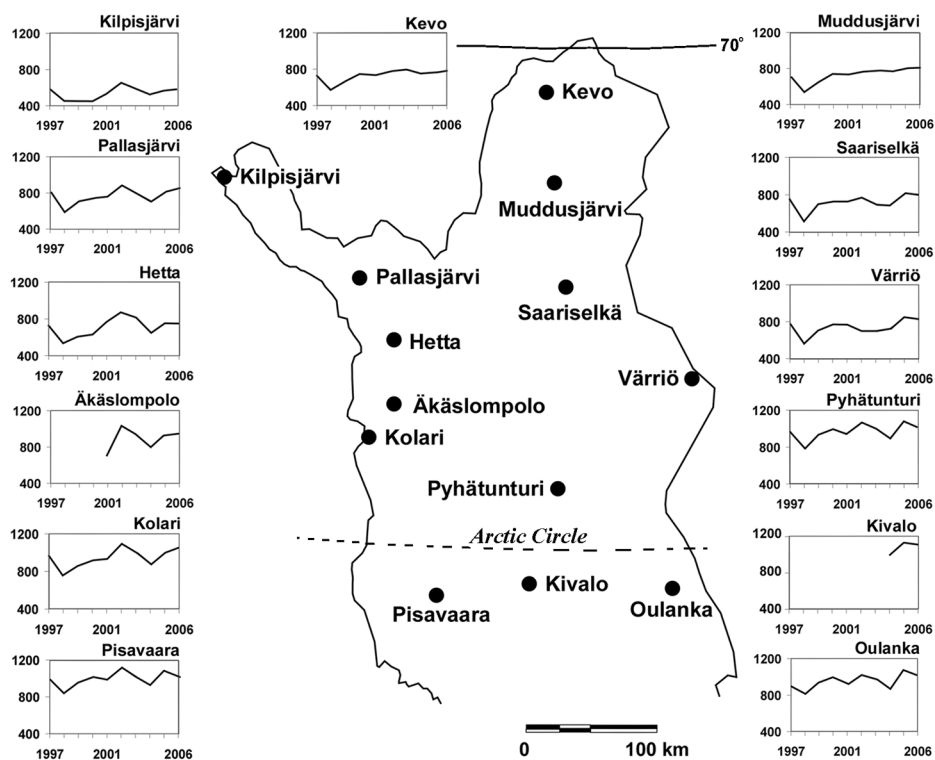


Fig. 1. Location of observation sites and annual effective temperature sums (ETS) during the period 1997–2006.

Table 1. Phenological observation sites, their locations, and mean effective temperature sum (ETS) of growth periods during 1997–2006.

Number	Observation site	Lat. N	Long. E	Altitude (m a.s.l.)	ETS (d.d.)
1	Pisavaara	66°16′	25°06′	117	996
2	Oulanka	66°20′	29°08′	160	953
3	Kivalo	66°21′	26°40′	153	1065
4	Pyhätunturi	67°01′	27°11′	215	973
5	Kolari	67°21′	23°50′	150	947
6	Äkäslompola	67°35′	67°12′	340	895
7	Värriö	67°45′	29°37′	350	744
8	Pallasjärvi	68°01′	24°09′	260	763
9	Saariselkä	68°24′	27°23′	300	723
10	Hetta	68°27′	23°30′	300	713
11	Muddusjärvi	69°07′	27°10′	155	728
12	Kilpisjärvi	69°03′	20°46′	480	541
13	Kevo	69°45′	27°01′	100	732

Table 2. Plant species and their spring and autumn phenophases under observation.

Species	Spring	Autumn
<i>Betula pendula</i>	Bud burst, leaves full sized	Leaf colouring
<i>B. pubescens</i>	Bud burst, leaves full sized	Leaf colouring
<i>Populus tremula</i>	Leaves full sized	Leaf colouring
<i>Sorbus aucuparia</i>	Bud burst, flowering	Leaf colouring, berries ripe
<i>Prunus padus</i>	Flowering	Berries ripe
<i>Vaccinium myrtillus</i>	Flowering	Berries ripe
<i>V. vitis-idaea</i>	Flowering	Berries ripe

imum thickness of snow cover, and melting date of the permanent snow cover were available from 15 weather stations of the Arctic Research Centre of the Finnish Meteorological Institute. These weather stations are located 14.2 kilometres (median value) from the phenological observation sites. We considered the weather stations' data to represent the areal climate of the observed species.

Analysis of data

We calculated the effective temperature sum (ETS) applying a threshold value of +5 °C for the entire thermal growing season, which begins when the daily mean temperature stays above +5 °C for at least five consecutive days and ends when temperature drops permanently below +5 °C (Venäläinen *et al.* 2005). The threshold of +5 °C is the threshold generally used in Finland. We also tested threshold temperatures between 0 °C and +5 °C. Statistical analysis based on different threshold temperatures showed no consistent differences in phenological trends. We also calculated monthly mean temperatures using the daily mean temperatures. We determined the length of the vegetative growth period for each species as the number of days between bud burst and leaf colouring. Similarly, we defined the length of the reproductive period as the number of days between flowering and the ripening of berries.

We used linear regression models in order to detect consistent trends in climate and in timing of plant phenophases during the observation years. Similarly, we used linear regression model and partial correlation to determine the relationship between the phenological events and environmental factors, i.e. ETS, mean May temperature, maximum snow thickness, and date of snow melt. We also tested mean March and mean April temperatures. As the mean May temperature was the most powerful factor explaining mean monthly temperatures, we excluded the other months from further analyses for simplicity. We calculated the relationship between the timing of phenophases in each species using the Pearson correlation. We used untransformed values in tests, since the data were normally

distributed and homoscedastic. Since only one average value was recorded for each species and phenophase at each observation site, statistical comparison between the observation sites was not possible. We corrected the significance levels in each table by using the sequential Bonferroni technique ($\alpha = 0.05$, Quinn and Keough 2002). All analyses were carried out using SPSS 12 for Windows (SPSS Inc. 2003).

Results

Variation in air temperature was quite similar at all of the observation sites during the study period (Fig. 1). The coldest summer was 1998; then the effective temperature sum (ETS) ranged from 461 at Kilpisjärvi to 839 at Pisavaara. The warmest summer was 2002 when the ETS ranged from 664 at Kilpisjärvi to 1115 at Pisavaara. According to the regression model, the ETS increased by 17.7 day degrees (d.d.) per year (Table 3). Simultaneously, the maximum snow thickness diminished annually by 3.5 cm, and the date of snow melt advanced on average by 1.4 days per year, from 27 May in 1997 to 6 May in 2006. The mean May temperature increased annually by 0.3 degrees. According to the regression model, an increase of one degree in mean May temperature advanced the snow melt by 3.8 days. Likewise, a decrease of one cm in maximum snow thickness advanced the snow melt by 0.3 days (Table 3).

The timing of the earliest vegetative phenophases advanced during the 10-year period 1997–2006 (Fig. 2). The bud burst of *Betula pendula* and *B. pubescens* occurred on average 1.7–1.8 days earlier each year, on 5 June in 1997 and on 14 May in 2006, and on 7 June in 1997 and 15 May in 2006, respectively (Fig. 2A and B). The bud burst of *S. aucuparia* advanced from 4 June in 1998 to 15 May in 2006 (Fig. 2D). However, a later spring phase, the timing of full-sized leaves, did not show any advancement in *Betula* sp. and *P. tremula*. The flowering of *S. aucuparia* and *P. padus* advanced from 30 June to 22 June and from 22 June to 12 June, respectively. The flowering of *Vaccinium myrtillus* and *V. vitis-idaea* advanced from 19 June to 10 June and from 4 July to 25 June, respectively (Fig. 3).

All regressions were statistically significant even when the extreme year of 2006 was excluded from the analysis (data not shown).

The spring phenophases advanced in pace with increasing mean May temperatures in all of the species (Fig. 4). For example, an increase of one degree in the mean air temperature in May corresponded to an advancement of bud burst by 4.7–4.8 days in *Betula* sp. (Fig. 4A). The full-sized leaves of *P. tremula* and the flowering of *S. aucuparia* and *V. vitis-idaea* did not advance significantly in pace with increasing May temperatures (Fig. 4); in the case of these phenophases, the date of snow melt was a better predictor than air temperature ($R^2 = 0.32\text{--}0.43$, $p < 0.001$, $n = 91\text{--}104$). The maximum thickness of the snow cover also appeared to be a statistically significant predictor of the timing of flowering. Nevertheless, a partial correlation with the elimination of the effect of snow melt showed that the impact of maximum thickness of snow cover was no longer statistically significant (data not shown). The spring phenophases occurred at stable ETS, which was indicated by an insignificant correlation between the phenophases and ETS ($p > 0.05$, data not shown).

Despite the advancement of the onset of spring, the earliest vegetative phenophases occurred at higher ETS values each year. *B. pendula* started growing annually at 3.0 d.d. and *B. pubescens* at 1.9 d.d. higher ETS values (Table 3). The pattern was similar but statistically insignificant for *P. tremula* and *S. aucuparia* (Table 3). Flowering occurred annually at a relatively stable ETS value ($p > 0.05$, data not shown).

In contrast to spring phenophases, the vegetative phenophases in the autumn did not show any consistent pattern during the observation years (Fig. 2). Similarly, the ripening of berries did not show any pattern (Fig. 3). The autumn phenophases occurred at stable ETS values ($p > 0.05$, data not shown).

Due to the advancement of the spring, the vegetative growth period lengthened annually by 1.6–2.3 days in the case of *Betula* sp. and *S. aucuparia* (Table 3). The growth period was not significantly changed for *P. tremula*. The duration of the reproductive period did not show any significant pattern (Table 3). The length of the vegetative growth period increased along with increasing ETS (Fig. 5A and B), whereas the reproductive period was independent on

Table 3. Linear regression coefficients between environmental variables, plant phenological variables, and observation year. Tablewise significance levels were corrected using sequential Bonferroni technique ($\alpha = 0.05$). Values set in boldface indicate significant regressions. b_1 indicates average annual change observed during monitoring period.

Dependent variable	Independent variable	n	R^2	p	b_1
ETS	Year	119	0.10	0.001	17.72
Maximum snow thickness	Year	110	0.29	< 0.001	−3.46
Date of snow melt	Year	110	0.15	< 0.001	−1.42
May temperature	Year	118	0.24	< 0.001	0.32
Date of snow melt	May temperature	110	0.45	< 0.001	−3.76
Date of snow melt	Max. snow thickness	110	0.32	< 0.001	0.28
ETS at bud burst in <i>B. pendula</i>	Year	55	0.26	< 0.001	3.05
ETS at bud burst in <i>B. pubescens</i>	Year	101	0.12	< 0.001	1.93
ETS at first leaves in <i>P. tremula</i>	Year	86	0.06	0.022	4.74
ETS at bud burst in <i>S. aucuparia</i>	Year	83	0.09	0.006	1.86
Growth period in <i>B. pendula</i>	Year	61	0.16	0.001	1.57
Growth period in <i>B. pubescens</i>	Year	100	0.18	< 0.001	1.65
Growth period in <i>P. tremula</i>	Year	88	0.01	0.330	0.36
Growth period in <i>S. aucuparia</i>	Year	90	0.21	< 0.001	2.31
Reproductive period in <i>S. aucuparia</i>	Year	84	0.00	0.737	0.09
Reproductive period in <i>P. padus</i>	Year	67	0.00	0.739	−0.11
Reproductive period in <i>V. myrtillus</i>	Year	106	0.00	0.512	−0.17
Reproductive period in <i>V. vitis-idaea</i>	Year	101	0.08	0.006	0.82

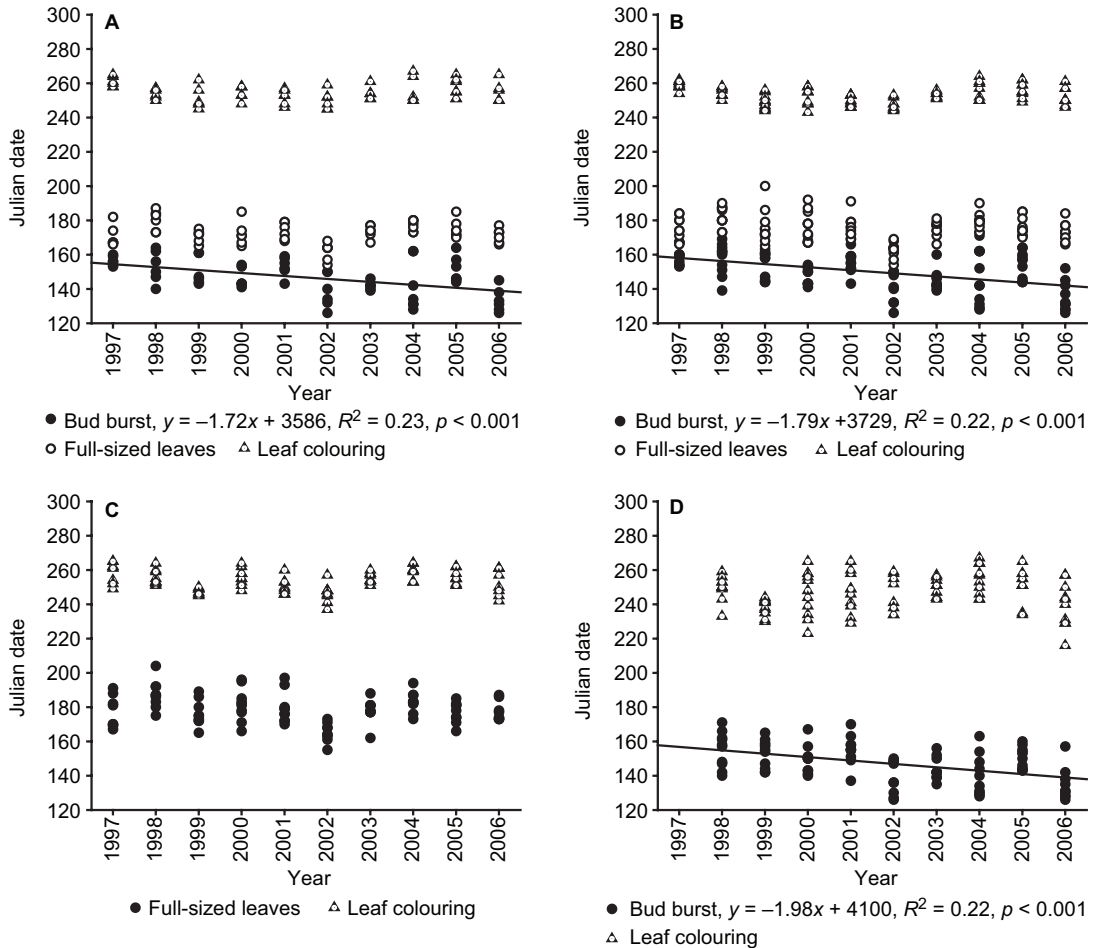


Fig. 2. Linear regression in vegetative phenophases in (A) *Betula pendula*, (B) *B. pubescens*, (C) *Populus tremula*, and (D) *Sorbus aucuparia* in 1997–2006. Tablewise significance levels were corrected using sequential Bonferroni technique ($\alpha = 0.05$). Regression lines and equations fitted to data are only presented if they were significant. $n = 61$ –106 in regression models.

ETS (Fig. 5C and D).

There was no correlation in the timing between the vegetative phenophases of a given species, except between bud burst and full-sized leaves in *B. pubescens* (Table 4). On the other hand, the reproductive phenophases (flowering vs. ripening of berries) showed a significant correlation in all species for which reproductive phenophases were recorded. In the case of *S. aucuparia*, flowering and bud burst were closely correlated in spring, whereas in autumn the ripening of berries and the time of leaf colouring showed no correlation (Table 4). The accumulation of ETS between flowering and ripening of berries was constant in *V. myrtillus* and *P. padus*

($p > 0.05$), whereas it increased annually by 16.4 d.d. in *V. vitis-idaea* ($R^2 = 0.15$, $p < 0.001$, $n = 102$), and by 11.9 d.d. in *S. aucuparia* ($R^2 = 0.11$, $p = 0.002$, $n = 88$).

Discussion

Our results indicate that the onset of spring occurred 0.8 to 2.0 days earlier each year in Finnish Lapland during the 10-year period 1997–2006. This leads to an overall advancement of 1–2 weeks in spring phenophases during the relatively short observation period. It should be noted that the increase in the mean May

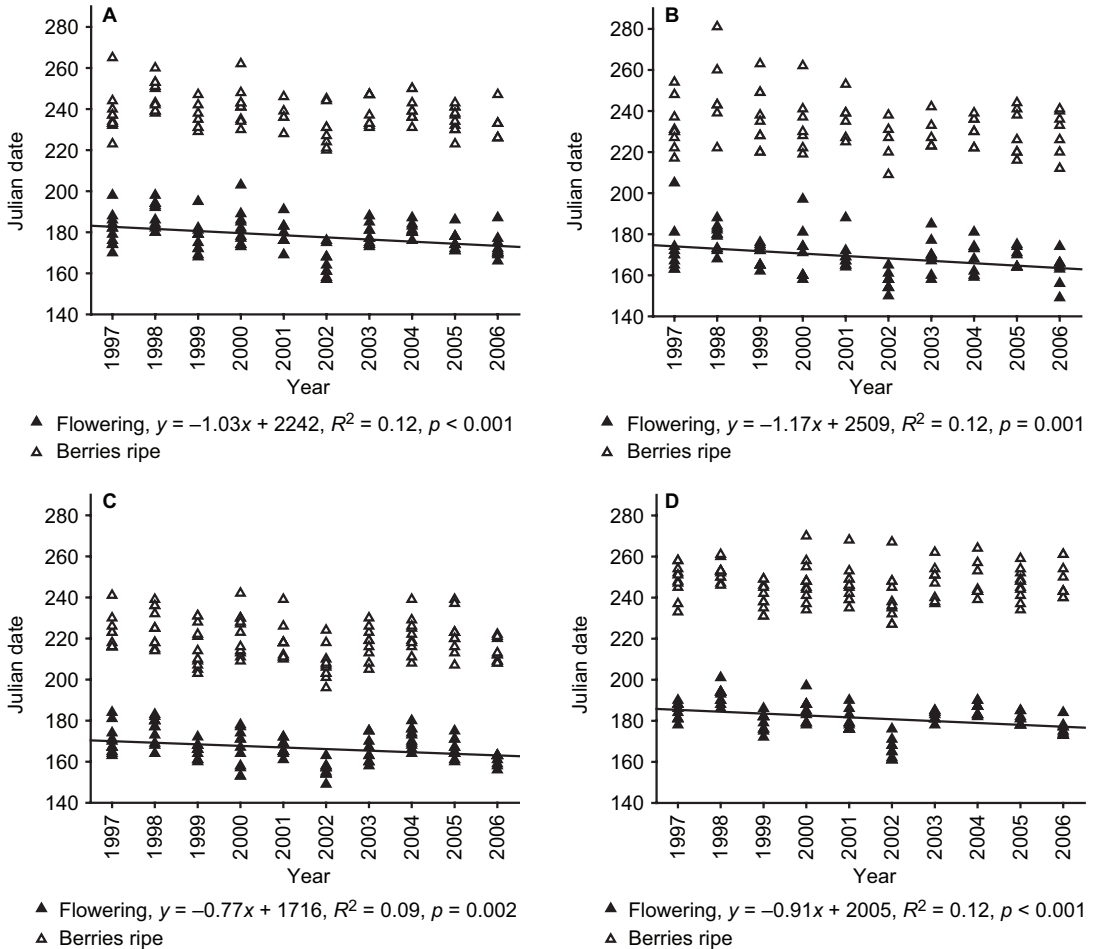


Fig. 3. Linear regressions in reproductive phenophases in (A) *Sorbus aucuparia*, (B) *Prunus padus*, (C) *Vaccinium myrtillus*, and (D) *V. vitis-idaea* in 1997–2006. Tablewise significance levels were corrected using sequential Bonferroni technique ($\alpha = 0.05$). Regression lines and equations fitted to data are only presented if they were significant. $n = 69$ –104 in regression models.

temperature during the observation period was quite high, 3 °C per decade. If this trend continues, climate warming would be more significant than is currently predicted as the predictions for Finland vary between 2 °C and 7 °C by the year 2080 (Jylhä *et al.* 2004, Ruosteenoja *et al.* 2005). Nevertheless, the short-term advancement was statistically significant even when the extreme year of 2006 was excluded from regression analyses. The earliest phenophases, such as the bud burst of trees, advanced most for all, whereas by the time when the leaves had developed to their full size, the advancement had levelled out. The phenological patterns were almost uniform for the various species regarding comparable

phenological phases. This is in accordance with Linkosalo (e.g. 1999, 2000a), who showed that the pattern of spring advancement was similar between the various species from year to year, which indicates a unanimous optimal response to climatic conditions. Bud burst is considered to be the most important phenophase in showing the most powerful response to temperature change (Chuine and Beaubien 2001, Scheffinger *et al.* 2003, Menzel *et al.* 2006a). In our work, each increase of one degree in the mean air temperature in May corresponded to an advancement of bud burst by 4.7–4.8 days and of flowering by 0–3.7 days, depending on the species. Karlsson *et al.* (2003) also detected that the change of

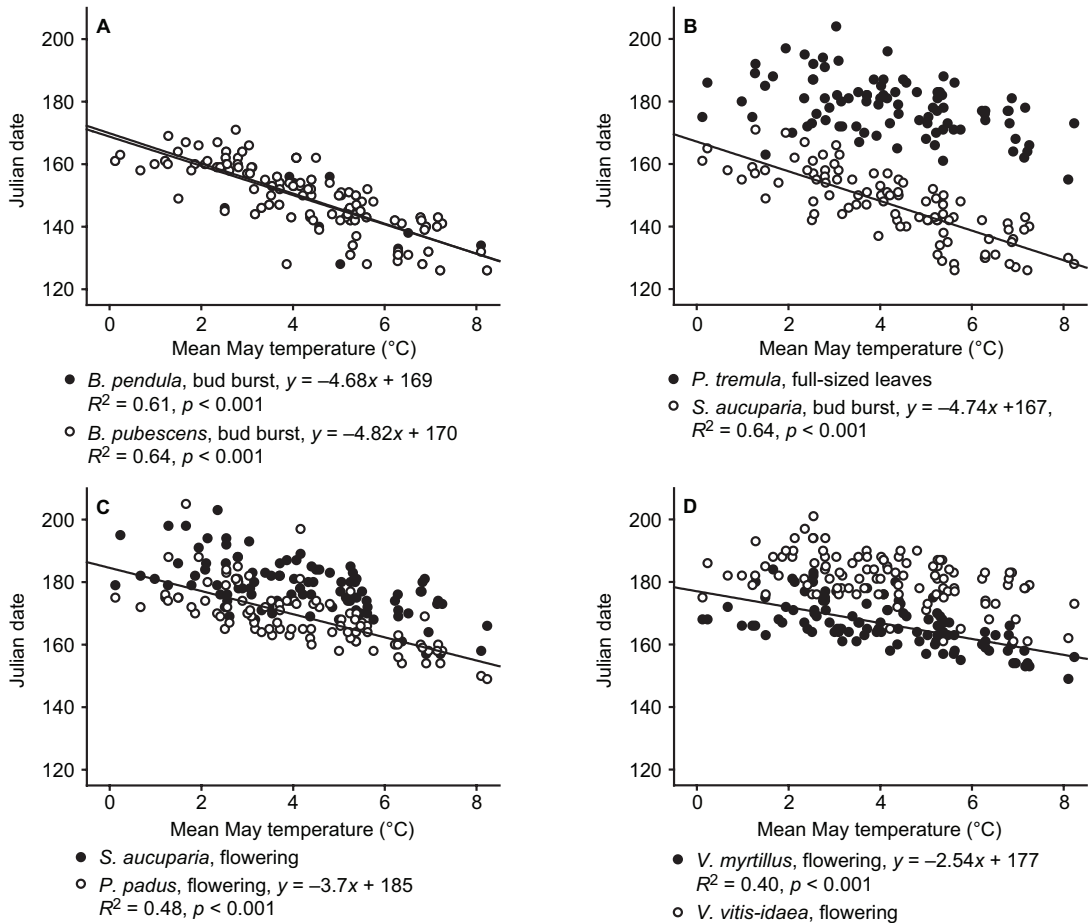


Fig. 4. Regression coefficients between the occurrence of vegetative phenophases and mean May temperature in (A) *Betula pendula* and *B. pubescens*, (B) *Populus tremula* and *Sorbus aucuparia* in 1997–2006. Regression coefficients between occurrence of reproductive phases and mean May temperature in (C) *S. aucuparia* and *Prunus padus*, and (D) *Vaccinium* sp. in 1997–2006. Tablewise significance levels were corrected using sequential Bonferroni technique ($\alpha = 0.05$). Regression lines and equations fitted to data are only presented if they were significant. $n = 62$ –106 in the regression models.

May temperature has the strongest influence on the date of budburst in mountain birch at high latitudes.

The advance in the onset of spring was observed in several earlier studies conducted in Europe (Ahas 1999, Menzel 2000, Grisule and Malina 2005, Menzel et al. 2006a) and North America (e.g. Schwartz 1998, Beaubien and Freeland 2000, Zhou et al. 2001). Nevertheless, studies from northern high mountains and the northernmost continental areas of Europe have shown delayed occurrence of spring due to greater snow thickness in winter, which in turn lead to delayed in snow melt (e.g. Høgda et al. 2001, Kozlov and Berlina 2002, Shutova

et al. 2005, 2006). In cold regions, the time of melting of snow cover in spring is the primary factor launching the growth period (Myneni et al. 1997, Suni et al. 2003, Wielgolaski and Karlsen 2006), while the thickness of the snow cover is an important factor impacting on the onset of flowering (Høgda et al. 2001). In our study, both the mean temperature of May and the timing of snow melt were good predictors of the spring phenophases, whereas the thickness of the snow cover had only an indirect impact by influencing the timing of snow melt.

Our regression models revealed that bud burst occurred at increasingly elevated ETS values each year, while flowering occurred at

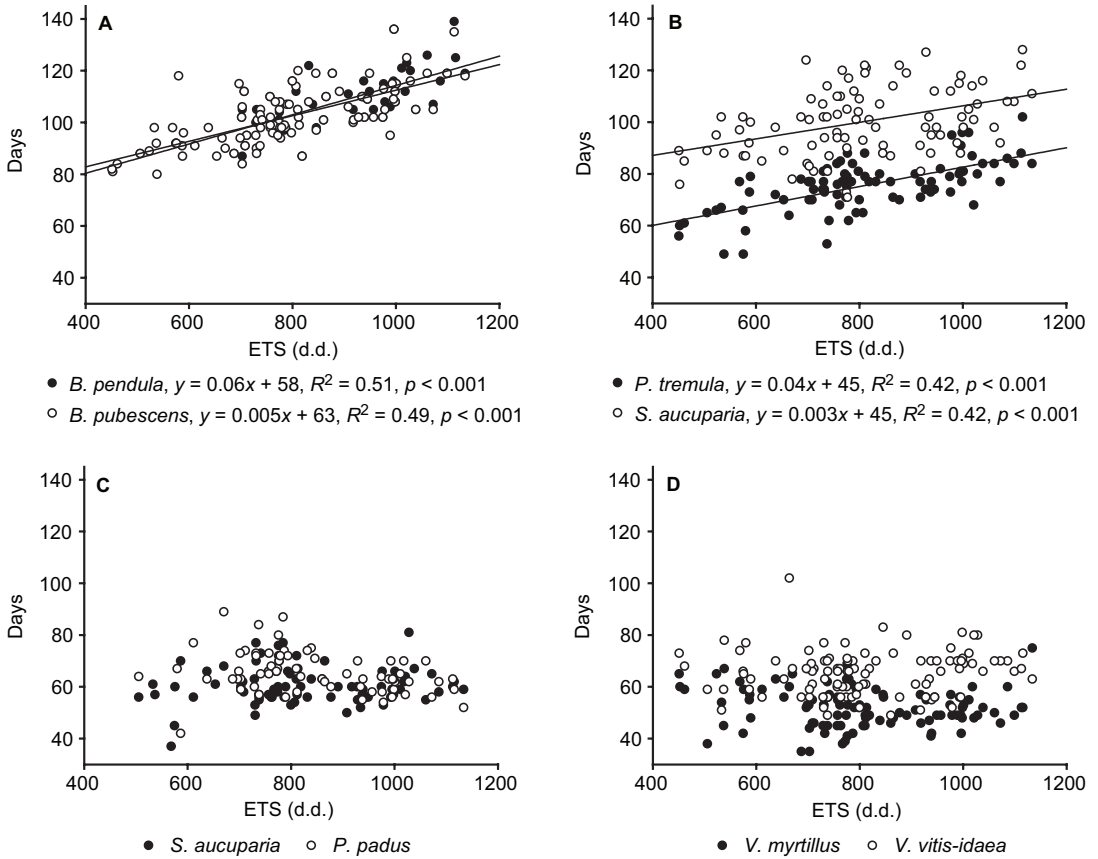


Fig. 5. Linear regressions between vegetative growth period in (A) *Betula* sp., (B) *Populus tremula* and *Sorbus aucuparia* and ETS, and between reproductive period in (C) *S. aucuparia*, *Prunus padus*, and (D) *Vaccinium* sp. and ETS. Tablewise significance levels were corrected using sequential Bonferroni technique ($\alpha = 0.05$). Regression lines and equations fitted to data are only presented if they were significant. $n = 61$ – 106 in the regression models.

relatively stable ETS values. This may indicate that the temperature requirements for greening are higher in the early spring when the risk of night frosts is still high and/or that photoperiodic constraints in the early spring have an influence on the requirement for elevated ETS. Photoperiodic factors are known to influence the spring-time development of trees (Partanen *et al.* 1998, Linkosalo and Lechowicz 2006). Increased frost damage to trees is considered to be a noteworthy consequence of climate warming, especially in boreal ecosystems (e.g. Hänninen 1995, 2006, Saxe *et al.* 2001). Organs characterised by early phenological development are more susceptible to frost damage than organs characterised by later phenological development (Linkosalo 2000b). The requirement for elevated ETS in

early spring would especially protect vegetative organs against frost damage, which would be important for the survival of the plant. Flowering at a stable ETS may be a consequence of the fact that flowering occurs later than bud burst and the probability of frosts is then lower.

Both vegetative and reproductive phenophases in the autumn remained relatively stable throughout the observation period. Earlier results of the monitoring of autumn phenophases vary considerably, which indicates that there are several factors influencing the autumn development of plants. Menzel (2000) showed that leaf colouring had been delayed by about 6 days in 1959–1996 in Europe. Braslavská *et al.* (2004) published results indicating that there has been no clear trend in the leaf colouring of *Betula pen-*

dula in central Europe since the 1950s. Kozlov and Berlina (2002) and Shutova *et al.* (2005) showed a trend of earlier yellowing of birch leaves in the Kola Peninsula. Factors triggering the colour change of leaves include both air temperature and light signal (Häkkinen 1999). According to Partanen (2004), the photoperiod may be the more important of these two factors, whereas in the High Arctic, higher temperatures may postpone the autumn phenophases (Marchand *et al.* 2004). The ripening of berries seems to be connected with the temperature of the preceding months (Dose and Menzel 2006). Menzel *et al.* (2006b) showed that fruiting of wild plants correlated negatively with higher temperature and showed an advancement of 2.5 days per decade. Still, wild plants are less closely reliant on temperature than cultivated plants (Menzel *et al.* 2006b).

The length of the vegetative growth period increased annually on average by 1.6–2.3 days for *Betula* sp. and *S. aucuparia*, in which the earliest phenological phase bud burst was recorded. *P. tremula* did not demonstrate such a pattern as the observations were started only when the leaves had reached their full size. This result emphasises the point that phenological observations should cover the entire growth period of the plants in order to provide a realistic picture of the trends over the years. In most studies, the length of the growth period has been increasing due

to advanced spring phenophases (e.g. Menzel and Fabian 1999, Menzel 2000, Chmielewski and Rötzer 2001). However, studies carried out at continental high latitudes and in alpine areas have shown a decrease in the length of the growth period (e.g. Høgda *et al.* 2001, Shutova *et al.* 2006). Strong regionality in the climate of northern Fennoscandia leads to great regional differences in vegetation and in the length of the growing season.

A statistically significant regression with respect to the length of the vegetative growth period and ETS indicates that temperature had a strong impact on the growth rhythms of the studied plants. However, due to the lack of growth measurements related to the observed plants we are not able to indicate what the ecological consequences of the lengthening of the growth period will actually be. A longer growth period may not necessarily be reflected in increased biomass production if there are other constraints that limit plant growth. For example, frost damage in the spring may reduce plant production. Compensation after injury may be retarded in those species whose meristems are produced in the previous season. On the other hand, all of the studied species have abundant bud banks, which ensure a high capacity for compensatory growth following frost injury. Frost risk may also differ between trees and dwarf shrubs, as the latter are adapted to overwintering under a

Table 4. Pearson correlation coefficients between timing of plant phenophases. In *S. aucuparia*, only four relevant correlations were calculated. Tablewise significance levels were corrected using sequential Bonferroni technique ($\alpha = 0.05$). Values set in boldface indicate significant correlations.

Species	Phenophases	<i>n</i>	<i>r</i>	<i>p</i>
<i>Betula pendula</i>	Bud burst/full-sized leaves	62	0.29	0.025
	Bud burst/leaf colouring	61	0.08	0.555
	Full-sized leaves/leaf colouring	61	0.10	0.450
<i>Betula pubescens</i>	Bud burst/full-sized leaves	105	0.44	< 0.001
	Bud burst/leaf colouring	100	0.15	0.140
	Full-sized leaves/leaf colouring	100	0.19	0.066
<i>Populus tremula</i>	Full-sized leaves/leaf colouring	88	0.21	0.046
<i>Sorbus aucuparia</i>	Bud burst/leaf colouring	90	0.28	0.009
	Bud burst/flowering	89	0.65	< 0.001
	Flowering/leaf colouring	88	0.28	0.007
	Flowering/ripening of berries	84	0.65	< 0.001
<i>Prunus padus</i>	Flowering/ripening of berries	68	0.72	< 0.001
<i>Vaccinium myrtillus</i>	Flowering/ripening of berries	104	0.64	< 0.001
<i>Vaccinium vitis-idaea</i>	Flowering/ripening of berries	99	0.49	< 0.001

cover of snow. Recovery from injuries depends on the phenological stage in *V. myrtillus* (Tolvanen 1997, Tolvanen and Taulavuori 1998). If resources are used for growth due to early snow melt and high temperatures, the recovery ability following frost damage may be low. Especially sexual production may be delayed, since the production of berries may need accumulation of resources over many seasons (Tolvanen 1997). In addition to frost, dry years, the extreme year in this respect being 2006, may limit plant growth despite favourable temperature conditions. Extreme years of drought may also speed up the yellowing of leaves in autumn. Also, indirect impacts, such as diseases, herbivory, and competition, may have negative impacts on the growth potential of plants (Arctic Climate Impact Assessment (ACIA) 2005).

Contrary to the vegetative phenophases, the length of the reproductive period, i.e. the time needed for the ripening of seeds, was independent of ETS. The dates between flowering and the ripening of berries were powerfully correlated, which indicates that the ripening of seeds reflection of the internal rhythm of plants rather than of ambient conditions. Another explanation is that the ETS requirement from flowering to the ripening of the berries is constant, as was the case with *V. myrtillus* and *P. padus*. For example, the earlier dates of ripening of berries of *S. aucuparia*, *P. padus* and *Vaccinium* sp. were explained by the earlier date of flowering instead of a higher ETS value by the time of berry ripening. If advanced flowering leads to earlier ripening of berries and seeds, this has crucial impacts on the ability of plant species to spread to colder areas. It is well known that the shortness of the growing season is among the most important limiting factors affecting the growth and reproduction of plants occurring at the limit of their distribution (Walker *et al.* 1995, Suzuki and Kudo 1997). Under conditions of elevated temperature, plants might be able to produce viable seed more frequently than under the extreme conditions they had to endure previously.

We observed a clear advancement in spring phenology during the last 10 years. However, a longer observation period is needed to determine whether the observed advancement is a consequence of the predicted climate change or

of normal climatic variability. Long observation series can be used in phenological models, which help to predict the timing of phenophases and the impact of changing environmental conditions on forest plants.

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