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Chapter 8

Forest tree phenology in the French Permanent Plot Network (RENECOFOR, ICP forest network)

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Characteristics of the French Permanent Plot Network (RENECOFOR)

In 1992, a forest network was created by the French National Forest Office to complete the existing French forest health monitoring activities. The main objective of this French Permanent Plot Network for the Monitoring of Forest Ecosystems (RENECOFOR), covering the whole of France, is to detect possible long-term changes in the functioning of a great variety of forest ecosystems, selected as regionally representative stands, and to determine the reasons for such changes. It consists of 102 permanent plots and 26,000 trees (10 different species), which are to be monitored for at least 30 years. Each plot has an area of about 2 ha, the central 0.5 ha of which is fenced (Ulrich, 1995). A total of 36 trees were numbered trees per plot for observation purposes. Stands were sampled in the different French bioclimatic areas (i.e. oceanic, continental, mountain and Mediterranean) and covered a wide range of ecological conditions (Table 8.1). The general topography is gently rolling (mean slope = 10%) with elevation ranging from 18 to 1850 m a.s.l. (mean = 501 m). The examined forests are composed of pure stands from 30 to 180 years, naturally regenerated or derived from plantations. The stands are structurally uniform with a closed canopy. Trees are mostly managed in high forests with regular thinnings (Lebourgeois, 1997; Cluzeau *et al.*, 1998).

Phenological observations (i.e. leaf unfolding and leaf yellowing) have been performed annually for 90 stands since 1997 (48 broadleaved stands and 42 coniferous forests) (Figure 8.1). Oak stands were mainly sampled in plain areas of northern France with a homogeneous distribution from west to east (20–350 m a.s.l.; mean: 200 m). Beech stands are located in the north-eastern plain (250–570 m a.s.l.; mean: 413 m) and in mountain areas in the south and south-east of France (400–1400 m a.s.l.; mean: 1031 m). Norway spruce, silver fir and larch stands correspond to high altitude forests in the east of France (400–1850 m a.s.l.; mean: 1000 m). For pine and Douglas fir stands, geographical locations and ecological conditions are more heterogeneous (15–1670 m a.s.l; mean: 450 m). From 1997 to 2003, 81 stands were observed continuously for 5 years and 46 stands during the whole period (7 years). Thus, from 1997 to 2003, a total of 503 and 278 observations, respectively, for leaf unfolding and leaf yellowing are available (Table 8.1). The course of phenological events was observed by local foresters at a weekly time step with binoculars (in most cases) between March and June for leaf unfolding (all species) and September and November for leaf yellowing (broadleaved trees and larch). Each year, the same local forester noted the date in julian days (jd) at which a given percentage of the 36 numbered trees presented a given stage of phenological development (Lebourgeois *et al.*, 2001). For budburst, the first date (bb1) corresponds to the day of year on which 10% of the trees present at least 20% of open buds in the crown: new green leaves are clearly visible but not completely developed. The second date (bb9) corresponds to the day of year on which 90% of the trees have reached the same stage of crown development. The notation principle for leaf yellowing is similar. The dates ly1 and ly9 correspond to the days of year on which 10% or 90% of the trees present at least 20% of crown yellowing. For oak, beech and larch stands, the length of the growing season (lgs) has been evaluated in four different ways according to the stage of development taken into account. In all cases, the duration is the number of days between a date for budburst and a date for leaf yellowing. The four lengths are the number of days between bb1 and ly1 (lgs11), bb1 and ly9 (lgs19), bb9 and ly1 (lgs91) and bb9 and ly9 (lgs99), respectively.

Table 8.1. Characteristics of the phenological data available in the French Permanent Plot Network (RENECOFOR) for the period 1997–2003. The two values in square brackets indicate the number of broadleaved and coniferous stands, respectively.

Species	Number of stands with phenological data only (number of observed trees)	Number of stands with phenological and daily climatic data	Number of phenological observations	
			Budburst	Leaf yellowing
Abies alba (AA)	10 (360)	10 (360)	66	
Fagus sylvatica (FS)	19 (684)	18 (648)	117	121
Larix decidua (LD)	1 (36)	1 (36)	7	7
Picea abies (PA)	8 (288)	8 (288)	53	
Pinus nigra ssp. *laricio (PN)*	2 (72)	2 (72)	10	
Pinus pinaster (PP)	5 (180)	2 (72)	13	
Pinus sylvestris (PS)	11 (396)	10 (360)	65	
Pseudostuga menziesii (PM)	5 (180)	4 (144)	27	
Quercus petraea (QP)	19 (684)	15 (540)	89	95
Quercus robur (QR)	8 (324)	8 (324)	50	49
Mixed *QR-QP*	2 (72)	1 (36)	6	6
Total	90 [48, 42] (3276)	79 [42, 37] (2880)	503	278

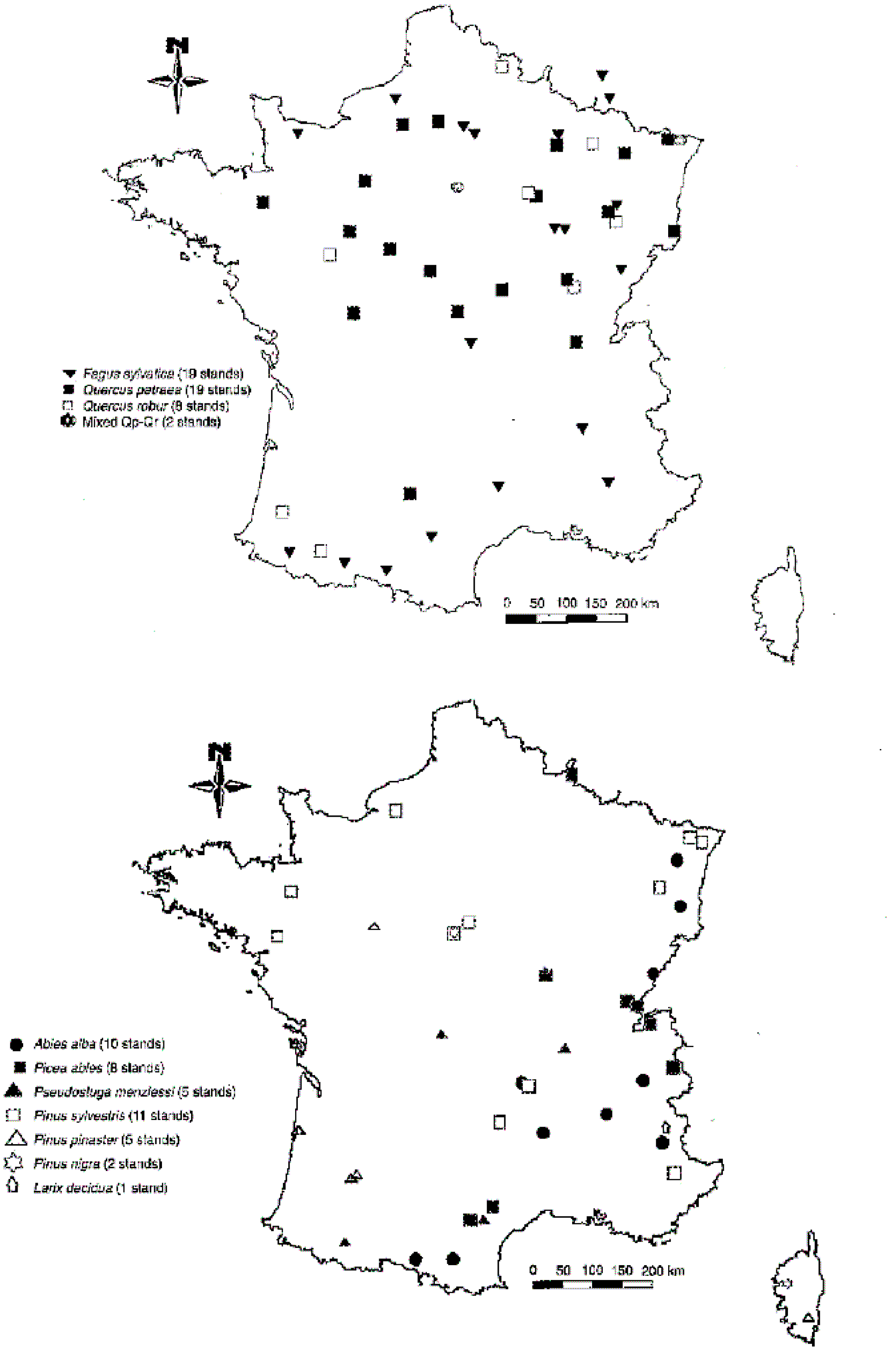

Figure 8.1. Geographical location of the 90 stands (48 broadleaved stands and 42 coniferous stands) sampled in the French Permanent Plot Network (RENECOFOR). For beech stands, two plots were sampled in the Grand-Duchy of Luxembourg.

Daily meteorological data from January 1997 to December 2003 were obtained from the RENECOFOR meteorological sub-network (20 stations) (Ponette *et al.*, 1996) and from the French National Climatic Network "Météo-France" (58 stations). Monthly minimum, maximum, mean temperatures and monthly sunshine durations were calculated for each year and for the whole period 1997–2003. Climatic data were complemented with global radiation estimations (in $MJ \cdot m^{-2}$). A GIS-based solar radiation model was used, taking both local parameters (topography) and global parameters (cloudiness and latitude) into account. The latter was run for the whole extent of French territory with a 50-m digital elevation model and for each month of the year.

The relationships between the annual timing of phenological phases and monthly climatic parameters and local ecological data (i.e. latitude, longitude, altitude, aspect and slope) were established by using simple or multiple regression analysis. The main objective of this first analysis of the French forest database is to provide simple models usable at a large regional scale. The results of multiple regression analysis are derived from the means of the period 1997–2003. Multiple regression procedure leads to an estimate of a linear equation of the form:

$$Y = \mathrm{a} + \mathrm{b1} \times X1 + \mathrm{b2} \times X2 + \ldots + \mathrm{bp} \times X\mathrm{p} \tag{1}$$

The regression coefficient b represents the contributions of each independent variable X (e.g. climatic data, geographical variables, etc.) to the prediction of the dependent variable Y (phenological phase). In each case, the selected model was the simplest and easiest to understand from a biological point of view. Each model is adjusted according to least squares criterion. Thus, the model maximizes the percentage (r^2) of variance explained. Relative model quality has been evaluated by the mean absolute error (MAE) and the root mean square error (RMSE). RMSE is representative of the size of a "typical" error but is more sensitive than other measures to the occasional large error: the squaring process gives disproportionate weight to very large errors. The RMSE is evaluated by the equation:

$$RMSE = \sqrt{\frac{1}{n} \sum_{j=1}^{n} \left(P_j - O_j\right)^2} \tag{2}$$

where P_j is the value predicted by the model, O_j the actual value and n the total number of observations. By means of the resulting equation, phenological phases can be calculated for any location or species within the area covered by the network.

Average phenological events in forest stands

On average, the beginning of the growing season starts on 24 April (bb1, jd 114), but greatly depends on species (Table 8.2 and Figures 8.2 and 8.3). In oak stands, budburst starts at the first week of April (jd 96), whereas the onset for beech stands occurs on 21 April (jd 111). The difference between both broadleaved species averages 15 days. The latest onset of spring can be observed at high altitude forests of silver fir, spruce and larch trees. For these stands, budburst starts on 10 May. For all species, the difference between the onset (bb1) and the end (bb9) of budburst averages 10 days. For broadleaved trees, the end of the growing season begins on 5 October (jd 278). The crown appears totally yellow on 22 October (jd 295). The average length of the growing season lasts between 153 and

204 days according to the species and phenological stages taken into account (Table 8.2). Compared with oak stands, a shorter duration of about 22 days can be observed in beech stands as a consequence of later budding and earlier autumn leaf colouring.

Table 8.2. Average characteristics of the growing season for each species in the French Permanent Plot Network (RENECOFOR). Means have been calculated from the period 1997–2003. The different dates are expressed in julian days (jd). For spring and autumn phases and for each species, the first line corresponds to the stage 10% (bb1; ly1) and the second line to the stage 90% (bb9; ly9).

Species	Date of budburst (bb1/bb9)					Date of leaf yellowing (ly1/ly9)				
(Number of stands)	Mean	STD	Min.	Max.	No.	Mean	STD	Min.	Max.	No.
Quercus petraea	94	9.5	78	124	95	282	14.1	248	330	101
(19)	106	10	88	131		299	14.1	154	330	
Quercus robur	97	14.3	48	125	50	281	14.4	251	326	49
(8)	111	17.2	55	137		298	14	147	326	
Fagus sylvatica	111	11.2	71	138	117	274	16.5	223	326	121
(19)	120	8.6	98	143		291	16.5	105	326	
Pinus pinaster	113	9.5	99	131	13					
(2)	124	7.7	111	136						
Pinus nigra laricio	120	17	104	159	10					
(2)	131	16.4	114	166						
Pseudostuga menz	120	11.8	97	141	27					
(5)	133	12.9	111	161						
Pinus sylvestris	123	12.3	90	154	65					
(11)	135	13.2	104	164						
Larix decidua	129	4.6	122	134	7	272	3.8	264	293	7
(1)	139	6.2	129	146		287	3.8	133	293	
Picea abies	130	11.5	97	152	53					
(8)	140	10.7	114	162						
Abies alba	131	11.7	102	172	66					
(10)	140	11.1	116	179						
Mean	114					278				
	124					295				

Species	Lgs11		Lgs19		Lgs91		Lgs99	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Quercus petraea	187	16	204	14	176	17	192	15
Quercus robur	184	25	201	25	170	28	187	26
Fagus sylvatica	162	22	179	23	153	20	170	21
Mean	**175**	24	**192**	24	**164**	23	**181**	22

Lgs: length of the growing season in days (see text for details); no.: number of phenological observations from 1997 to 2003.

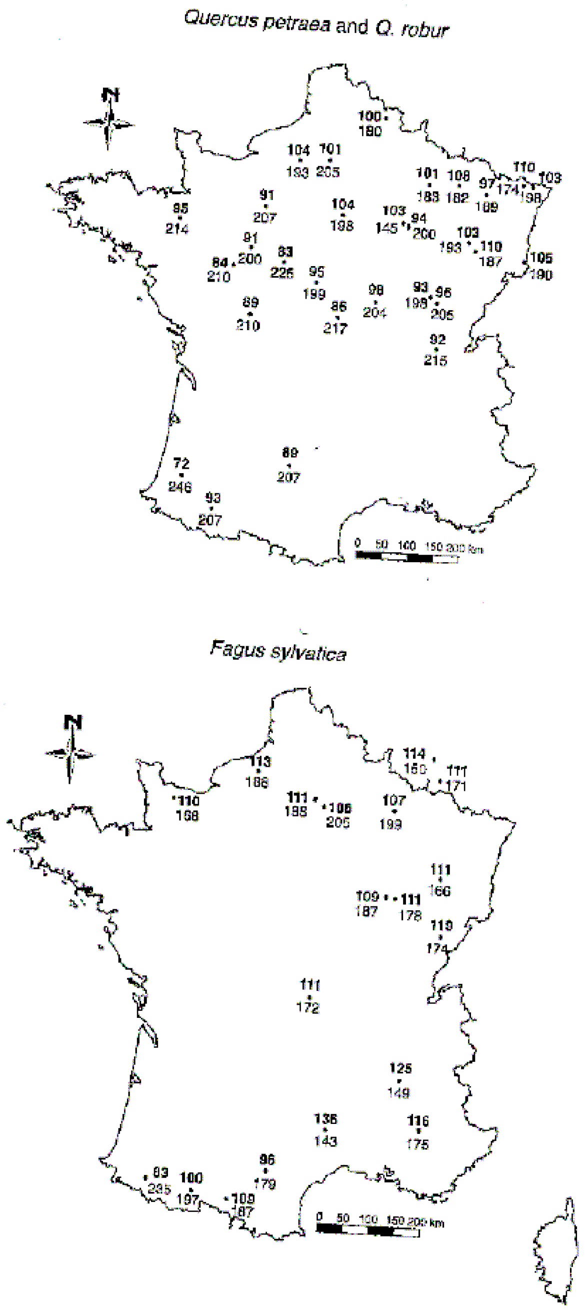

Figure 8.2. Average dates (in julian days) of budburst (in bold) and length of growing season (lgs 19) for broadleaved species (means for the period 1997–2003).

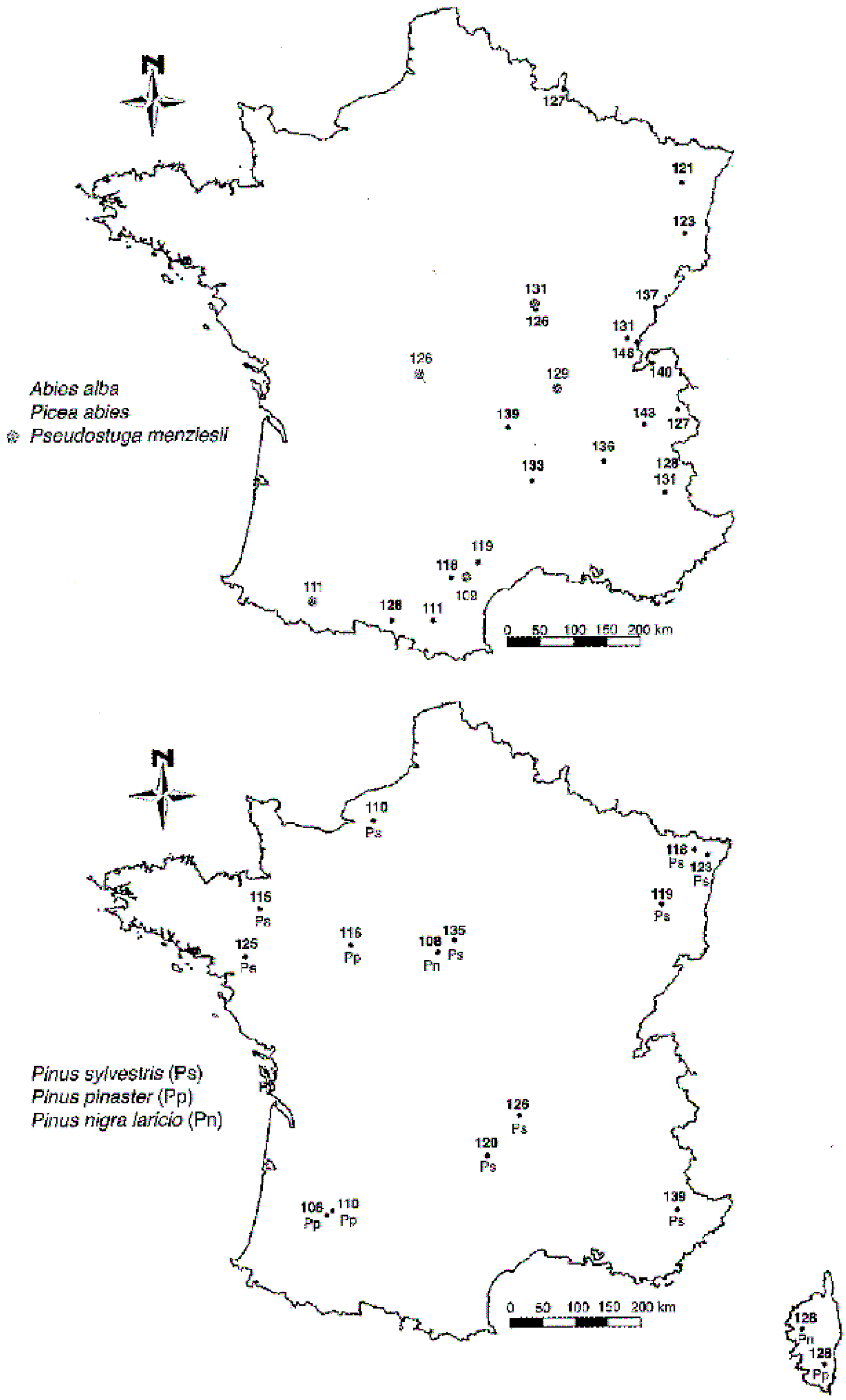

Figure 8.3. Average dates (in julian days) of budburst (bb1) for coniferous species (means for the period 1997–2003).

The timing of spring and autumn events shows strong regional variations and depends highly on the local ecological parameters such as altitude or mean air temperature. On average the green wave in France shifts annually by 3.6 days per degree of longitude from west to east (Figure 8.4). For oak stands, an early onset of the growing season between 10 and 15 days can be observed in oceanic and south regions (at the end of March) (Figure 8.2). In these warmer regions, the length of the growing season is often above 210 days. A later budburst occurs in the continental part of France (in the middle of April) with a growing season of 180–190 days. For oak trees, the regression equation indicates a mean delay of leaf unfolding and duration of growing season by 2.4 days and 4.6 days per degree of longitude from west to east, respectively.

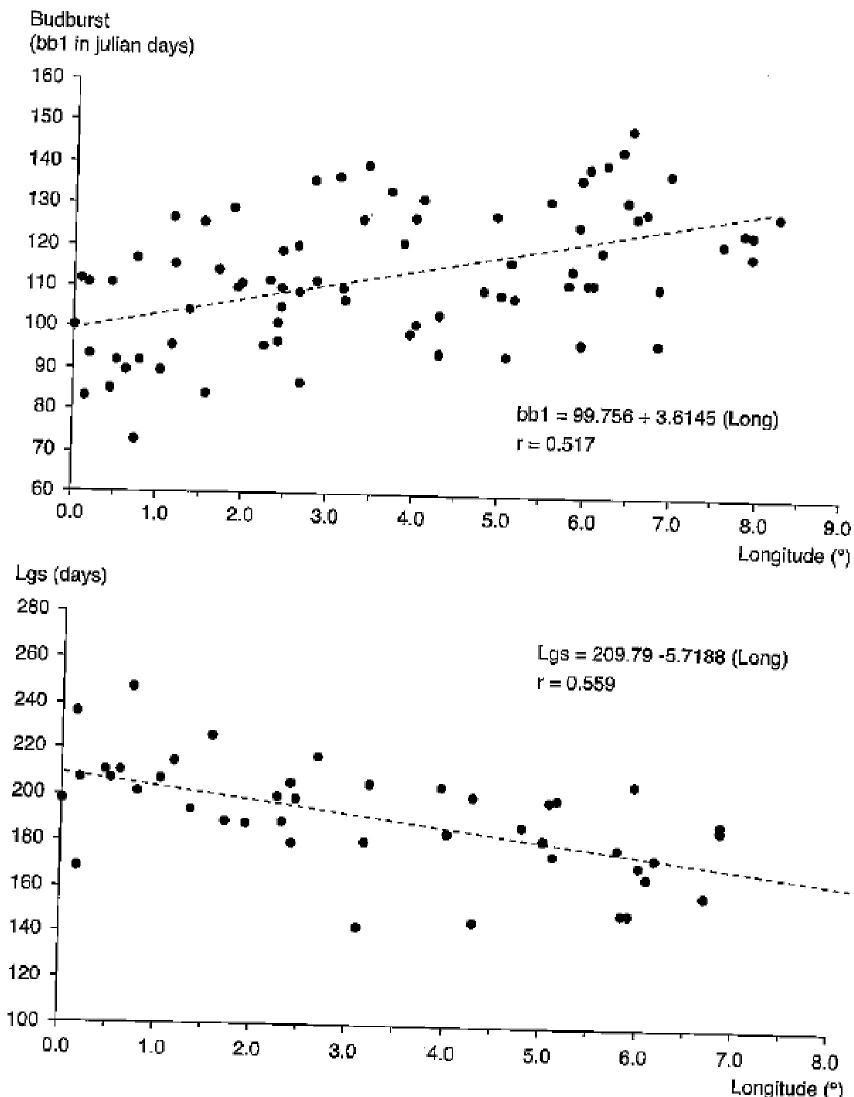

Figure 8.4. Relationship between longitude and average date of budburst (bb1: 90 stands) and length of growing season (lgs19: 48 broadleaved stands) in the French Permanent Plot Network (RENECOFOR). Means have been calculated for the period 1997–2003.

Concerning the effect of altitude, the regression equation indicates that a 100 m increase in altitude is associated with a delay in budburst and length of growing season of about 2 and 3 days, respectively (Figure 8.5). For all phenological parameters, temperature is the most important driving force for the timing of the different events. Correlations with the mean annual temperature appear highly significant (r values superior to 0.6), but the highest correlations are observed with monthly spring conditions. Thus, an increase of 1°C in March–April mean temperature corresponds with an advance of budburst by about 6 days and with an extension of the growing season by about 10 days (Figure 8.6). Analyses of autumn phases show that high maximum September–October temperatures delay the onset of leaf colouring. The response to temperature is about +3.8 days per °C ($r = 0.63$; 42 broadleaved stands).

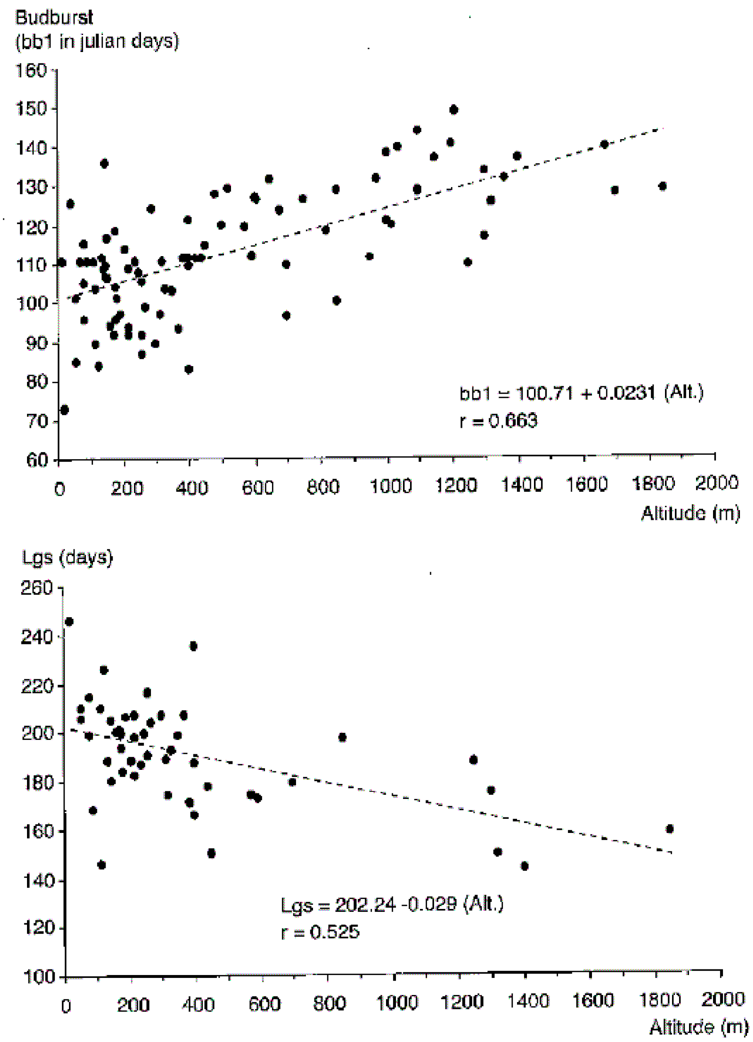

Figure 8.5. Relationship between altitude (m) and average date of budburst (bb1: 90 stands) and length of growing season (lgs19: 48 broadleaved stands) in the French Permanent Plot Network (RENECOFOR). Means have been calculated from the period 1997–2003.

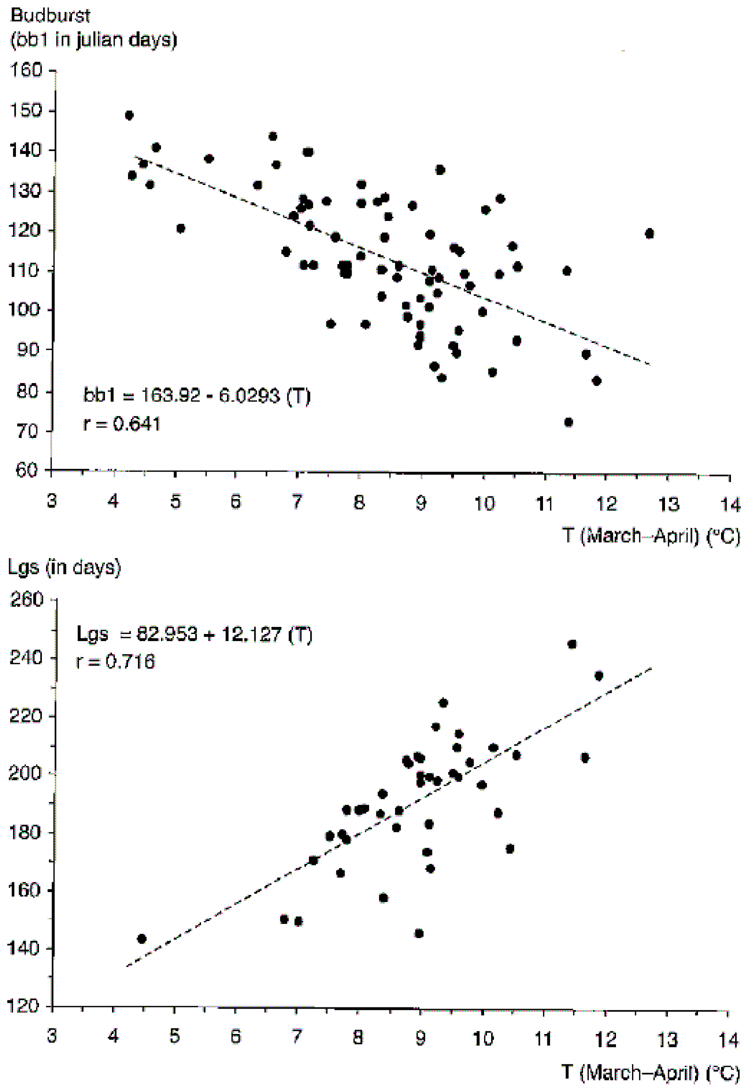

Figure 8.6. Relationship between early spring temperature and average date of budburst (bb1: 90 stands) and length of growing season (lgs19: 48 broadleaved stands) in the French Permanent Plot Network (RENECOFOR). Means have been calculated from the period 1997–2003.

Predictive models of phenological events

The different models explain between 47% and 92% of the variance depending on species and phenophases (Table 8.3 and Figure 8.7). Altitude, latitude and temperature play a major role in the timing of the growing season for the studied forests. For leaf unfolding, leaf yellowing and length of the growing season, the best adjustments have been observed for bb1, ly9 and lgs19, respectively. In all cases, the goodness of fit r^2 for leaf yellowing was always smaller. The accuracy of the models varies from 3 to 10 days according to the species and phenological parameters taken into account. For budburst (bb1), the global model explains 81% of the variance with a mean absolute error of 5.7 days. The goodness of fit is higher for broadleaved trees than for coniferous stands with values of 79.3% and 60.5%, respectively. The mean absolute error of the regressions is 5.6 days and 6.6 days, respectively. The onset of spring events is predicted with an accuracy of less than 3 days for beech and silver fir stands.

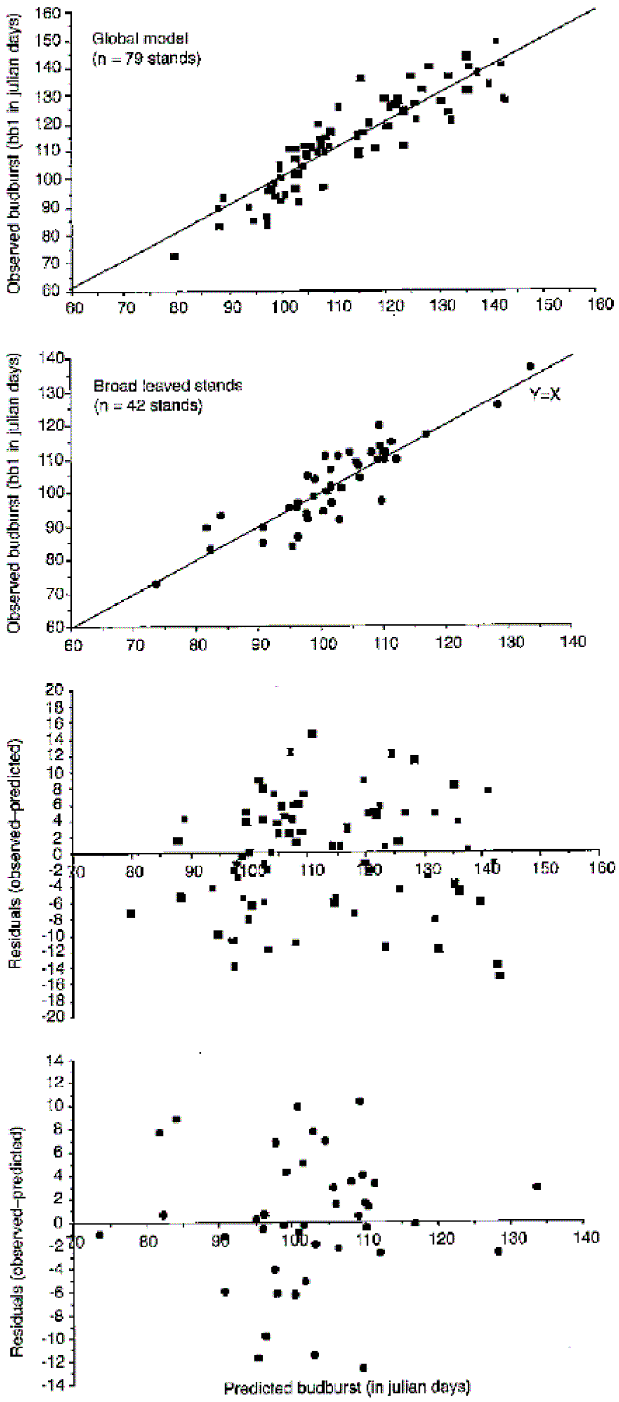

Figure 8.7. Observed and predicted dates of budburst (bb1 in julian days) (see Table 8.3 for details).

Table 8.3. Results of the multiple regression analysis of the different phenophases for each group of species. The results are derived from the means of the period 1997–2003.

Species	Phase	Intercept	Sp.	Alt.	Lat.	Long.	Annual mean	Max March	Max Sept.–Oct.	Rg Jan.	Sunshine duration Feb.	Sunshine duration Jan.–Feb.
				(m)	°	°	Temperature (°C)			(MJ·m⁻²)	(hours)	
All species (79)	bb1	– 9.87	16.071	0.021	2.638		– 1.734					
	bb9	44.09	15.544	0.017	1.728		1.574					
Broadleaved species (42)	bb1	– 60.68		0.032			– 2.394					
	ly9	235.44		– 0.011					3.464			
	lgs 19	255.25		– 0.038	– 2.595			5.707				
Fagus sylvatica (18)	bb1	– 111.77		0.032	4.881		– 2.164					
	ly9	228.44		– 0.010					3.875			
	lgs 19	312.55		0.037	4.303		8.273					
Quercus sp. (24)	bb1	– 491.24			10.779	2.466				0.020		
	ly9	423.11		– 0.054	– 2.415							
	lgs 19	1094.33			– 16.366	– 4.139				– 0.029		
Coniferous (37)	bb1	142.50		0.022							– 0.319	
Abies alba (10)	bb1	1956.89			31.977							3.68
Pinus sylvestris (10)	bb1(*)	55.81					8.238				0.937	

Table 8.3: continued.

Species	Phase	r^2	F	MAE	RMSE
All species (79)	bb1	80.6	77.0	5.7	7.1
	bb9	75.3	56.4	5.9	7.6
Broadleaved species (42)	bb1	79.3	48.6	4.3	5.6
	ly9	50.4	19.7	6.1	7.8
	lgs 19	78	45	7.5	9.8
Fagus sylvatica (18)	bb1	92.7	59.1	2.3	2.9
	ly9	47.3	6.7	7.7	9.7
	lgs 19	76.6	15.3	8.5	10.4
Quercus sp. (24)	bb1	76.8	22.01	3.9	4.7
	ly9	50.7	10.81	4.4	5.3
	lgs 19	72.4	17.49	6.2	7.6
Coniferous (37)	bb1	60.5	25.9	5.3	6.6
Abies alba (10)	bb1	91.9	39.46	1.9	2.6
Pinus sylvestris (10)	bb1(*)	55.6	4.382	4.1	6.3

bb1 and bb9: budburst; ly9: leaf yellowing; lgs19: length of the growing season (see text for details). Sp: species (code 0 for broadleaved trees; code 1 for coniferous species); m: mean temperature; x: maximum temperature; Rg: monthly sum of global solar radiation. Insol: sunshine duration. r^2: coefficient of determination. MAE and RMSE: mean absolute error and root mean square error. The number in brackets corresponds to the number of stands.
All the equations are significant at the 99.9% level excepted (**) $P < 0.01$ and (*) $P < 0.05$.

Conclusions

On average, the spring phase starts on 24 April and the growing season lasts 181 days in the French Permanent Plot Network. Our observations are in agreement with the average growing season observed in national phenological networks in Central Europe, which starts on 23 April and lasts 188 days (Chmielewski and Rötzer, 2001). Moreover, phenological events show high species and spatial variability. The growing season for oak stands in western and southern France starts at the beginning of April and lasts at least 210 days whereas the budburst of high altitude coniferous stands located in eastern France occurs in the middle of May. Compared with oak stands, the length of the growing season is reduced by about 20 days in beech forests (about 170 days). The difference of spring events averages 15 days (later leaf unfolding for beech trees at the beginning of May).

The regression models for the calculation of the different phenophases of forest stands, which are presented in this chapter, are intended to provide a simple improvement to phenological models at a large regional scale. The equations described are particularly suitable because of their low input requirements, that is, altitude, latitude and mean monthly temperature. As previously observed for Europe (Kramer, 1995a; Chmielewski and Rötzer, 2001, 2002; Rötzer and Chmielewski, 2001; Menzel *et al.*, 2003), the annual timing of spring and autumn phenophases is to a great extent a response to temperature. In the forest network, phenological events highly reflect the thermal regime in France. The mean annual temperature is a decisive parameter, but higher correlations are also often observed with the spring thermal regime (March–April for leaf unfolding) or early autumn conditions (September–October for leaf yellowing). Thus, a temperature increase of 1°C leads to an advance in leaf unfolding of 6 days, a delay in leaf colouring of 4 days and a lengthening of the growing season by 10 days. Our observations agree with observations made throughout Europe. On average, an increase by 1°C in the mean February to April temperature, T_{24}, corresponds to an advanced beginning of growing season by 6.7 days (period 1969–1998; budburst = 149.4 – 6.68 × T_{24}; r = – 0.83) (Chmielewski and Rötzer, 2001). In Germany, such an increase promotes earlier leaf unfolding by 6.4 days and 2.7 days for beech and pedunculate oak, respectively (Menzel *et al.*, 2003). In England, thermal conditions in early spring explain 70% and 50% of the leaf unfolding of pedunculate oak and beech, respectively (Sparks and Carey, 1995; Sparks and Yates, 1997). Leaf colouring in autumn seems to be a more complex process and less dependent on air temperature. The goodness of fit is largely lower than for spring phases (about 50% against 80% or more) and no significant relationship to air temperature has been observed for oak stands. Further more detailed studies are necessary. The goodness of fit and the accuracy of our models appear to be very similar to those obtained with more sophisticated models that have a complex structure or need several hourly or daily climatic input data. The MAE and the explained variance average 4.6 days and 76.7% for leaf unfolding and 7.5 days and 78% for duration of the growing season. These values are close to the MAE of 4.4–5.0 days found by Rötzer *et al.* (2004) for the daily temperature leaf unfolding models of beech, oak, pine and spruce in southern Germany. In the Netherlands, the sequential thermal model of Sarvas (1974) predicts leaf unfolding of beech with accuracy between 4 and 6 days (Kramer, 1994, 1995b).

Timing of phenological events play a major role in calibrating forest growth models (Chuine *et al.*, 1999; Kramer and Mohren, 1996; Kramer *et al.*, 1996, 2000). The impact of global warming on the extension of the growing season will depend on the extent of the change in leaf unfolding and leaf fall in the future (Menzel, 2000; Ahas *et al.*, 2002). Thus, further investigations have to be carried out to elaborate predictive models at a lower temporal scale and to analyse the interrelations on phenology and tree growth (Rötzer *et al.*, 2004). In this first step of the work, we intended only to study spatial and species variability for French forest ecosystems and to define simple phenological models usable by foresters or researchers at a large-scale with simple local variables.

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