OBSERVATIONS AND PREDICTION OF PHENOLOGICAL TRENDS IN TWO ITALIAN PHENOLOGICAL GARDENS

TREND FENOLOGICI E PREVISIONALI PER LE SPECIES PRESENTI IN DUE GIARDINI FENOLOGICI ITALIANI

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Abstract
In most climates, following dormancy, the annual timing of spring phenological events is mainly driven by temperature. Variations in phenological stages are therefore considered a valuable source of information for investigating the possible impact of climate variability and change on plant species. Recent European studies indicating changes in phenological stages in plant and animal species provide evidence that ecosystems are responding to climate change. However, most information is still scarce and limited to temperate and cold ecosystems of northern latitude. To investigate the inter-annual variability in the beginning of growing season and flowering phases in Italy, phenological data-sets (1986-2007) from two sites of the Italian Phenological Garden network were analyzed. The sites were Oristano, Sardinia, Italy (39° 53' N, 8° 37' E, 11 m above sea level) and S. Pietro Capofiume, Emilia Romagna, Italy (44° 39' N, 11° 37' E, 10 m above sea level). The gardens were established in the early 1980s following the guidelines of the International Phenological Gardens in Europe (IPG). Phenological observations were taken on Mediterranean forest species and shrubs in Sardinia, Italy and on several forest species typical of higher latitude in Emilia Romagna, Italy. Data analysis was conducted to describe the phenological behavior of native and non-native species, and to assess their sensitivity to temperature. Only one species showed earlier flowering and another had earlier bud break. In both cases, there was some evidence that the change was related to higher temperatures prior to the phenological phase. There was no trend towards earlier bud break or flowering for the other non-native or native species.

Keywords: Mediterranean species, High latitude species, Degree days, Plant development

Riassunto
I*l ritmo degli eventi fenologico primaverili delle specie arboree, una volta superata la dormienza invernale, è guidato principalmente dalle variazioni dei valori dalla temperatura dell'aria. Di conseguenza, le variazioni interannuali degli eventi fenologici rappresentano un'importante fonte di informazione per lo studio dell'impatto delle variazioni e dei cambiamenti climatici sulle specie vegetali. Recentemente, molti studi hanno reso evidente che la variazione della sequenza delle fasi del ciclo biologico di specie animali e vegetali costituisce un importante indicatore della risposta degli ecosistemi ai cambiamenti climatici in atto. Tuttavia, le ricerche in questo campo sono ancora relativamente poche, e per lo più dedicate allo studio degli ecosistemi delle più elevate latitudini. Relativamente pochi studi sono, invece, stati dedicati agli ecosistemi mediterranei. In questo lavoro sono presentati i risultati dell'analisi di due serie storiche di osservazioni fenologiche (1986-2007) relative a due stazioni sperimentali incluse nella Rete dei Giardini Fenologici Italiani: Oristano, in Sardegna, (39° 53' N, 8° 37' E, 11 m s.l.m.) e S. Pietro Capofiume, in Emilia Romagna, (44° 39' N, 11° 37' E, 10 m s.l.m.). I due Giardini Fenologici furono costituiti all'inizio degli anni ottanta secondo le norme stabilite della rete internazionale europea* International Phenological Gardens in Europe *(IPG). L'analisi ha riguardato specie mediterranee arboree e arbustive in Sardegna e specie forestali tipiche di latitudini più elevate in Emilia Romagna. Il comportamento fenologico è stato messo in relazione alla variabilità nell'andamento meteorologico con l'obiettivo di valutarne la sensibilità alle possibili variazioni climatiche. Solo per una specie è stato evidenziato un anticipo della fase di fioritura, mentre un altro caso è stato osservato un ritardo nella fase di germogliamento. In entrambi i casi, il comportamento fenologico è stato messo in relazione con i valori più elevati della temperatura dell'aria registrati nel periodo antecedente la fase fenologica. Per tutte le altre specie, non native e native, non è stato evidenziato un trend verso un anticipo dell'inizio della stagione vegetativa o della fioritura*.

***Parole chiave**: Specie mediterranee, Specie delle alte latitudini, Gradi giorno, Sviluppo delle piante*

Introduction

Phenology is the study of periodic plant and animal life cycle events and how they are influenced by environmental changes, especially seasonal variations in temperature and precipitation driven by weather and climate (Schwartz, 2003). Examples include studies on the timing of leafing and flowering of plants, agricultural crop stages, insect emergence, and animal migration. All of these events are sensitive environmental integrators, which are important for both scientific and practical applications. Thus, phenological models can be used as predictors of ecological changes related to agricultural production, drought monitoring, wildfire risk assessment, and in the management of pests (Betancourt *et al.* 2007). Moreover, variations in phenological stages are a valuable source of information for investigating the possible impact of climate change on plant species (Chmielewsky and Rötzer 2002).

Recent studies indicating changes in phenological stages in plant and animal species provide evidence that ecosystems are responding to climate change (Menzel 2000; Wolfe *et al.* 2005, Menzel *et al.* 2006). Many research projects were conducted to assess local and regional changes in phenology of plant and animal species throughout Europe (Ahas and Aasa 2006; Chmielewsky and Rötzer 2002; Menzel et al 2006), North America (Wolfe *et al.* 2005, Bradley et al 1999), and Asia (Ho *et al.* 2006; Zheng *et al.* 2002). Although changes in phenophase timing of crops and fruit trees potentially has large economical importance, the relationship between climate warming and responses of crops and fruit trees is less well known (Chmielewsky *et al.* 2004, Estrella *et al.*, 2007).

National networks of integrated phenological observations and tools to analyse them at multiple scales provide valuable phenological records, so maintenance of the observation networks has become a higher priority. Long-term phenological monitoring, over a wide range of latitudes and elevations, is an essential component of earth observation programs and global change monitoring. Moreover, the actual timing of phenological events is also of importance for other issues in education, agriculture, human health, tourism and recreation, bio-diversity and ecology education (Bruns *et al.*, 2003). For example, the International Phenological Gardens (IPG) network of Europe was established in 1957 by F. Schnelle and E. Volkert with the aim of obtaining comparable data by observing genetically identical plants of different trees and bushes throughout Europe (Chmielewski, 1996).

Phenological trends at high latitude sites were reported in several papers. In Ireland, a 30-year dataset of phenological observations was analyzed to determine the beginning and the end of the growing season for *Tilia cordata* in relation to air temperature. This illustrated the sensitivity of *Tilia* as a climate change indicator (Donnelly *et al.* 2006). Recently, Menzel *et al.* (2006) conducted a study on a phenological network dataset relative to 542 plant species in 21 European countries for the period 1971-2000. This was an early attempt to report a regional scale meta-analysis on the effects of global warming on the onset of spring phenological events and lengthening of the growing season for mid- and high-latitude locations. The results showed that 78% of leafing, flowering, and fruiting phases were significantly advanced and only 3% were delayed, whereas no defined behavior was observed for fall phenological phases. This study demonstrated that species' phenology was responsive to temperature of the preceding months in the winter and spring. Moreover, the pattern of observed springtime changes matched the warming trends recorded across European countries.

Although much evidence on the effects of climate change on ecosystems is available for northern latitudes, less information was reported for Mediterranean and semi-arid ecosystems (Penuelas *et al.* 2002; Spano *et al.* 1999). Therefore, this study was conducted to investigate the phenological behavior of some Mediterranean and higher latitude species that were planted in two phenological gardens located at different latitudes within Italy and the variability in phenophase occurrence between 1986 and 2007.

Materials and methods

The experimental sites are located in Oristano, Sardinia, Italy (39° 53' N, 8° 37' E, 11 m above sea level) and S. Pietro Capofiume, Emilia Romagna, Italy (44° 39' N, 11° 37' E, 10 m above sea level). In the Oristano phenological garden, the soil is alluvial, sub–alkaline with sand predominating in the first 0.3-m layer and sand–clay in the 0.3–0.6-m layer. The mean annual rainfall is about 581 mm with a large water deficit from May to September. The average annual air temperature is about 17°C. The range of mean maximum and minimum air temperature is small because of proximity to the sea. The winter season can be dry or wet with mild temperatures that are not low enough to cause plant dormancy. Wind directions are typically from the sea (West) or land (East).

In the San Pietro Capofiume phenological garden, the soil is clay-loam, with high pH. The climate is near-continental with some influence from the Adriatic Sea. The area is often foggy with thermal inversion during winter and early spring. Summers are hot and humid. Mean annual rainfall is about 600 mm with two main rainy periods in April and October.

Both gardens were set up in the early 1980s following guidelines of the International Phenological Gardens in Europe (IPG). Phenological observations were taken on forest species and Mediterranean shrubs in Sardinia and on several forest species, which are typical of higher latitudes, in Emilia Romagna using the BBCH scale system (Meier, 1997). The Oristano species included *Pistacia lentiscus*, *Olea europea*, *Myrtus communis*, *Quercus ilex*, *Spartium junceum*, *Robinia pseudoacacia*, *Cercis siliquastrum*, *Salix chrysocoma*, *Tilia cordata*, *Populus tremula*, *Celtis australis*. The S.Pietro Capofiume species were *Salix smithiana*, *Salix viminalis*, *Ligustrum vulgare*, *Corylus avellana*, *Cornus mas*, *Cornus sanguinea*, *Quercus robur*, *Fagus sylvatica*, *Laburnum anagyroides*, *Crataegus monogyna*, *Prunus psinosa*, *Prunus avium*, *Spartium junceum, Robinia pseudoacacia, Tilia cordata*.

Tab. 1 - Mean and extreme phenological stage dates by species in Oristano (n = number of recorded years).
Tab. 1 - *Date medie, tardive e precoci delle principali fasi fenologiche osservate per le specie presenti nel sito di Oristano (n = numero di anni di osservazione).*

	n	Mean Date	Earliest	Latest
Bud Break				
Salix chrysocoma (Willow)	14	15 Mar	23 Feb (1989)	10 May (1996)
Robinia pseudoacacia (False Acacia)	19	01 Apr	17 Mar (2002)	22 Apr (1993)
Cercis siliquastrum (Judas Tree)	18	04 Apr	02 Mar (1989)	20 Jun (1991)
Olea europea (Olive)	13	07 Apr	15 Mar (1996)	24 Apr (2007)
Spartium junceum (Spanish Broom)	6	06 Apr	23 Mar (1994)	22 Apr (1993)
Pistacia lentiscus (Lentisc)	18	17 Apr	14 Mar (1995)	31 May (2005)
Tilia cordata (Lime)	18	10 Apr	27 Mar (1997-98)	21 Apr (2005)
Myrtus communis (Myrtle)	17	22 Apr	30 Mar (1994)	10 Jun (1987)
Quercus ilex (Holm oak)	13	28 Apr	8 Apr (2006)	20 May (1995)
Flowering				
Salix chrysocoma	11	02 Apr	06 Mar (1989)	01 Jun (1996)
Cercis siliquastrum	17	08 Apr	26 Mar (1990)	29 Apr (2005)
Pistacia lentiscus	16	17 Apr	28 Mar (1990)	04 May (1994)
Spartium junceum	5	27 Apr	13 Apr (1994)	21 May (1992)
Robinia pseudoacacia	19	25 Apr	5 Apr (2006)	09 May (1992)
Olea europea	13	08 May	17 Apr (2001)	26 May (1999)
Quercus ilex	13	7 May	21 Apr (1999)	5 Jun (1995)
Tilia cordata	16	19 May	16 Apr (1996)	17 Jun (2004)
Myrtus communis	19	14 Jun	31 May (1999)	26 Jun (1991)

Tab. 2 - Mean and extreme phenological stage dates by species in S.Pietro Capofiume (n = number of recorded years).
Tab. 2 - *Date medie, tardive e precoci delle principali fasi fenologiche osservate per le specie presenti nel sito di S.Pietro Capofiume (n = numero di anni di osservazione).*

	n	Mean Date	Earliest	Latest
Bud Break				
Prunus avium (Wild Cherry)	14	22 Mar	02 Mar (2006)	06 Apr (1996)
Robinia pseudoacacia	14	12 Apr	28 Mar (1997)	24 Apr (1998)
Spartium junceum (Spanish Broom)	14	04 Apr	16 Mar (2006)	23 Apr (1996)
Tilia cordata (Lime)	14	11 Apr	01 Apr (2004)	18 Apr (1996)
Flowering				
Prunus avium	18	06 Apr	22 Mar (2002)	21 Apr (2005)
Robinia pseudoacacia	18	05 May	13 Apr (2006)	26 May (1995)
Spartium junceum	18	14 May	22 Apr (2004)	01 Jun (2006)
Tilia cordata	18	05 Jun	20 May (2004)	16 Jun (1995)

Meteorological variables were recorded by a weather station located in the phenological Garden sites. Maximum and minimum air temperature values were used to calculate cumulative degree-days (CDD) from 1 January using a temperature threshold of 0°C. The CDD were calculated using the TM Model (Cesaraccio *et al.* 2001), which uses daily maximum and minimum air temperature to estimate hourly temperature and degree hours. The degree hours are summed over a day to calculate degree days and the daily values are accumulated to obtain CDD. The Cesaraccio *et al.* (2001) method provides good accuracy for CDD calculations. The analysis was done separately for native and non-native species to assess differences.

Results and discussion

Mean and extreme phenological dates for some of the species are reported in Tab. 1 and 2. The mean dates of bud break occurred between 15 March and 28 April in Oristano, with a greater range for the non-native species (*Cercis siliquastrum* and *Salix chrysocoma*), and between 22 March and 12 April in S.Pietro Capofiume, with a greater range for *Spartium*. The mean flowering dates were between 4 days (*Cercis siliquastrum*) to 54 days (*Myrtus communis*) after the mean bud break dates. Again, *Salix chrysocoma* showed the widest range in flowering date occurrence (about 90 days) and *Myrtus communis* the lowest range (27 days) in Oristano. Flowering dates occurred between 15 (*Prunus avium*) and 55

Tab. 3 - Predicted and observed flowering dates (day of the year or doy) and cumulative degree day (CDD) values starting from 1 January by species in Oristano for an earlier (1986-96) and a later (1997-2007) time period. Means, standard deviations (σ), coefficients of variation (CV), and root mean square errors (RMSE) are reported.

Tab. 3 - *Date di fioritura previste e osservate e relativi gradi-giorno cumulati dal 1 gennaio per le specie presenti nel sito di Oristano per i periodi 1986-1996 e 1997-2007. Sono riportati i valori della media, della deviazione standard (σ), del coefficiente di variazione (CV) e del Root Mean Square Error (RMSE).*

Species	Statistic	1986-1996			1997-2007		
		Pred (doy)	Obs (doy)	CDD	Pred (doy)	Obs (doy)	CDD
Cercis	**mean**	100	98	1001	104	101	1286
	σ	8	9	152	8	11	397
	CV(%)	8	9	15	8	11	31
	RMSE	11			9		
Tilia	**mean**	147	143	1705	141	137	1776
	σ	6	24	417	6	15	293
	CV(%)	4	16	24	5	11	16
	RMSE	21			16		
Robinia	**mean**	122	120	1284	119	111	1415
	σ	8	8	125	7	7	303
	CV(%)	7	6	10	6	7	21
	RMSE	8			14		
Myrtus	**mean**	171	168	2177	163	166	2215
	σ	9	6	168	7	9	302
	CV(%)	5	4	8	4	5	14
	RMSE	8			9		
Pistacia	**mean**	112	108	1156	114	109	1429
	σ	6	12	204	7	7	342
	CV(%)	6	11	18	6	7	24
	RMSE	15			11		
Olea	**mean**	135	129	1438	130	130	1618
	σ	7	10	216	7	13	280
	CV(%)	5	8	15	5	10	17
	RMSE	16			12		
Quercus	**mean**	134	135	1540	130	123	1511
	σ	7	14	236	7	6	278
	CV(%)	5	10	15	5	5	18
	RMSE	14			11		

(*Tilia cordata*) days after bud break in S.Pietro Capofiume.

In Tab. 3, observed CDD values and predicted and observed flowering dates at the Oristano garden are reported for several species for two observation periods (1986-1996 and 1997-2007). The observed CDD values between January 1 and the flowering dates varied between species and increased from the 1986-1996 to the 1997-2007 period for all species but *Quercus*. Earlier mean flowering dates, however, were observed only for *Tilia, Robinia*, and *Quercus*. Except for *Quercus*, the Mediterranean species showed little variation in observed dates of flowering for the two periods. In comparison with Oristano, the mean heat accumulation was less (i.e., lower CDD) in S. Pietro Capofiume for flowering of *Robinia* and *Tilia*, but the respective flowering dates occurred about 7 and 15 days later in S. Pietro Capofiume (Tab. 3 and 4).

Linear trends of bud break and flowering dates observed in the Oristano garden are reported by species in Tab. 5. For *Salix*, a non-native species, a positive trend in bud break date versus year was observed. The trend line showed an increase from about doy = 60 to 90 over a 14 year period. Another positive trend line was found for *Pistacia*, which is a native species. The trend line of doy versus year increased from about 90 to 130 days over an 18 year period. Both *Myrtus* and *Quercus*, native species, showed negative trends for doy versus year. *Myrtus* decreased the doy from about 130 to 100 days over 17 years, and *Quercus* decreased from about 130 to 90 days over 13 years between January 1 and bud break. No significant relationship between flowering date and year was found for any species but Robinia. The linear trend in doy decreased from about 125 to 105 days over a 19 year period.

Tab. 6 shows the regression equations and statistics for the number of degree days per day (CDD/DOY) observed in Oristano versus year for the corresponding species with signicant trend in bud break and flowering dates. A significant positive trend of the CDD/DOY versus year was found only for the non-native species *Robinia*, where the CDD were calculated from January 1 to the flowering date and DOY is the corresponding number of days. The trend of the ratio CDD/DOY, which is a measure of the heat units available prior to flowering, increased from about 9 to 14 over 19 year period. A positive trend in CDD/DOY versus year was observed for the corresponding bud break date for the native species *Quercus*. The trend line showed an increase from about 11 to 15 over a 14 year period. The only species to show earlier flowering was *Robinia* and the only species to show earlier bud break was *Quercus*. The earlier flowering and bud break were likely to be at least partially due to an increased number of degree day over the observed period. There was no trend towards earlier bud break or flowering for the other non-native or native species. Most likely other factors, in addition to temperature, played an important role in determining the occurrence of phenological stages. Moreover, other studies (Scheifinger *et al.*, 2002; Chmiele-wsky and Rötzer, 2002) showed that a di-scontinuity in phenological and temperature time series behavior were recognized in Europe in the late 1980s, which was not detected in this study, probably because of the shortness of the analyzed time series and the fact that this discontinuity might be effective in a previous period.

The predicted flowering dates were estimated using the CDD model (Cesaraccio *et al.*, 2001), and the root mean square error (RMSE) between predicted and observed flowering dates were calculated over the years of record. The RMSE values varied largely with species at both sites, but generally the RMSE was approximately 10% of the observed dates (Tab. 3 and 4).

Conclusions

The data presented in this paper show that there is not a clear signal of advancing bud break or flowering for the species grown in the two gardens during the period of record. Although the cumulative degree days from January 1 to the phenological phases were higher in the most recent decade, other factors (rainfall, soil moisture, extreme events, etc.) in addition to warmer temperatures could be affecting phenological behavior in the Mediterranean climate. This might not be the case in more humid climates where water is less limiting.

Tab. 4 - Predicted and observed flowering dates (day of the year or doy) and cumulative degree day (CDD) values starting from 1 January by species in S. Pietro Capofiume. Means, standard deviations (σ), coefficients of variation (CV), and root mean square errors (RMSE) are reported.

Tab. 4 - Date di fioritura previste e osservate e relativi gradi-giorno cumulati dal 1 gennaio per le specie di S.Pietro Capofiume. Sono riportati i valori della media, della deviazione standard (σ), del coefficiente di variazione (CV) e del Root Mean Square Error (RMSE).

		1990-2007		
Species	**Statistic**	**Pred (doy)**	**Obs (doy)**	**CDD**
Prunus	**mean**	95	95	561
	σ	8	10	89
	CV(%)	9	10	16
	RMSE	8		
Robinia	**mean**	127	126	975
	σ	5	11	211
	CV(%)	4	9	22
	RMSE	12		
Tilia	**mean**	157	156	1538
	σ	10	8	159
	CV(%)	6	5	10
	RMSE	8		
Spartium	**mean**	137	136	1150
	σ	5	14	234
	CV(%)	4	10	20
	RMSE	12		

Tab. 5 - Least square regression equations and statistics for the day of the year for bud break and flowering versus year in Oristano.

Tab. 5 - *Regressioni e significatività dei trend per le date di germogliamento e fioritura osservate nel Giardino di Oristano.*

Species	Bud Break		Flowering	
Salix chrysocoma	y = 2.25x + 57.95	*	y = 2.52x + 77.71	ns
Robinia pseudoacacia	y = 0.0082x + 92.44	ns	y = -0.84x + 125.22	***
Cercis siliquastrum	y = 0.26x + 92.86	ns	y = 0.43x + 94.70	ns
Tilia cordata	y = 0.00x + 101.22	ns	y = -1.36x + 157.08	ns
Olea europea	y = 0.57x + 92.89	ns	y = 0.00x + 129.19	ns
Spartium junceum	y = -5.00x + 108.67	ns	y = -1.20x + 121.40	ns
Pistacia lentiscus	y = 1.96x + 89.26	***	y = 0.12x + 106.98	ns
Myrtus communis	y = -2.29x + 135.93	***	y = -0.23x + 169.09	ns
Quercus ilex	y = -1.59x + 132.12	**	y = -0.86x + 135.55	ns

Tab. 6 - Least square regression equations and statistics for the average number of degree-day per day (CDD/DOY) for bud break and flowering versus year for species that show significant trends in Tab. 5.

Tab. 6 - *Regressioni e significatitá dei trend per il numero di gradi-giorno per giorno (CDD/DOY) per le specie con trend statisticamente significativo nella Tab. 5.*

Species	Bud Break		Flowering	
Salix chrysocoma	y = - 0.15x + 307.15	ns		
Robinia pseudoacacia			y = 0.21x - 413.57	**
Tilia cordata			y = 0.09x - 175.85	ns
Pistacia lentiscus	y = 0.05x - 75.10	ns		
Myrtus communis	y = 0.14x - 255.82	ns		
Quercus ilex	y = 0.25x – 481.86	**		

* P<0.10 ** P<0.05 *** P<0.01

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