The use of a flowering stability index for bioclimatic research

C.A. Cenci **, A.M. Olivieri *, G.Bassi **

** Dipartimento di Produzione Vegetale e Tecnologie Agrarie, Università di Udine*
*** Cattedra di Botanica Sistematica, Università di Udine,*
Dipartimento di Biologia ed Economia Agroindustriale
via Cotonificio 108, 33100 Udine (Italia) Fax 0039 432 558784

Abstract. – Finlay and Wilkinson analysis was used to study the stability, over 21 years, of the beginning of flowering of 53 species. This approach allows to study the behaviour of a single species in respect to the average behaviour of all species. Twenty-one out of 25 docile species are sensitive, while the remaining 4 are docile (their beginning of flowering time was relatively constant). The 28 recalcitrant species are characterized by unpredictability in the beginning of flowering time.

Key words – Phenology, wild vegetation, flowering forecasting.

Introduction

An early awareness of the phenological phases of plant species is of great assistance in various sectors of human activity: agriculture (use of pesticide, choice of crops), public health (allergies), tourism and environment (monitoring and creation of both local and global ecological and climatological models) (Puppi Branzi, 1993; Lieth, 1994).

Phenological research, starting with data which indicate the single phases of the development of individual plants in space and time, has as its main objective the creation of suitable prediction models.

Mathematical prediction models can be distinguished as «phenological» or «phenoclimatic». The former require long series of phenological data to identify the «marker species» (White, 1979; Marletto and Sirotti, 1993). In contrast, «phenoclimatic» models are based on the assumed dependency relationships of the phenological phases on the various climatic variables (White, 1979; Castonguay *et al.* 1984; Oger and Glibert, 1989; Marletto *et al.*, 1992; Cenci *et al.*, 1995).

The phenological stage most often considered is probably flowering because of all the stages it is the easiest to record and it is highly suitable for ecological and physiological interpretations. The environmental conditions during the plant's

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flowering period and the sensitivity of these to variations often have a considerable impact on the final yield of a crop; one example of this is the fact that the quantity of pollen liberated into the atmosphere during the flowering period of certain crops is a good indicator of the potential yield (Vossen, 1994).

In plants the flowering period is determined by the interaction between genetic factors in the species and environmental factors in the zone in which the plant performs its life cycle. The interaction of these factors, comprising components which are not always known, manifests itself in the considerable between-year variability of the flowering period for each species, with a consequent difficulty in its prediction.

The aim of this work was the identification of species whose flowering period is stable in relation to the environment in which it undergoes its life cycle. Finlay and Wilkinson (1963) analysis was used to evaluate the progress of different varieties of barley with changing environment, taken to be the combination of the pedoclimatic characteristics and the antropic factors. Without measuring the different environmental components, the «environment» was expressed with a «biological» value calculated, in this case, from the mean flowering dates for each year for the species considered. The relationship between the behaviour of an individual species and the environmental component expressed in these terms will provide, for the antesic phase, a useful «index» for the genotype-environment interaction (Bassi *et al.*, 1995).

The intention was to perform a preliminary evaluation of this methodology to establish whether it will be possible to use it for monitoring ecological and climatological changes.

Material and Methods

The entire data set of the beginning of flowering for 53 species recorded by Prof. Montelucci† (1899-1983) at Guidonia (near Rome, 42° N lat) for 21 consecutive years were used. The data, expressed as the number of days from the 1st January for each year from 1960 to 1980, were analysed with the Finlay and Wilkinson (1963) method, which calculates the linear regression for each species on the mean date of flowering for the different years. This analysis was performed with Costat 4.0 software (CoHort software).

The linear regression may or may not be significant and supplies a regression line of the form $Y = a + bx$, defined with two parameters :

1) «a», the intercept on the y axis, which indicates the mean value of the beginning of flowering;

2) «b», the angular coefficient for the line, which is used as a «stability index» of the flowering in relation to the general behaviour.

The species whose behaviour can be predicted in relation to the mean of all the species (linear regression statistically significant at $P \leq 0{,}05$) will be defined as docile in this paper while those whose beginning of flowering is not correlated with the average behaviour over the years, that is to say not predictable, will be labelled recalcitrant (regression not significant).

The docile species were further divided into two classes: unstable (or sensitive) when the angular coefficient was greater than one and stable when «b» was less than one.

It can be demonstrated that the mean of the angular coefficients for all the species was equal to unity.

RESULTS

The parameters from the Finlay and Wilkinson analysis, together with the salient data relative to the beginning of flowering for the 53 species considered are reported in table 1, together with the code which identifies the biological form according to Pignatti (1982).

As can be seen in table 1, the value «a», which indicates the mean precocity of the beginning of flowering, varied from 11.4 (that is, the 11th January) for *Galanthus nivalis* to 291.5 (19th October) for *Eryobotrya japonica*, with a mean of 107.7. The angular coefficient «b» varied from -0.22 in *Galanthus nivalis* to 2.14 for *Crepis sancta*. The negative «b» value (precocity in flowering for *Galanthus nivalis* inversely proportional to the general mean trend) was, in this case, only an apparent effect as the regression was not significant.

Almost half the species (25 of 53) were classified as docile as the regression was statistically significant and, of these, only the species *Rubus ulmifolius, Ornithogalum umbellatum, Carduus pycnocephalus* and *Ligustrum vulgare* were stable as the angular coefficient recorded was less than unity (Tab. 1). The stability of these species is due to the fact that, although being significantly correlated with the general mean, their flowering was relatively constant compared with all the others when evaluated in the 21 year period considered.

In contrast, the behaviour of the species *Crepis sancta, Pinus halepensis, Vicia sativa, Phlomis fruticosa, Plantago lanceolata, Silene alba* and *Laurus nobilis* was very unstable, as, for each variation of the general mean for the year in question, the date of flowering changed by a factor greater than one (from 2.14 to 1.75 times for the species mentioned above). These species, classified as unstable docile or sensitive, amplified the environmental variations for the year.

The behaviour of 28 species defined as recalcitrant was unpredictable as their regression coefficients were not significant. These species often had a low value of «b».

Figures 1, 2 and 3 show the behaviour of the three classes of species classified as stable docile, unstable docile (or «sensitive») or recalcitrant. It should be noted that the scale of the X and Y axes is different, so that the mean of the regressions does not appear to be bisecting. The dispersion of the points around the regression line (dotted lines) and the relative gradient of the latter in comparison with the line with a gradient equal to unity (bisector, marked in bold type) are clearly visible.

These means had values will oscillated from 100.7 (1977 season) to 114. 4 (1980 season) with an average value of 107.7 (18 April).

Figure 4 presents the trends of the means of the flowering dates for the 21 years studied. The trends relating to the docile and recalcitrant species are very different. In particular, the reasonable degree of uniformity for the recalcitrant species can be noted. The trend recorded for the docile types can be related, particularly in the last phase, two a ten-year cycle similar to that of the sun.

TABLE 1

CODE OF LIFE-GROWTH FORMS (1), PARAMETERS FROM FINLAY & WILKINSON ANALYSIS AND BEGINNING OF FLOWERING DATE FOR 53 SPECIES OBSERVED FOR 21 YEARS AT GUIDONIA (ROME)

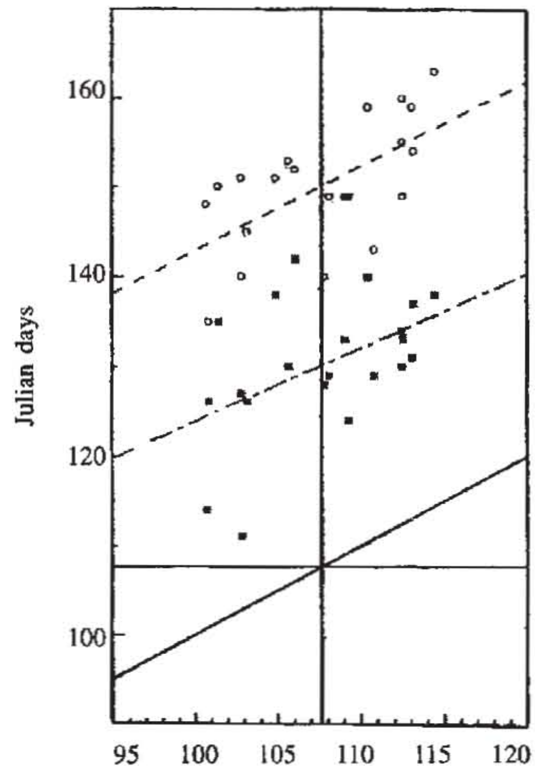
Family	Species	Code	«a»	«b»	R^2	Signif.	Mean date	Max. date	Min. date	Diffe-rence	D.S.
Amarylidaceae	*Gamanthus nivalis* L.	42	11,4	–0,22	0,008	ns	11-01	14-02	29-12	48	11,02
Cruciferae	*Cardamine hirsuta* L.	13	27,0	1,23	0,157	ns	27-01	19-02	21-12	61	14,14
Papaveraceae	*Fumaria officinalis* L.	13	27,1	0,76	0,010	ns	27-01	2-04	6-11	148	34,70
Ulmaceae	*Ulmus minor* Miller	72	32,2	0,43	0,055	ns	1-02	12-02	9-01	34	8,26
Ranunculaceae	*Ranunculus ficaria* L.	42	35,0	0,89	0,117	ns	4-02	19-02	3-01	47	11,76
Euphorbiaceae	*Euphorbia helioscopia* L.	13	35,3	1,38	0,110	ns	4-02	7-03	1-01	65	18,88
Compositae	*Crepis sancta* (L.) Babcock	13	52,8	2,14	0,288	*	22-02	19-03	13-01	65	18,12
Buxaceae	*Buxus sempervirens* L.	71	53,7	0,22	0,011	ns	23-02	9-03	27-01	41	9,35
Rosaceae	*Prunus pissardii* (Carriére)	72	54,5	1,11	0,163	ns	23-02	13-03	1-02	40	12-50
Rosaceae	*Prunus spinosa* L.	72	56,8	1,07	0,194	*	26-02	27-03	7-02	48	11,08
Rosaceae	*Prunus persica* (L.) Batsch	72	63,2	0,56	0,095	ns	4-03	21-03	21-02	28	8,24
Rhamnaceae	*Rhamnus alaternus* L.	72	65,2	1,49	0,320	**	6-03	28-03	16-02	40	11,93
Ranunculaceae	*Anemone apennina* L.	43	67,6	1,09	0,230	*	9-03	27-03	7-02	48	10,27
Aceraceae	*Acer negundo* L.	73	70,0	1,04	0,266	*	11-03	22-03	22-02	28	9,19
Oleaceae	*Forsythia viridissima* Lindl.	72	71,4	1,04	0,324	**	12-03	27-03	26-02	29	8,29
Liliaceae	*Ornithogalum umbellatum* L.	42	71,6	0,95	0,283	*	13-03	28-03	22-02	34	8,07
Liliaceae	*Muscari neglectum* Guss. ex Ten.	42	71,9	1,06	0,401	**	13-03	24-03	28-02	24	7,61
Plantaginaceae	*Plantago lanceolata* L.	54	72,4	1,94	0,688	***	13-03	4-04	21-02	42	10,60
Umbelliferae	*Tordilium apulum* L.	13	77,6	1,47	0,213	*	19-03	12-04	13-02	58	14,48
Pinaceae	*Pinus halepensis* Miller	73	78,0	2,06	0,607	***	19-03	8-04	20-02	47	11,98
Lauraceae	*Laurus nobilis* L.	72	80,4	1,75	0,578	***	21-03	7-04	2-03	36	10,46
Boraginaceae	*Borago officinalis* L.	13	80,8	1,60	0,350	**	22-03	8-04	22-02	45	12,26
Leguminosae	*Cercis siliquastrum* L.	73	91,4	0,26	0,009	ns	1-04	4-05	4-03	61	12,46
Oleaceae	*Syringa vulgaris* L.	72	96,0	1,20	0,470	***	6-04	19-04	24-03	26	7,93
Compositae	*Crepis vesicaria* L.	13	100,6	1,34	0,447	***	11-04	26-04	22-03	35	9,07
Gramineae	*Hordeum murinum* L.	13	100,8	1,68	0,417	**	11-04	25-04	4-03	52	11,84
Leguminosae	*Vicia sativa* L.	13	103,0	2,05	0,661	***	13-04	29-04	21-03	39	11,47

TABLE 1 (concluded)

Family	Species	Code	«a»	«b»	R^2	Signif.	Mean date	Max. date	Min. date	Diffe-rence	D.S.
Labiatae	*Phlomis fruticosa* L.	71	104,0	2,04	0,456	***	14-04	4-05	20-03	45	13,68
Papaveraceae	*Papaver rhoeas* L.	13	104,9	0,88	0,175	ns	15-04	4-05	27-03	38	9,51
Leguminosae	*Trifolium campestre* Schreber in Sturm	13	108,4	1,59	0,702	***	18-04	3-05	3-04	30	8,59
Hydrangaceae	*Philadelphus coronarius* L.	71	115,3	0,62	0,122	ns	25-04	7-05	2-04	35	8,01
Caryophyllaceae	*Silene alba* (Miller) E.H.L. Krause in Sturm	55	116,1	1,79	0,317	**	26-04	14-05	25-03	50	14,40
Gramineae	*Avena sterilis* L.	13	118,1	0,48	0,082	ns	28-04	11-05	17-04	24	7,59
Leguminosae	*Robinia pseudacacia* L.	72	118,3	1,35	0,545	***	28-04	9-05	10-04	29	8,32
Gramineae	*Poa trivialis* L.	51	120,9	0,59	0,150	ns	1-05	12-05	15-04	27	6,86
Leguminosae	*Lathyrus annuus* L.	13	121,7	0,52	0,124	ns	2-05	17-05	15-04	32	6,74
Compositae	*Carduus pycnocephalus* L.	55	127,5	0,94	0,248	*	7-05	20-05	20-04	30	8,61
Oleaceae	*Ligustrum vulgare* L.	71	130,2	0,82	0,236	*	10-05	22-05	21-04	31	7,68
Gramineae	*Dactylis glomerata* L.	51	140,2	0,34	0,091	ns	20-05	26-05	6-05	20	5,06
Rhamnaceae	*Paliurus spina-christi* Miller	72	142,9	0,55	0,179	ns	23-05	31-05	9-05	22	5,93
Compositae	*Coleostephus myconis* (L.) Reichenb.	13	143,7	1,28	0,282	*	24-05	14-06	2-05	43	10,94
Campanulaceae	*Campanula erinus* L.	13	144,6	0,57	0,061	ns	25-05	10-06	25-04	46	10,54
Punicaceae	*Punica granatum* L.	73	147,2	0,88	0,080	ns	27-05	1-07	5-05	57	14,12
Gramineae	*Gaudinia fragilis* (L.) Beauv.	13	147,8	0,08	0,003	ns	28-05	11-06	17-05	25	6,32
Rosaceae	*Rubus ulmifolius* L.	71	150,2	0,95	0,377	**	30-05	12-06	15-05	28	7,05
Guttiferae	*Hypericum perforatum* L.	53	152,3	0,49	0,069	ns	1-06	20-06	16-05	35	8,38
Dipsacaceae	*Scabiosa maritima* L.	55	157,7	0,43	0,153	ns	7-06	21-06	30-05	22	5,03
Scrophulariaceae	*Verbascum blattaria* L.	55	164,8	0,58	0,065	ns	14-06	4-07	28-05	37	10,34
Scrophulariaceae	*Verbascum sinuatum* L.	55	174,1	0,57	0,106	ns	23-06	11-07	3-06	38	7,97
Liliaceae	*Asparagus acutifolius* L.	43	234,2	0,81	0,037	ns	22-08	19-09	14-07	67	19,06
Primulaceae	*Cyclamen hederifolium* Aiton	42	237,6	0,75	0,107	ns	26-08	20-09	3-08	48	10,48
Compositae	*Dittrichia viscosa* (L.) W. Grenter	53	247,4	0,83	0,095	ns	4-09	23-09	12-08	42	12,23
Rosaceae	*Eryobotrya japonica* (Thunb) Lindley	73	291,5	0,70	0,031	ns	18-10	30-11	27-09	64	18,03

(1) Code = Code of life-growth forms: 13 = T scap; 42 = G bulb; 43 = G rhiz; 51 = H caesp; 53 = H scap; 54 = H scap; 54 = H ros; 55 = H blenn; 71 = NP; 72 = caesp; 73 = P scap; (Pignatti, 1982)
ns: not significant; *: P≤0,05; **: P≤0,01; ***: P≤0,001

Stability index
Example of two STABLE DOCILE species

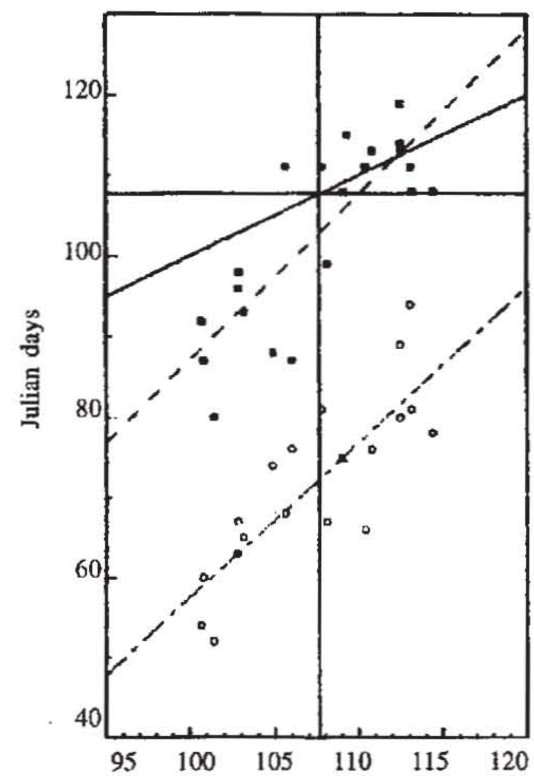


Year mean

— 107.7 (mean of the 53 species)
-·- 130.2 + 0.82 × *Ligustrum vulgare* L.
-- 150.2 + 0.95 × *Rubus ulmifolius* Schott
° *Rubus ulmifolius* Schott
* *Ligustrum vulgare* L.

Fig. 1 – Linear regression for two stable docil species (c.a. <1) according to the Finlay & Wilkinson analysis.

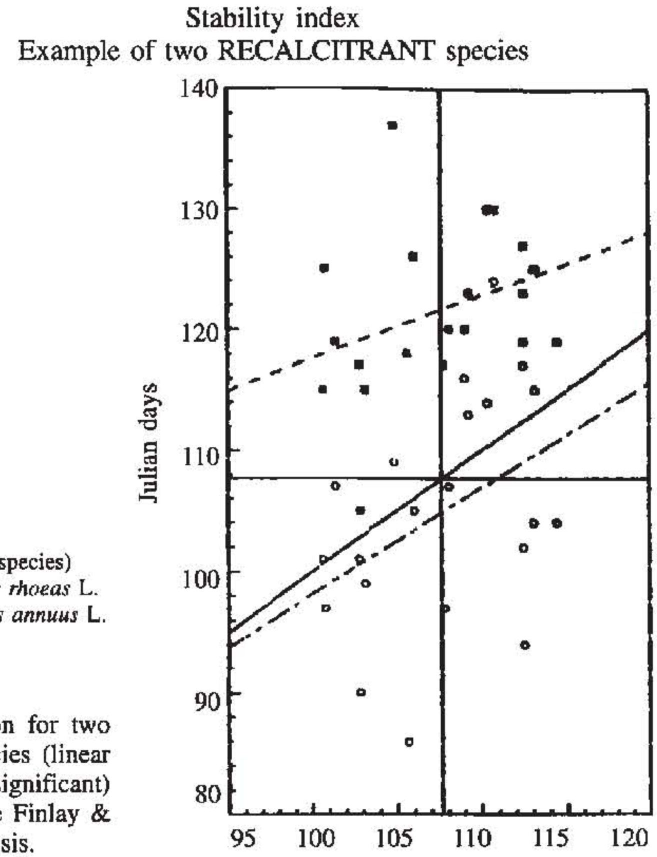
Stability index
Example of two UNSTABLE DOCILE species



Year mean

— 107.7 (mean of the 53 species)
-·- 72.4 + 1.94 × *Plantago lanceolata* L.
-- 103.0 + 2.05 × *Vicia sativa* L.
° *Plantago lanceolata* L.
* *Vicia sativa* L.

Fig. 2 – Linear regression for two unstable docil species (c.a. >1) according to the Finlay & Wilkinson analysis.



Year mean
—— 107.7 (mean of the 53 species)
—· 104.9 + 0.88 × *Papaver rhoeas* L.
-- 121.7 + 0.52 × *Lathyrus annuus* L.
° *Papaver rhoeas* L.
* *Lathyrus annuus* L.

Fig. 3 – Linear regression for two recalcitrant species (linear regression not significant) according to the Finlay & Wilkinson analysis.

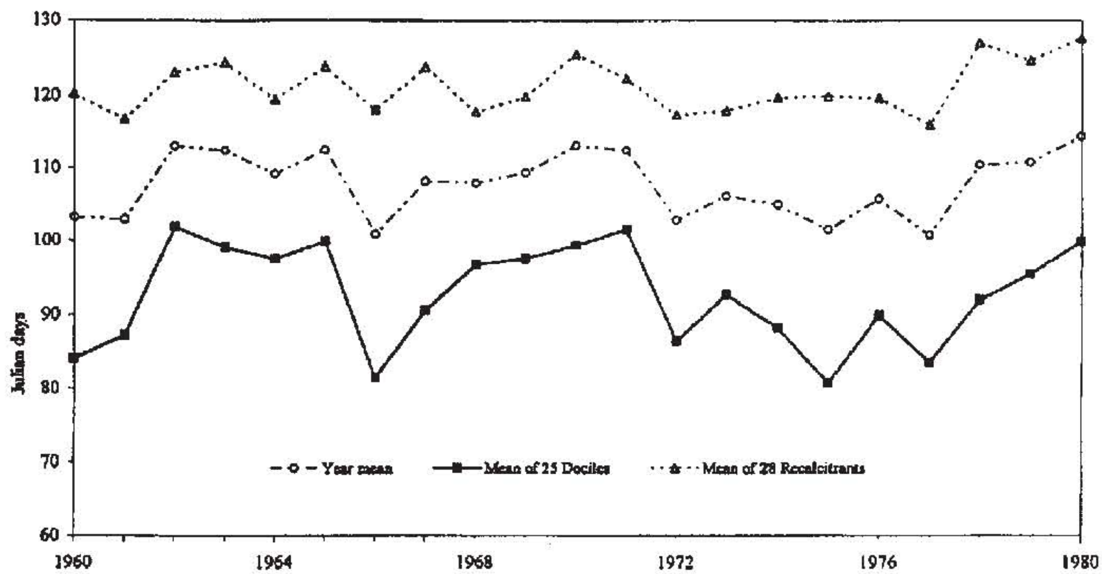


Fig. 4 – Trend of the means of flowering dates for the 53 species over 21 years

The differences between the two trends is probably due to the distribution of the flowering data: in the months of March, April and May, the docile types had the highest frequency of flowering, at the expense of the recalcitrant types. All

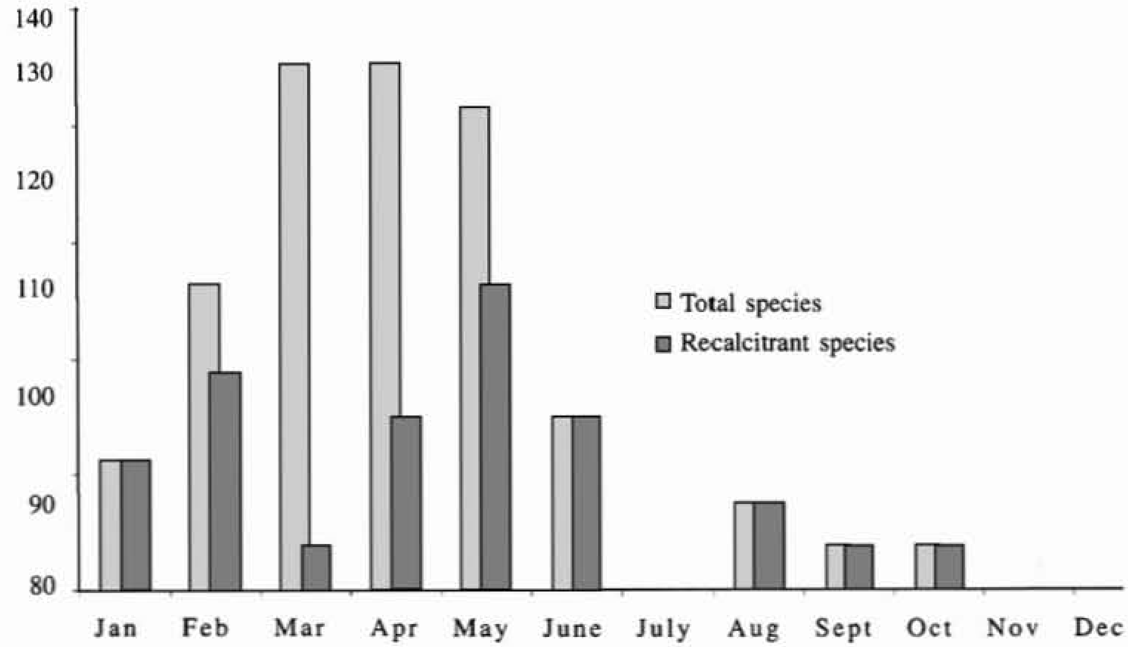


Fig. 5 – Relationship between the groups of species and the flowering period

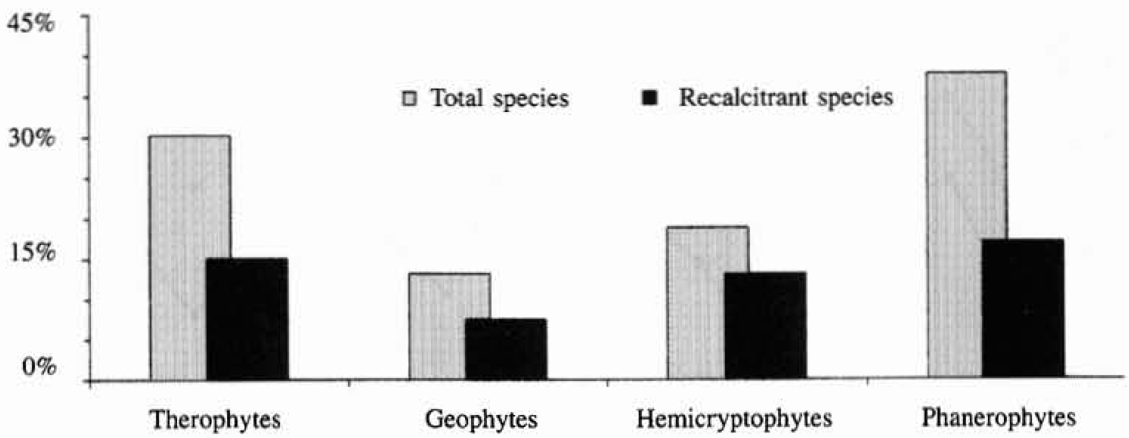


Fig. 6 – Relationship between the biological from and the group of species considered

the species which, on average, began to flower in the June - January period were recalcitrant (Fig. 5).

In Figure 6, the 53 species analysed together with the recalcitrants are related with their biological forms. It can be seen that there was no close relationship between the two types of classification.

DISCUSSION

The beginning of flowering dates for the 53 species recorded over 21 years supplied, at least for the locality examined, useful biological data representing a combination of the climatic and environmental variables (temperature, rain, soil, light intensity, photoperiod, pollutants etc.) which act in the same place. Furthermore, when this data was related to each species with the Finlay and Wilkinson analysis, it allowed an evaluation of the stability of flowering for the individual species against the mean behaviour. This approach, also used for other phenophases, can be of great assistance in both «phenological» and «phenoclimatic» predictive models, as it requires neither climatic data nor indicator species. In fact, the results from the present study indicate the docile species which could be viewed as «indicator species» for that specific environment. In contrast with the work of White (1979) who analysed the behaviour of species taken two by two, in our study each species was compared with the mean of all the species analysed.

The Finlay and Wilkinson analysis can provide even more interesting information is extended to include the data recorded in the various stations in national and international phenological gardens. In fact, using only the data from certain clones of plants or species present in all the stations, it becomes possible to compare the various «biological» data both between and within stations, and thus highlight the likely different stabilities for the phenological events in the various species. The results are more significant the higher the number of species (or clones) and years considered. It is hypothesised that this information, together with that derived from the already tested classical methods, could help in valid ecological and climatological monitoring work on both a regional and global scale, whose usefulness is already confirmed by the scientific community (Lieth, 1994).

The lack of a large number of species with more than 20 years of observations has probably prevented the confirmation of the presumed relationship between flowering stability and the biological form of the plant species concerned.

RIASSUNTO

L'analisi di Finlay e Wilkinson è stata impiegata per analizzare il variare nel corso di 21 anni, dell'inizio di fioritura di 53 specie. Questo metodo permette di valutare il comportamento di una specie rispetto al comportamento medio di tutte le specie.

In base all'analisi della regressione lineare le specie sono state suddivise in due classi denominate docili (25 specie) e recalcitranti (28 specie). L'inizio di fioritura di queste ultime non è prevedibile in quanto i loro coefficienti di regressione non sono significativi. Nell'ambito delle specie docili, a loro volta, sono state individuate delle – docili stabili – e delle – instabili o sensitive – a seconda che presentino nei 21 anni una fioritura rispettivamente con oscillazioni molto basse o molto ampie.

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