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Phenological traits of vegetation: examples of some phytocoenoses from selected vegetation-series.

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Abstract

The rhythms of growth, flowering and fruiting of plant communities (symphenological patterns) are conditioned by synchronizing and asynchronizing factors. Phenological behaviours of species can be categorized into types and their synchrony or asynchrony (diversity) can be evaluated by numerical methods. Moreover, the phenological traits of a phytocoenosis can be compared and related with other features and criteria of classification. Each phytocoenosis has a typical symphenological pattern that is subject to variations (anomalies) depending on the weather and also on the stress and disturbance level: pheno-anomalies can lead to variations in the fitness of some species and possibly to the loss of biodiversity.
In fact, the phenological traits enrich the bio-indication value of plants and should always be considered when attaining a global view of plant communities.

Key words: Symphenology, phenological types, diversity, pheno-anomalies, synchrony.

Riassunto

Analisi fenologica della vegetazione: esempi relativi ad alcune fitocenosi inserite in contesti seriali di vegetazione.
I ritmi di crescita vegetativa, di fioritura e di fruttificazione delle piante componenti le comunità vegetali (ritmi sinfenologici) sono condizionati da fattori sincronizzanti e desincronizzanti.
Il comportamento fenologico delle specie può essere classificato in tipi e la sincronia o asincronia interspecifica (diversità fenologica) può essere valutata mediante metodi grafici e numerici. Inoltre, i tratti fenologici delle specie di una fitocenosi si possono paragonare e mettere in relazione con caratteristiche e criteri di classificazione di altra natura (forme biologiche, gruppi sintassonomici, gruppi ecologici, etc.). Ciascuna fitocenosi ha una configurazione sinfenologica tipica che è soggetta a variazioni (feno-anomalie) a seconda dell'andamento meteorologico e anche del livello di stress e disturbo: le anomalie fenologiche possono in certi casi portare a variazioni della "fitness" di alcune specie, fino alla perdita di biodiversità.
In conclusione, le caratteristiche fenologiche apportano un consistente arricchimento al valore di bio-indicazione delle piante e dovrebbero essere sempre considerate negli studi vegetazionali che si prefiggono di comporre una visione globale delle comunità vegetali.

Parole chiave: Sinfenologia, tipi fenologici, diversità, feno-anomalie, sincronia.

Introduction on phenological traits

The symphenological analysis of phytocoenoses allows us to assess the specific and collective rhythms of the growth, flowering and fruiting in plant communities.

Each intraspecific phenological pattern can be quantitatively defined as a statistical distribution characterized by such parameters as time of phenophase occurrence (mean), duration (range), synchrony (variance) and skewness (Rathcke & Lacey 1985).

It can be assumed that the phenological timing of plant species is optimally adapted to the seasonal period favourable for growth and reproduction and that natural selection acts by means of synchronizing and asynchronizing factors (Frankie et al. 1974; Augspurger 1985; Rathcke & Lacey 1985; Wheelwright 1985; Primack 1985).

Among synchronizing factors (temperature, rain, frost, drought risks, canopy shade, related species) climatic factors prevail (Lieth 1974; Opler *et al*. 1976): they may limit phenological ranges either directly (by unfavourable conditions for development) or indirectly (for example, flowering season can be affected by favourable or unfavourable conditions for pollen transfer and vectors (Clarke 1893; Robertson 1895; Frankie *et al*. 1974).

Asynchronizing factors are mostly biotic: competition for pollinators and seed dispersal, seed reduction caused by interspecific pollination (McNeilly & Antonovics 1968; Waser 1978)

So each plant community is characterised by a peculiar phenological pattern, depending on the environment and species composition. The degree of synchrony among individuals (variance) can determine the duration of phenophases at population level, while the degree of synchrony among species can be considered as a measure of the phenological diversity (Gentry 1974, Sakai 2001).

The symphenological pattern of a plant community is usually represented graphically by phenological calendars, phenological spectra (Balátová-Tulácková 1970, Dierschke 1972, Lieth 1974, Schwartz 2003) and by cumulative symphenograms (Busulini 1953), whereas the synchrony or the asynchrony (diversity) can be evaluated graphically (by symphenological spectra) or by numerical methods.

Phenological types

With regard to both the reproductive (from the anthesis to seed dispersal) and the vegetative cycle (from the start of leafing to leaf fall or drying), species can be categorized into phenological types (Smith *et al*. 1998), thus the phenological pattern of vegetation can be represented by means of these types.

The phenological types can be selected *a priori*: for practical purposes the features and the number of types should be selected in order to fit with each climatic zone. Classification of flowering phenology in tropical forests has been attempted by different authors (Gentry 1974, Frankie *et al*. 1974, Opler *et al*. 1980, Bawa 1983, Auspurger 1983, Newstrom *et al*. 1994) in different ways (Sakai 2001**),** while a few studies have examined phenological types in temperate zones (Carbiener 1982, Osada *et al*. 2003, Tal 2011)**.** Newstrom *et al*. (1994) suggested that phenological patterns could be described and classified considering: date of onset, duration, frequency, synchrony and regularity.

A framework of phenological types fitting with temperate phytocoenoses is proposed in fig. 1: the types are based on regularity, date of onset and duration of phenological cycles.

Symphenological spectra built up on these bases could be employed to highlight ecological differences between phytocoenoses (fig. 2).

Phenological types can be alternatively singled out *a posteriori* by numerical methods, such as clustering (Smith *et al*. 1998). This approach is useful in studying the phenological behaviour of groups of species, as was shown regarding the flowering timing of the summit *Vaccinium* heaths in the Emilian Apennines (Puppi *et al*. 1994). The dendrogram (based on the Pearson correlation matrix between the dates of full flowering) identified two main groups of species with homogeneous flowering behaviour: the first group is composed of plants with specialized ecology and early flowering (strongly influenced by snow melting day, with DDG temperature thresholds around 0°C); while the second group consists of plants with wider ecology, more thermophilous and generally late flowering (unaffected by snow melting time; with positive DDG temperature thresholds).

- Main phenological types
1) more than one cycle per year (or continuous reproduction or leafing)
2) only one new cycle per year (highly synchronized)
- Sub-types
a) Start of the cycle
1) Winter
2) Spring
3) Summer
4) Autumn
b) Length of the cycle
1) short (until 5 months)
2) medium (6 - 8 months)
3) long (9 -11 months)
4) very long (one year or more)

Fig. 1 - Phenological types of temperate phytocoenoses: the types are based on regularity, date of onset and duration of phenological cycles.

Symphenological diversity

Climate and other synchronizing factors tend to homogenize the phenological responses of plants, whereas competition, acting as an asynchronizing factor, increases phenological diversity.

Each plant community is in fact characterized by a particular equilibrium of these tendencies.

In order to evaluate the phenological diversity of phytocoenoses, Shannon's (H) and other indices can be calculated using the phenological types as categories (Sarmiento 1983).

As an example we reckon the value of phenological diversity (H) and the evenness (J) of some phytocoenoses (*Vaccinium* heath, *Castanea* wood, *Quercus pubescens* wood) belonging to different phytoclimatic belts (tab. 1). The data come from previous symphenological studies (Puppi *et al*. 1993, Puppi *et al*. 1994): for each phenological type the number of species is taken as an estimate of the type frequency. The finding is that the sub Mediterranean woods have higher diversity values

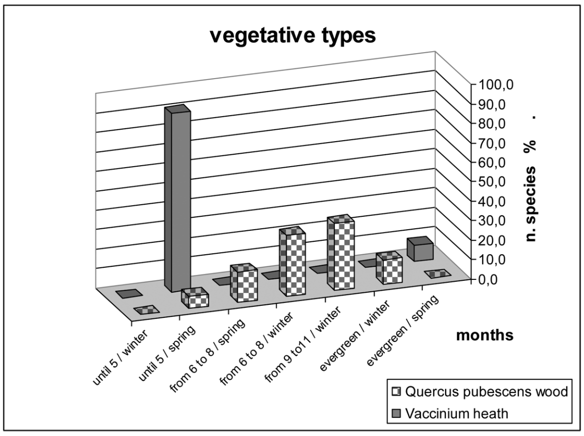

Fig. 2 -Vegetative phenological types of two phytocoenoses of the Emilian Apennines: a *Vaccinium* heath (*Hyperico richeri-Vaccinietum*, subalpine belt) and a *Quercus pubescens* wood (*Knautio-Quercetum pubescentis*, sub Mediterranean belt).

than the *Vaccinium* heaths.

Symphenological diversity can also be evaluated through numerical methods, with no need to classify species by phenological types. Ferrari *et al.* (1983) follow this approach in surveying the flowering pattern of several plant communities: on the basis of binary matrices, derived from the anthesic calendars of the associations, the minimum number (k) of time units (e.g. months) necessary to observe the anthesis of all the species is calculated, taking K as an index of phenological diversity.

In both the cited cases, the phenological diversity appears to be related to the species richness of the communities: the relationship seems to be non-linear (fig. 3).

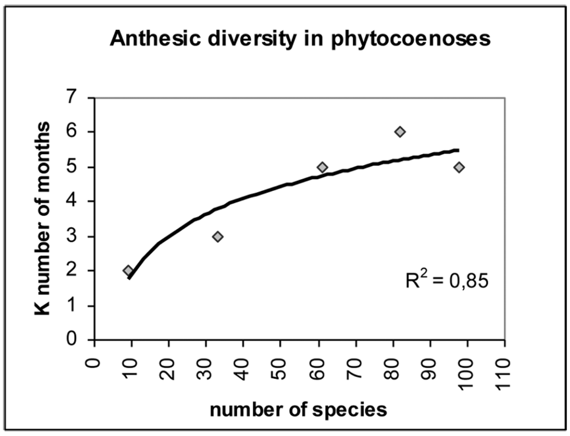

Fig. 3 - Anthesic diversity in 5 plant communities (data from Ferrari *et al.* 1983): K is the minimum number of time units (months) necessary to observe the flowering of all the species.
The value of K shows a significative non linear relationship with the number of species of the communities (R^2=0.85 **).

Vegetative diversity	N	S	H	J
Vaccinium heath	24	2	0,29	0,41
Castanea sativa wood	37	6	1,46	0,82
Quercus pubescens wood	32	5	1,45	0,90

Tab. 1 - The table reports the values of vegetative phenological diversity (H) and evenness (J) of three phytocoenoses, together with the number of species (N) and the number of phenological types (S): the indices were calculated on the basis of the types listed in fig.1: for each phenological type the number of species is taken as an estimate of the type frequency. The data come from previous symphenological studies (Puppi *et al.* 1993, Puppi *et al.*1994) carried out in the province of Bologna (N Italy). The subalpine *Vaccinium* heath has low values of H and J, whereas the submediterranean woods, dominated by *Castanea* and *Quercus,* show high phenological diversity.

Relationships with other plant traits

The phenological traits of a phytocoenosis can be compared and related with other features and criteria of classification (Taxonomy, Syntaxonomy, Chorology, pollination types, ecological and morpho-physiological traits) in order to assess the relationship between seasonal timing and the other attributes of plants.

An analysis performed on some sub Mediterranean woods (belonging to the associations *Knautio-Quercetum pubescentis* and *Ostryo-Aceretum opulifolii*) showed interesting correspondences between Phenology and Syntaxonomy, as well as life forms and some ecological features (Puppi *et al.* 1993). The characteristic species of the higher syntaxa exhibited different phenological behaviour (fig. 4): the mesophilous species of *Laburno-Ostryion* showed the longest growing season and the earliest flowering peak (April), while the *Cytiso-Quercion* species (xerophilous) had the shortest vegetative cycle and a late flowering period (May-June**).** The flowering behaviours of some groups of ecological index species (Landolt, 1977) were also compared: the full bloom peaks were found to occur earlier in the indicators of shade than in the indicators of full light. As far as Life Forms (Raunkiaer, 1934) are concerned, in Phanerophytes and Geophytes the full bloom peak occurred earlier than in Hemicryptophytes and Chamaephytes.

Another analysis carried out on ruderal grasslands (*Salvio-Dactyletum*) of the Emilian Po plain, focused

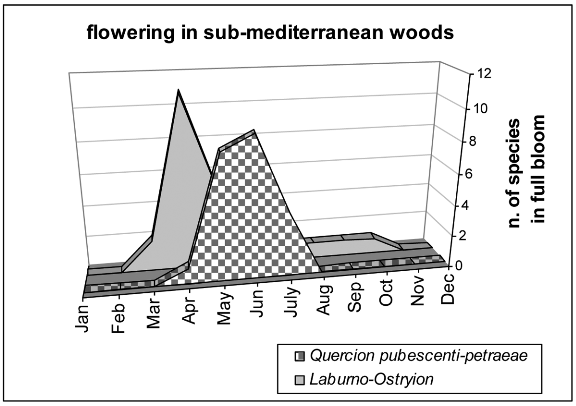

Fig. 4 - Anthesic behaviour of character species: the species of the alliance *Laburno-Ostryion* reach the blooming peak earlier (April) than those of *Quercion pubescenti-petraeae* (May-June).
The data come from a study carried out in the hills near Bologna on sub Mediterranean woods (ex Puppi *et al.* 1993).

on the relationship of flowering and fruiting time with Life Forms: the results show that the blooming and fruiting peaks occur earlier in the Therophytes than in the Hemicryptophytes and Geophytes (fig. 5).

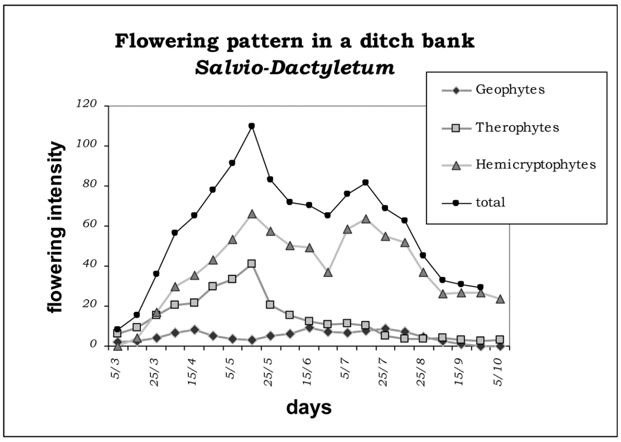

Fig. 5 - Flowering pattern of a grassland of the association *Salvio-Dactyletum* (on a ditch bank, near Castel S. Pietro (BO). The intensity of flowering is calculated following Busulini's method (1953). The whole Symphenogram is decomposed into parts in order to analyse phenological behaviour of the Life Forms (Raunkiaer).

Pheno-anomalies

Each phytocoenosis has a typical symphenological pattern that is subject to variations (anomalies) depending on the weather and also on the stress or disturbance level.

In fact, besides the climate, "disturbance" can also produce "pheno-anomalies".

It is well known that the disturbance caused by mowing determines anomalies in the phenological cycles of many plant species (delayed flowering and fruiting, new blooming, etc.)

In fig. 6 a reproductive symphenogram is reported, aiming to show the impact of mowing on the ruderal grassland already analysed in fig. 5. The results show that the intensity of flowering is clearly lower than in the undisturbed site (chiefly concerning the Hemicryptophytes), nevertheless, two weeks after the mowing, a partial recovery of the flowering wave begins.

The defoliation by grubs in a wood too, determines changes in the vegetative and reproductive cycles. In fig. 7 the vegetative resilience of *Ostrya carpinifolia,* after a 100% defoliation by *Lymantria dispar,* is displayed. Caterpillars begin to browse the young leaves in April, just after the budburst, and bring about the complete defoliation of trees in two months (at the beginning of June): the vegetative recovery of the trees starts only two weeks later, being completed in about two months (end of August), with a considerable loss of photosynthetic resources.

Climatic fingerprints (Root *et al*. 2003)

In Europe, climatic change has already caused a significant shift in phenophases timing: an advance of spring phases (7.5 days during the period 1971-2000) and an extension of the growing season. Nevertheless, species have been found to respond differently to climate change (Menzel *et al*. 2006, Sparks, Menzel & Stenseth 2009).

This prospect raises many questions about the consequences of these phenological shifts on the species and the communities; the attention is focused chiefly on the impact of extreme climatic events and of anomalous years. Obviously, it will be expedient to concentrate phenological and ecological studies on the most vulnerable phytocoenoses.

As an example, a phenological analysis of the pheno-anomalies of a *Vaccinium* heath (summit vegetation of the Tosco-Emilian Apennines) is given (fig. 8): Two extreme years (1984 and 2003) are compared with a year with average meteorological conditions (covering the period 1980-2005). Significant shifts are observed in the main flowering peaks (about one month between 1984 and 2003): moreover there are differences in the shape and in the length of the flowering waves. The phenological pattern in the warmest years observed, could be useful to identify the most sensitive species and to forecast the future trends.

Consequences of asynchronous responses to climate change

The effects of a phenological shift on a given population of a species will also depend on whether the other species on which it relies (for food, pollination, seed dispersal, etc.) change with it.

The more specialized the relationship between species, the more vulnerable each of them are likely to be to the phenological effects of climate change (Stenseth & Mysterud 2002; Ash & Vitter 2007; Haggerty & Mazer 2008). On the one hand, if species that benefit from each other respond differently to climate change, then one or both of them may exhibit population declines (e.g. if a plant population flowers on average five days earlier but its pollinators haven't arrived). On the other hand, if a population flowers early enough to "escape" one or more of its "natural enemies" (e.g. flower bud-eating larvae and the host plant) it may reap the benefits of high flower and fruit production.

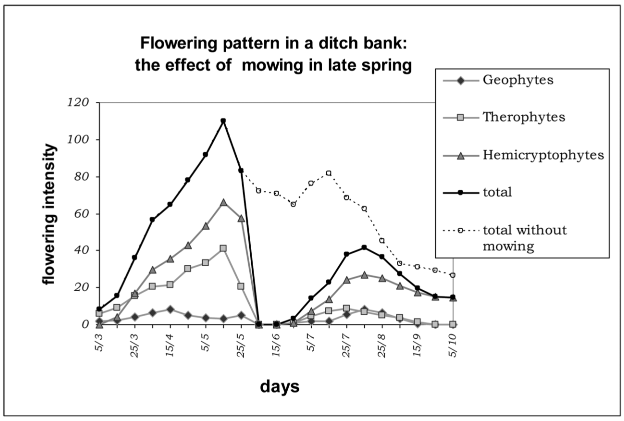

Fig. 6 - Symphenogram showing the effect of mowing (5 June) on the flowering pattern of the same grassland as Figure 5. The intensity of flowering is clearly lower than in the undisturbed site (chiefly concerning the Hemicryptophytes), nevertheless, two weeks after the mowing a partial recovery of the flowering wave begins.

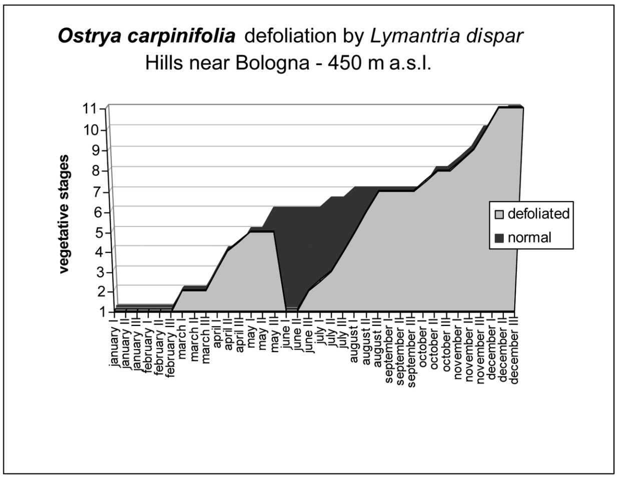

Fig. 7 - Phenogram showing the effect of the defoliation by grubs (*Lymantria dispar*) in a woody species (*Ostrya carpinifolia*): the phenophases follow the key of the Italian Phenological Gardens. Caterpillars begin to browse the young leaves in April just after the budburst (vegetative stage 3) and achieve the complete defoliation of trees in two months (at the beginning of June): two weeks later the vegetative recovery of the trees starts, which is accomplished (vegetative stage 7 = leaves fully developed) in about two months (end of August), with a considerable loss of photosynthetic resources: the senescence of leaves (stage 8 and 9) seems to appear without any significant delay.

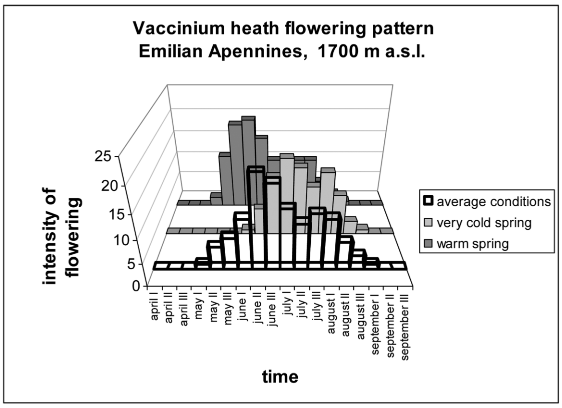

Fig. 8 - Symphenograms of the flowering pattern of a *Vaccinium* community (*Hyperico richeri-Vaccinietum*). Three different years are compared: a year with average meteorological conditions covering the period 1980-2005, a year with a very cold spring (1984) and a year with a very warm spring (2003). One can observe significant shifts between the main flowering peaks (about one month between 1984 and 2003) and differences in the shape of symphenograms and in the length of the flowering season.

Conclusions

We found that the analysis of phenological traits of vegetation seems to be a useful tool in characterizing ecological features of phytocoenoses, in surveying natural and anthropic impacts (indicator value) and in predicting the plant responses to environmental changes.

Pheno-anomalies can lead to variations in the fitness of some species and consequently the competitive relationships within a plant community will alter, possibly until the loss of biodiversity.

In order to predict the consequences of climatic impact on plants it is important to assess the phenological fingerprints of the most sensitive phytocoenoses and to construct pheno-climatic models suitable for forecasting future scenarios.

Indeed, a global view of plant communities, both in descriptive and functional terms, increases their bio-indication value and their benefit in the applications for the sustainable management of ecosystems.

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