POSSIBLE SYNERGIES BETWEEN PHENOLOGICAL AND CROP PROTECTION MODELS: AN EXAMPLE FOR LOBESIA BOTRANA

Article

POSSIBLE SYNERGIES BETWEEN PHENOLOGICAL AND CROP PROTECTION MODELS: AN EXAMPLE FOR *LOBESIA BOTRANA*

POSSIBILI SINERGIE FRA MODELLI FENOLOGICI E DI PROTEZIONE DELLE PIANTE: UN ESEMPIO PER *LOBESIA BOTRANA*

Luigi Mariani *[1], Osvaldo Failla[1], Paolo Capece[2]

[1]: Università degli Studi di Milano, Dipartimento di Produzione Vegetale
[2]: SAR Sardegna
** Corresponding author: E-mail address luigi.mariani@unimi.it*

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Abstract

The operational availability of information about *Lobesia botrana* (*Lepidoptera Tortricidae*) (*Denis et Schiffermüller*) and crop phenology of vine *(Vitis vinifera L.)* should enhance the effectiveness of IPM activities, especially in the crucial pre-flowering phase, when the oviposition of the anthophagous generation, sometimes responsible of significant damages in Sardinia, takes place. On the ground of this, phenological models referred to vine and moth should be important tools for spatial extension of field observations. This evidence justify the work described in this paper and founded on the analysis of the relationship between phenological phases of vine and onset of attack of Lobesia botrana. This analysis was carried out by means of (i) a simulation model of the insect biological cycle and (ii) a simulation model of the grapevine phenology referred to the two varieties *Cabernet Sauvignon* e *Chardonnay*. Both models were applied to the Alghero (SS - Sardinia) time series 1951-2006 of temperature data. Results are discussed and possible future improvements of the method are analyzed.

Key words: phenology, crop protection, models, grapevine, European vine moth

Riassunto

La disponibilità operativa di informazioni fenologiche riferite all'insetto e all'ospite può accrescere l'efficienza delle attività di difesa integrata, specialmente nella cruciale fase di pre-fioritura in cui ha luogo l'oviposizione della generazione antofaga. Alla luce di ciò i modelli matematici riferiti a vite e Lobesia possono rivelarsi utili strumenti per l'estensione spaziale delle osservazioni di campo.

Questo lavoro si fonda sulla descrizione della relazione fra le fasi fenologiche della vite (Vitis vinifera L.) *e l'attacco del lepidottero tortricide* Lobesia botrana (Denis et Schiffermüller) *per mezzo di (i) un modello di simulazione del ciclo biologico dell'insetto e (ii) un modello di simulazione della fenologia delle vite riferito alle due varietà* Cabernet Sauvignon *e* Chardonnay*. Entrambi i modelli sono applicati ad Alghero (SS - Sardegna) con riferimento alle serie storiche 1951-2006 di temperature dell'aria al suolo, analizzando in particolare la prima fase dell'attacco.*

I risultati ottenuti vengono discussi e le possibili future migliorie sono altresì analizzate.

Parole chiave: *fenologia, protezione dei vegetali, modelli, vite, tignoletta della vite*

Introduction

Defense of crops against insect pests damage is crucial to improve quantity and quality of crop production; in this sector is quite important the adoption of Integrated Pest management (PIM) programs, aimed to limit the damage of insects and to reduce the number of treatments with chemicals, with positive effects for farm economy and more generally for environment and human health.

In a perspective of IPM, the decision about "if", "where" and "when" adopting chemicals or other tools to fight insects could be driven by information coming from observation (visual or aided by insect traps or other instruments) or from simulation models.

Simulation models of a generic insect-host system embedded in a generic agroecosystem are driven by meterological variables which (i) determine the activity of insects and hosts and (ii) modulate the insect-host-agroecosystem interactions.

More specifically, this paper is referred to European vine moth, *Lobesia botrana (Denis et Schiffermüller) (Lepidoptera Tortricidae)*, the principal insect pest of European vineyards. The larvae of the 1st generation of Lobesia feed on flowers and usually cause harvest loss only if infestation levels exceed one larval nest per cluster. They reach the maturity after 25-30 days and become chrysalides on the same clusters or in other parts of the plant (Servadei *et al.*, 1972; Cravedi, 1995). The larvae of the 2nd and 3rd generations feed on berries, causing yield loss and the spread of rots like *Botrytis cinerea* (*Persoon*). Thus the economic damage levels are potentially much lower than those for the attacks of 1st generation (Pavan *et al.*, 2005), but they represent the major problem in south of Italy.

The application of insecticides against the 1st generation of grape berry moths to reduce the 2nd generation is not considered in IPM programs until there is only a weak or modest correlation between the infestation level of the two generations. In any case, the 2nd generation is better controlled by specific treatments. Moreover, treatments against the 1st generation are frequently associated with spider mite outbreaks and can cause the death of honeybees (Pavan *et al.*, 2005).

In this work the relationship between the phenological phases of vine and the onset of attack of Lobesia botrana was described by means of (i) a simulation model of insect biological cycle and (ii) a simulation model of grapevine phenology.

Material and metods

This work was carried out in north west Sardinia (Italy) and more specifically in the area of Alghero, (Santa Maria La Palma), with *Cabernet Sauvignon* and *Chardonnay* varieties.

The following data were adopted:

- the observed phenology recorded in the Agrometeorological Service of Sardinia database and referred to some vineyards close to Alghero (SS);
- phenological data supplied by the *Cantina di S. Maria la Palma* for the vineyard of Olmedo (SS);
- phenological data from many vineyards under phytosanitary monitoring;
- temperature data from weather station of Alghero (1951-2006) belonging to National Weather Service of the Italian Airforce;
- observations on *Lobesia botrana* from Arca *et al.* (1993).

Modelization of vine phenology and **Lobesia botrana** *flights*

Phenological simulations were carried out adopting the approach defined for IPHEN (Mariani *et al.* 2007), a project aimed at the development of a prototype of a nation-wide phenological monitoring network, enabled to obtain real-time grapevine observational maps based on BBCH scale and initially referred to two vine varieties (*Cabernet Sauvignon* and *Chardonnay*). The analysis method was based on the adoption of the Normal Hear Hours (NHH).

Crop phenology is usually simulated by the progression of a quantity named Biological Time (BT) which is normally expressed as a Thermal Time (TT) due to the fact that temperature is the main regulator of the rhythmic appearance of phenological phases (Oliveira, 1998). TT is often expressed as summation of Growing Degree Days (GDD) above a particular threshold, variable with the selected crop (10°C is widely accepted as base temperature for Vitis vinifera). In the IPHEN framework TT is expressed as Normal Heat Hours (NHH), an analogue of Chill Units more sensitive that GDD to physiological effects of a particular temperature.

The mechanism of production of NHH from hourly mean temperatures (Fig. 1) is based on a generalized response function which varies from 0 to 1. The function adopted is a beta function (Wang and Engel, 1998) that gives 0 for temperatures outside minimum and maximum cardinals (respectively Tmin = 7 °C and Tmax = 35 °C) and 1 for temperatures at optimum (Topt = 26 °C):

$$fvn(T) = [2(T-T_{min})^{\alpha} (T_{opt}-T_{min})^{\alpha} (T - T_{min})^{2\alpha}]/(T_{opt}-T_{min})^{2\alpha} \quad (1)$$

$$\text{for } _{Tmin}<=T<=T_{max}$$

$$\text{and } fvn(T) = 0 \quad \text{for } T<T_{min} \text{ or } T>T_{max}$$

$$\text{where } \alpha=ln[2/ln((T_{max}-T_{min})/(T_{opt}-T_{min}))]$$

This algorithm was applied to hourly temperatures obtained applying the Parton and Logan's algorithm (Mariani, 2002) to daily maximum and minimum data from the CSA-Cma and the Italian Airforce's Meteorological Service weather stations.

The BBCH phase was obtained on the base of NHH cumulated from the beginning of the year, using two distinct empirical equations for *Cabernet sauvignon* and *Chardonnay*, calibrated by regression of the meteorological and phenological historical data (calibration and validation activities are presented in Mariani *et al.*, 2007). For crop phenology at National level, a specific set of equations for *Cabernet Sauvignon* and *Chardonnay* was calibrated with data referred to the whole Italian territory (Calò *et al.*, 1997; Mariani *et al.*, 2007). For the local activity of this work a new set of equations was produced regressing NHH of Alghero on 2006 phenological data gauged at Olmedo (SS). These equations are listed in Tab. 1; linear or logarithmic models were adopted because they show the best correlation coefficients.

The validation of these equations was carried out on phenological phases 71 and 77 of 2000-2004 period referred to some vineyards of Alghero area. The results of the correlation analyses are presented in Tab. 2 and show a highly significant correlation.

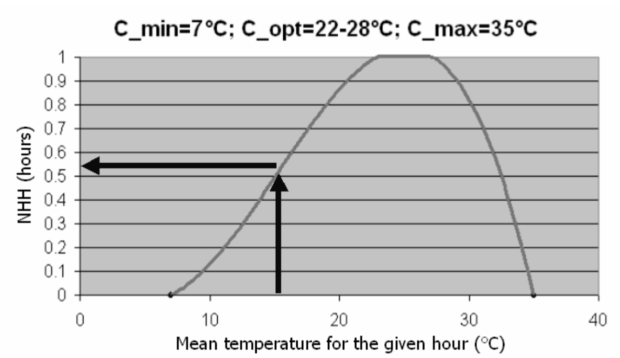

Fig. 1 – Example of production of NHH from hourly mean temperatures (1 hour at 15°C represents 0.55 NHH). Cmin, Copt and Cmax are respectively for minimum, optimum and maximum cardinal

Fig. 1 *– Esempio di produzione di NHH a partire dalle temperature medie orarie (un'ora a 15°C rappresenta 0.55 NHH). Cmin, Copt e Cmax rappresentano rispettivamente il cardinale minimo, ottimale e massimo.*

Tab. 1 – Regression equations describing the correlation between BBCH phase and NHH values (correlation for Olmedo 2006).

Tab. 1 *– Equazioni di regressione che descrivono la correlazione fra fase BBCH e valori delle ore normali di caldo (analisi svolta su dati 2006 di Olmedo).*

Variety	Reference period	equation	r^2
Cabernet S	vegetative	BBCH = 1E-24*NHH^9.5639	0.9167
	reproductive	BBCH = 27.28*Ln(NHH) – 123.27	0.9707
Chardonnay	vegetative	BBCH = 8E-15*NHH^ 5.9521	0.8111
	reproductive	BBCH = 29.77*Ln(NHH) - 138.03	0.9614

Tab. 2 – Correlation analysis between simulated and measured dates of beginning of BBCH phases 71 ad 77 for years 2000-2004. Simulation was carried out on data of Alghero weather station (Meteorological service of Italian Air Force).

Tab. 2 *– Analisi di correlazione fra valori simulati e misurati delle date d'inizio delle fasi BBCH 71 e 77 per gli anni 2000-2004. Simulazioni svolte su dati della stazione meteorologica di Alghero (Servizio Meteorologico dell'Aeronautica Militare).*

Variety	***MAE***	RMSE	EF	CRM	CD	Slope	Intercept	r^2	Significance	Average observed	Average simulated
Cabernet S.	7.35	5.80	0.60	0.03	0.56	1.24	-36.71	0.73	0.001715	175.38	170.40
Chardonnay	6.59	5.60	0.52	0.01	0.59	0.97	6.53	0.54	0.015961	165.37	163.50

Tab. 3 – Cumulated thermal units corresponding to the beginning and the end of the four flights of adults of *Lobesia botrana* (Arca *et al* 1993).

Tab. 3 *– Unità termiche cumulate in coincidenza con inizio e fine del volo delle quattro generazioni di* Lobesia botrana *(Arca* et al *1993).*

Flight	beginning	end
First	270	470
Second	825	1070
Third	1510	1990
fourth	2035	2530

Tab. 4 – Time serie 1951-2006 of Alghero (source: Servizio Meteorologico dell'Aeronautica Militare): the criteria of Mediterraneity are referred to monthly precipitation (rm), monthly mean temperature (tdm), precipitation of winter semester (rwi) and yearly precipitation (ry).

Tab. 4 *– Serie storica 1951-2006 di Alghero (fonte: Servizio Meteorologico dell'Aeronautica Militare): i criteri di mediterraneità sono riferiti a precipitazioni mensili (rm), temperatura media mensile (tdm), precipitazione annua (ry) e del semestre invernale (rwi).*

Index	Condition of mediterraneity	Alghero station
Rivas Martinez's	Almost two months 2 * tdm < rm	4 months (June, July, August and September) show 2 * tdm < rm
Koeppen's	Rwi/ry>0.7	Rwi/ry=0.77

Simulation of Lobesia botrana behaviour was carried out by means of an empirical model for moth adult flight (hereafter named Lobesia botrana flight model - LBfm), based on the summation of thermal units above a threshold of 8°C (Arca *et al.*, 1993). The thresholds for the beginning and the end of flight of first, second and third generation were deduced from Arca, Cossu *et al.* (1993) and adjusted on the base of 1993 observational data; final values are listed in Tab. 3.

Results

Fig. 2 shows the precipitation and temperature climatology for the viticultural area of Santa Maria La Palma, described with the Bagnouls and Gaussen's diagram. The presence of a true Mediterranean climate is evident because the Koeppen's and Rivas Martinez's criteria of Mediterraneity are both satisfied (Tab. 4).

1951-2006 time series of daily maximum and minimum temperatures of Alghero were analysed with both (i) the Lobesia botrana model and (ii) the grapevine phenology model.

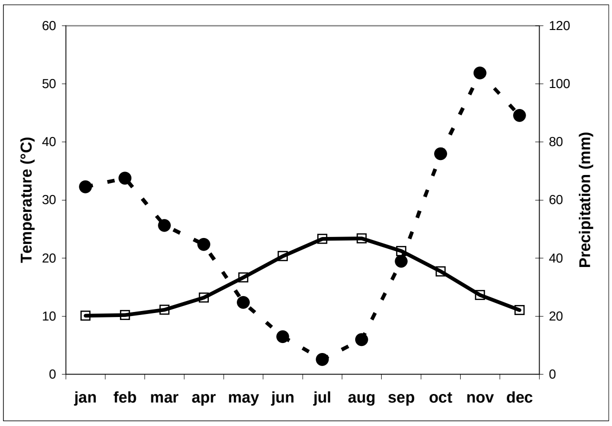

Fig. 2 – Bagnouls and Gaussen's diagram showing that Alghero station presents a Mediterranean climate with summer drought.

Fig. 2 *– Il diagramma di Bagnouls e Gaussen mostra che la stazione di Alghero presenta un clima mediterraneo con siccità estiva.*

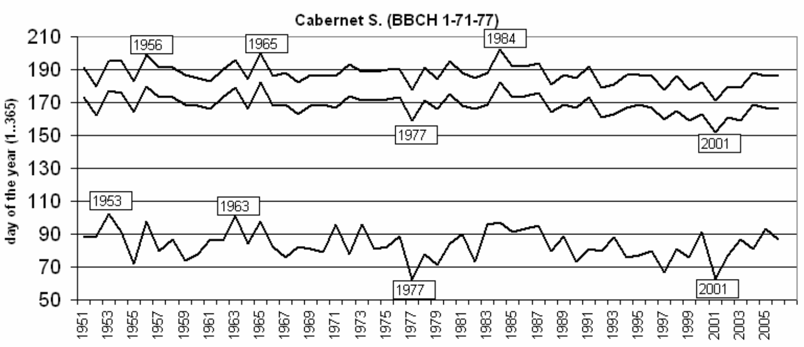

Fig. 3 – Behaviour of phenological stages 3, 71 and 77 simulated for *Cabernet sauvignon* with IPHEN model on time series 1951-2006 of Alghero weather station (National Weather Service of Italian Air Force). Lines represent respectively BBCH 3- Beginning of bud swelling (lower line), BBCH 71- fruit set (medium line) and BBCH 77- berries beginning to touch (upper line). Main anomalous years are highlighted.

Fig. 3 *– Comportamento delle fasi fenologiche 3, 71 e 77 simulate per* Cabernet sauvignon *con il modello IPHEN operante sulle serie storiche 1951-2006 della stazione di Alghero (Servizio Meteorologico dell'Aeronautica Militare). Le linee rappresentano rispettivamente BBCH 3- Inizio apertura gemme, (in basso), BBCH 71- allegagione (linea intermedia) e BBCH 77 - chiusura grappolo (linea in alto). Gli anni evidenziati sono i più anomali.*

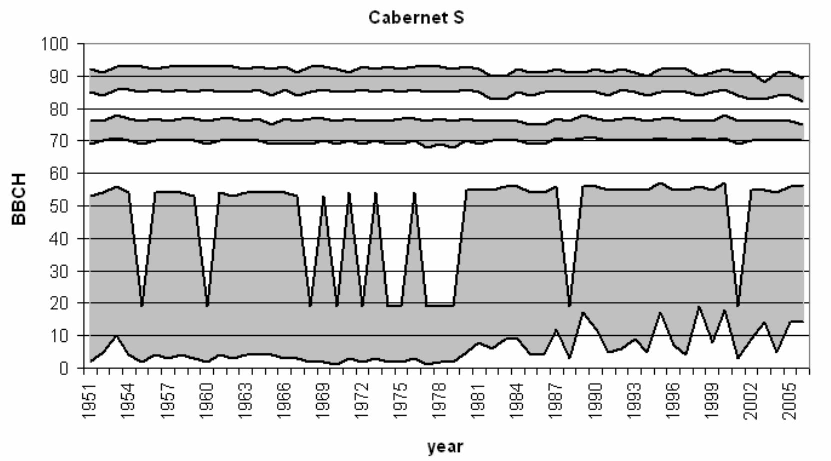

Fig. 4 – Cabernet sauvignon variety: BBCH phenological phase coincident with the beginning and the end of the three flights of *Lobesia* (simulation for Alghero time series 1951-2006).

Fig. 4 *– Varietà Cabernet sauvignon: Fase fenologica BBCH corrispondente con l' inizio e la fine dei primi tre voli di* Lobesia botrana *(simulazione riferita alla serie storica 1951-2006 della stazione meteorologica di Alghero).*

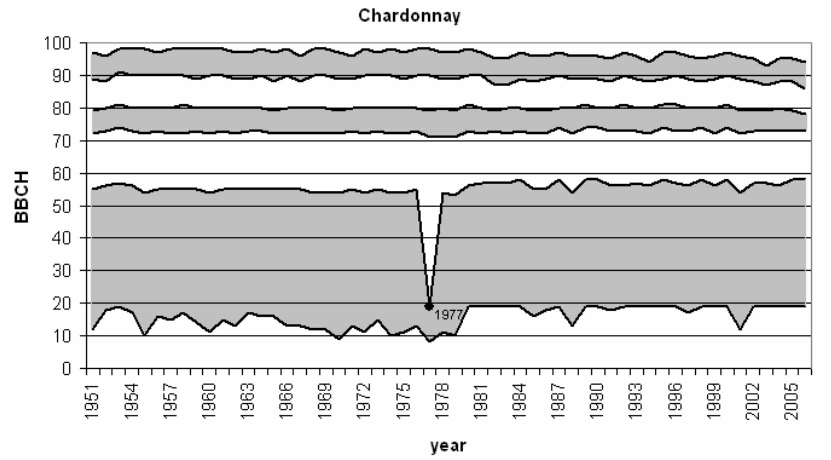

Fig. 5 - Chardonnay variety: BBCH phenological phase coincident with the beginning and the end of the three flights of *Lobesia* (simulation for Alghero time series 1951-2006).

Fig. 5 – Varietà Chardonnay: fase fenologica BBCH corrispondente con l'inizio e la fine dei primi tre voli di Lobesia botrana *(simulazione riferita alla serie storica 1951-2006 della stazione meteorologica di Alghero).*

The beginning of BBCH phases 3, 71 and 77 simulated with the vine phenology model is shown in Fig. 3; we can observe that the years with earliest appearance of phase 3 (1977 and 2001) preserved this characteristic also in phases 71 and 77. Analogously, years with late appearance of phase 3 conserve their lateness in phases 71 and 77.

Diagrams in Fig. 4 and 5, referred to Alghero time series 1951-2006, show the BBCH phenological phase coincident with the beginning and the end of the three flights of Lobesia. These diagrams show a characteristic interannual variability and a tendency towards early flights associated with shorter length. In particular the discontinuity analysis with the method of Bai and Perron (2003) shows that the second and third flight anticipated (Tab. 5) with a discontinuity dropping in 1991 for the beginning of the second and third flight, in 1996 for the end of the second flight and in 1987 for the end of the third one. Results of the change point analysis referred to the end of the third flight are diagrammed in Fig. 6.

Two diagrams showing an example of interaction of the output from the two selected models are shown in Fig. 7: year 1951 presents an early first flight, a second flight almost contemporaneous to that of 2003 and a third flight early than in 2003.

Discussion

Selected models highlight a significant inter-annual variability which is more important for the first flight, because spring temperature is the most limiting factor for phenology of crops and insects.

The strong variability of the phenological phase corresponding to end of the first flight can be considered as an artefact, because BBCH scale attributes the code 19 to plants with 9 or more leaves unfolded; in our diagram, only when inflorescence become clearly visible the vegetative code 19 is substituted by the reproductive code 53.

Results of the two models adopted for this work show that

1 for early cultivar like *Chardonnay,* the peak value of adults lies closer to the

Tab. 5 – Results of a discontinuity analysis on the time series 1951-2006 of *Lobesia botrana* flight data carried out with the test of Bay and Perron (2003).

Tab. 5 – *Risultati dell'analisi di discontinuità condottqa con il test di Bay e Perron (2003) e riferita aulle serie 1951-2006 dei primi tre voli di* Lobesia botrana

		Adopted confidence level	**Most probable year of discontinuity**	**Confidence interval of 90%**	**Effect of discontuity**
first flight	begin	90%	unidentified		
	end	90%	unidentified		
second flight	begin	90%	1991	1985-1999	earliness
	end	90%	1996	1992-2000	earliness
third flight	begin	90%	1991	1985-1999	earliness
	end	90%	1987	1985-1990	earliness

blossoming than for the *Cabernet sauvignon*, effect that should be considered as a symptom of different susceptibility of cultivars with different earliness.

2 in some specific years the flight of adults of *Lobesia botrana* happens significantly before the flowering phase of vine. This has some important effects for IPM due to the lower risk of mortality for bees and the different behaviour of larvae, which can feed on other organs of vine such as developing sprouts, giving other kinds of damage.

Both kinds of models are obviously prone to errors that are the product of (i) the imperfect knowledge of the driving variables, (ii) the imperfect knowledge of the initial state of the system (ii) a quite simplified description of the system and of its subsystems (insect, plant physiology) which ignore the effects of important factors like behaviour of farmer, water and nutrient availability. By consequence these models should be considered as a tool useful to guide observational activities to support the final IPM decision of farmers.

Conclusions and future developments

The use of two dynamical models simulating respectively grapevine phenology (varieties *Chardonnay* and *Cabernet sauvignon*) and flight of *Lobesia botrana* was described with reference to Alghero time series of temperature ("single point" application); nevertheless in the future these models should be applied to:

- present and forecasted meteorological data, taking into account that automatic networks supply a real time availability of data and that recent improvements in medium range weather forecasts gives the availability of forecasted data of sufficient quality for operational purposes up to 7-10 days after the forecast emission
- territorial data produced by means of a geostatistical approach like that applied in IPHEN project (Mariani *et al.*, 2007).

The operational availability of this information should enhance the effectiveness of IPM activities, especially in the crucial pre-flowering phase, when the oviposition of the anthophagous generation, sometimes responsible of significant damages in Sardinia, takes place. Eggs are laid near the flower cluster (which will be attacked by the larvae). Thus, the treatment period is circumscribed at the pre-flowering phase, because a delay might have an effect on the same blossoming and would cause a lower efficacy of the treatment.

The synergy between the models under consideration should promote a better choice of the optimal phase for insecticide sprays in S. M. La Palma area. In addition, interesting findings should result for *Vermentino* DOCG area, or in Gallura, characterized by strong land heterogeneity, due to the scattered location of vineyards with altitude ranging from the sea level up to 600 m in elevation.

In these cases, the spatialization of the phenological data might prove to be helpful for the operators of the vineyard management sector and who might plan pest control taking into account the matching of actual phenological phases of the phytophagous and the host

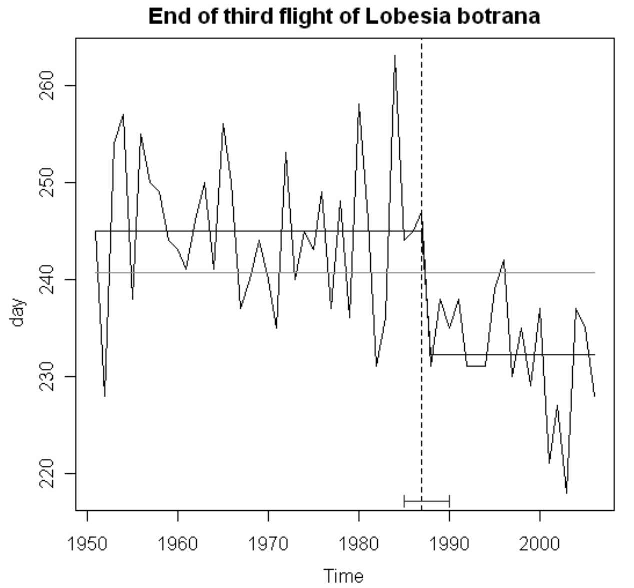

Fig. 6 - Results of change point analysis for the end of the third flight of *Lobasia botrana.* The analysis shows a discontinuity that with a confidence level of 90% drops between 1985 and 1990; the most probable year of discontinuity is 1987.

Fig. 6 – *Risultati dell'analisi di change point riferita alla fine del terzo volo di* Lobesia botrana. *L'analisi mostra una discontinuità che con un confidenza del 90% ricade fra il 1985 e il 1990. Anno più probabile di discontinuità è il 1987.*

plant instead of a fixed scheduling simply based on the phenology of vine, in order to reduce the pesticide impact on grower's health and ecological equilibrium as well as to save money.

The maps already produced in the IPHEN project proved to be satisfying about depicting the Sardinian region's heterogeneity, particularly in reproducing the gradual change in maturation observed in the same wine-growing areas moving from the coast toward the inland, even if an increase in the reference set size of the phenological monitored vineyards have to be considered.

Among future developments we would mention the following ones:

- refinement of the phenophase evaluation algorithm by proper calibration and validation;
- employment of the model to make forecasts up to 10 days;
- use of a more detailed digital terrain model in order to obtain a better territorial description of vine phenology and *Lobesia botrana* variability.

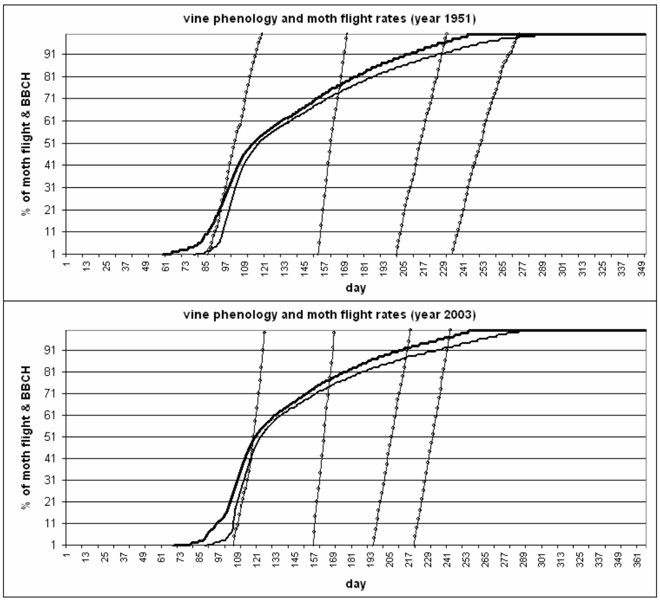

Fig. 7 – Moth flight rate and BBCH values *for Cabernet sauvignon* and *Chardonnay* (thick lines) during years 1951 and 2003.

Fig. 7 – Percentuali di volo di Lobesia *e fasi BBCH* per Cabernet sauvignon *e* Chardonnay *negli anni 1951 e 2003.*

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