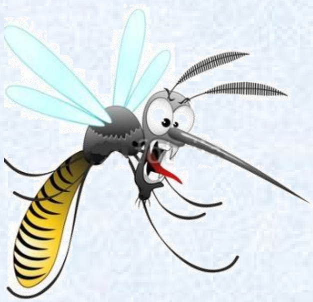
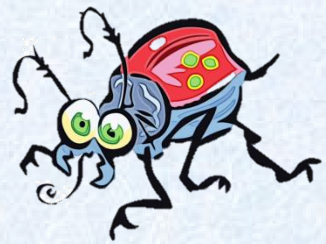
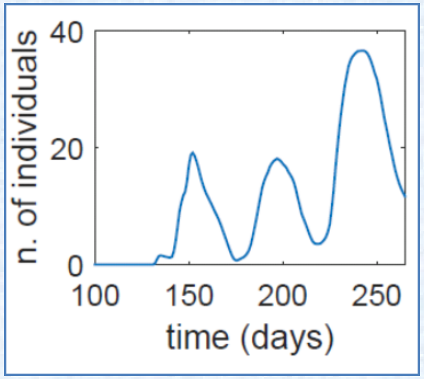
Modelli stocastici nella lotta ai parassiti

Sara Pasquali – CNR IMATI Milano







Sustainable pest management

24.11.2009 EN Official Journal of the European Union L 309/71

DIRECTIVES

DIRECTIVE 2009/128/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 21 October 2009

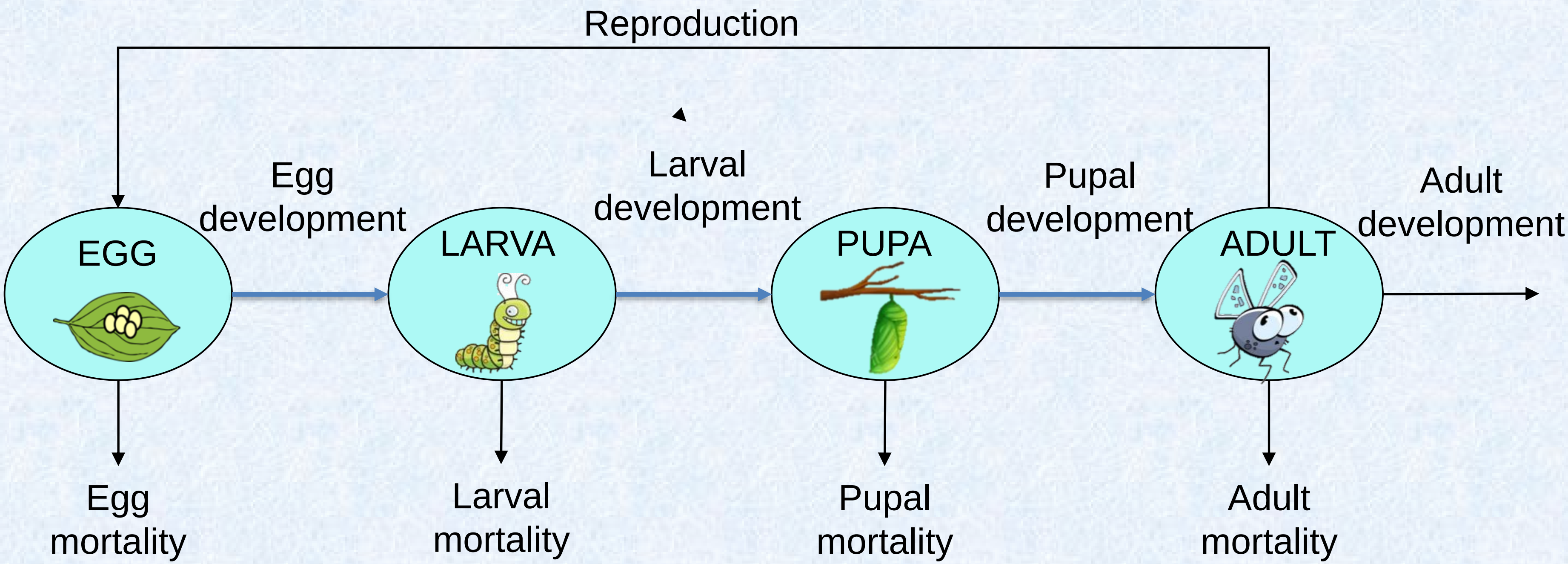
establishing a framework for Community action to achieve the sustainable use of pesticides

(Text with EEA relevance)

ADVANTAGES

- Reduce environmental impact
- Reduce health impact
- Increase product quality

Stage-structured population



Population dynamics models

$$\frac{\partial\phi^i}{\partial t}+\frac{\partial}{\partial x}\left[v^i(t)\phi^i-\sigma^i\frac{\partial\phi^i}{\partial x}\right]+m^i(t)\phi^i=0,\qquad t>t_0,\qquad x\in(0,1)$$

$$\left[v^i(t)\phi^i(t,x)-\sigma^i\frac{\partial\phi^i}{\partial x}\right]_{x=0}=F^i(t)$$

$$\left[-\sigma^i\frac{\partial\phi^i}{\partial x}\right]_{x=1}=0$$

$$\phi^i(t_0,x)=\hat{\phi}^i(x)\qquad\qquad i=1,2,\dots,s$$

Fokker-Planck equations

x = physiological age (percentage of development in a stage)

$v^i(t)$ = development rate function in stage i

$m^i(t)$ = mortality rate function in stage i

Population dynamics models

$$\frac{\partial \phi^i}{\partial t} + \frac{\partial}{\partial x}\left[v^i(t)\phi^i - \sigma^i \frac{\partial \phi^i}{\partial x}\right] + m^i(t)\phi^i = 0, \qquad t > t_0, \qquad x \in (0,1)$$

$$\left[v^i(t)\phi^i(t,x) - \sigma^i \frac{\partial \phi^i}{\partial x}\right]_{x=0} = F^i(t)$$

$$\left[-\sigma^i \frac{\partial \phi^i}{\partial x}\right]_{x=1} = 0$$

$$\phi^i(t_0,x) = \hat{\phi}^i(x) \qquad i = 1, 2, \dots, s$$

Fokker-Planck equations

$\phi^i(t,x)dx$ = number of individuals in stage i with age in $(x, x+dx)$

$N^i(t) = \int_0^1 \phi^i(t,x)dx$ n. of individuals in stage i at time t

$F^1(t) = \int_0^1 b(t)f(x)\,\phi^s(t,x)dx$ egg production flux

$F^i(t) = v^{i-1}(t)\phi^{i-1}(t,x)$ $i > 1$ flux from a stage to the next

σ^i constant diffusion coefficients

$\hat{\phi}^i(x)$ initial distributions

Physiological age: Wiener vs. Gamma

$$\frac{\partial \phi(t,x)}{\partial t} + \frac{\partial}{\partial x}\left[v(t)\phi(t,x) - \sigma \frac{\partial \phi(t,x)}{\partial x} \right] = 0 \qquad t > t_0$$

$\phi(t,x)$ denotes the p.d.f. of the physiological age $X_N(t)$ satisfying

$$dX_N(t) = v(t)dt + \sqrt{2\sigma}dw(t) \qquad X_N(0) = 0 \quad w(t) \text{ Wiener process}$$

This equation allows regressions in the physiological age.

1

$$dX_G(t) = \tilde{v}(t)dt + dL(t) \qquad X_G(0) = 0$$

$L(t)$ homogeneous Gamma process with shape function αt and rate μ

2

$$dX_G(t) = dL(t) \qquad X_G(0) = 0$$

$L(t)$ inhomogeneous Gamma process with shape function $\alpha(t)$ and rate μ

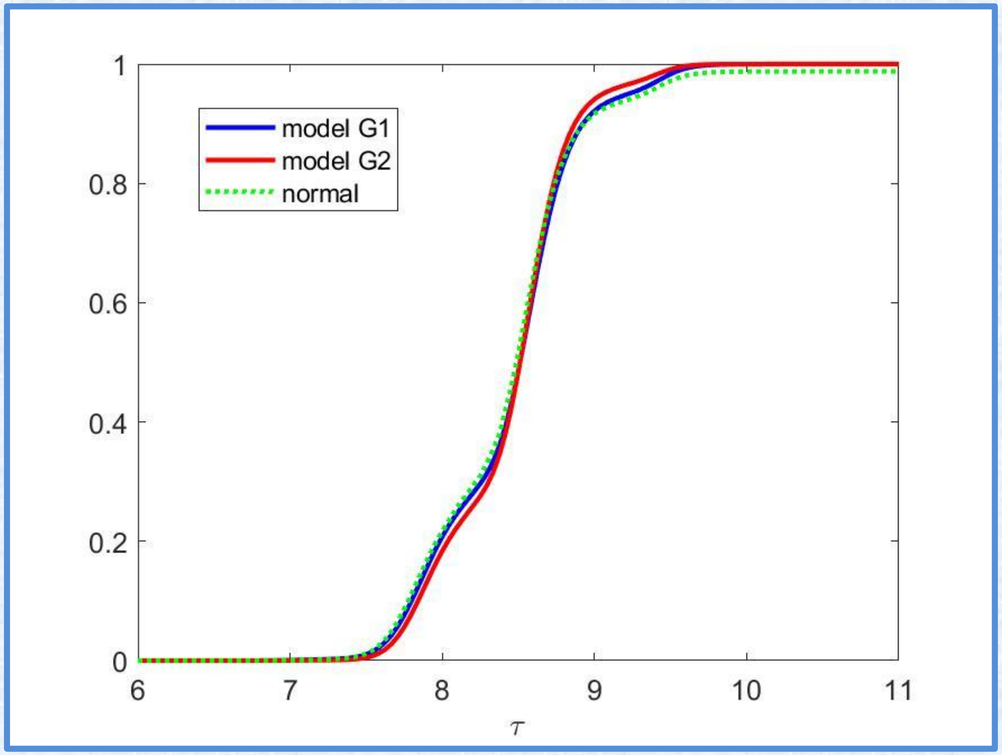
Population dynamics (Gamma)

$$E(X_G(t)) = E(X_N(t)) \longrightarrow$$

$$\tilde{v}(t) = v(t) - \frac{\alpha}{\mu} \qquad \textbf{1}$$

Constraint on $v(t)$

$$\alpha(t) = \mu \int_0^t v(s)ds \qquad \textbf{2}$$



Cumulative distributions of the residence time

Population dynamics models

$$\frac{\partial \phi^i}{\partial t} + \frac{\partial}{\partial x}\left[v^i(t)\phi^i - \sigma^i \frac{\partial \phi^i}{\partial x}\right] + m^i(t)\phi^i = 0,$$

$$\left[v^i(t)\phi^i(t,x) - \sigma^i \frac{\partial \phi^i}{\partial x}\right]_{x=0} = F^i(t), \quad t > t_0, \; x \in (0,1)$$

$$\left[-\sigma^i \frac{\partial \phi^i}{\partial x}\right]_{x=1} = 0$$

$$\phi^i(t_0,x) = \hat{\phi}^i(x) \qquad\qquad i = 1,2,\ldots,s$$

Buffoni and Pasquali, 2007
Structured population dynamics: continuous size and discontinuous stage structure
J. Math. Biol. 54: 555-595

$v^i(t), m^i(t)$ development and mortality rate functions

$b(t)f(x)$ fecundity rate function

$\left.\begin{array}{l} \\ \\ \end{array}\right\}$ Biodemographic functions

Good estimate of biodemographic functions $\Rightarrow$ **Reliable population dynamics model**

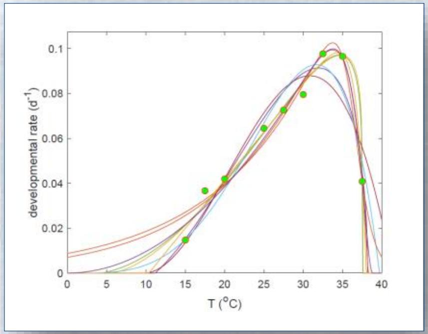
Biodemographic functions

$v^i(t), m^i(t)$ development and mortality rate functions

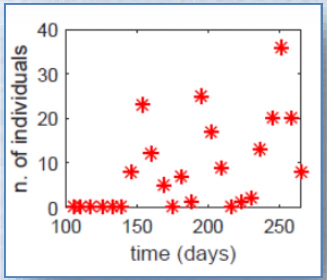
$b(t)f(x)$ fecundity rate function

Biodemographic functions

Data on the biology of the species available → Least square method



Data on the biology of the species NOT available → Statistical estimation method based on population dynamics data



In the following we focus on the estimation of the mortality using population dynamics data

Mortality estimate

CASE 1

$m^i(t)$ of known functional form

least square method

Gilioli, Pasquali , Marchesini, 2016
A modelling framework for pest population dynamics and management: An application to the grape berry moth - Ecol. Model. 320: 348-357

Bayesian method

Lanzarone, Pasquali, Gilioli ,Marchesini, 2017
A Bayesian estimation approach for the mortality in a stage-structured demographic model
J. Math. Biol. 75: 759-779

Mortality estimate

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CASE 2

$$m^i(t) = \sum_{j=1}^{n_i} \alpha_{ij}\xi_{ij}(t)$$

$\xi_{ij}(t)$ suitable basis (ex. splines)

α_{ij} parameters to be estimated

Wood, 2001
Partially specified ecological models
Ecol. Monograph. 71(1): 1-25

Pasquali and Soresina, 2022
Mortality estimate driven by population abundance field data in a stage-structured demographic model. The case of *Lobesia botrana*. *Ecological Modelling*, *464*, 109842.

Mortality estimate

$$m^i(t) = \sum_{j=1}^{n_i} p_{ij}\xi_{ij}(t)$$

Wood, 2001
Partially specified ecological models
Ecol. Monograph. 71(1): 1-25

$\xi_{ij}(t)$ cubic spline basis

p_{ij} parameters to be estimated

u measurement error -- real abundance in $[Y, Y+u]$

Objective: minimize $\sum_i max\left\{0; \left(Y^i - N^i(t)\right) w_i \left(Y^i + u^i - N^i(t)\right)\right\}$

w_i weight Y^i observation $N^i(t)$ simulated abundance

$\boldsymbol{p} = (p_{ij})_{\mathrm{i}\,=\,1,\,\ldots\,,\,\mathrm{s};\,\mathrm{j}\,=\,1,\,\ldots\,,n_i}$ vector of parameters

$\boldsymbol{Y}$ vector of observations $\boldsymbol{N}$ vector of simulated abundances

Mortality estimate

- Starting from an initial value for $\boldsymbol{p}$, we solve the system of PDE to obtain the simulated abundances at the observation times

- We consider slight changes in the parameter to approximate the Jacobian of $\boldsymbol{N}$

$$J_{ij} = \frac{N^i(p + \delta_j e_j) - N^i(p - \delta_j e_j)}{2\delta_j}$$

δ_j small increments ; e_j vectors of the canonical basis

- we construct a quadratic model to approximate the fitting objective

$$q(\boldsymbol{p}) = \sum_i max\left\{0; \left(Y^i - \sum_h j_{ih} p_h\right) w_i \left(Y^i + u^i - \sum_h j_{ih} p_h\right)\right\}$$

- we minimize $q(\boldsymbol{p})$ and obtain a parameter $\boldsymbol{p}$ used to repeat the procedure until convergence.

At the end of the process we obtain the optimal parameter $\overline{\boldsymbol{p}}$

Confidence bands

For large samples, the estimator $\widehat{\boldsymbol{p}} = argmin_{\boldsymbol{p}}\, q(\boldsymbol{p})$ has approximately a multivariate normal distribution with mean $\overline{\boldsymbol{p}}$ and covariance matrix

$$C_J(\widehat{\boldsymbol{p}}) = \frac{q(\widehat{\boldsymbol{p}})}{d - n_p}(\boldsymbol{J}^T \boldsymbol{W} \boldsymbol{J})^{-1}$$

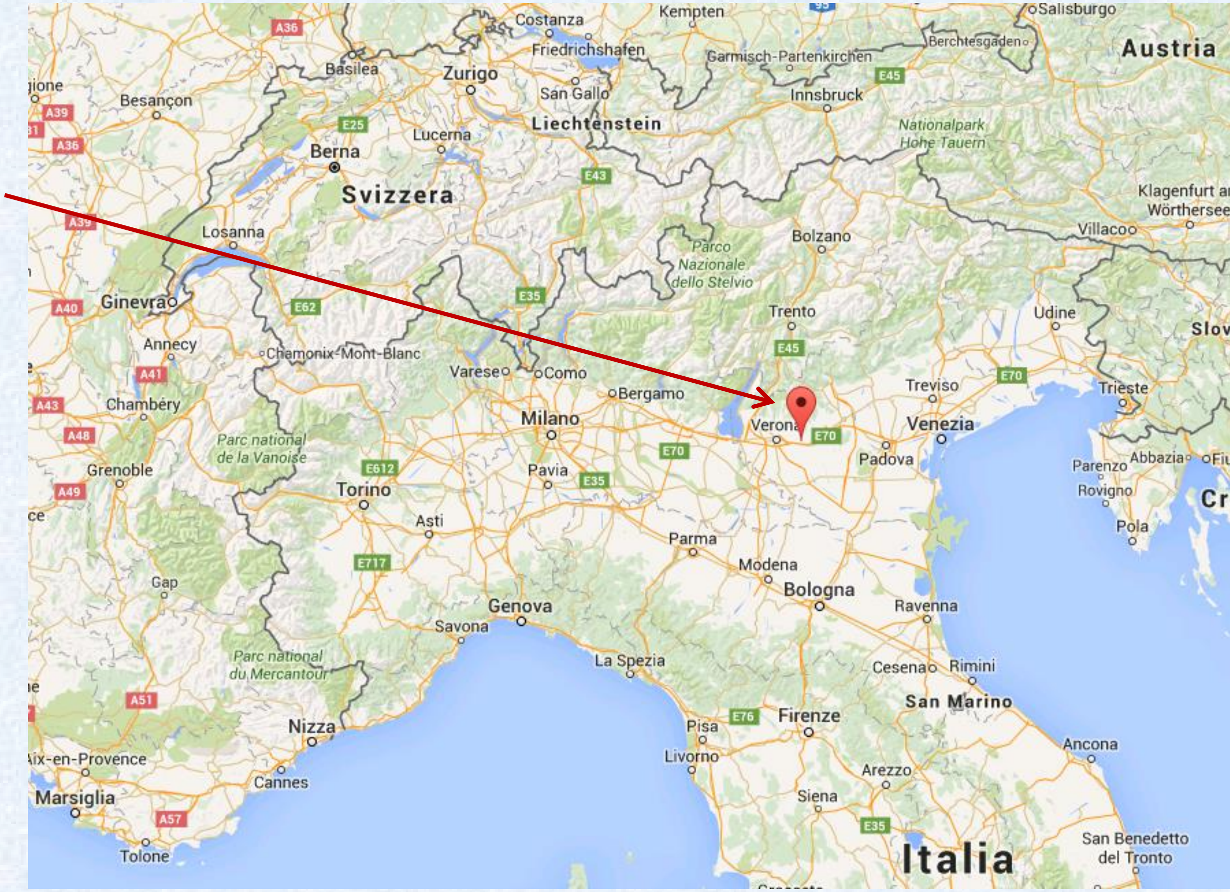
$d =$ n. of observations and $n_p =$ n. of parameters

- We draw a certain number of parameter values from the multivariate normal distribution corresponding to different mortality functions
- With a MATLAB routine we obtain the confidence bands for mortality
- The different mortalities produce different dynamics from which we obtain confidence bands for the dynamics

Confidence bands give a measure of the uncertainty in the estimates.

Case study: the grape berry moth

Estimate the mortality in order to fit the abundance data collected in a vineyard in Colognola ai Colli (Italy) for three years (2008, 2009 and 2011)



Data collected for the cultivar Garganega, from April to September (grape harvest).
Immatures: on a sample of 100 bunches of grapes.
Adults: pheromone traps.

Data on grape berry moth

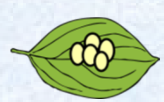
INPUT DATA FOR MODEL SIMULATION

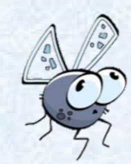
- Temperatures recorded by a meteorological station placed nearby the vineyard

- N. of adults catches per week until larvae of the first generation are detected

FURTHER DATA FOR MORTALITY ESTIMATION

Weekly data for

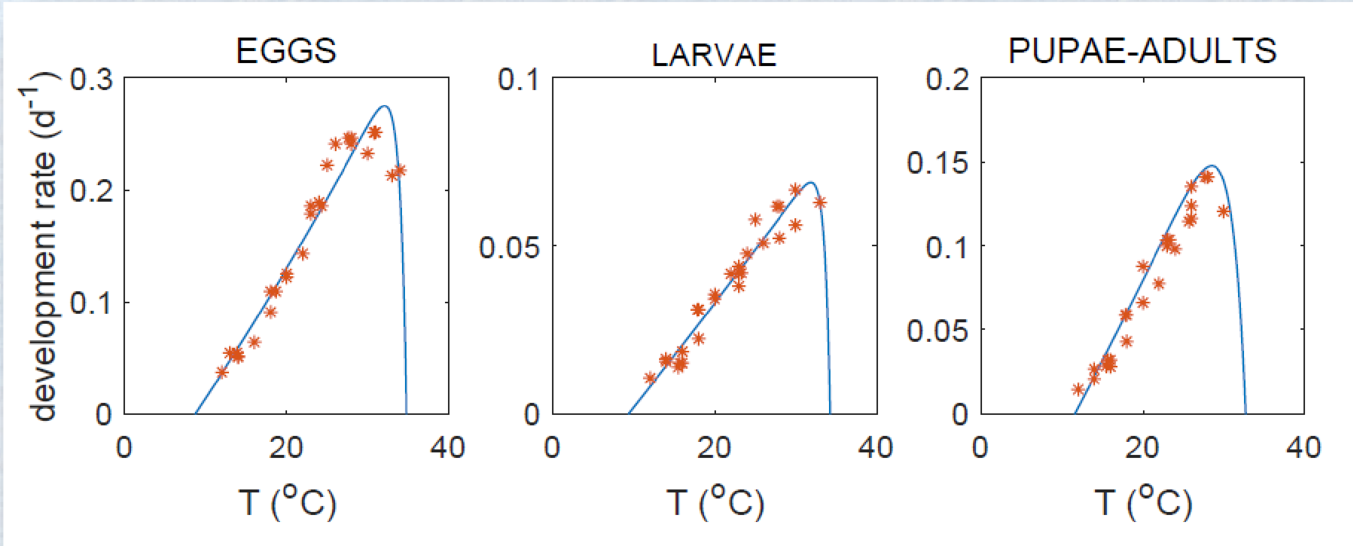


- eggs
- larvae
- pupae
- adults

L. Botrana biodemographic functions

Development:
Lactin functions

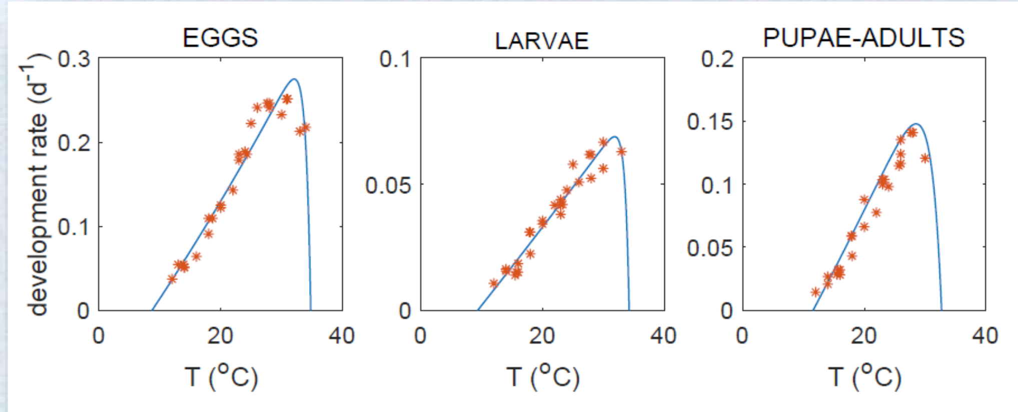


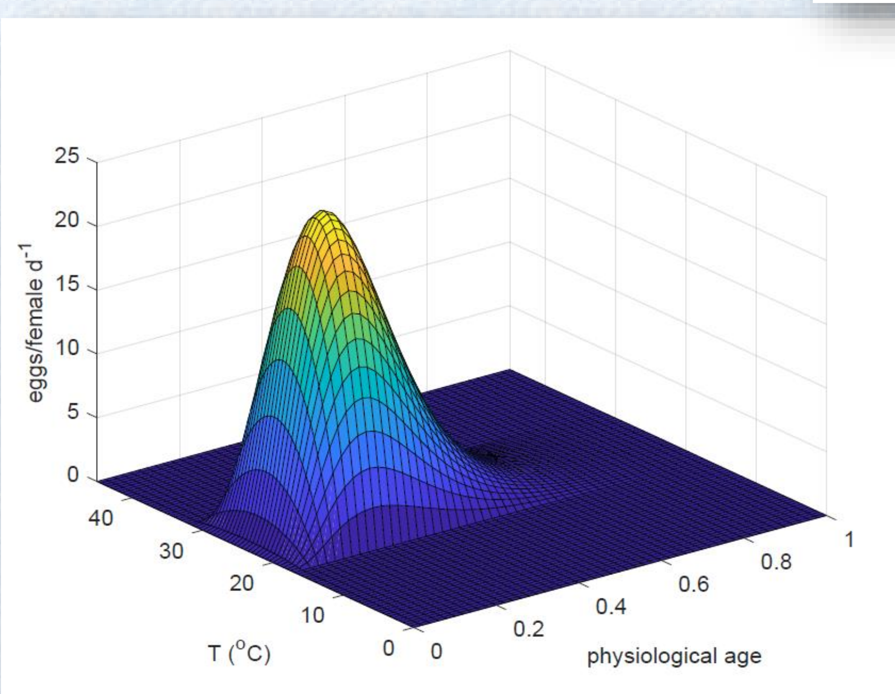
Same development rate function for pupae and adults

Gutierrez, Ponti, Cooper, Gilioli, Baumgärtner, Duso, 2012
Prospective analysis of the invasive potential of the European grapevine moth *Lobesia botrana* (De & Schiff.) in California. Agr. Forest Entomol. 14, 225–238.

L. Botrana biodemographic functions

Development:
Lactin functions



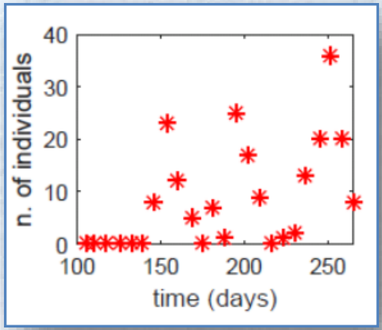


Fecundity function

$$a x^b e^{-cx} \left[1 - \left(\frac{T - T_L - T_0}{T_0} \right)^2 \right]$$

L. Botrana mortality rate function

$\boxed{m^i(T) \text{ mortality rate function}}$??? No literature data



Data on population dynamics to estimate mortality rate function

$$\boxed{m^i(t) = \sum_{j=1}^{5} p_{ij}\xi_{ij}(t)}$$

$\xi_{ij}(t)$ cubic splines built on the nodes $[0,20,40]$

Objective: minimize $\sum_i max\left\{0; \left(Y^i - N^i(t)\right) w_i \left(Y^i + u^i - N^i(t)\right)\right\}$

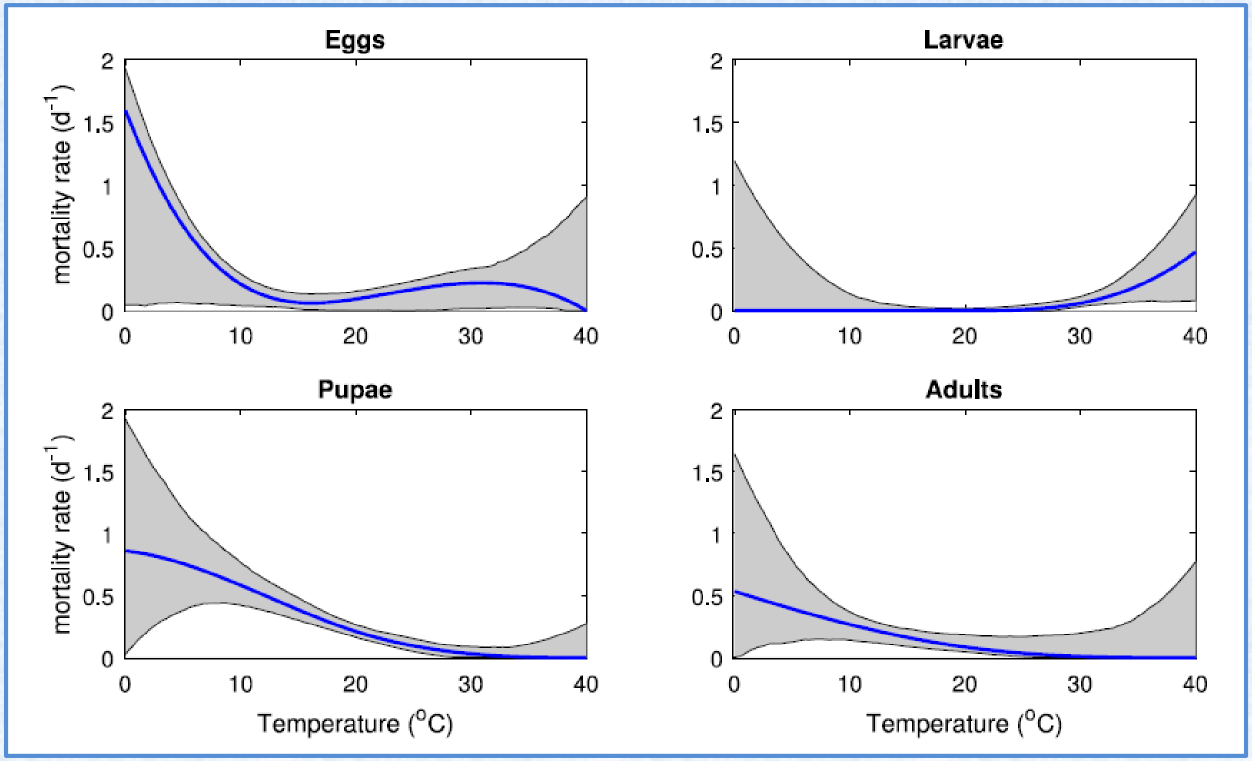
Weights for larvae >> weights for the other stages

- Grape berry moth particularly dangerous in larval stage
- Measurments of larvae more reliable than for the other stages

$\boxed{u^i}$ 10% for larvae, 50% for eggs and pupae

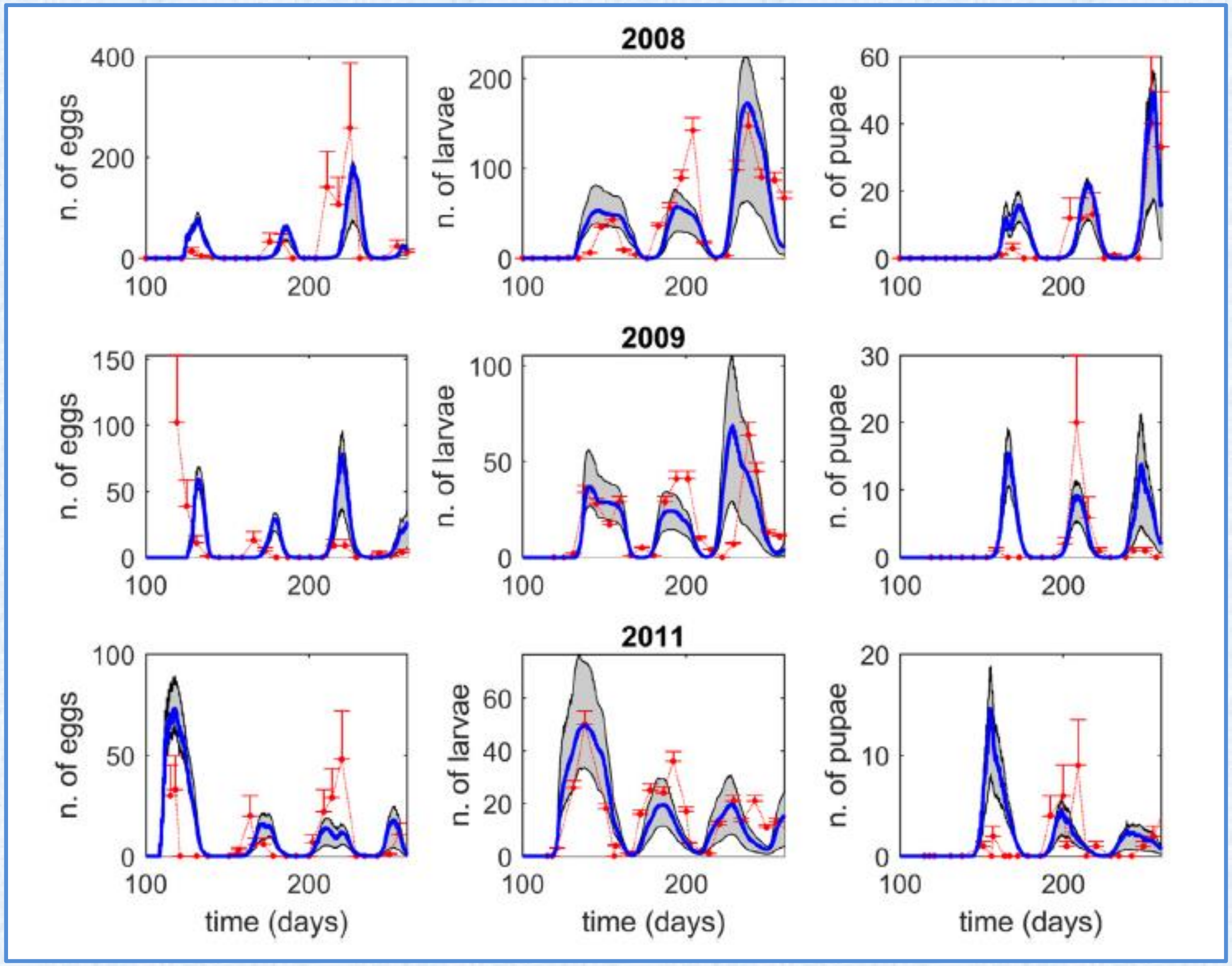
L. Botrana: mortality

Use data for 3 years: 2008 2009 2011



95% confidence bands for mortality: obtained drawing 500 values of the parameter vector from its multivariate normal distribution corresponding to 500 mortalities for each stage

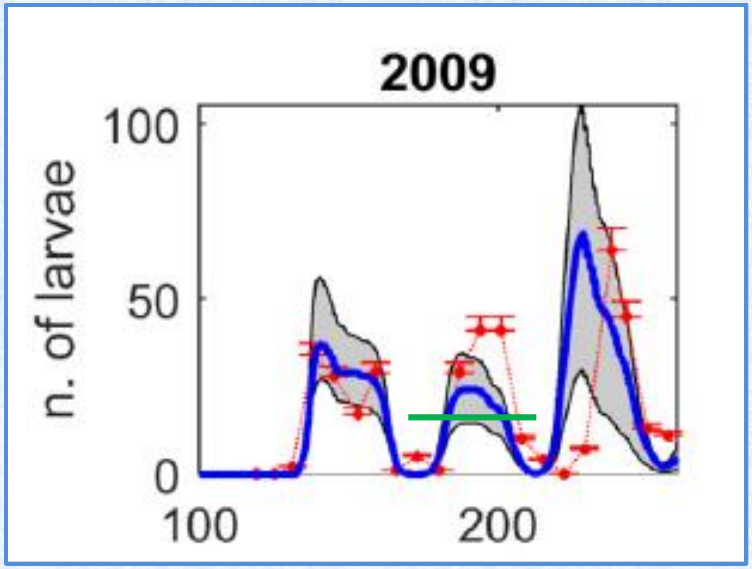
L. Botrana: dynamics



HIGHER WEIGHT FOR LARVAE

Pest control

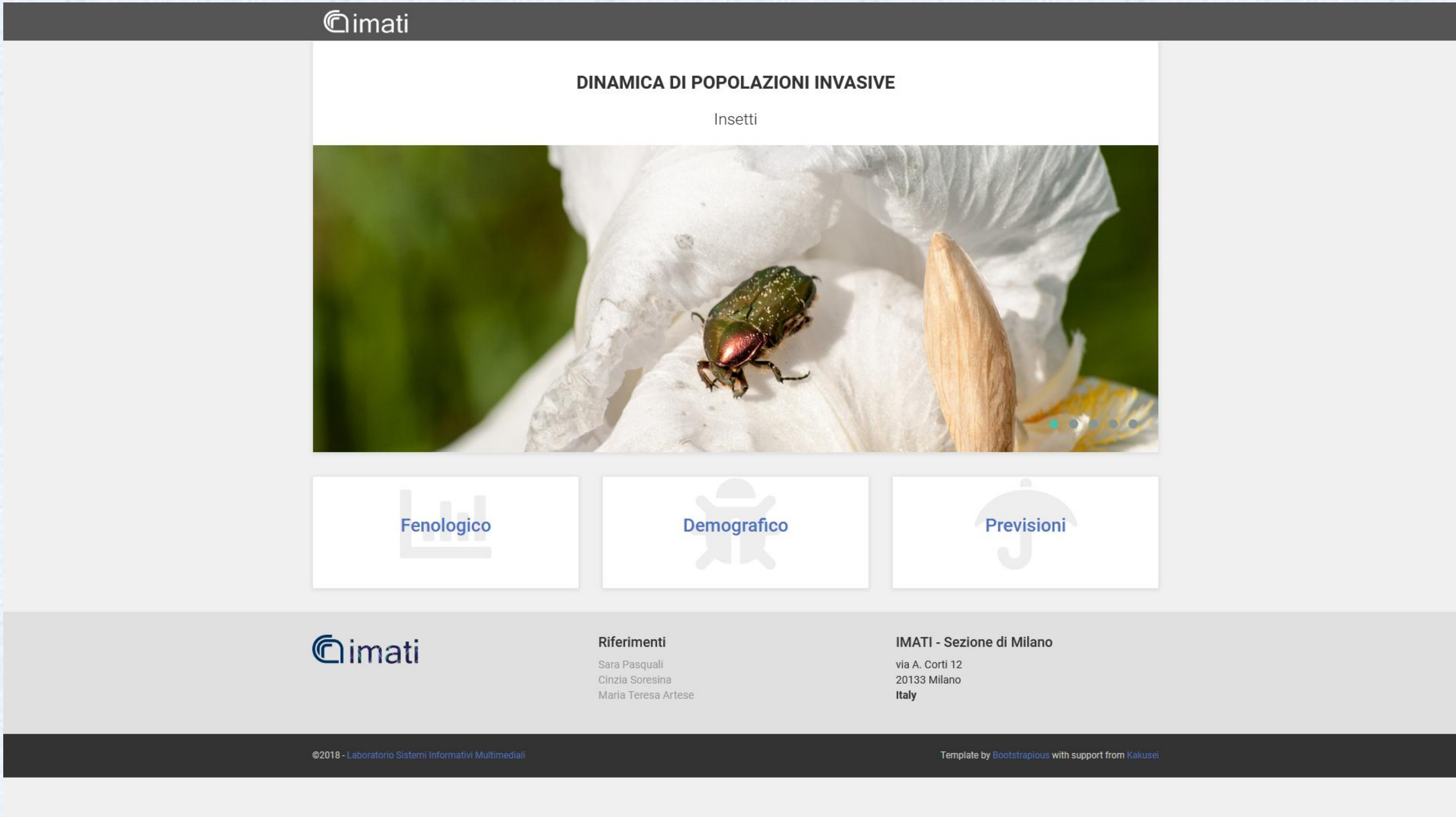
Population dynamics models can be used to forecast the dynamics and control if alert thresholds are crossed.



Larvae of 2nd generation: most damaging stage

Red: collected data
Blue: simulated dynamics
Green: control threshold for treatment in 2nd generation

Web service


imati
DINAMICA DI POPOLAZIONI INVASIVE
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Fenologico
Demografico
Previsioni
imati
Riferimenti
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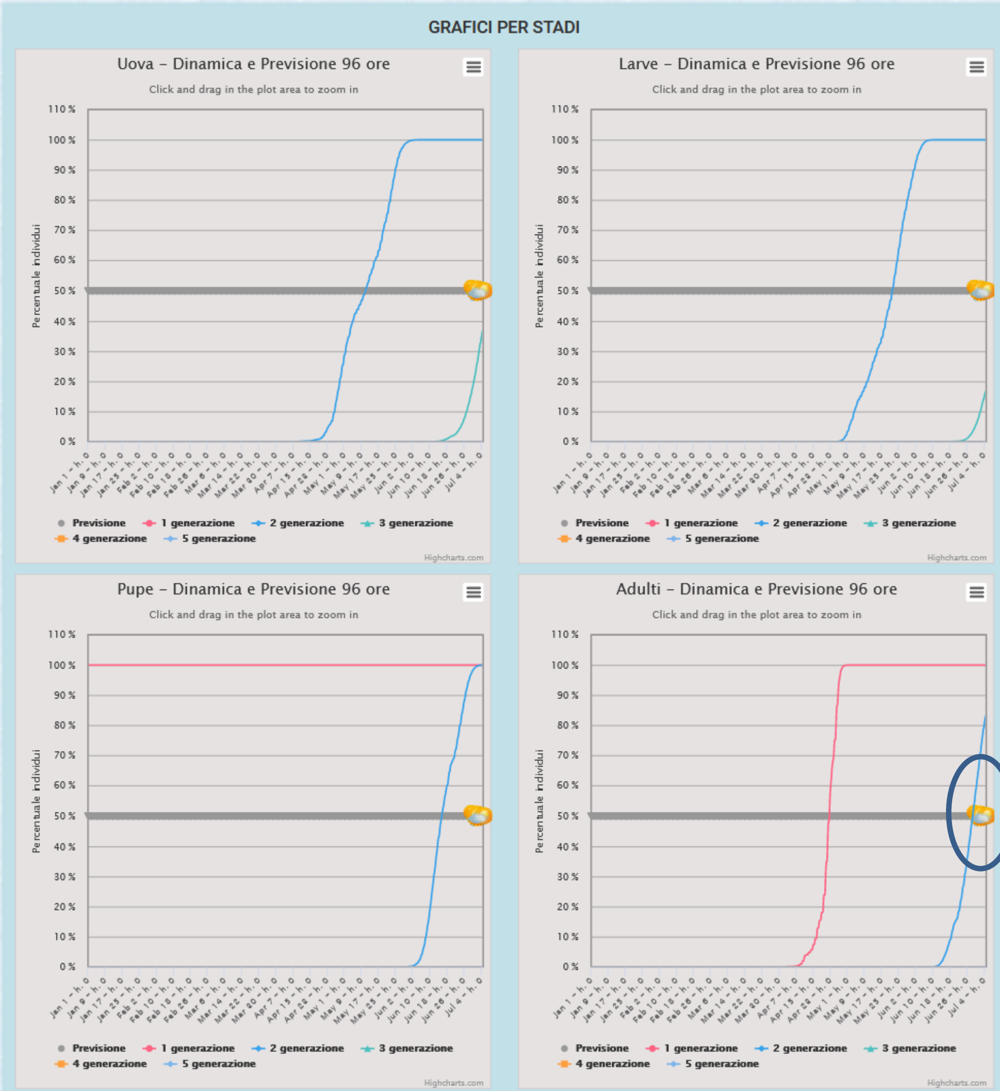
Web service


GRAFICI PER STADI
Uova – Dinamica e Previsione 96 ore
Click and drag in the plot area to zoom in
Percentuale individui
Larve – Dinamica e Previsione 96 ore
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Percentuale individui
Pupe – Dinamica e Previsione 96 ore
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Percentuale individui
Adulti – Dinamica e Previsione 96 ore
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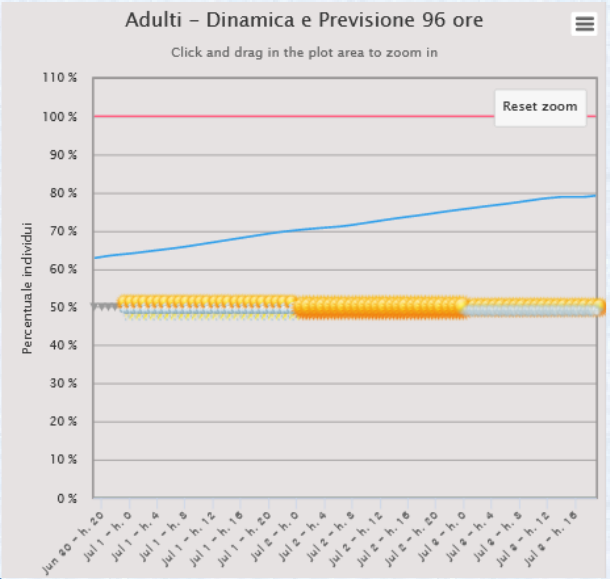
Percentuale individui
Previsione
1 generazione
2 generazione
3 generazione
4 generazione
5 generazione
Highcharts.com


Adulti – Dinamica e Previsione 96 ore
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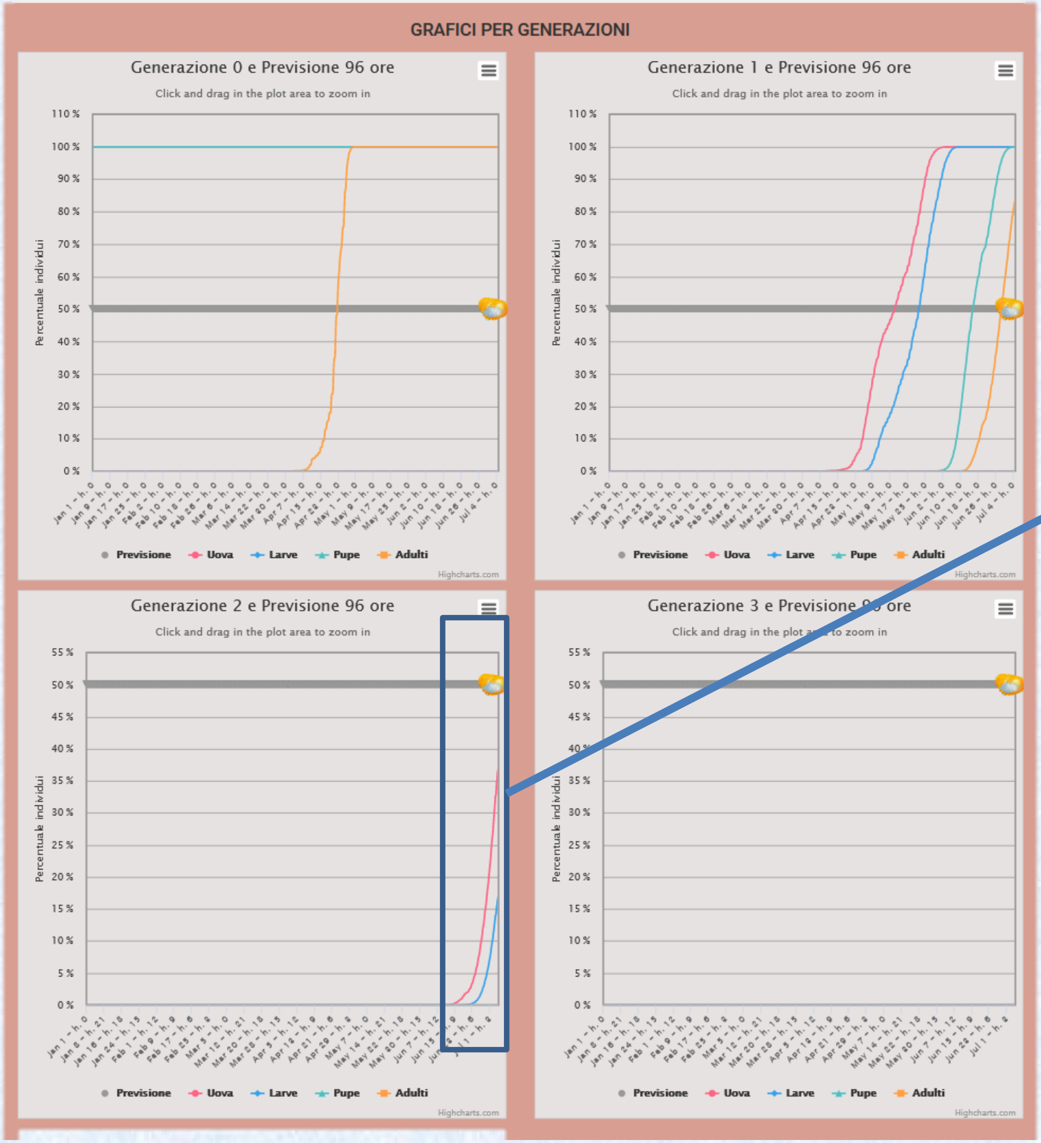
Web service



GRAFICI PER GENERAZIONI
Generazione 0 e Previsione 96 ore
Click and drag in the plot area to zoom in
Percentuale individui
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Uova
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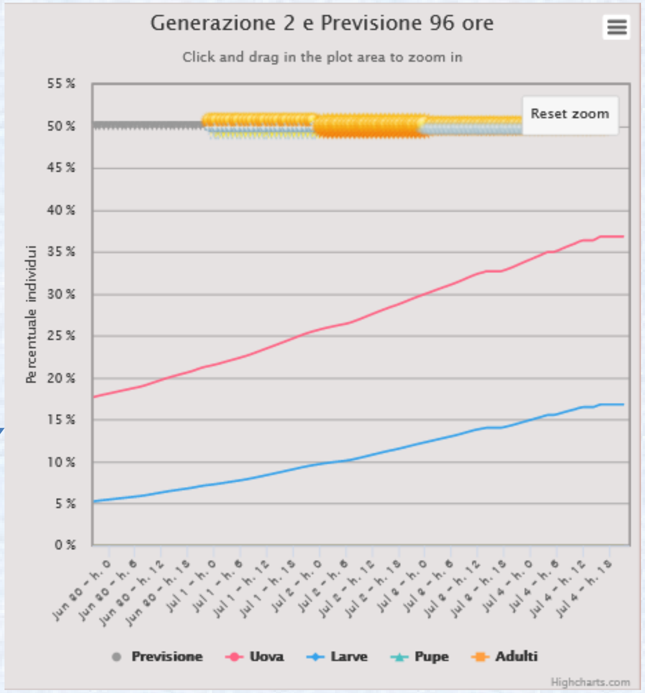
Generazione 1 e Previsione 96 ore
Generazione 2 e Previsione 96 ore
Generazione 3 e Previsione 96 ore
Highcharts.com



Generazione 2 e Previsione 96 ore
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GRAZIE