Modeling Green Peach Aphid populations exposed to elicitors inducing plant resistance on peach

Alberto Lanzoni[1] Francesco Camastra[2] Angelo Ciaramella[2]
Antonino Staiano[2] Giovanni Burgio[1]

[1]**Dipartimento di Scienze e Tecnologie Agro-Alimentari**
Alma Mater Studiorum-Università di Bologna
Italy

[2]**Dipartimento di Scienze e Tecnologie**
Università di Napoli Parthenope
Italy

Integrated pest management (IPM) combines chemical, biological, and agronomic control to provide targeted and efficient pest management solutions

IPM is now mandatory in all the member states of the EU

Insecticides are designed to be extremely effective at killing targeted pests but also have the potential to adversely affect non-target natural enemies

For many years natural enemies and insecticides were considered incompatible.
This is likely to be true for broad-spectrum insecticides such as organophosphates and carbamates this is not the case for newer insecticides that have higher selectivity and more desirable ecotoxicological profile

Natural and synthetic compounds called **elicitors** that induce similar defense responses in plants as induced by the pathogen infection

LAMINARIN ⟶ β-1,3-glucan derived from the brown algae *Laminaria digitata*

Chemical plant elicitor induces

- production of phenolic compounds
- accumulation of phytoalexins
- expression of a set of pathogenesis-related proteins

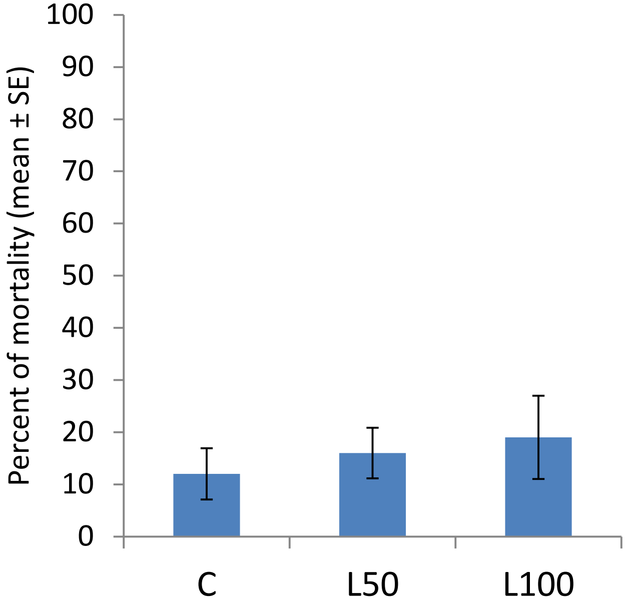
In grapevine leaves induce a significant protection against

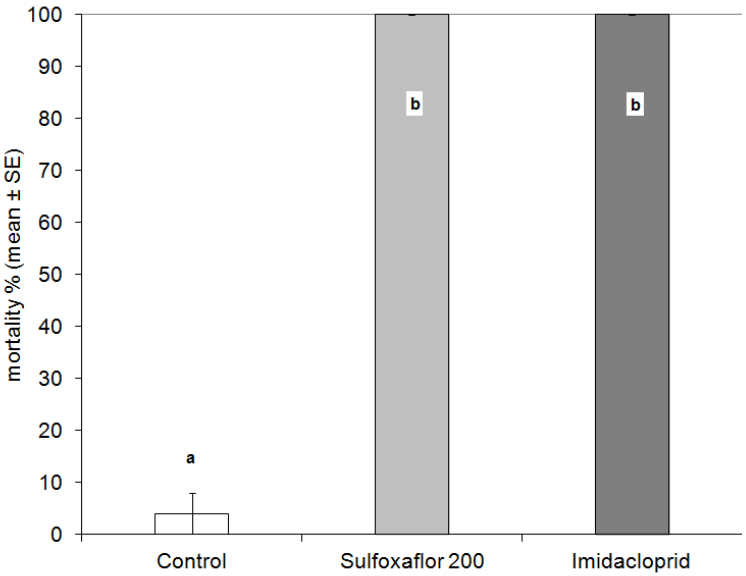
- Gray mould *Botrytis cinerea*
- Downy mildew *Plasmopara viticola*

Field trials gave indications about laminarin efficacy against aphids on apple orchards

- How to study and caracterize/quantify possible effects on Green Peach Aphid (GPA) *Myzus persicae* in the laboratory or better with so called *in-planta* trials since, to be effective, inductors require the response of the plant?

Not with DL_{50} or classical insecticide efficacy trials





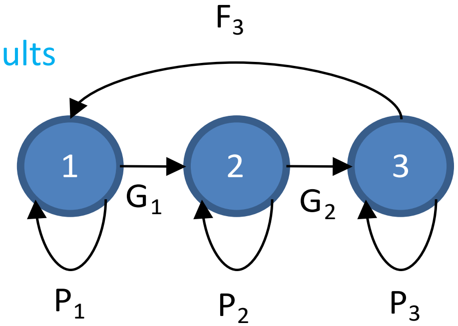
Using demographic toxicological analysis that estimates the total effect of a compound at population level

The model

Life cycle graph of the Green Peach Aphid (GPA) *Myzus persicae*

The number in the nodes correspond to stages

(1) = small (N1 + N2) nymphs (2) = big (N3 + N4) nymphs (3) = adults



G_1, survival of small nymph stages into big nymph stages
G_2, survival of big nymph stages into adult stage
P_1, survival of small nymph stages within small nymph stages
P_2, survival of big nymph stages within big nymph stages
P_3, survival of adult within adult stage;
F_3, fecundity of adults.

The relative stage/size-classified population projection matrix is

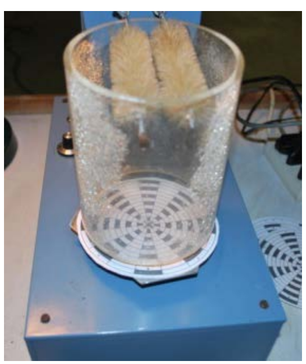
$$\begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix}(t+1) = \begin{bmatrix} P_1 & 0 & F_3 \\ G_1 & P_2 & 0 \\ 0 & G_2 & P_3 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix}(t)$$

and the vectors $\mathbf{n}(t)$ and $\mathbf{n}(t+1)$ give the state of the population, i.e. the number of individuals in each of the three stages, at time t and $t+1$

Bioassay carried out in a greenhouse to assess the population-level responses of two different concentrations of laminarin against the GPA on peach plants

Potted peach plants were inoculated with GPA (nymphs of mixed ages and adults) and after a week treated with laminarin

- 50 ml/hl
- 100 ml/hl
- Control ⟶ water only



- After 2 days and on five subsequent intervals, a group of plants was sampled
- For the sampling of aphids on peach plants, a brushing machine was used (Leaf Brushing Machine)
- The number of specimens of each GPA stage present was counted

Data consisting of population time series were used to generate a stage-classified projection matrix

Population matrix parameter estimation by QP

Most of the methods utilized for estimating the parameters of age or stage-classified models rely on following cohorts of identified individuals

However in semi-field, *in-planta* or field studies the observed data typically consisted of a time-series of population vectors $\mathbf{n}(t)$ for $t = T_1, T_2, \ldots, T_n$, where individuals are <u>not distinguished</u>

The relationship between the observed data and the values of the parameters that produced the series involves an estimation process called ***inverse problem***

The set of parameters that minimize the residual between the collected data and the model output was firstly estimated using the **quadratic programming** method

Inverse methods for time series

Quadratic programming → routine **qp** on GNU Octave

Constraints: $P_i \geq 0$; $G_i \geq 0$; $P_i + G_i \leq 1$; $P_i \leq 1$; $F_i \geq 0$

$$\longrightarrow \hat{p} = \begin{bmatrix} P_1 \\ G_1 \\ P_2 \\ G_2 \\ P_3 \\ F_3 \end{bmatrix}$$

DEMOGRAPHIC PARAMETERS

The dominant eigenvalue (λ_1) of the population matrix is equal to the **finite rate of increase** (λ) of a population with a stable age distribution

λ represent the population multiplication rate → the number of times the population increases per unit of time

The **net reproductive rate** (R_0) is the mean number of offspring by which an individual will be replaced by the end of its life, and thus the rate by which the population increases form one generation to the next

$$R_0 < 1 \Leftrightarrow \lambda_1 < 1$$
$$R_0 = 1 \Leftrightarrow \lambda_1 = 1$$
$$R_0 > 1 \Leftrightarrow \lambda_1 > 1$$

< 1, the population is diminishing

= 1, the population is stationary

> 1, the population is increasing

- ✓ Matrix Population Models are a powerful tool for assessing the effects of a toxicant on arthropods both in laboratory and semifield conditions
- ✓ **All the results rely on how much the estimated parameters of the matrix are able to represent the observed population dynamic**

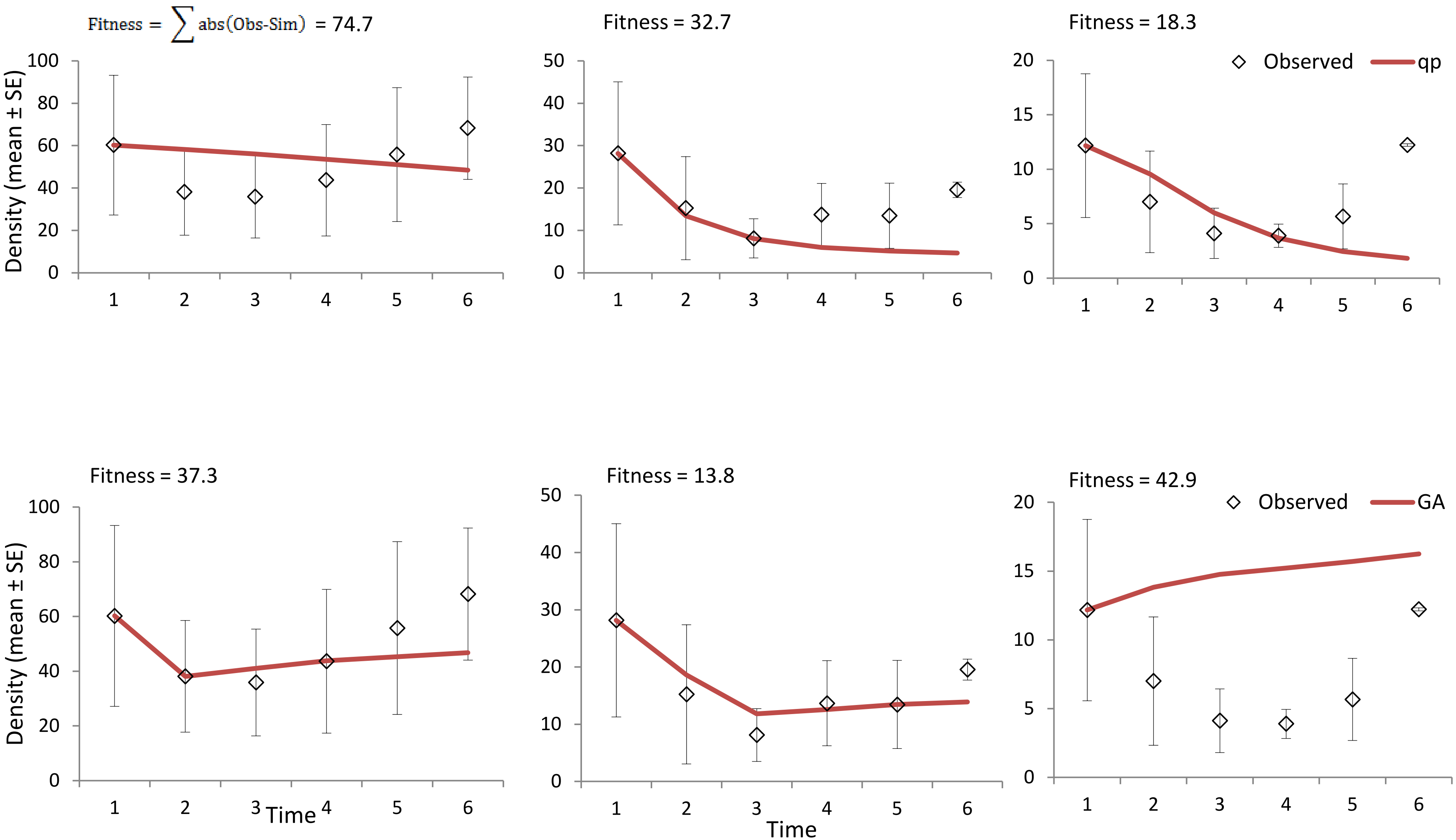
Genetic algorithms (GA)s

- GA is a method for solving optimization problems, constrained or unconstrained, based of natural selection
- GA evolves a population of individual solutions through a number of generations
  - At each generation, the population is subject to genetic operators of selection, crossover and mutation which combine the parent individuals to create new individuals for the next generation
  - Over successive generations, the population moves (evolve) toward an optimal solution.
  - The selection of individuals for reproduction is made on the basis of their goodness w.r.t. a criterion, named fitness (the function one wants to optimize)

Population matrix parameter estimation by GA

- **Individual**: real number coding
- **Population size**: 300
- **Max generations**: 600
- **Selection**: roulette wheel
- **Crossover**: scattered (creates a random binary vector and selects the genes where the vector is a 1 from the first parent, and the genes where the vector is a 0 from the second parent, and combines the genes to form the child)
- **Elite count**: 0.05*Population Size
- **Crossover Rate**: 0.8
- **Mutation**: uniform
- **Mutation rate**: 0.01
- **Fitness function**: $\sum \mathrm{abs}(\mathrm{Obs}\text{-}\mathrm{Sim})$

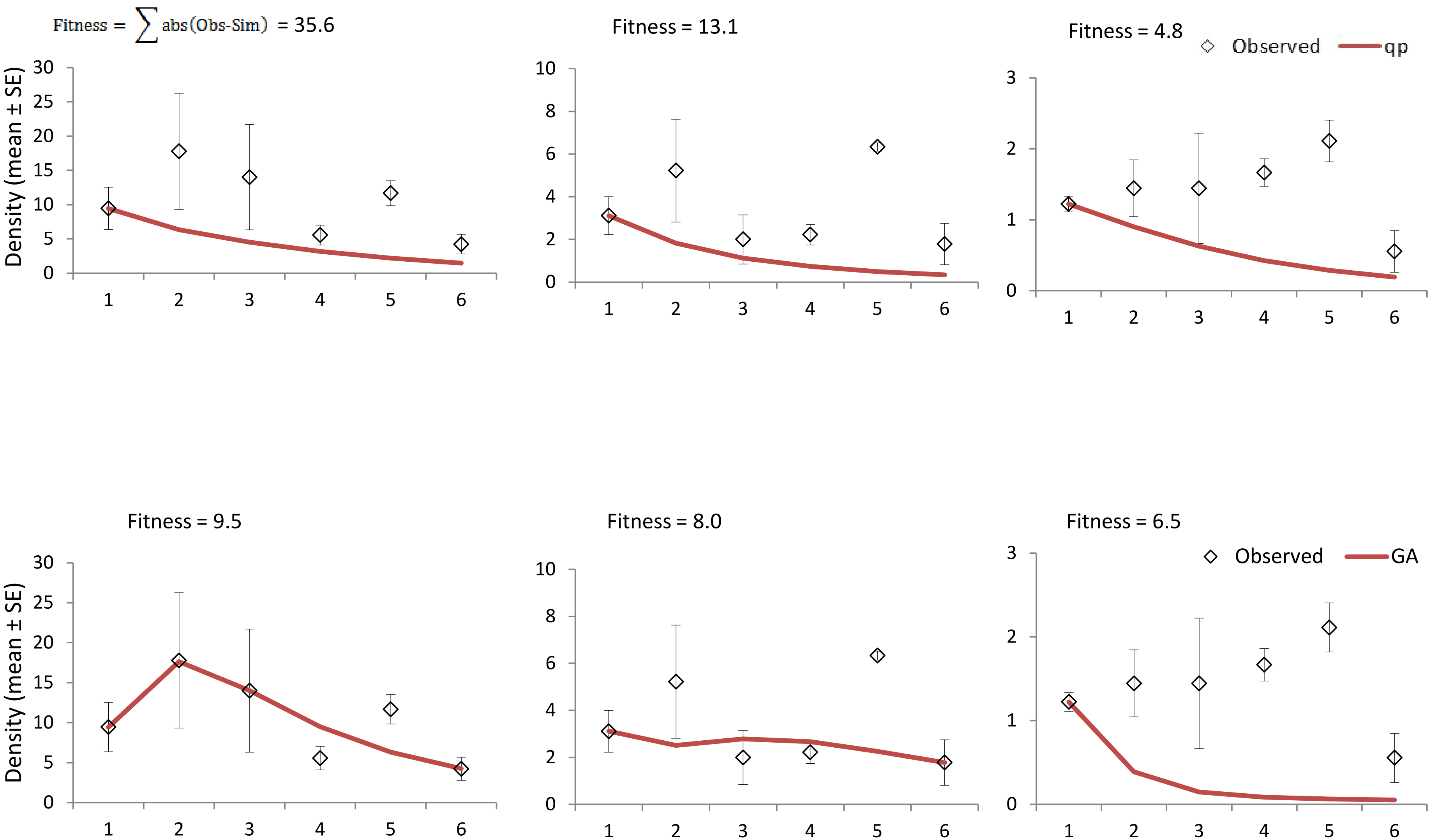
Control



Observed values are means over 3 replicates
qp are predictions based on matrix estimated by quadratic programming
GA are predictions based on matrix estimated by Genetic Algoritms

We took **n**(1) as known and used the estimated matrix to project the population to *t* = 6

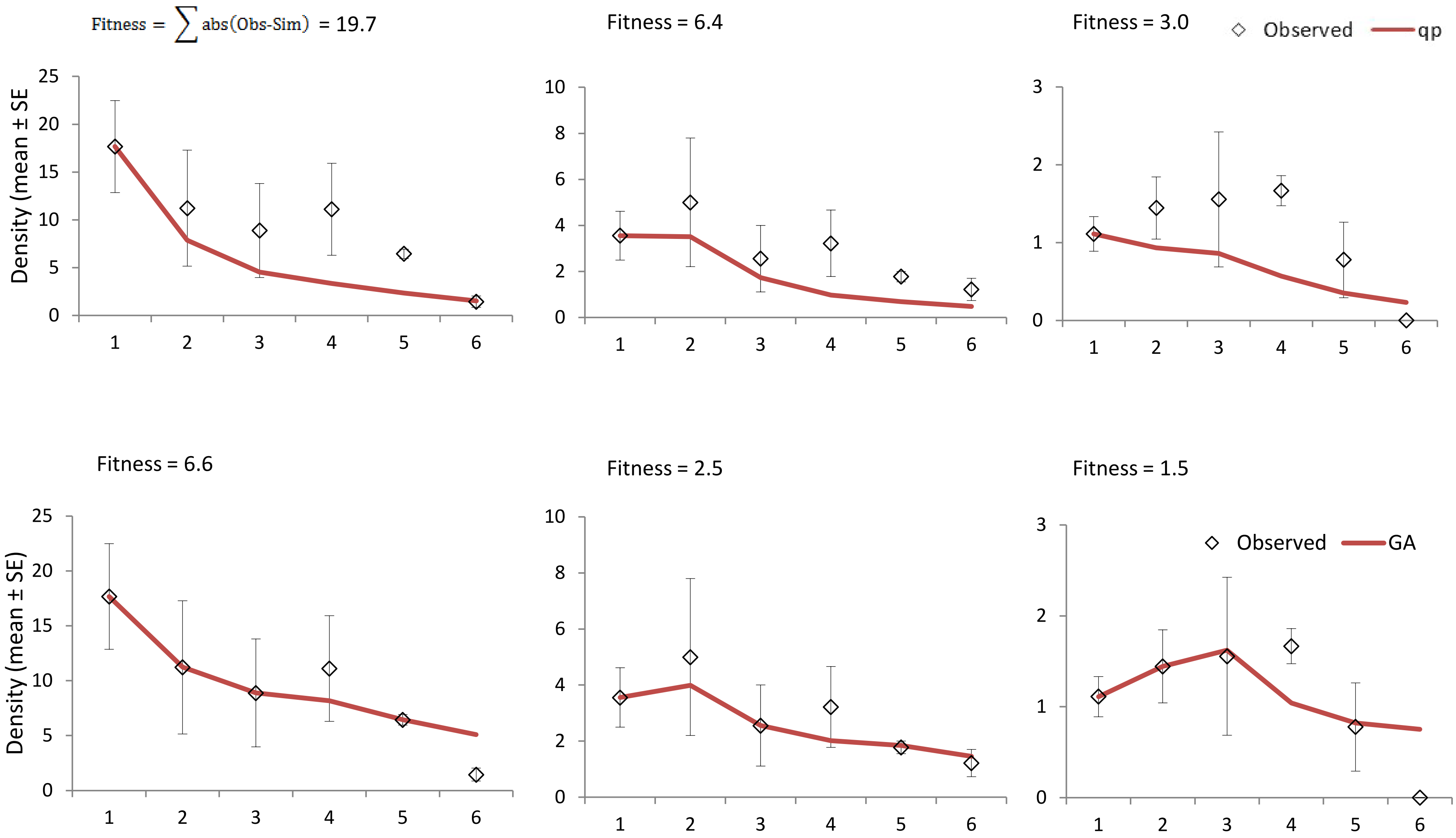
Laminarin 50 ml/hl



Observed values are means over 3 replicates
qp are predictions based on matrix estimated by quadratic programming
GA are predictions based on matrix estimated by Genetic Algoritms

We took **n**(1) as known and used the estimated matrix to project the population to *t* = 6

Laminarin 100 ml/hl

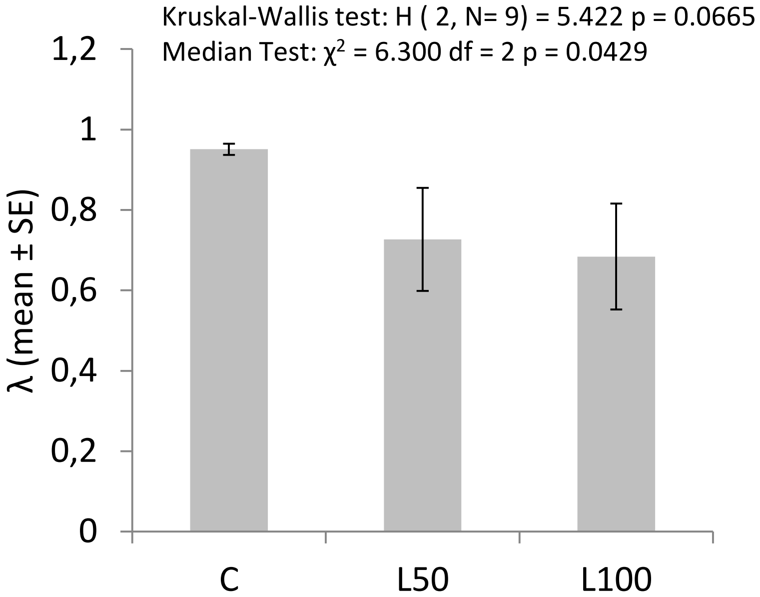


Observed values are means over 3 replicates
qp are predictions based on matrix estimated by quadratic programming
GA are predictions based on matrix estimated by Genetic Algoritms

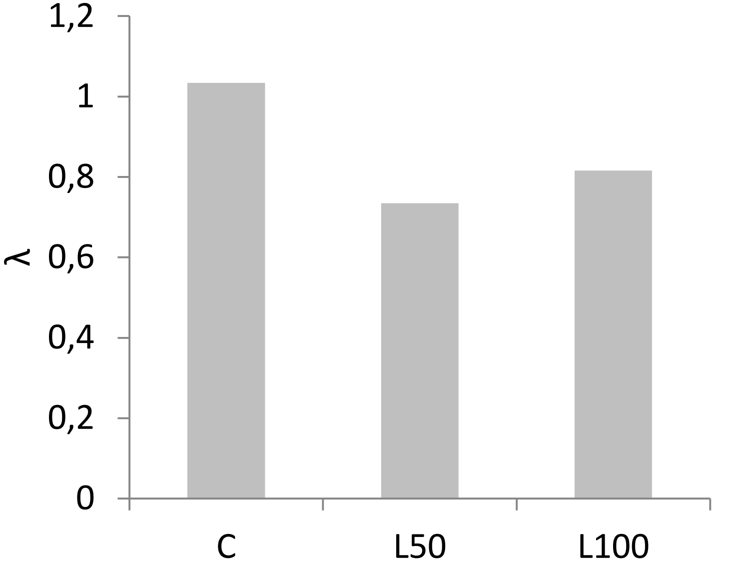
We took **n**(1) as known and used the estimated matrix to project the population to *t* = 6

Finite rate of increase (λ)

λ represent the population multiplication rate → the number of times the population increases per unit of time



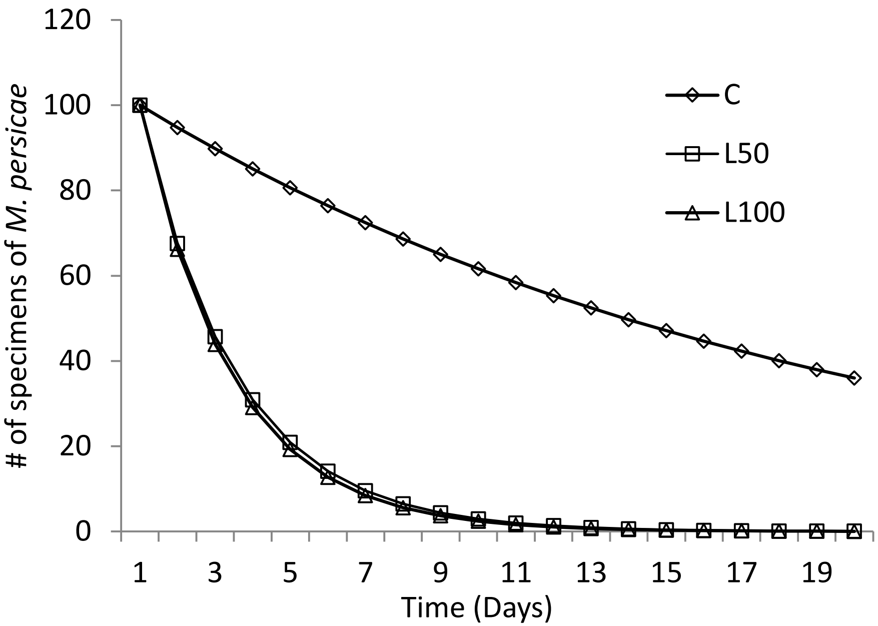
matrix estimated by quadratic programming



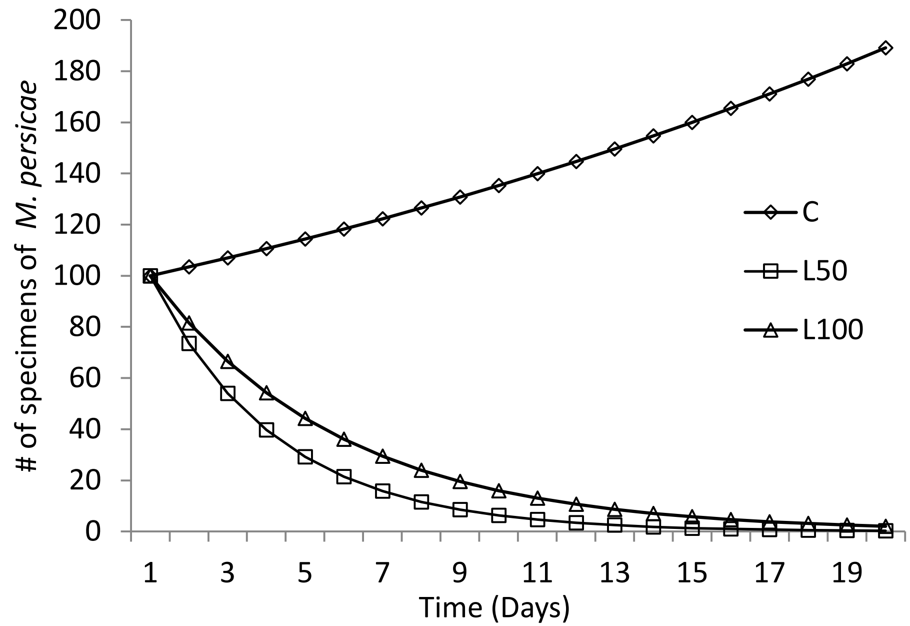
matrix estimated by Genetic Algorithms

Projection: the simplest form of analysis

Projection of a population of *M. persicae* starting from a vector **n**(0) of 100 specimens in a stable stage distribution



matrix estimated by quadratic programming



matrix estimated by Genetic Algorithms

TAKE HOME MESSAGE

- ✓ The new EU directive on IPM are asking for effective pest control strategies and agrochemicals preferentially with reduced negative impact on the environment and optimal protection and utilization of existing biodiversiry
- ✓ Population-level approaches estimating the total effect of insecticides on populations is increasingly important when choosing new pesticides for IPM
- ✓ MPMs are essential tools for this topic but accurate estimation of matrix parameters can be difficult
- ✓ GA optimization have proved to be an effective method for inverse estimation of MPM parameters
- ✓ Laminarin seems to be a promising tool for ecologically sound control of GPA for IPM programs