

Population dynamics of *Orius laevigatus* and *Frankliniella occidentalis*: a mathematical modelling approach

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Abstract

A mathematical model was utilised to study the population dynamics of the predator *Orius laevigatus* (Fieber) and its prey, *Frankliniella occidentalis* (Pergande). The INSIM programme, a simulation environment for chained boxcar trains and age-structured populations, was used for the simulations. The population interactions between *O. laevigatus* and *F. occidentalis* were simulated with different ratios of prey and predators. The simulations demonstrated that releasing *Orius* predators 10 days after the appearance of thrips, they can effectively control pest populations. The predator showed to be particularly effective when released in a 1:1 prey: predator ratio. Although the simulations are preliminary, they underline the importance of timing releases of *Orius* and of certain prey:predator ratios. In the *Orius*/thrips system, other variables like the influence of the host plant, like architecture and chemistry, and the (micro-)climate were not considered. For this, a model needs to be developed which is able to simulate a more complex and realistic system. However, our first simulations show that *Orius* can be effective in controlling thrips population, confirming field data collected in northern Italy.

Key words: *Orius laevigatus*, *Frankliniella occidentalis*, population dynamics, mathematical model, biological control.

Introduction

Since its introduction into Italy, the western flower thrips (WFT), *Frankliniella occidentalis* (Pergande), has become a major pest of ornamentals and vegetables including strawberry, eggplant, pepper and tomato. An extensive review of the pest status, biology, economic importance and control methods of WFT is reported in Tommasini (2003). Among the control strategies mentioned is an effective alternative to chemical management, biological control by predatory *Orius* spp. (Anthuridae). Species belonging to *Orius* sp. seem to be particularly promising candidates for the control of thrips pests in greenhouses and they currently receive much attention (Tommasini, 2003).

Modelling of the population dynamics of *Orius* and the thrips-*Orius* interactions can be helpful in (1) to optimize the mass-rearing system of the predator, (2) to improve the release strategies of *Orius* and (3) to evaluate the influence of parameters that affect the efficacy of biological control.

The aims of this study were: i) to study the population dynamics of three *Orius* species with particular attention to *Orius laevigatus* (Fieber), the species that is presently mass-reared in Italy and ii) to investigate the dynamics of the prey-predator system by a mathematical simulation of the populations.

Description of the simulation model

For the simulation we have utilised the INSIM programme (INsect SIMulation), a package described in detail by e.g. Diederick (1991). INSIM is a simulation environment for chained boxcar trains and age-structured population. It includes modules calculating

the number and developmental stages of insects by means of boxcars. Van Delden (1993) presented an example of utilisation of INSIM by a simulation of growth and development of *F. occidentalis* and *Neoseiulus (Amblyseius) cucumeris* Oudemans and their interactions on sweet pepper.

For the input parameters of the model we utilised data taken from Tommasini and Nicoli (1993), Fischer *et al.* (1992), van Delden (1993) and Alauzet *et al.* (1994).

1) Population dynamics of *Orius* at *ad libitum* prey

The population dynamics of predators was studied under the condition of abundant prey (*ad libitum*) and at constant temperature. In this way we can simulate the growth of the populations and forecast the number of individuals of all the developmental stages of the insects. Such data are particularly helpful to optimise the mass-rearing system of the predators. INSIM simulates a population growing in an unlimited way according to the equation:

$$\frac{dN}{dt} = r N$$

Starting with a population size N_0 , the population size at time t is calculated by integration of dN over time period $t-t_0$. The exponential growth curve is:

$$N_t = N_0 e^{rt}$$

and the intrinsic rate of population increase is:

$$r = \frac{[\ln(N_t/N_0)]}{t-t_0}$$

For the input of the data we considered:

- Rate of development [1/days vs temperatures (°C)]; lower temperature threshold for all the stages (EGG, L1-L2-L3-L4-L5, MALES, PREFEM, OVFEM) vs days (PREFEM = pre-ovipositing females; OVFEM = ovipositing females). Simple linear regression was used to estimate the lower temperature threshold by

using the x intercept method.

- Relative mortality rate (RMR) calculated as

$$\text{RMR} = \frac{-\ln(1-M)}{t},$$

where M is the rate of mortality and t is the development time in days for egg, larval stage and ovipositing females.

- Fecundity (egg/female/day); we have considered 10 classes of fecundity, each class = 4 days.

For biological parameters of *Orius* species we considered *F. occidentalis* (WFT) and *Ephestia kuehniella* (Zeller) (MFM) as preys. The output is the total number of the population over time (calculated as the sum of EGG, L1-L2-L3-L4-L5, MALES, PREFEM, OVFEFEM vs days).

2) Prey/predator population dynamics model

For this approach we have utilised a simulation of the interaction between *F. occidentalis* and *N. cucumeris* (van Delden, 1993), and adapted the input data for *O. laevigatus*.

Input data for the prey-predator model were:

- Biological data of thrips [development times of all life stages; fecundity (egg/female/day); RMR].
- Biological data of *Orius* (see above).
- Functional response of *Orius* (type Holling II; $a = 0.2$; plateau = 24 thrips adults). For the calculation of the functional response equation, see section 3 of material and methods, below.

3) Calculation of the functional response

When a natural enemy (here *Orius*) kills part of the pest population (here thrips) the number of prey killed will depend both on the pest and predator density. In the dynamic system we use, this can be determined by coupling the functional response formula of the predator to the population dynamics formula of the pest. The rate of change of the prey (host population) will be:

$$\frac{dN}{dt} = r N - f(N_p, N),$$

where $f(N_p, N)$ is the functional response of the enemy to the prey. For the predator the rate of change becomes:

$$dN_p = f(N_p, N) - b N_p,$$

where b is the relative mortality rate of the enemy. The function $f(N_p, N)$ may be one of the three types of Holling's functional response curves (Holling, 1966; for a summary of functional response models, see Mols, 1993).

We did not have precise data to determine the functional response of *Orius*, but utilising an experiment on the predation of *Orius* in *ad libitum* conditions (Tommasini and Nicoli, 1993) and some preliminary data about the walking speed of the predator (satiated females = 7.9 cm/sec; hungry females = 12.1 cm/sec, Tommasini, unpublished data), we have derived a response for *Orius* by a programme written by P. Mols (PREDATOR, Mols, 1993). With this simulation model that considers the behavioural component of the functional response, we have simulated the predation capacity of *Orius* at different prey densities. Then with the knowledge of the maximum level of predation (Tommasini and Nicoli, 1993), we could derive the plateau of

the functional response curve.

We chose a functional response of type II because it is commonly found in predator arthropods and because other studies on *O. laevigatus* have shown a type-II response (Isenhour and Yeargan, 1981; McCaffrey and Horsburgh, 1986; Sauced-Ginzalez and Reyes-Villanueva, 1987; Isenhour et al., 1990; Coll and Ridgway, 1995). For Holling's type II functional response, we used the random predator equation:

$$N_{\text{pred}} = N_0 (1 - \exp(a - (T - N_{\text{pred}} T_h))),$$

where T_h is the handling time, T is total time available, N_0 the prey density and a is the parameter of the Holling function; considering the behavioural components of the functional response, $a = V D S_r$ (V = walking time, D = reactive distance of predator to prey, S_r = success ratio). Our simulations with the PREDATOR programme are based on the fact that the velocity depends on the hunger level of the predator and may also change after prey consumption (Mols, 1987; Mols, 1993).

In the simulation we calculated different prey/predator stage combinations and different prey: predator ratio: a) thrips eggs and *Orius* eggs (at several prey: predator ratios); b) thrips females and *Orius* females (10 thrips female/m²: 10 *Orius* female/m² after 10 days; 10 thrips female/m²: 5 *Orius* female/m² after 10 days; 10 thrips female/m²: 1 *Orius* female/m² after 10 days).

Results

1) Population dynamics of *Orius* at *ad libitum* prey

Many simulations were carried out with combinations of different preys (WFT and MFM) and *Orius* spp. (*laevigatus*, *insidiosus*, *niger*). As an example of simulation results, the growth of *O. laevigatus* populations on WFT at 26 °C, starting with 10 ovipositing females, is shown in figure 1.

After studying all the simulation results, we came to the following conclusions:

- the population dynamics of *O. laevigatus* and *O. majusculus* were very similar on WFT but on MFM the growth of *O. majusculus* was faster due to lower larval mortality and fecundity was higher than that of *O. laevigatus*;
- the population growth of *O. laevigatus* on WFT was slightly slower than on MFM; the higher fecundity on MFM is partially compensated by a higher mortality in the larval stages (higher RMR);
- for *O. majusculus* the population growth was slightly faster on MFM than WFT: this can be explained by the higher fecundity on MFM eggs;
- *O. insidiosus* was very similar in biological characteristics to *O. laevigatus* and *O. majusculus*;
- *O. niger* was characterised by a very low fecundity, resulting in an intrinsic rate of increase of 0.

2) Prey/predator population dynamics model

We simulated the population interactions between *O. laevigatus* and *F. occidentalis* with different prey: predator ratio. When starting with *F. occidentalis* eggs and *Orius* eggs.

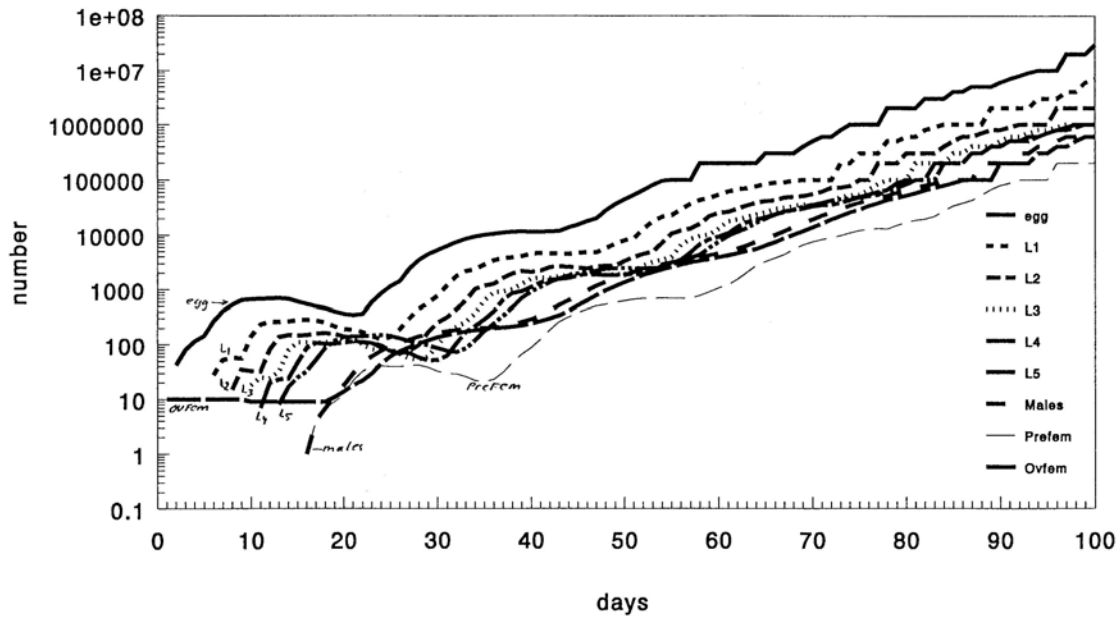


Figure 1. Simulated growth of populations of *O. laevigatus* on *F. occidentalis*, in conditions of abundant prey and at constant temperature (26 °C).

In general for several prey: predator ratio, *Orius* controlled well the thrips populations, and for several prey: predator ratios, we found that generally *Orius* did control the thrips populations sufficiently until 90 days from introduction. However, after this time the thrips populations showed a drastic increase.

When starting with thrips and *Orius* females, the following was found for three prey: predator ratios. When starting with a population of 10 thrips female/square meters and 10 *Orius* females/square meters after 10 days

(ratio 1:1), the predator controlled the pest very well (figure 2). The populations reached a fluctuating equilibrium at low level of the pest. When starting with 10 thrips female/square meters and 5 *Orius* after 10 days (figure 3), we initially observed a slow population increase of both pest and predator during the first 80 days, followed by a fast increase of the pest population thereafter. When starting with an initial population of 10 thrips/square meters and 1 *Orius* female/square meters after 10 days, the thrips populations increased exponentially after 30 days (figure 4).

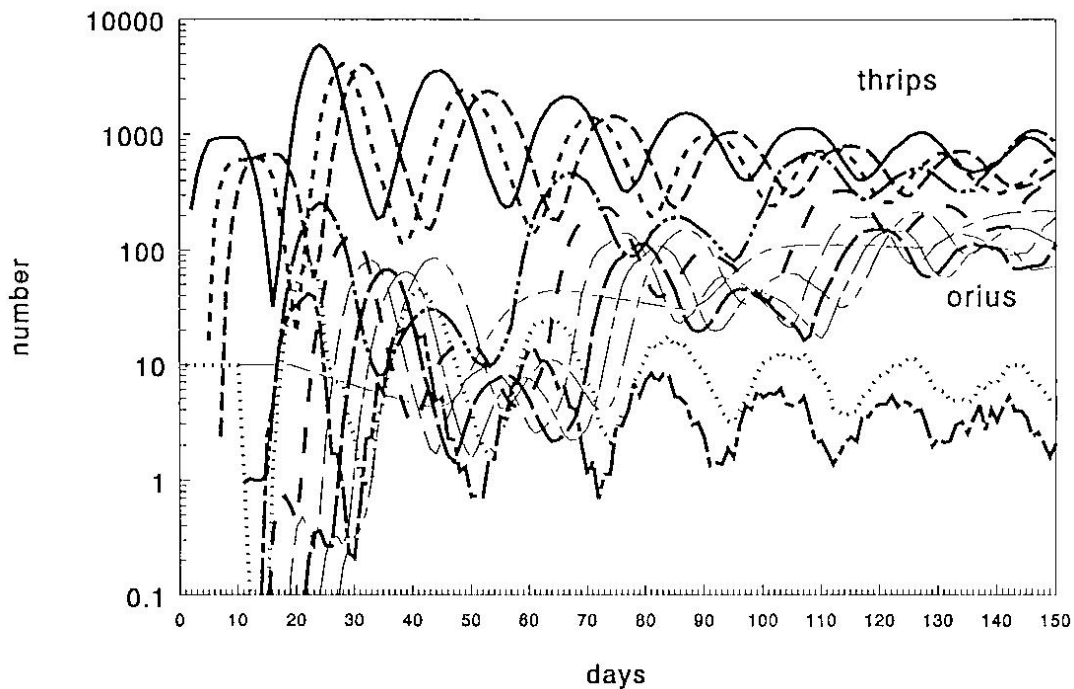


Figure 2. Simulated prey/predator population dynamics between *O. laevigatus* and *F. occidentalis*, starting with a population of 10 thrips female/square meter and 10 *O. laevigatus*/square meter after 10 days.

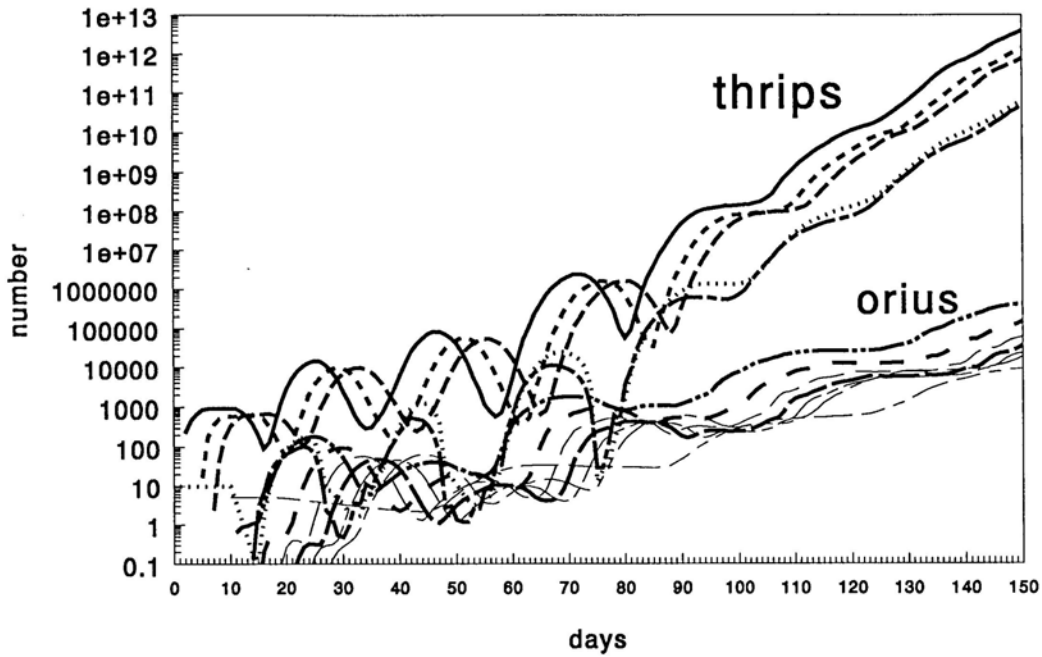


Figure 3. Simulated prey/predator population dynamics between *O. laevigatus* and *F. occidentalis*, starting with a population of 10 thrips female/square meter and 5 *O. laevigatus*/square meter after 10 days.

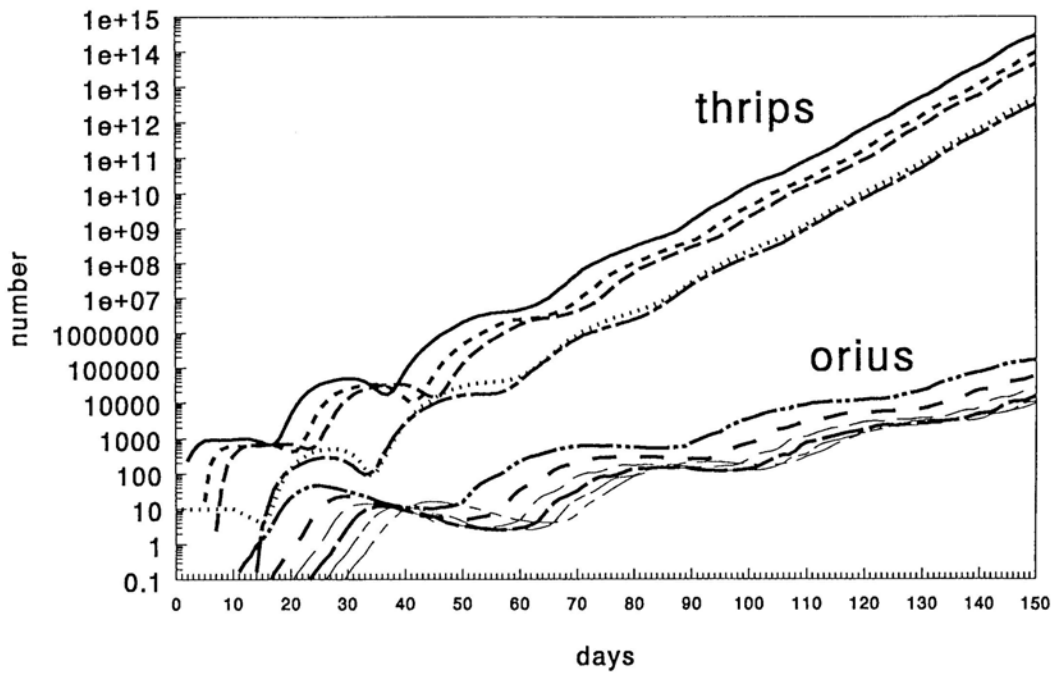


Figure 4. Simulated prey/predator population dynamics between *O. laevigatus* and *F. occidentalis*, starting with a population of 10 thrips female/square meter and 1 *O. laevigatus*/square meter after 10 days.

Discussion and conclusions

The population dynamic study learned us that this approach can be helpful to obtain insight in the dynamics of the predators (developmental stages) species in condition of abundant prey presence. As a result, more effective mass-production methods can be developed. It also made clear that one of the predator species, *O. niger*, is obviously not suitable for mass-rearing and biological control.

The results of the modelling of prey-predator population dynamics indicate that both the ration prey: predator and the introduction moment of the predator is important to obtain sufficient control. We further conclude that *O. laevigatus* is effective at high thrips densities, but that the predator probably needs an alternative host at low thrips densities. We performed the *O. laevigatus*-thrips simulations before this predator became a common and popular control agent of *F. occidentalis* (e.g. Tommasini, 2003), because we were interested to have

an idea of the potential of *Orius* in controlling thrips infestations in northern Italy. The capacity of *O. laevigatus* to control *F. occidentalis* in greenhouses with pepper and eggplant of northern Italy is discussed by Tommasini (2003): the predator appeared to effectively control thrips and is suitable to be released also in combination with natural enemies used for control of other pests. Tommasini's findings are confirmed by results of other authors (Brødsgaard and Enkegaard, 1995; Wittmann and Leather, 1997). For successful thrips control by *O. laevigatus*, sampling and precise timing of releases is most important. Early release of *Orius*, as soon as thrips are detected, is resulting in early establishment of the predator and in a good interaction between prey and predator (Tommasini, 2003). Our simulations demonstrated that releasing *Orius* 10 days after the appearance of thrips may result in effect control of the pest, particularly at a release ratio of 1 predator per 1 prey. This study was performed with a relatively simple predator-prey system, because we did not consider variables such as the influence of the host plant on the searching behaviour. The importance of plant characteristics for thrips/*Orius* interactions is discussed by Coll and Ridgway (1995). Their work indicates, for example, that *O. insidiosus* searches less effectively for *F. occidentalis* thrips on tomato than on bean and pepper plants. Therefore, further investigations should be carried out in order to develop a more realistic model taking into account the influence of the host plant, the (micro) climate and the phenology of the pest and natural enemy.

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