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Developing a subpopulation-based model for the olive fruit fly *Bactrocera oleae* (Diptera: Tephritidae): conceptual model outline †

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Abstract: *Bactrocera oleae* Rossi (olive fruit fly) is a dipteran of the family Tephritidae, considered the key pest of olives in Mediterranean countries, where it causes losses of great economic impact. Natural pest control is an important alternative or complement to the use of plant protection products against *B. oleae*. This is an ecosystem service that can be enhanced if we are able to predict its behavior, which can be done through computer models simulating interactions between animals, agricultural management and climate. In this paper we present the conceptual model of a spatially explicit subpopulation-based model being developed for *B. oleae* in olive groves. In this modelling technique, the simulated dynamic landscape is segmented into non-overlapping cells, where the subpopulations of *B. oleae* are represented as separate but interacting entities. Our model is based on the Animal Landscape Man Simulation System (ALMaSS), which comprises a highly detailed and realistic landscape representation, incorporating data on different aspects of farm management, crop development, and climate, and where simulated entities operate. We present the general outline of *B. oleae*'s life cycle, as well as succinct information on how these organisms interact with their environment. This is a step for the development of the final model and its implementation in ALMaSS.

Keywords: subpopulation-based simulation; complex agroecosystems; olive crops; *Bactrocera oleae*

1. Introduction

The dissemination of monoculture-dedicated land use and intensive agricultural practices has favoured the specialization and spreading of pests in the landscape, which is partly mitigated by pesticide application, but has led to several environmental problems. In these systems, natural pest control is an ecosystem service that could be alternatively or complementarily used, contributing to long-term sustainable and resilient agriculture.

For this ecosystem service to be used efficiently, we have to be able to predict its behaviour. This can be done using computer models that simulate animals in their environment [1,2]. To develop such models (1) the life history of the animal is delineated, (2) a conceptual model is outlined based on that life history, and (3) the conceptual model is coded into a system that allows to perform simulations. In the case of large populations of animals, spatially explicit subpopulation-based modelling techniques can be used. In these, the simulated dynamic landscape is segmented into non-overlapping cells, where the subpopulations of animals are represented as separate but interacting entities.

In here we present the outline of the conceptual model being developed for *Bactrocera oleae* Rossi in olive groves. This is a dipteran of the family Tephritidae and is considered the key pest of olives in the Mediterranean. Life cycle of this insect comprehends four developing stages: egg, larva, pupae and adult. Adults first emerge in spring and begin their activity, feeding on nectar or honeydew [3]. During this period, they usually attack olives from the previous season that remained on the trees. In early summer, high temperatures inhibit ovarian maturation of females. It is thought that, during this period, the flies can disperse through great distances and colonize other groves [4]. When females interrupt their reproductive diapause, they begin producing eggs and initiate oviposition when the fruits reach the proper development. Normally females lay one egg per olive fruit. During summer and early fall, the development of the fly is completed within the olive fruit, with pupation occurring inside it and adults emerging later in the season. From mid-autumn onwards, an increasing number of third instar larvae leave the olive fruit and pupate in the soil, where they overwinter, and emerge in the following spring. Olive fruit flies may also overwinter as adults and also, although less commonly, as eggs and larvae in unharvest fruits. The larvae developing stage is the damaging one, because larvae feed upon the pulp, resulting in quantitative and qualitative losses of table olives and oil. Life cycle of *B. oleae* greatly depends on climatic conditions, varying from 30–80 days during summer or in warmer areas, and up to 130 days during winter or in colder areas. Hot and dry summers cause a delay in the increase of *B. oleae* population, while humid and warm summers allow early infestations of the olive fruit. The number of generations of *B. oleae* is variable and depends on climatic and agronomic conditions. In areas with continental climate, 2 or 3 generations are observed per year while in Mediterranean coastal areas 3 or 4 generations are observed per year. Biotic factors, such as predation and parasitism may affect the number of pupae in the ground and the number of larvae in the fruits, respectively [5].

2. Conceptual model for *B. oleae*

The model for *B. oleae* will be developed under the framework of the Animal Landscape Man Simulation System (ALMaSS) [1], which comprises a highly detailed and realistic landscape representation, incorporating data on different aspects of farm management, crop development, and climate. This system has a spatial resolution of 1 m and a selectable time-step of 1 day.

The model for *B. oleae* considers the behavior of all life stages, (1) egg, (2) larva, (3) pupa, and (4) female (Figure 1), on a daily basis, according to climate variables and simulated changes in the landscape. Climate variables are daily precipitation (P – mm), daily air or soil temperature (T – °C), daily air relative humidity (RH – %), and daily wind intensity (V – m s^{-1}).

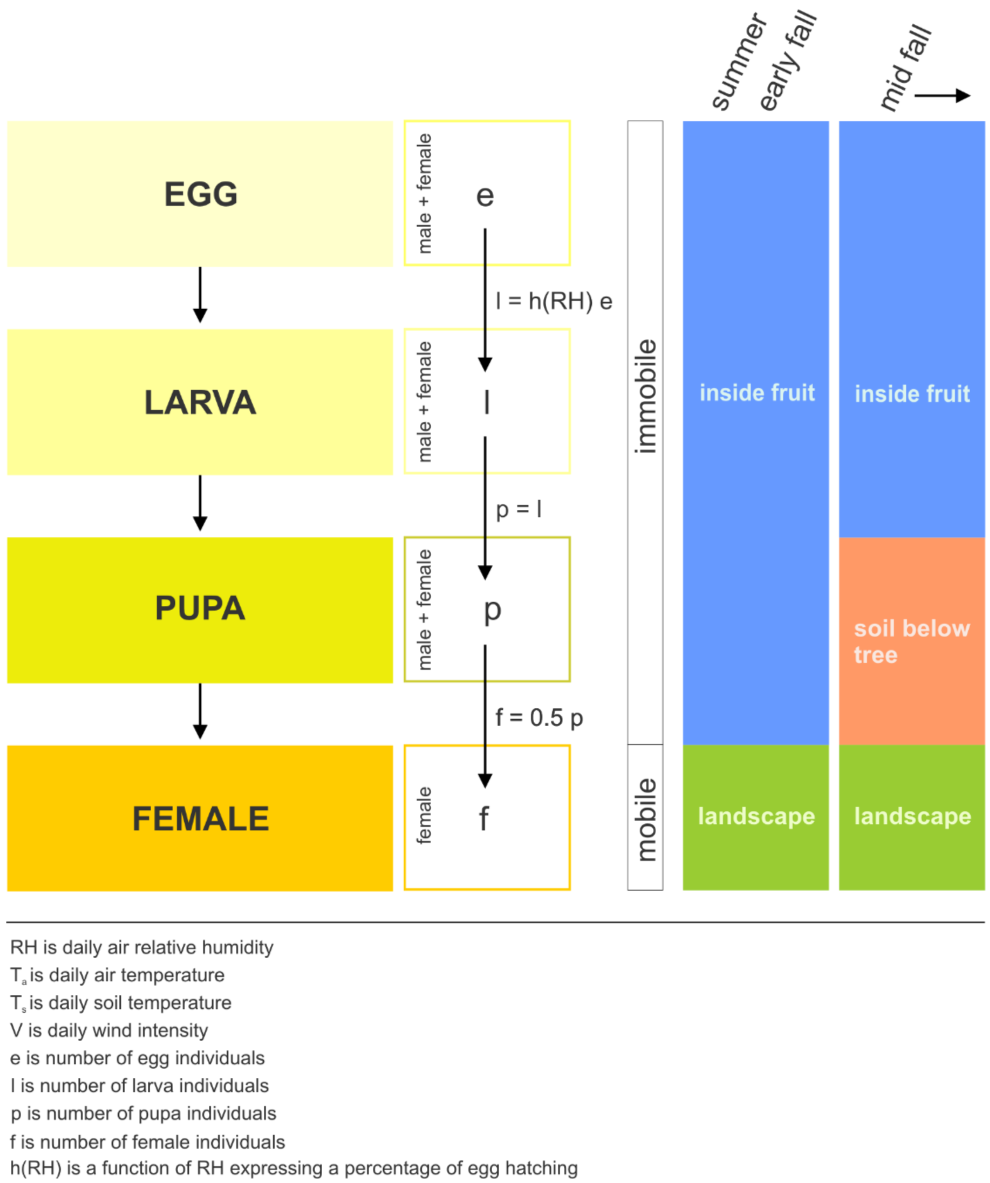

Figure 1. Life stages of *B. oleae* and other features considered in this model.

Flies develop into the next life-stage if they do not die before. For simplification, the three instars of the larval development were merged, and an overall larval stage is considered. Egg and larval stages occur inside the olive fruit. Pupal stage may occur (1) inside the olive fruit if the egg is laid in summer or early fall, and (2) in the soil below the olive tree if the egg is laid in mid fall or after. Eggs and pupae are not considered mobile. Female life stage occurs in the landscape, with most functions restricted to olive groves but passing through other vegetation patches to move to adjacent olive groves.

Egg hatching is dependent on RH, so the number of larvae will be k(RH) of the number of eggs right before evolving to larvae. The number of females corresponds to 0.5 of the number of pupae existent right before evolving to females, since the sex ratio is 1:1 approximately [6]. In this model only females are considered because they control the number of next generation individuals that will be created. Also, behavior of adult flies in terms of feeding does not damage the olive fruits, so we don't have to consider both males and females.

The simulation starts on January 1st, simulating only pupae in the soil of olive groves. When the pupal stage in the soil period is complete, the flies emerge as females (adults) and start ovarian development and movement. They complete several generations until harvesting, when, for simplification, only pupae continue to the following stage and all others are removed from the simulation.

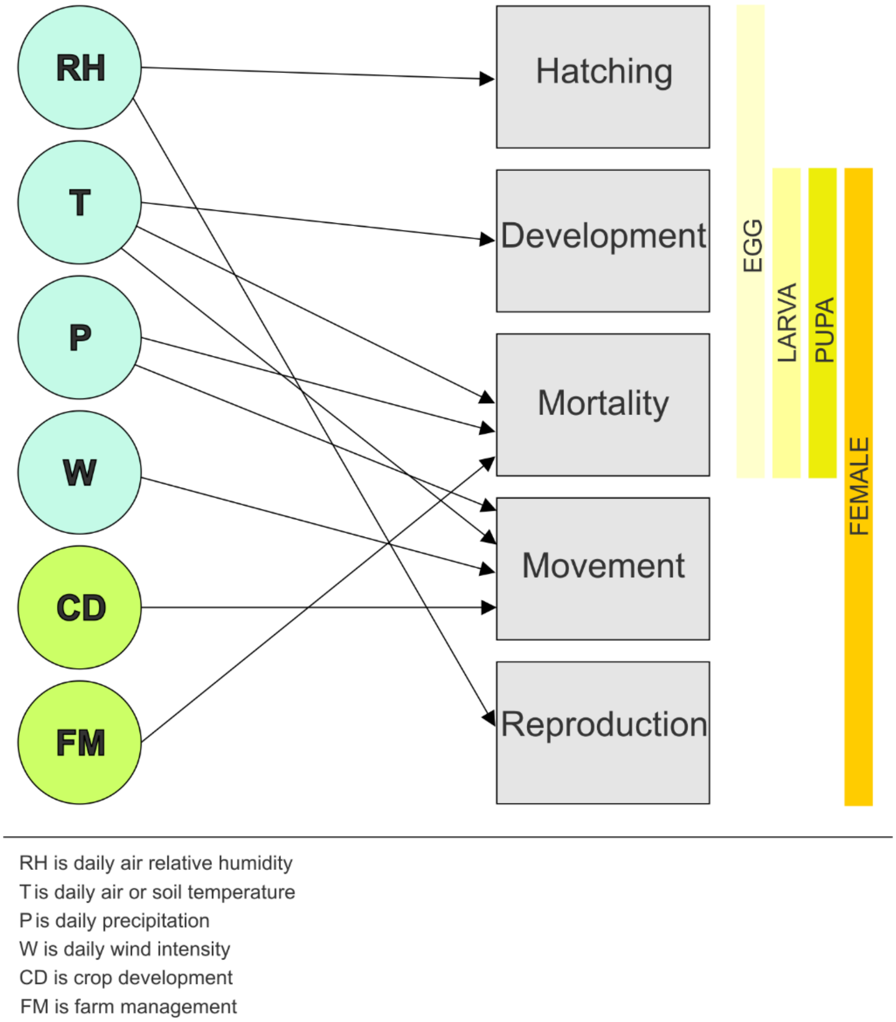

Figure 2. Variables and functions comprised in the model of *B. oleae*.

Figure 2 shows (1) hatching, development, mortality, movement and reproduction functions, (2) the variables they depend on – climate, crop development and farm management, and (3) the life stages when these functions occur.

3. Final remarks

The conceptual model for *B. oleae* is in its final stage of development. Coding and calibration using daily climate variables and data relative to individuals sampled in 2011 and 2012 in a study site are the next steps of this work. Daily climate data have been calculated from hourly measurements at the study site. The landscape model for that study site is also being developed. We expect that the future simulations will help to better understand *B. oleae*'s behavior in its environment.

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Conflicts of Interest: The authors declare no conflict of interest.

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