SHORT NON-REFEREED PAPER

THE DESIGN OF AN AGENT-BASED MODEL FOR SIMULATING THE POPULATION DYNAMICS OF *ELDANA SACCHARINA* (LEPIDOPTERA: PYRALIDAE)

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Abstract

Eldana saccharina Walker (Lepidoptera: Pyralidae) is a stalk borer pest which continues to plague the sugar industry in South Africa. The pest feeds on the internal tissue of sugarcane stalks, causing losses in sucrose and cane yields. Various control methods have been proposed in an attempt to suppress the pest and decrease its detrimental impact on the industry. These control methods are, however, often difficult and costly to test, implement and develop further in an iterative manner. In an attempt to better understand the behaviour and population dynamics of *E. saccharina*, it is proposed that an agent-based simulation model be developed, which accurately simulates the stalk borer's biology, feeding habits, mating behaviour, dispersal patterns and other characteristics. In particular, the complex mating behaviour of *E. saccharina* requires careful consideration and structural implementation in the model, as it plays a primary role in the continued prevalence of the pest. Once a carefully calibrated simulation model, which incorporates the natural variation of an ecological system, has been designed, certain control strategies can be further developed and tested using the model prior to in-field implementation. This approach aims to minimise cost and assist in the ongoing development of an integrated pest management (IPM) system. The modelling framework for a novel, agent-based model of *E. saccharina* is presented in this paper, as well as details of modelling approaches adopted to incorporate some of the biological attributes of the pest.

Keywords: Eldana saccharina Walker, sugarcane pest infestation, agent-based simulation, modelling approach, population dynamics, integrated pest management

Introduction

The stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) was first recorded in 1939 as a pest of sugarcane in South Africa by virtue of its suitability for egg laying in dead leaf material (Atkinson, 1979). This infestation has resulted in decreased sugarcane quality (measured as a decrease in sucrose yield) and has a negative impact on total plant biomass (Goebel and Way, 2003). In light of this, *E. saccharina* remains a major concern to the sugar industry and, as such, is the subject of numerous research efforts and proposed control strategies at the South African Sugarcane Research Institute (SASRI). Current control measures include sugarcane variety development (Keeping and Rutherford, 2004), chemical control (Leslie, 2009) habitat management (Conlong and Rutherford, 2009) and the sterile insect technique (SIT) (Potgieter *et al.*, 2011; Conlong and Rutherford, 2009).

Limiting factors hindering roll-out of these control methods include economic constraints on continual, incremental development of suitable implementation techniques, as well as a means for practically evaluating the anticipated relative impact of the technique when applied to infested sugarcane (personal communication[1]).

The successful development of a model that accurately depicts the pest's biological attributes, such as its feeding habits, mating behaviour and dispersal patterns, is expected to facilitate testing control strategies before in-field implementation. This will provide further insight into the ongoing efforts of developing an IPM for the effective management of *E. saccharina.*

Methods

Agent-based modelling is the computational study of social agents interacting in an autonomous manner as evolving systems. It allows for the study of complex adaptive systems and facilitates investigations into how macro-phenomena develop from micro-level behaviour among heterogeneous sets of interacting agents (Janssen, 2005). By simulating *E. saccharina* moths as individual agents who are governed by their biological preferences and limitations, the resulting relationships between these agents can be used to accurately predict population dynamics of the pest over space and time, based on local interactions. The resulting simulation may be a more realistic presentation than is possible with the current simulations of *E. saccharina*, such as those of Hearne *et al.* (1993), Horton *et al.* (2002) and Potgieter *et al.* (2011).

The software chosen to develop the simulation model is *AnyLogic 7.1.2* (The Anylogic Company, 2015).

Successful model implementations

The first step in the development of an agent-based model for *E. saccharina* was to design a robust, detailed simulation framework upon which further structures incorporating biological details and population dynamics of the pest could later be built. The proposed model structure, based on the life cycle and biological considerations of the pest, is depicted in Figure 1. Each aspect of the life cycle requires translation to executable simulation code in an agent-based model structure.

The model is set up to simulate one hectare of sugarcane, which translates to approximately 130 000 individual sugarcane stalks. The model time-step was chosen to be hourly in order to accurately include all relevant aspects of the *E. saccharina* mating process, which is confined to certain hours of the night.

Toggle buttons were included which allow the user to specify whether the different life stages of the pest should be shown or hidden during the simulation. This functionality is expected to

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be useful where large numbers of agents are present in the simulation, but when a user wishes to focus on only one life stage for analysis purposes. Running statistics have been included that track the number of adult male and female moths present, the number of larvae that have penetrated cane stalks and the temperature history profile of the simulation. Temperature influences the rate at which the moths mature and is thus a crucial factor for inclusion in a realistic model of the pest (Way, 1995).

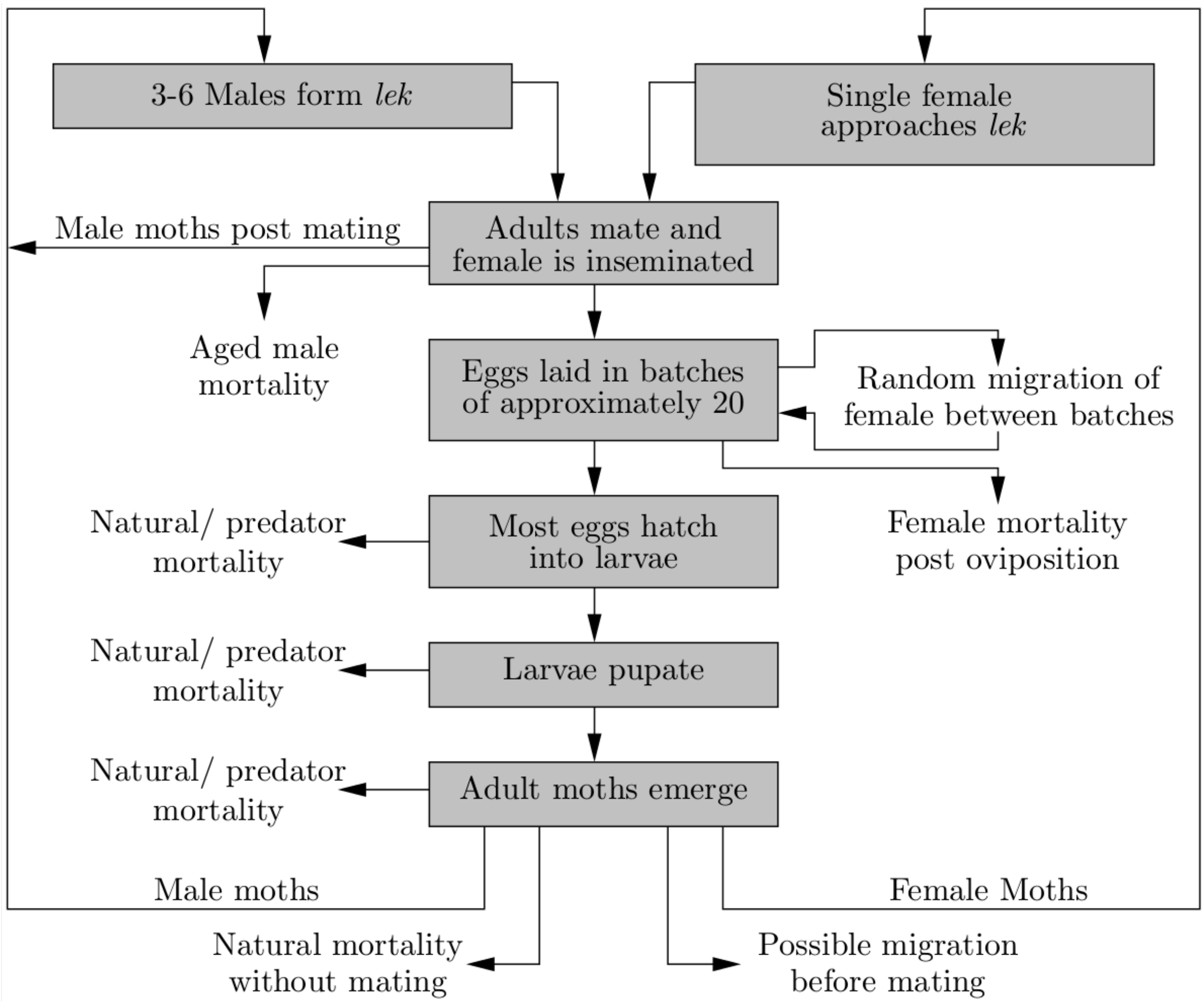

Figure 1. Flow diagram of the general life cycle followed by individual agents in the proposed agent-based simulation model of the growth and spread of an *Eldana saccharina* Walker (Lepidoptera: Pyralidae) population (van Vuuren *et al.*, 2014).

Temperatures are drawn from a linked Excel spreadsheet which provides an average temperature for the geographical region over the calendar period simulated. This reading is then incorporated in conjunction with a predetermined statistical distribution to provide some fluctuation in the input temperatures during subsequent simulation runs.

Current progress

The intricate mating behaviour of *E. saccharina* is currently being implemented in the simulation model. *E. saccharina* follows a *lek*-mating process whereby, after nightfall, a group of approximately 3-6 males commune on the leaf canopy of the sugarcane stalks and put on a display (Atkinson, 1981). A nearby female who is attracted by the display then approaches the *lek* and chooses a male with which to mate – assumed to be the male releasing the strongest pheromone (Conlong, 2014). Once the mating process is complete, the female will fly to several different, suitable oviposition sites, laying batches of approximately 20 eggs at each site.

At present, the reconstruction of the mating process in AnyLogic is achieved by defining an independent third object class, apart from the male and female object classes. When a male reaches adulthood and is ready to form a *lek* and mate, an action is executed in the simulation to create a '*lek* agent'. Owing to the *lek* being considered as an independent entity, it is possible to determine whether there are sufficient numbers of other male agents in the surrounding area to form a *lek.* If a *lek* is formed, it can serve as a defined point with specific attributes in the simulation space, such as pheromone strength, which females can seek out and move towards.

If the criteria stipulated to form a *lek* are insufficient (such as too few adult males in the vicinity of a particular moth), no *lek* is formed and an automatic event function tests for the possibility of that male 'starting' a *lek* again after a certain time period has elapsed. If a male is included in a *lek* whose inception was triggered by another agent, he no longer possesses the ability to begin his 'own' *lek.*

Once a *lek* has been formed in the region of a group of males, its location is calculated as the centroid of the locations of the *lek*-included males and it can then be sought out by a female who is ready to mate.

At present, this modelling approach appears to successfully replicate the basic structure of the mating process documented by Atkinson (1981). This approach must, however, still be tested thoroughly to determine to what extent it is sufficient for final use in the model.

Future work

Moving forward, a thorough testing of the *E. saccharina* mating process will be pursued in order to ensure it is both in line with the literature, as well as implementable on a large scale. This also extends to the post-mating period, during which females find suitable oviposition sites for their eggs (Berry, 2010 & Conlong, 2007). This process will be modelled using random walk and biased walk random movement by the individual agents, and will consequently affect the spatial distribution of the pest within the simulation space. The population dynamics of *E. saccharina* will also be carefully calibrated.

After the different aspects of the model have successfully been integrated and verified, validation will be conducted by performing specific situational simulation runs and comparing the results with those of actual studies performed in similar conditions. This will provide an indication of the extent to which the model accurately emulates the moth's behaviour and allow for an accurate, polished framework which can be used in further research and control measure evaluations.

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