Proceedings of the 2014 ORSSA Annual Conference
pp. 62–70
www.orssa.org.za/wiki/uploads/Conf/2014ORSSAConferenceProceedings.pdf

ORSSA Proceedings
ISBN
978-1-86822-656-6

Prerequisites for the design of an agent-based model for simulating the population dynamics of *Eldana saccharina* Walker

BJ van Vuuren*, L Potgieter† & JH van Vuuren‡

Abstract

Although South Africa boasts one of the most distinguished sugar producing industries in the world, the commercial success of the *South African Sugar Association* (SASA) continues to suffer as a result of the damage caused by a variety of pest species such as *Eldana saccharina* Walker (Lepidoptera: Pyralidae). This stalk borer pest feeds on the internal tissue of the sugarcane stalks, causing yield losses in sucrose. Owing to the fact that *E. saccharina* has specific preferences in terms of egg-laying sites, it has been suggested that suitably heterogeneous crop layouts in sugarcane may be an effective means to localize infestation effects and contribute towards pest suppression. In order to determine good sugarcane field layouts to aid in pest suppression in this manner, it is proposed that a simulation model of *E. saccharina* spatial behavioural patterns be developed and tested for differing ages and varieties of sugarcane. To facilitate the design of such an agent-based simulation model which simulates *E. saccharina* biology, various characteristics of the pest, such as its feeding habits, mating behaviour and dispersal patterns, must be incorporated into the model framework. These characteristics, as well as their impact and incorporation in the aforementioned model, are discussed in this paper. Furthermore, a suitable simulation modelling framework is suggested based on these considerations.

Key words: Sugarcane pest infestation, Eldana saccharina Walker, agent-based simulation.

1 Introduction

Sugarcane cultivation in South Africa dates as far back as the early 1600s. In 1635, Portuguese explorers shipwrecked near the mouth of the Umzimkulu River, where they discovered that sugarcane was one of the crops grown by local inhabitants [23]. The sugar industry expanded following the establishment of the agricultural society in 1848 and,

*Department of Industrial Engineering, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa, email: 16057651@sun.ac.za

†Department of Logistics, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa, email: lpotgieter@sun.ac.za

‡**(Fellow of the Operations Research Society of South Africa)**, Department of Industrial Engineering, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa, email: vuuren@sun.ac.za

today, about 428 000 hectares of cane produce, on average, 2.5 million tons of sugar per year [22].

The stalk borer, *Eldana saccharina* Walker, was first recorded in 1939 as a pest infiltrating sugarcane when a severe infestation occurred in the Umfolozi area. This infestation, however, did not spread and eventually died out in 1950 [13]. It then resurfaced in the Hluhluwe area during the early 1970s [6] and has since spread to much of the local sugarcane industry, but for inland crop areas where the insect is limited by the cooler temperature [1]. Evidence suggests that *E. saccharina* infests sugarcane by virtue of its suitability for egg-laying in dead leaf material [1, 20]. This infestation results in decreased cane quality (measured as a decrease in sucrose yield) and has a negative impact on total plant biomass [11]. An early study showed that, on average, mature infested cane exhibits a percentage loss which is comparable to that of the percentage of internodes damaged[1] [17].

In light of this, *E. saccharina* remains a topical concern in the sugar industry and the *South African Sugar Research Industry* (SASRI) continues to spearhead research efforts towards finding a means of effectively controlling the pest. A number of control measures currently exist, achieving only limited success. These include cane variety development [10, 16], chemical control [13], biological control, habitat management [8, 9, 10] and the *sterile insect technique* (SIT) [18].

The most limiting factors hindering roll-out of more recent methods, such as biological control, habitat management and SIT, include economic constraints on continuous, incremental development of optimal implementation techniques, as well as the lack of a means for practical evaluation of their relative impact when applied to infested sugarcane [9].

The purpose of this paper is to identify a number of prerequisites for the design of an agent-based simulation model which can be used to assess *E. saccharina* control methods before costly in-field testing is conducted. This will aid in acquiring a measure of insight into their predicted effectiveness and optimal implementation of the techniques in a time-efficient, economically viable manner.

This paper is a report on a work in progress within a larger study currently in progress at Stellenbosch University. It is the intention of the study to incrementally progress towards the development of a fully fledged agent-based simulation of *E. saccharina* by laying solid model foundations which will allow future researchers to periodically add elements discussed in this paper with a view to increase the model realism and complexity.

Various possibilities for such a simulation model are outlined in this paper, which is organised as follows. A brief description of the development of an *integrated pest management* (IPM) system approach is provided in §2, whereafter, a review of existing behavioural models and their shortcomings is presented is §3. This is followed by a discussion of the general characteristics of an agent-based simulation model and relevant biological attributes of *E. saccharina* in §5. Thereafter, a model framework is proposed in §6, based on the considerations described in §5. The paper then closes with a conclusion and discussion on the possible future development of this topic in §7.

---

[1] An internode is the softer part of the cane located between two adjacent growth rings.

2 Integrated pest management system approach

IPM systems aim to combine a series of control methods in order to achieve better overall pest management whilst decreasing the use of pesticides, thereby decreasing associated environmental problems. As a result, IPM is considered more sustainable in the long run [18]. Ideally, a number of the techniques mentioned in §1 should be applied in conjunction with one another to a sugarcane crop in order to achieve improved control of *E. saccharina*.

When applied together, research shows that the existing *E. saccharina* control methods can endorse one another [10]. In view of this knowledge, it is important to identify the shortcomings in the individual control methods, as well as the role of possible interactions between them. Determining these intricacies on either individual or interacting control methods using in-field testing is both costly and labour-intensive, and there is not always sufficient time available to conduct large-scale in-field tests in order to observe these effects. For this reason, simulation is becoming an increasingly attractive alternative to assist in the design and development of integrated control techniques [9].

3 Existing *E. saccharina* simulation models

A number of working simulations have been developed in the literature for evaluating the estimated effect of particular pest control methods imposed on sugarcane fields.

The first work of this nature was performed by Van Coller [24] and Hearne *et al.* [12] who employed a system of differential equations to model the change in population growth in the various stages of the life cycle of *E. saccharina*. This model primarily provided insight into the biological control of the pest through parasitoids, but did not explicitly take into account the spatial spread of an *E. saccharina* population. Specifically, the model enabled policies for the timing, frequency and magnitude of parasitoid releases to be tested for their relative effectiveness in the biological control of *E. saccharina*.

Horton *et al.* [14] later designed a model which was aimed at investigating the effects of insecticides and early cutting as control measures for *E. saccharina*. This model also explicitly included the effects of temperature on the pest's life cycle, but again assumed a homogeneous spread of the population over the spatial habitat. The function of this model was to produce a damage index which measures the extent of cane damage under different temperature patterns to assist in determining the time for harvesting.

Most recently, Potgieter *et al.* [19, 20] developed a discretised reaction-diffusion model of the growth and spread of *E. saccharina* population over time and space. An accompanying SIT simulation tool was also developed whereby the effectiveness of SIT could be investigated in different scenarios. Notably, these tools could be applied in the context of heterogeneous spatial domains — including realistic sugarcane field layouts — and, together, form a framework which can be extended for use in an IPM programme.

Despite the advancement in understanding of *E. saccharina* population growth and relative success achieved by the aforementioned simulation models, each model is founded upon approximations of the pest on a population level. Local interactions of individual moths are not simulated and incorporated explicitly into the population dynamics; instead, approximate changes are executed in the simulations at each discrete time step. Furthermore, the models focus on single control measures, limiting their development and flexibility in the context of IPM systems. The resulting analyses therefore yield conclusions that do not necessarily reflect the continuous, changing nature of *E. saccharina* on a localized level.

4 Benefits of agent-based simulation

In an attempt to address the shortcomings of the existing simulation models described above, an approach is advocated in which the individual members of a population of *E. saccharina* are simulated, thereby incorporating the effects of local interactions between individual stalk borers.

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 [15]. 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 predict population dynamics of the pest in a more realistic manner over space and time, based on local interactions, than is possible in the simulation models described in §3.

It is anticipated that an autonomous, agent-based simulation model of *E. saccharina* may serve two main functions. Firstly, the model can be used to validate and support existing high-level averaging models of the stalk borer, such as those discussed in §3. This may assist in developing more advanced, accurate mathematical models for further understanding and prediction of the spreading of the pest. Secondly, a simple working model of *E. saccharina* can provide a platform facilitating the testing and evaluation of various control mechanisms, either alone or in combination, before expensive in-field testing is pursued.

Moreover, a computerised agent-based simulation model can be equipped with a visually intuitive interface facilitating the interpretation of model results by parties who do not have the necessary training required to understand complex mathematical models. Such a simulation model of *E. saccharina* can incorporate easily configurable variable factors affecting the spatial spread and temporal growth of the pest population. Users of the model can then investigate the effects of minor changes to the system and use these observed effects to predict the potential success of *E. saccharina* control measures in practice. This directly addresses a current shortcoming in the sugarcane industry where confidence levels cannot easily be associated with the expected outcomes of implementing proposed *E. saccharina* control methods, based on the predictions of existing simulation models. Often, further experiments and methodology have to be developed simply to verify whether a mathematical model or control method will operate as expected. A realistic agent-based model can assist in providing a simple, quick verification mechanism which, in turn, may increase confidence levels and creativity in the design of new *E. saccharina* control methods and IPM systems alike.

5 General considerations of agent-based simulation

In an agent-based model, each agent is initialised using a series of parameters, variables and functions [26]. Parameters keep a fixed record of facets of each agent which control their appearance and activity throughout the simulation. Variables indicate aspects of the agent's behaviour which are incorporated into its decision making process and can change during the course of a simulation. These decisions are made according to functions of both the parameters and variables governing agent behaviour. Simulations can also accommodate so-called *events* such as removal of an agent from the simulation or the introduction of a new agent to the simulation. These events are based on several requirements which, if satisfied, execute the event.

The proposed simulation model of *E. saccharina* aims to link the biological aspects and preferences of the stalk borer to functions and events which govern each individual agent in the simulation. The primary aspects of the simulation and the corresponding biological characteristics which must be incorporated are discussed below.

5.1 Different types of agents

Primarily, the simulation should incorporate both male and female *E. saccharina* moths as separate populations. The members of these populations should conform to typical behaviour of the stalk borer, unless otherwise required. Furthermore, all moths may initially be deemed fertile, unless the effects of SIT are incorporated into the simulation, in which case, a different type of agent may be introduced.

5.2 The introduction of new agents

In order to simulate the stochastic nature of an *E. saccharina* population size, the simulation requires the incorporation of an event whereby a new agent can be introduced into the simulation environment. Such introductions should result from mating of adult *E. saccharina* moths.

The life-cycle of *E. saccharina* is typical of that of insects. Eggs hatch into larvae, after which pupation occurs and, finally, adult moths emerge [2]. Carnegie [6] and Way [25] investigated the duration of each stage of the life cycle and the factors which affect moth development. These findings should be incorporated into the simulation to allow for the realistic introduction of new agents into the model and realistic timings between mating and moth emergence.

5.3 The removal of existing agents

Since the simulation will be of living organisms, an event must also be incorporated whereby the agents perish and are removed from the simulation. Mortality of the moth occurs haphazardly during its life cycle and natural enemies are not considered a notable factor in the mortality of *E. saccharina* [18]. Realistic mortality rates, as proposed by Van Coller [24], should be consulted in terms of natural removal of agents from the simulation.

5.4 The spatial movement of agents

Although *E. saccharina* is considered a relatively weak flier, Atkinson [3] describes instances where females may travel for mating purposes. Furthermore, Carnegie [6] notes cases where mated females migrate in search of oviposition sites. *E. saccharina* may also migrate in search of more mature sugarcane which is its preferred habitat [1]. Studies related to other moth species indicate that mobile and sedentary genotypes exist in populations that display dispersal capacity in the field [21]. The observations of Atkinson and Carnegie [5] correlate with these studies. These kinds of spatial movements should be included in the simulation.

5.5 The interaction between agents

The *lek mating* process followed by *E. saccharina* is described by Atkinson [3] and should be incorporated into the simulation preceding the introduction of a new agent, as described in §5.2. The frequency of mating between agents, as well as the number of times they mate, should adhere to the observations of Carnegie [6].

5.6 External influences on the agents

Other characteristics of the environment which affect *E. saccharina* behaviour and survival should also be incorporated into the model.

The effect of temperature on mortality and maturation rates of *E. saccharina* should, for example, be incorporated into the simulation, perhaps employing the polynomial fit to corresponding stage mortality and maturation data proposed by Potgieter [18]. These effects should give rise to seasonal cycles which affect the dominant life stages of *E. saccharina* significantly. The annual May milling season should also be captured in the simulation as it is considered the largest eradicator of the pest [4].

6 Suggested simulation modelling framework

We propose the basic model structure depicted in Figure 1 for the order and flow of events in an agent-based simulation of *E. saccharina*, taking into account the referenced biological considerations. It is suggested that each agent in the simulation follow this basic life cycle which should be programmed within a stochastic framework according to the biological factors discussed in §5.

In order to achieve effective visualisation of the population dynamics and behaviour of *E. saccharina* in the simulation model, it is proposed that male and female agents should be denoted by different colours within a graphical display of the sugarcane field layout. Furthermore, each stage of the life cycle should also be displayed in a different shade of the above-mentioned colours in order to indicate the number of eggs, larvae and pupating moths of each sex which exist within the population.

It is suggested that the time step adopted in the simulation model should be measured in days in order to be able to gauge individual activities of the moths, while simultaneously

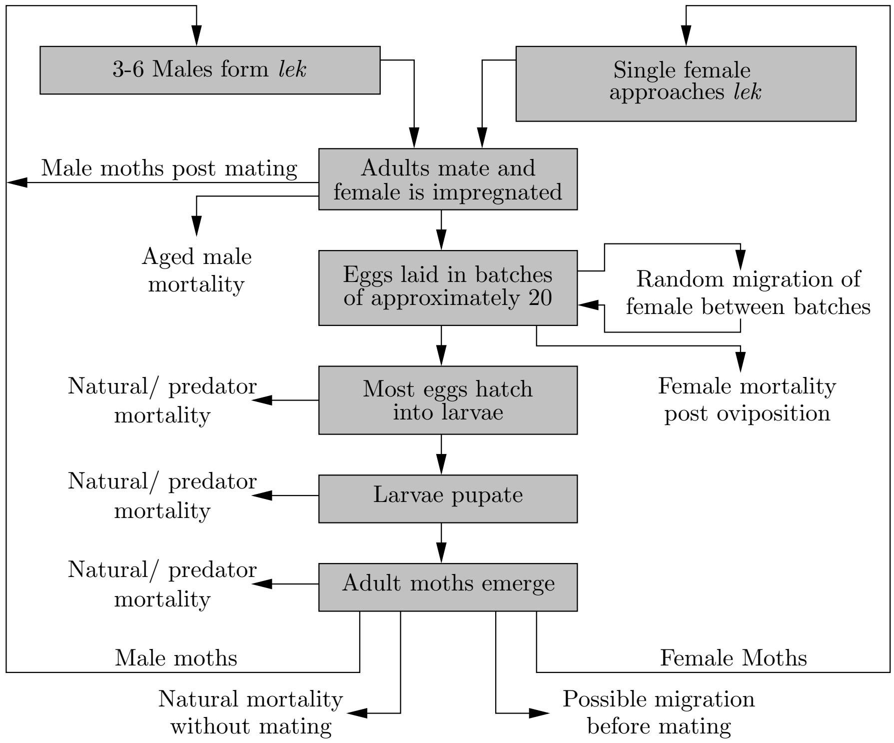

Figure 1: *Flow diagram of the life cycle followed by individual agents in the proposed agent-based simulation model of the growth and spread of an E. saccharina population.*

facilitating the ability to perform an assessment of the long-term development of the population. The model should, thus, possess the ability to be sped up and slowed down for the purposes of observation.

7 Conclusion and discussion

A number of prerequisites have been outlined in this paper for consideration when designing an agent-based simulation model of the population dynamics of *E. saccharina*. This model is expected to aid primarily in investigating possible mechanisms for the control or eradication of *E. saccharina* and, in doing so, diminish its negative effects on sugarcane production.

The next phase in this ongoing research project involves a detailed development of the proposed agent-based simulation which incorporates biological and behavioural attributes of the stalk borer discussed in §5 within the framework suggested in §6.

References

[1] Atkinson PR, 1979, *Distribution and natural hosts of Eldana saccharina Walker in Natal, its oviposition sites and feeding patterns*, Proceedings of the South African Sugar Technologists Association,

53, pp. 111–115.

[2] Atkinson PR, 1980, *On the biology, distribution and natural host-plants of Eldana saccharina Walker*, Journal of the Entomological Society of South Africa, **43**, pp. 171–194.

[3] Atkinson PR, 1981, *Mating behaviour and activity patterns of Eldana saccharina Walker (Lepidoptera: Pyralidae)*, Journal of the Entomological Society of South Africa, **44(2)**, pp. 265–281.

[4] Atkinson PR, 1984, *Seasonal cycles of Eldana borer in relation to available control measures*, Proceedings of the South African Sugar Technologists Association, **58**, pp. 165–167.

[5] Atkinson PR & Carnegie AJM, 1989, *Population dynamics of the sugarcane borer, Eldana saccharina Walker (Lepidoptera: Pyralidae), in Natal, South Africa*, Bulletin of Entomological Research, **79**, pp. 61–80.

[6] Carnegie AJM, 1974, *A recrudescence of the borer Eldana saccharina Walker (Lepidoptera: Pyralididae)*, Proceedings of the South African Sugar Technologists Association, **55**, pp. 116–119.

[7] Carnegie AJM, 1981, *Combating Eldana saccharina Walker: A progress report*, Proceedings of the South African Sugar Technologists Association, **55**, pp. 116–119.

[8] Conlong DE, 1990, *A study of pest-parasitoid relationships in natural habitats: An aid towards the biological control of Eldana saccharina (Lepidoptera: Pyralidae) in sugarcane*, Proceedings of the South African Sugar Technologists Association, **64**, pp. 111–115.

[9] Conlong DE, 2014, *Senior Entomologist at the South African Sugarcane Research Institute*, Mount Edgecombe, [Personal Communication], Contactable at `Des.Conlong@sugar.org.za`

[10] Conlong DE & Rutherford RS, 2009, *Conventional and new biological and habitat interventions for integrated pest management systems: Review and case studies using Eldana saccharina Walker (Lepidoptera: Pyralidae)*, pp. 241–261 in Peshin R & Dhawan AK (Eds), *Integrated pest management: Innovation-development process*, Springer, New York (NY).

[11] Goebel FR & Way MJ, 2003, *Investigation of the impact of Eldana saccharina (Lepidoptera: Pyralidae) on sugarcane yield in field trials in Zululand*, Proceedings of the South African Sugar Technologists Association, **26**, pp. 805–814.

[12] Hearne JW, van Coller LM & Conlong DE, 1991, *Determining strategies for the biological control of a sugarcane stalk borer*, Ecological Modelling, **73**, pp. 117–133.

[13] Heathcote RJ, 1984, *Insecticide testing against Eldana saccharina Walker*, Proceedings of the South African Sugar Technologists Association, **58**, pp. 154–158.

[14] Horton PM, Hearne JW, Apaloo J, Conlong DE, Way MJ & Uys P, 2002, *Investigating strategies for minimising damage caused by the sugarcane pest Eldana saccharina*, Agricultural Systems, **74**, pp. 271–286.

[15] Janssen MA, 2005, *Agent-based modelling*, prepared for the Internet Encyclopaedia of Ecological Economics, [Online], [Cited April 4th, 2014] Available from `http://isecoeco.org/pdf/agent_based_modeling.pdf`

[16] Keeping MG & Rutherford RS, 2004, *Resistance mechanisms of South African sugarcane to the stalk borer Eldana saccharina (Lepidoptera: Pyralidae): A review*, Proceedings of the South African Sugar Technologists Association, **78**, pp. 307–312.

[17] King AG, 1989, *An assessment of the loss in sucrose yield caused by the stalk borer, Eldana saccharina, in Swaziland*, Proceedings of the South African Sugar Technologists Association, **63**, pp. 197–201.

[18] Potgieter L, 2013, *A mathematical model for the control of Eldana saccharina Walker using the sterile insect technique*, PhD Dissertation, Stellenbosch University, Stellenbosch.

[19] Potgieter L, van Vuuren JH & Conlong DE, 2011, *Modelling the effects of the sterile insect technique applied to Eldana saccharina Walker in sugarcane*, ORiON, **28(2)**, pp. 59-84.

[20] Potgieter L, van Vuuren JH & Conlong DE, 2012, *A reaction-diffusion model for the control of Eldana saccharina Walker in sugarcane using the sterile insect technique*, Ecological Modelling, **250(2013)**, pp. 319–328.

[21] Schumacher P, Weyeneth A, Webe DC & Dorn S, 1997, *Long flights in Cydia pomonella L.(Lepidoptera: Tortricidae) measured by a flight mill: influence of sex, mated status and age*, Physiological Entomology, **22**, pp. 149–160.

[22] South African Sugar Association, 2013, *SASA: Facts and figures*, [Online], [Cited April 4th, 2014], Available from `http://www.sasa.org.za/sugar_industry`

[23] Snyman SJ, Baker C, Hucket BI, McFarlane SA, van Antwerp T, Berry S, Omarjee J, Rutherford RS & Watt DA, 2008, *South African Sugar Research Institute: Embracing biotechnology for crop improvement research*, Sugartech, **10(1)**, pp. 1–13.

[24] van Coller LM, 1992, *Optimum biological control strategies for a problem in the sugar industry — A mathematical modelling approach*, MSc Thesis, University of Natal, Pietermaritzburg.

[25] Way MJ, 1995, *Developmental biology of the immature stages of Eldana saccharina Walker (Lepidoptera: Pyralidae)*, Proceedings of the South African Sugar Technologists Association, **69**, pp. 83–86.

[26] XJ Technologies Company, 2007, *AnyLogic 6 Users Guide*, [Online], [Cited April 2nd, 2014], Available from `https://www7.informatik.uni-erlangen.de`