Development of the Cabbage Root fly in agricultural landscape : seeing agroecosystems from a fly point of view.

Parisey N., Montagu R., Ezanic A., Cortesero A.M. and Le Ralec A.

Abstract

A spatially explicit individual-based simulation model has been developed to represent aerial pests population dynamics in agricultural landscapes. The application of the model to *Delia radicum* (Cabbage Root fly) population dynamics is briefly explained in this article.

A few scenarios of interactions between flies and elements of the landscape were played out to explain the spatio-temporal heterogeneity of *D. radicum* population which was recorded in Western Brittany during weeks 17 to 21 of year 2009.

While an early work, this study forms the basis for the development of further simulation models that can be used to analyze how changes in landscape structure impact upon local pest densities, trophic levels (according to niche theory) and, ultimately, economical damages.

1 Introduction

During the last 40 years, despite a large development in the use of synthetic chemicals, crop losses have not significantly decreased [7]. Because synthetic chemicals cause a growing threat on ecosystems health, new strategies are needed for both an economically and ecologically sound crop production. In such a view, several projects lead by the French National Institute for Agricultural research (INRA) try to assess if the landscape structure and composition can be used to control crop pests population and economical damages.

One such project[1] will collect and analyze geomatic, biological and agronomical data on Brassicaceae (cabbage) pests population in Western Brittany. One major goal of such study is to create decision support systems for agricultural purpose. Such systems are supposed to help in organizational decision-making activities for agricultural purpose. An example of such system is a 'warning system' capable of predicting when (not) to apply chemical treatments.

For example, since 15 years, ordinary differential equation (EDO) models have been used to investigate the population dynamics of several pest flies [5, 6, 1]: *Psila rosae* (carrot fly), *Delia antiqua* (onion fly) and *Delia radicum* (cabbage root fly). These models are able to predict accurately the possible augmentation of flies population according to meteorological data. Hence, they are actively used as warning systems [2].

However, spatial heterogeneity in population dynamics can lead to very dissimilar ecological situations from one landscape to another [3]. A spatial warning system will not only predict when possible outbreak will strike but also where. Using a Multi-Agent Systems (MAS), it is theoretically possible to answer such a question. MAS are well know for their ability to tackle with spatially and ecologically relevant problematics [3, 8, 2, 4, 9]. In this study, we have used a generic simulation platform [11] to define a MAS which ultimate goal is to answer questions such as :

- what type of landscape composition can (des)advantage Brassicacae's pests ?
- what spatial/landscape variables can reduce pests populations and their economical damages ?

In the following chapters, we will detail how we constructed our model and what are the current results and ongoing work.

[1] The PICLg 'Brassinse' program which is led by the UMR 'INRA/Agrocampus Ouest/Universit de Rennes 1' Bio3P
[2] http://www.loiret.chambagri.fr/extranet/index.php?tg=articles&topics=98

2 From spatially homogeneous to spatially explicit population models

2.1 *D. radicum* life cycle in a nutshell

D. radicum is a species with several generations per year, depending on temperature. It passes through several development stages during its life cycle : egg, larva, pupa and adult. Its aging process depends heavily on temperature and is usually expressed in Growing-degree per Day (GDD). The adults feed on nectar and pollen while the larvae feed on host plant roots (i.e. mostly Brassicacae roots). Eggs are laid by adults close to the host plant. They hatch as larvae who feed and then enter a pupa state. This state can be followed directly by an adult state or the pupa can enter a **diapause** (a long halt in the metamorphosis) conditioned by low temperatures during a few days. Furthermore, high temperatures can also arrest pupal development of *D. radicum* temporarily, this is called **aestivation**.

Damages caused by the larvae on seedlings and young plants can lead to 90% yield loss for the farmers[1]. As a matter of fact, *D radicum* is an important source of cabbage loss in Western Brittany.

2.2 Field data

Sponsored by the Brassinse program, several field surveys where conveyed in Western Brittany regarding Brassica oleracea pests, mainly *D. radicum*. A Geographical Information System (GIS) was created to store and analyze the collected data. A few example of maps and raw data stored in our GIS include : orthophotographic representation and large scale biophysical landcover of Western Brittany ; land use at fine grained level [3] within landscapes of several square kilometers, topographic maps, . . .

To test the spatial properties of our model, we used data from a field survey taken in the region of Saint-Adrien (postal code : 22390). This survey tracked colonization/dispersion by *D. radicum* within a a 12 km^2 agricultural landscape during week 17 to 21 of 2009. To follow colonization/dispersion, *D. radicum* eggs laid in specially prepared cabbage plants were counted each week in 23 different parcels randomly situated within the agricultural landscape.

At least 4 new surveys of the very same kind will take place in 2010 in Western Brittany and around the region of Nantes and Angers. Those data, available in late august, will be processed and used to validate and/or recalibrate our model.

2.3 Description of the Multi-Agent model and its input

Using a generic multi-agent platform [11], we have designed a reactive Multi-Agent System modeling *D. radicum* development in agricultural landscapes.

We modelled life cycles of eggs, larvae, pupae and host plants within a Cellular Automata (CA) because (1) a batch of eggs will hatch and grow at the same place and nearly at the same speed and (2) host plant don't move around. On top of that CA, we modeled adult as homogeneous reactive agents.

As a rule of thumb, most of *D. radicum* biological processes follow a Weibull distribution which is function of the temperature[5, 6, 1]. This means that the inputs necessary to our model are :

- GIS data : a rasterized landcover map (25 m^2 per pixel or less) containing information on hedgerows/forests, productive land use, human habitations and constructions.
- meteological data : hourly and daily temperature (within soil and 2m above ground), wind speed and direction.

Furthermore, our agents need rules and parameters for numerical resolution of their behaviors hence we integrated previously published literature results in our model.

2.4 Adapting previously published results to Agent Based simulations

We have adapted to a stochastic agent based simulation the differential equation functions that were used in previous Leslie's models [6, 1] to deal with :

- Temperature-dependent development of insect stages,
- Reproduction, depending both on biological age (for fertility) and preoviposition,

[3] maximum imprecision below a couple meters

- Diapause/aestivation,
- Flight activity, most notably the sensitivity to wind speed.

In our model, the most notable spatial addition to previous models concerns ageing, reproduction and the flight activity. Based on expert knowledge (personal communication from Pr. A.-M. Cortesero), we added a simple **feeding process** based on absence or presence of food source at the current fly location. This slightly modifies ageing and reproduction :

- Mortality occurs when an agent reach the maximum age (as in previous models) or if they cannot feed. Hence, if an agent spend too much time in an unfavorable terrain, it will die (as in [8]).
- The feeding process will also affect reproduction as it is important for individual fly to have enough energy before giving birth. Logically, terrain where eggs will be laid must be within reasonable reach of food sources.

Moreover, as simulation of movements is one the most important factor in a spatially explicit model [9], we taken extra care in modeling the **flight activity** of *D. radicum* as follow :

- According to maximum flight speed, the raster size was determined in order for a 2 dimensional random walk with spatial step of 5 m and a time step of 33″ to be a good approximation of a fly's brownian motion,
- The interaction of flight activity with landscape elements are theoretically very important. In landscape ecology, there is a commonly accepted principle that landscape elements can have an impact as barrier, corridor or filter for a given species [10]. We explored such relations by adding
  - a corridor effect of hedgerows simulated by a sensitivity to wind direction and wind speed decreased by current coverage,
  - a barrier effect of large water bodies (rivers, Atlantic ocean,. . .) which 'bounce back' flies.
- Finally, we added ecological chemistry knowledge in this model by allowing the flies brownian motion to be influenced by the presence of food source in the vicinity.

We have implemented all those features in our model and are, at the moment, testing parameters sensibilities and different ecologically relevant scenarios.

3 Preliminary Results

So far, our results are comparable to previous models [6] in term of qualitative and quantitative prediction of population dynamics. In those models, the preponderant control over population dynamics is made by temperature. In particular, it affects diapaused populations which in return will control the maximum number of generation per year. In figure 1, we can see that our model (1.c) gives comparable results with field data (1.a) and other ODE predicted values (1.b). There is a perceptible time shift between field data, ODE results and our simulations. We think it is because we are currently using meteorological data that were recorded too far away from our field survey and we plan on acquiring data of better quality (i.e. recorded closer to our field).

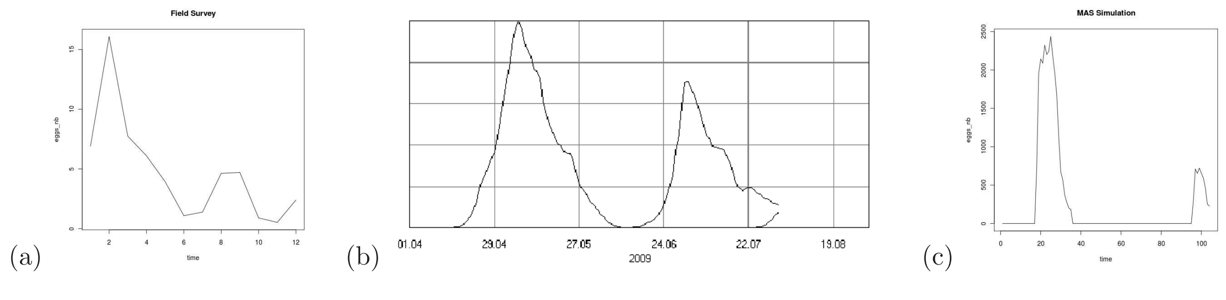

Figure 1: Number of eggs laid per generation in : (a) field data ,(b) ODE model [6] and (c) our Multi-Agent simulations. Time period are from : (a) 26/04/09 to 30/05/09, (b) 01/03/09 to 01/08/09 and (c) 19/04/09 to 09/08/09

As you can see in figure 1, the first flight is when most eggs will be laid. This could lead to high damage to young cabbage. There is at least two main environmental control over the first flight :

- Temperature : in that case, all the 1st generation flies were already in the landscape, in diapause, and they emerged at the same time after having accumulated enough energy all along winter. Then, the hot days will enable a few more generation but the vast majority of the flies will diapause until next season.
- Landscape heterogeneity : When the 1st generation flies emerge, they travel fast and away during a few days. The Western Brittany landscape being a coastal landscape, it exists a lot of large water bodies that will constrain the flies flight. In such a case, the higher population of the first flight could be a higher density of flies and the 2nd and 3rd generation flies are born after dispersion, i.e. they come from less and less dense populations.

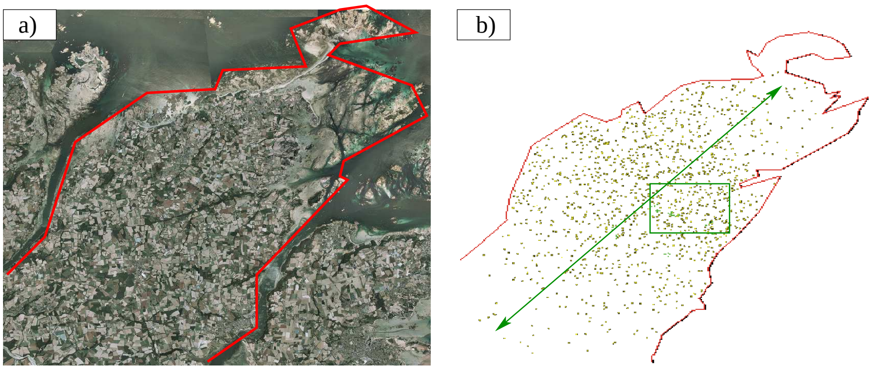

Figure 2: Spatial heterogeneity derived from barrier effect. We can see in a) an orthophotography of our landscape with outlined barrier effect and in b) a Multi-Agent simulation of the flies density which shows an asymmetric flies density along the main axis of the peninsula. The specific landscape of the 2009 field survey is shown within a bounding box in b).

Figure 2 shows an example of spatial heterogeneity caused mainly by the barrier effect of neighboring large water bodies. Such a result is a clear sign that both temporal and spatial factors affect *D. radicum* population dynamic. We intent to finely calibrate our model so it can be used to explain the spatial heterogeneity within field data.

4 Conclusion and Perspective

In this paper, we described a Multi-Agent System for predicting *D. radicum* population dynamic both in time and space. This is an early work and our immediate perspectives are to assess our model sensitivity and to test a wide range of new scenarios of interactions between the *D. radicum* individuals and elements of the landscape. Based on similar approaches [3, 8, 2, 4], our model is certainly capable of uncovering emergent interactions between landscape elements and *D. radicum* population behaviors.

References

[1] Sondgerath D. and Miiller-Pietralla W. A model for the development of the cabbage root fly (delia radicum l.) based on the extended leslie model. *Ecological Modelling*, 91:67–76, 1996.

[2] Arrignon F., Deconchat M., Sarthou J.P., Balent G., and Monteil C. Modelling the overwintering strategy of a beneficial insect in a heterogeneous landscape using a multi-agent system. *Ecological Modelling*, 205:423–436, 2007.

[3] Bousquet F. and Le Page C. Multi-agent simulations and ecosystem management: a review. *Ecological Modelling*, 176:313–332, 2004.

[4] Vinatier F., Tixier P., Le Page C., Duyck P.-F., and Lescourret F. Cosmos, a spatially explicit model to simulate the epidemiology of cosmopolites sordidus in banana fields. *Ecological modelling*, 220(18):2244–2254, 2009.

[5] Hommes M. and Gebelein D. Simulation models for the cabbage root fly and the carrot fly. *Bulletin OILB SROP*, 19(11):60–65, 1996.

[6] Otto M. and Hommes M. Development of a simulation model for the population dynamics of the onion fly delia antiqua in germany. *Bulletin OPP/PPO*, 30:115–119, 2000.

[7] E.-C. Oerke. Crop losses to pests. *The Journal of Agricultural Science*, 144(1):31–43, 2006.

[8] Hazel R. Parry, Andrew J. Evans, and Derek Morgan. Aphid population response to agricultural landscape change: A spatially explicit, individual-based model. *Ecological Modelling*, 199:451–463, 2006.

[9] Hosseini P.R. Pattern formation and individual-based models: The importance of understanding individual-based movement. *Ecological Modelling*, 194(4):357–371, 2006.

[10] H.H. Wagner and M.-J. Fortin. Spatial analysis of landscapes: concepts and statistics. *Ecology*, 86:1975–1987, 2005.

[11] U. Wilensky. Netlogo. Developed at the Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL, 1999.