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Insect Life-Cycle Modeling (ILCYM) Software

A New Tool for Regional and Global Insect Pest Risk Assessments Under Current and Future Climate Change Scenarios

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Abstract

The Insect Life Cycle Modelling (ILCYM) software is a novel tool to support the development of process-based temperature-driven and age-stage structured insect phenology models and to apply these models through a geographic information system (GIS) for insect species distribution and risk mapping. ILCYM is an open-source computer aided tool with three main modules: the model builder, the validation and simulation module, and the potential population distribution and risk mapping module.

ILCYM Modelling Concept

Insects require a certain amount of heat to develop from one developmental stage to another in their life-cycle. Their developmental rate, which is a reciprocal value of the developmental time, is determined by the metabolic rate, which reflects the velocity of the energy-supplying biochemical processes in the organism. Besides development, other processes that determine an insect species' life history, such as survival and reproduction, are also strongly influenced by temperature. ILCYM's conceptual framework therefore reposed on the application of temperature-dependent nonlinear relationships for representing all insect life cycle processes.

The Model Builder

The models builder uses same shape distribution approach combined with a rate summation and cohort up-dating technique as described in Figure 1.

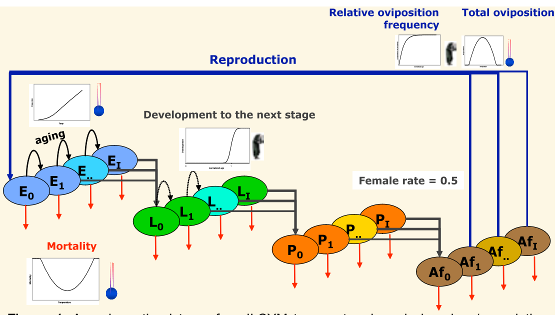

Figure. 1. An schematic picture of an ILCYM temperature-based phenology/ population model using a rate summation and cohort up-dating approach. The population is structured in different life stages represented in a "box car train" (p.e. eggs [E], larvae [L], pupae [P], and adults [Af = adult females]) and into groups of individuals of the same age within each life stage (i.e. cohorts) represented in a "box car" (p.e. E_0, E_1, E_2,..E_x). When running the model, each "box car" is up-dated in daily intervals, i.e. the daily development rate is added to the physiological age (rate summation) and the number of individuals in the cohort is minimized by the daily mortality and the proportion of individuals that develop into the next life stage.

ILCYM provides a list of non-linear functions which are adequate for describing the temperature dependency of the different processes in the species life history (i.e. development, survival, and reproduction). For each specific temperature-process the function that fits the experimental data best can be selected (see Figure 2 for outputs produced by ILCYM).

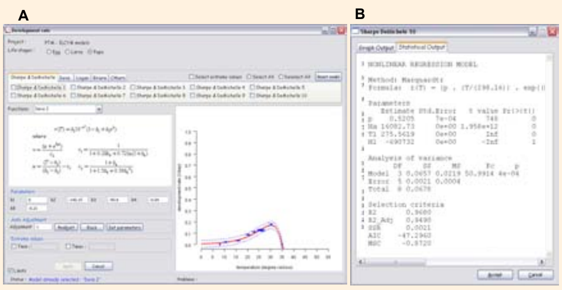

Figure 2. ILCYM software outputs showing functions and parameter values used to describe simulation of *P. operculella* larva development (A). The output on the right side (B) presents the equation fitted, model parameter values and their standard errors, ANOVA table, and selection criteria for comparing the model fit with other models

Validation and Simulation

The validation is achieved by comparing experimental life table data obtained from fluctuating temperature studies with model outputs produced by using the same temperature records as input data (Figure 3).

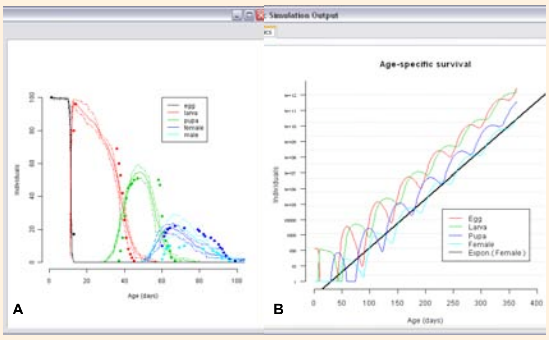

Figure 3. A) Observed and simulated stage-specific survival; the dots (•) are observed data and lines are the results from stochastically simulated life tables (Tmin = 15°C and Tmax 25°C) for *P. operculella* stages egg, larva, pupa, female and male, respectively, full lines: average survival; scattered lines: maximum and minimum survival obtained from the 4 life tables simulated. **B)** Potential population increase of *P. operculella* over a period of one year with multiple overlapping generations using the model established for a constant temperature of 15°C (minimum) and 25°C (maximum), respectively. Model started with 100 eggs; seven overlapping generations were produced but the stable age-stage distribution was not reached after one year.

Potential Population Distribution and Risk Mapping

Life table parameters

ILCYM also output, the net reproduction rate R_0(♀/♀), mean generation time *T* (days), Intrinsic rate of increase r_m; finite rate of increase e^{r_m} and the doubling time $Dt = Ln(2)/r_m$ From these life table parameters, three indices are estimated.

Risk indices

The establishment risk index (*EI*), the generation index (*GI*) and the activity index (*AI*)

Temperature inclusion in the phenology model

Using the a cosines approximation of temperature, the risk indices are estimated and mapped under present and projected SRES emission scenarios for predicting responses to present and climate change (Figure 4)

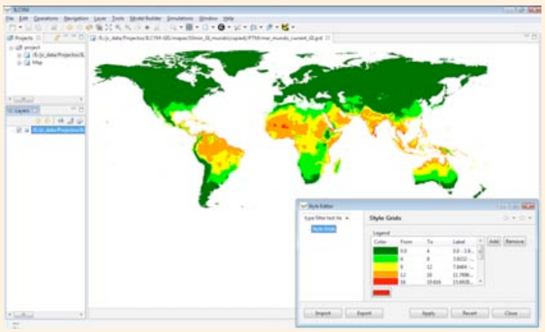

Figure 4. ILCYM's "risk mapping" interface; here showing the generation index simulated for *P. operculella* globally. The number of generations the pest might develop per year are visualized by different colors; the appearance of the map (ranges, colors, etc.) can be modified using the 'Style Editor'.

Conclusions

- ILCYM provides advanced insect modeling techniques and analytical tools that can be used by scientists who are not experts in this field.
- The program interactively leads the user through the different steps of developing a pest phenology model and conducting spatial simulations. However, ILCYM restricts the user to certain predefined modeling designs and might not provide solutions for each problem.
- Outlook: future versions will include two-species interaction models to study parasitoid-host systems.

The ILCYM software and manual can be downloaded from www.cipotato.org/ilcym

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