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PODYAM: a modeling framework for simulating population dynamics in agricultural mosaics

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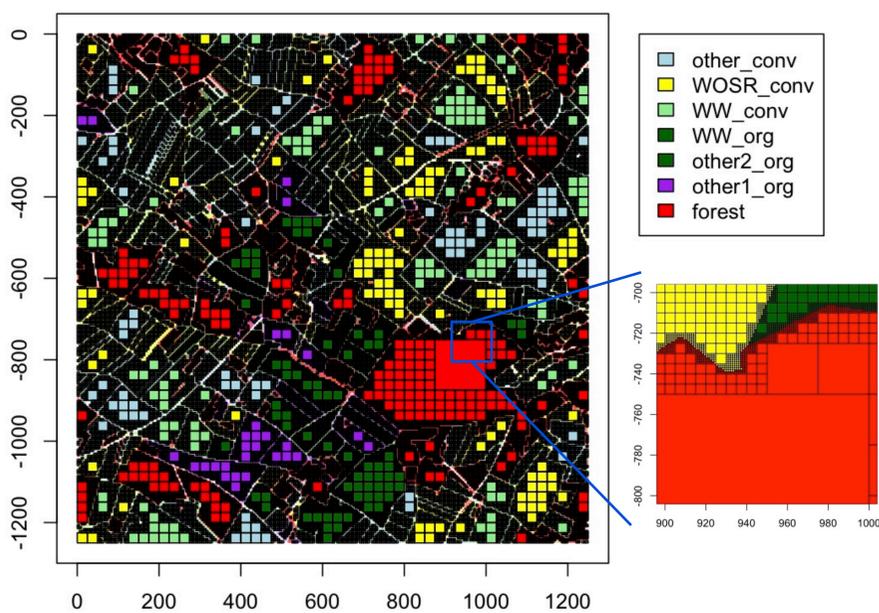
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Integrated Pest Management (IPM) requires that several control methods be combined in order to control simultaneously several pests (weeds, diseases, animal pests), which can interact among themselves. Furthermore, some pests can disperse among fields while others may remain in the field during part of the next crop's cycle, adding possible interactions between pests of different crops or different cropping systems. Many models have been developed to predict disease epidemics and insect pests' population dynamics and to help design control strategies for a single pest on a single crop. But it is often difficult to design IPM strategies based on these models because of the lack of common formalisms or even common state variables between the different models. We propose a modeling framework in which any pest or disease could be simulated, allowing detecting antagonisms or synergies between strategies aimed at controlling different pests. Our main interest is in predicting the effect, on aerial diseases and pests, of the configuration of different control strategies in agricultural landscapes.

Structure of the framework:

- Space: 2D space, rasterized at multiple resolutions to allow representing each organism at the relevant scale



- Organisms (insects, plants, pathogens): the population in each pixel is broken down into its different stages/organs/states=>one matrix for each species (rows=pixels at the relevant level of space, columns=stages)
- Environment: one data.frame for each level of space (rows=pixels, columns= user-defined variables)
- Biological processes: a set of generic functions is applied at each time step, with several degrees of customization thanks to nested functions (sub-process function names are considered as parameters of process functions).

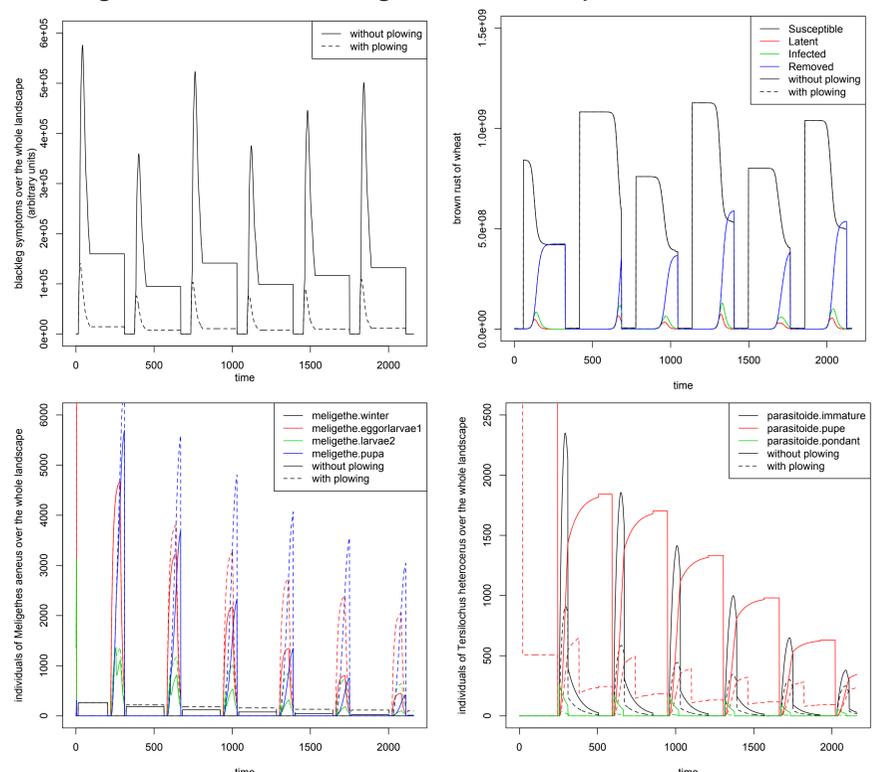
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  ),
  wheat=list(
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  ),
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        functional_response="yieldlossHansen",
        parameters=list(preys="oilseedrape.flower", #
        ) #end parameters
      ) #end meligethes.egglaying.everywhere
    ), #end predation
    growth=list(
    ), #end growth
    development=list(
    ), #end development
    dispersal=list(
    ), #end dispersal
  ), #end meligethes
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        condition=TRUE,
        functional_response="sigmoid_accessibility",
        parameters=list(preys="wheat.vegetative", #
        ) #end parameters
      ), #end brownrust.S1.everywhere
      brownrust.S2.everywhere=list(
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        functional_response="sigmoid_accessibility",
        parameters=list(preys="wheat.vegetative", #
        ) #end parameters
      ) #end brownrust.S2.everywhere
    ), #end predation
    growth=list(
    ), #end growth
    development=list(
    ), #end development
    dispersal=list(
    ), #end dispersal
  ), #end brownrust
  parasitoid=list(
  ), #end parasitoid
) #end PARAMETERS
```

- Cultural practices: crop management is defined as a set of functions that can modify both the populations and the environment

This framework was used to implement three existing models:

- DEPCI (Papaix et al, 2012), a simple compartmental model simulating brown rust (*Puccinia recondita*) epidemics
- MOSAIC-PEST (Vinatier et al, 2012), a tri-trophic model simulating the development of pollen beetle (*Meligethes aeneus*) of oilseed rape and its parasitoids *Tersilochus heterocerus*
- SIPPOM-WOSR (Lô-Pelzer, 2010), a complex model simulating the evolution of blackleg disease of oilseed rape (*Leptosphaeria maculans*)

The implementation of DEPCI was straightforward and used only generic functions. MOSAIC-PEST was also easily implemented because all of its functions could be mapped to the biological processes included within PODYAM, and only one subprocess (oilseed rape yield loss) required writing a specific function because it uses an empirical relationship including the temperature and rain before the arrival of pollen beetles in the field and so was not well adapted to our framework where functions modify state variables in a Markov process. The adaptation of SIPPOM was more complicated because the model was not defined in terms of state variables ; new process functions were written for each module of SIPPOM. The implementation of these models within PODYAM allowed us to test the effect of control strategies on both blackleg disease and pollen beetle:



Examples of simulations made with PODYAM, with a wheat-oilseed rape rotation, with or without plowing before wheat sowing.

Conclusion: The modeling framework proved to be generic enough to include three models that were developed with different formalisms (compartment model, age-structured population model, complex model with compartments and empirical relationships), with organisms defined at different scales (pixel, field). The first simulations confirmed that there is a trade-off between the control of blackleg by soil tillage and the biological control of pollen beetle by its parasitoid. In the future, this framework will be coupled with a database of equations and parameters of demographic models for several pests and natural enemies, among which to choose in order to build easily multi-pest models which could be used to design IPM strategies at the landscape scale.