Modèle multi-agents de dynamique de la colonie d'abeilles.

François Brun

Formation Introduction à la modélisation pour la protection intégrée des cultures.

30 novembre au 4 décembre 2015

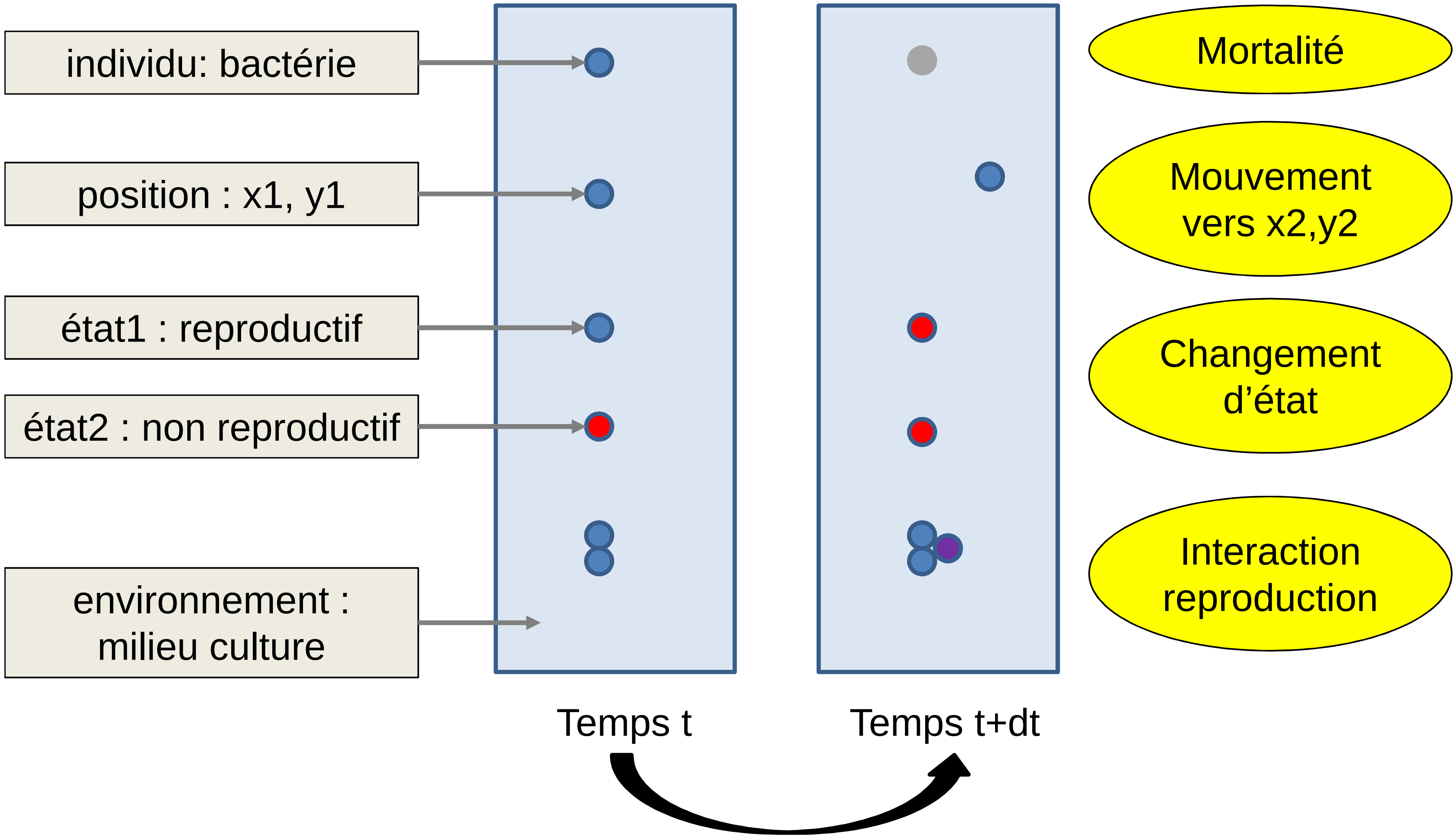
Objectifs du cours

- Qu’est-ce qu’un modèle multi-agents ?

- Application à la dynamique de la colonie d'abeilles

Exemple : population de bactéries

- Même système mais, ici, une représentation des individus



Définition d'un modèle multi-agents

- un système multi-agents (SMA)
  - Différents agents/individus dans un environnement
  - Processus d'évolution des agents
  - Interactions entre les agents selon certaines relations
  - Possibilité de différents types d'agents (par exemple : les coccinelles et des pucerons)
- Cas particulier : modèle basé sur les individus (*IBM pour Individual-Based Modelling*).
  - agents de même nature.
  - Par exemple : les plantes dans une culture.
  - premier IBM: Jeu de la vie de John Conway (1970)

- Agents :
  - Organes (ex. feuille), organisme (ex. plante, insecte,…), groupe (ex. parcelle),…
  - Avec des propriétés bien définies qui peuvent évoluer dans le temps.
- Processus souvent considérés :
  - Création d’un nouvel individu et sa disparition (mortalité)
  - Développement (ex : phénologie)
  - Mouvement des individus
  - Interactions (par exemple : reproduction, communication,…)
- Chaque agent évolue en fonction de règles propres et d’interaction => la dynamique du système en émerge.

Dynamique d’une colonie d'abeilles

- Pourquoi ce exemple ?
  - modèle développé et utilisé dans la communauté scientifique
  - Ouvert : disponible publiquement.

    http://beehave-model.net/
- BEEHAVE : un modèle décrivant la dynamique du système « colonie d’abeille ».
  - Développement des individus et dynamiques de la population
  - Exploration des ressources floristiques
  - Prise en compte de facteurs de dépérissement

- Article Becher et al, 2014.
- Modèle repris dans travaux dans le cadre du projet RISQAPI en cours INRA, ACTA, ITSAP,…

  (Fabrice Requier et François Brun)

50 YEARS WITH IMPACT — Journal of Applied Ecology — 1913 British Ecological Society 2013 — CELEBRATING 100 YEARS

Journal of Applied Ecology 2014, **51,** 470–482 doi: 10.1111/1365-2664.12222

BEEHAVE: a systems model of honeybee colony dynamics and foraging to explore multifactorial causes of colony failure

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Summary

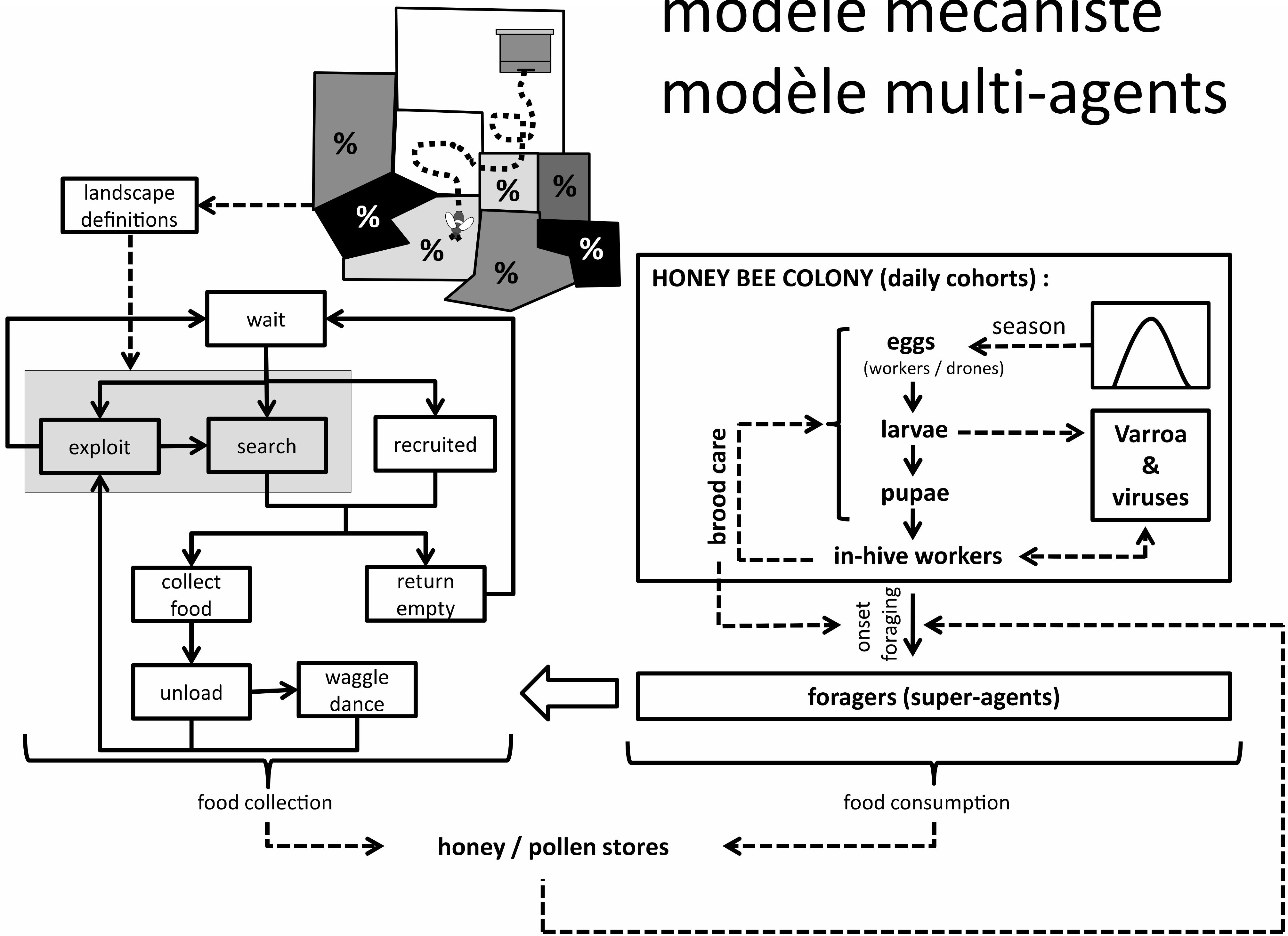
1. A notable increase in failure of managed European honeybee *Apis mellifera* L. colonies has been reported in various regions in recent years. Although the underlying causes remain unclear, it is likely that a combination of stressors act together, particularly varroa mites and other pathogens, forage availability and potentially pesticides. It is experimentally challenging to address causality at the colony scale when multiple factors interact. *In silico* experiments offer a fast and cost-effective way to begin to address these challenges and inform experiments. However, none of the published bee models combine colony dynamics with foraging patterns and varroa dynamics.

2. We have developed a honeybee model, BEEHAVE, which integrates colony dynamics, population dynamics of the varroa mite, epidemiology of varroa-transmitted viruses and allows foragers in an agent-based foraging model to collect food from a representation of a spatially explicit landscape.

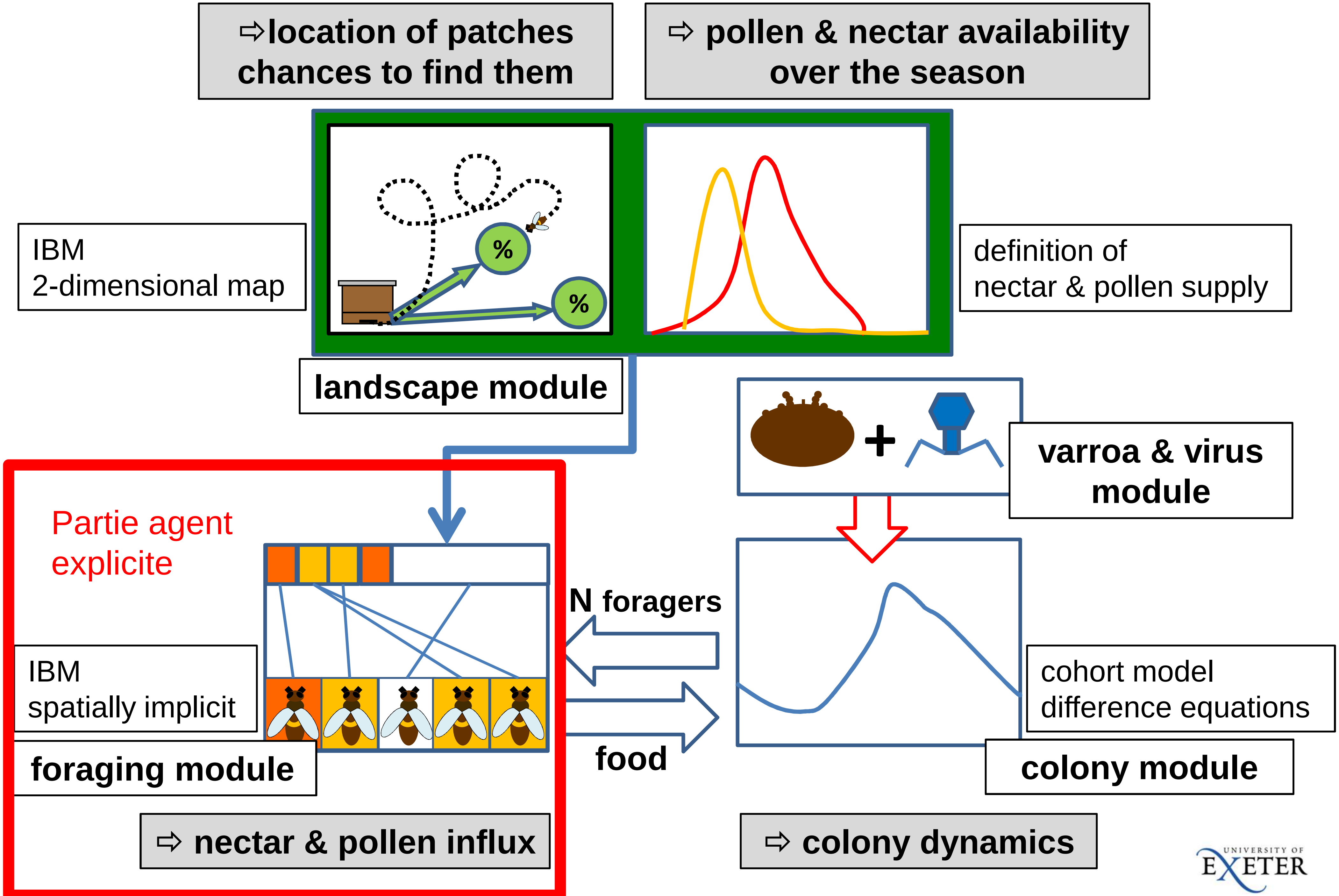
3. We describe the model, which is freely available online (www.beehave-model.net). Extensive sensitivity analyses and tests illustrate the model's robustness and realism. Simulation experiments with various combinations of stressors demonstrate, in simplified landscape settings, the model's potential: predicting colony dynamics and potential losses with and without varroa mites under different foraging conditions and under pesticide application. We also show how mitigation measures can be tested.

4. *Synthesis and applications*. BEEHAVE offers a valuable tool for researchers to design and focus field experiments, for regulators to explore the relative importance of stressors to devise management and policy advice and for beekeepers to understand and predict varroa dynamics and effects of management interventions. We expect that scientists and stakeholders will find a variety of applications for BEEHAVE, stimulating further model development and the possible inclusion of other stressors of potential importance to honeybee colony dynamics.

modèle mécaniste
modèle multi-agents



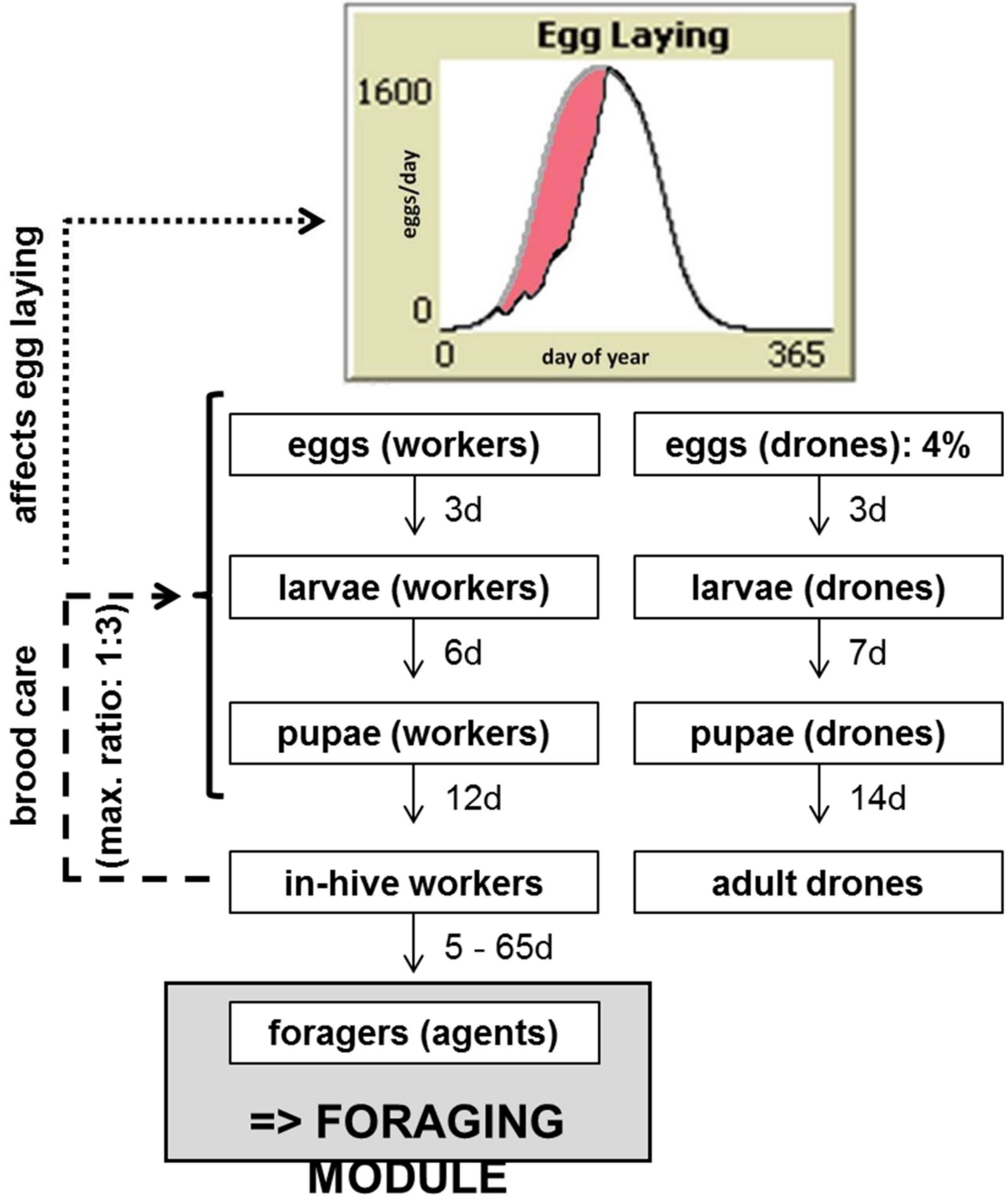
structure



⇨ location of patches chances to find them
⇨ pollen & nectar availability over the season
IBM
2-dimensional map
%
%
definition of nectar & pollen supply
landscape module
+
varroa & virus module
Partie agent explicite
N foragers
food
IBM
spatially implicit
foraging module
cohort model
difference equations
colony module
⇨ nectar & pollen influx
⇨ colony dynamics

Dynamique de la colonie

- À l'origine de la création des butineuses (agents)



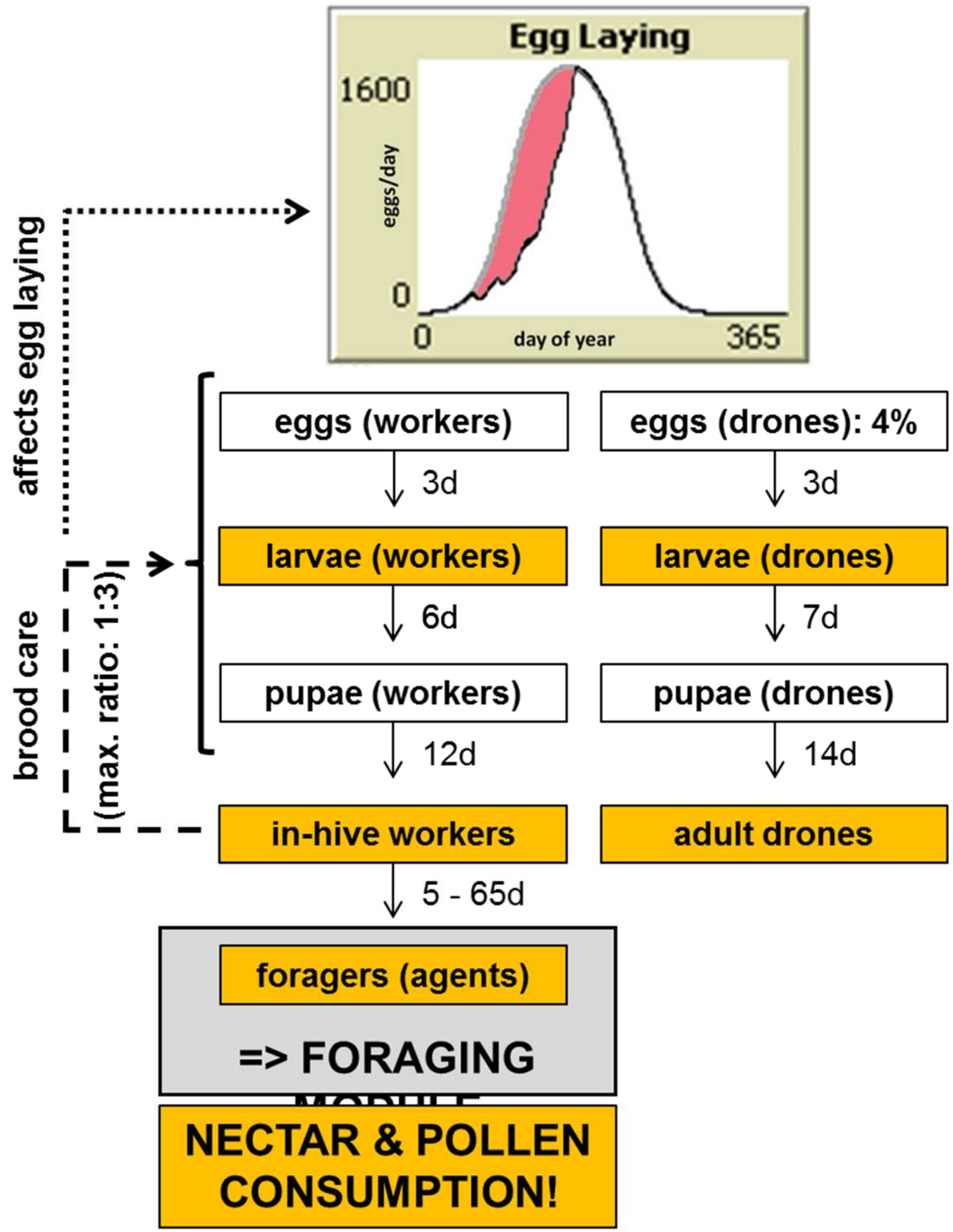
Dynamique de la colonie

Consomme les ressources

- nectar
- pollen

Mortalité lée

- au développement
- au butinage
- manque de ressources
- manque de nurses
- virus



module Varroa

based on Martin 1999, 2001:

 # phoretic mites

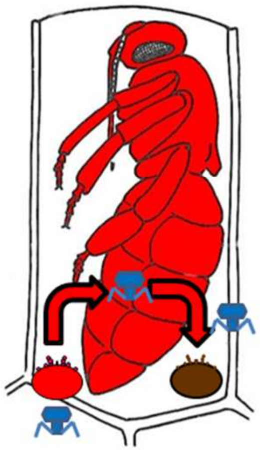
REPRODUCTION
random distribution of phoretic mites on brood cells:

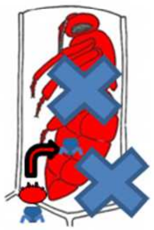
suitable drone cells (preferred)

suitable worker cells

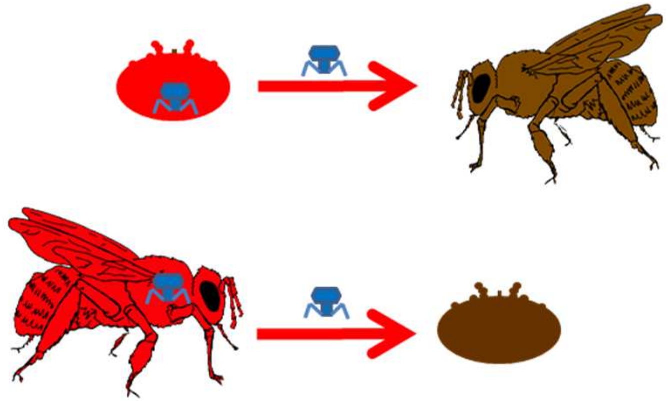
VIRUS TRANSMISSION
Viruses: Deformed wing virus (DWV) or Acute paralysis virus (APV)

= f life span
via pupae..





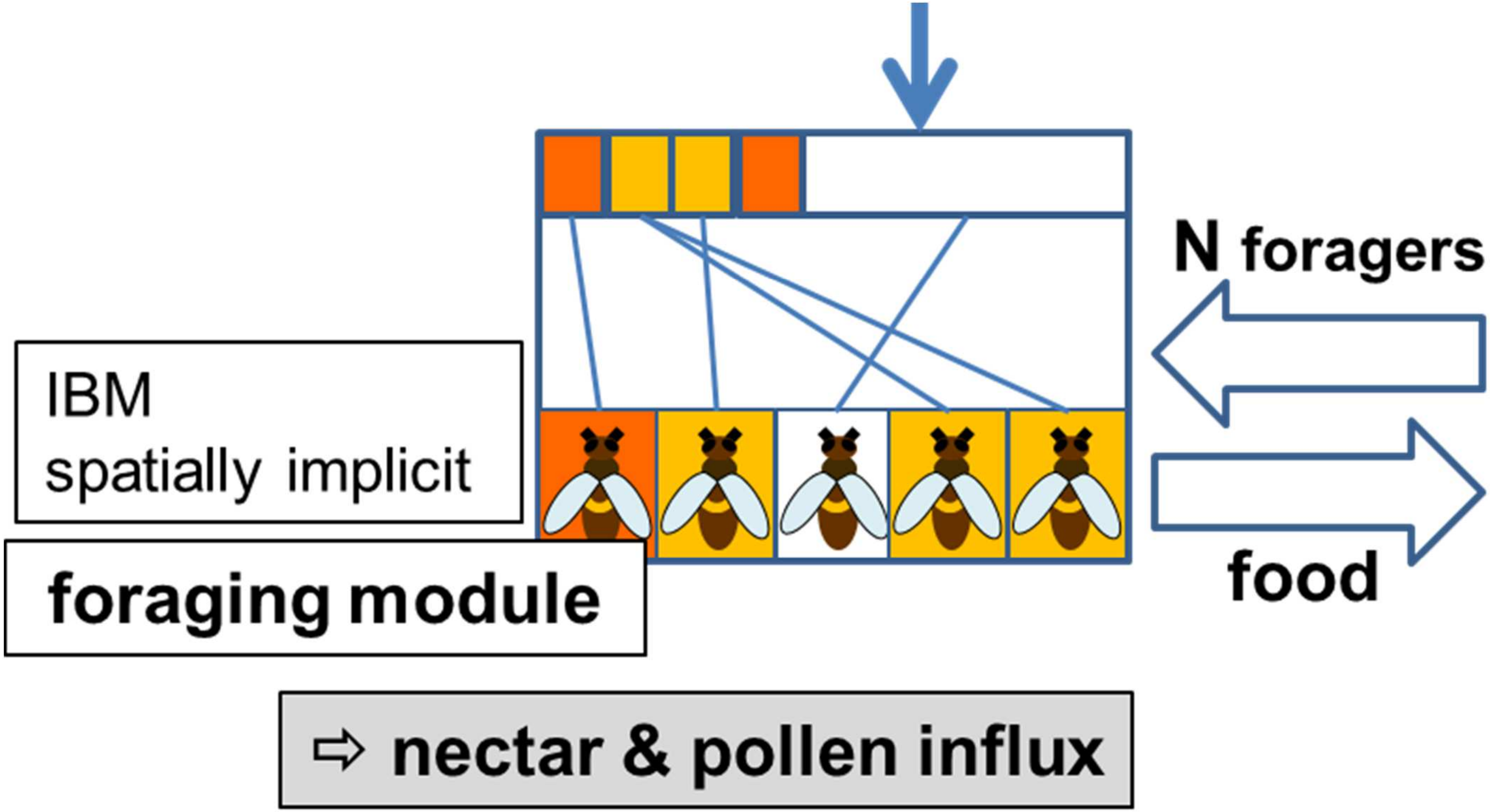
APV!



..or via phoretic mites - adult workers

Module de butinage

- 2 types d'agents
  - Type 1 : Avec 1 forager = 100 individus (temps de calcul)
  - Type 2 : patch de ressources florales

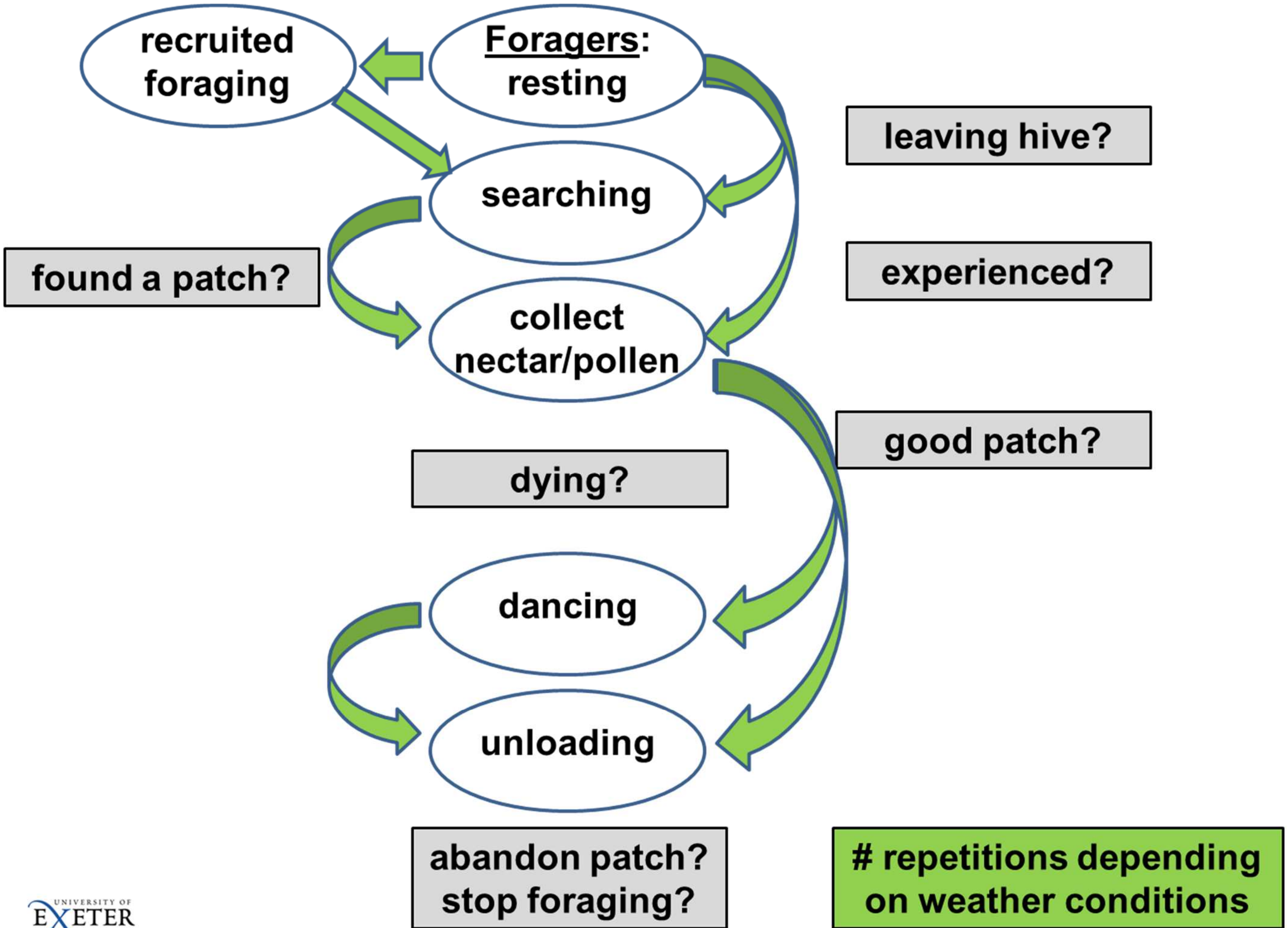


1 variable d'état pour chaque forager

Tab. 2: Activities of forager squadrons in the foraging submodel.
Forager activities during a day are stored in the forager's state variable "activityList" (Tab. 1).

Activity	Definition
lazy	Lazy bees will not forage on that day and cannot be recruited
resting	Resting bees, can be recruited to an advertised flower patch by dancers or may start foraging spontaneously in a following foraging round
expForaging	Experienced foragers, engaged in nectar or pollen collection at a certain patch
searching	Scouts, searching a new flower patch for nectar or pollen
bringingNectar	Successful nectar foragers, bringing back nectar
bringingPollen	Successful pollen foragers, bringing back pollen
recForaging	Foragers, recruited to an advertised flower patch by a dancer. They will search for this patch in the next foraging round

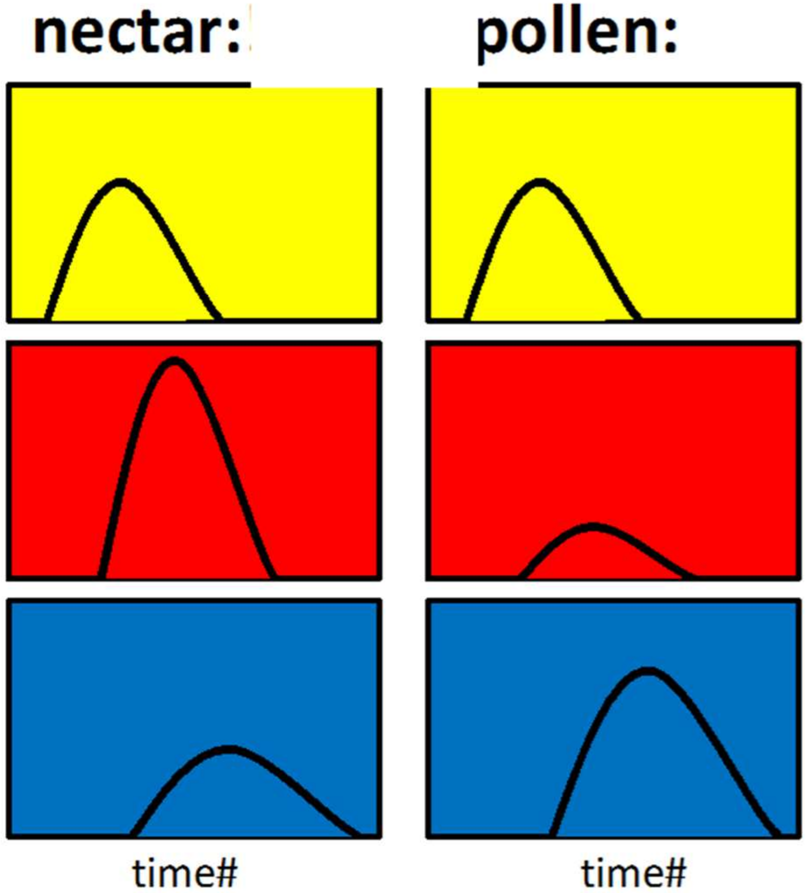
Module de butinage



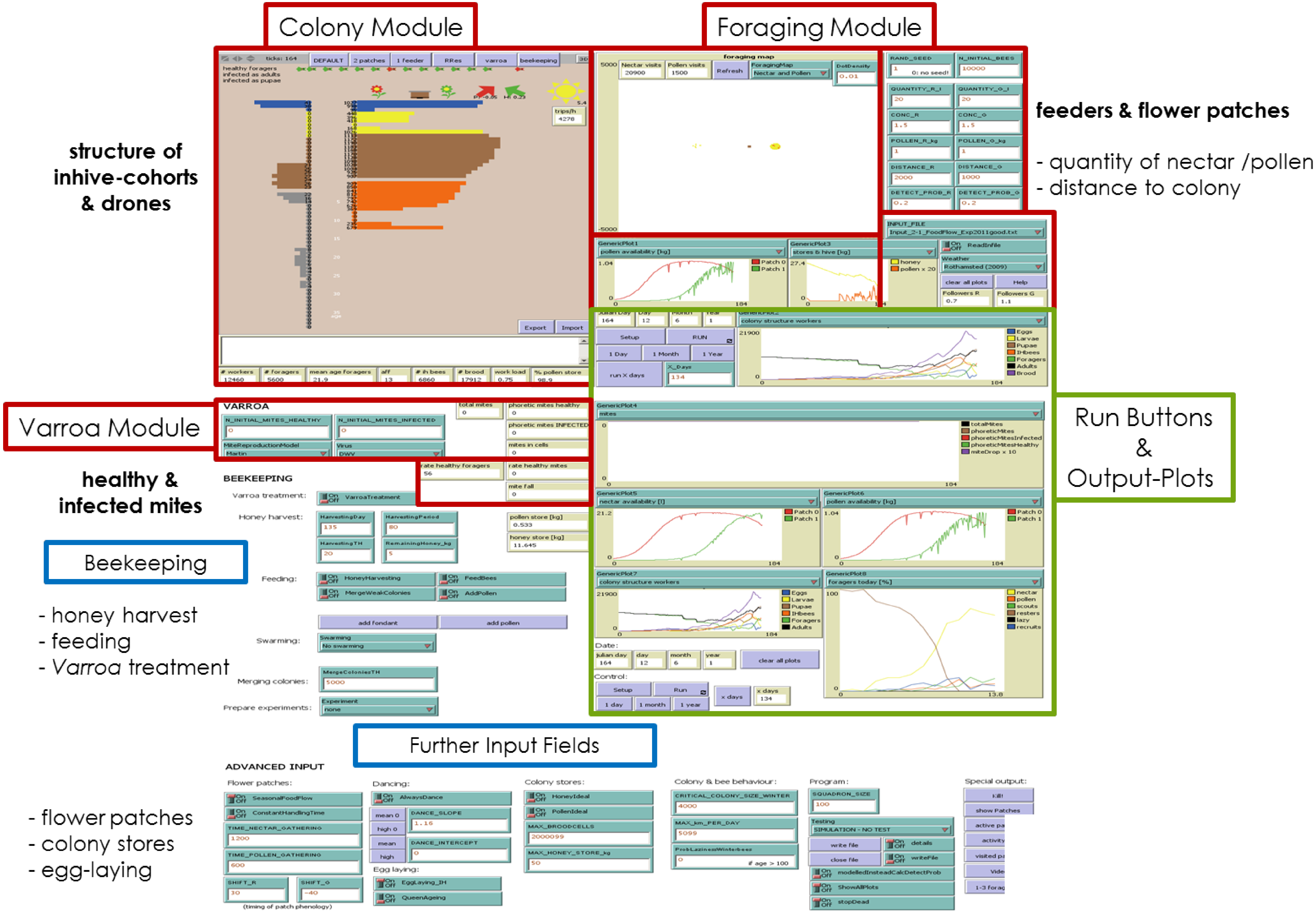
UNIVERSITY OF EXETER

Module d'interprétation du paysage

Carte des ressources au cours du temps ➔ dynamique des ressources



Interface sous NetLogo



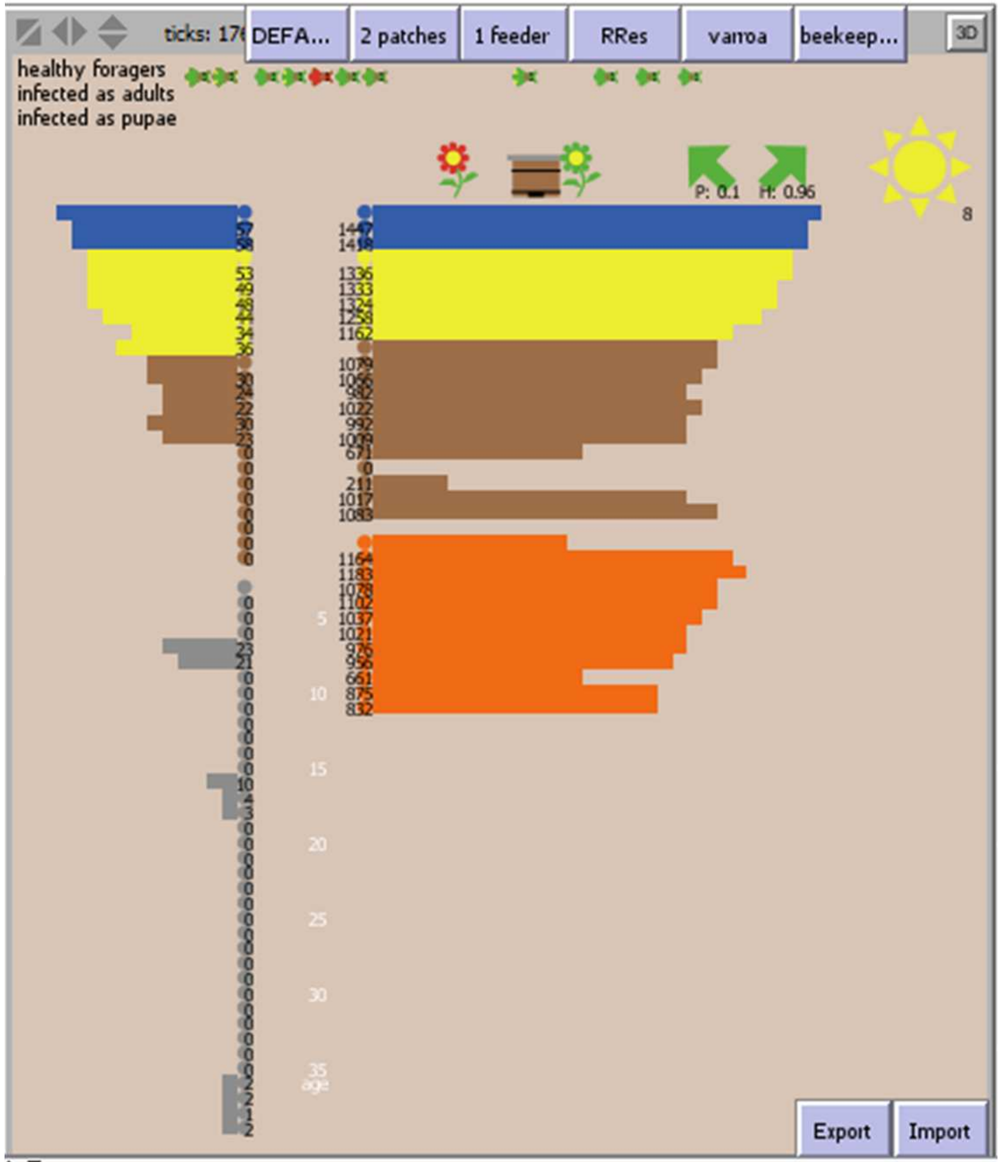
Extrait de code netlogo

Exemple simple

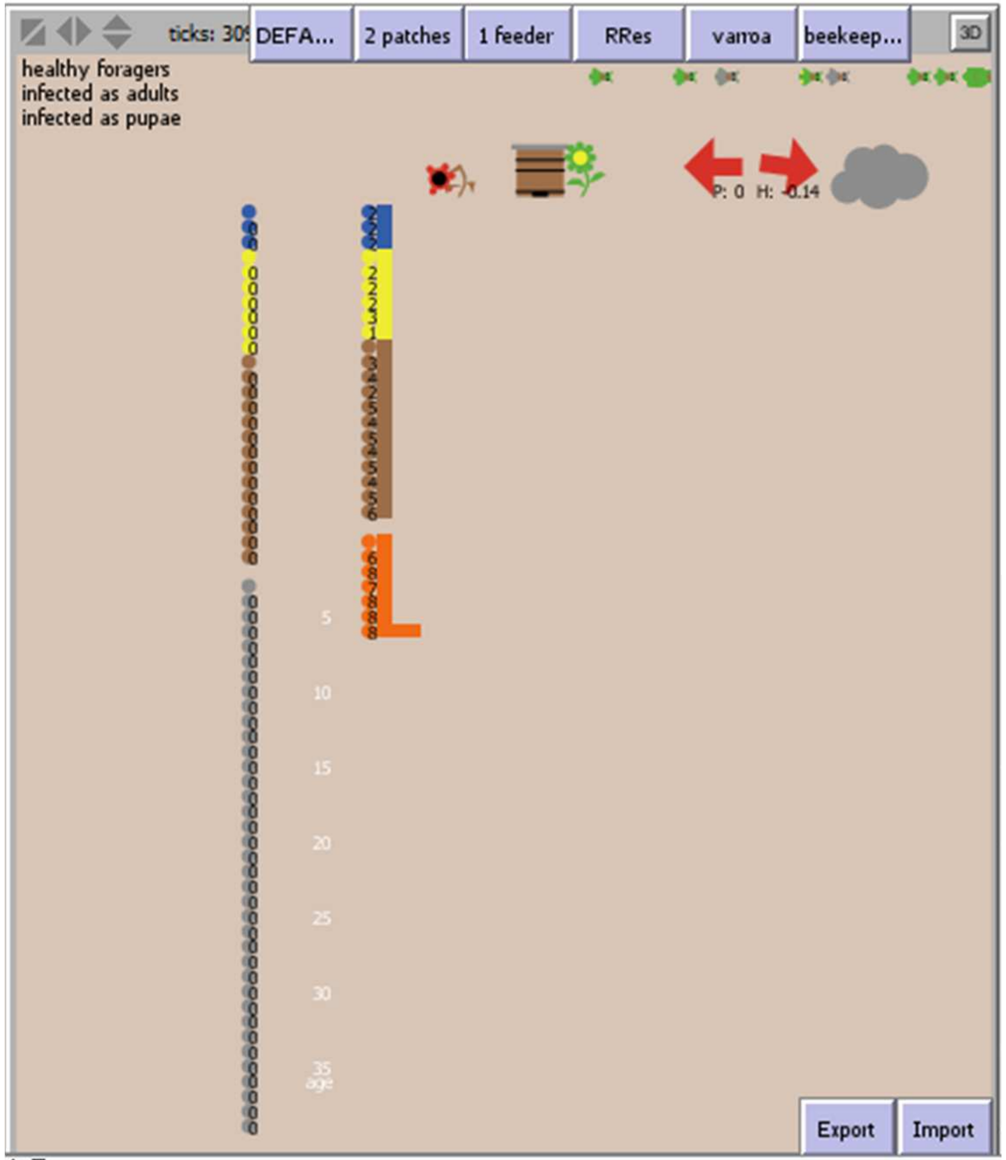
```
to ForagersDevelopmentProc
 ; foragers age by 1 day, forager turtles move forward
 ask foragerSquadrons
 [
  set age age + 1
  fd 1.8   ; movement on GUI
 ]
end
```

Visualisation butinage

Un jour favorable



Un jour défavorable



Sorties agrégées

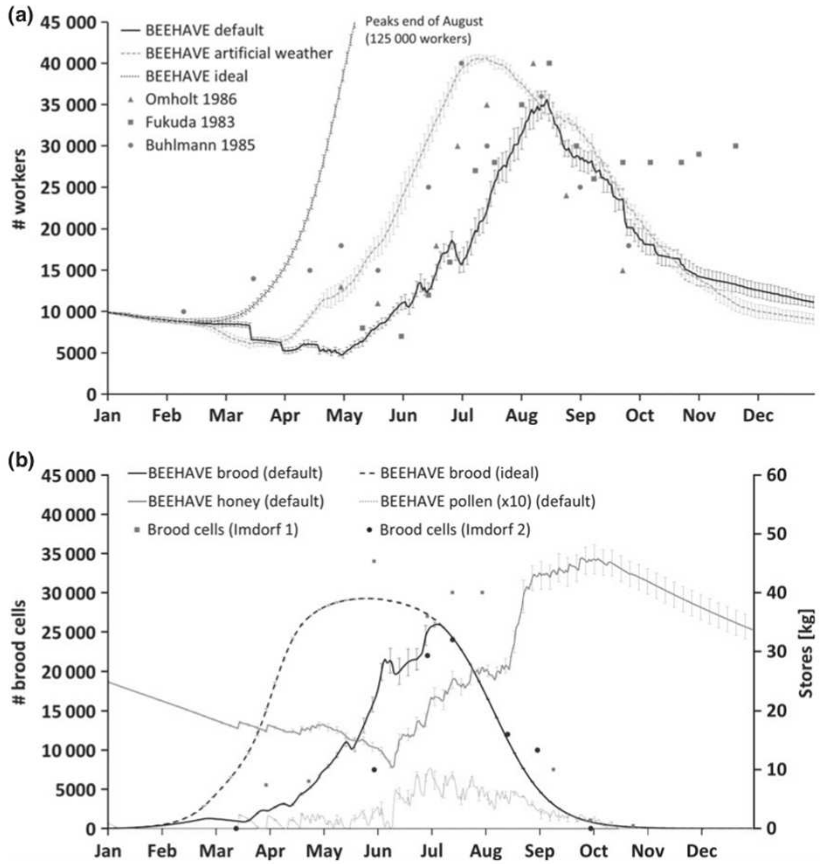


Fig. 2. (a) Colony dynamics of BEEHAVE under three sets of conditions: the default setting (continuous line), a setting with favourable, artificial weather data (dashed line) and a setting with ideal food supply that requires no foraging (dotted line) (mean ± SD; $n = 10$) in comparison with data from literature (data redrawn from Schmickl & Crailsheim 2007). Under ideal food supply, the model colonies peak at the end of August (125 000 workers) and contain about 80 000 bees at the end of the year (y-axis truncated for clarity). Error bars are shown for every second day. (b) Numbers of worker brood cells, and honey and pollen stores under the BEEHAVE default setting, and numbers of brood cells under 'ideal' conditions (mean ± SD; $n = 10$). Note that pollen stores are shown as increased by a factor of 10 for clarity in the figure. Empirical brood data redrawn from Imdorf, Ruoff and Fluri (2008) (squares: fig. 7 ('control'), $n = 8$; circles: fig. 14 ('carnica'), $n = 54$). Error bars are shown for every fifth day.

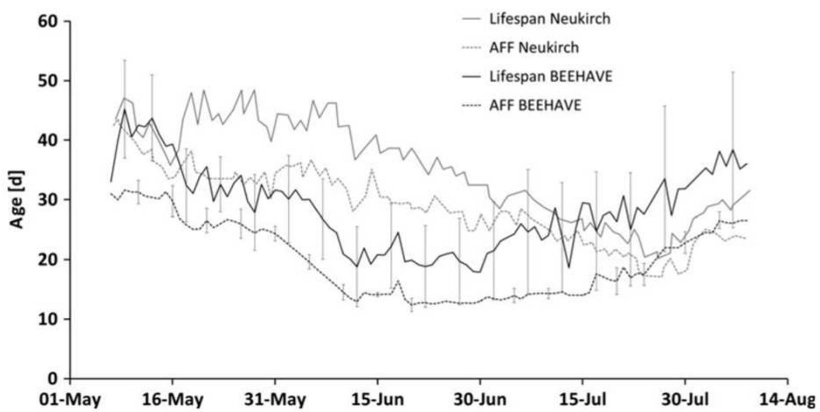


Fig. 3. Modelled average age of first foraging (AFF) of workers and average life span (mean ± SD; $n = 10$ simulations, under default setting) depending on their hatching date, in comparison with empirical data (redrawn from Neukirch 1982, fig. 1). Error bars are shown for every fifth day.

Quelques mises en garde sur les SMA

Problèmes liés au code informatique

- Passage des spécifications du modèle au code informatique pour les modèles multi-agents : pas une solution unique, risque très important d'erreurs ou d'incohérences

MODEL TESTING

Verification of the code

The correctness of the code was thoroughly checked during model development. Visual testing was performed using a wide range of plots and symbols that allow monitoring of the model behaviour (Table S1, Supporting information (worksheet 'Plots') lists all output options of the BEEHAVE interface). 'Assertions' are placed at various locations in the code and stop the program if state variables assume values beyond a defined range (Table S1, Supporting information (worksheet 'Assertions') provides a list of all assertions included in the program). Finally, the complete code was scrutinized separately by two co-authors who were not involved in writing the program.

Problèmes de compréhension du modèle produit

- Modèle résultant = très très complexe

⇒difficile de se l'approprier, de bien le comprendre

- Un effort sur l'exploration est nécessaire pour en comprendre le fonctionnement globale

⇔Analyse de sensibilité

(mais grand nombre

de paramètres)

SENSITIVITY ANALYSIS

In our sensitivity analysis, we varied one parameter at a time, but over large ranges. This goes far beyond local sensitivity analysis, the most common type of sensitivity analysis in ecological modelling, where parameters are changed by only 5–10%. We thus performed 61 'sensitivity experiments' (Railsback & Grimm 2012), which give a quite comprehensive overview of how single parameters affect model behaviour. Our analysis did not, however, cover interaction between parameters, which would have required a global sensitivity analysis based on some systematic sampling of parameter space (Saltelli *et al*. 2008; Saltelli & Annoni 2010). Although such an analysis might be desirable, it requires running the model for a very large number of parameter combinations, with significant run time and computing power implications.

Problèmes de temps de calcul

- Lié :
  - Nombre d'agents
  - Interactions entre ces agents…
- Ici, une ruche, c'est ~10000 individus en hiver et jusqu'à 50000 individus !

$\Rightarrow$ Solution : 1 agent = « groupe d'individus homogènes »

Ici, « super-individuals », avec pour les butineuses

1 forager = 100 individus

conclusion

- SMA : souvent très séduisants
- Un bon moyen d'agréger la connaissance dans un domaine scientifique
- Continuité par rapport aux modèles à compartiment lors que l'on veut mieux prendre en compte la variabilité individuelle
- Des outils dédiés assez facile à prendre en main (Netlogo,…)
- Mais :
  - difficulté de mise en œuvre dès que la complexité augmente
  - pas toujours justifiés de recourir à ces formalismes pour répondre à une question pratique