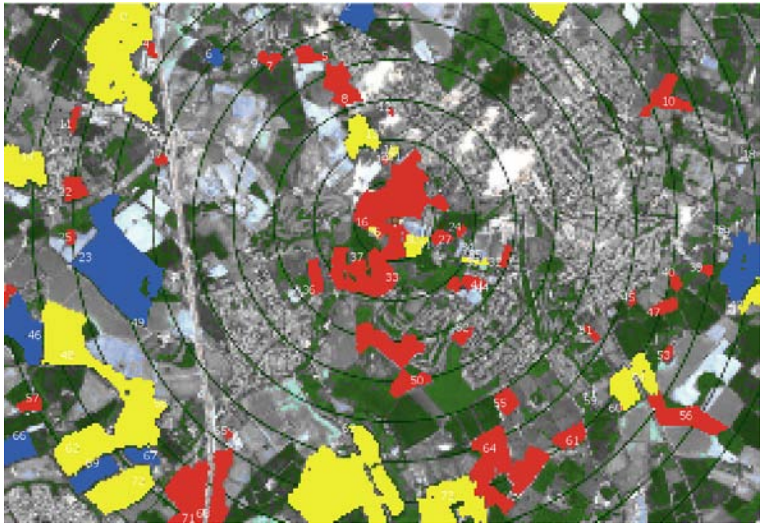
A review of honeybee models and a short introduction to the new integrated colony model BEEHAVE

Volker Grimm



HELMHOLTZ
ZENTRUM FÜR
UMWELTFORSCHUNG
UFZ

Presentation based on project: Honeybee population dynamics: integrating the effects of factors within the hive and in the landscape (Rothamsted Research, UK, 2009-2013). Co-funded by BBSRC (88%) and Syngenta (12%)

Matthias Becher*, **Pete Kennedy***, **Jenny Swain**, **Judy Pell**, **Juliet Osborne***: Rothamsted Research, UK

*Current address: University of Exeter

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Grimm V, Becher MA, Kennedy PJ, Thorbek P, Osborne J. **Ecological modeling for pesticide risk assessment of honeybees and other pollinators**. In: Fischer D, Moriarty T. *Pesticide risk assessment for pollinators: A SETAC Pellston workshop*. SETAC Press, Pensacola, FL (in press)

Becher MA, Thorbek P, Kennedy PJ, Osborne J, Grimm V. **Towards a systems approach for understanding honeybee decline: a stock-taking and synthesis of existing models**. *Journal of Applied Ecology* (in press)

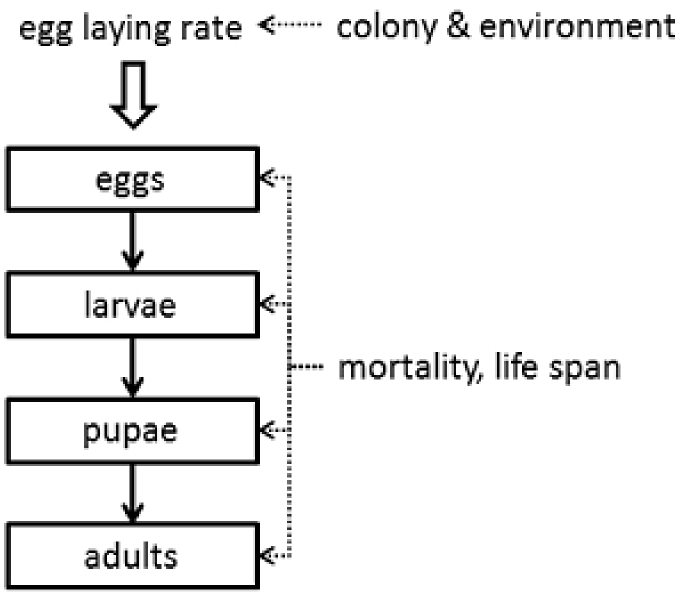
Becher MA, Thorbek P, Kennedy PJ, Grimm V, Osborne J. <**BEEHAVE: an integrated model of honeybees dynamics**>. To be submitted to *Journal of Applied Ecology* (within next 4 weeks)

Honeybee models: overview

Three categories of models:

1. Within-hive colony dynamics (8)
2. Varroa mite population dynamics within hives (11)
3. Foraging (12)

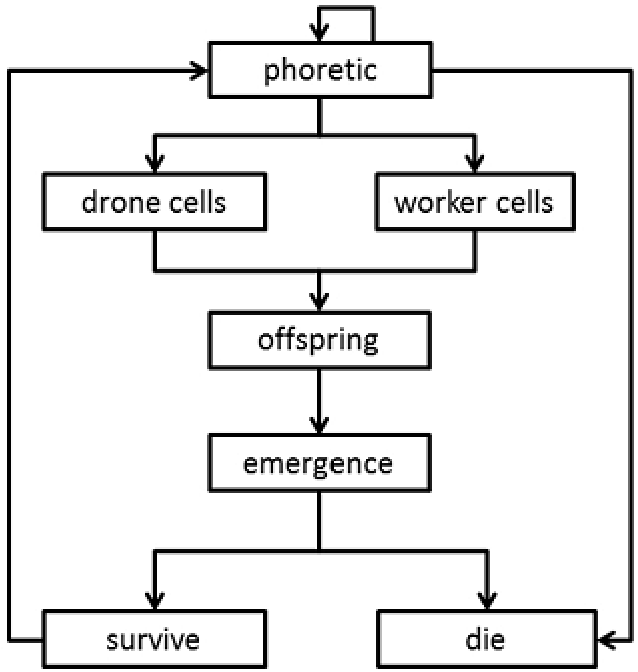
1. Within-hive colony dynamics



Most important models:

- BEEPOP (deGrandi-Hoffmann et al. 1989): beekeeping management
- HoPoMo (Schmickl and Crailsheim 2007): science (drivers, feedbacks)
- Khoury et al. (2011): Impact of forager mortality on colony development

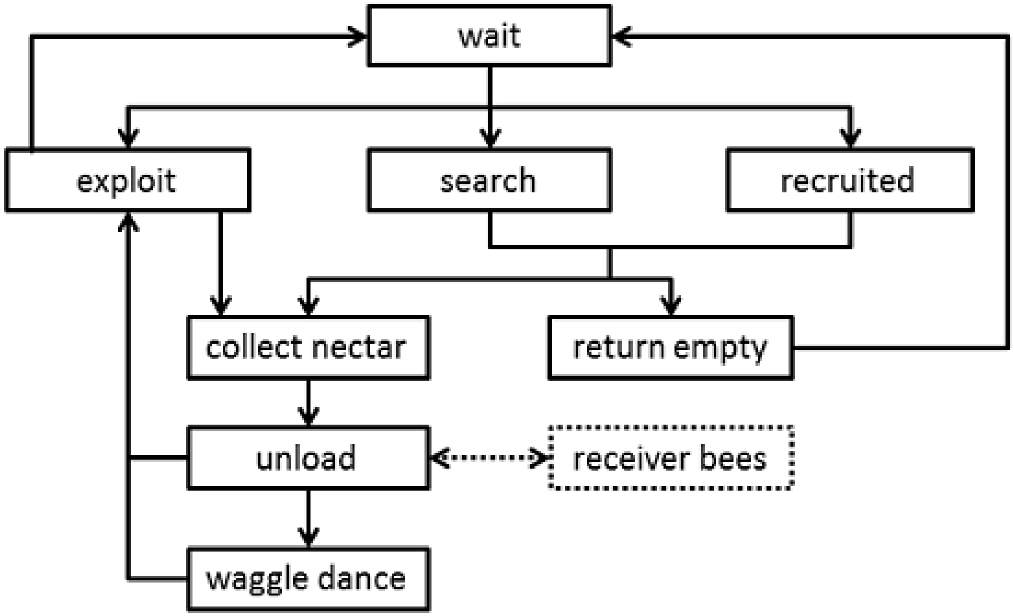
2. Varroa mite population dynamics



Most important models:

- Martin (1998): understand varroa effects on honeybees, beekeeping management
- Martin (2001): Martin (1998) combined with BEEPOP, virus transmission

3. Foraging



Most important models: hard to tell

- Most models use "energetic efficiency" as basis for foraging decisions
- None of the models linked to colony dynamics, explicit landscape structure and dynamics, or pollen collection

Representation of stressors

Factors	Omholt 1986	deGrandi-Hoffman et al. 1986	Martin 2001	AlGhamdi & Hoopingarner 2004	Thompson et al. 2005/2007	Schmickl & Crailsheim 2007	Becher et al. 2010	Khoury et al. 2011	Omholt & Crailsheim 1991	Calis et al. 1999a	Calis et al. 1999b	Boot et al. 1995	Wilkinson & Smith 2002	deGrandi-Hoffman & Curry 2004	Sumpter & Martin 2004	Vetharaniam & Barlow 2006	Vetharaniam 2012	All forager models	BEEHAVE
Genetic diversity																			
Varroa mites			+	+				(+)	+	+	+	(+)	+	+	+	(+)	(+)		+
Viruses			+												+				+
Bacterial pathogens																			
Nosema spp.								(+)											+
Loss of forage quantity						+													+
Forage nutritional quality																			+
Beekeeping practice			(+)	(+)				(+)		(+)	(+)		(+)	+	(+)	(+)			+
Pesticides – inside hive					+														+
Pesticides – outside hive					+			(+)											+
Forager death unknown cause		(+)			(+)	+		+					(+)	(+)					+

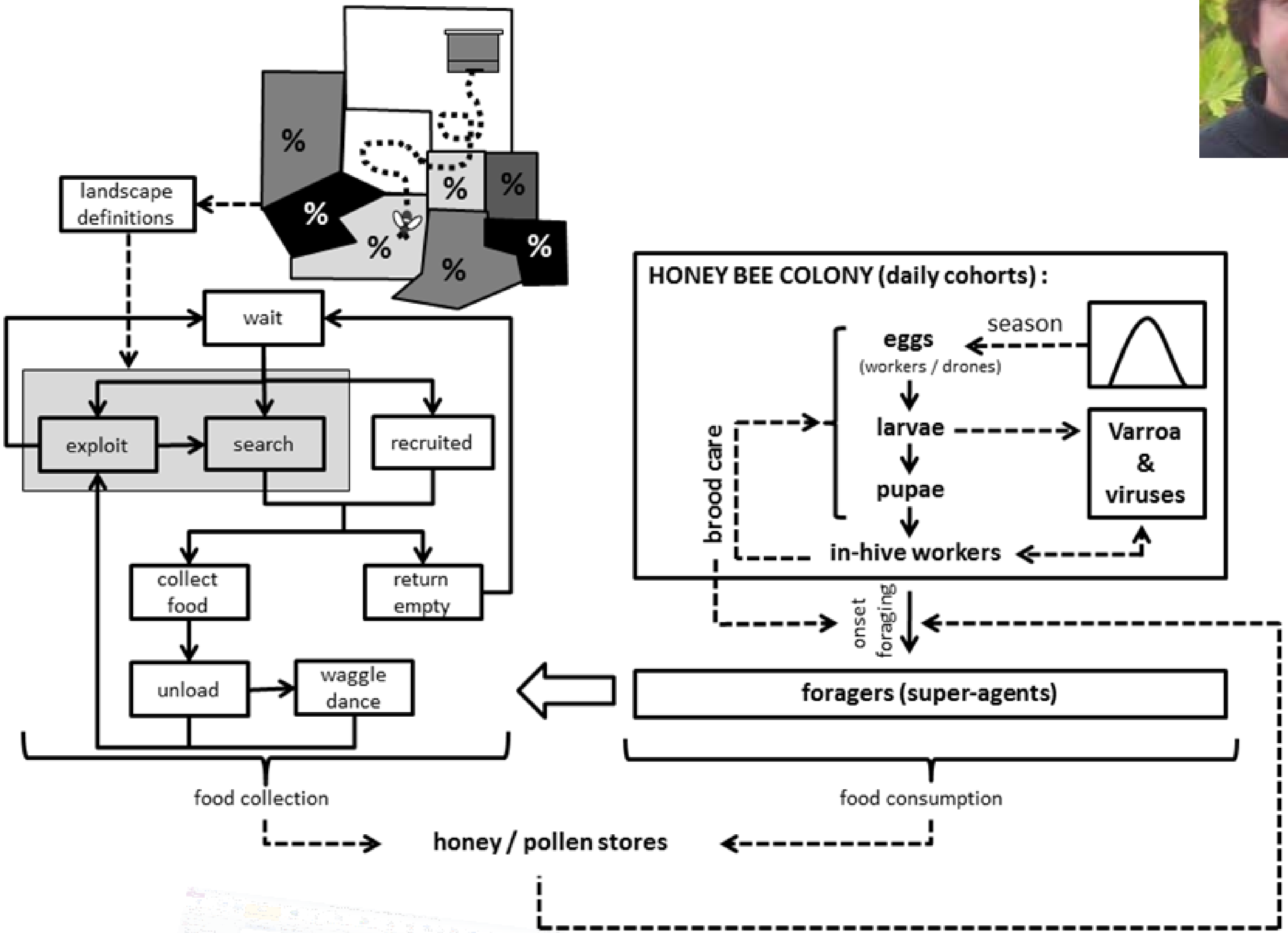
Conclusions from review

- Model **testing**, **validation**, and **analysis** of most models was very limited
  - No clear separation of **imposed** and **emergent** dynamics
  - No clear indication of how much **calibration** was involved
  - Limited or no **sensitivity analysis**
- For foraging models, a **benchmark** test exist: the Seeley et al. (1991) feeder experiment

Conclusions from review

- **Well-tested building blocks** exist in existing models
- A model that would allow **integrating stressors** within and outside the hive does not yet exist
- Colony structure and important **feedback loops** need to be included (e.g., "age of first foraging")
- **Egg-laying rate, weather, colony structure,** and **availability of nectar and pollen** should drive the dynamics

BEEHAVE: developed by Matthias Becher



BEEHAVE

Colony module (in-hive, daily time steps):

- Similar to BEEPOP
- Feedbacks: brood care, amount of honey and pollen
- Consumption of nectar and pollen

Varroa module (daily time steps):

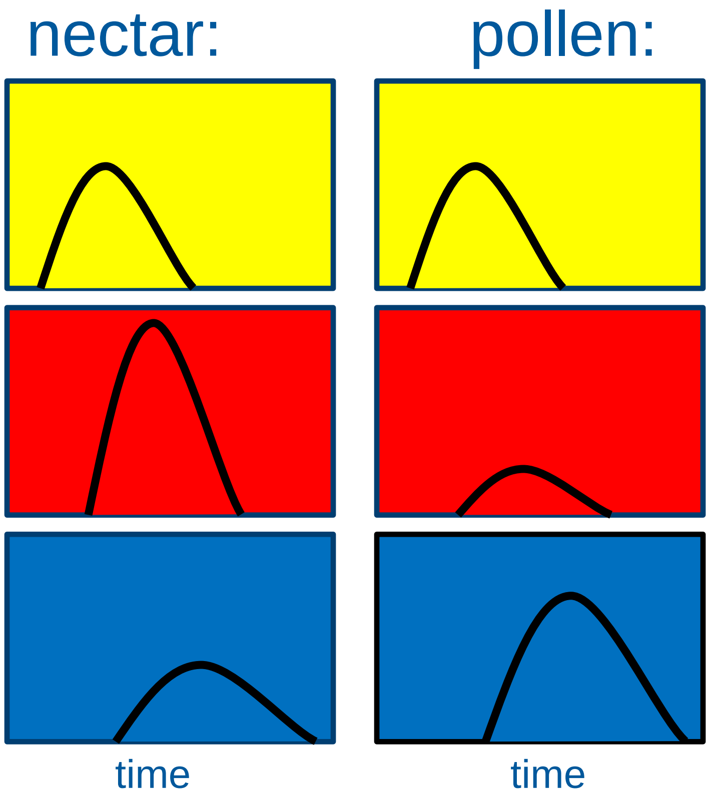
- Similar to Martin (2001)
- Transmits either deformed wing or acute paralysis virus

Foraging module (minutes):

- Driven by energetic efficiency
- Can be linked to hetegerogeneous and dynamics landscape
- Includes pollen collection

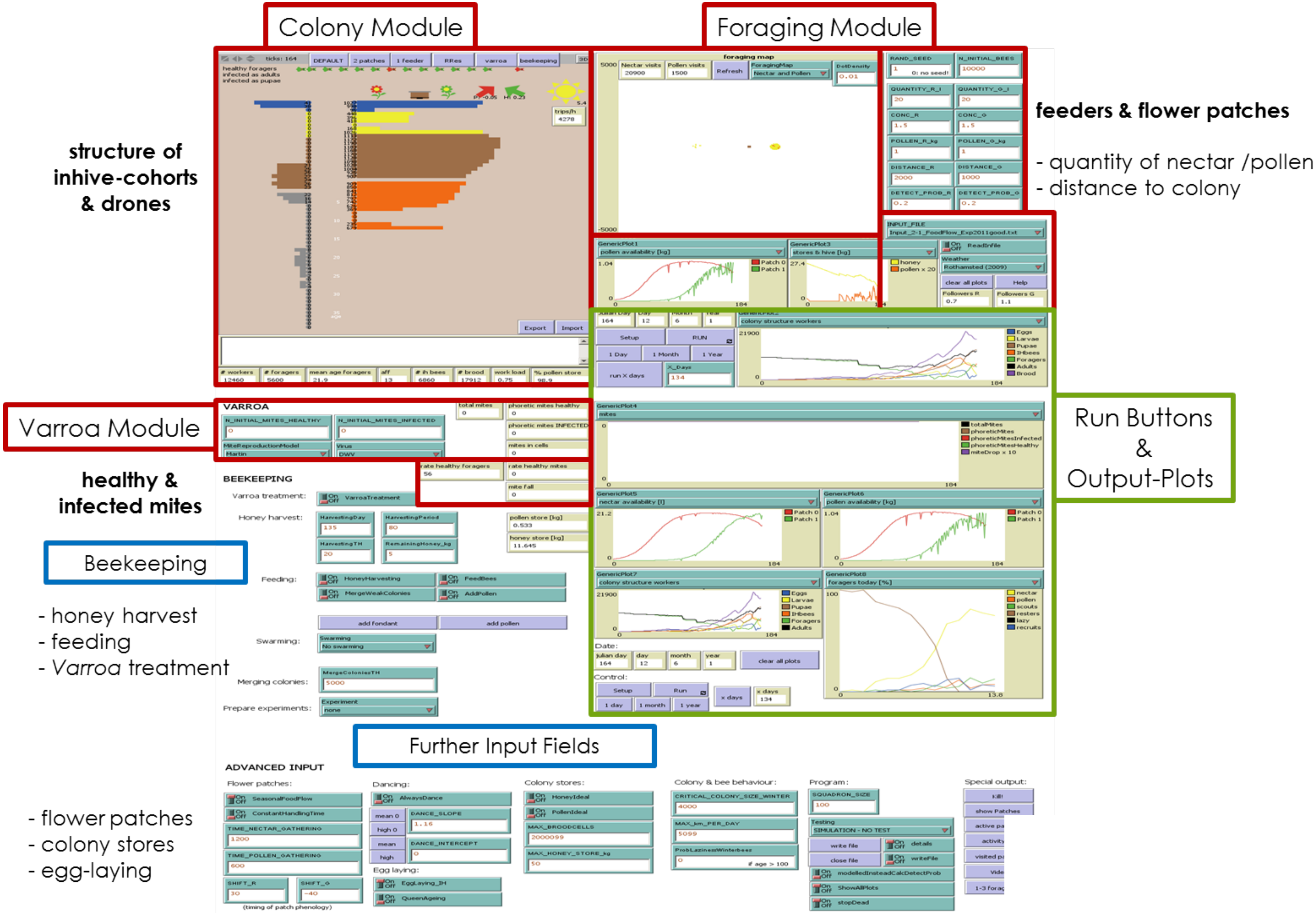
Automated calculation of:

- number of patches
- distance to apiary
- area of patch
- chance to find the patch
- crop type (colour)



Documentation, testing, validation

- Implemented in **NetLogo** (free software platform)
- Documented in **ODD** format (ca. 40 pages)
- User **manual** and **guided tour** exist (ca. 60 pages)
- Extensive **testing** (debug code, consistency tests, visual output)
- **Validation**:
  - Age of first foraging, lifespan
  - Number of reproductive cycles of varroa in a year
  - Seeley's feeder experiment



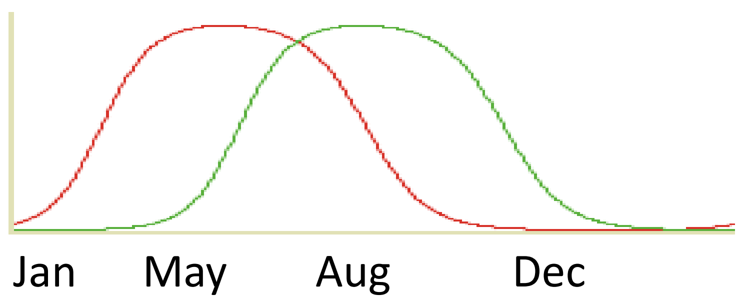
Colony Module
Foraging Module
structure of inhive-cohorts & drones
feeders & flower patches
- quantity of nectar /pollen
- distance to colony
Varroa Module
healthy & infected mites
Run Buttons & Output-Plots
Beekeeping
- honey harvest
- feeding
- Varroa treatment
Further Input Fields
- flower patches
- colony stores
- egg-laying

1st Example Scenario

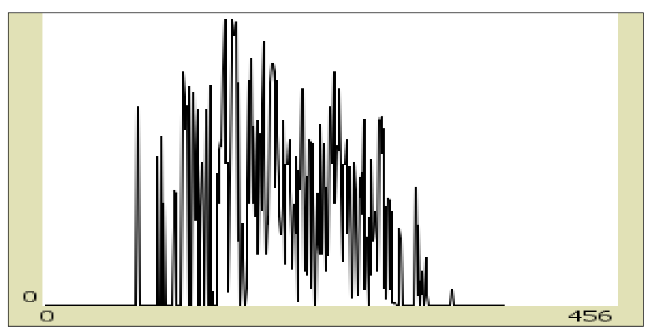
NO VARROA

N initial bees:	**10000**	
2 patches:		
Distance:	**1500 m**	**500 m**
Nectar concentration:	**1.5 mol/l**	**1.5 mol/l**
Pollen (max):	**1 kg/day**	**1 kg/day**

Nectar flow:

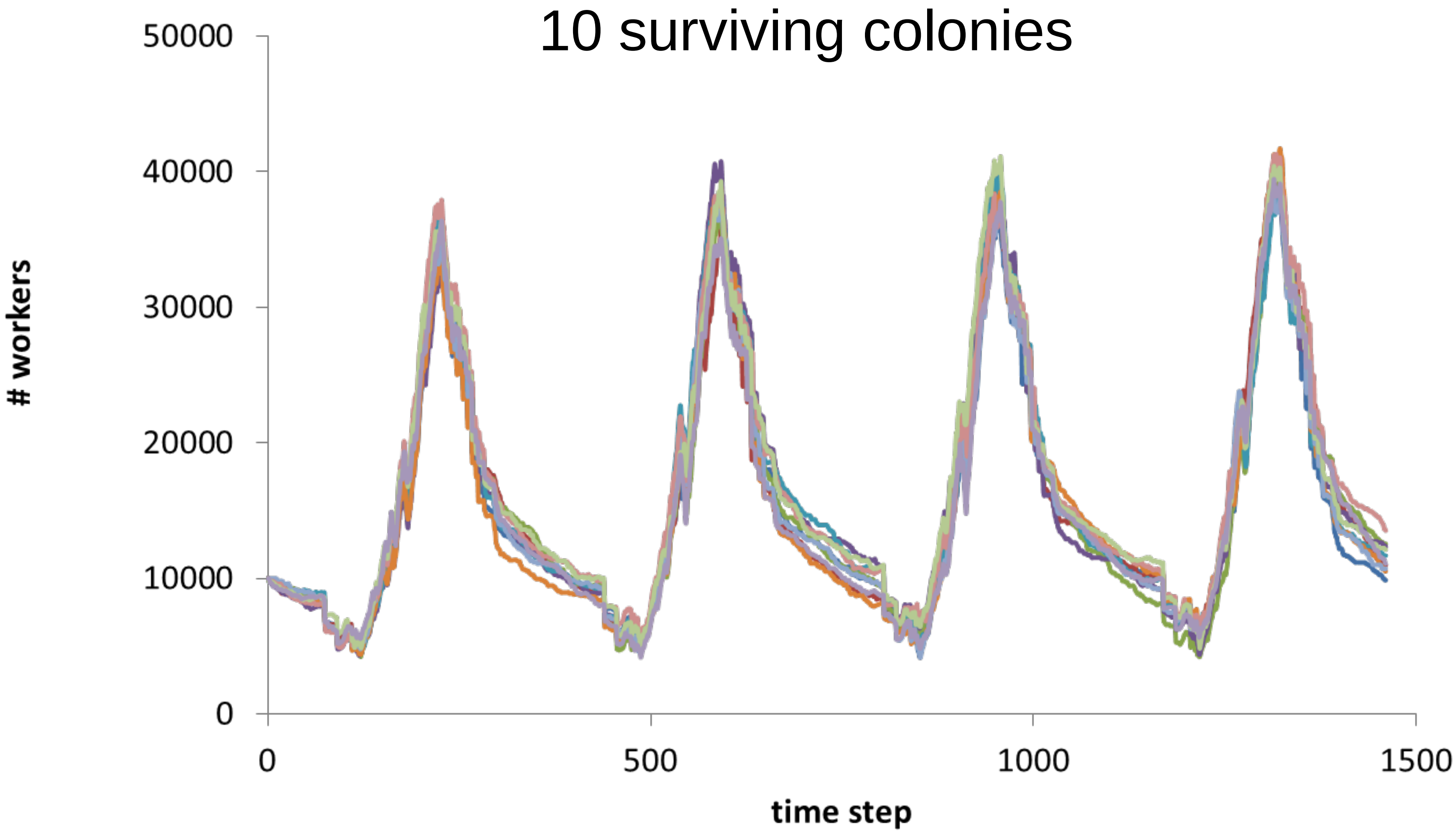


Daily foraging period based on real weather:



1st Example Scenario

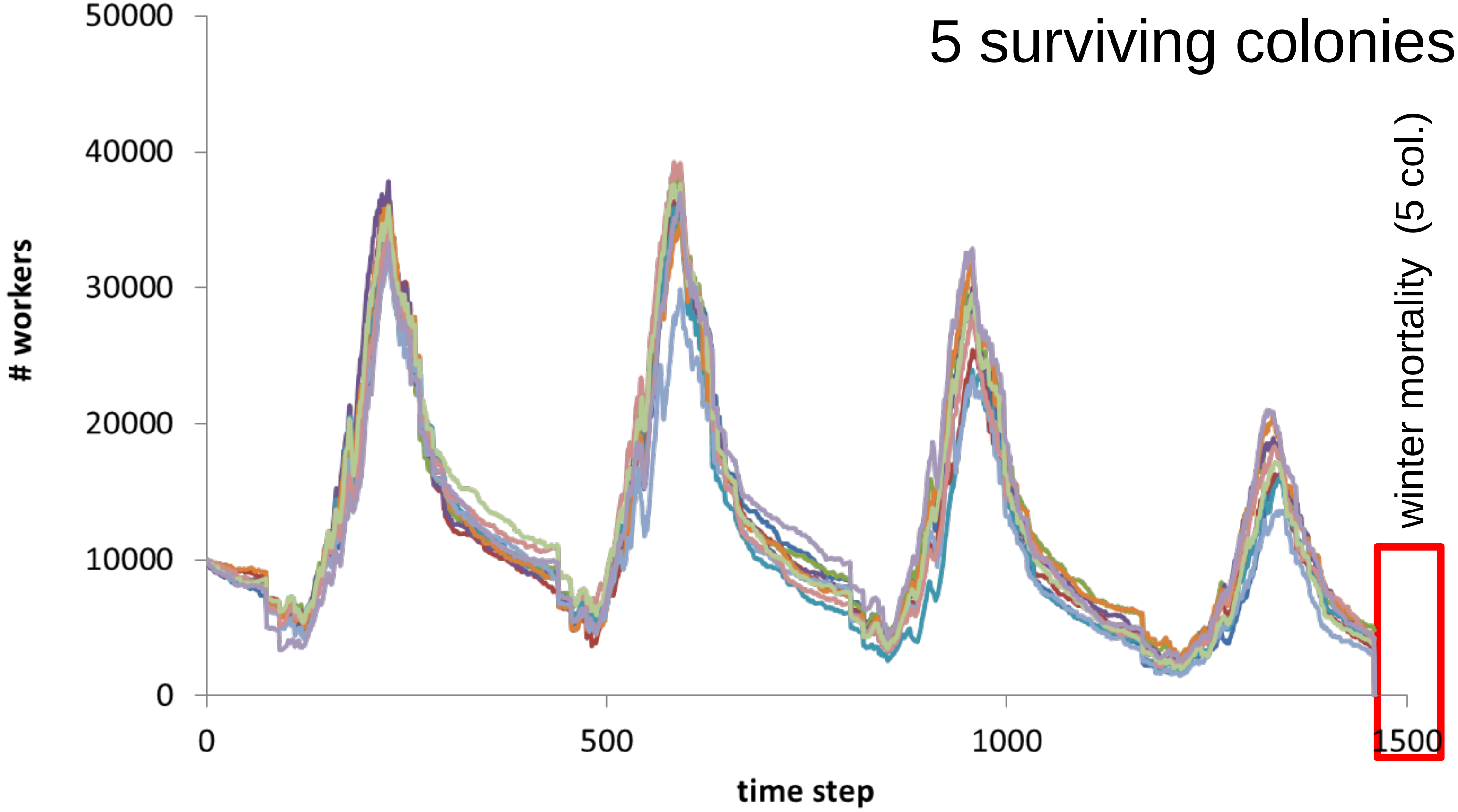
N adult workers (10 colonies) - <u>no varroa</u> – flower patches at 500 & 1500 m



2nd Example Scenario

N adult workers (10 colonies) - <u>with varroa and DWV</u>

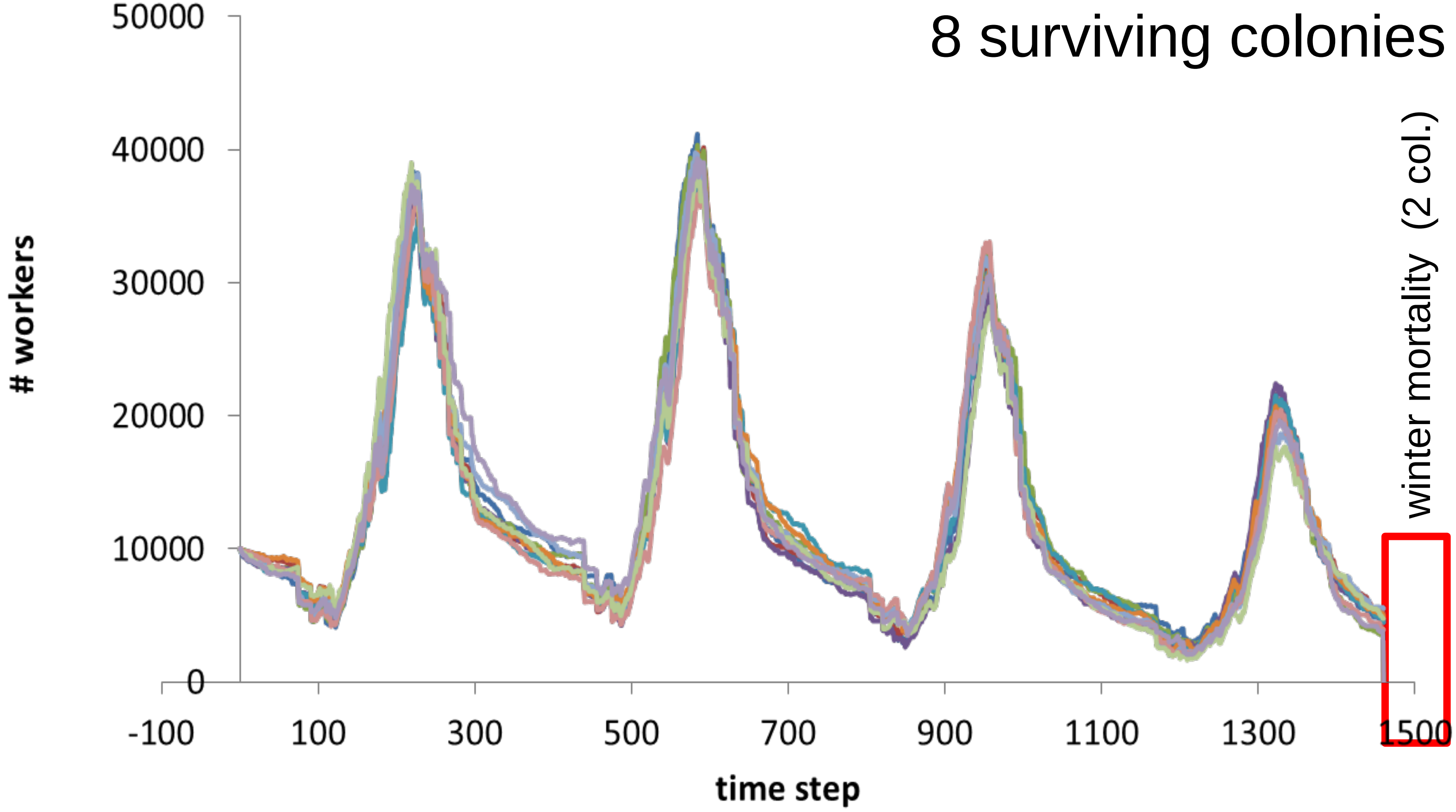
– flower patches at 500 & 1500 m



3rd Example Scenario

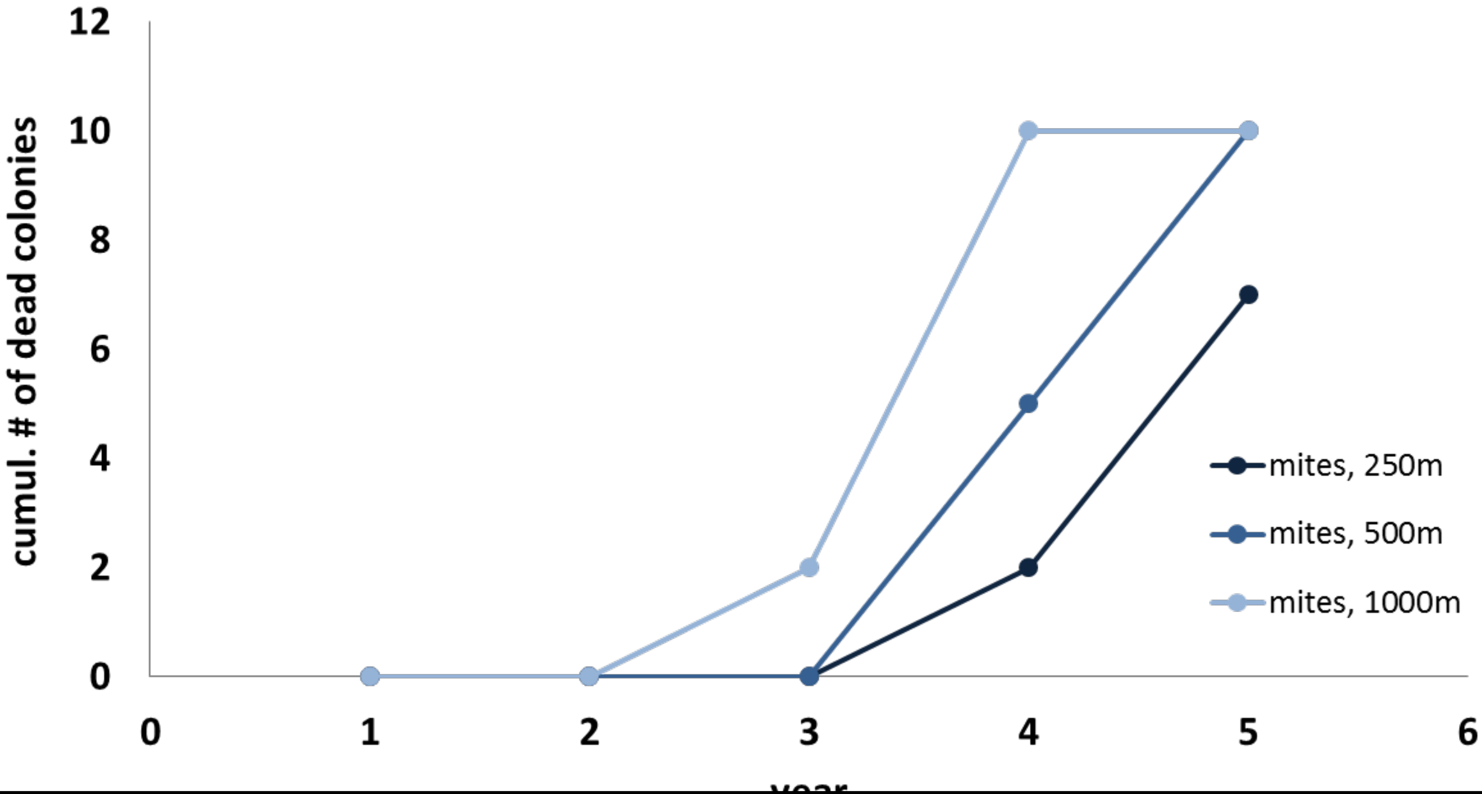
N adult workers (10 colonies) - <u>with varroa and DWV</u>

– flower patches at 250 & 1500 m



3rd Example Scenario

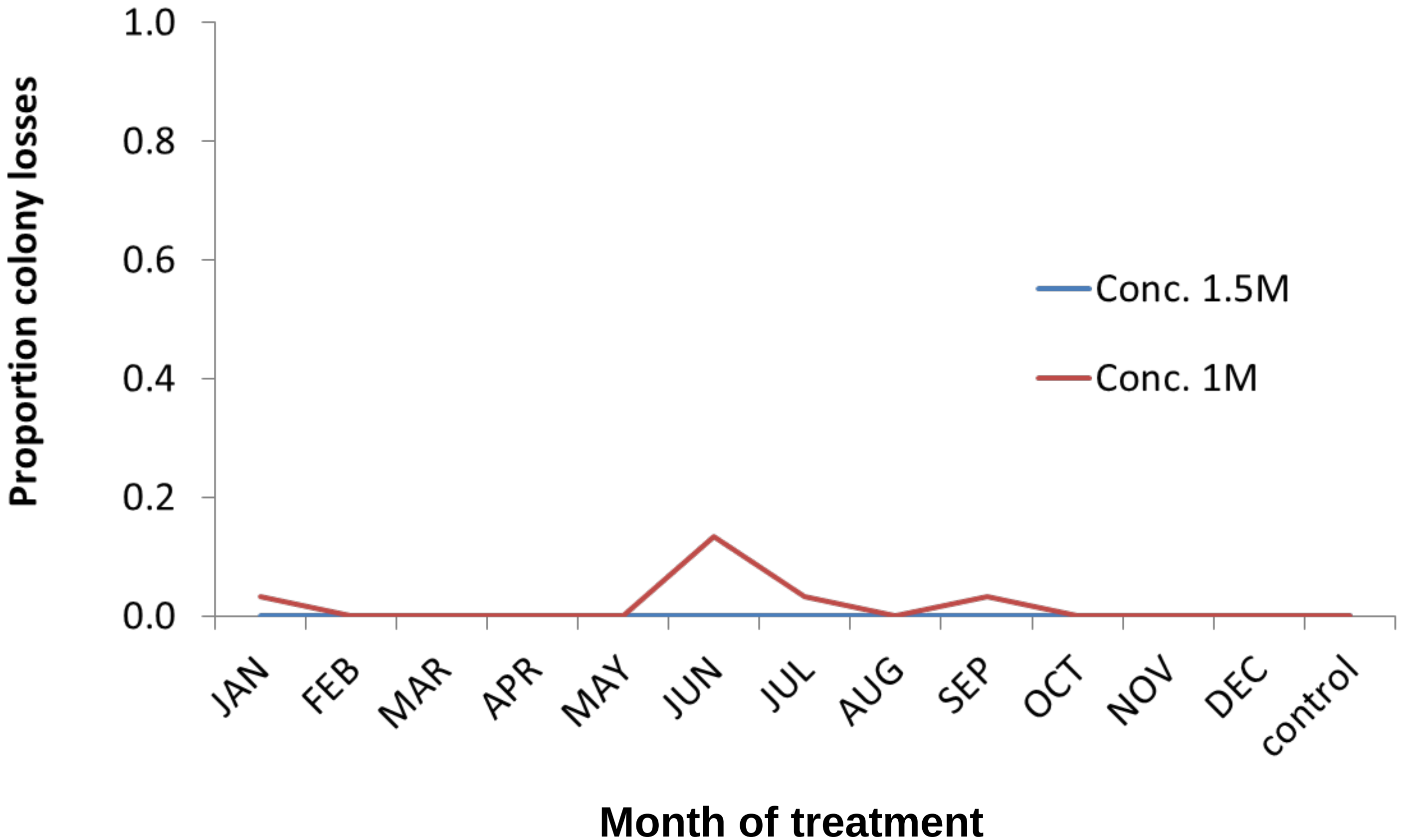
N adult workers (10 colonies) - <u>with varroa and DWV</u>
– close flower patch: 250, 500 & 1000m



First combination of foraging AND Varroa model:

Improved food availability can compensate loss of diseased bees

No varroa – nectar feeder at 1000 m - sugar concentration 1.0/1.5 mol/l – double mortality per foraging trip for 30 days (equivalent to increase in forager mortality from ca. 15 to 30%) (similar to **Khoury/Henry** scenario)



BEEHAVE: to do list

Get it published as soon as possible

- Designed so that others can test and use it
- Offer training courses, workshops

2 PhD students currently working on

- Multiple stressors, landscape structure and dynamics (Juliane Horn, UFZ)
- Specific pesticide module (Jack Rumkee, Univ. Exeter/Syngenta)

From one to many colonies

Summary

- Three types of models (within-hive, varroa, foraging)
- Well-tested modules exist, but no integrated model
- BEEHAVE: first attempt to link within-hive dynamics to foraging in heterogeneous and dynamic landscape
- BEEHAVE (or refinements) would be suitable for regulatory risk assessment

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Juliane Horn

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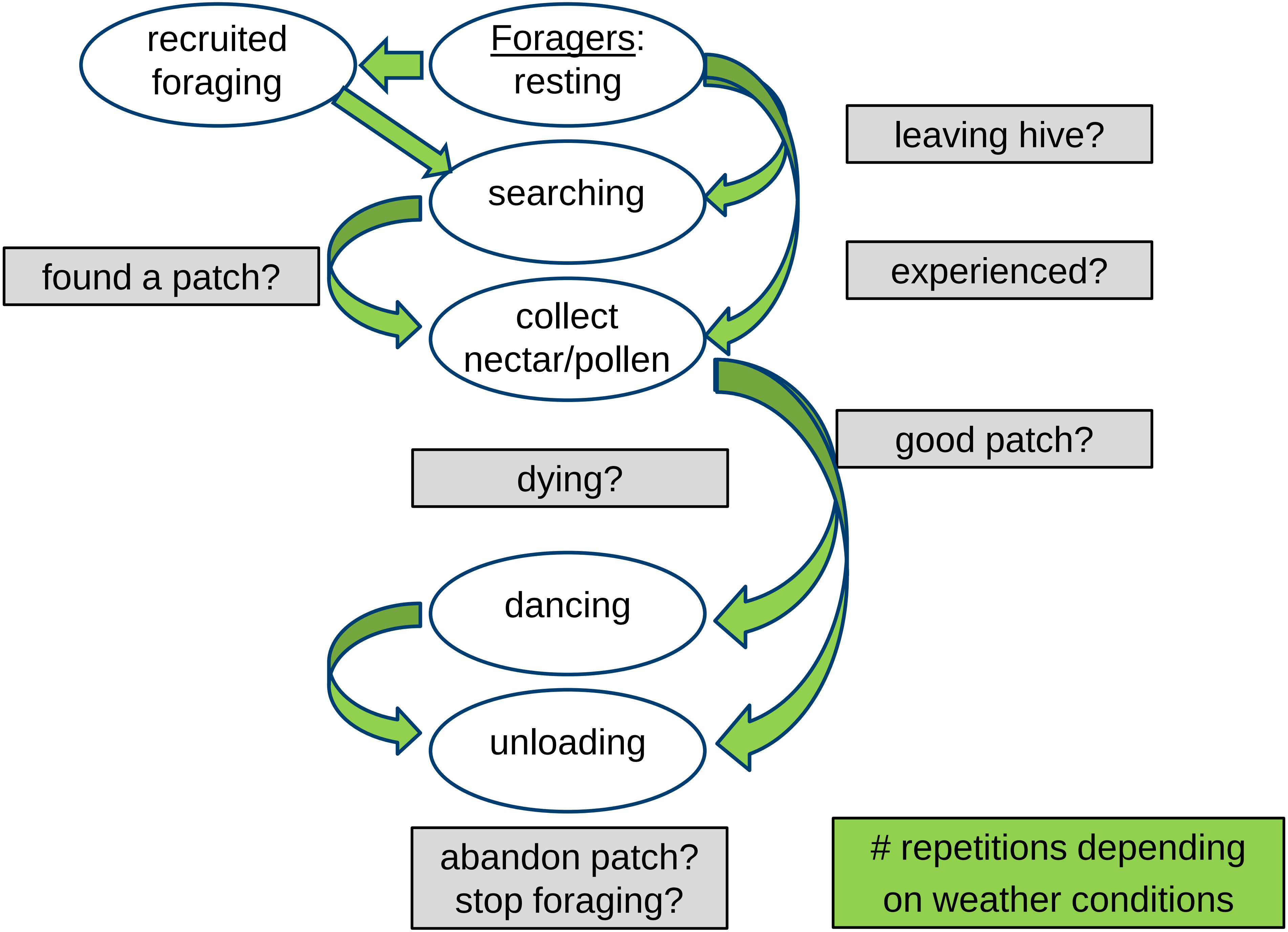
Foragers:
resting
recruited foraging
searching
collect nectar/pollen
dancing
unloading
leaving hive?
experienced?
found a patch?
good patch?
dying?
abandon patch?
stop foraging?
repetitions depending on weather conditions