Applying a mechanistic honey bee colony model to assess multiple factors impacting colony overwintering survival

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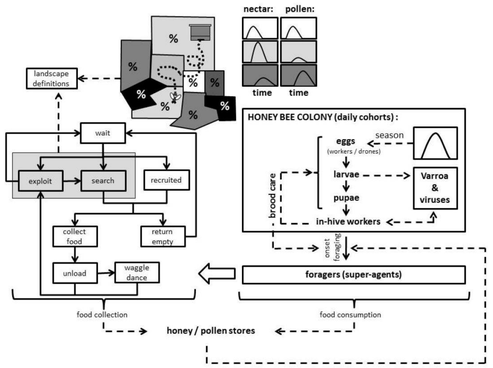
STUDY GOALS

Can colony models be applied to help interpret, inform and complement higher-tier studies in risk assessments for honey bees?

- Assessment of BEEHAVE as a tool to model large colony feeding studies and their outcomes in a specific region in the U.S. (North Carolina)
- Assessment of relative importance of factors for colony success:
  - Initial colony condition
  - Beekeeping interventions
  - Resource availability (spatially and temporally) to the colony
  - Weather conditions

BEEHAVE: A HONEY BEE COLONY MODEL

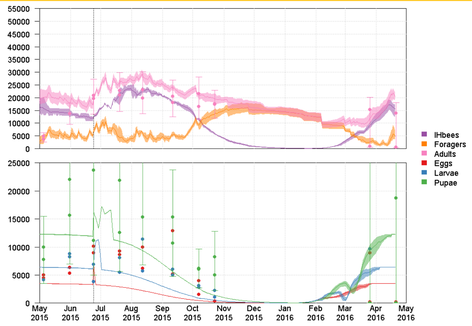
- BEEHAVE is the most comprehensive honey bee colony model currently publicly available (Becher et al. 2014)
- Brood development with feedback from pollen and nectar stores and brood nursing by adult bees
- Mite population model included
- Foraging activity dependent on colony stores and brood nursing requirements
- Mechanistic representation of foraging in the landscape
- Landscape represented as input of distinct patches with limited nectar and pollen availabilities



BEEHAVE overview

BEEHAVE CALIBRATION

- Calibration of BEEHAVE using data sets from two studies conducted in the same year
- Calibration and validation criteria were derived using measured values plus within-apiary variability and measurement error
- Focus on accuracy of modeled adult bee numbers and honey stores at the end of the foraging season (late October)



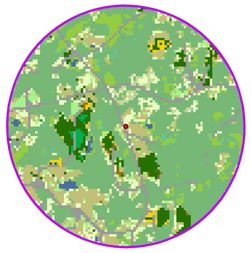
Example of BEEHAVE outputs compared to study data

LARGE COLONY FEEDING STUDIES

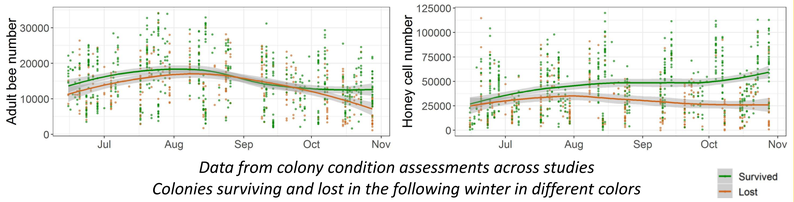
- Higher-tier study used in pesticide risk assessment
- 5 hives with pesticide-spiked sugar syrup and 2 untreated control hives are set up at 12 apiaries (sites)
- Colonies fed spiked sucrose syrup for 6 weeks
- Colony condition is assessed throughout summer, fall and the following spring
- Duration of a single study: ~18 months
- Cost of a single study: $600,000 - $1,200,000 depending on analytical efforts
- High overwintering losses (up to 79%) in control colonies have been observed in some studies, complicating the assessment of effects of pesticides
- Overwintering losses in untreated controls suggest that stressors other than pesticides play an important role

DATA FROM LARGE COLONY FEEDING STUDIES

- Data from untreated control colonies available for 7 studies conducted between 2013 and 2017
- Data sets used as input to BEEHAVE:
  - Initial colony condition (number of brood, adult bees, amount of honey and pollen)
  - Feeding timing and amount
  - Location: landscape composition can be retrieved (USDA Cropland Data Layer)
  - Weather
- Colony condition assessments (CCAs)
  - Data were compared to BEEHAVE output
  - Variability in CCA data and measurement error assessed
  - *Overwinter survival can be linked to last CCA before winter:*
    - High probability of survival if >19,000 adult bees and/or >30 kg honey are present in the colony
    - Low probability of survival if <4,000 adult bees are present and/or <2 kg honey are present in the colony



Example landscape composition around study apiary



Data from colony condition assessments across studies
Colonies surviving and lost in the following winter in different colors

Acknowledgements

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BEEHAVE SIMULATIONS: PRELIMINARY RESULTS

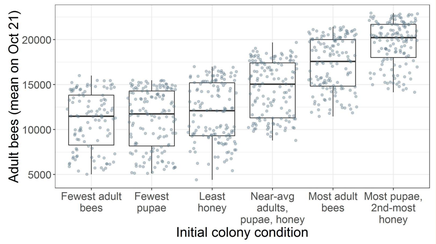
I. ASSESSMENT OF FACTORS IMPACTING FALL COLONY CONDITIONS

Testing of range of factors observed across colony feeding studies combined:

- Initial colony conditions at time of study initiation (late June – early July)
- Feeding pattern (feeding timing and amount: syrup volume and sugar content)
- Landscape composition around apiaries
- Weather (between study years)

Results:

- Initial colony condition and feeding pattern important for fall colony condition
- Landscape compositions tested and weather (within range of studies) were not very important for fall colony condition



Impact of colony condition at study initiation on fall colony size

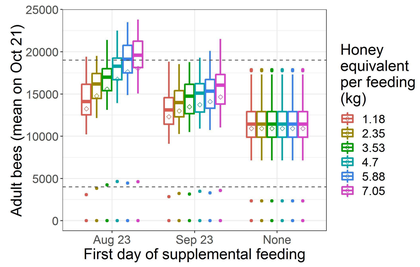
II. INFORMING STUDY DESIGN: COLONY FEEDING PATTERNS

Identification of feeding patterns leading to likely colony overwinter survival:

- Compilation of hypothetical patterns that cover range of patterns in studies

Results:

- Early start of supplemental feeding is important (August)
- Increase in amount sugar fed is only effective in combination with early start of supplemental feeding



CONCLUSIONS

- BEEHAVE can be calibrated and parameterized to represent the dynamics observed in control colonies of colony feeding studies
- Impacts of study design and environmental conditions on fall colony strength, and subsequent overwinter survival, can be tested systematically
- Honey bee colony models like BEEHAVE could provide tools for higher-tier risk assessment:
  - Inform study designs to increase likelihood of overwinter survival in control colonies, which is essential for effects data interpretation
  - Contribute information to higher-tier risk assessments and extrapolate from available study data, potentially reducing number of large colony feeding studies necessary (in BEEHAVE, the inclusion of exposure-effects model would be needed for this objective)

Reference

Becher et al. 2014. BEEHAVE: A systems model of honeybee colony dynamics and foraging to explore multifactorial causes of colony failure. *J Appl Ecol*, 51: 470–482.

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