Organization of work via the "common stomach" in social insects

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BDA 2015 Workshop:
Summary and references

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Wasp societies and nest construction

- The nest is the center of social life
- Paper processed by the wasp from cellulose, water and saliva
- The nest is built itself slowly by stigmergy
- Cooperative process

Papers on building algorithms of Polistes

- **Karsai I., and Pénzes, Z. (2000).** Optimality of cell arrangement and rules of thumb of cell initiation in *Polistes dominulus*: a modeling approach. Behavioral Ecology 11: 387-395. PDF
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- **Karsai I., and Pénzes Z. (1998).** Nest shapes in paper wasps: can the variability of forms be deduced from the same construction algorithm? Proc. R. Soc. Lond. B. 256: 1261-1268. PDF
- **Karsai, I. (1997)**: Brood patterns on the wasp combs: influence of brood to the egg laying and building. Ethology Ecology and Evolution 9: 27-44. PDF
- **Karsai, I., Pénzes, Z. and Altenburg, K. (1996)**: Working Automously: Searching and Piling: building compact structures by group of robots. ICMAS'96. Workshop Notes #3. Animal societies as an alternative metaphorical basis for DAI. International Conference on Multiagent Systems 1996. Kyoto, Japan. pp 8.
- **Karsai, I., Pénzes Z. and Wenzel, J. W. (1996):** Dynamics of colony development in *Polistes dominulus*: a modeling approach. Behav. Ecol. Sociobiol. 39: 97-105. PDF
- **Karsai, I. and Z. Pénzes (1996)**: Intraspecific variation of the combs of *Polistes dominulus*: parameters, maturation, nest size and cell arrangement. Ins. Soc. 43: 277-296. PDF
- **Karsai, I. and Wenzel, J. W. (1995)**: Nests built on the dorsum of conspecifics in *Polistes*: the value of anomalous behavior. J. Anim. Behav. 50: 1429-1431. PDF
- **Karsai, I. and Theraulaz, G. (1995)**: Nest building in social wasps: postures and constraints. Sociobiology 26: 83-114. PDF
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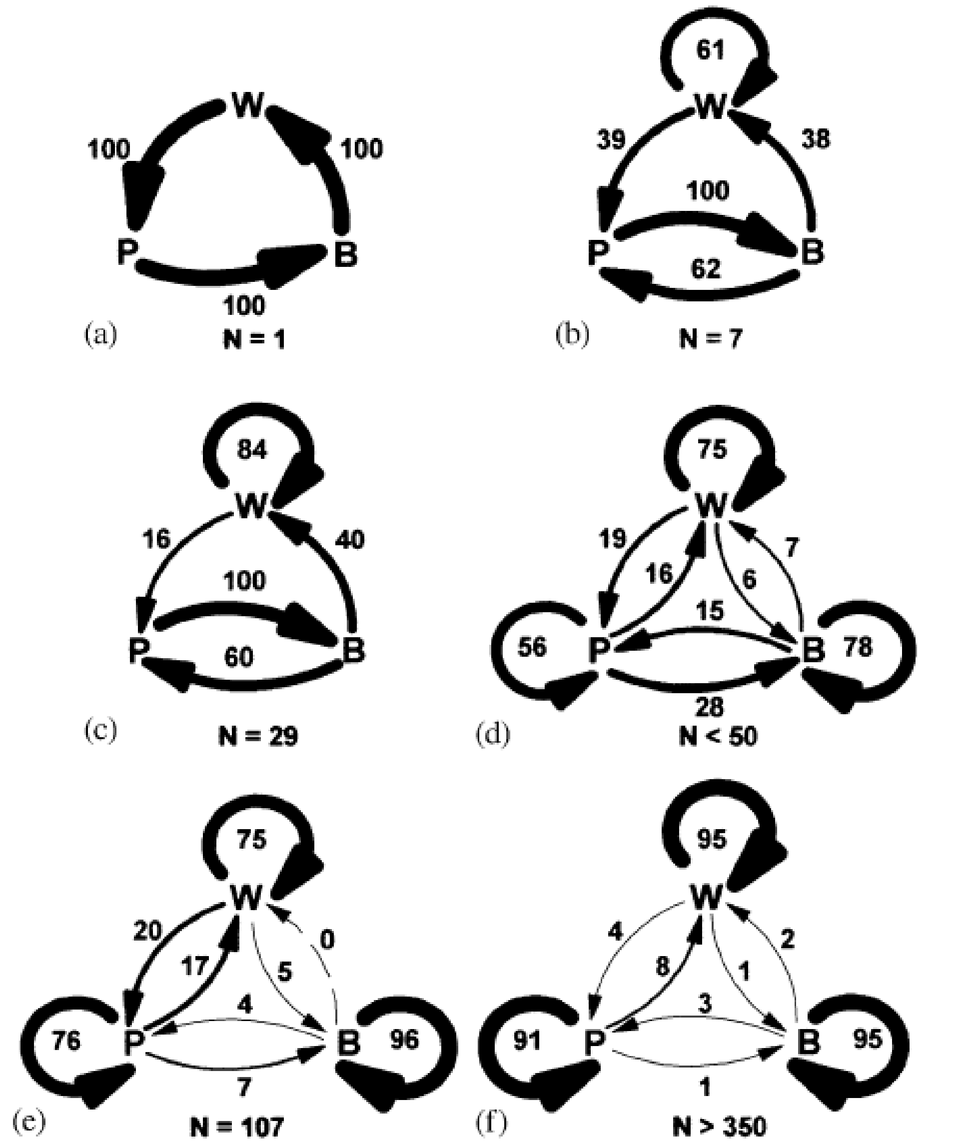
- **Karsai, I. and Pénzes, Z. (1993)**: Comb building in social wasps: self-organization and stigmergic script. J. Theor. Biol. 161: 505-525. PDF

Colony size affects behavior and task partition occurs

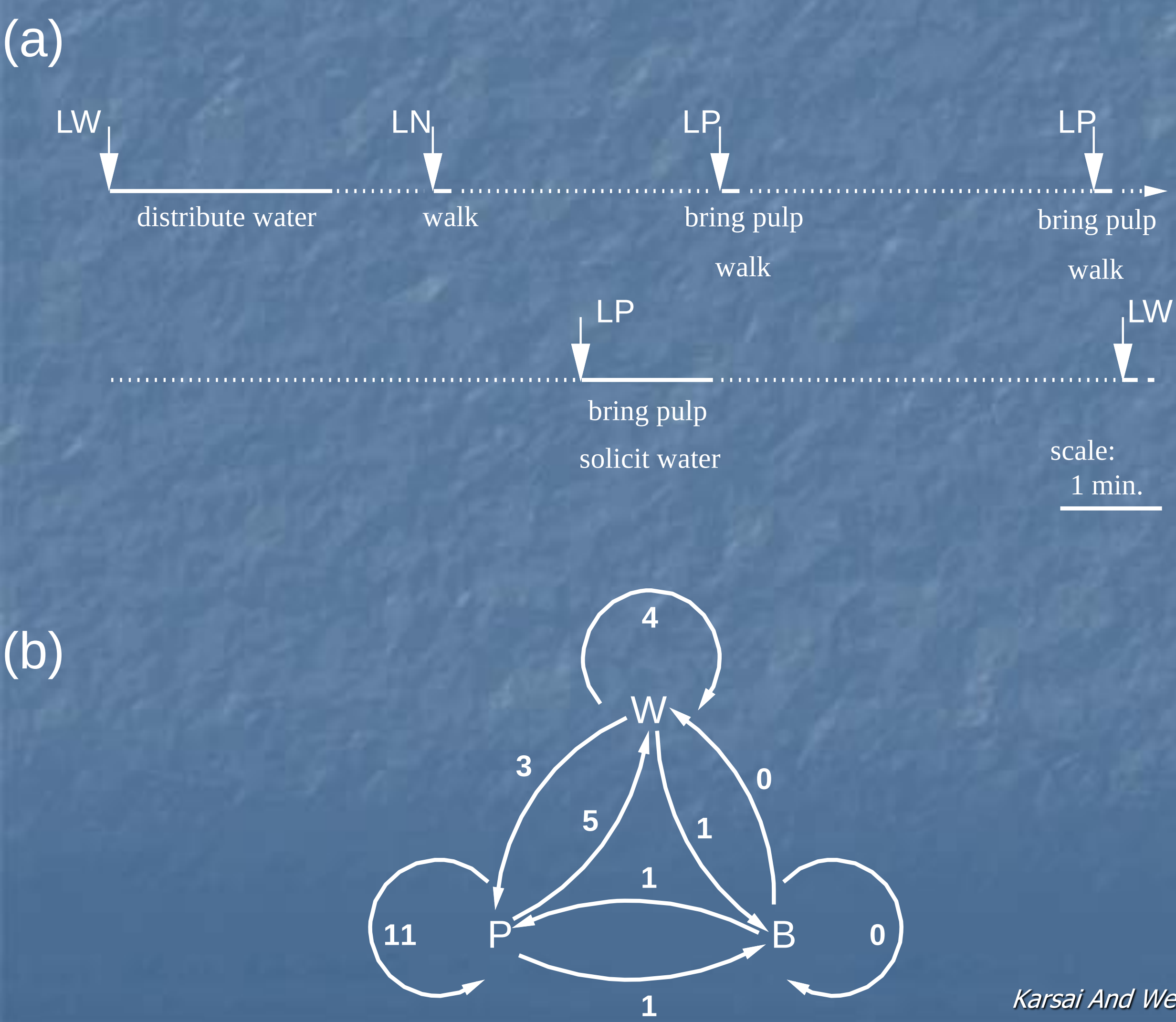


- If there is only one individual, it must undertake each task in a given sequence
- As colony size increases, specialization occurs
- In larger colonies specialization is very high.

Karsai And Wenzel PNAS 1998

Field study in Panama on *Metapolybia*

The behavior of an individual

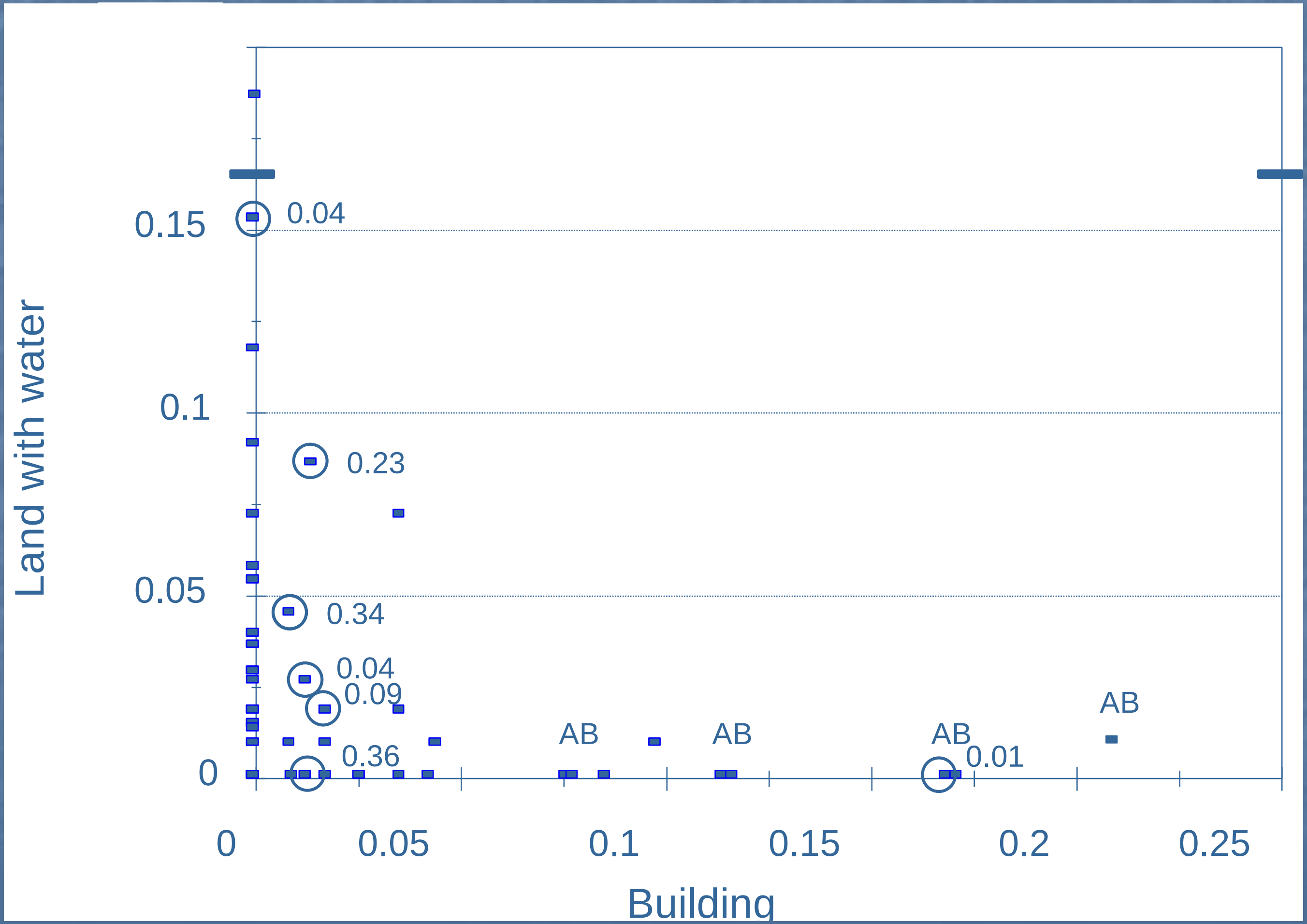


- (a) Time line: short-term flexibility of a wasp's activity LW: land with water, LP: land with pulp, LN: land without load, solid line: wasp on nest; broken line: wasp off nest.
- (b) Transitions between different tasks related to building for the same wasp observed over four days. W: water foraging, P: pulp foraging, B: building.

Karsai And Wenzel JIB 2000

The behavior of individuals

Relative occurrence of Building and Water collecting for each individual.

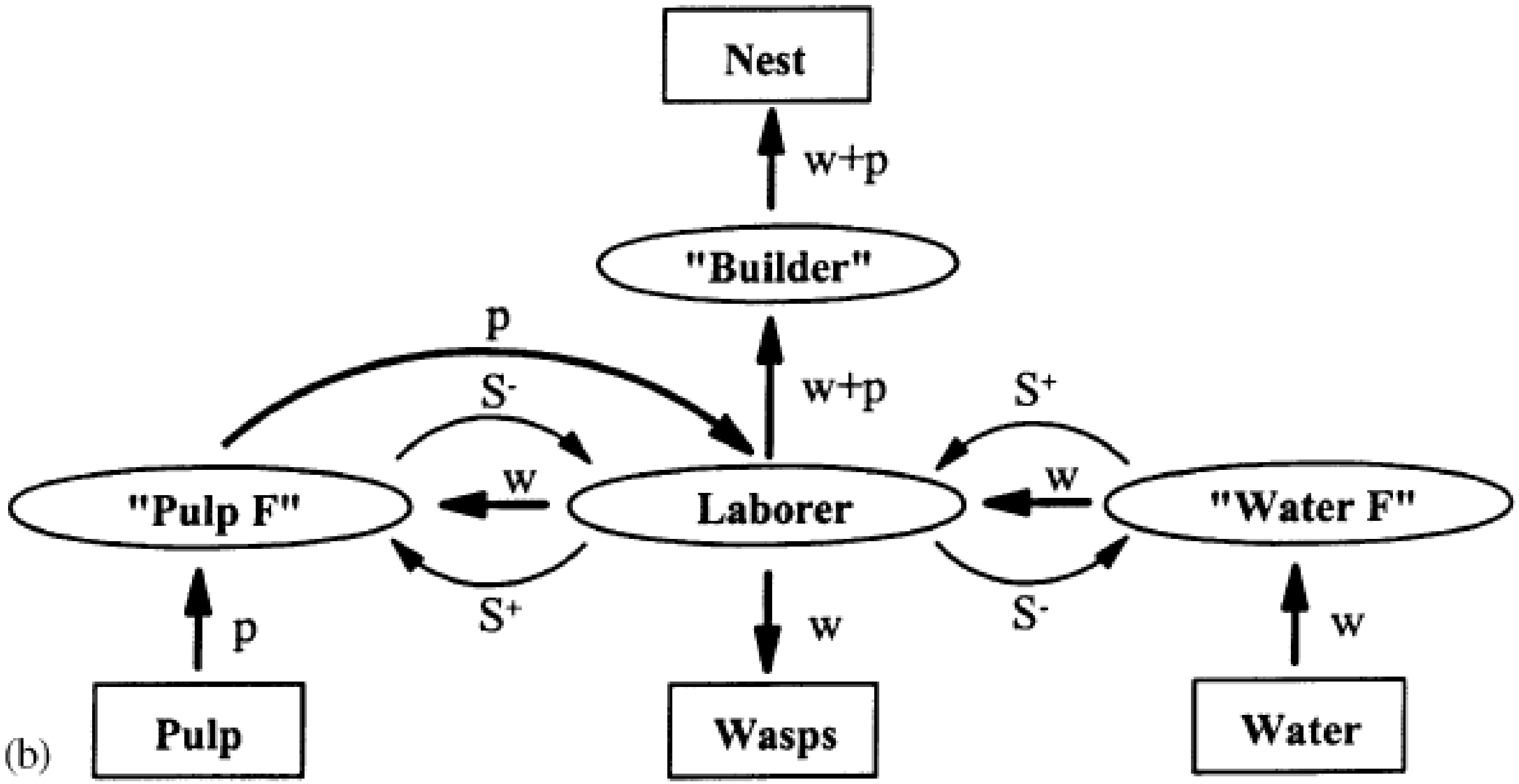


AB denotes the most active builders.

Circles denotes individuals who transported pulp loads to the nest

Karsai And Wenzel JIB 2000

Tasks, materials and functions



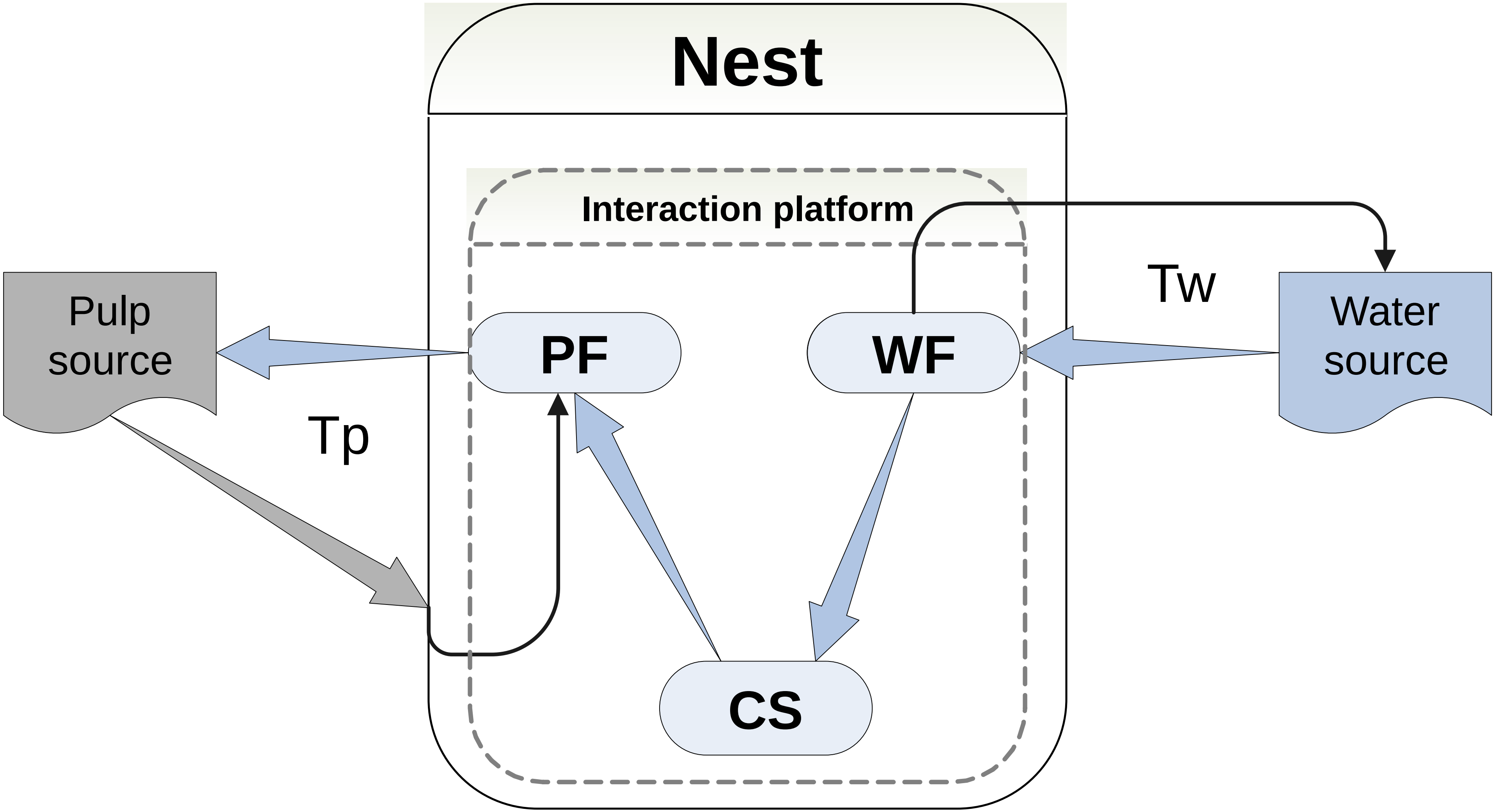
Karsai And Wenzel JIB 2000

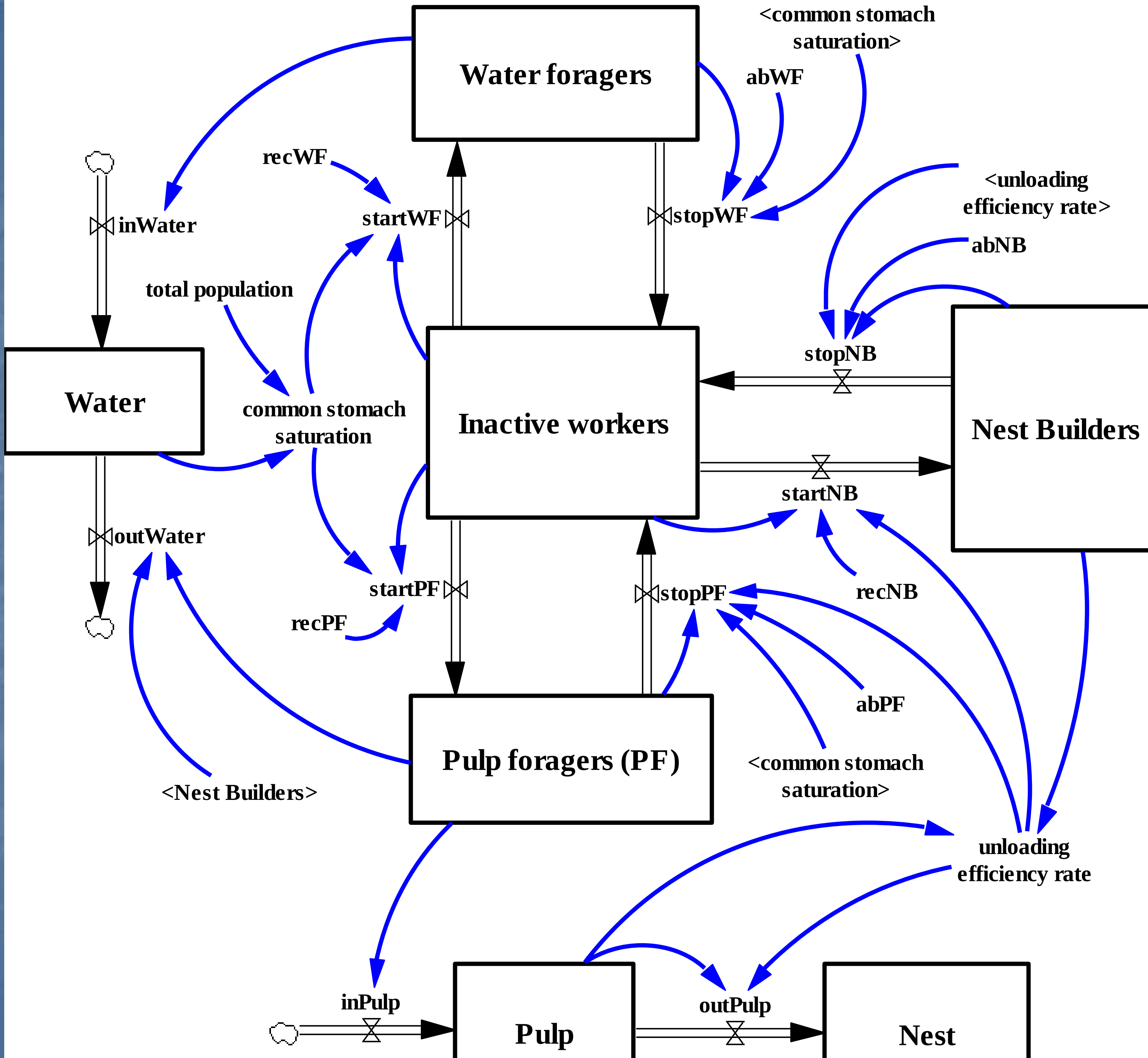
W: water; P: pulp; S: water saturation

Important concepts of the model

- Parameters need to be estimated from real colonies.
- No initial differences among individuals necessary (Specialization will be emergent).
- Explain many wasps doing “nothing” phenomena
- Water is not only building material, but also a regulator.
- There is a **common stomach** of the colony where water is stored temporarily.
- The quantity of water in the common stomach regulates the work.
- No need: stimulus threshold curves or learning to explain task fidelity

Material flow and tasks

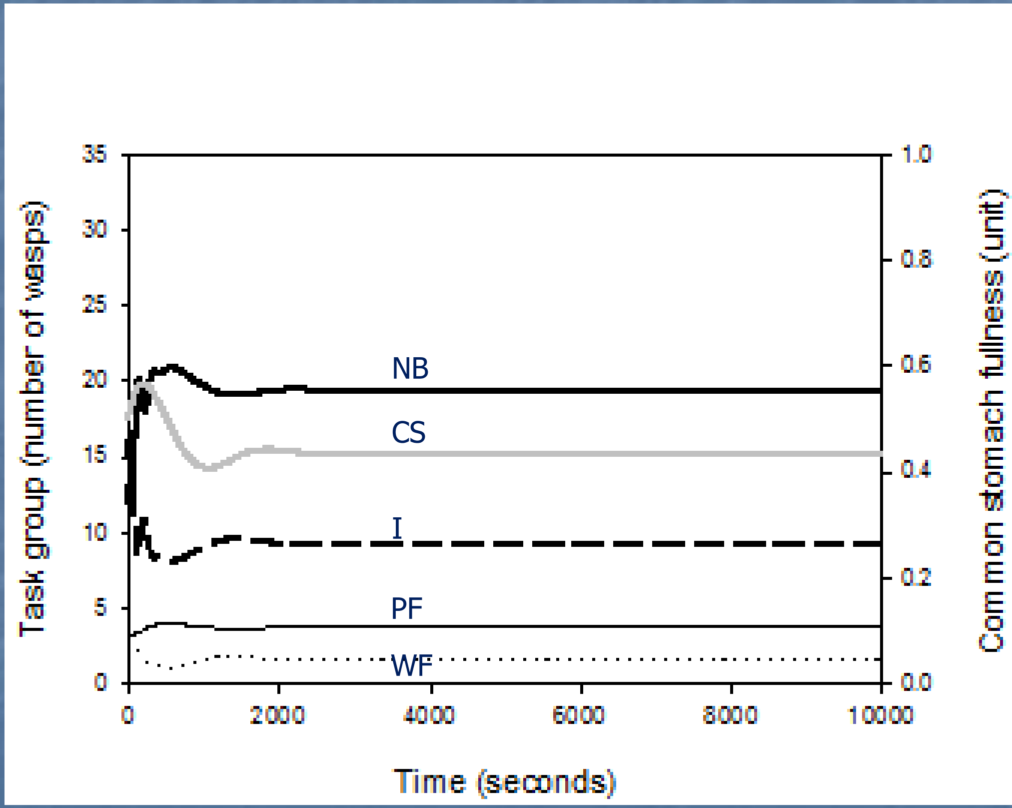




Karsai and Schmickl 2011 Behav Ecol

Prediction of the model

- Work groups emerged
- Common stomach and task groups stabilized
- This pattern was independent on the starting conditions of the task groups or the common stomach.
- Similar task mix was observed in natural colonies



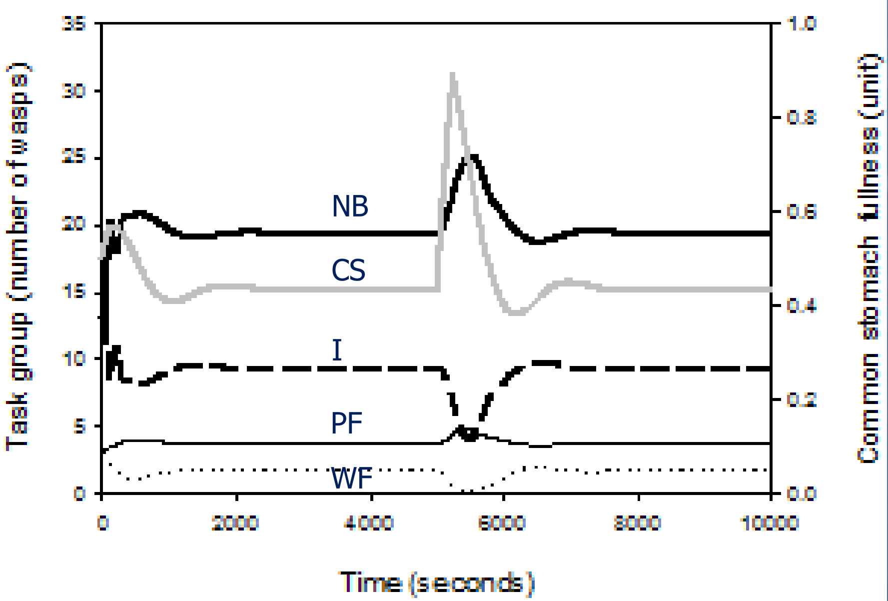
Karsai and Schmickl 2011 Behav Ecol

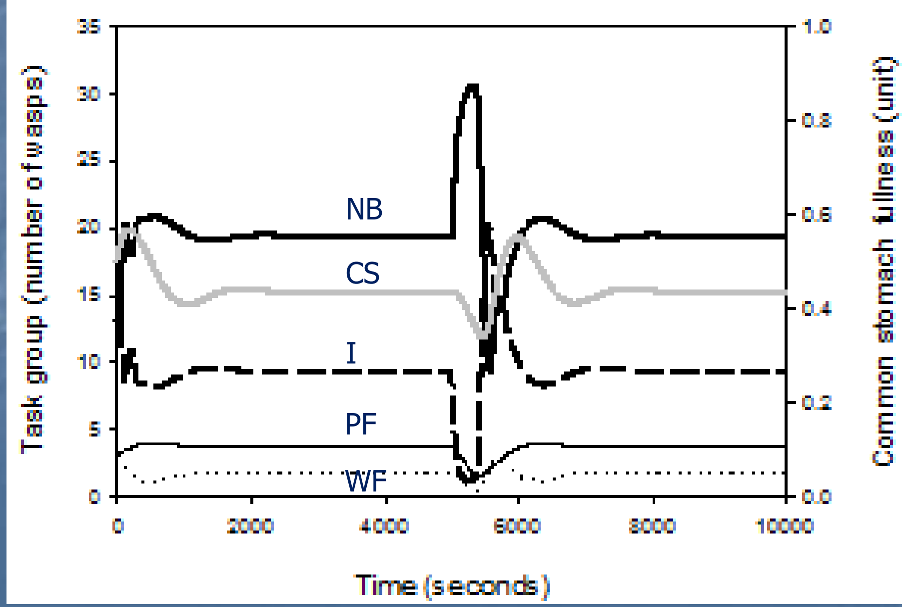
Testing the model

- The model covered the basic construction operation of the wasps very well
- The model is stable and predictive
- The task partition is emergent
- Parameters came from my study or literature
- Testing uses different data from my study and literature
- Testing idea: the model should repeat the perturbation experiments can be found in the literature on real colonies (Jeanne, 1996, Karsai and Wenzel, 2000)

Add water and pulp

- Increased construction by different ways
- Agree with field experiments? Yes





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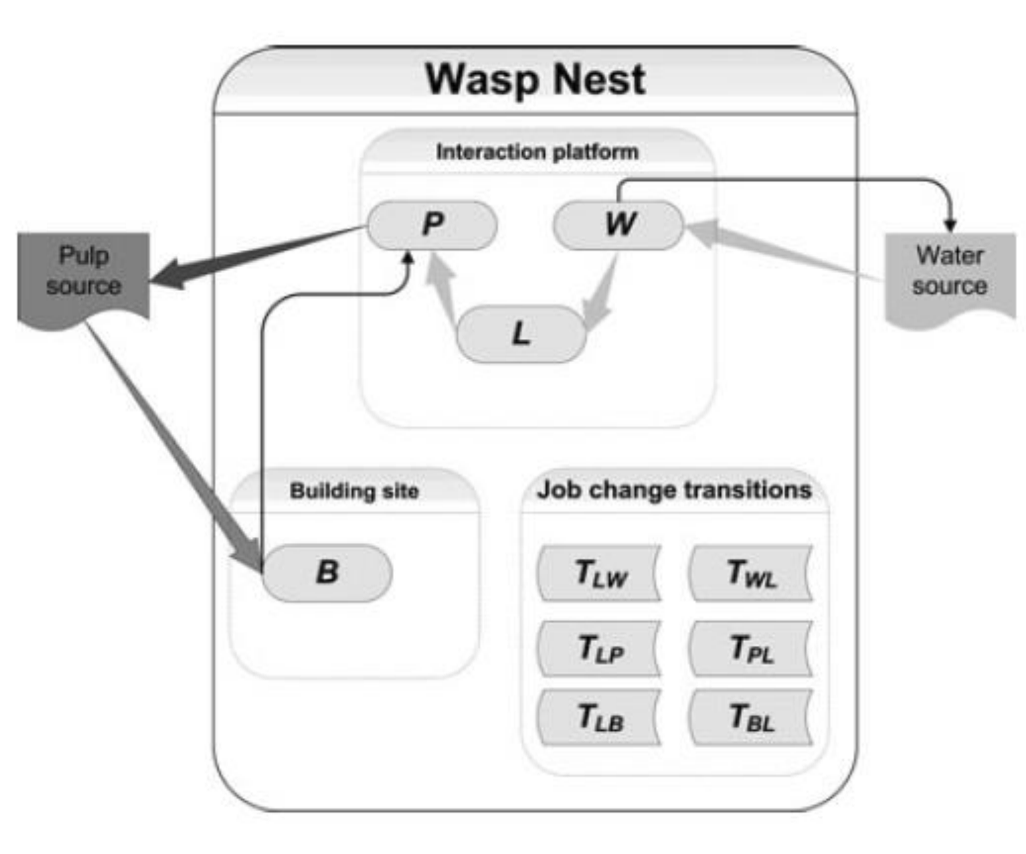
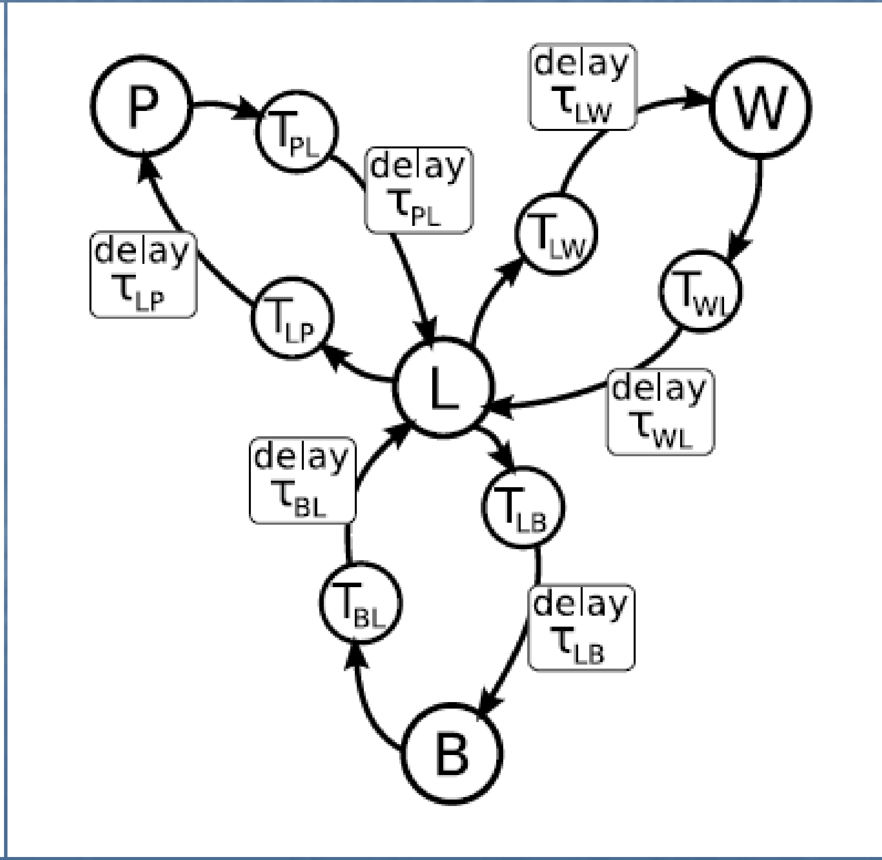
Cost of task switching

- Time delay in task switching causes a cost
- Wasps in transitional state do not work

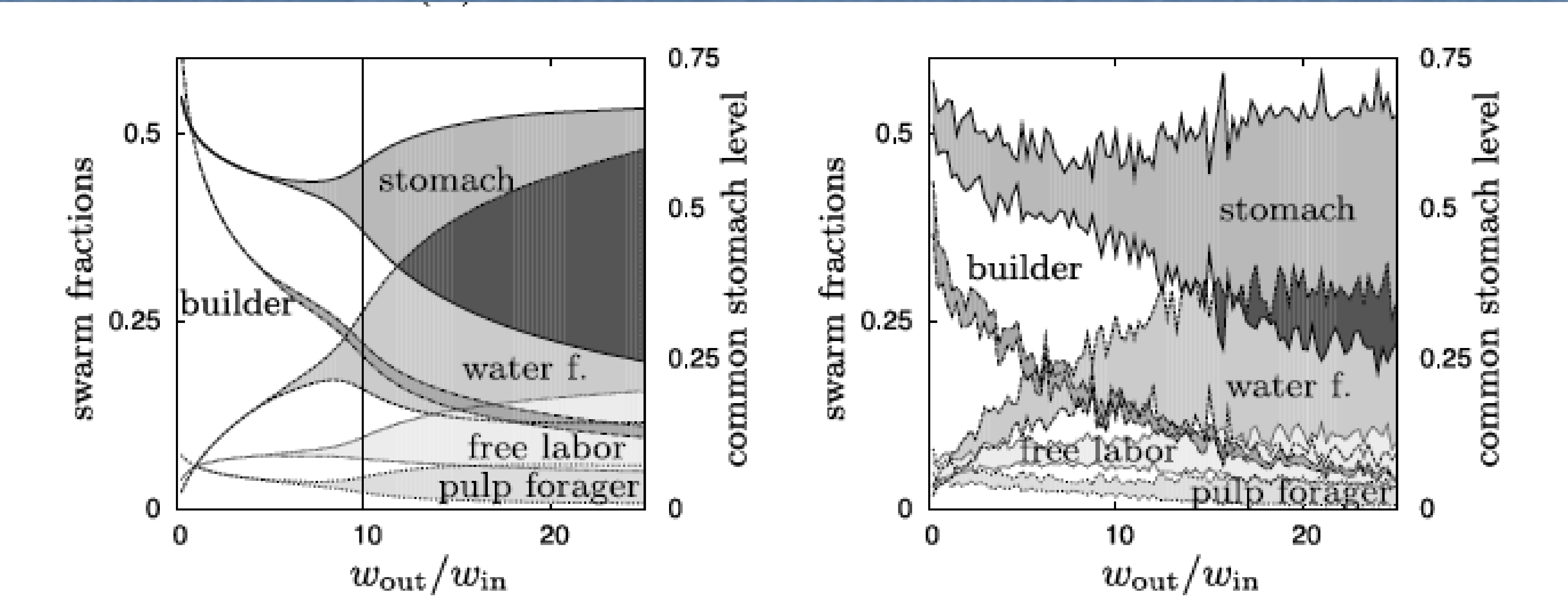




Hamann, Karsai and Schmickl 2013 Bull. Math. Biol.

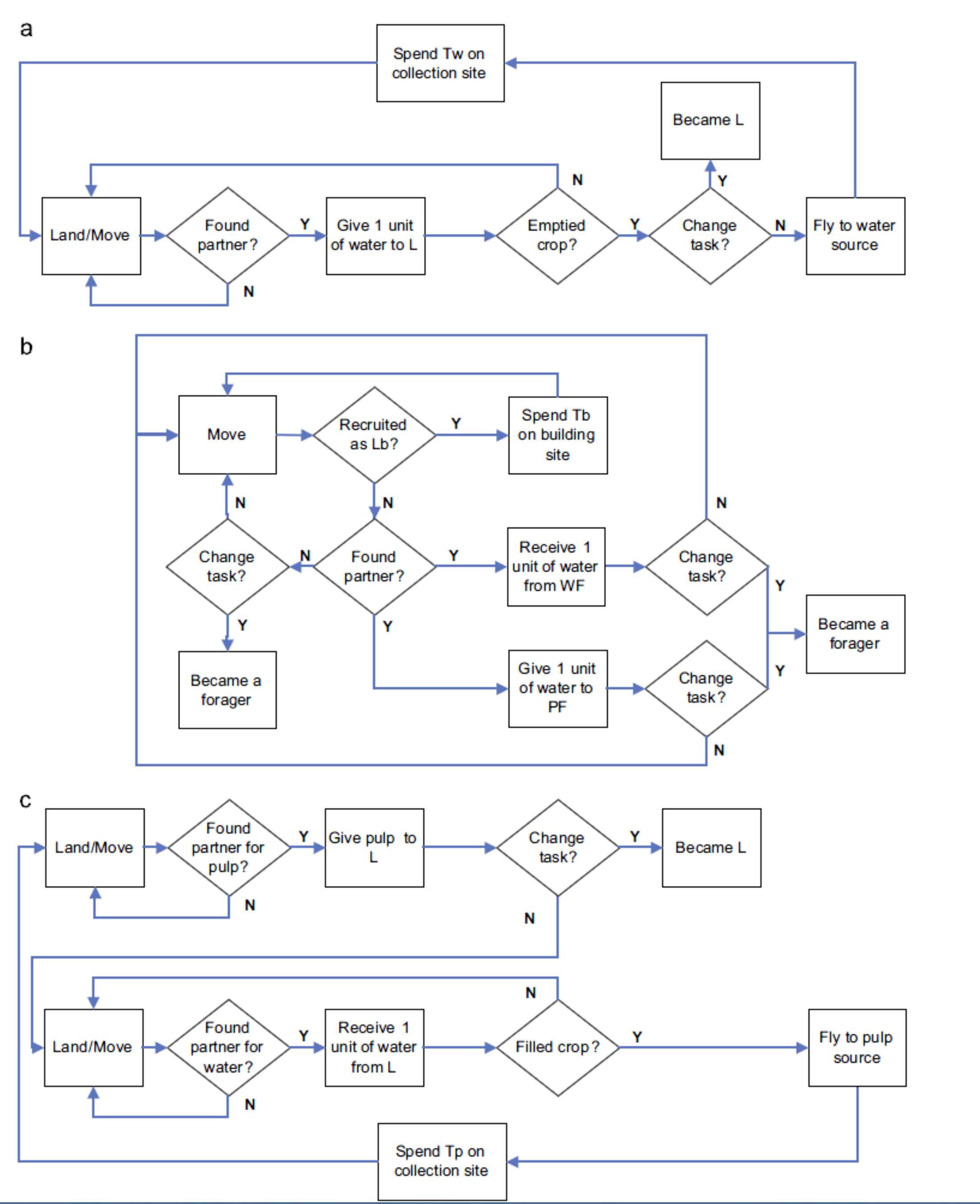
Cost of task switching

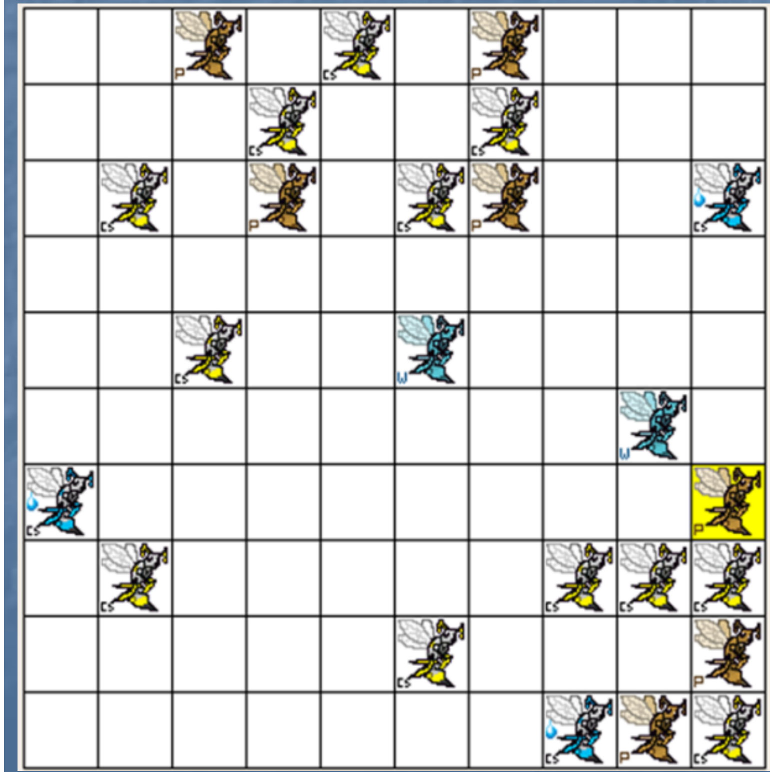
- Bifurcation diagrams: lines are fixed point attractors; areas after bifurcations show the range of possible oscillation between min and max values (Hopf bifurcation is about 6)



Hamann, Karsai and Schmickl 2013 Bull. Math. Biol.

Agent based models

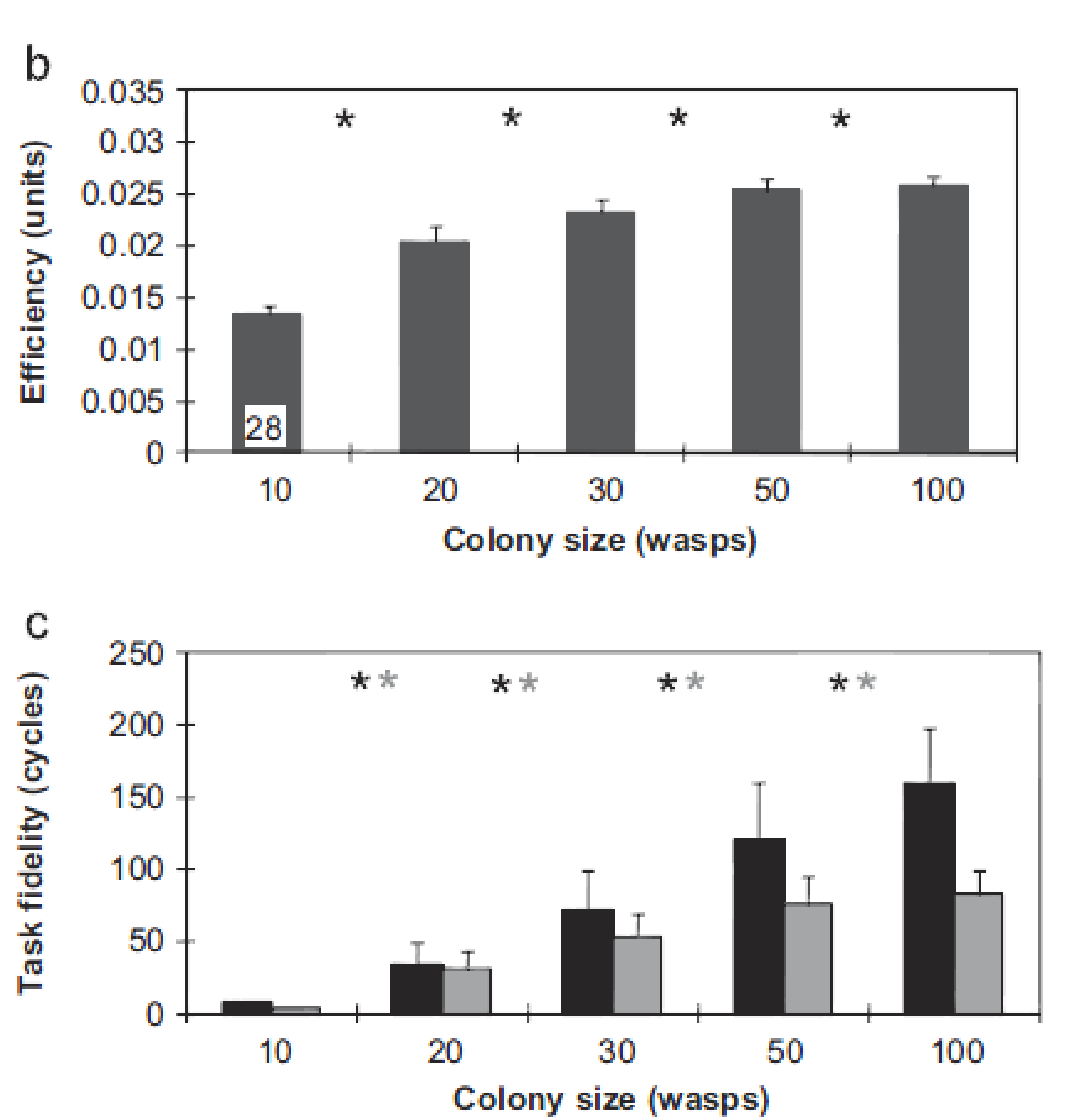




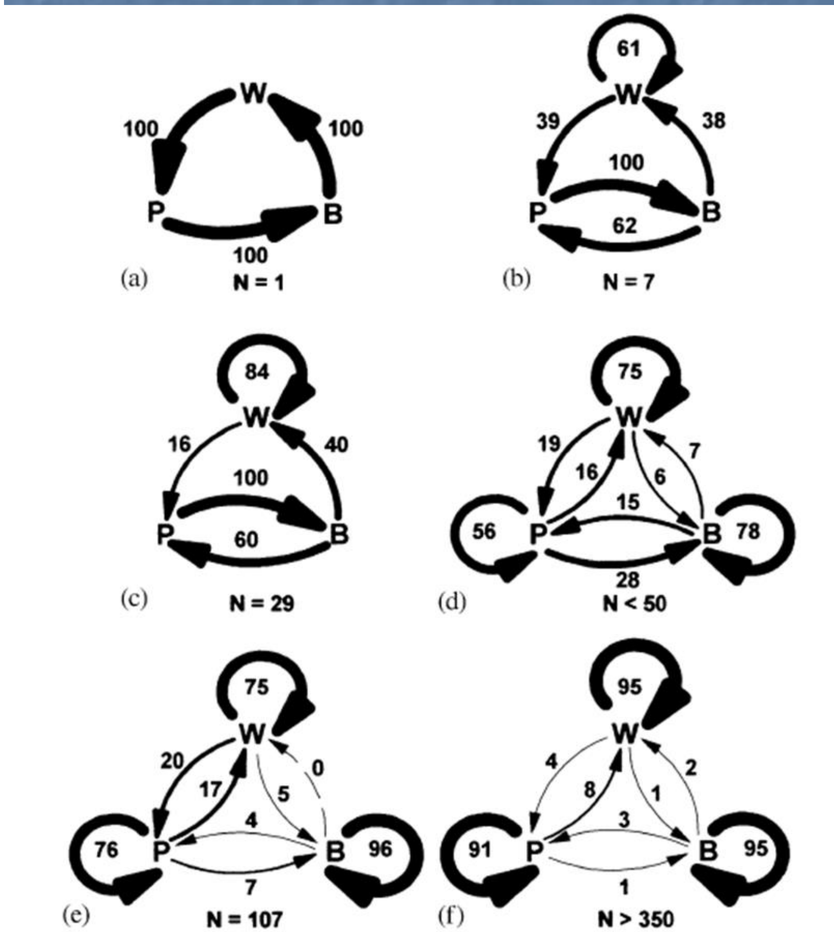
Karsai and Phillips 2011 J. Theor. Biol.

Colony size

- Colony level efficiency and task fidelity increased as in real wasps

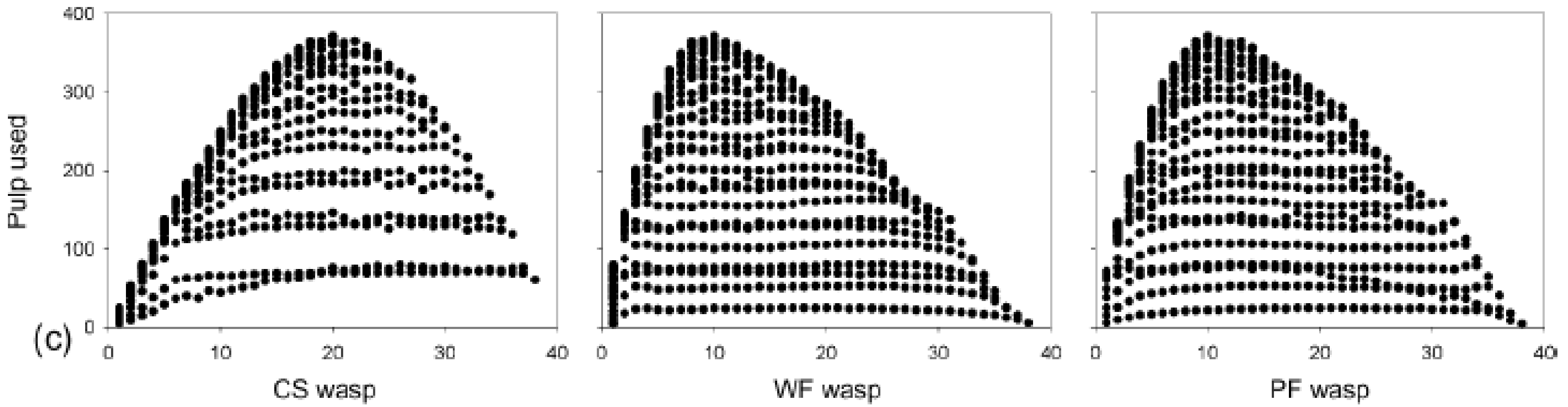


Karsai and Phillips 2011 J. Theor. Biol.



Karsai and Wenzel PNAS 1998

- Simplified study: colony size 40 and water and pulp collecting assumed to take the same time
- All possible task mixes are produced and wasps are not allowed to change
- The measured efficiency of that mix (one dot is an average efficiency of a given colony composition)
- Most efficient: 20 laborer, 10 WF and 10 PF

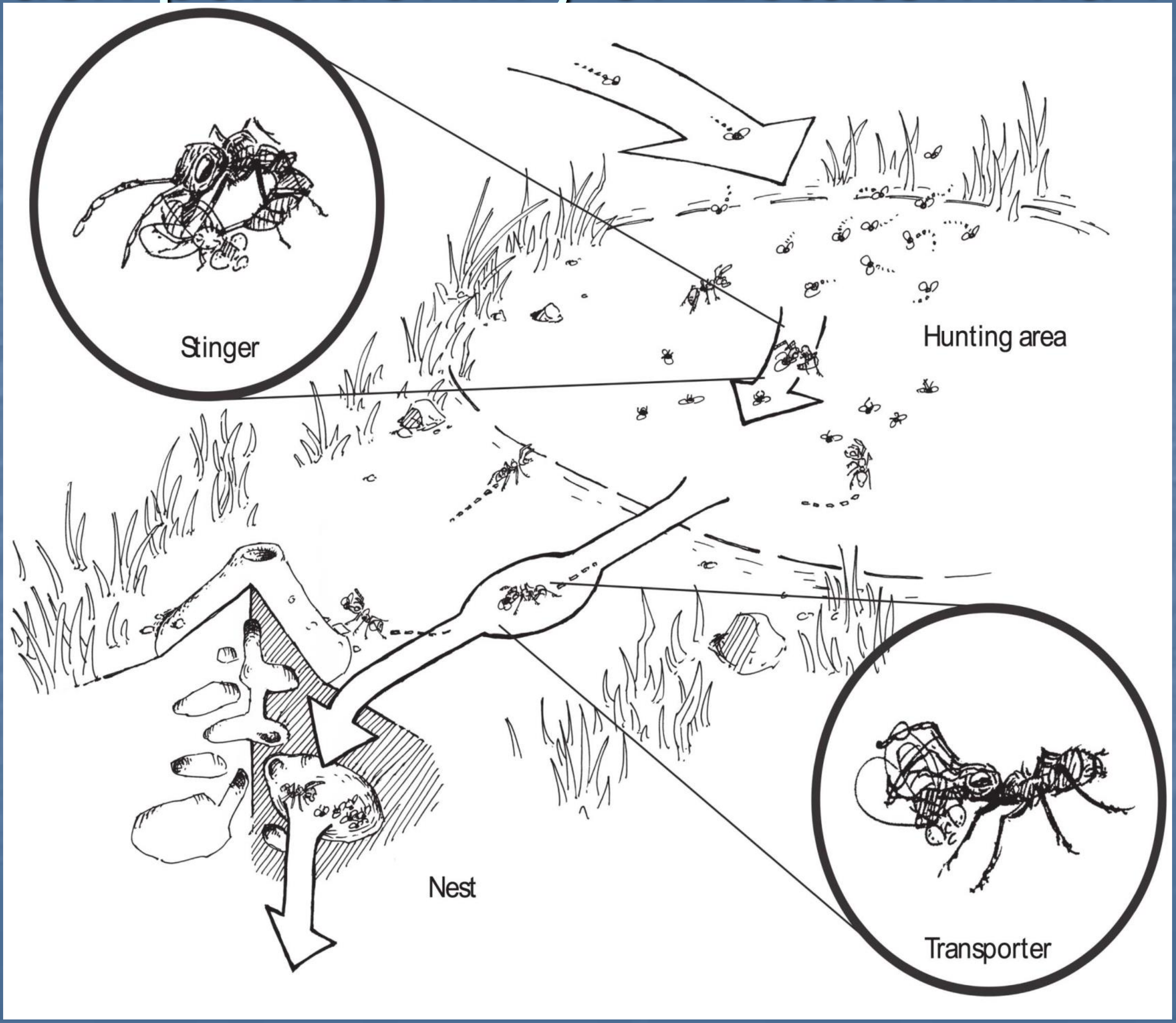


Karsai and Runciman 2011 MSMDS

Organization of work via the common stomach

- Does not need to assume:
  - Demand driven system based on switching off and on of work of specialized workers.
  - Space limitation of builders
  - That individuals have different propensity to different job types
  - Threshold adaptation mechanisms and sigmoid response curves
  - Learning or other mechanisms exist at individual level that ensure task fidelity

Task partitioning of Ectatomma ruidum



Schmickl & Karsai
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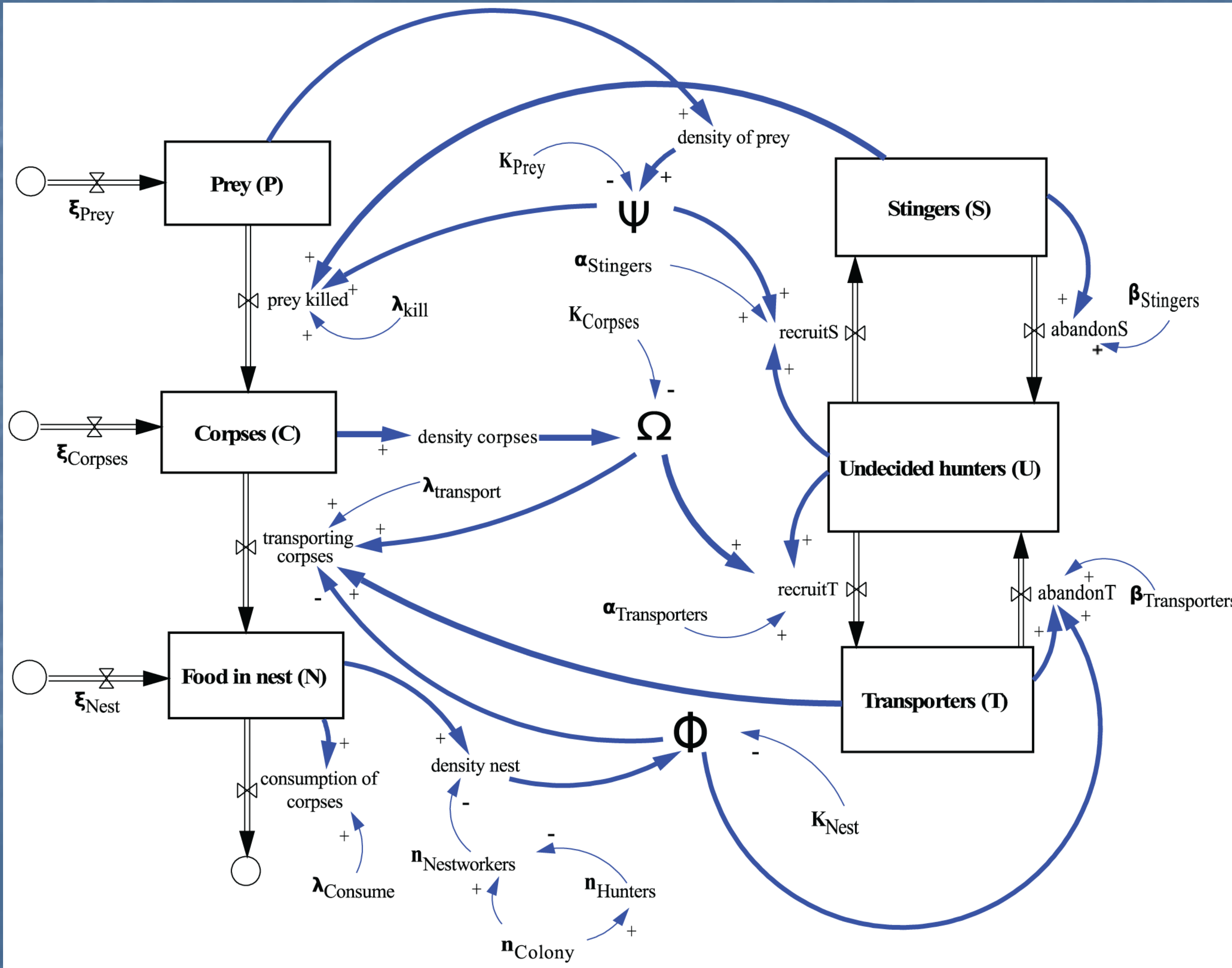
Task partition model based on common stomach



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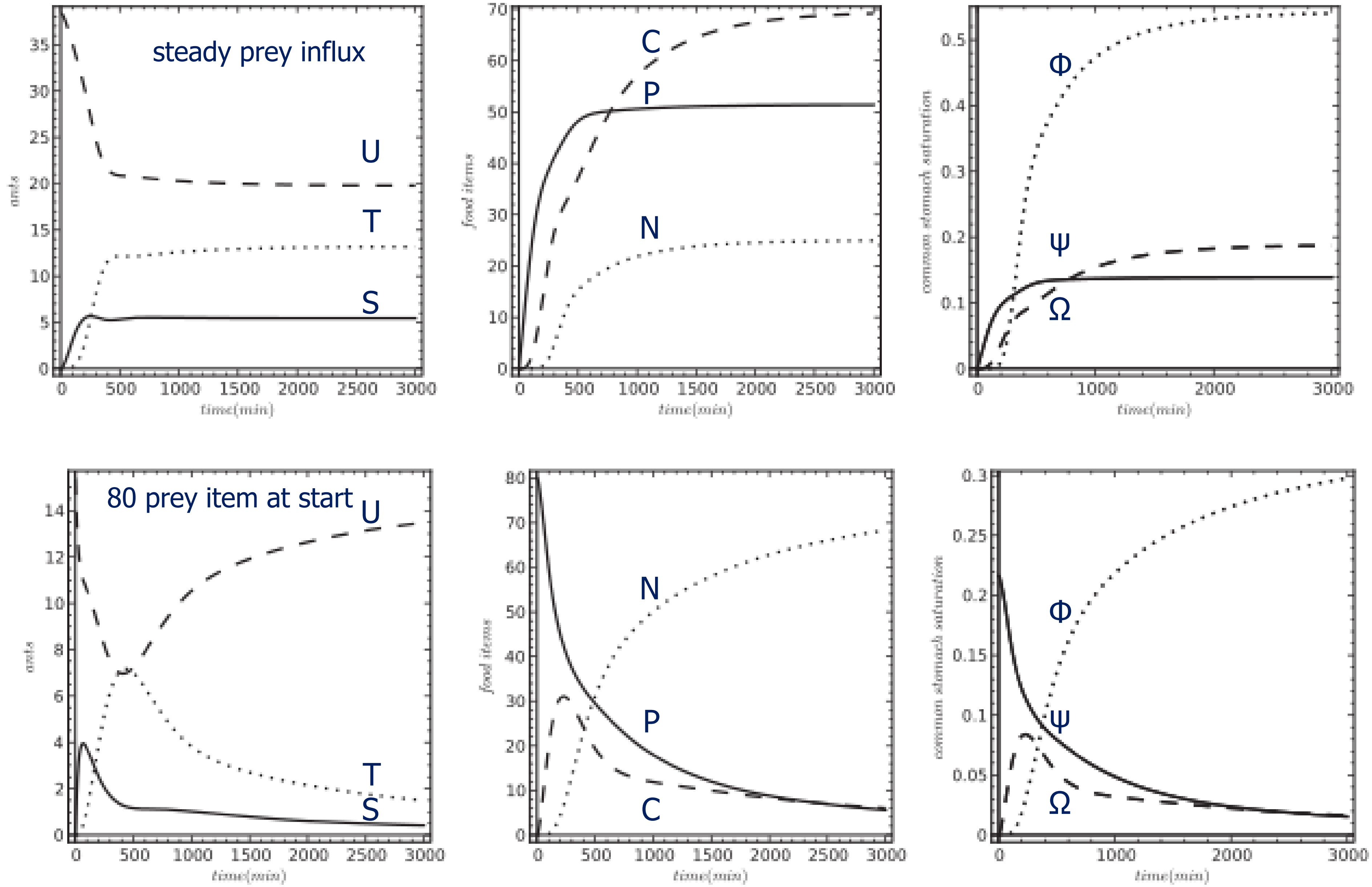

U: Undecided
T: Transporter
S: Stinger

P: Prey
C: Corpse
N: Food in nest

ψ: Prey saturation
Ω: Corpse saturation
Φ: Nest saturation with food

Conclusions

- Task partitioning in insect societies is a self-organized process and an emergent and adaptive way of organizing workflow.
- The models were able to predict the basic behaviour and the effect of perturbations on the real systems.
- The model assume very little on the abilities of individuals
- The common stomach is also a buffer against environmental fluctuation and this in turn provides a steadier processes.
- Using the common stomach as a regulator and buffer also provides secondary advantages in the form of additional work that these common stomach wasps can provide while they hold water, such as patrolling, defense and so on (they are not really idle, but multitaskers)
- The common stomach ensures having highly effective foragers. Both efficiency and task fidelity increase with colony size. This in turn results in highly effective foragers. The colony needs to use only a few of these highly effective foragers; this in turn decrease forager loss.
- The material itself provide a direct feedback to the regulation. This is more robust than response stimulus curves.

Papers on task partitioning

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- **Hamann H., Karsai I. and Schmickl T. (2012).** Time delay implies cost on task switching: a model to investigate the efficiency of task partitioning. Bulletin of Mathematical Biology.
  Karsai I. and Phillips M.D. (2012). Regulation of task differentiation in wasp societies: A bottom-up model of the "common stomach" J. Theor. Biol. 294:98-113. PDF
  Karsai I. and Runciman A. (2011). The "common stomach" as information source for the regulation of construction behavior of the swarm. Mathematical and Computer Modelling of Dynamical Systems. 18: 13-24. iFirst, 1-12: DOI:10.1080/13873954.2011.601423 PDF
  Karsai I. and Schmickl T. (2011). Regulation of task partitioning by a "common stomach": a model of nest construction in social wasps. Behavior Ecology 22: 819-830. PDF
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  Karsai I and Runciman A. (2009). The effectiveness of the "common stomach" in the regulation of behavior of the swarm In Proceedings MATHMOD 09 Vienna Full papers CD volume, 6th Vienna Conference on Mathematical Modelling. February 11-13 2009, Vienna University of Technology, Austria.ARGESIM report no 34 (eds. I Troch and F. Breitenecker). ISBN 978-3-901608-34-6. ARGESIM Publishing House, Vienna: 851-857. PDF
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