Evolutionary transition to eusociality by the coevolution of sex ratios and life-history

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Background

Kin selection theory has emphasized the role of sex ratios and sex determination systems for the evolution of eusociality. Haplo-diploidy and female biased sex ratio have been argued to promote the evolution of eusociality. Specific life-histories common in the hymenoptera promote sex ratio biases that could influence social evolution.

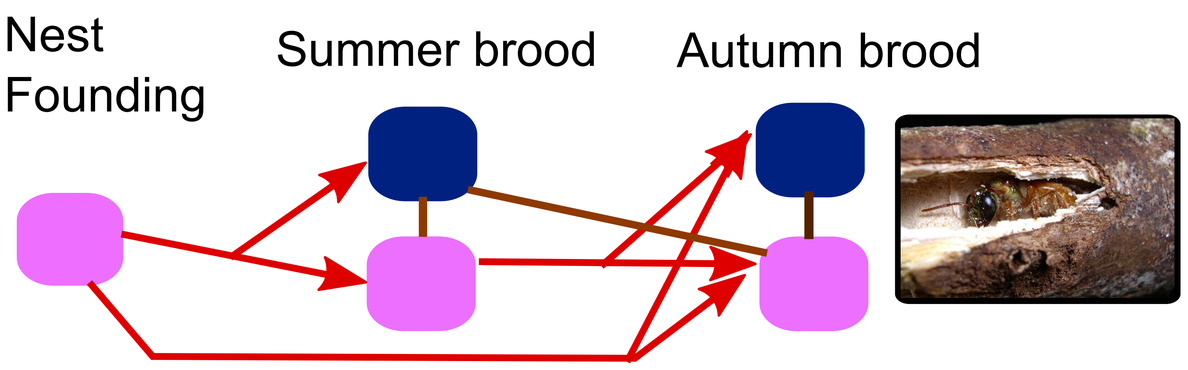
Research questions

- How do different life-history set-ups influence the outcome of social evolution?
- When do haplodiploid genetic systems favour the evolution of eusociality?

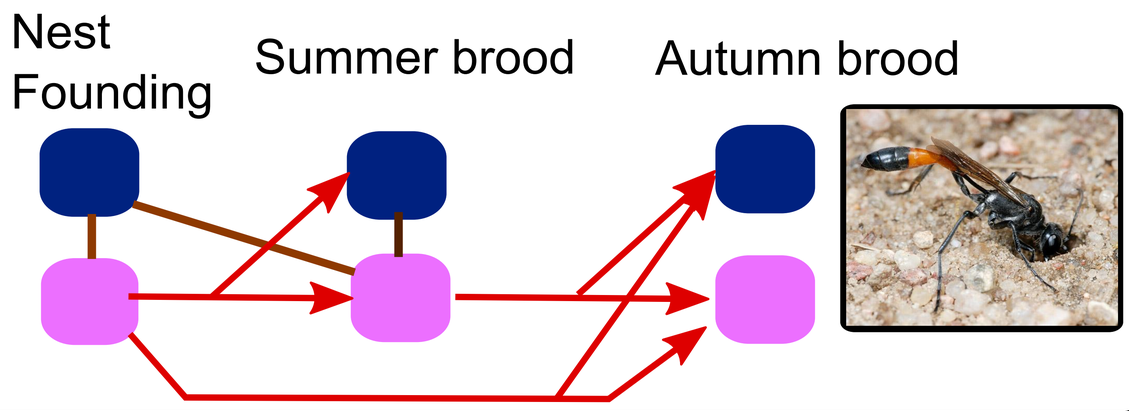
Life Histories

Females · Males · Reproduction · Helping · Mating

Female Hibernation (Halictine)



Larval Diapause (Sphecid)



The model

- Partially overlapping generations determined by female (S_f) and male (S_m) survival.
- Three evolvable traits:
  - summer sex ratio (z_1) - autumn sex ratio (z_2)
  - probability of staying to help (h)
- Fecundity $F(H)$ increases linearly with number of helpers H, at a rate of b (benefit of helping).
- Q_k: number of matings per male in mating event k.
- u_i : Equilibrium frequency of the class i.
- v_i : Reproductive value of the class i.
- R : the relatedness between a female and the offspring it cares for (dau: *daughter*, *son*, *sis*: sister, *bro*: brother).

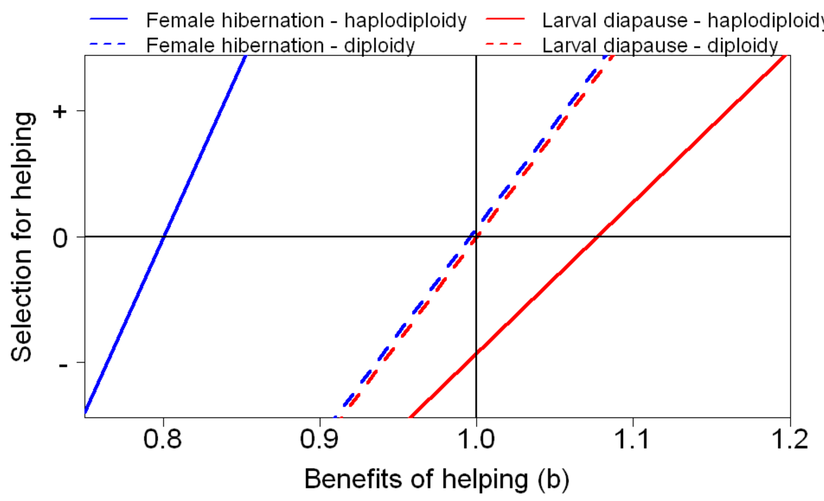
Transition matrix and inclusive fitness expressions

$$\begin{bmatrix} \mathbf{1} & \mathbf{2} & \mathbf{3} & \mathbf{4} & \mathbf{5} & \mathbf{6} & \mathbf{7} \\ 0 & 0 & \frac{1}{2}F(H)(1-z_2) & \frac{1}{2}F_0(1-z_2) & 0 & \frac{1}{2}F(H)(1-z_2) & \frac{1}{2}F_0(1-z_2)Q_1 \\ 0 & 0 & F(H)z_2Q_2 & F_0z_2Q_2 & 0 & 0 & S_mQ_2 \\ S_f & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{1}{2}F_0(1-z_1)(1-h) & \frac{1}{2}F_0(1-z_1)(1-h) & 0 & 0 & 0 & 0 & 0 \\ \frac{1}{2}F_0(1-z_1)h & \frac{1}{2}F_0(1-z_1)h & 0 & 0 & 0 & 0 & 0 \\ 0 & S_f & 0 & 0 & 0 & 0 & 0 \\ F_0z_1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

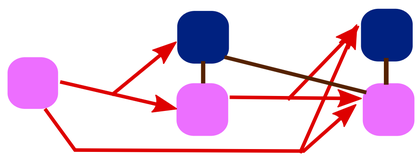
1: Foundresses 3: Surviving foundresses 5: Helpers 7: Summer males
2: Sperm 4: Summer females 6: Surviving sperm

$$W_{z_1} = S_f F_0[(1-z_2)R_{dau} + z_2 v_2 R_{son}] + (1-h)(1-z_1)F_0 v_4 R_{dau} + z_1 F_0 v_7 R_{son}$$
$$W_{z_2} = u_3((1-z_2)F(H)R_{dau} + z_2 F(H) v_2 R_{son}) + u_4((1-z_2)F_0 R_{dau} + z_2 F_0 v_2 R_{son})$$
$$W_h = (1-h)((1-z_2)F_0 R_{dau} + z_2 F_0 v_2 R_{son}) + S_f hb((1-z_2)F(H)R_{sis} + z_2 F(H) v_2 R_{bro})$$

Results

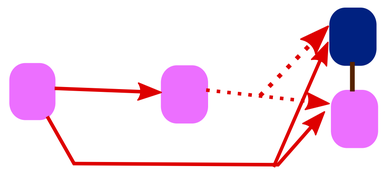


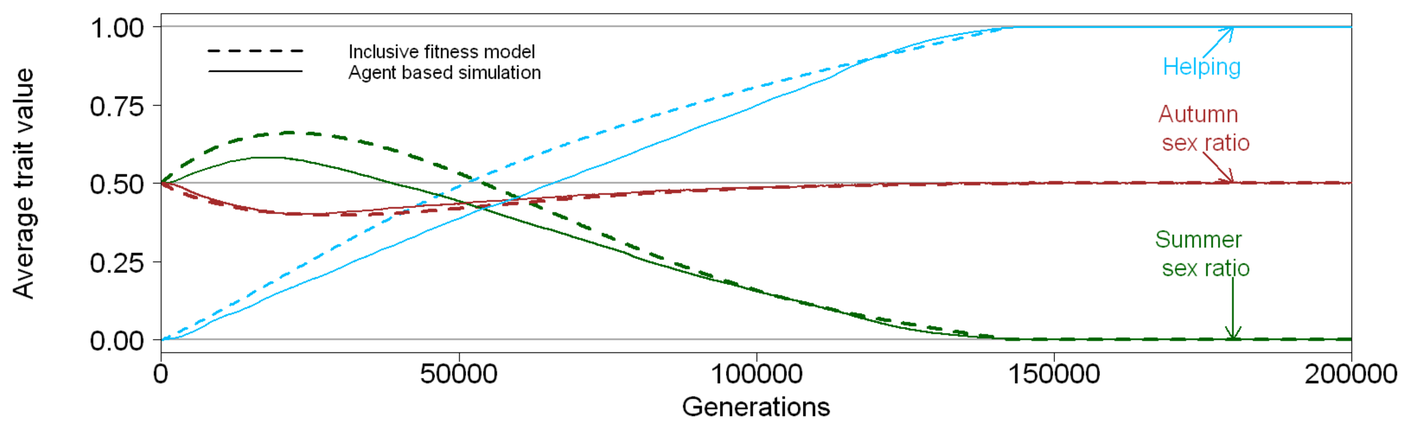
Solitary bivoltine



Evolutionary transition

Eusocial univoltine





Conclusions

- The coevolution of sex ratios and helping leads to a evolutionary transition in social behaviour and life-history
- Haplodiploidy can both favour and hinder the evolution of eusociality .
- Our model points out the importance of traits such as sex ratio manipulation and lifetime monogamy in the evolution of eusociality.