BSc Project Viva

Computational Evolution

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Evolution - nature's optimisation method

- Darwin's *inversion of reasoning* [1]
- natural selection: fitness, competition
- mutations and genetic diversity
- aims of the project:
  - (i) modelling evolution in a simple simulation
  - (ii) quantitative analysis of population dynamics
  - (iii) investigation of adaptation to various environments

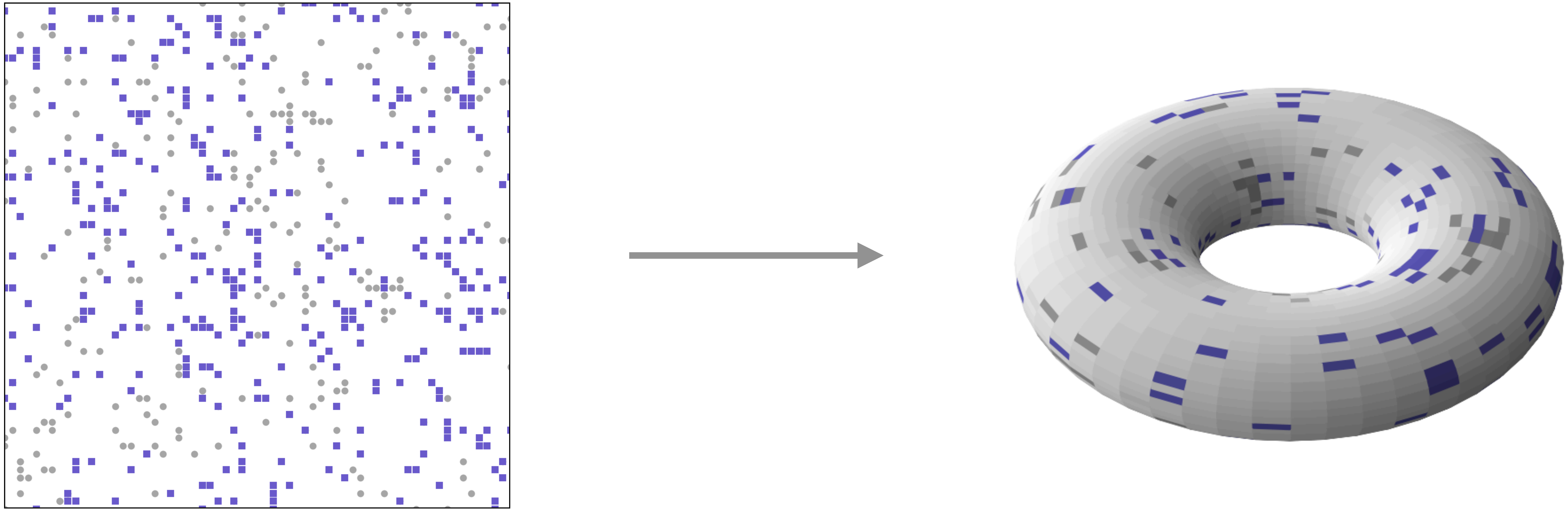
The simulation

move | eat | reproduce | starve

constant speed,
random rotations

asexual

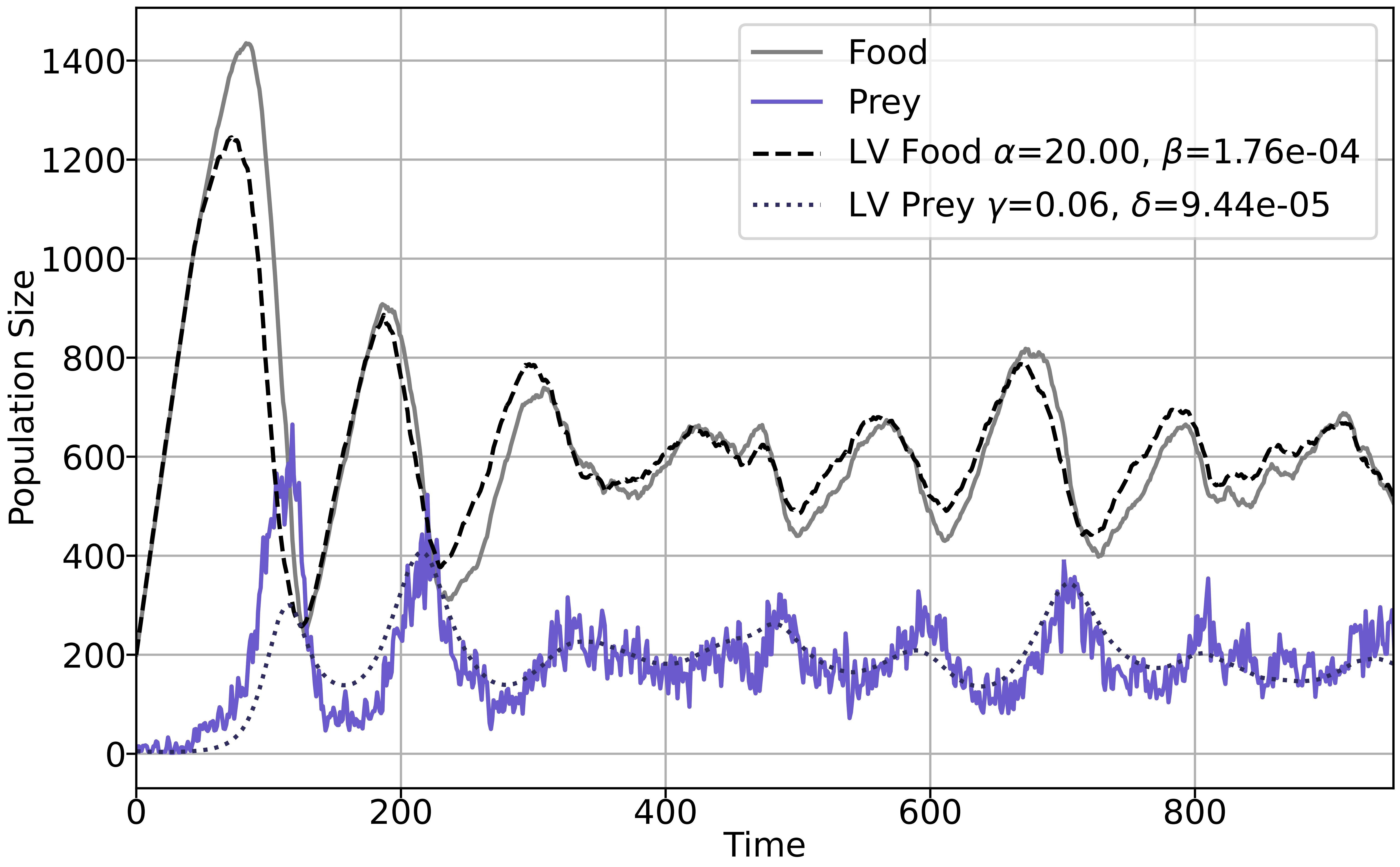
BMR:
health loss / dt



(Wa-Tor, rotation genes: see[2])

Lotka-Volterra validation I

For agent-food populations with no mutation



Modified difference equations for agent (y) and food (x) population changes in time:

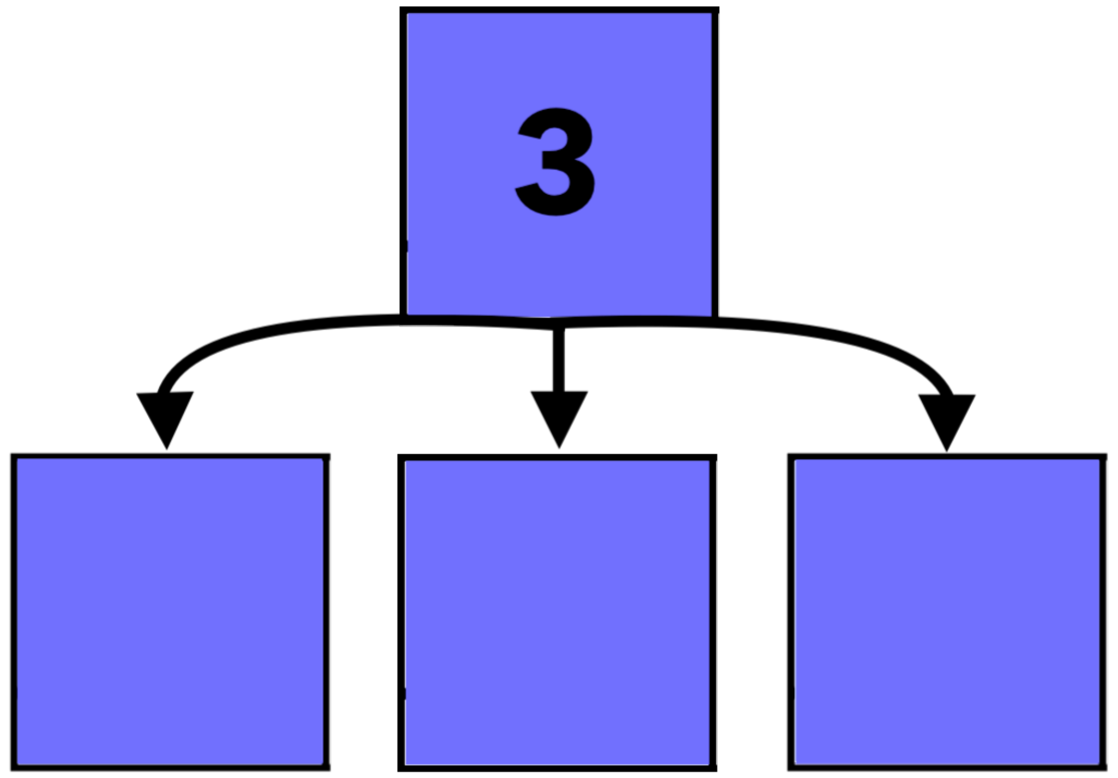
$$\frac{dx}{dt} = \alpha - \beta xy$$

$$\frac{dy}{dt} = \delta xy - \gamma y$$

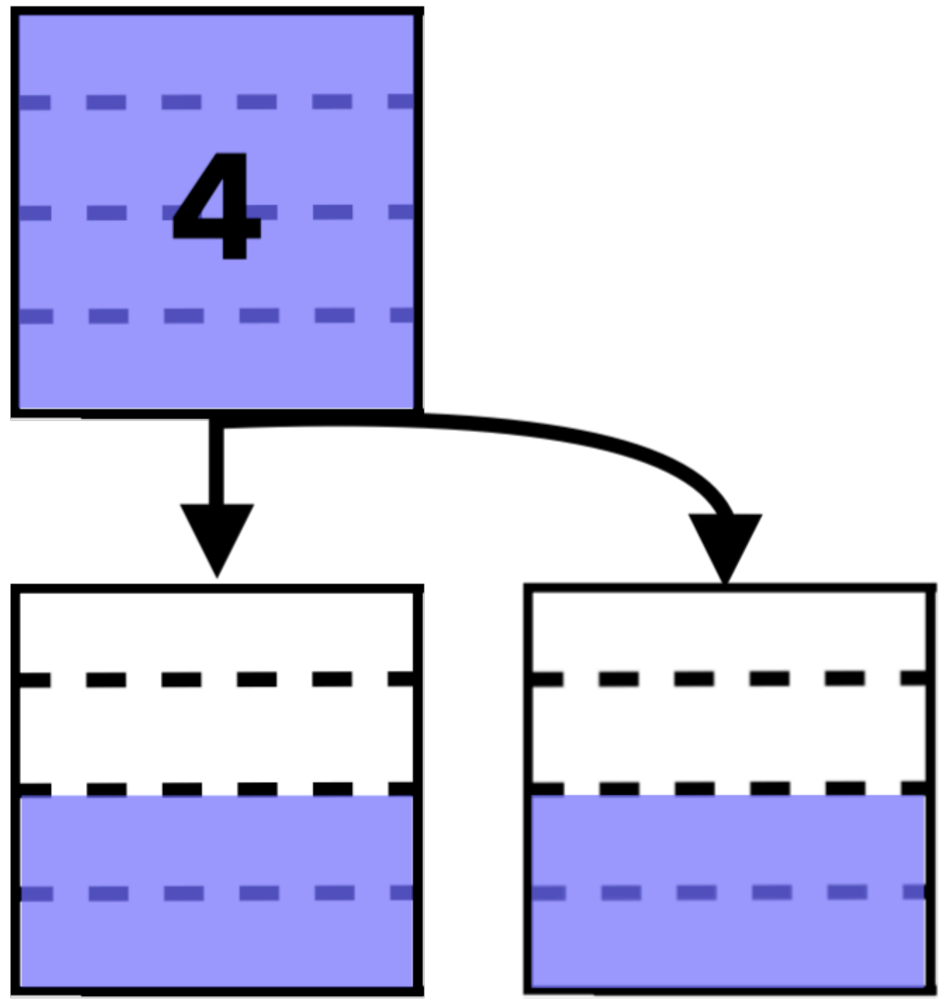
with constant factors α, β, γ and δ.

The simulation - Genes

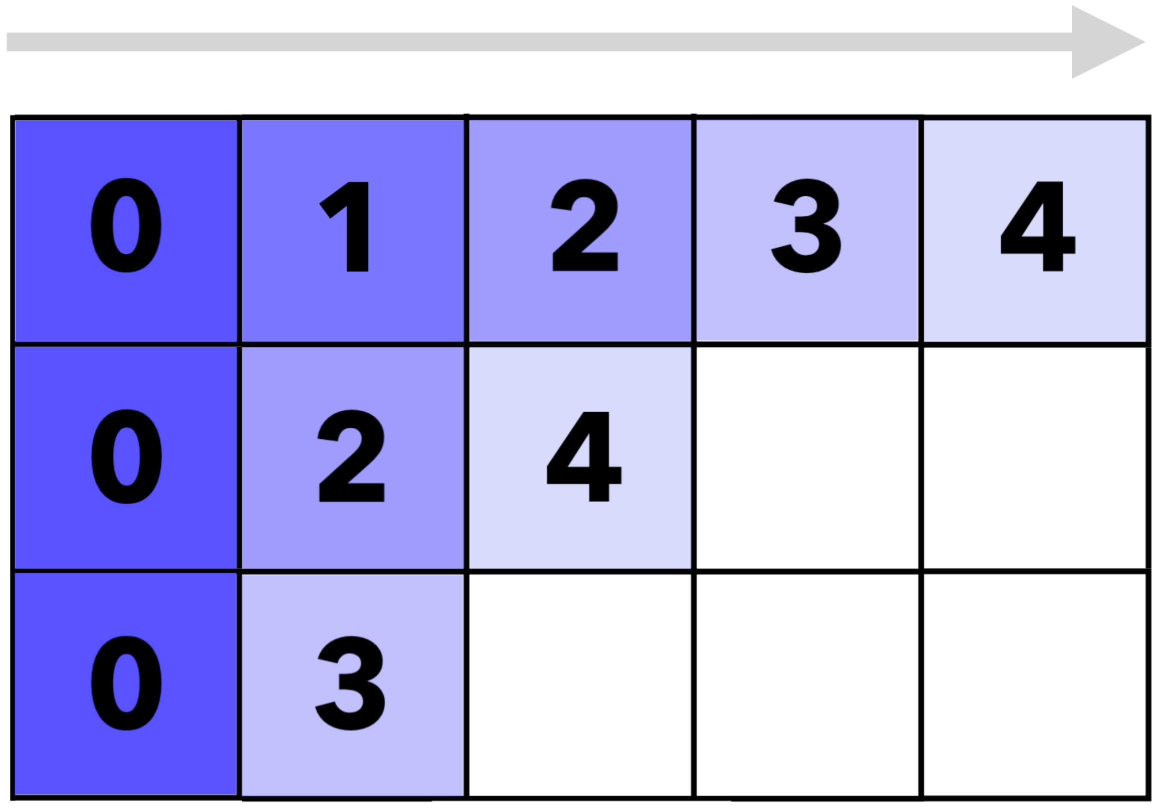
Number of offspring



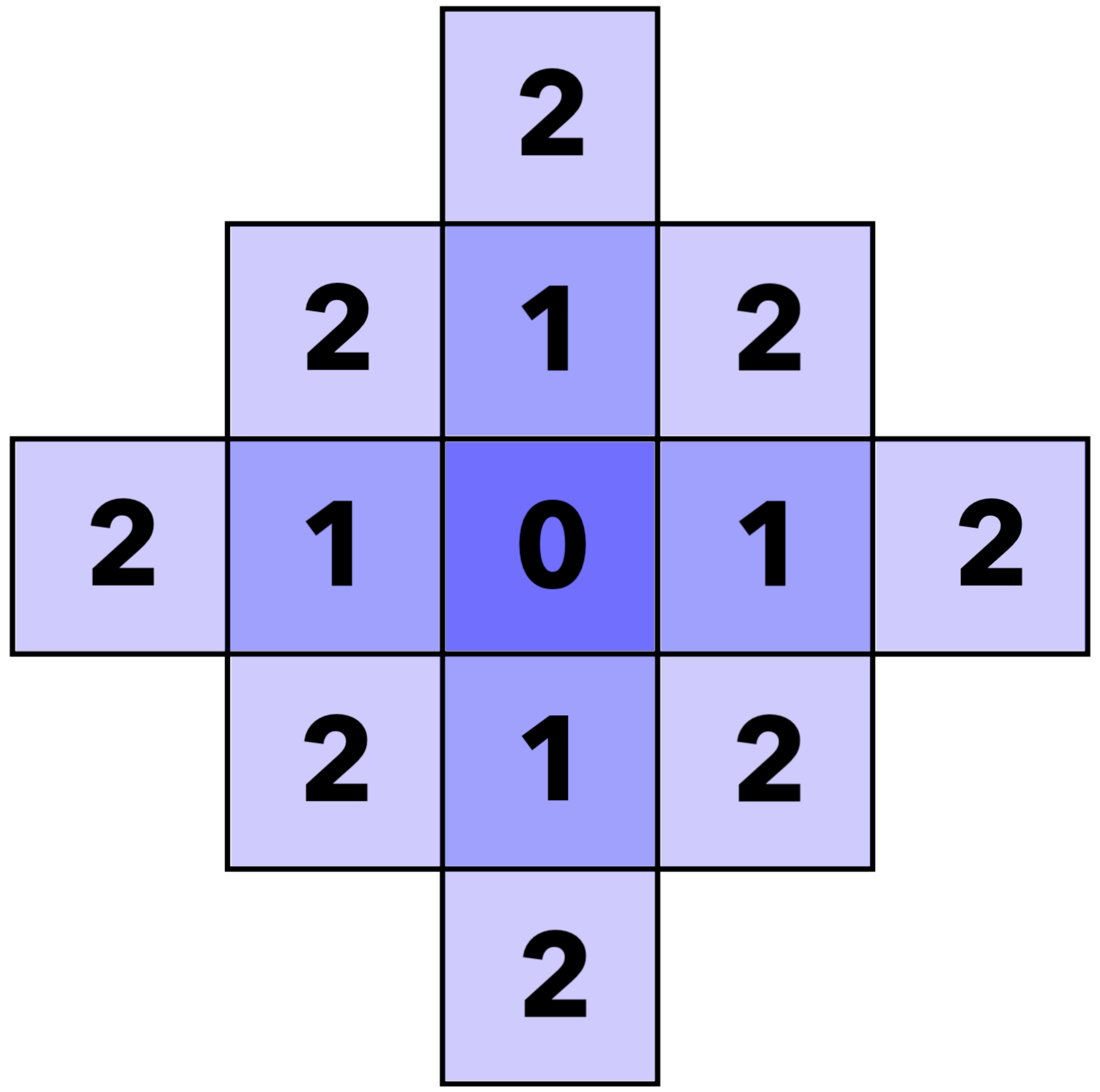
Reproduction threshold



Speed
(Inverse)

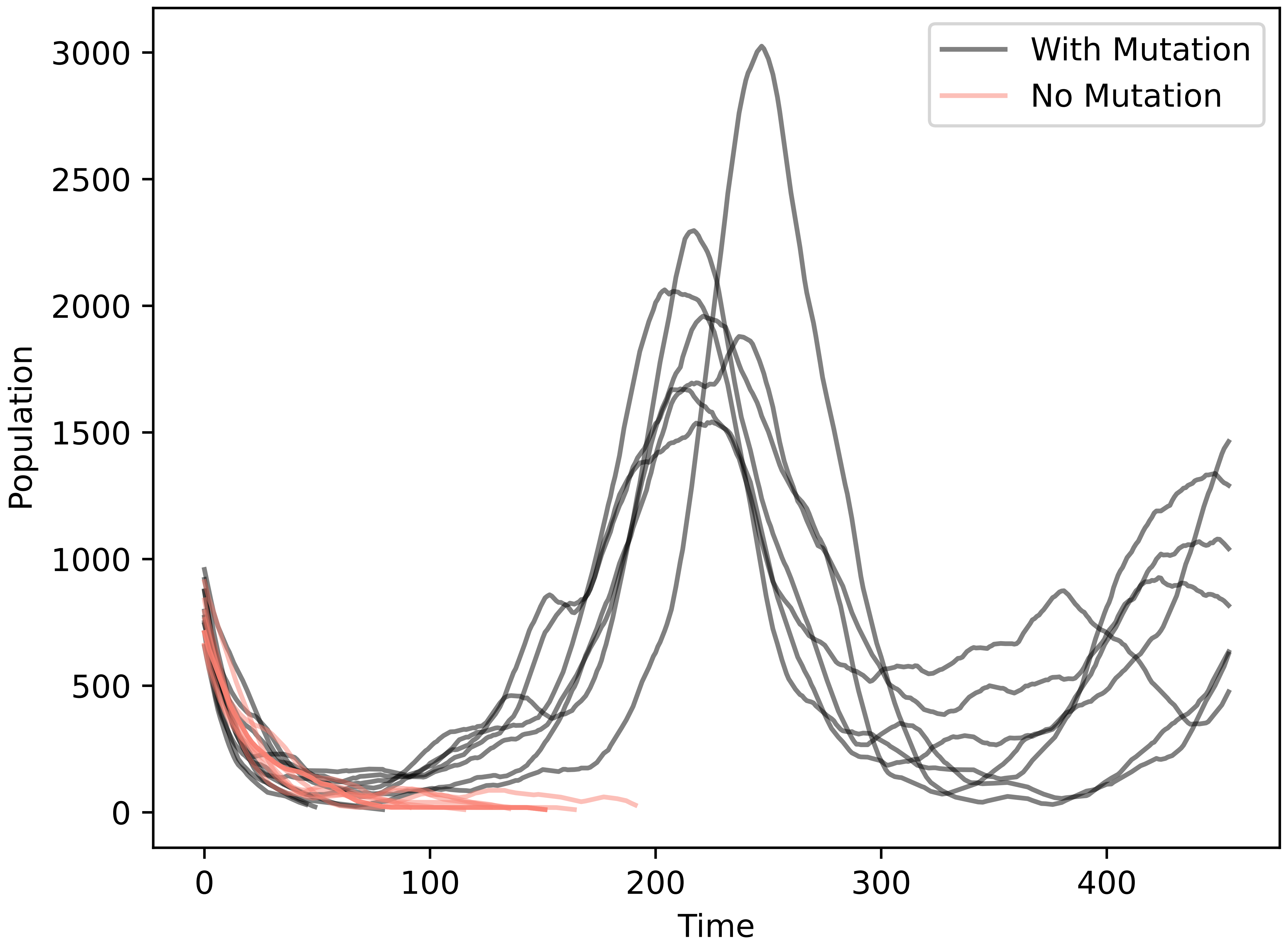


Sight

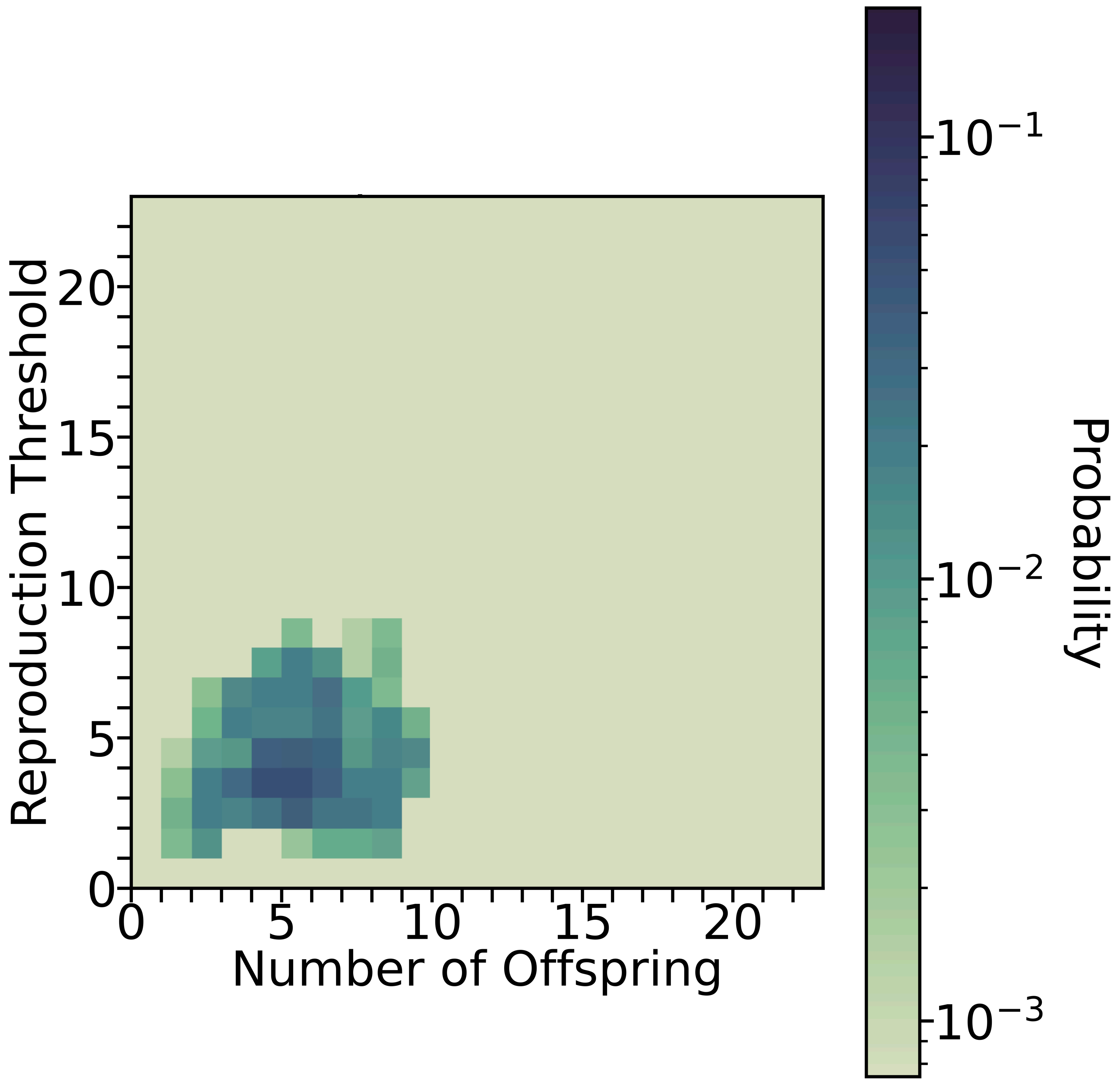


Changing environments I

Mutations and the ability to adapt



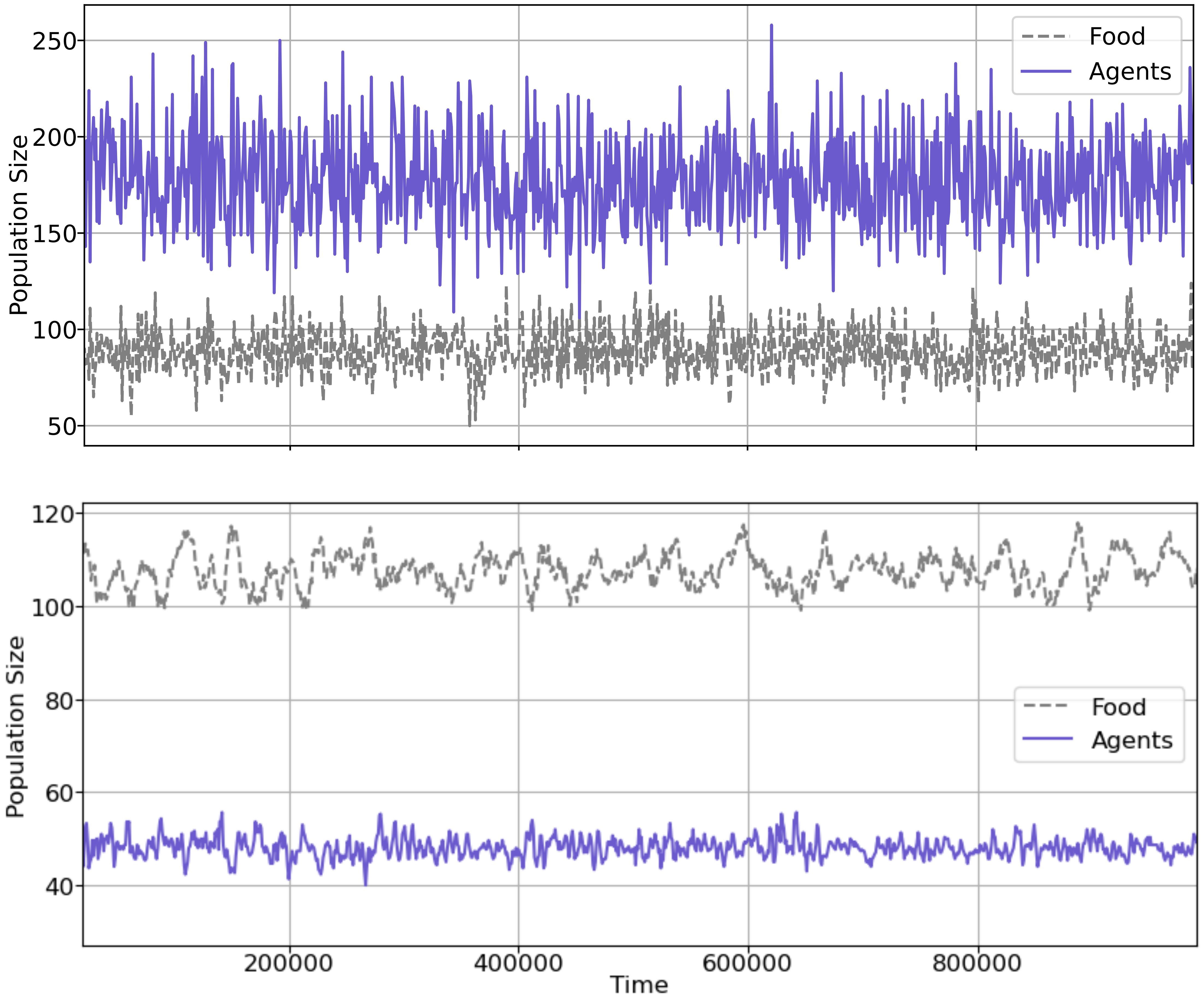
Sight gene in a highly selective environment (low food density)



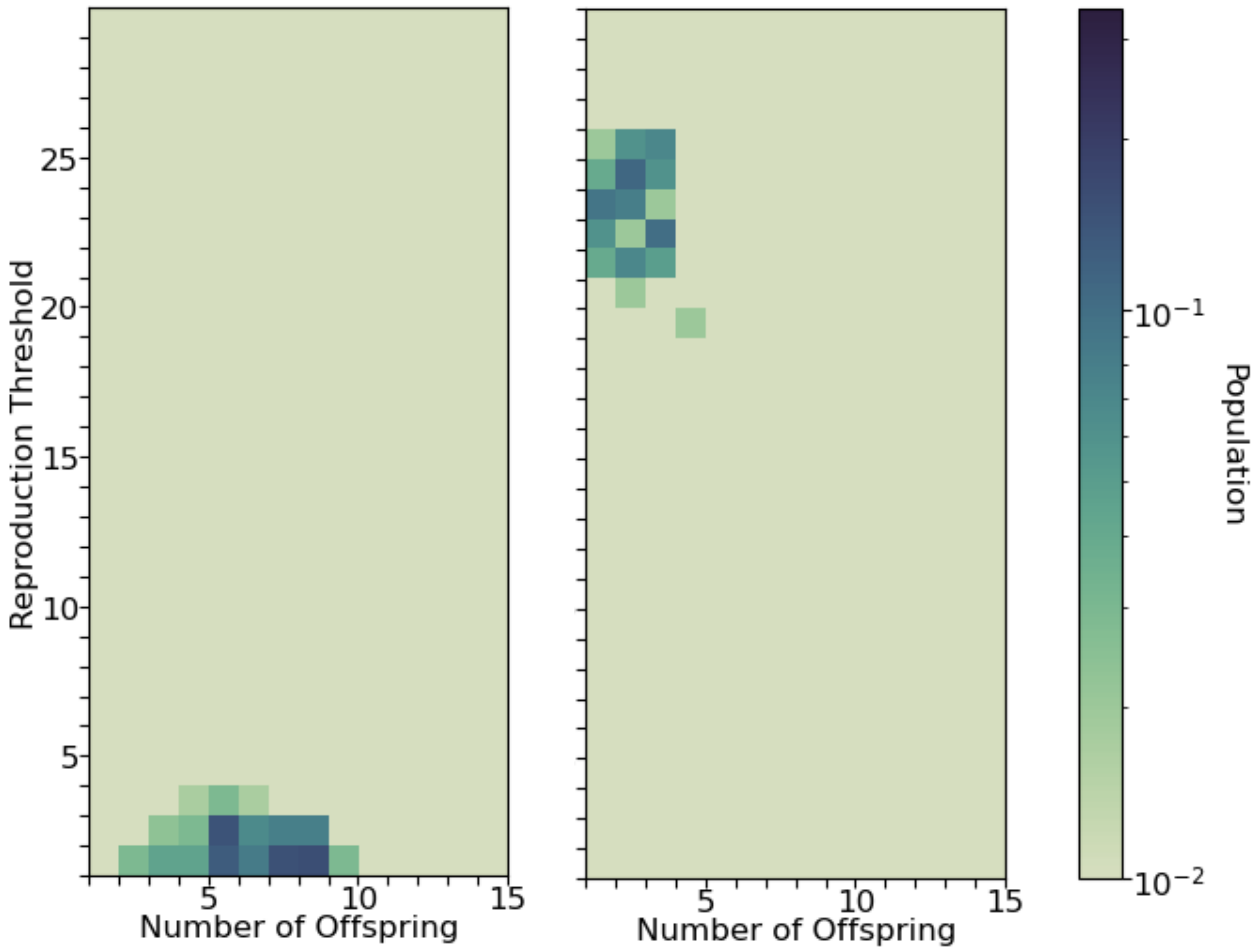
Gene-space spread

Changing environments II

Tuna and Whale - r/K or fast/slow



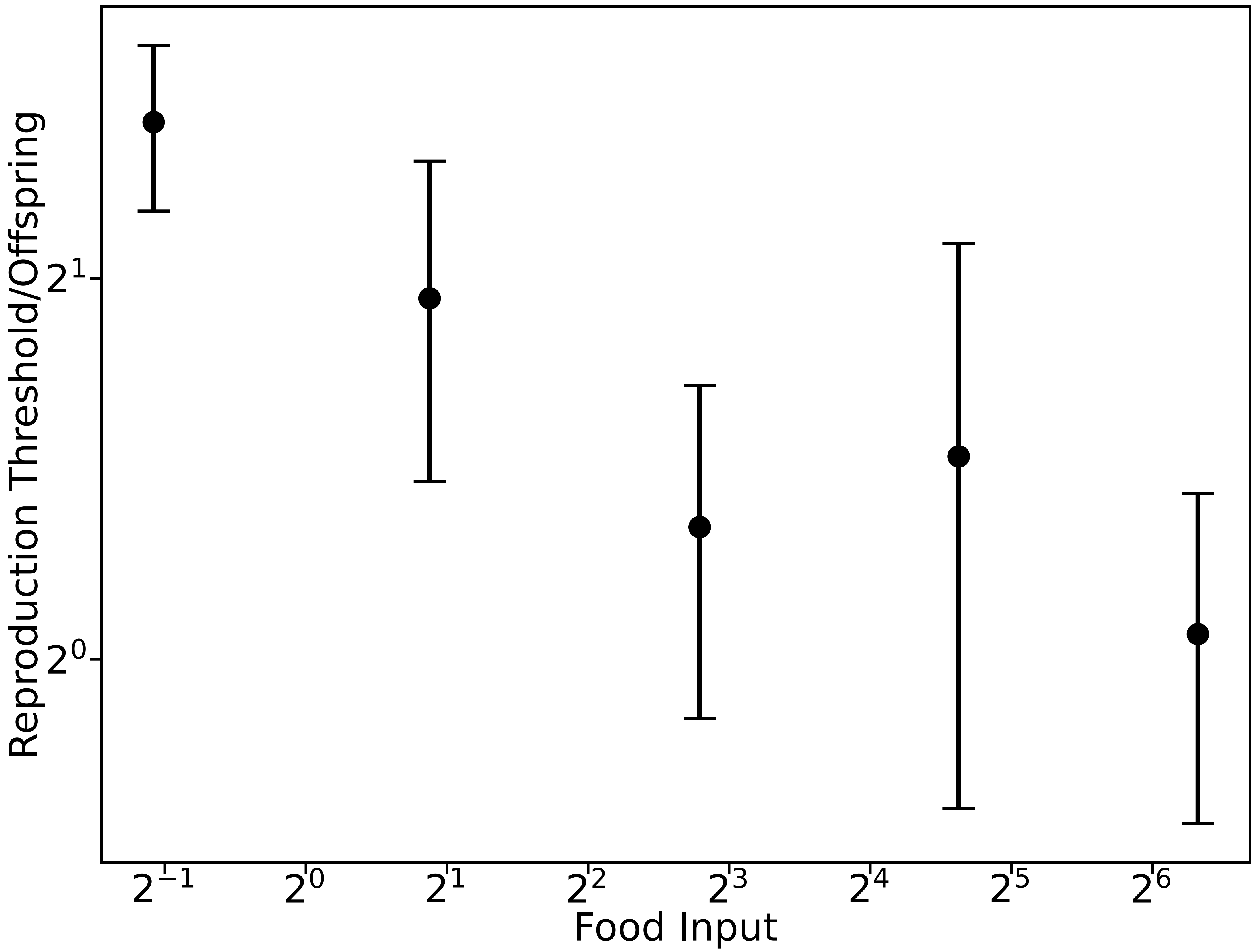
r (top) and K (bottom) strategist characteristic population oscillations



r (left) and K (right) *reproductive strategist* gene-space occupancies

Changing environments II

Reproduction threshold and Number of offspring



- scarce food:

  need for storage
  → higher reproduction threshold

- abundant food:

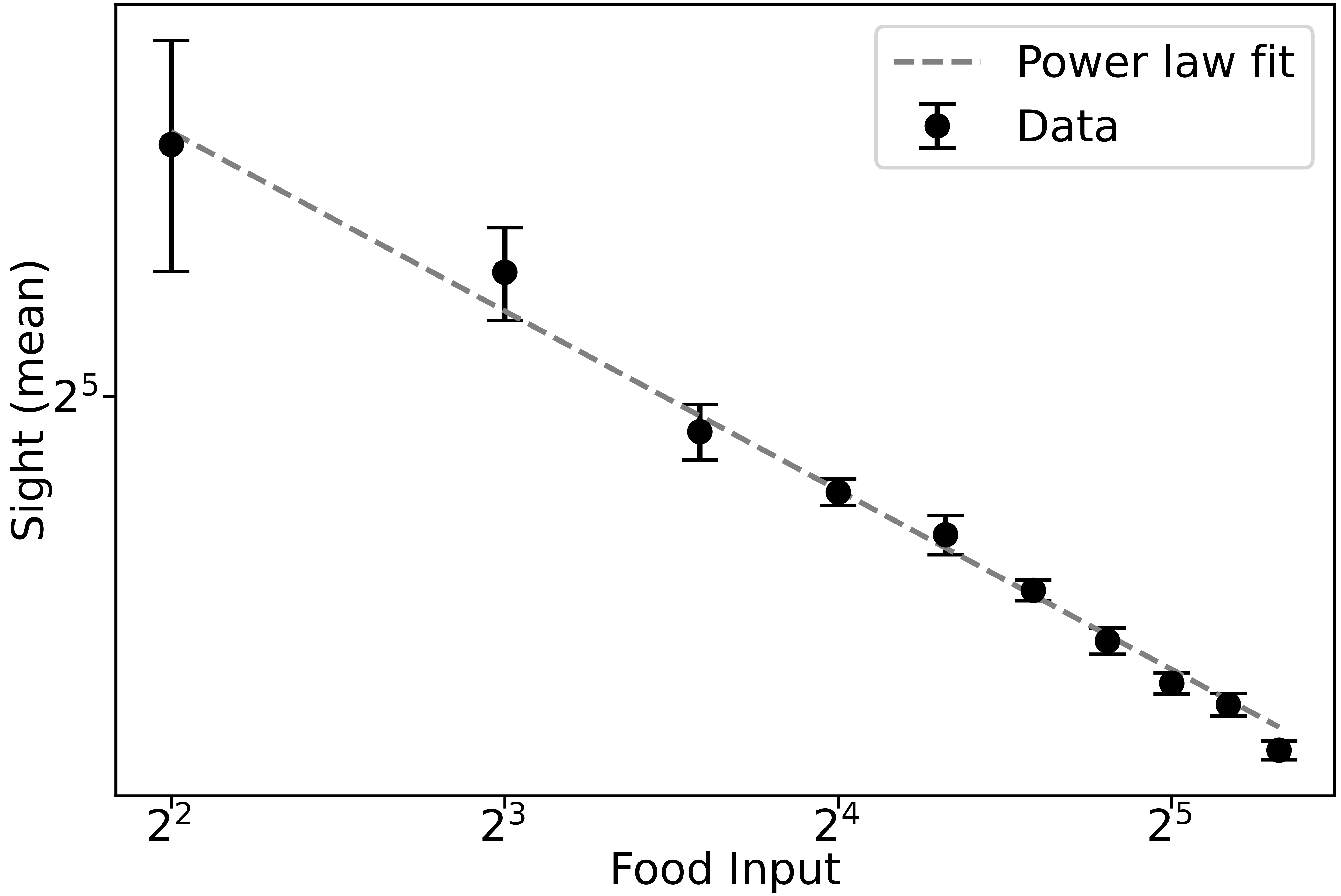
  can survive without long storage
  → lower ratio

Changing environments III

Sight and spatial food distribution - earthworm to eagle

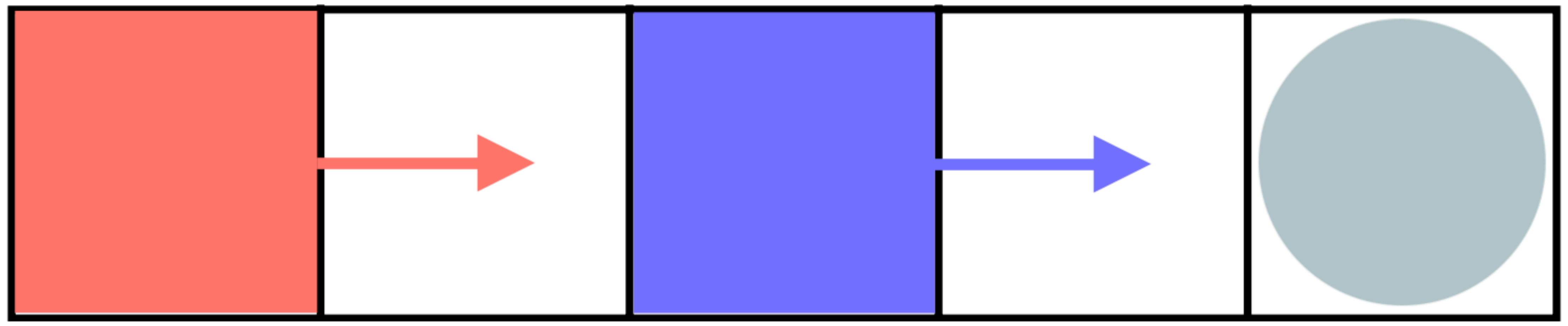
Power law dependence:

- p-value of 0.26 (by χ^2 test)
- hint at a non-trivial relationship (inverse square root), dependent on agent population, reproduction, average manhattan distance between foods

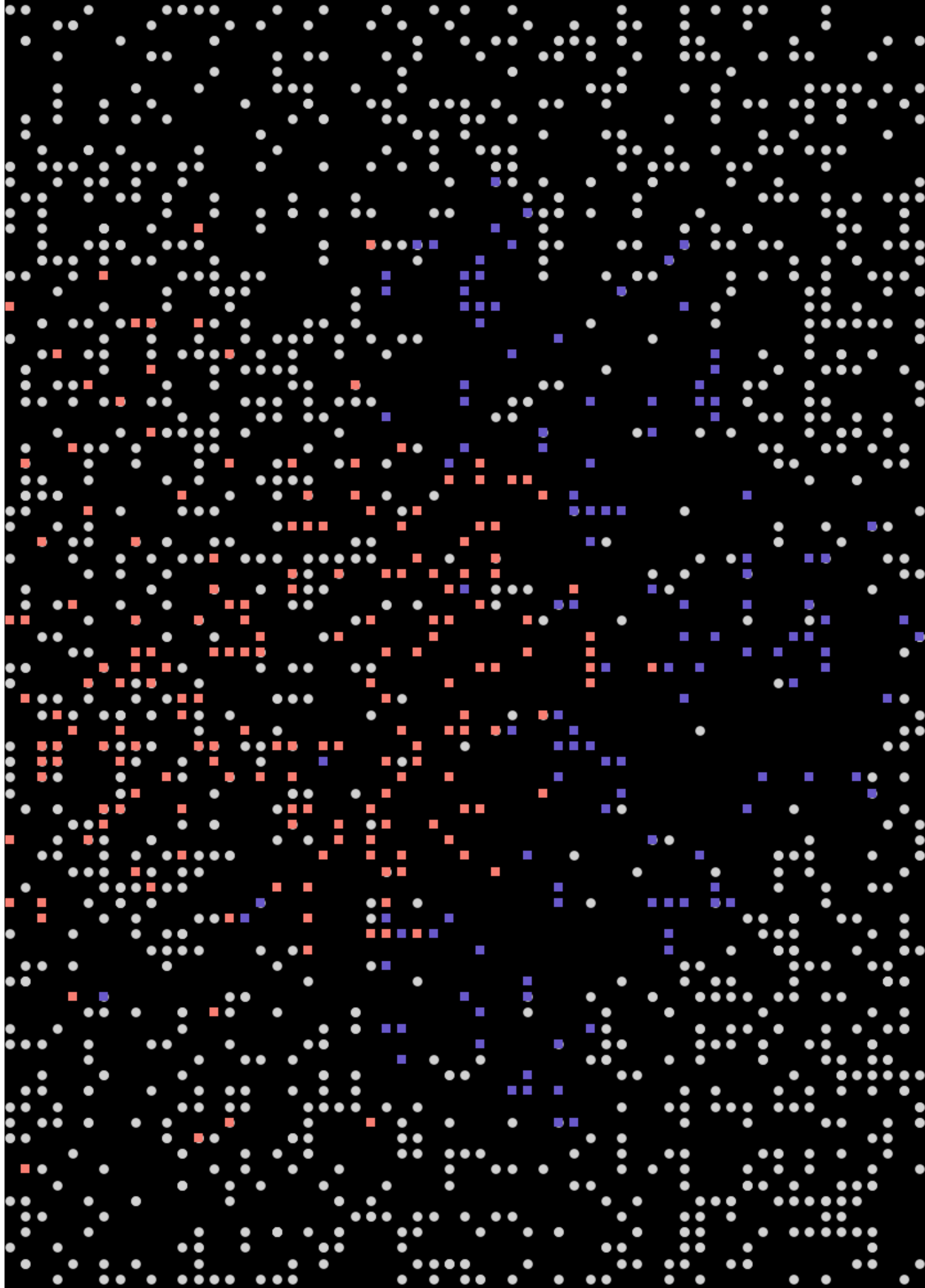


Power law (ax^b) fit parameters: $a = 94.02 \pm 3.56,\ b = -0.45 \pm 0.02$

Predators and prey

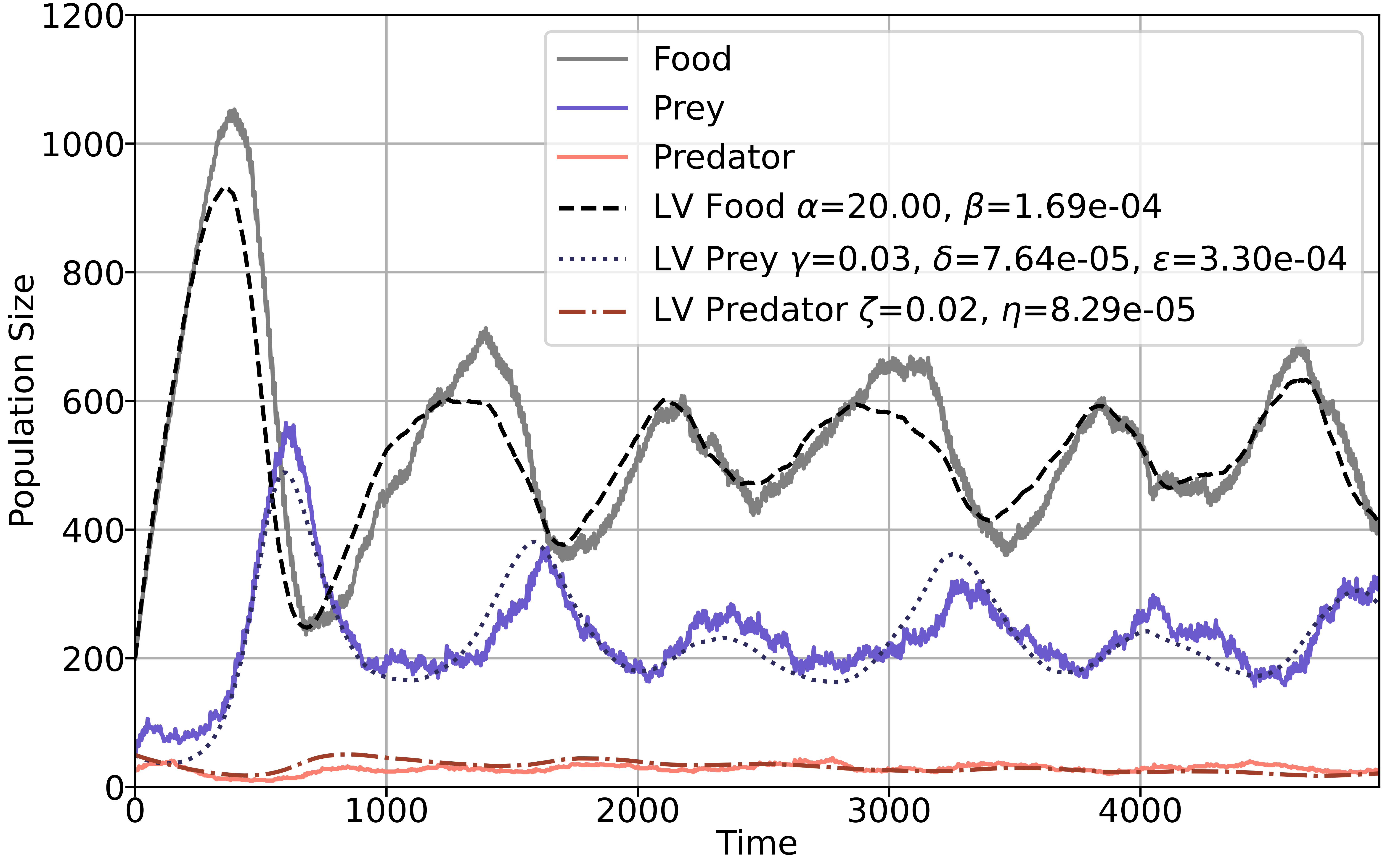


- same set of genes
- chasing and fleeing logic



Lotka-Volterra validation II

For predator-prey populations



3-species difference equations for food, prey and predator (x, y, z) system in time:

$$\frac{dx}{dt} = \alpha - \beta xy$$

$$\frac{dy}{dt} = -\gamma y + \delta xy - \epsilon yz$$

$$\frac{dz}{dt} = -\zeta z + \eta yz$$

with constant factors α through η.

Survival condition for predators [3]:

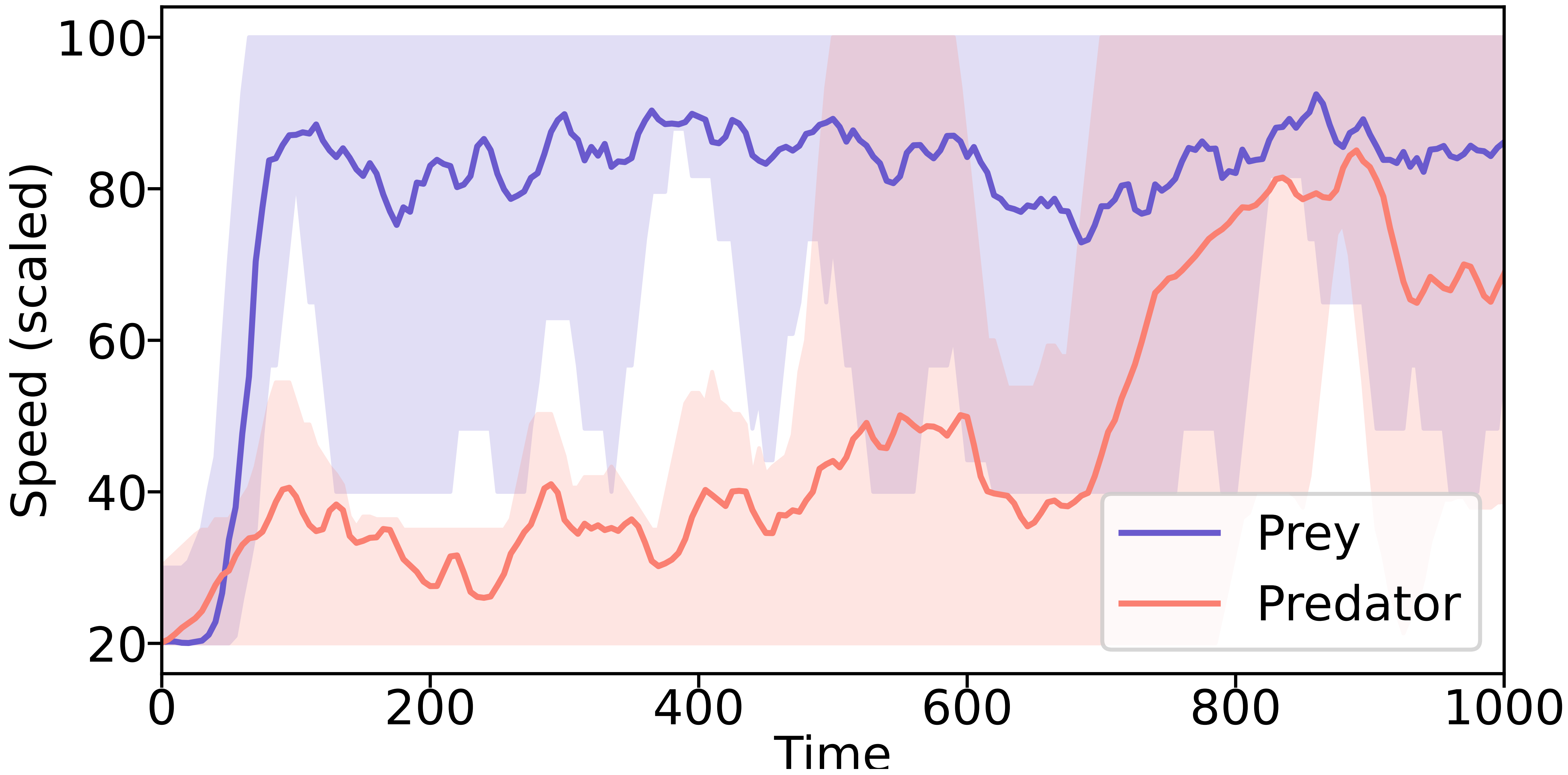
$$\alpha\eta \geq \zeta\beta$$

Coevolution

Speed: a one way road - cheetah and gazelle

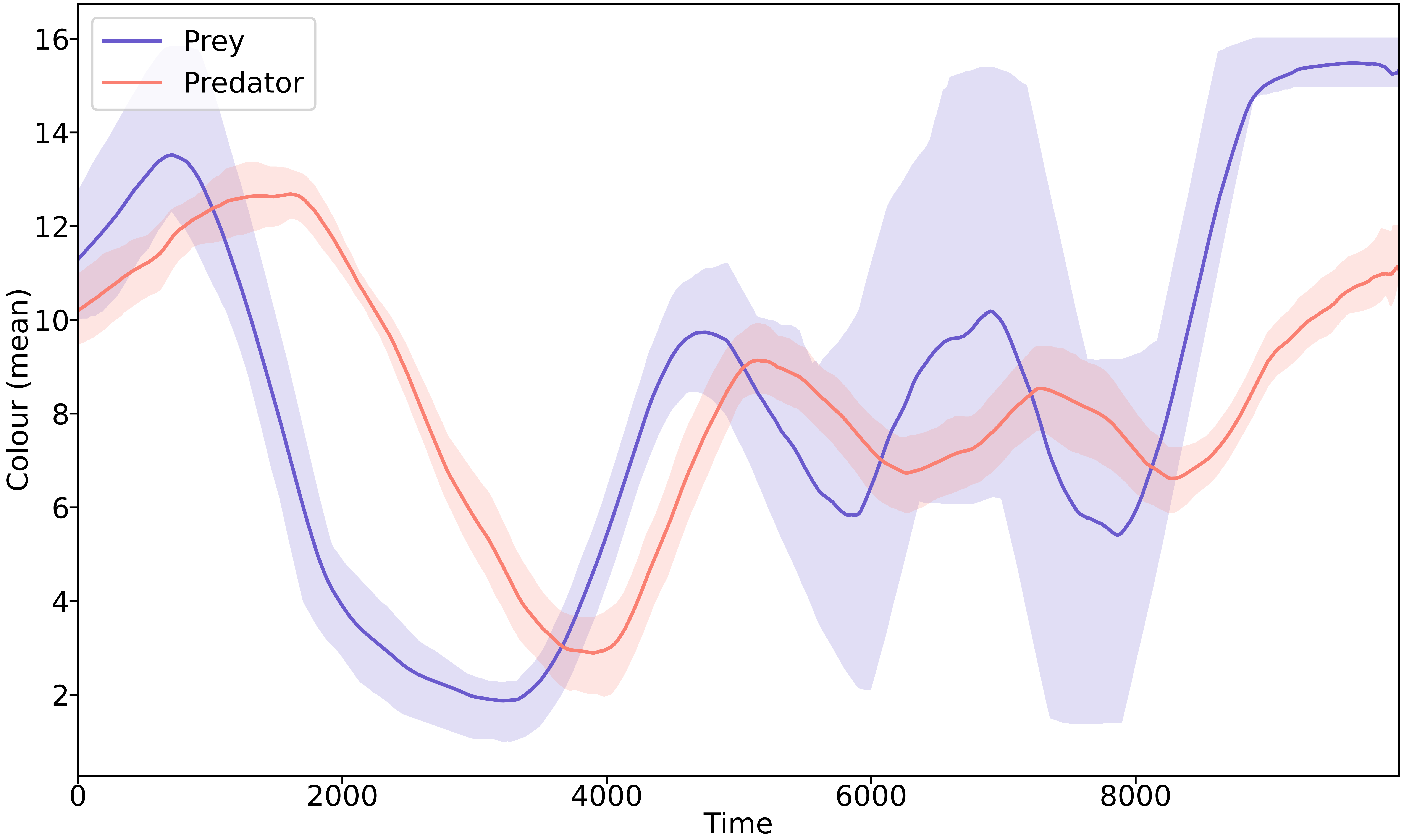
slower gazelles are easy prey, strong drive to become faster

predators have to catch up, but energy requirements are super-linear: upper limit



Coevolution

Colour: the chase in gene-space - guppy [4], snakes, frogs



Maximising the fitness landscape

Evolution as an optimisation problem

- The fitness landscape (F) is a function of the gene-space distribution itself at a given time:

$$F[\vec{g}, t; \vec{\theta}, G(\vec{g}, t)]$$

  where $\vec{g}$ is the gene-space coordinate and $\vec{\theta}$ are the environmental parameters.

- Rapidly changing landscape will mean the optimisers (agents) in gene-space evolve constantly - exact stable solution is never found.

- Sometimes approximate solutions are enough – see search in sequence space in protein analysis [5] and 2018 Nobel Prize in Chemistry

Possible extensions to project

- Speciation tracking (ML classifier)
- Investigate camouflage effect of colour (relative to environment)
- Other genes, eg. strength, size
- Discuss emergence of self-organised criticality and connection to Bak-Sneppen model [6], Extremal Optimisation [7]

References

(1) Dennett, D. (2009). Darwin's Strange Inversion of Reasoning. *Proceedings of the National Academy of Sciences of the United States of America*. 106 Suppl 1. 10061-5. 10.1073/pnas.0904433106.

(2) Dewdney, A. K. “COMPUTER RECREATIONS.” *Scientific American* 251, no. 6 (1984): 14–26. http://www.jstor.org/stable/24969495.

(3) E. Chauvet, J. Paullet, J. Previte, and Z. Walls. “A Lotka-Volterra Three-Species Food Chain.” *Mathematics Magazine* 75, no. 4 (2002): 243–55. https://doi.org/10.2307/3219158

(4) JG. Godin, H. McDonough, Predator preference for brightly colored males in the guppy: a viability cost for a sexually selected trait, *Behavioral Ecology*, Volume 14, Issue 2, March 2003, Pages 194–200, https://doi.org/10.1093/beheco/14.2.194

(5) Romero, P., Arnold, F. Exploring protein fitness landscapes by directed evolution. *Nat Rev Mol Cell Biol* **10**, 866–876 (2009). https://doi.org/10.1038/nrm2805

(6) P. Bak, K. Sneppen, Punctuated equilibrium and criticality in a simple model of evolution, *Phys. Rev. Lett.* 71 (1993) 4083–4086

(7) S. Boettcher, A. Percus, Nature's way of optimizing, *Artificial Intelligence*, Volume 119, Issues 1–2, 2000, Pages 275-286, https://doi.org/10.1016/S0004-3702(00)00007-2

Appendix A

Sight and food density (linear plot)