Can time-lag in niche construction solve the tragedy of the common?

Phuong NGUYEN
Postdoc – iEES
Supervisors: Manon Costa, Florence Débarre, Nicolas Loeuille

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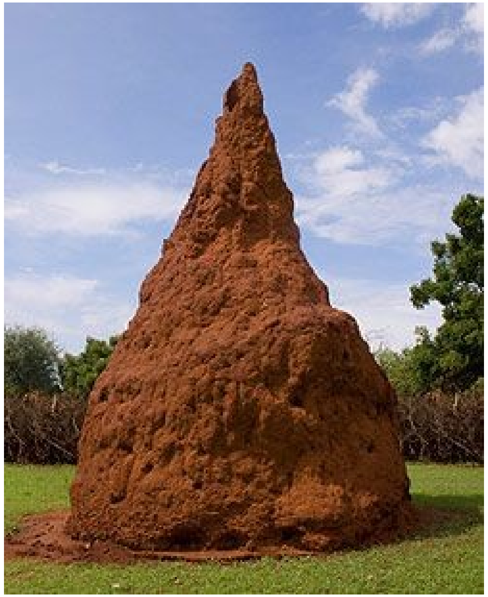
Niche construction is ubiquitous

Organisms modify the surrounding environment which then feedback on them and the neighbouring species

Beavers build dams

Termites build nests



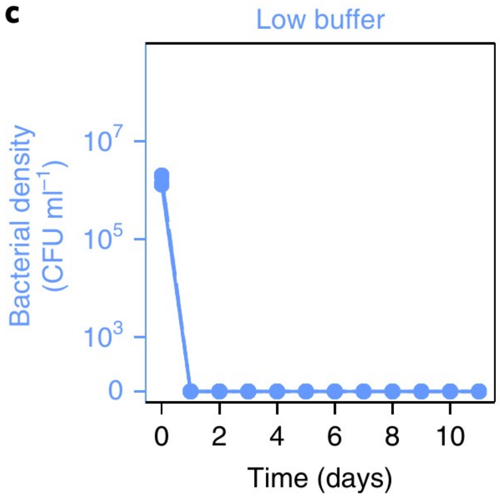
Trees produce oxygen

Niche construction is ubiquitous

Organisms modify the surrounding environment which then feedback on them and the neighbouring species

Niche construction can also be negative

Time-lag in niche construction

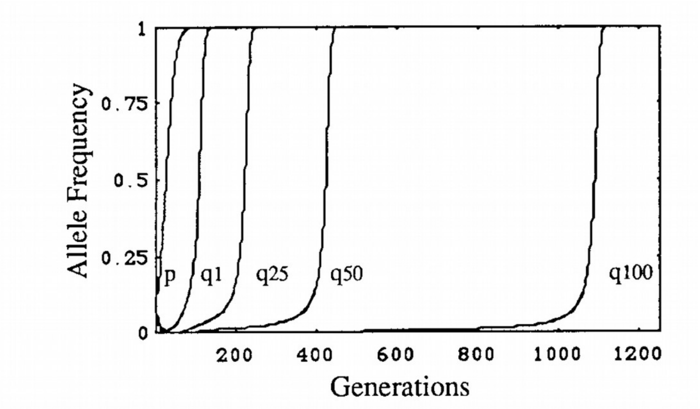


Bacteria population
collapse
 (Ratzke et al 2018)
Effect occurs in days

Shell bed
Effect last for
millions of years

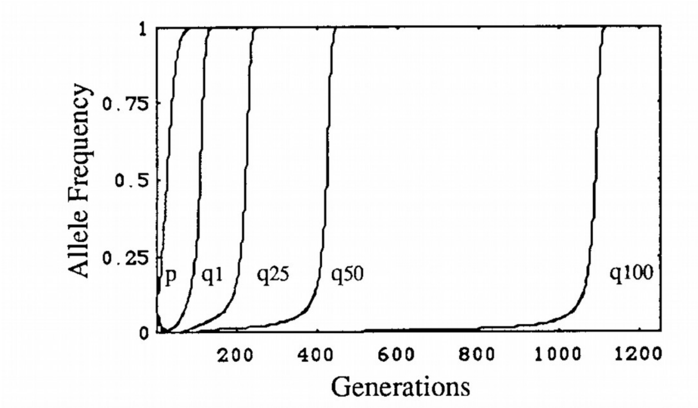
Effect occur in
Individuals’ generations

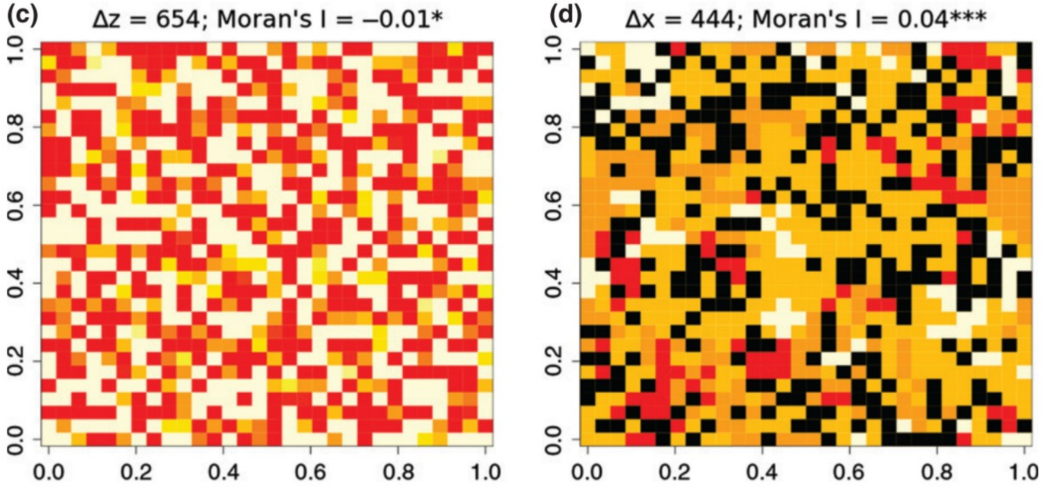
Time-lag in niche construction



Niche construction genes facilitate other genes (Laland 1996)

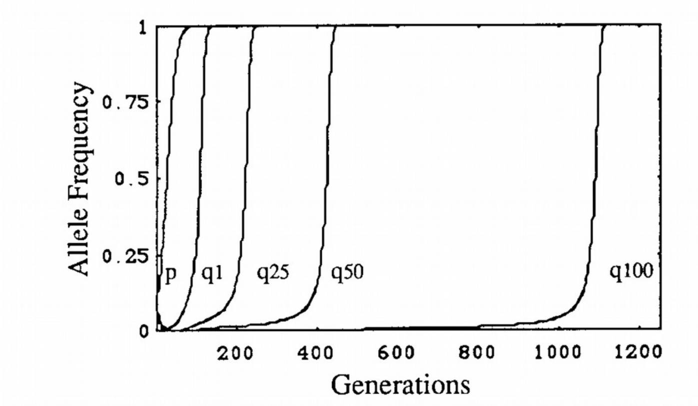
Time-lag in niche construction



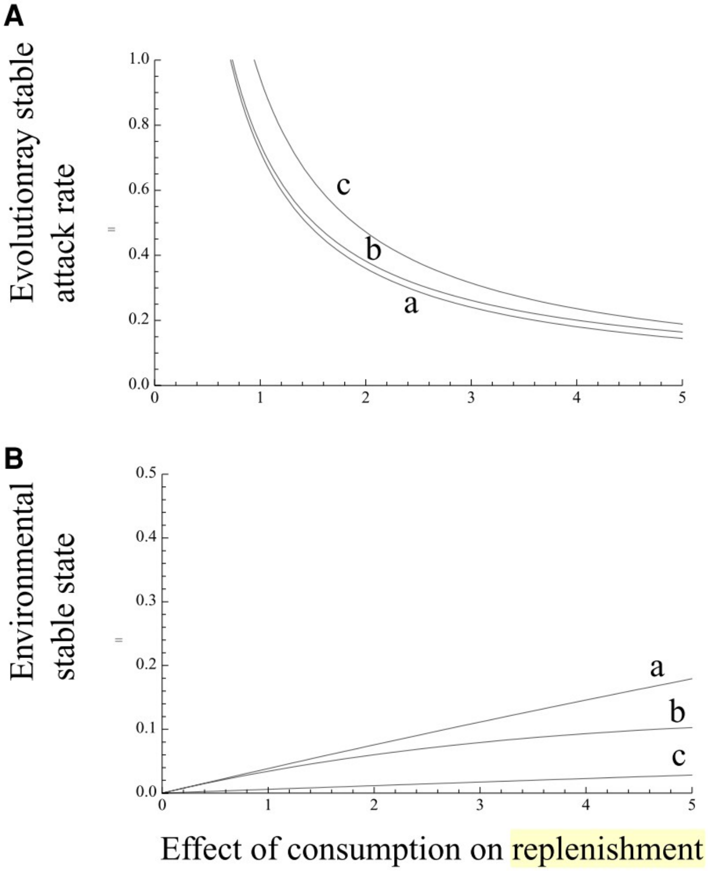


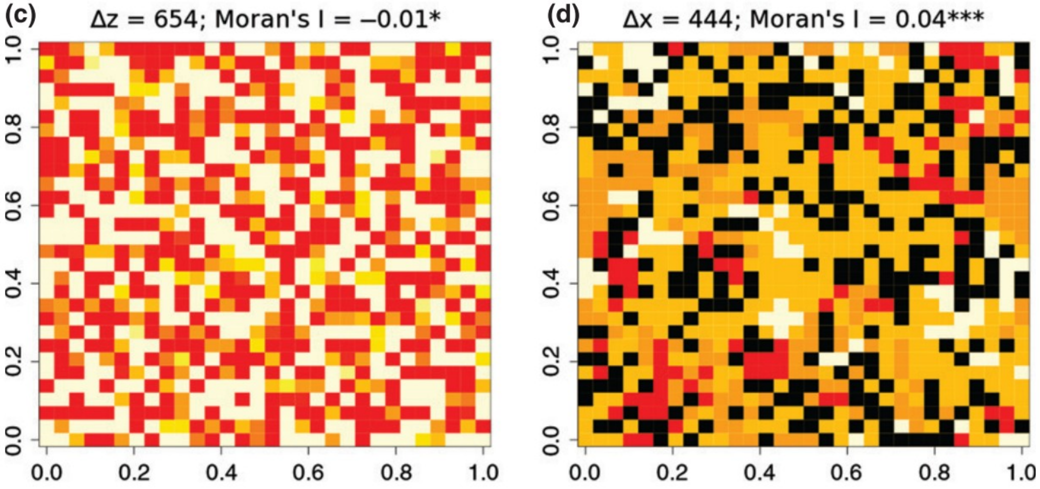
Time lag in the recover of resource lead to diversify (Loeuille and Leibold 2014)

Time-lag in niche construction

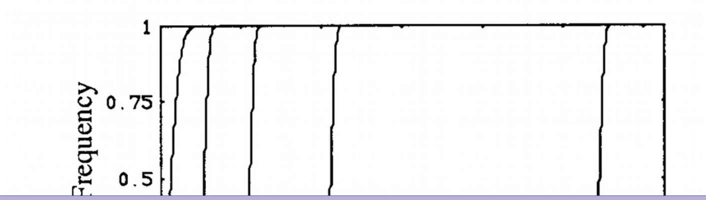


Time-lag selects for prudent attack rate (Lehmann 2008)

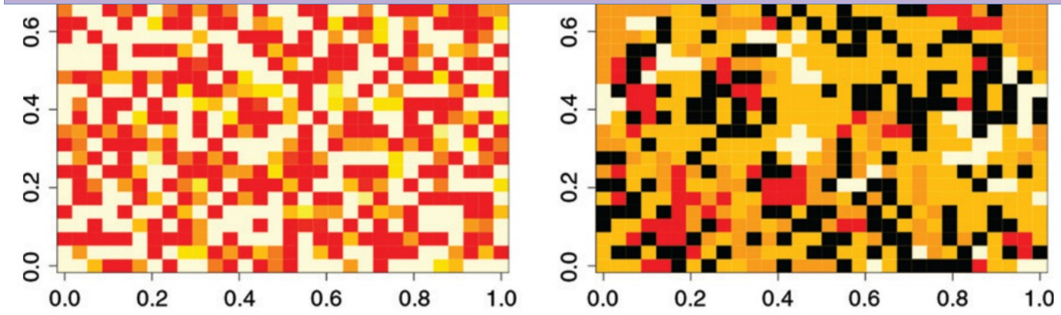




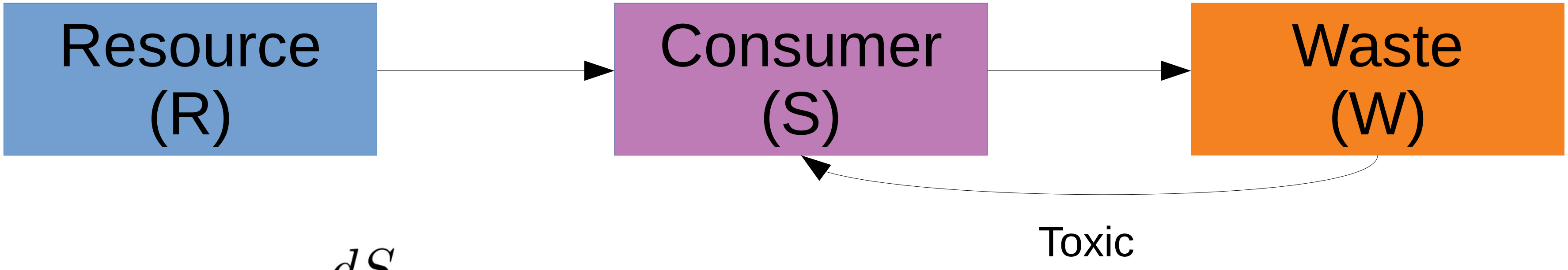
Time-lag in niche construction



Can time-lag in niche construction select for lower production of waste?



Homogeneous unstructured population



Resource
(R)

Consumer
(S)

Waste
(W)

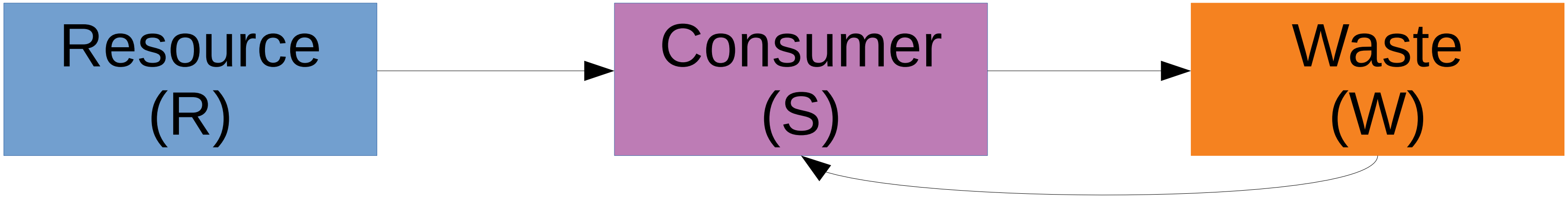
Toxic

$$\frac{dS}{dt} = c\rho SR - dS - SvW$$

$$\frac{dR}{dt} = I_R - cSR - \delta_R R$$

$$\frac{dW}{dt} = I_W + hcS - \delta_W W$$

Homogeneous unstructured population



Resource (R)

Consumer (S)

Waste (W)

Toxic

$$\frac{dS}{dt} = \boxed{c}\rho SR - dS - SvW$$

$$\frac{dR}{dt} = I_R - cSR - \delta_R R$$

$$\frac{dW}{dt} = I_W + h\boxed{c}S - \delta_W W$$

Higher consumption
=
higher waste production

Evolution without time-lag

Reproduction ratio of the consumer

$$\mathcal{R} = \frac{c_{mut}\rho R^*(c_{res})}{d + vW^*}$$

$$\frac{\partial \mathcal{R}}{\partial c_{mut}} = \frac{\rho R^*(c_{res})}{d + vW^*}$$

Evolution without time-lag

Reproduction ratio of the consumer

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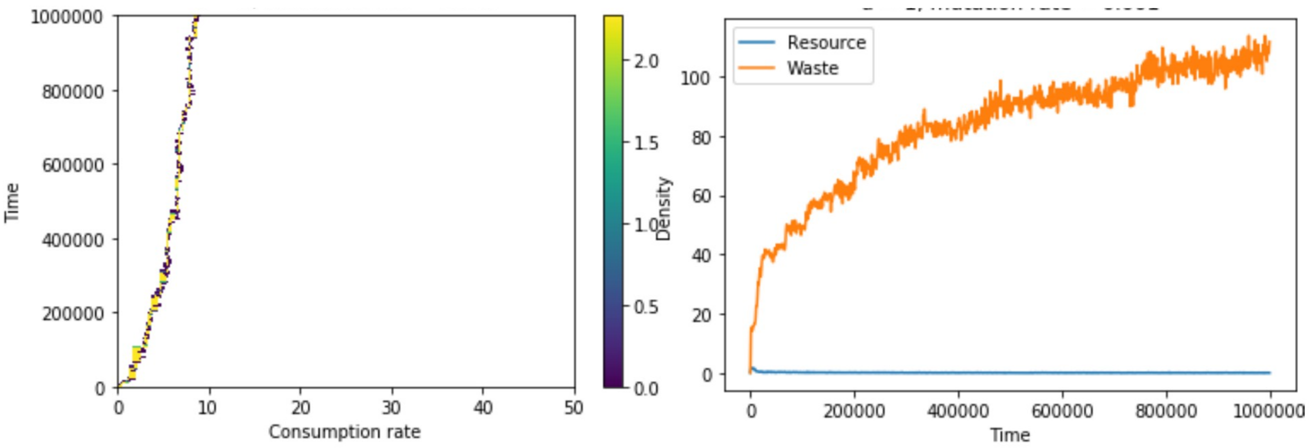
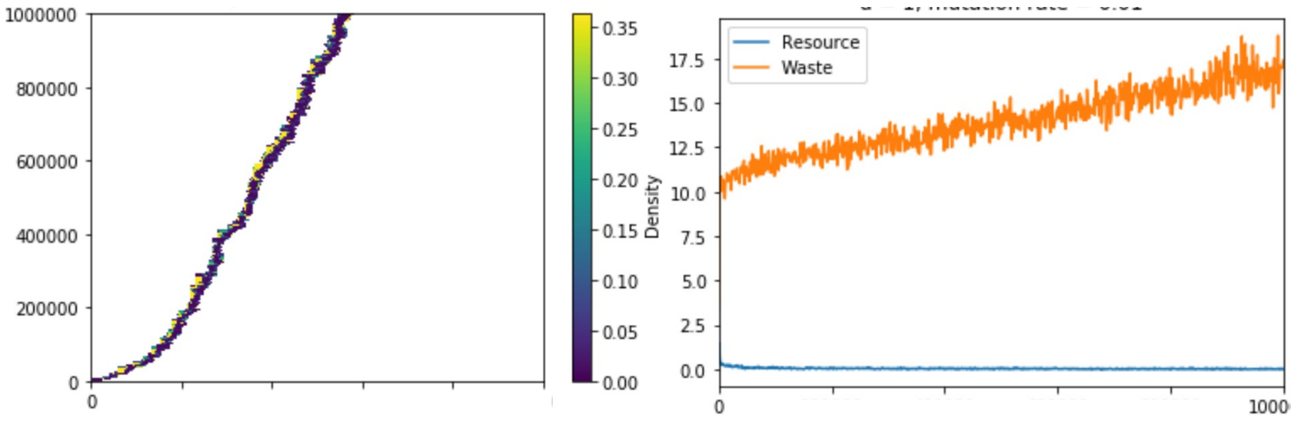
$$\frac{\partial \mathcal{R}}{\partial c_{mut}} = \frac{\rho R^*(c_{res})}{d + vW^*}$$

Simulation with small mutation rate = 0.001



Numerical results with time-lag

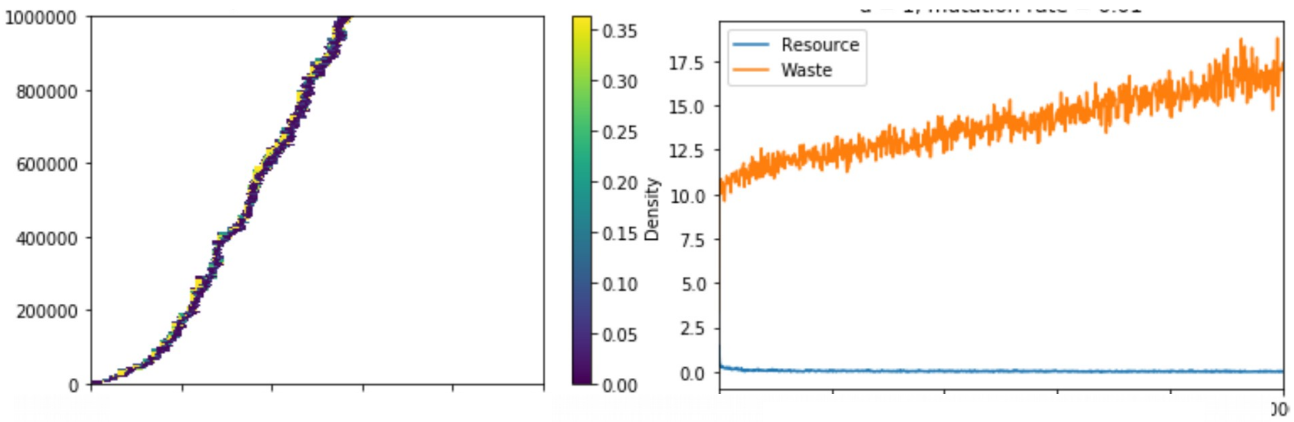
Mutation rate = 0.01



Waste dynamics is much faster than resource dynamics

Numerical results with time-lag

Mutation rate = 0.01



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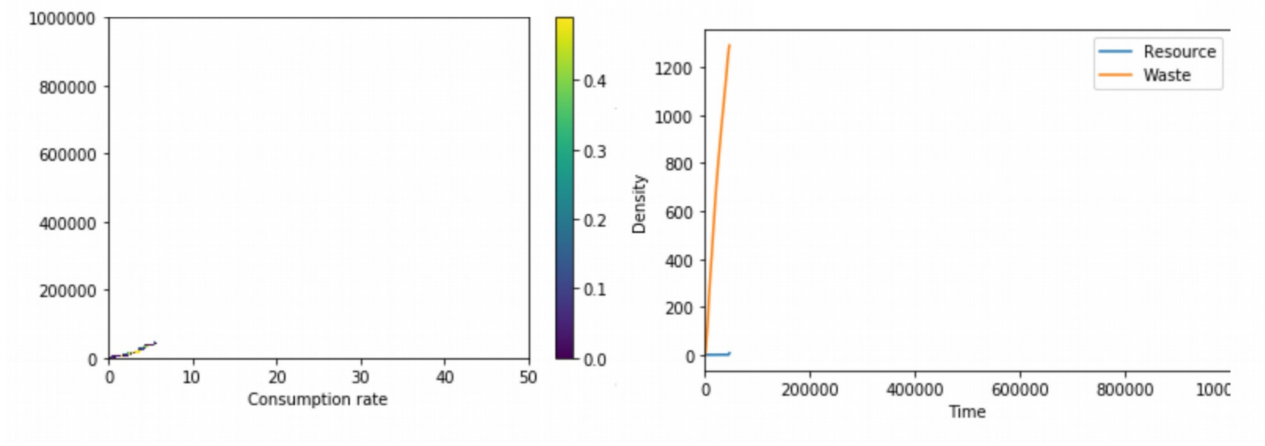
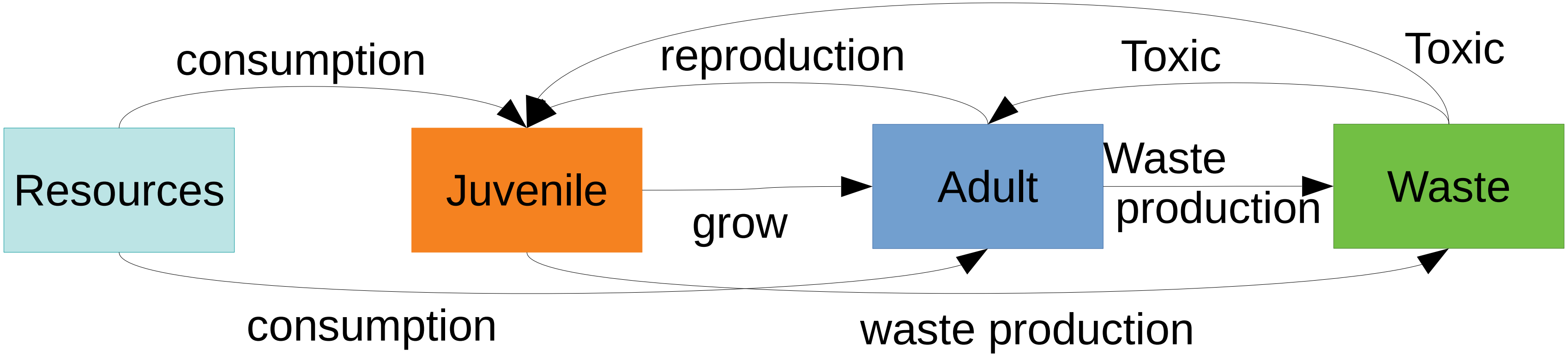


Waste dynamics is much slower than resource dynamics

Structured population: Time-lag between generation



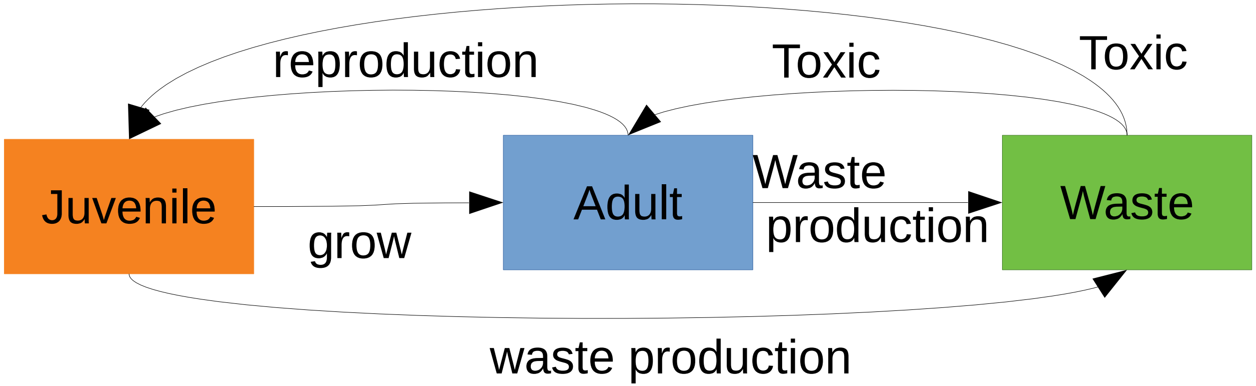
$$\frac{dJ}{dt} = A\rho(c_A, R) - d_J J - \omega_J(W)J - Jg(c_J, R)$$

$$\frac{dA}{dt} = Jg(c_J, R) - d_A A - \omega_A(W)A$$

$$\frac{dR}{dt} = I_R - \delta_R R - m(c_J)JR - n(c_A)AR$$

$$\frac{dW}{dt} = I_W - \delta_W W + p_J(c_J)J + p_A A$$

Simplified structured population



$$\frac{dJ}{dt} = A\rho(c_A, R) - d_J J - \omega_J(W)J - Jg(c_J, R)$$

$$\frac{dA}{dt} = Jg(c_J, R) - d_A A - \omega_A(W)A$$

$$\frac{dW}{dt} = I_W - \delta_W W + p_J(c_J)J + p_A A$$

$$\rho(c_A, R) = c_A R$$

$$g(c_J, R) = c_J R$$

$$\omega_J(W) = v_J W$$

$$\omega_A(W) = v_A W$$

$$p_J(c_J) = h_J c_J$$

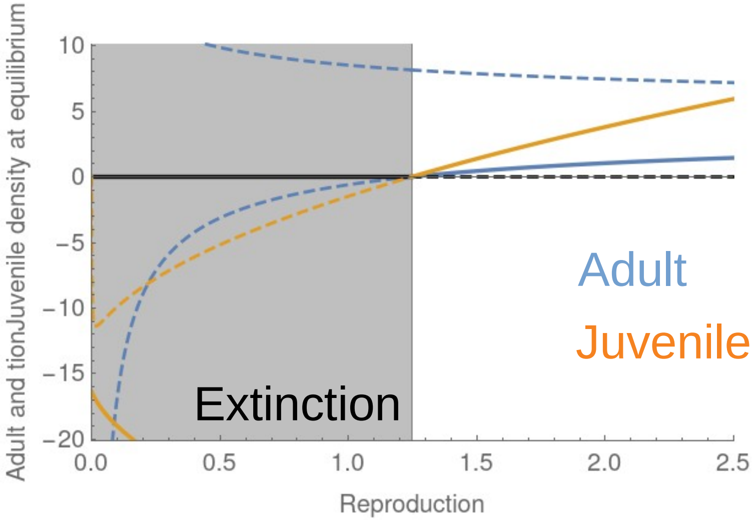
* Higher growth rate produce higher waste density

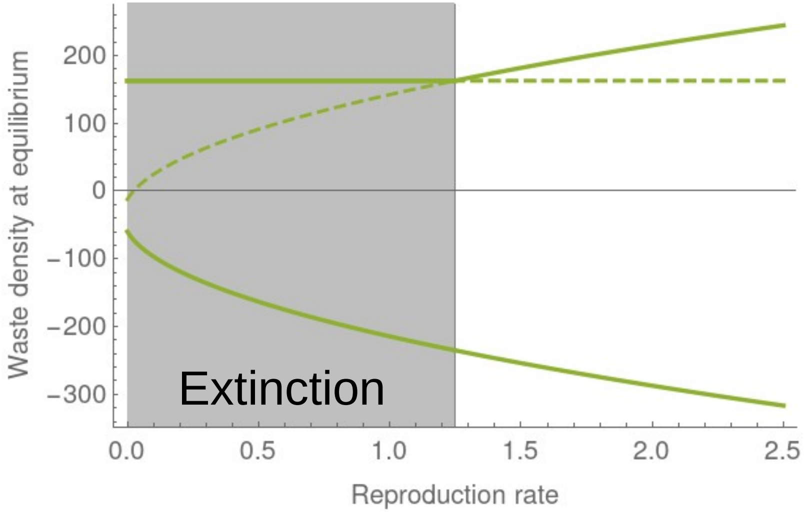
Ecological equilibrium

$$\mathcal{B} = \frac{c_A R c_J R}{\left(\frac{I_W}{\delta_W} v_A + d_A\right)\left(\frac{I_W}{\delta_W} v_J + d_J + c_J R\right)} > 1$$

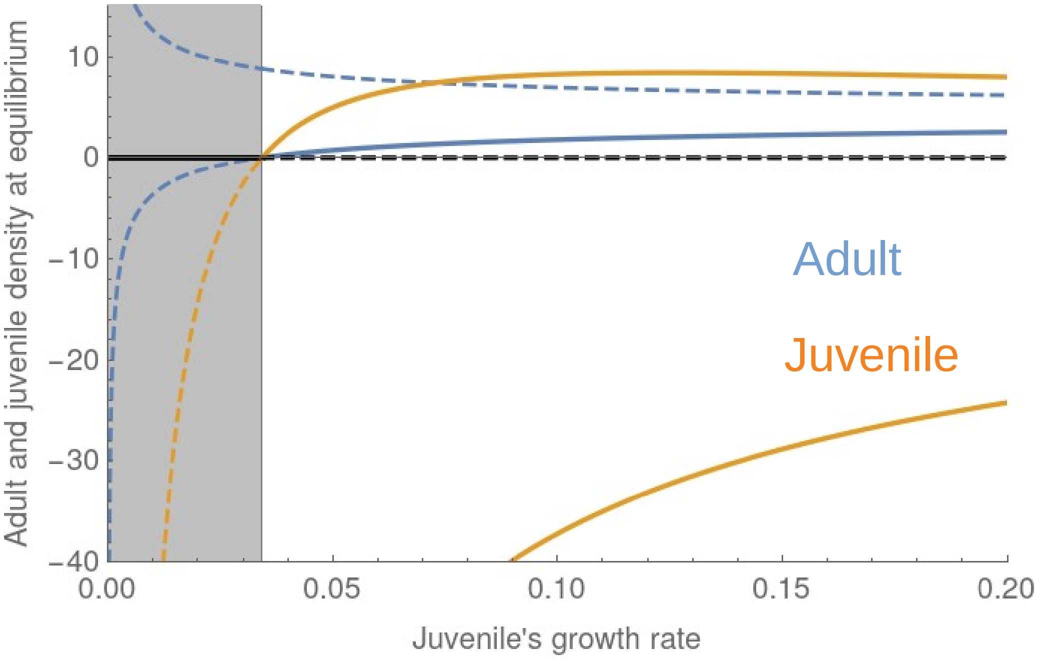
Ecological equilibrium

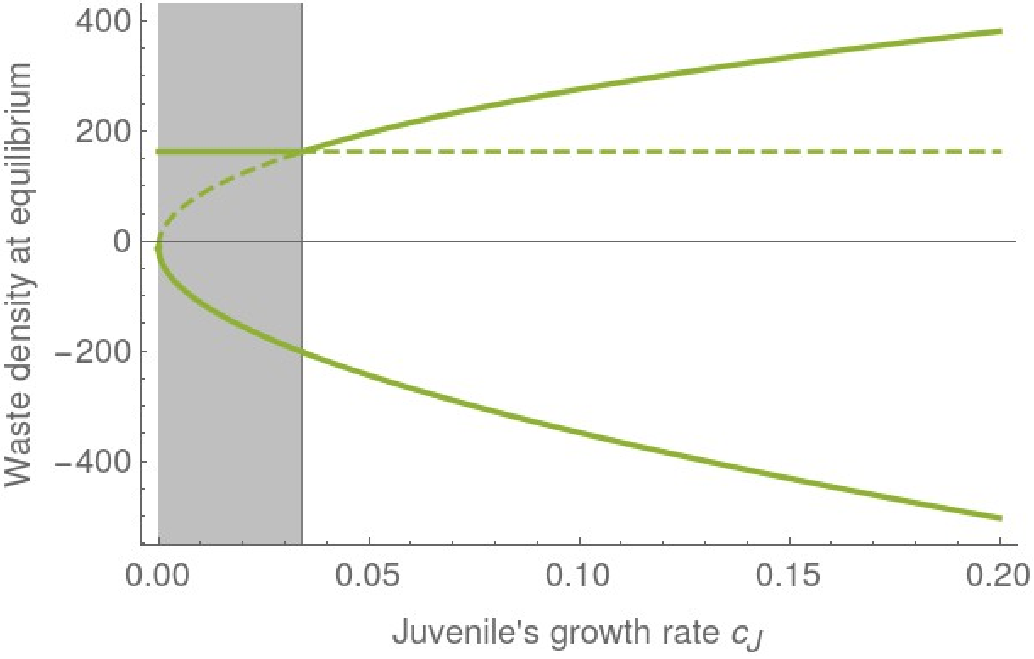
$$\mathcal{B} = \frac{c_A R c_J R}{\left(\frac{I_W}{\delta_W} v_A + d_A\right)\left(\frac{I_W}{\delta_W} v_J + d_J + c_J R\right)} > 1$$





Ecological equilibrium





Invasion fitness

$$\mathcal{B}_{mut} = \frac{c_{Jmut} R c_A R}{(c_{Jmut} R + d_J + v_J W^*(c_{Jres}))(d_A + v_A W^*(c_{Jres}))}$$

$$\mathcal{B} = \frac{c_A R c_J R}{\left(\frac{I_W}{\delta_W} v_A + d_A\right)\left(\frac{I_W}{\delta_W} v_J + d_J + c_J R\right)}$$

Invasion fitness

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$$\mathcal{B} = \frac{c_A R c_J R}{\left(\frac{I_W}{\delta_W} v_A + d_A\right)\left(\frac{I_W}{\delta_W} v_J + d_J + c_J R\right)}$$

Condition that select for smaller growth rate:

$$c_A R < d_A + v_A W^*(c_J))$$

If the density of the waste in the environment is sufficiently large, smaller growth rate can be selected for?

Invasion fitness

$$\mathcal{B}_{mut} = \frac{c_{Jmut} R c_A R}{(c_{Jmut} R + d_J + v_J W^*(c_{Jres}))(d_A + v_A W^*(c_{Jres}))}$$

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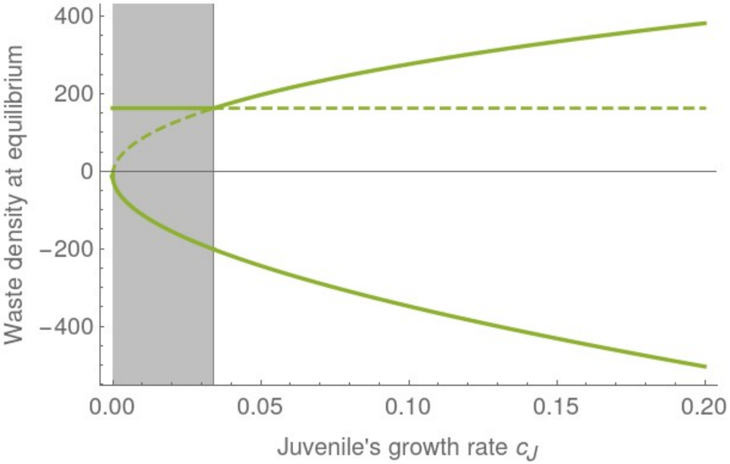


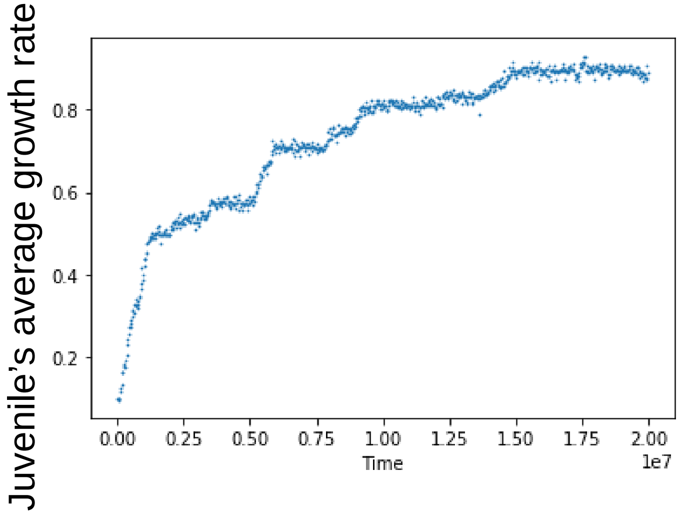
Condition that select for smaller growth rate:

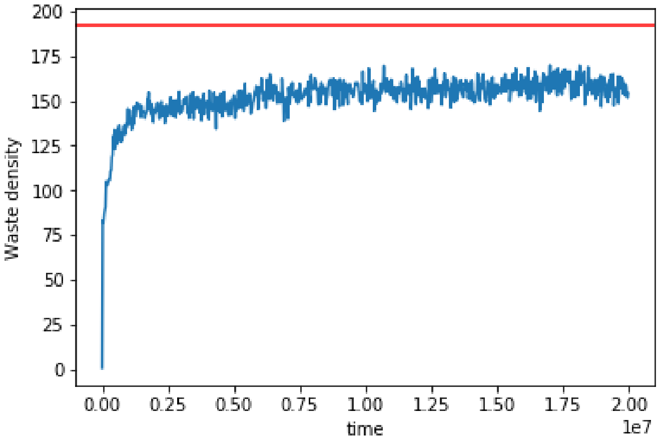
$$c_A R < d_A + v_A W^*(c_J))$$

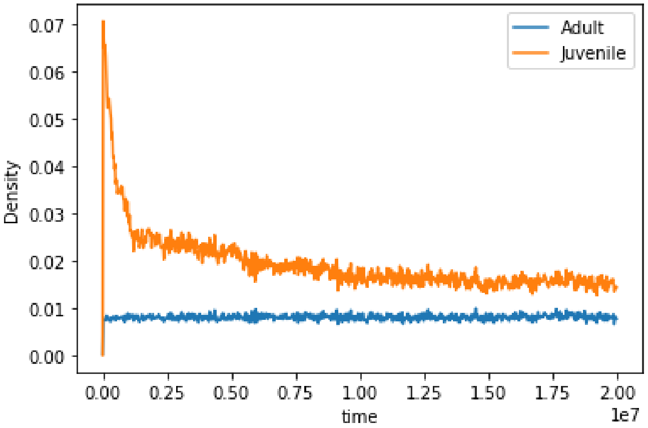
If the density of the waste in the environment is sufficiently large, smaller growth rate can be selected for? Not under the adaptive dynamic framework

$$\lim_{c_J \to +\infty} W^*(c_J) = \frac{c_A R - d_A}{v_A}$$

Simulation with moderate mutation rate

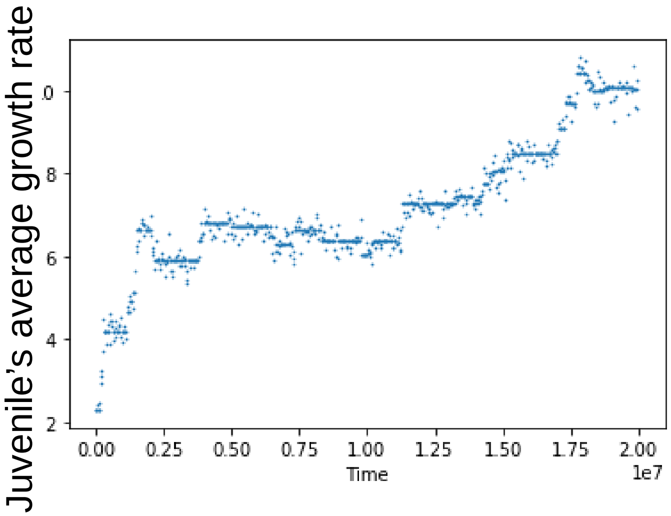


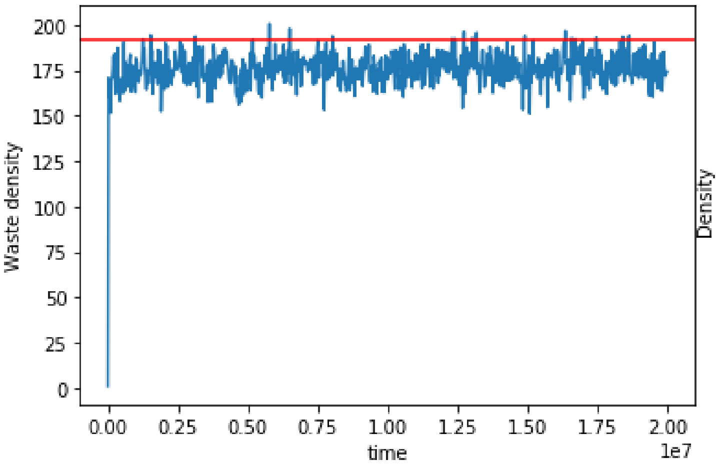


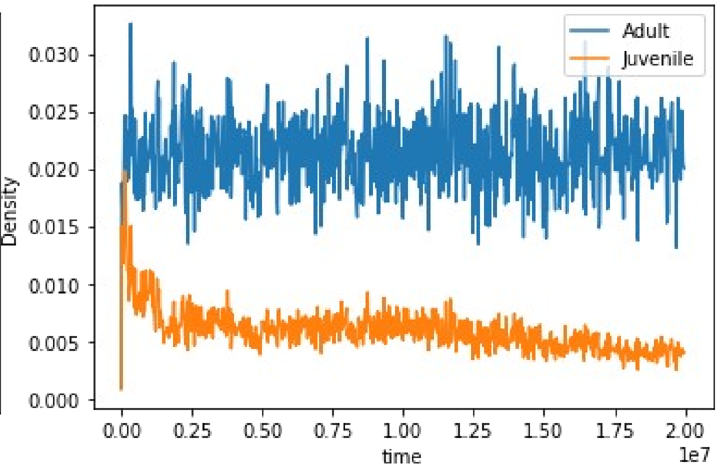


Starting population has small growth rate (0.1) → small initial waste production

Simulation with moderate mutation rate



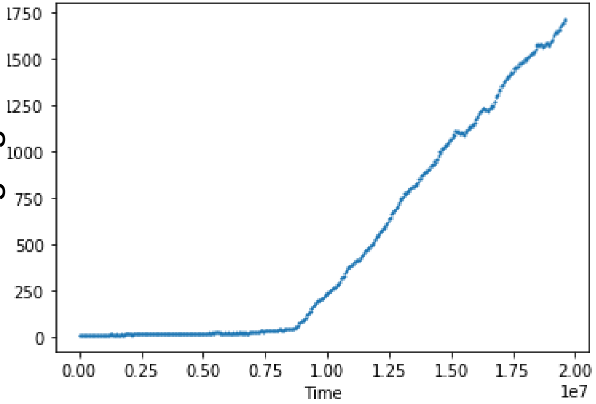


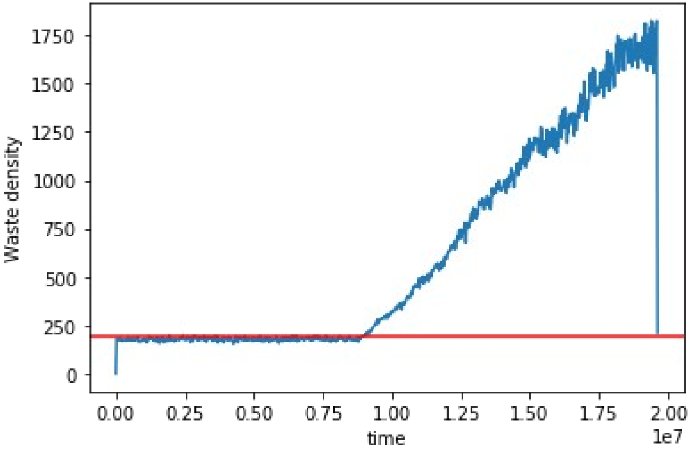


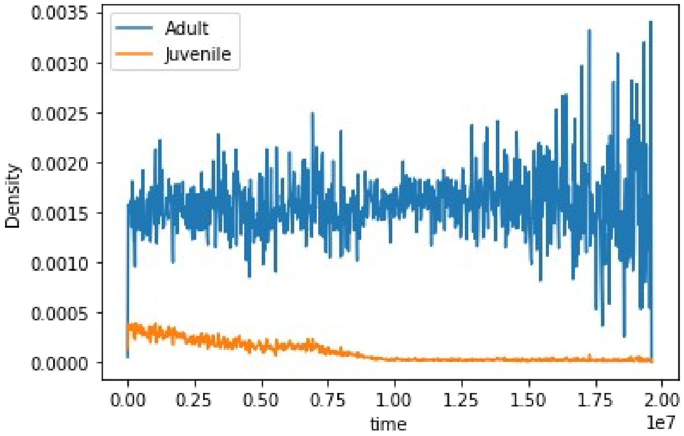
Starting population has larger growth rate (2.3) → larger initial waste production

Simulation with moderate mutation rate

Juvenile's average growth rate







Starting population has very high growth rate (8.1) → larger initial waste production

Trade-off between growth and reproduction

$$\left.\begin{array}{l} \dfrac{d\rho(c_J)}{dc_J} < 0 \\[2ex] \dfrac{dg(c_J)}{dc_J} > 0 \end{array}\right\}$$

Higher growth rate at juvenile results in lower reproduction in adult

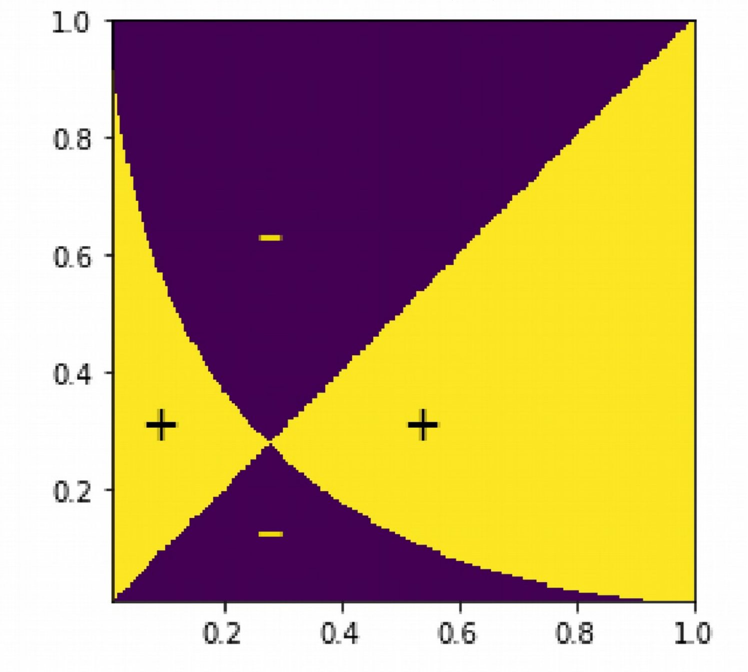
$$\frac{dp_J(c_J)}{dc_J} > 0$$

Higher growth rate results in higher waste production

Evolutionary singular strategy

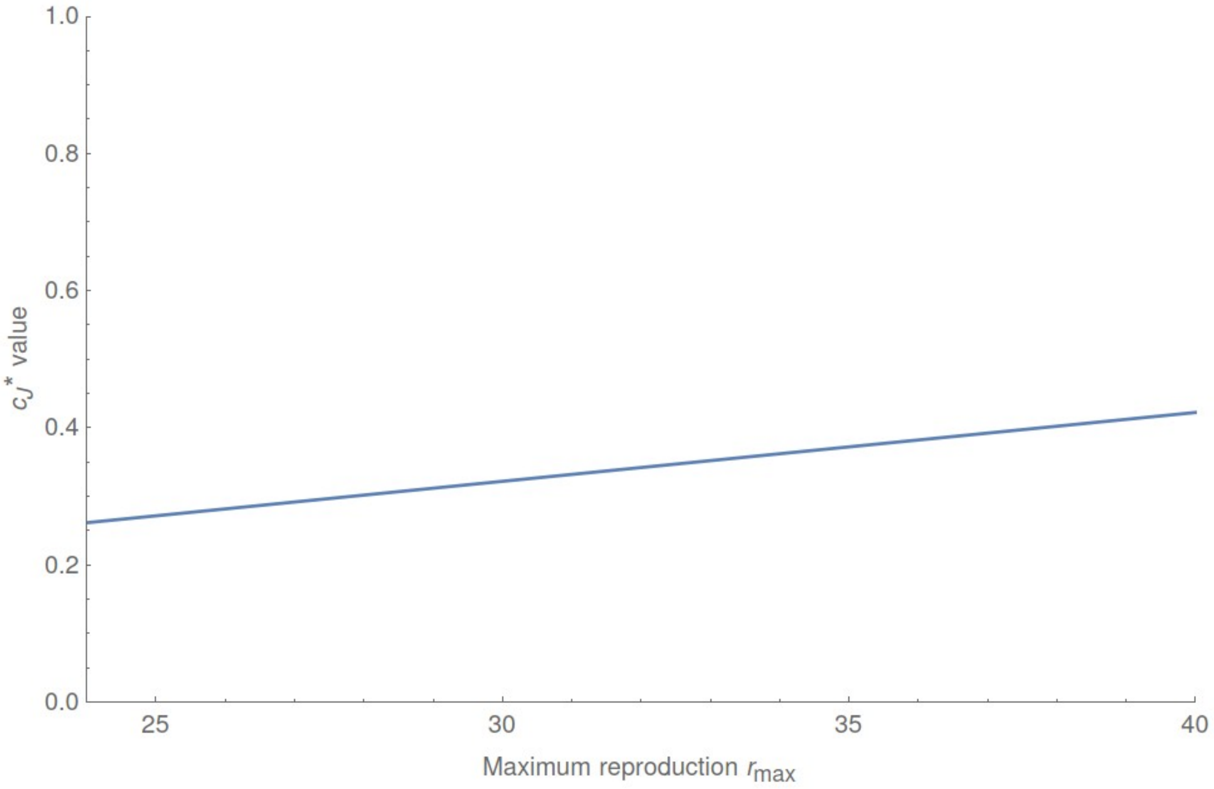
$$\left(d_A + v_A W^*(c_J) = R\left(\rho(c_{Jm}) + c_{Jm} \frac{d\rho(c_{Jm})}{dc_{Jm}} \right) \right) \Big|_{c_{Jm}=c_J=c_J^*}$$

PIP for linear function: $\rho(c_J) = r_{max} - a c_J$



If a singular strategy is evolutionary stable, it is also convergence stable

Effect of different parameters on the ESS



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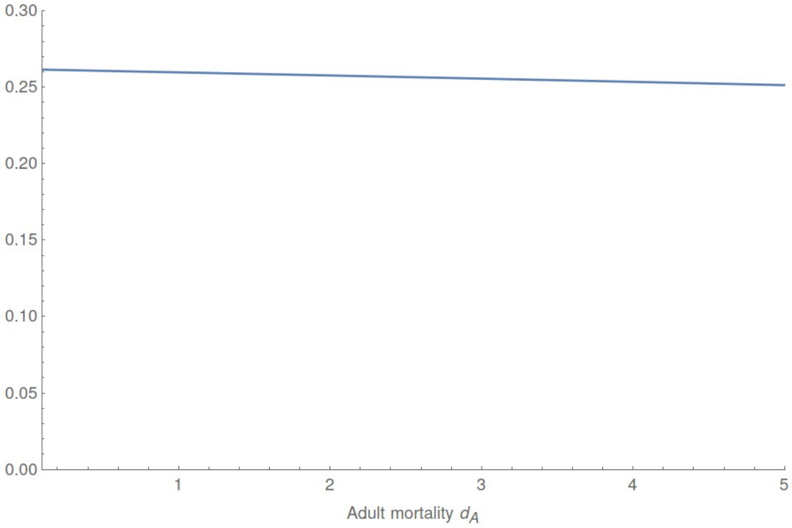

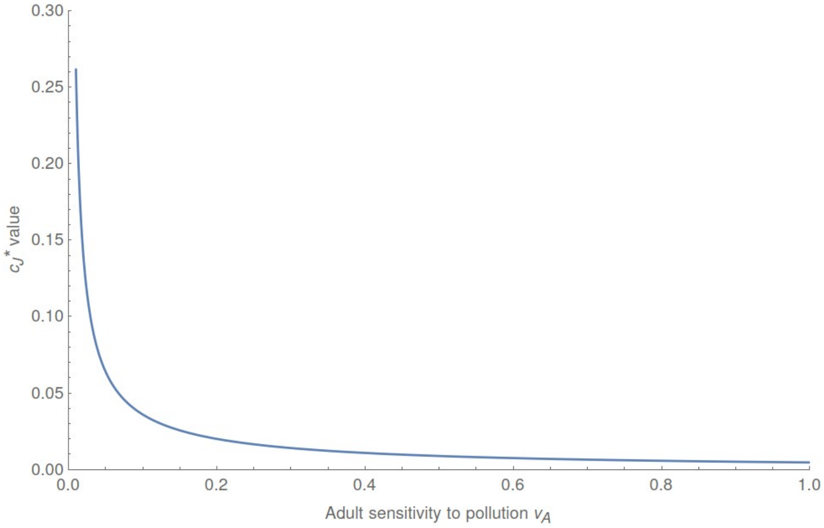

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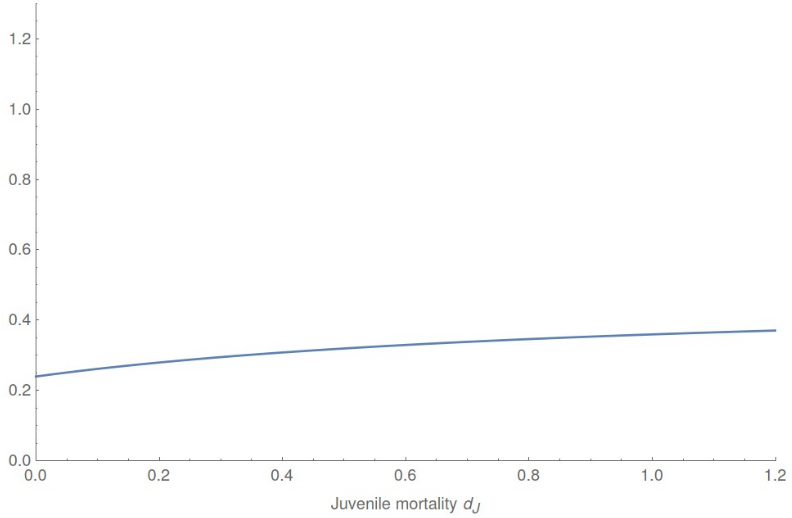
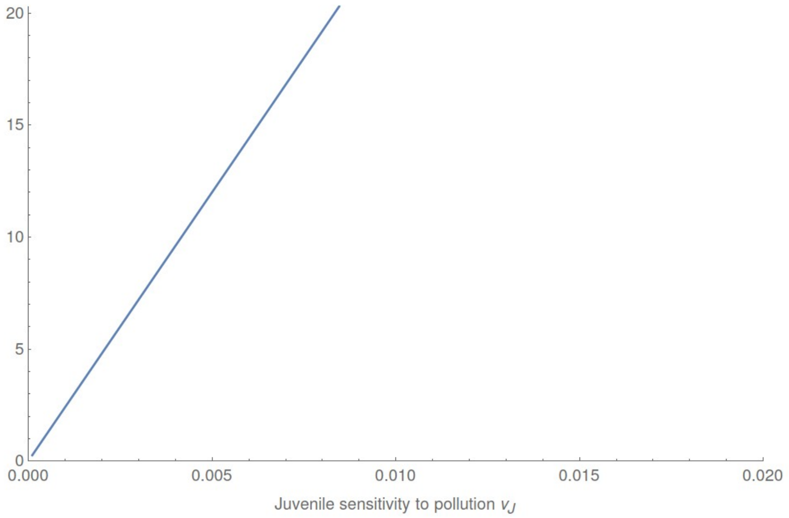




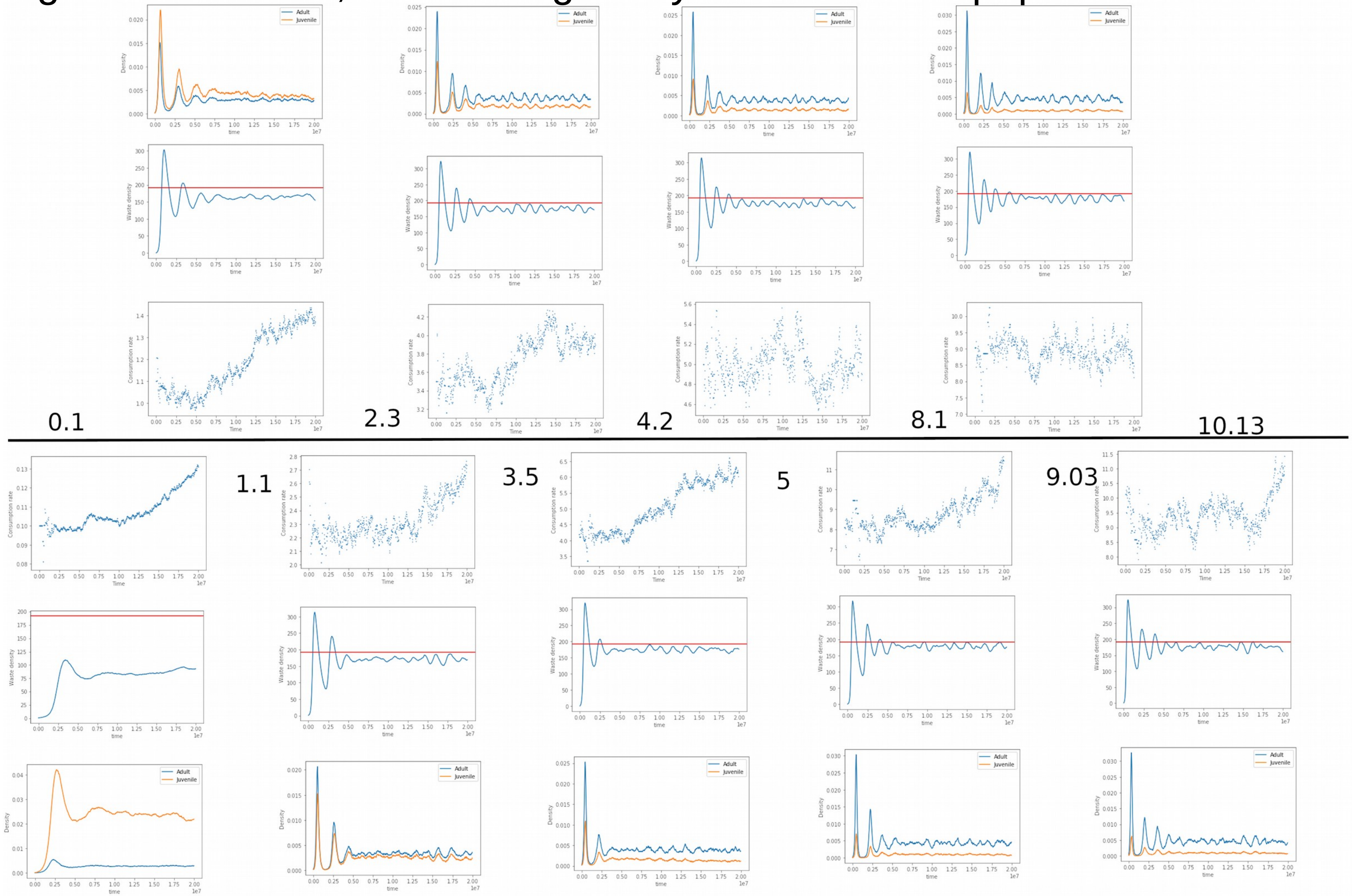
Conclusions

- In a homogeneous unstructured consumer population, the lag between the dynamics of the niche and the dynamics of the niche constructor cannot select for lower waste production
- In a structured population with juvenile and adult consumers, without any direct trade-off, selection for lower waste production cannot be selected for if the evolution of the consumer is slow
- If the consumer can evolve fast, lower waste production can be maintained for some short periods of time.
- Only a direct cost on waste production can select for lower waste production

On going analysis

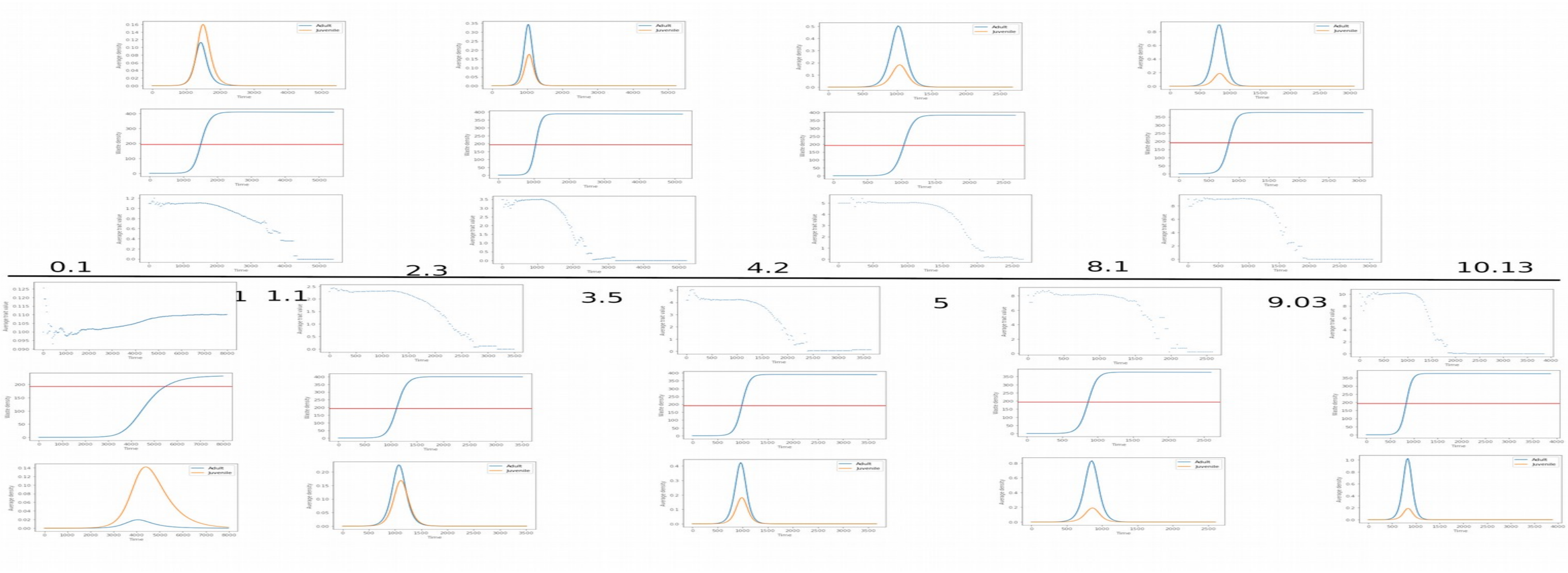
- Simulations for different speed of the dynamics of the niche.
- Incorporating resource dynamics.

High mutation rate, slow ecological dynamics of both population and waste



Starting value of the growth rate

High mutation rate, very slow waste dynamic



Starting value of the growth rate

Acknowledgment

Supervisors:

- Manon Costa
- Florence Débarre
- Nicolas Loeuille

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ChairMMB

And thank you for your attention!