Evolutionary tipping-points in a changing climate

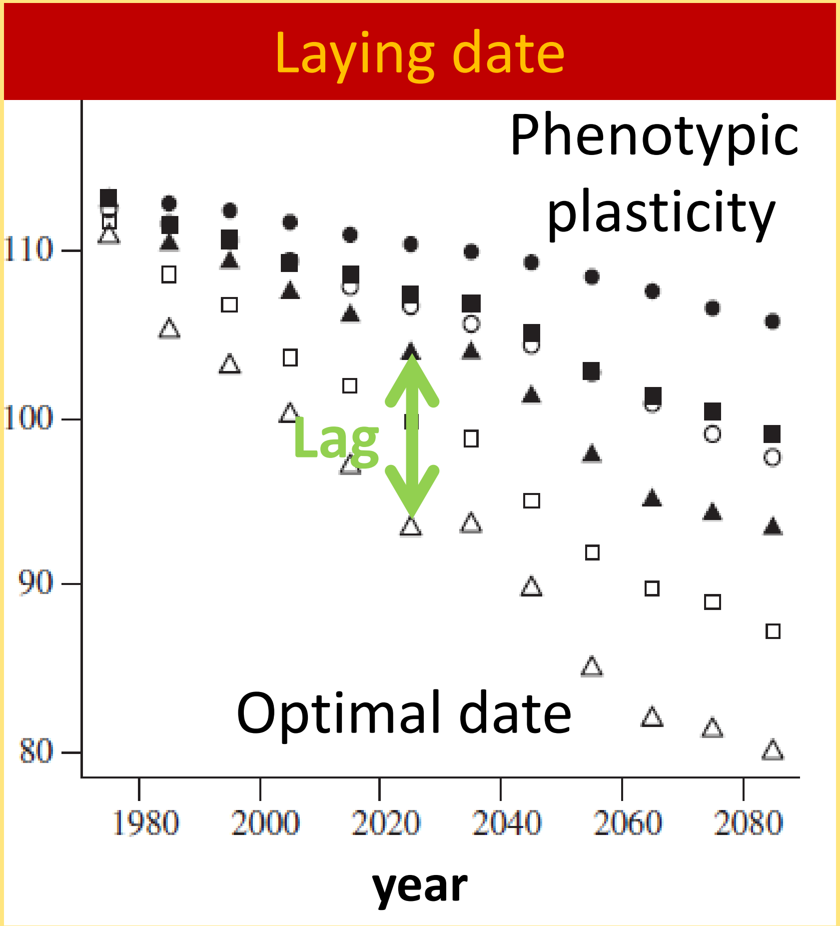
Ophélie Ronce

Climate warming will favor different phenotypes

Gienapp *et al.* 2013

Parus major

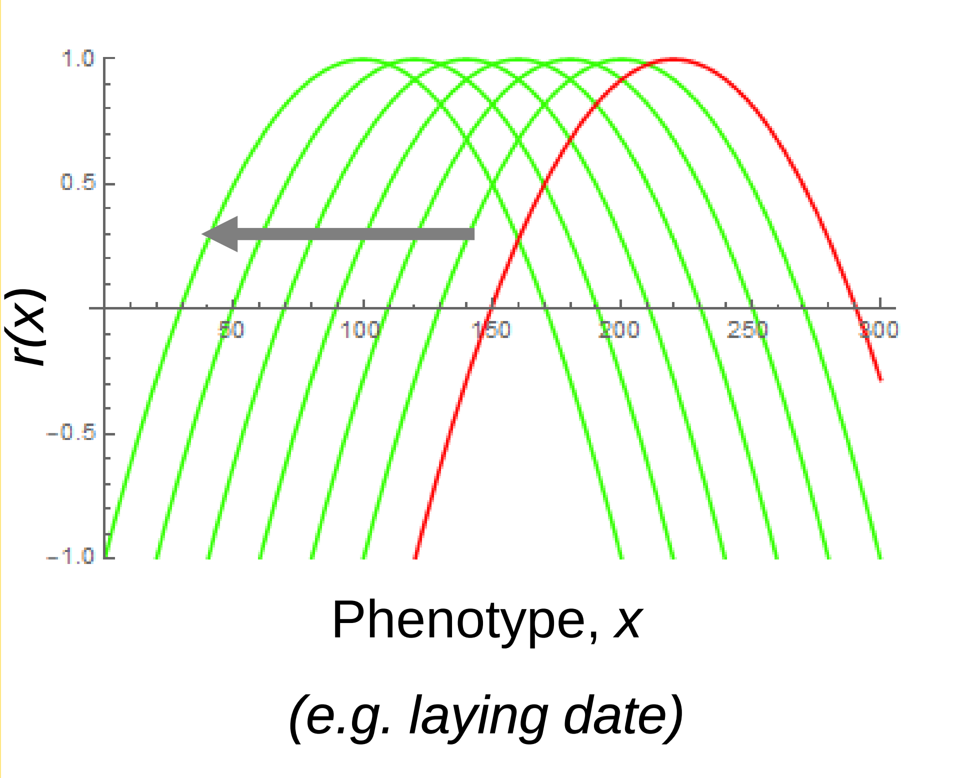
Selection for genotypes with earlier laying date



Modelling adaptation in a changing environment

Lynch *et al.* 1991

Malthusian fitness *r* of individual with phenotype x



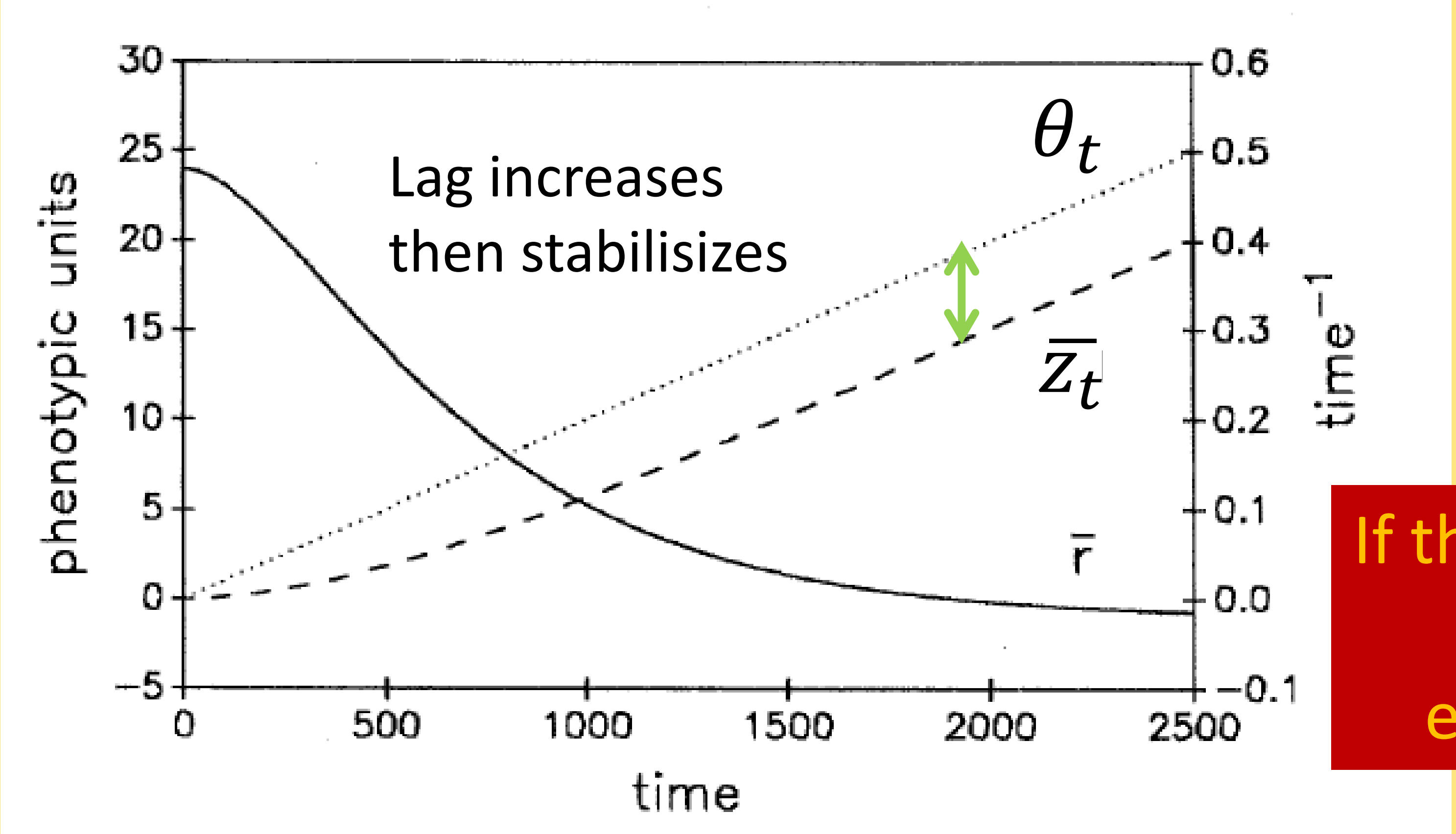
Quadratic selection

Optimal phenotype changes linearily through time with speed *c*

Modelling adaptation in a changing environment

Lynch *et al.* 1991

Mean phenotype evolves to track the shifting optimum with a constant lag



If the lag is too large: extinction

Modelling adaptation in a changing environment

Gaussian distribution of phenotypic values

$$\frac{d\bar{z}_t}{dt} = G\beta_t$$

with selection gradient

$$\beta_t = \frac{d\bar{r}_t}{d\bar{z}_t}$$

When the phenotype evolves as fast as the optimum moves

$$\lim_{t \to +\infty} \beta \equiv \hat{\beta} = \frac{c}{G}$$

Modelling adaptation in a changing environment

Quadratic selection

$$\bar{r}_t = r_m - \frac{s}{2}(\bar{z}_t - \theta_t)^2$$

Directional selection gradient

$$\beta_t = \frac{d\bar{r}_t}{d\bar{z}_t} = s(\theta_t - \bar{z}_t)$$

Linear function of the lag

Modelling adaptation in a changing environment

Lynch *et al.* 1991

Mean phenotype evolves to track the shifting optimum with a constant lag

Lag is larger when

$$\lim_{t \to +\infty} (\theta_t - \bar{z}_t) = \frac{c}{sG}$$

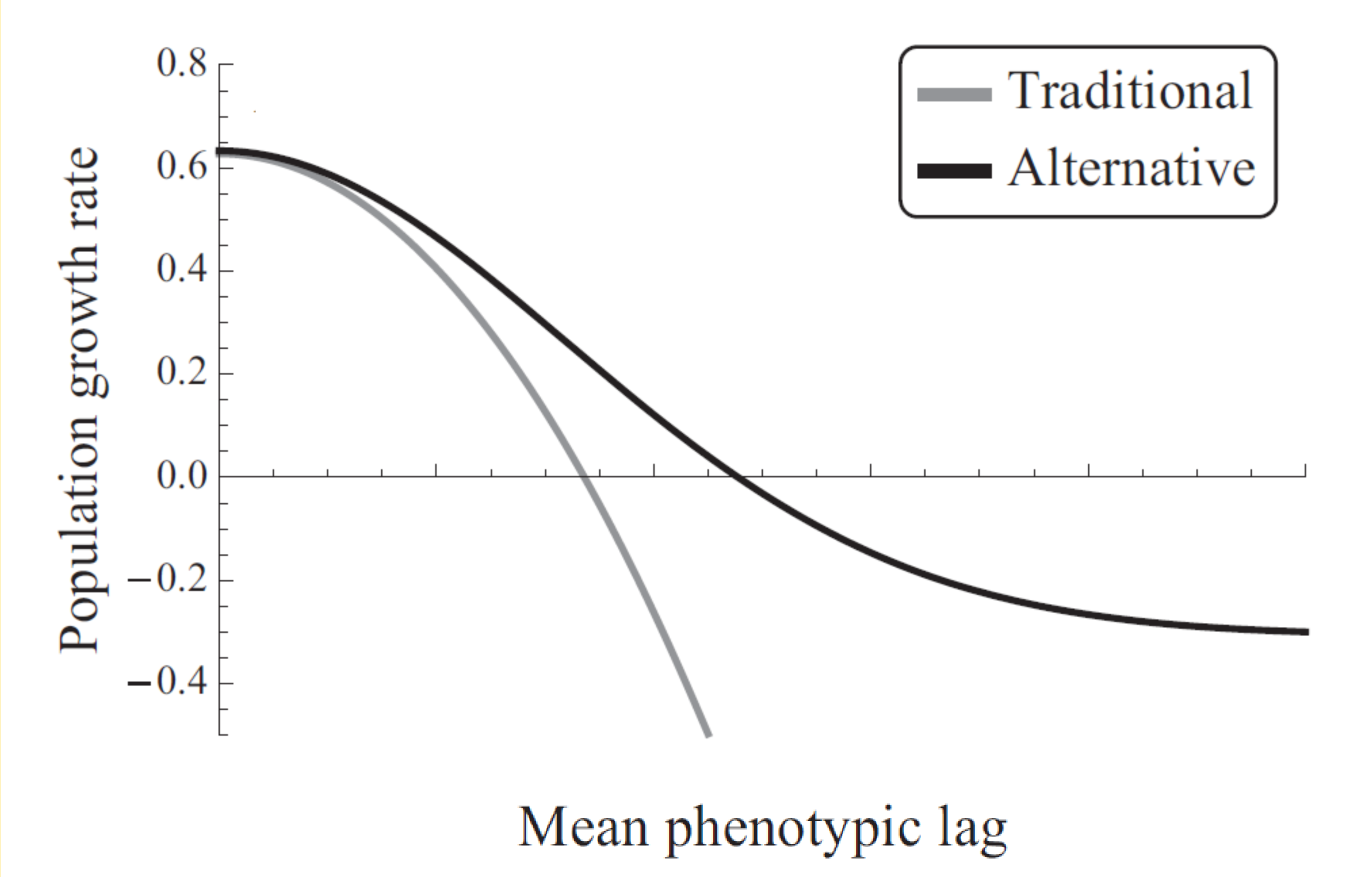
Speed of climate change is greater

Strength of stabilizing selection is weaker

Genetic variance is smaller

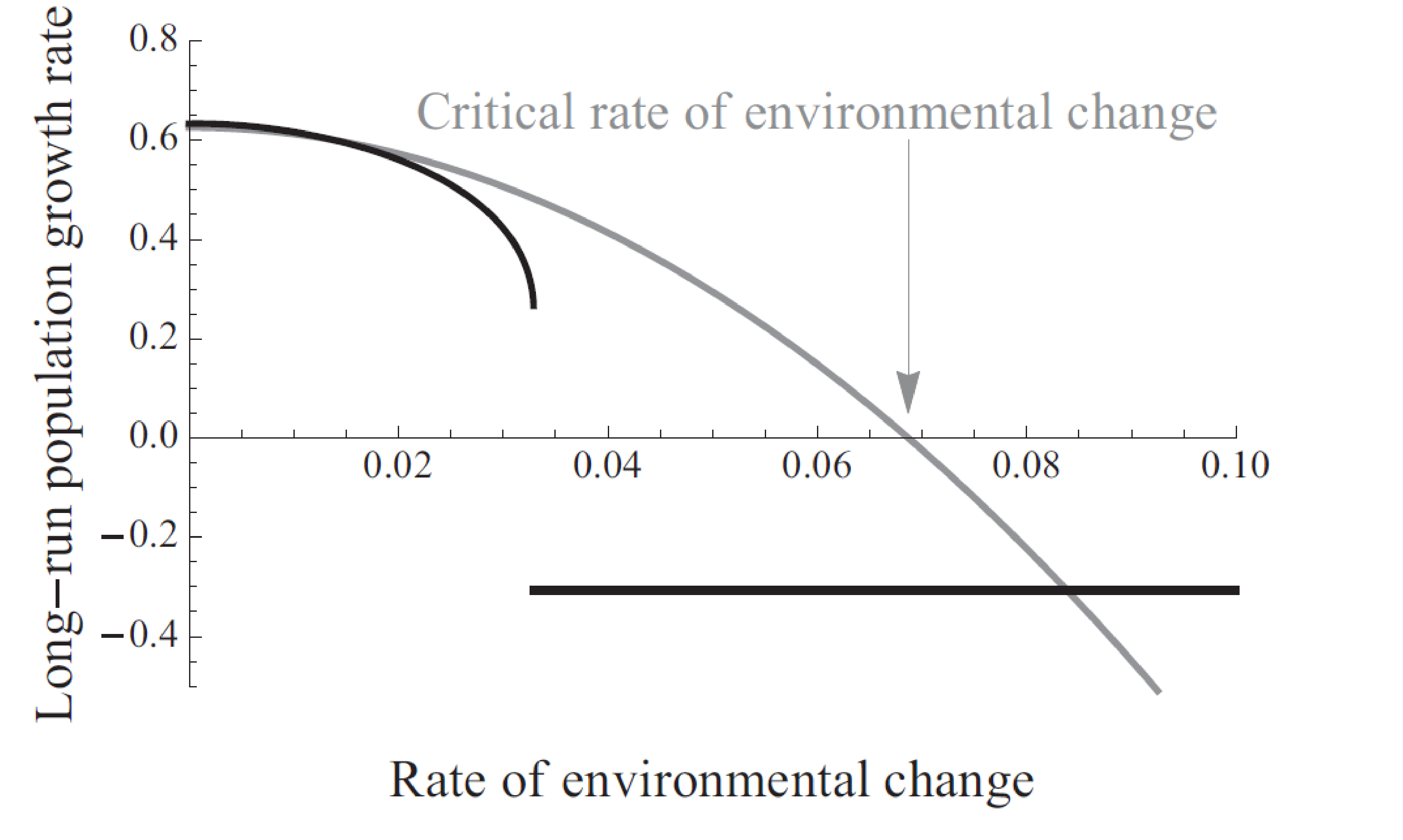
Evolutionary tipping points

Osmond & Klausmeier 2017



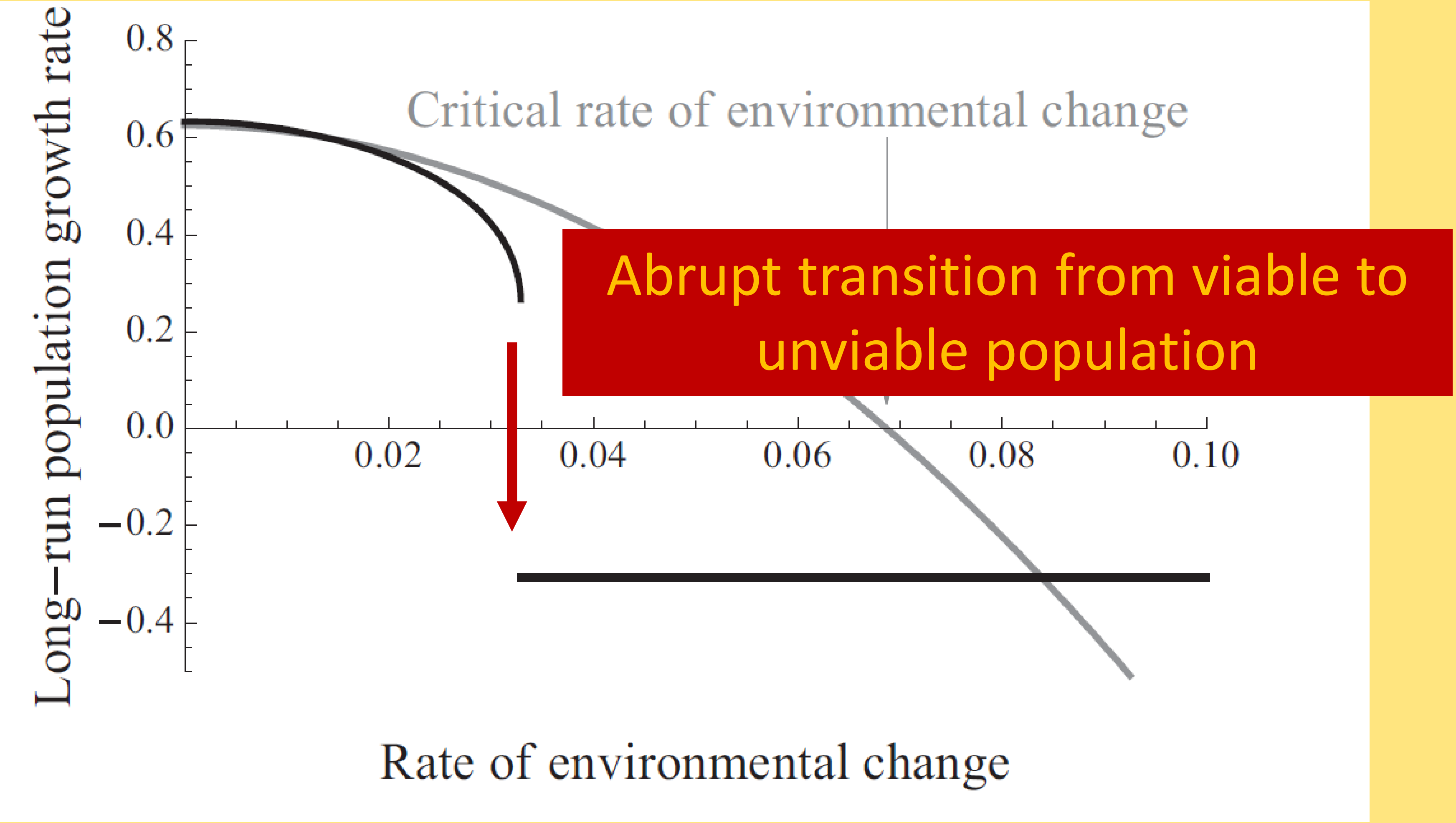
Evolutionary tipping points

Osmond & Klausmeier 2017

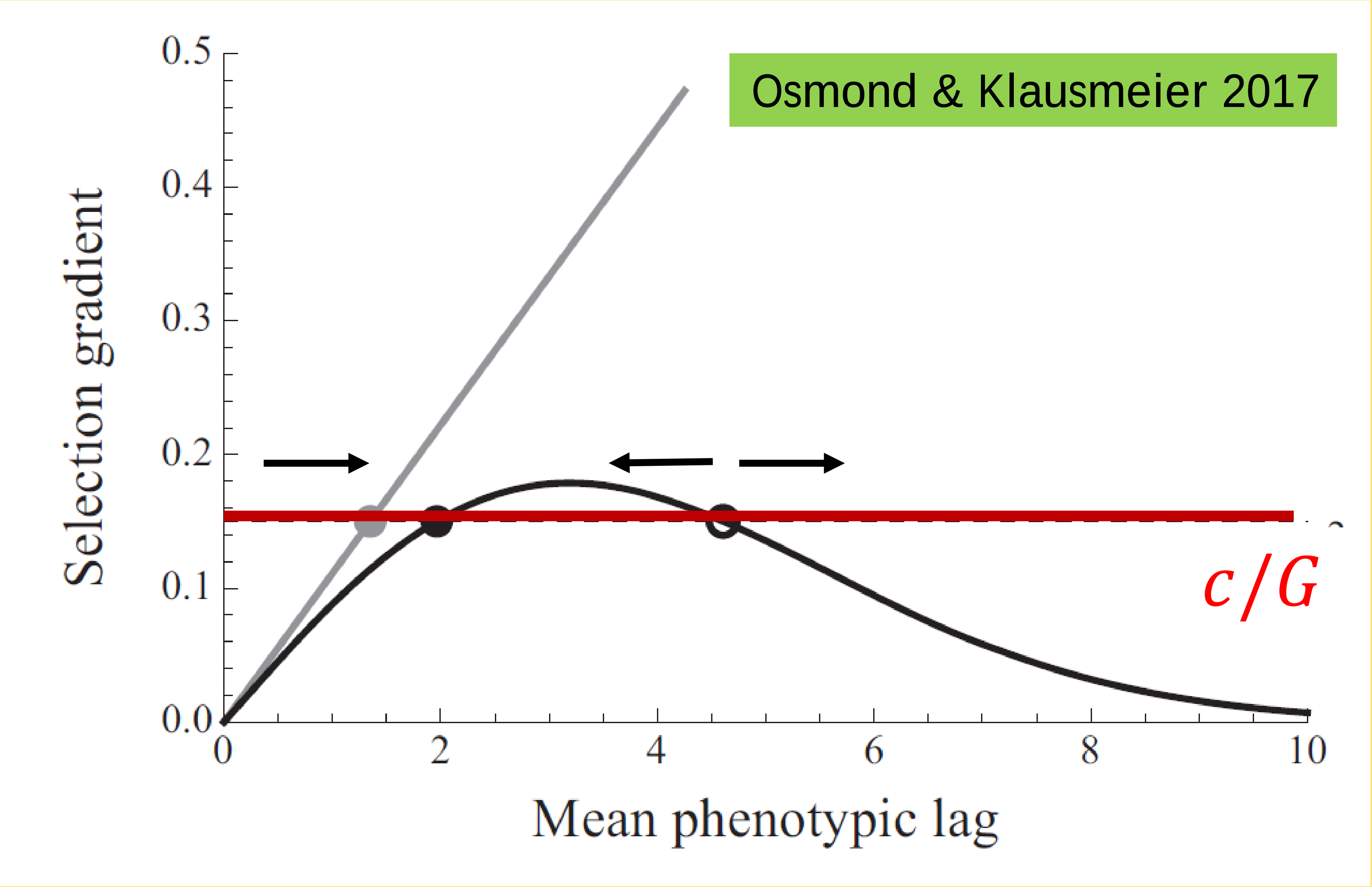


Evolutionary tipping points

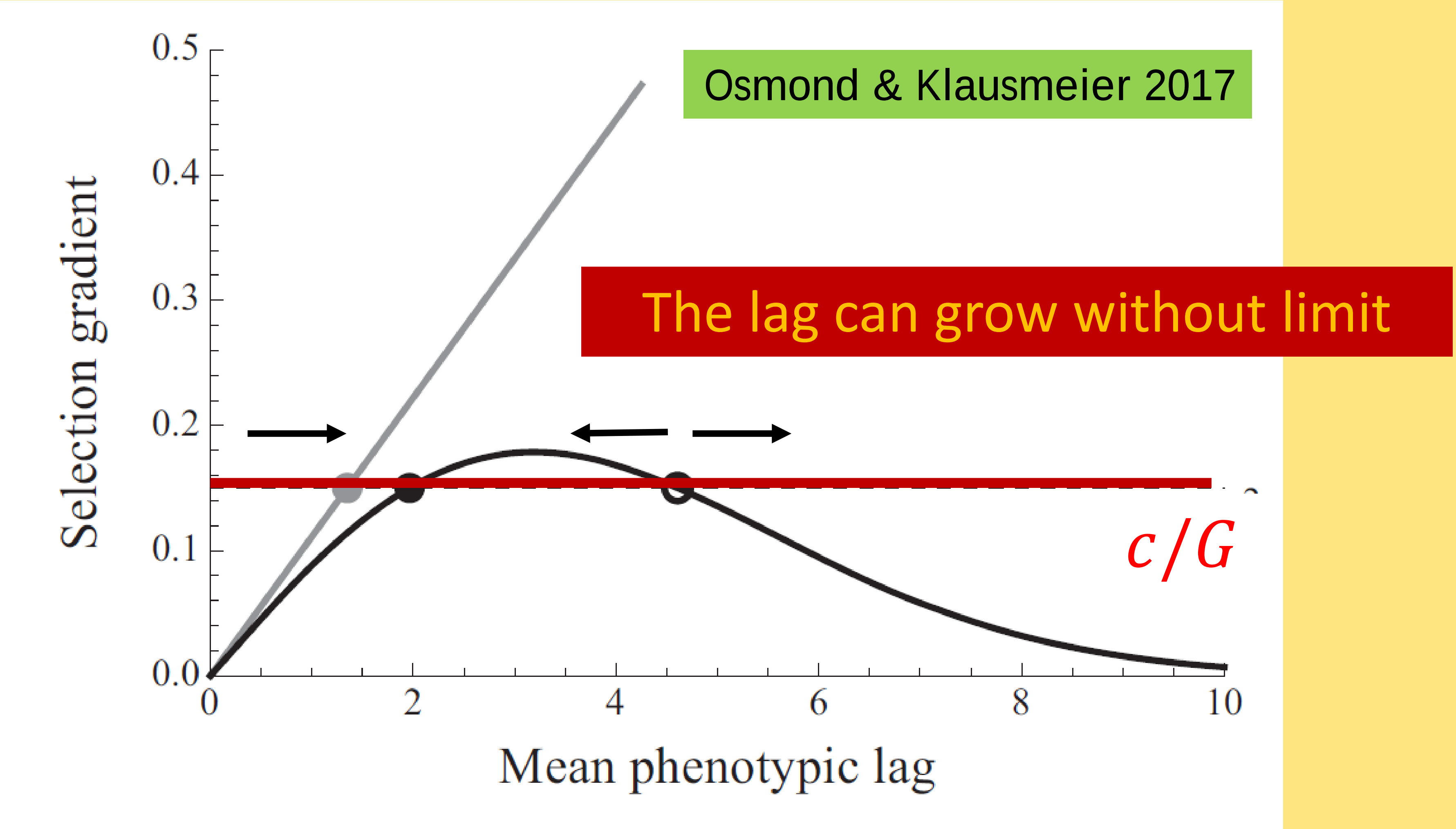
Osmond & Klausmeier 2017



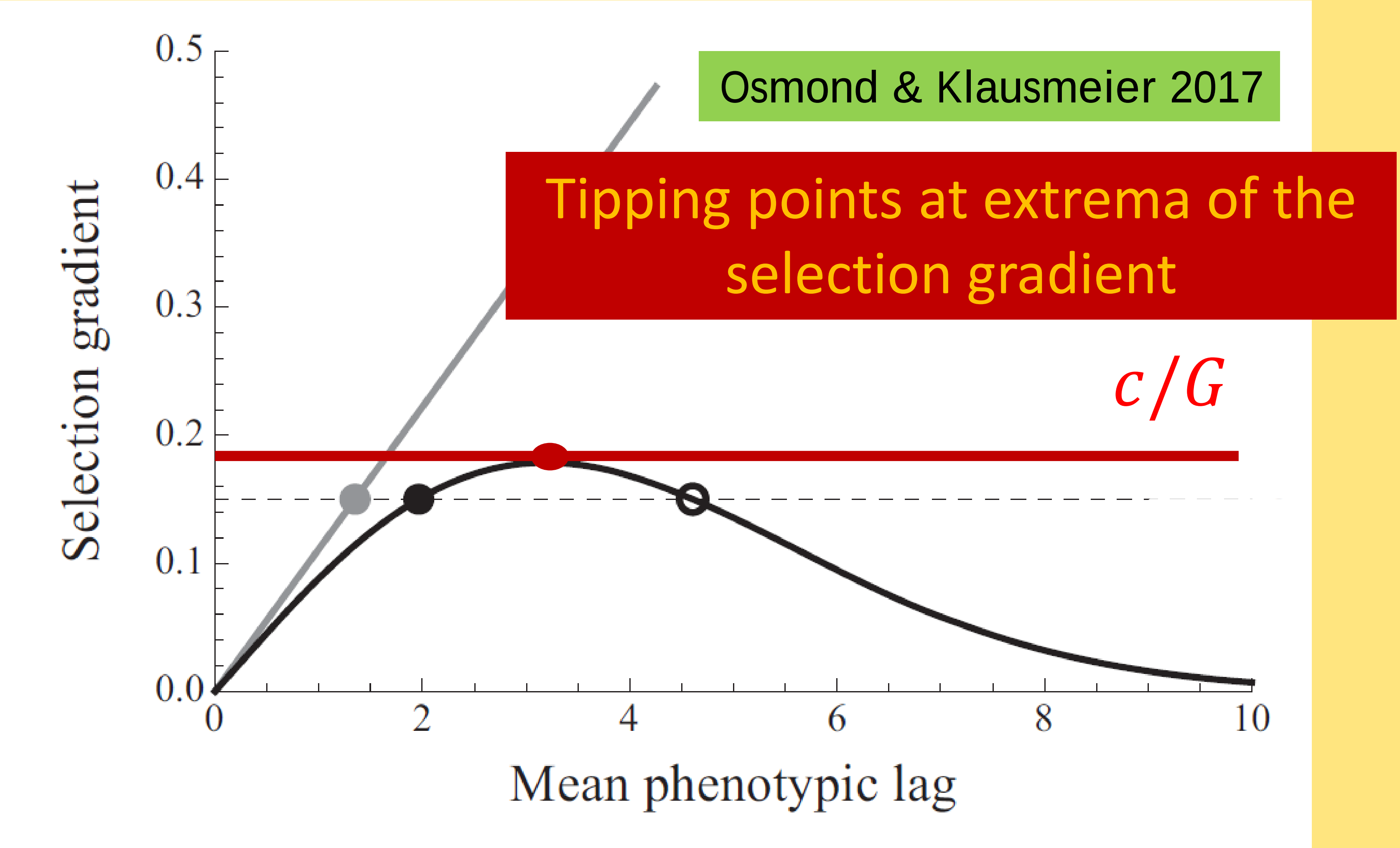
Evolutionary tipping points



Evolutionary tipping points



Evolutionary tipping points



Evolutionary tipping points

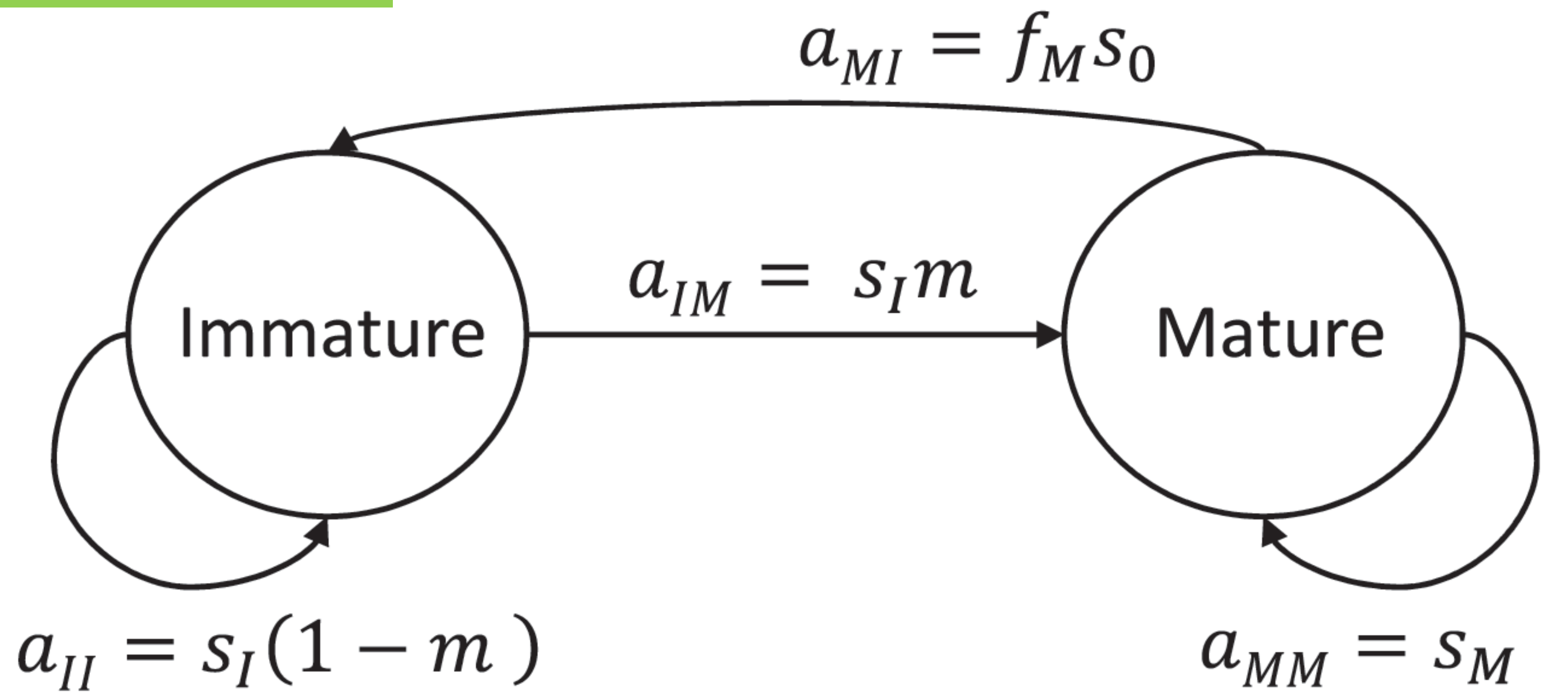
Tipping points emerge when the fitness landscape has inflection points

Is it common?

Sally Otto

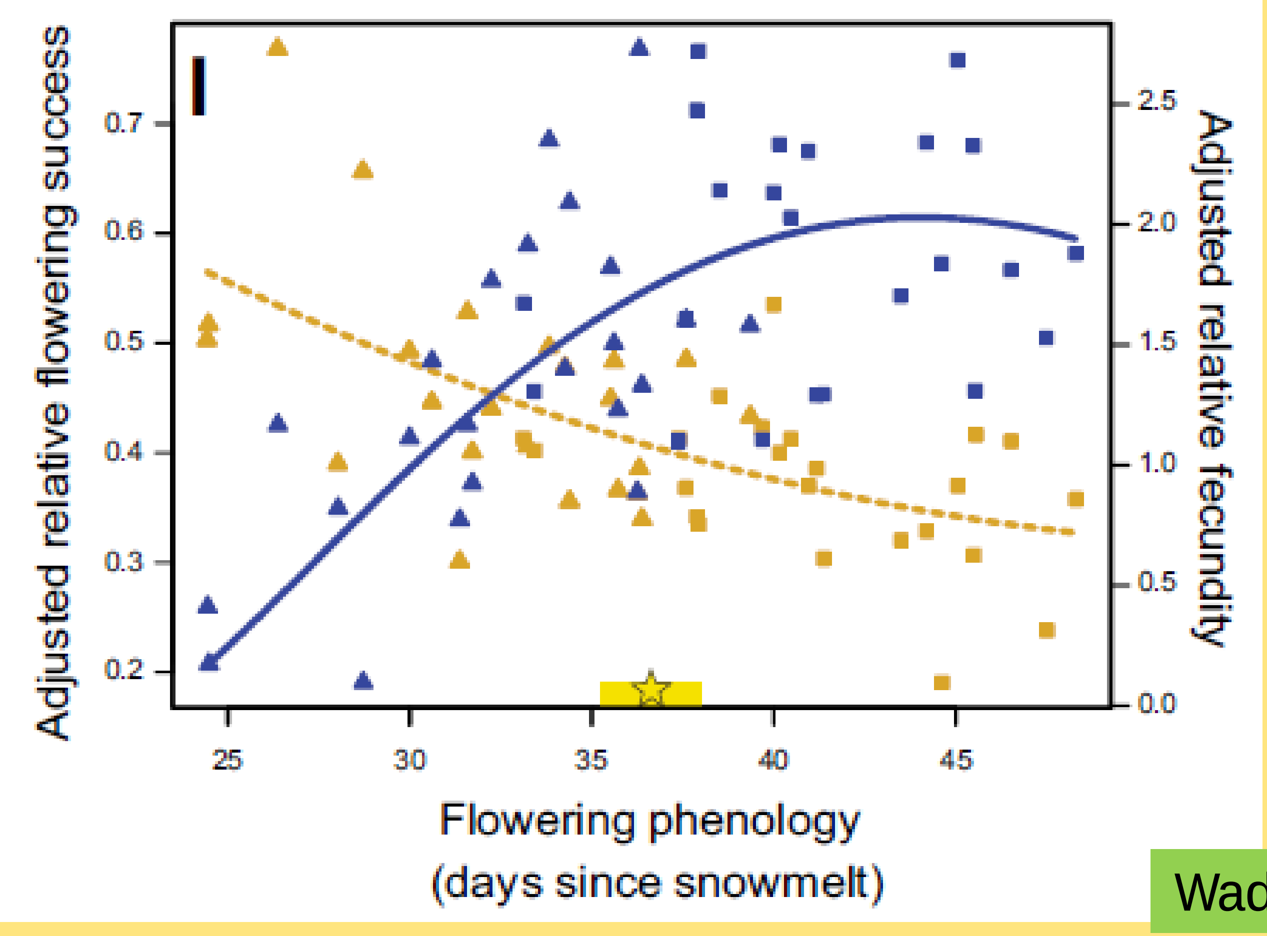
A simple stage-structured model

Cotto et al. 2019



The evolving trait affects two transitions rates with different optima but **quadratic function**

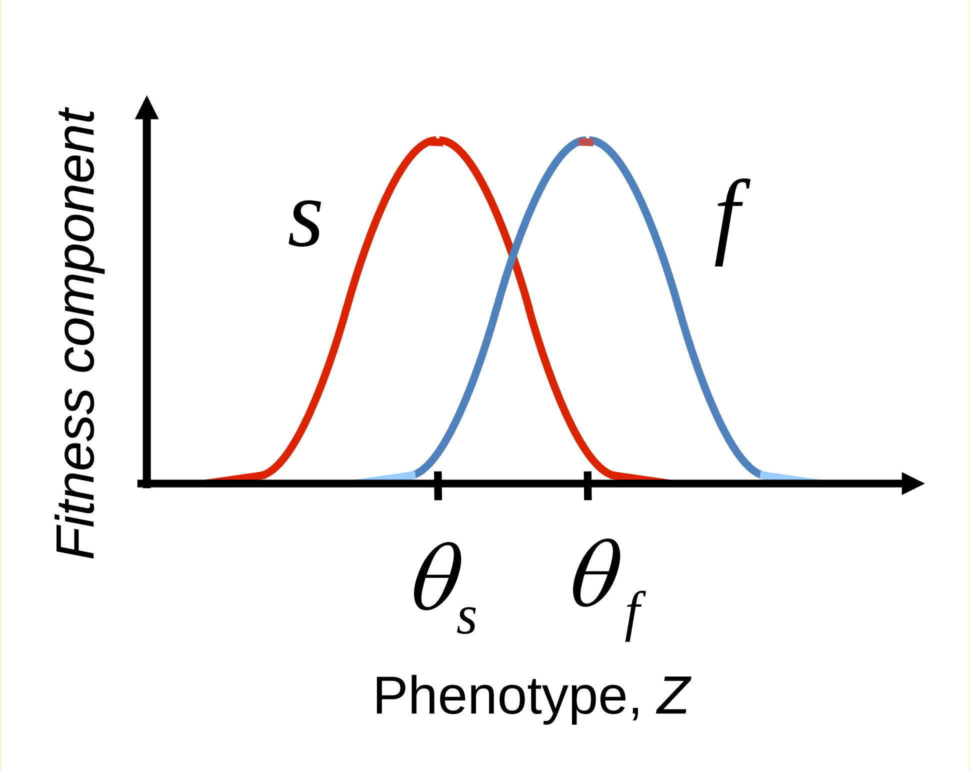
Different optimal trait values maximize different life history components



Boechera stricta

Wadgymar et al. 2017

A simple stage-structured model

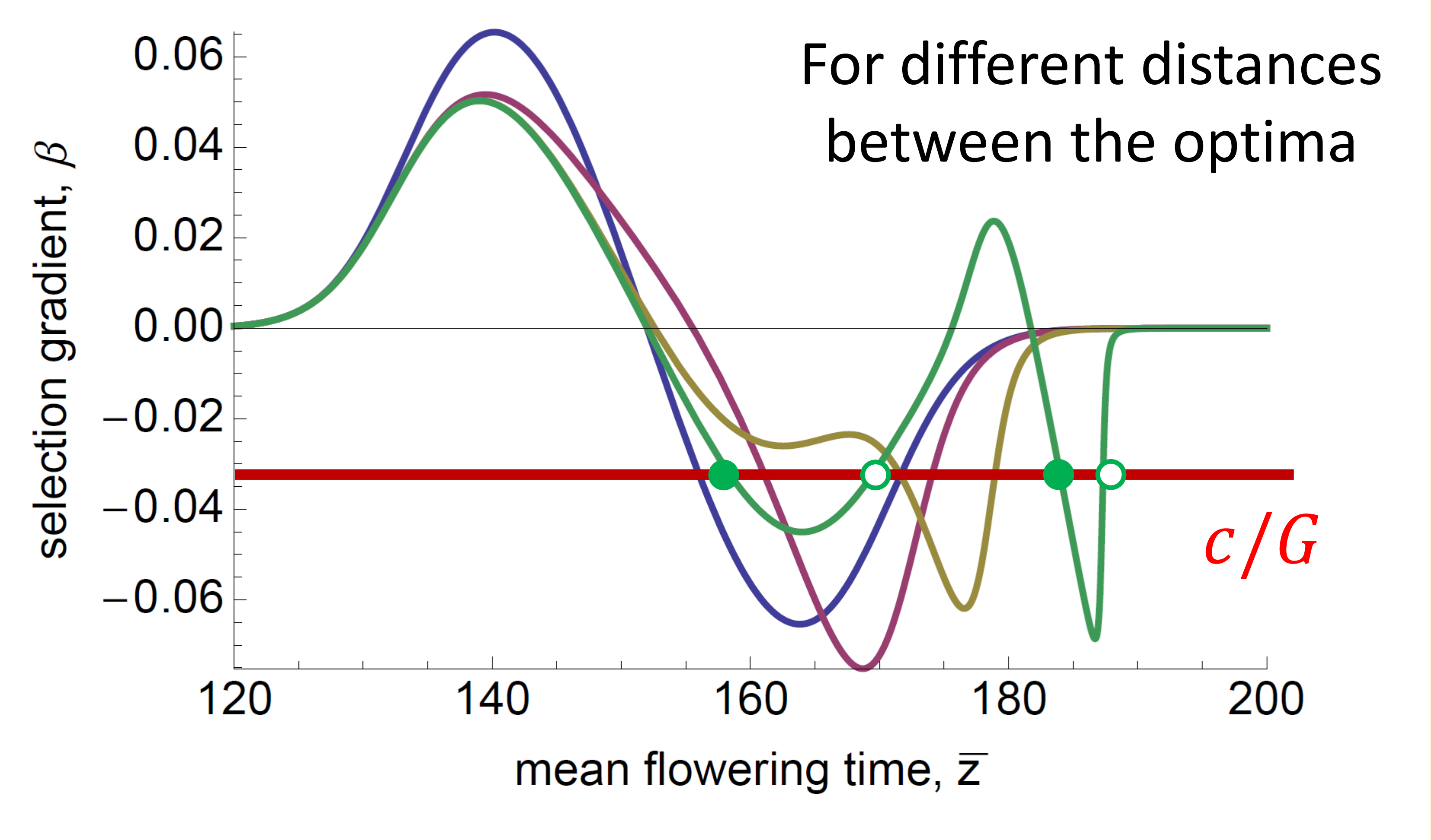


Optimal flowering date maximizing fecundity may differ from the date maximizing adult survival

Both optima change with climate warming

Life history trade-off

A simple stage-structured model



General stage-structured model

- Stage-structured demographic model

$$\mathbf{N}[t+1] = \mathbf{A}[t]\mathbf{N}[t]$$

Stage = age, size, etc

Demographic transitions: vital rates

$$a_{ij} = \left| \begin{array}{l} t_{ij} \\ f_{ij} \end{array} \right.$$

Change in stage for the same individual: survival, growth

Production of new individuals: fecundity

General stage-structured model

Selection gradient

Weak selection

Instantaneous transition rates between stages are quadratic functions

$$\beta = \sum_{i,j} e_{i,j} \mathbf{V}_{\mathbf{i,j}}{}^{-1} (\boldsymbol{\theta}_{i,j} - \bar{\mathbf{z}})$$

How fast transition rate between i and j declines when phenotype not optimal

Optimal phenotypic value maximizing transition between i and j

General stage-structured model

Selection gradient

$$\beta = \sum_{i,j} e_{i,j} \mathbf{V_{i,j}}^{-1} (\boldsymbol{\theta}_{i,j} - \bar{\mathbf{z}})$$

Elasticity of population growth rate to change in transition between i and j

$$e_{ij} = \frac{\partial \ln(\bar{\lambda})}{\partial \ln(a_{ij})}$$

Strength of selection on this transition

General stage-structured model

Selection gradient reaches an extremum when

$$\sum_{i,j} e_{i,j} V_{i,j}^{-1} \left(\frac{\mathrm{d} \log e_{i,j}}{\mathrm{d}\overline{z}} (\theta_{i,j} - \overline{z}) - 1 \right) = 0.$$

True only if elasticities vary with the phenotypic lag

They do in many situations!

Special cases

Selection affects a single transition in the life cycle

Tipping-point when

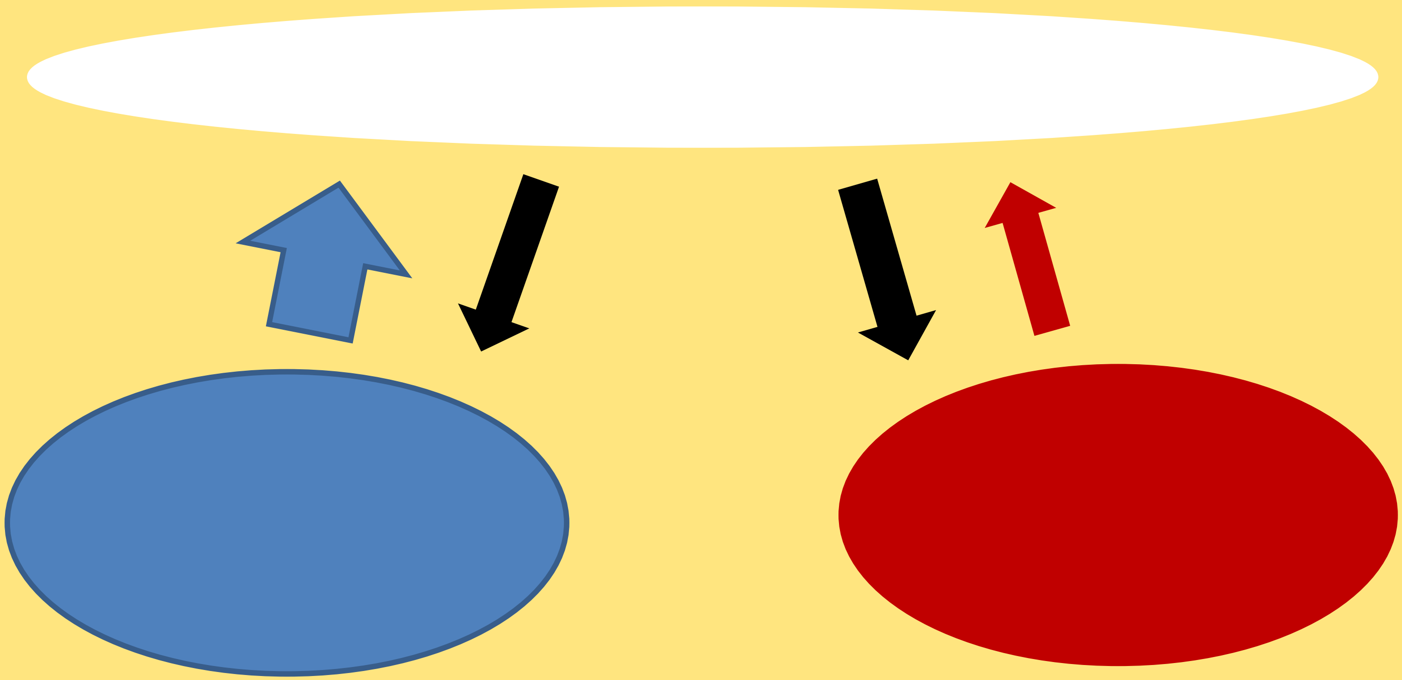
$$\frac{\partial \log e_{i,j}}{\partial \log \overline{a_{i,j}}} = \frac{1}{V_{i,j}^{-1}(\theta_{i,j} - \bar{z})^2}$$

Effect of change in transition on its demographic contribution

Lag load affecting this transition

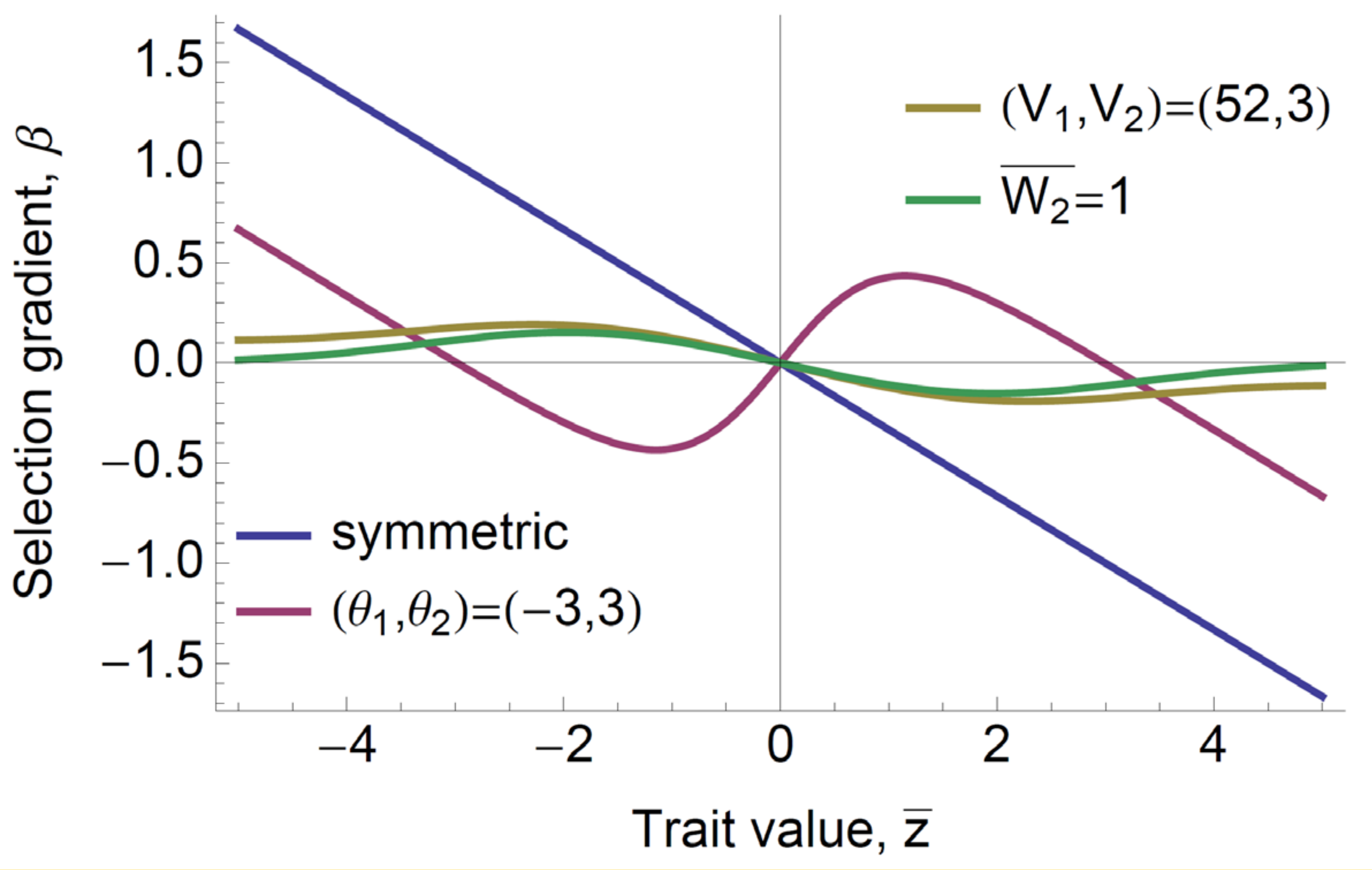
Special cases

Patchy population with hard selection



Special cases

Patchy population with hard selection



Evolutionary tipping points

Can occur easily in many different types of structured population:

Age structure

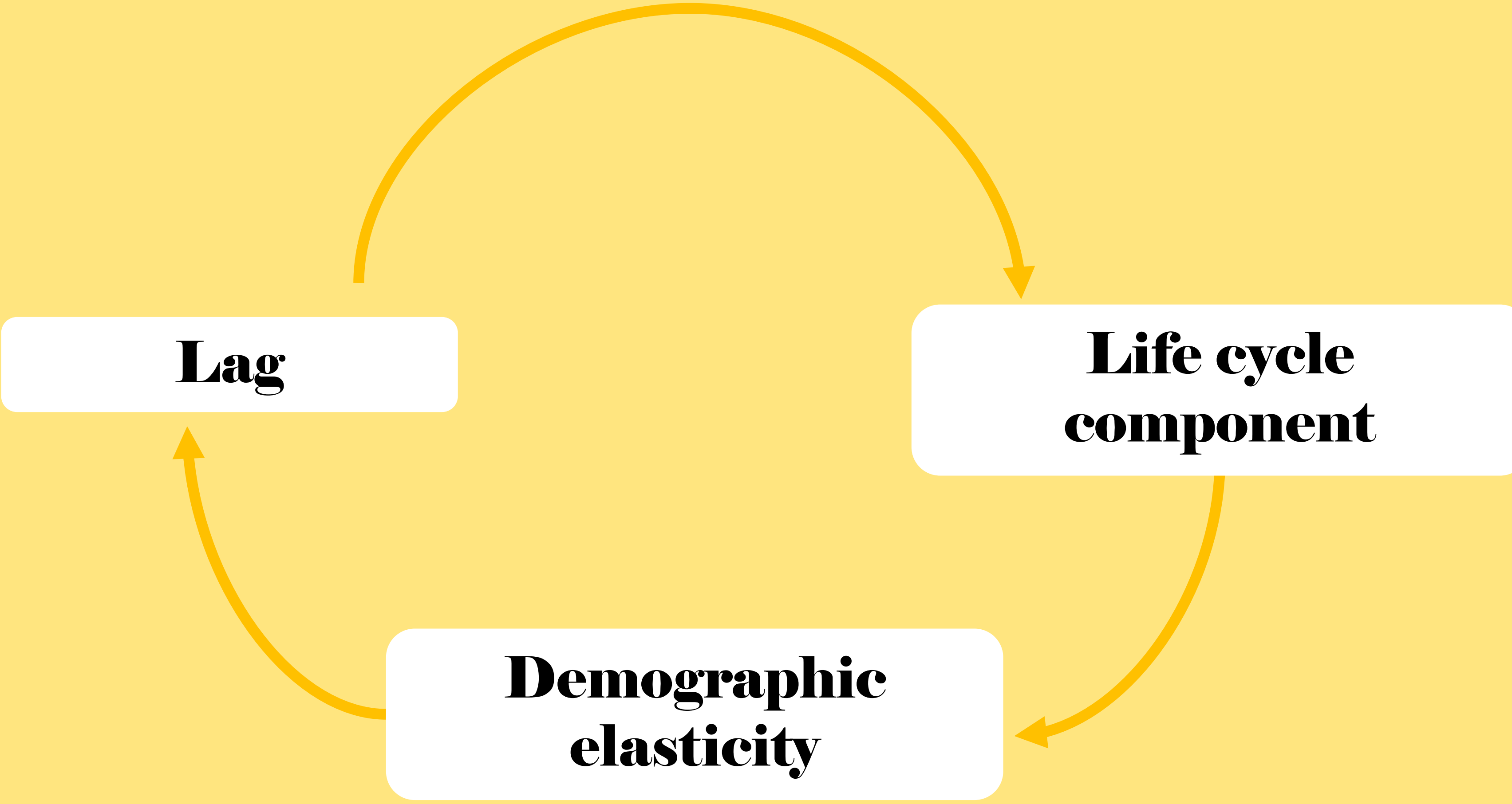
Stage (e.g. size) structure

Spatial structure with hard selection

Not with soft selection

Not with sex structure

Feedback loops between demography and evolution



Evolutionary tipping points

Are not oddities

May seriously complicate adaptation to climate change in structured populations

Maladaptation begets more maladaptation