Exploring the eco-evo dynamics of populations using integral projection models (IPMs)

An illustrated introduction to IPMs

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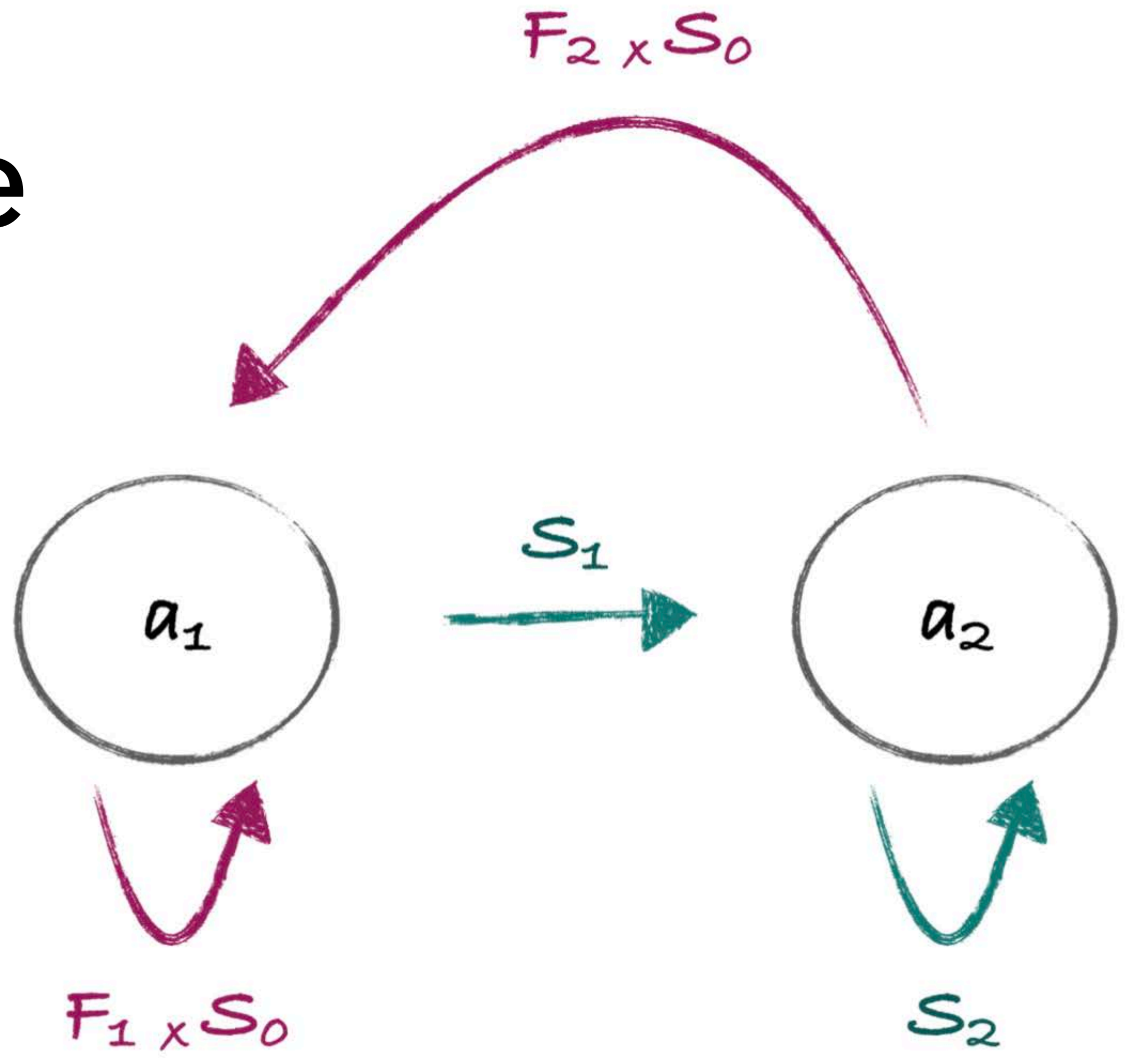
‘Pop dynamics & Genetics day’- December 2022 - CBGP

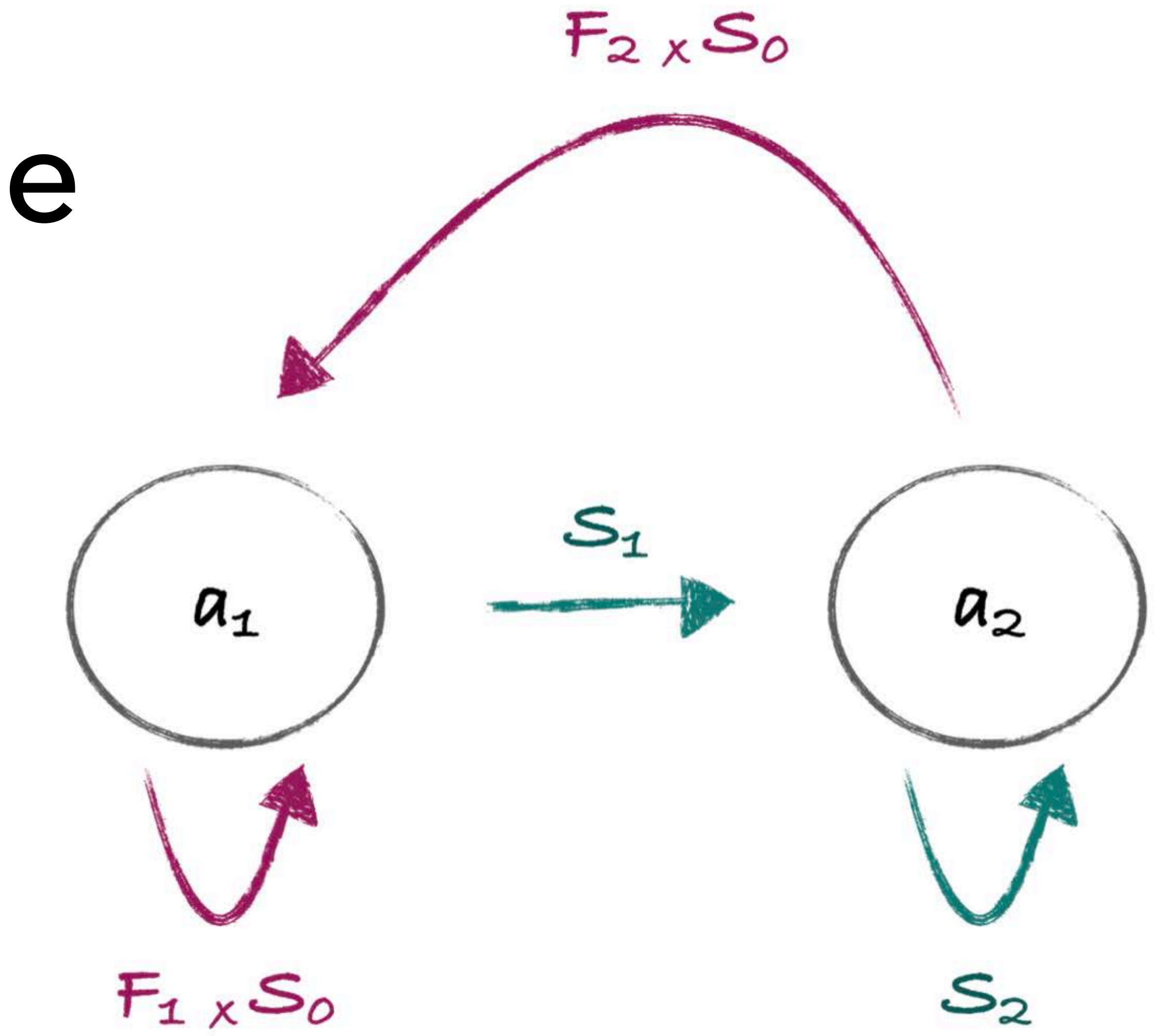
Principle of (matrix) population projection models

Swallow example



Principle of (matrix) population projection models

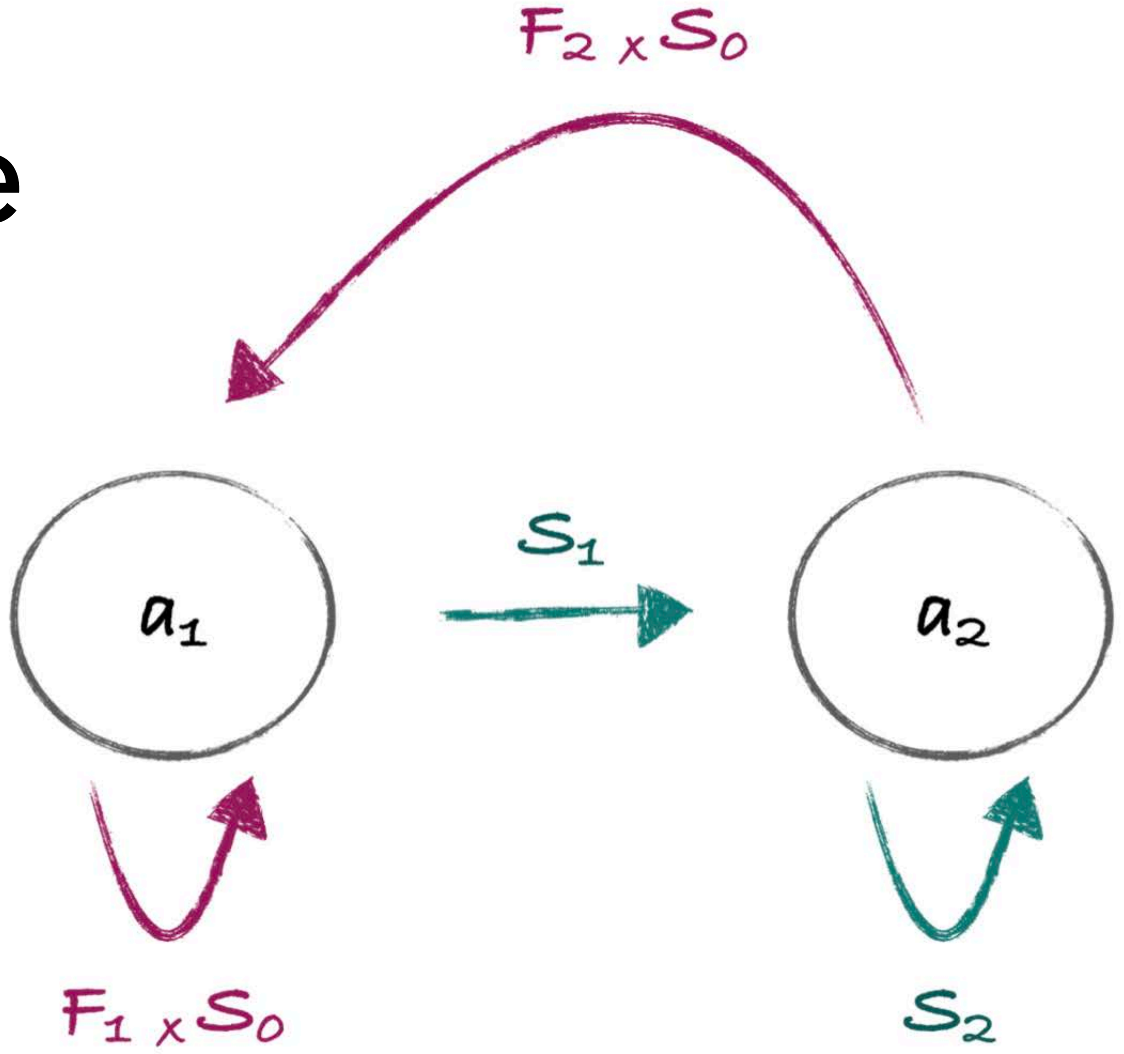
Swallow example



$$N_{(t+1)} = \begin{bmatrix} F_1 \cdot S_0 & F_2 \cdot S_0 \\ S_1 & S_2 \end{bmatrix} \cdot N_{(t)}$$

Principle of (matrix) population projection models

Swallow example



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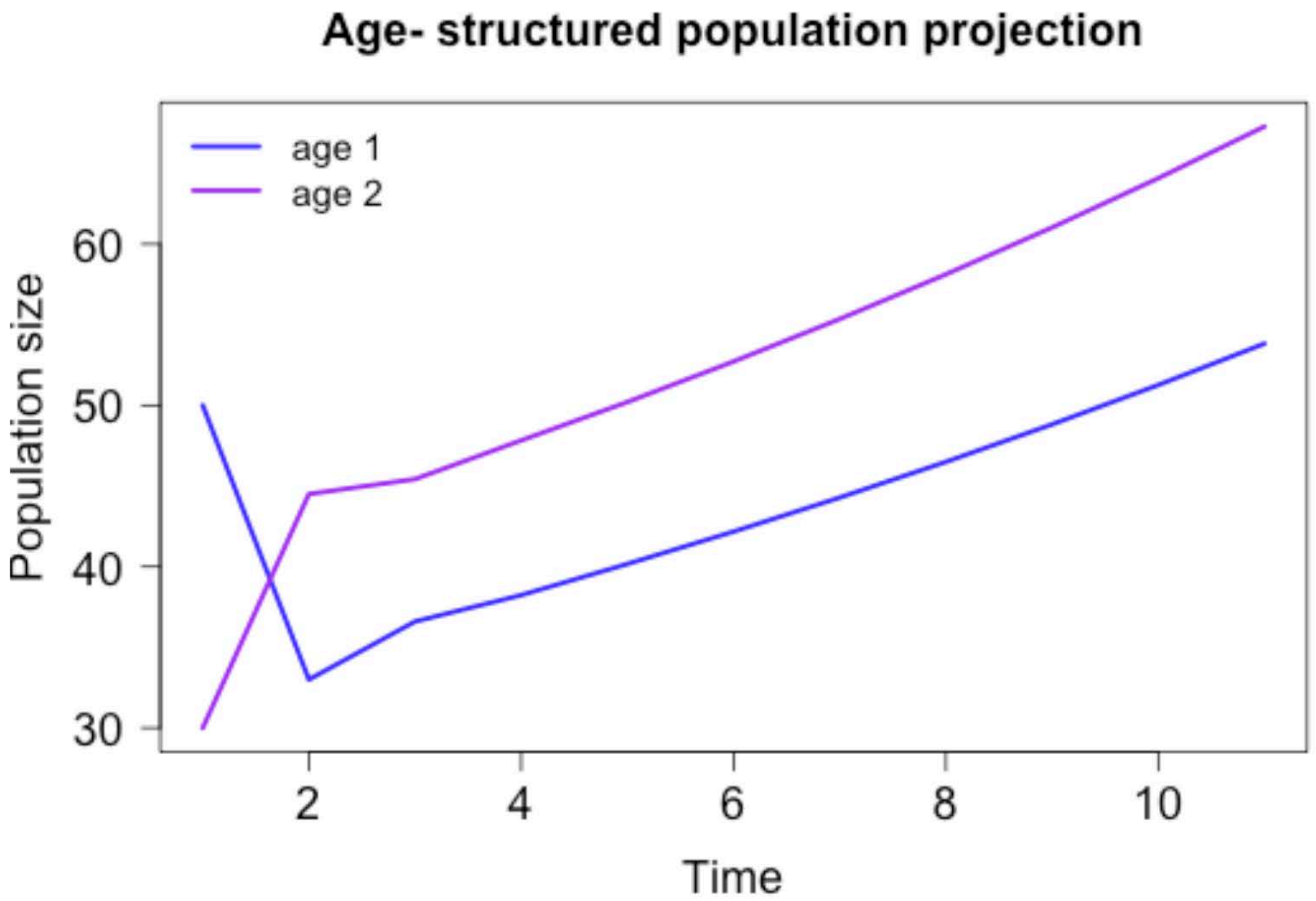
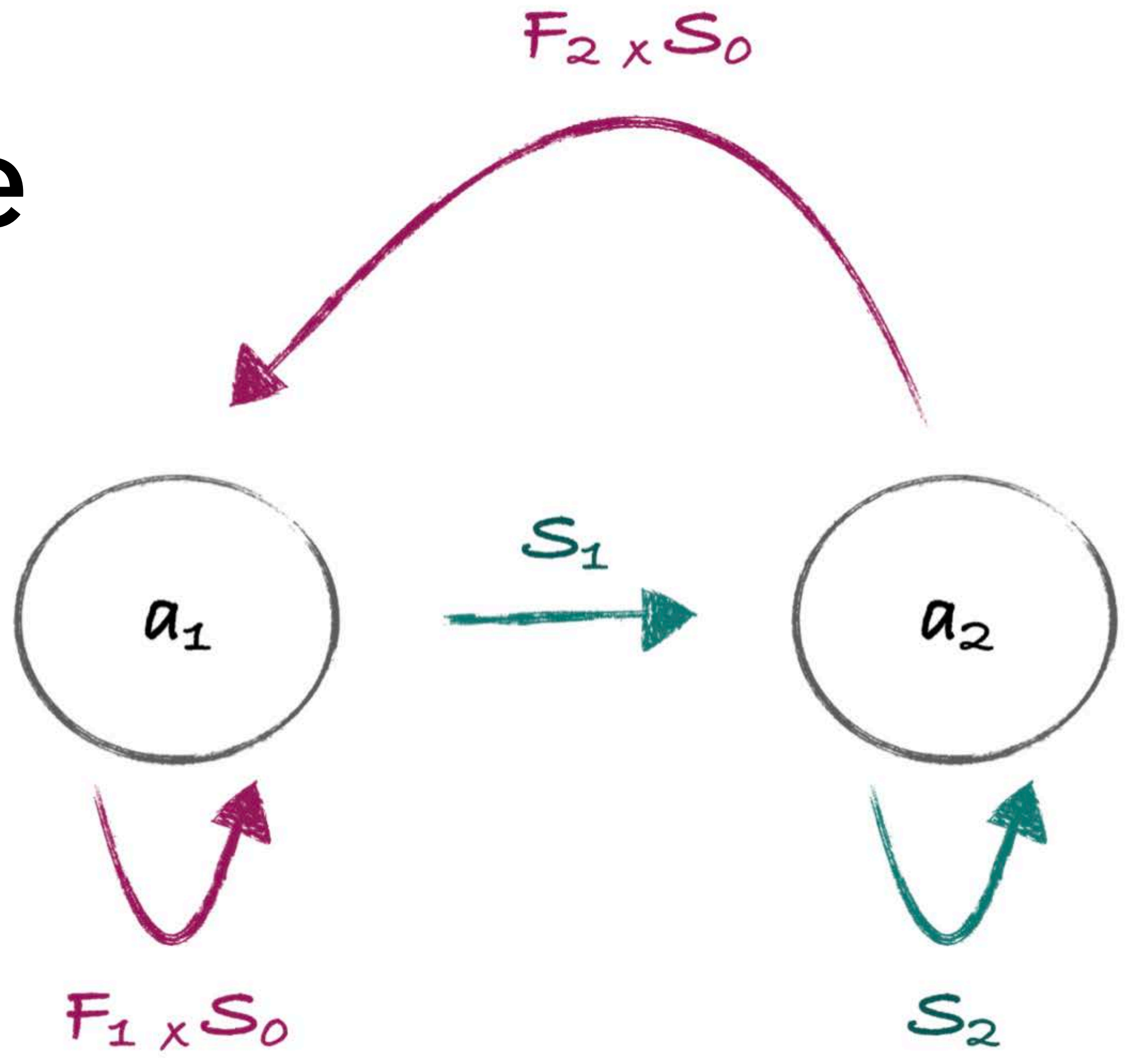


Principle of (matrix) population projection models

Swallow example



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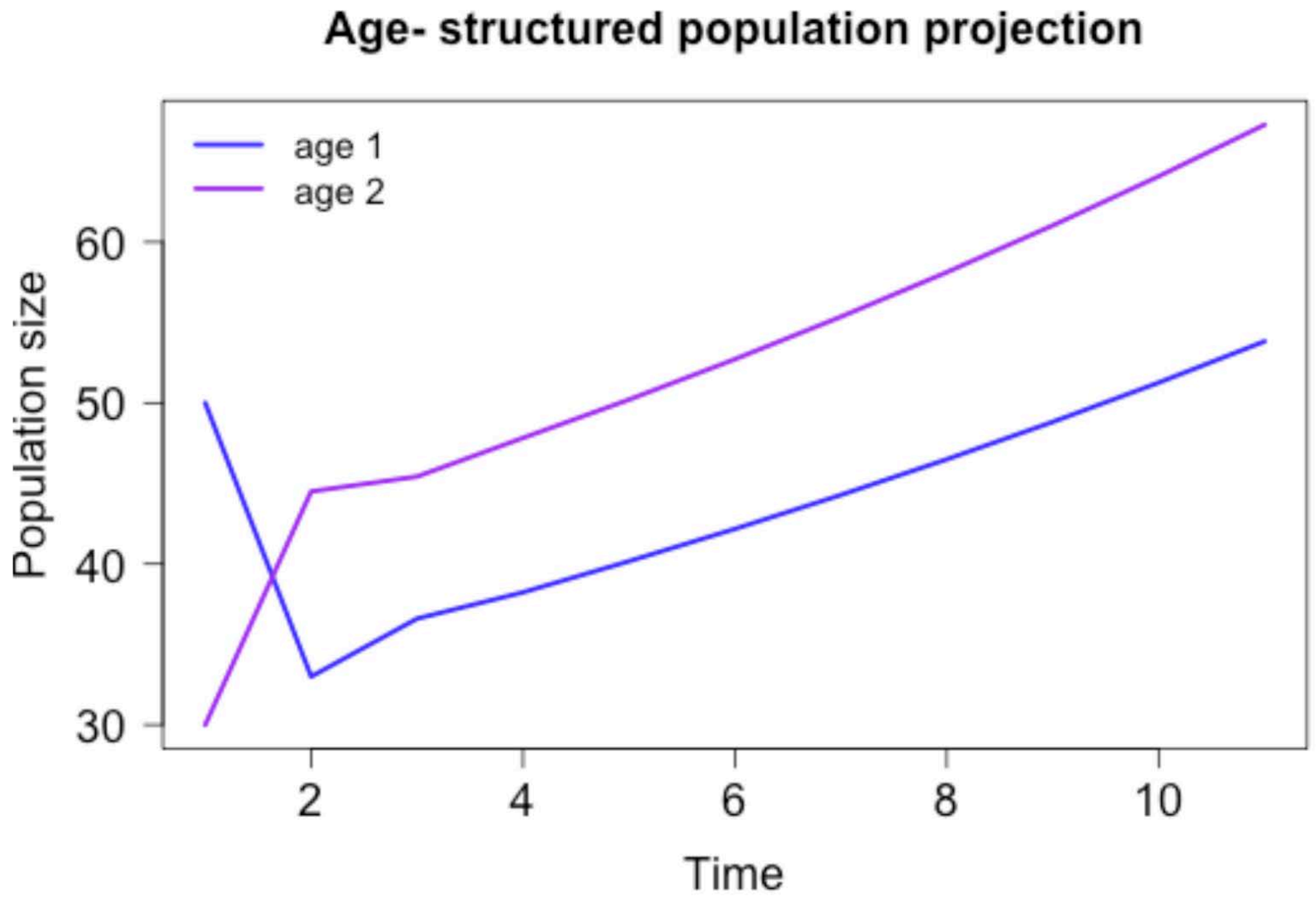


- **Forecast pop. dynamics**
  growth rate, reproductive values, generation time, stable age structure, population viability, extinction risk

Populations' responses to environmental changes

Population size

Life history traits

Gene frequencies

Phenotypic traits

- Not only numerical
- **Integral projection models** aim at modeling (to predict, or perturb) the **numbers of individuals (ecological dynamics) conjointly with their traits (evolution)**

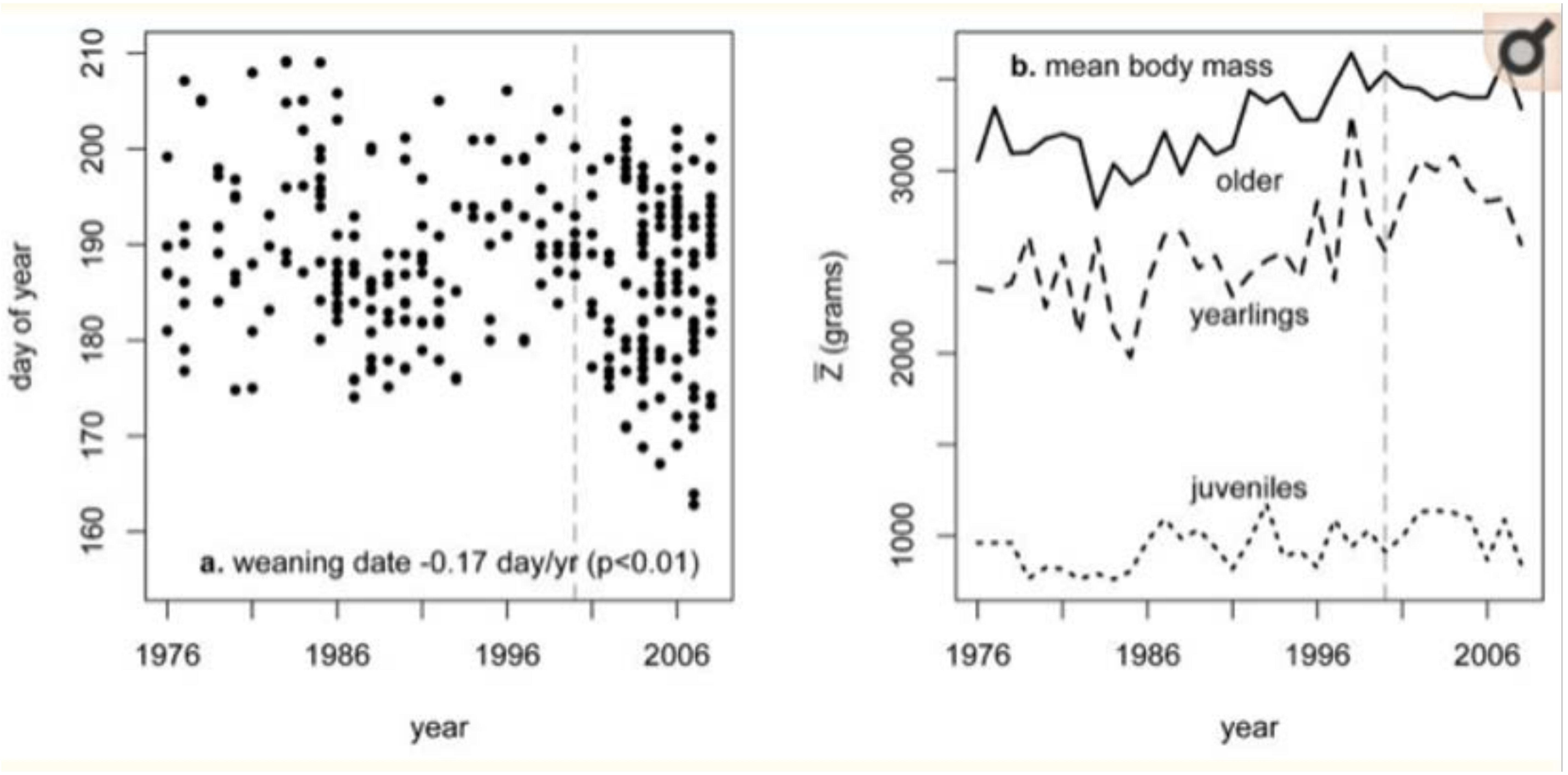
When/why are IPMs interesting ?

- Heterogeneity among individuals: **fitness-related traits** under selection influence **vital rates (survival, growth, reproduction, dispersal)** and response to environmental changes.

- Continuous trait (e.g. size, body weight, territory quality, genes, social rank, leaf surface, antler size) summarizes fitness differences among individuals better than age

The marmot example

1 - Link environment to phenotypic trait

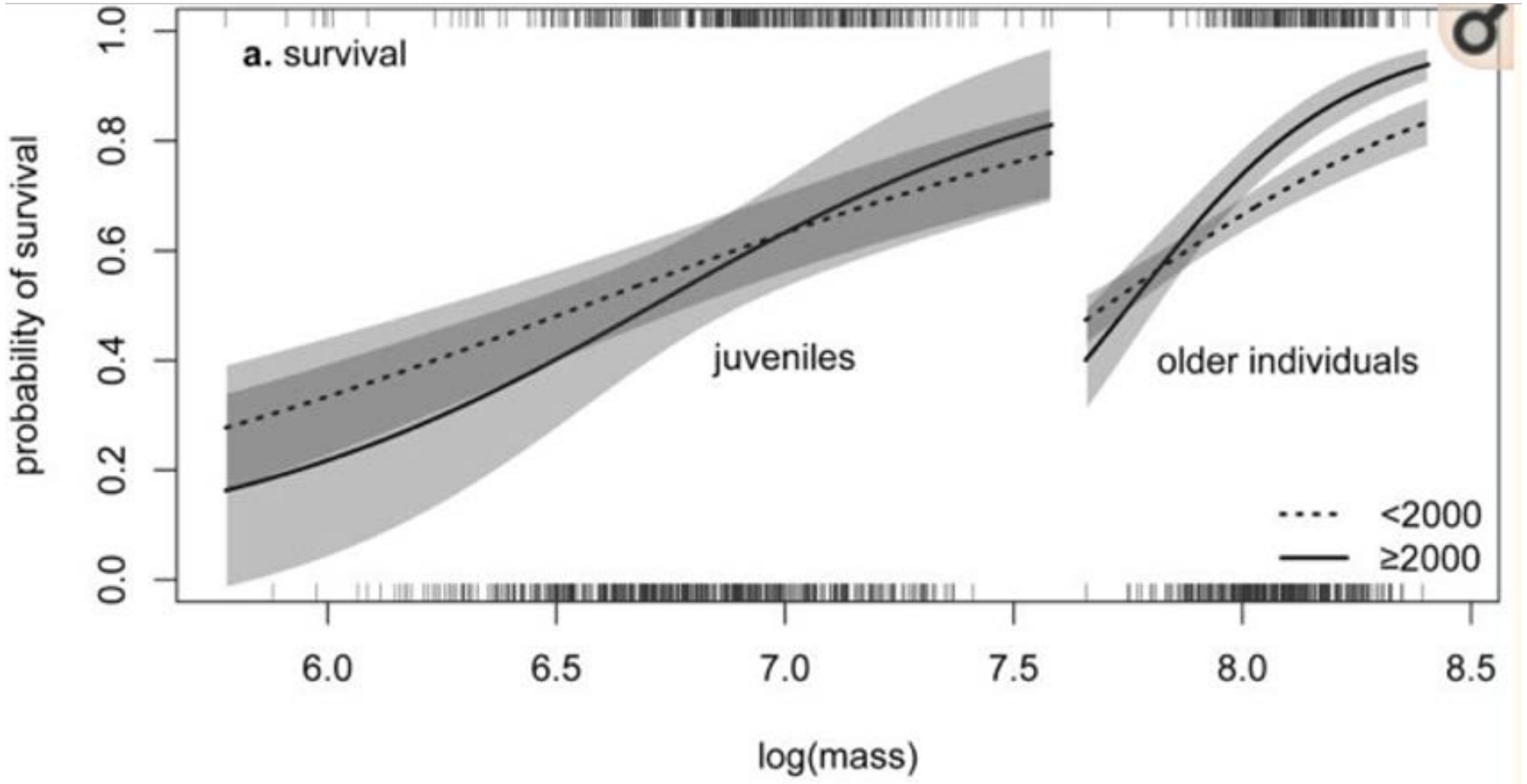


Marmota flaviventris
from Ozgul et al. 2010

- Climate warning -> earlier emergence -> marmots grow bigger before hibernation

The marmot example

2 - Link phenotypic trait to vital rates



- Climate warning -> heavier adults survive better

Marmota flaviventris

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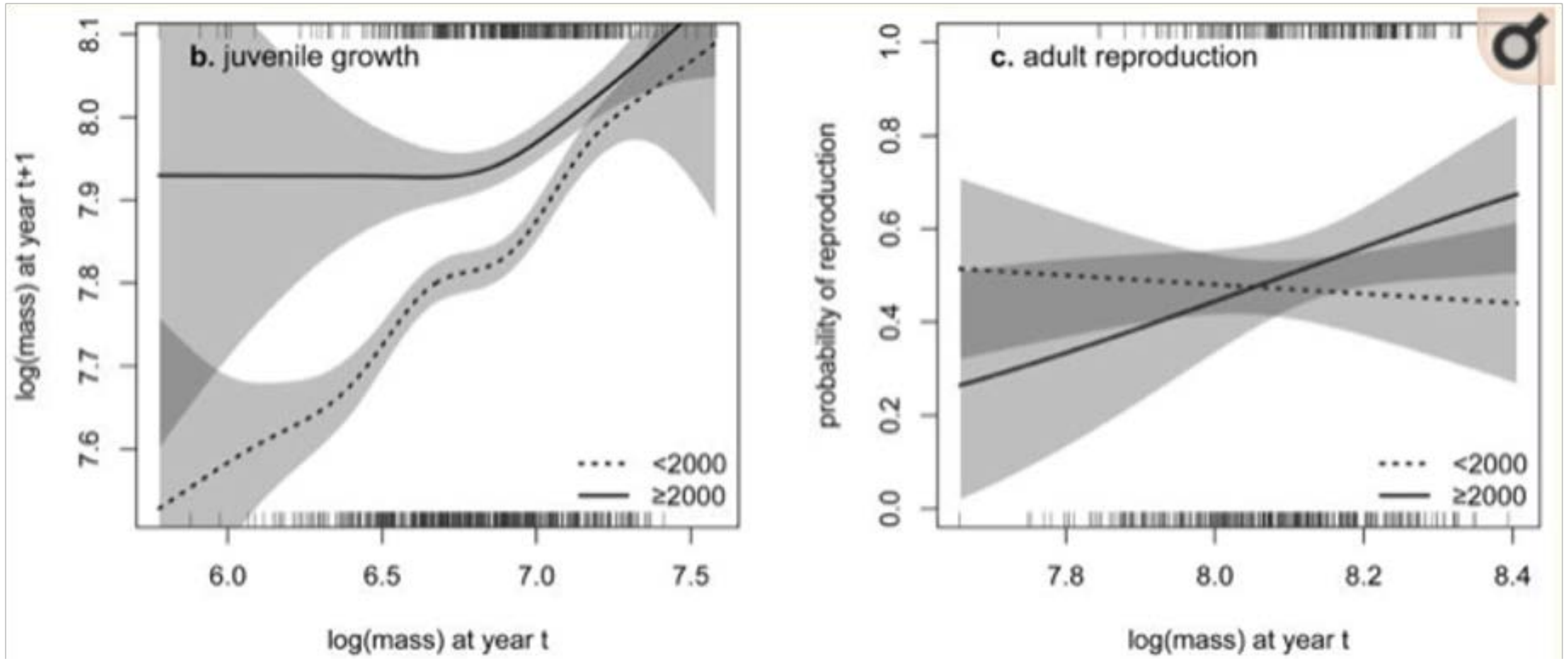
The marmot example

2 - Link phenotypic trait to vital rates

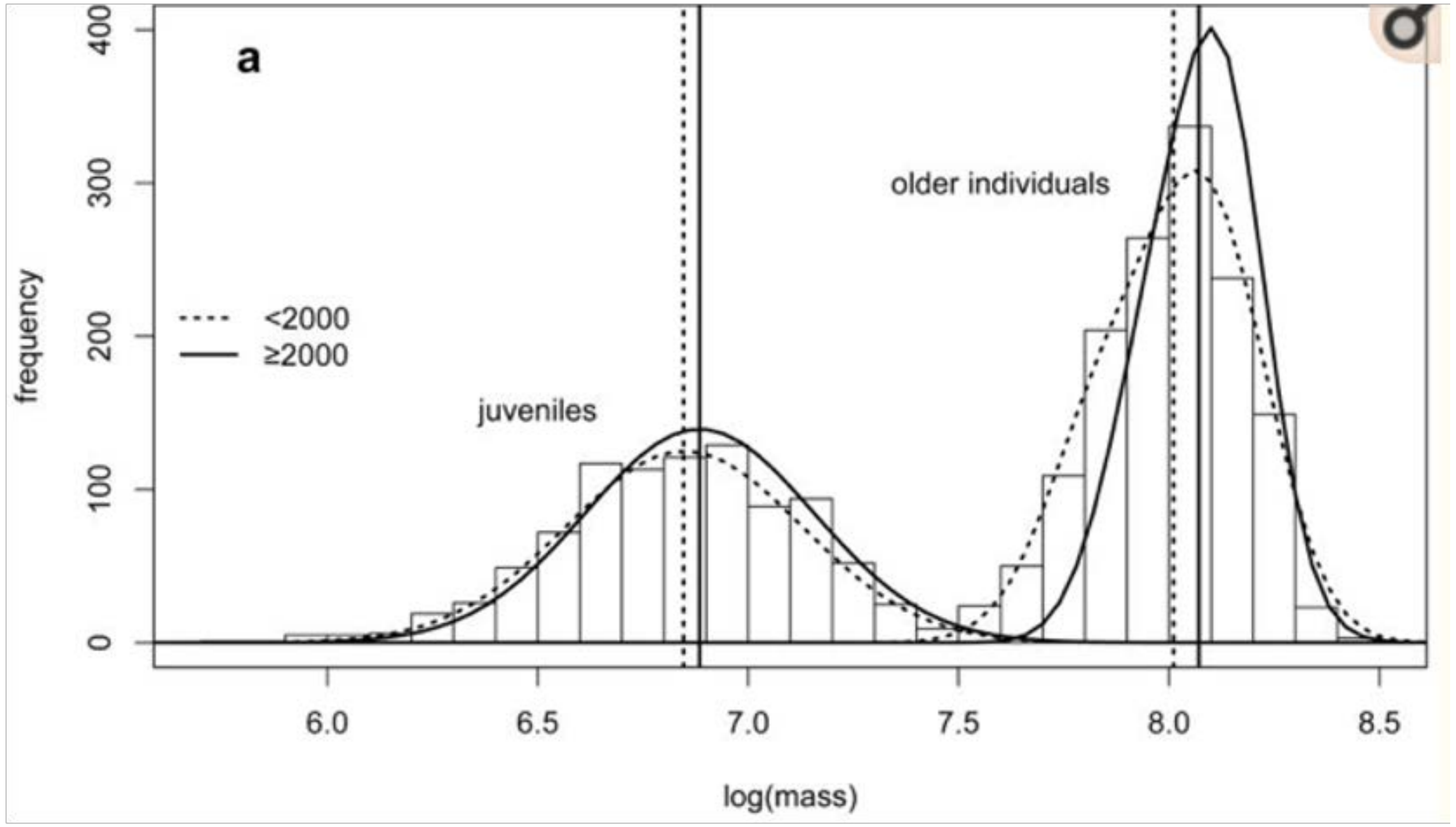


Marmota flaviventris
from Ozgul et al. 2010

- Climate warning -> juveniles grow heavier, heavier reproduce better

The marmot example

3 - Projected dynamics

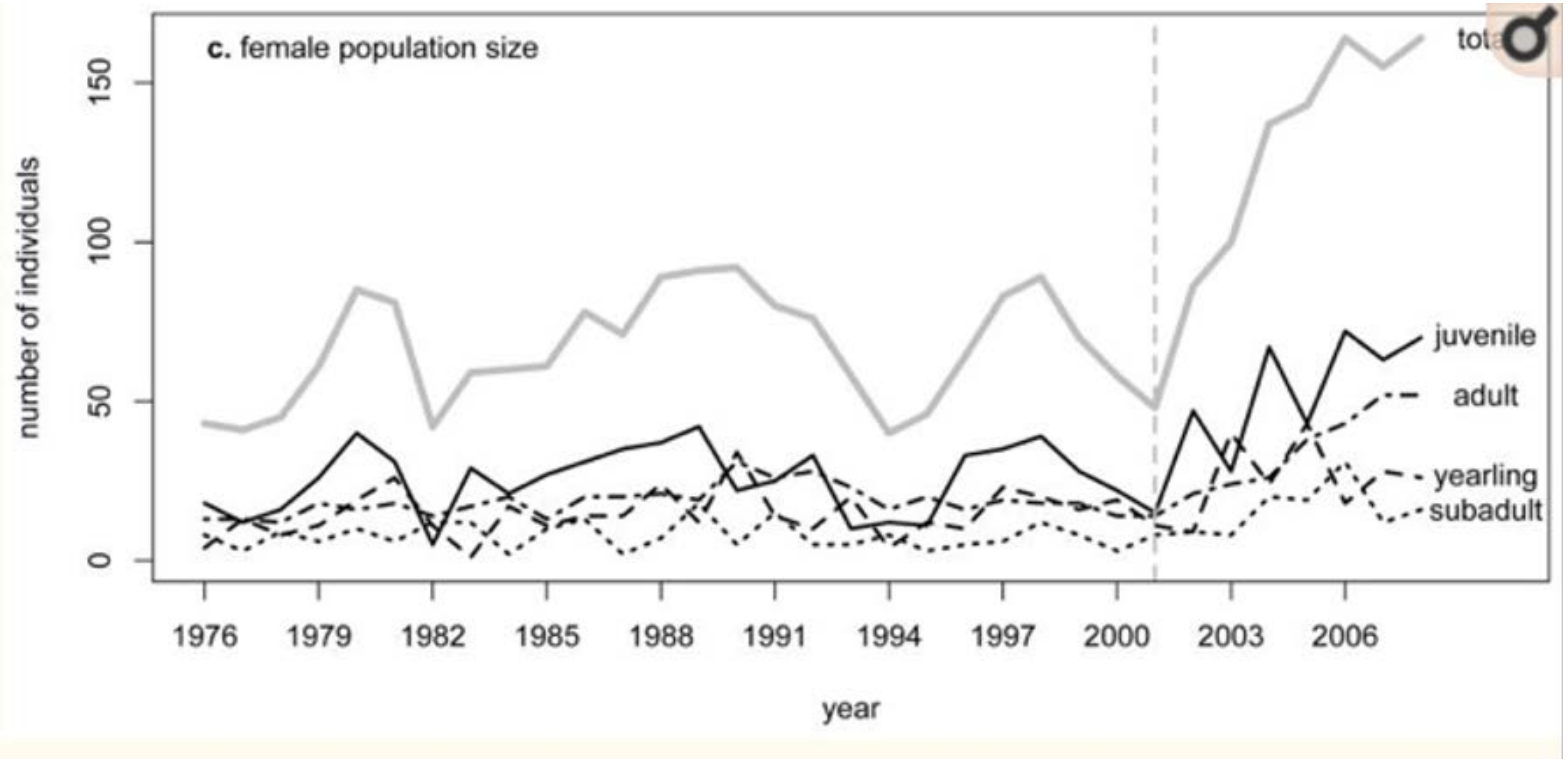


Marmota flaviventris
from Ozgul et al. 2010

- Climate warning -> directional selection for heavier individuals

The marmot example

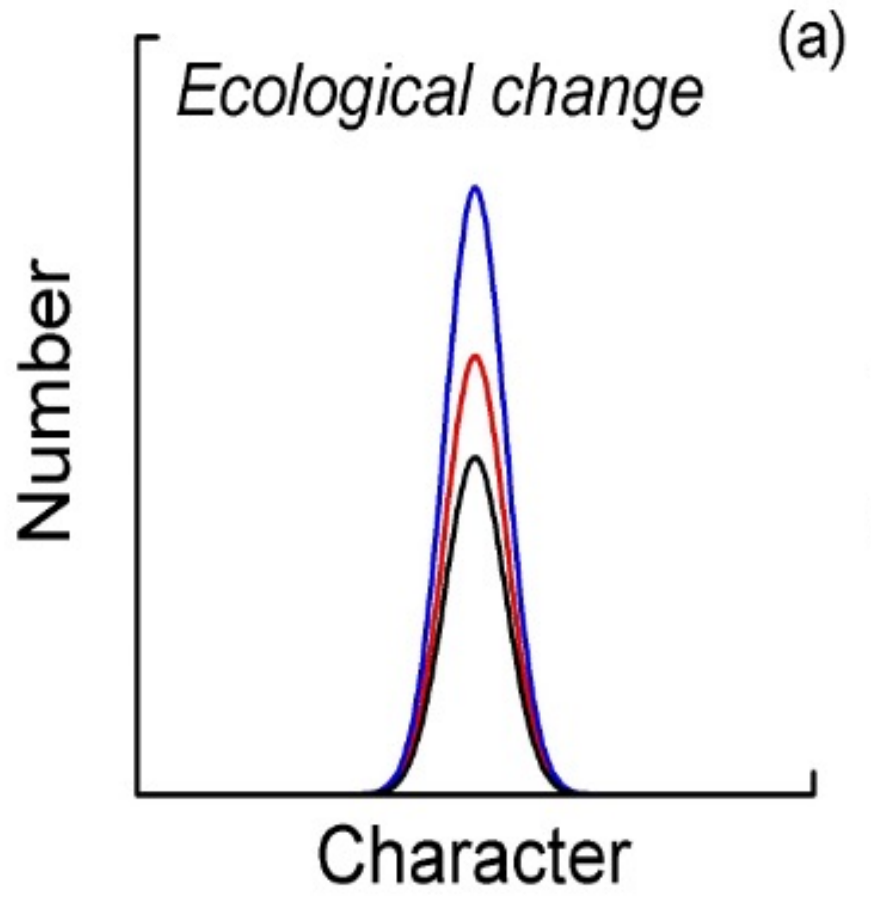
3 - Projected dynamics



Marmota flaviventris
from Ozgul et al. 2010

- Climate warning -> increase in population size
  - direct impact through increased winter survival of adults
  - indirect impact through modification of the phenotype - fitness map (body weight - vital rates)

Modeling populations' eco-evolutionary dynamics using IPMs



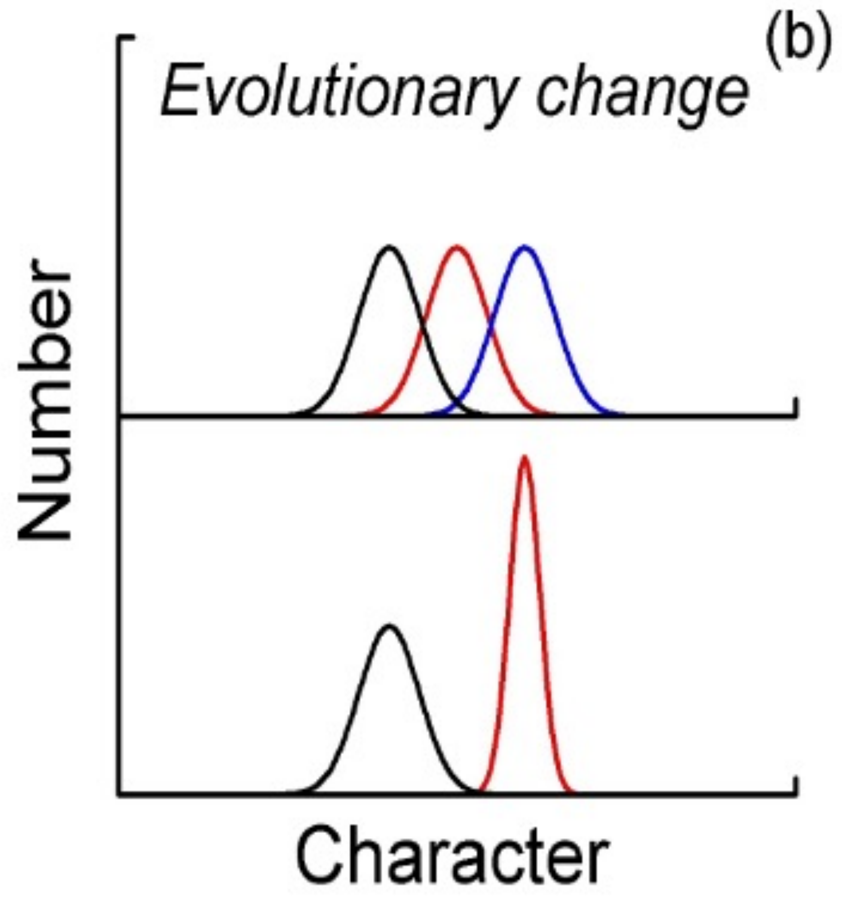
Environment

Vital rates

Ecological dynamics

Change in population size

Modeling populations' eco-evolutionary dynamics using IPMs



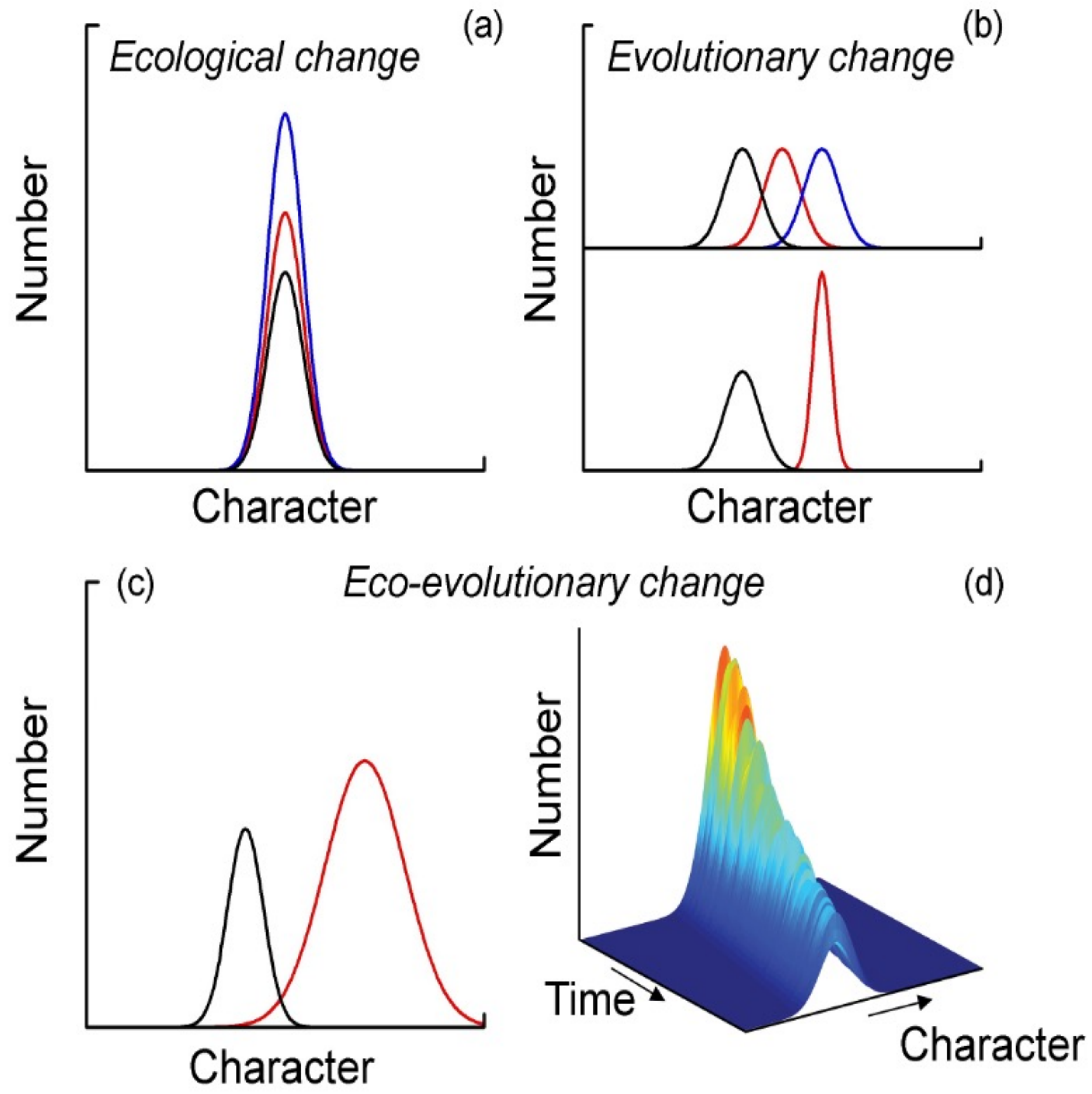
Environment

Optimal phenotype

Evolutionary dynamics

Shift in the trait distribution

Modeling populations' eco-evolutionary dynamics using IPMs



Environment

Vital rates

Optimal phenotype

Ecological dynamics

Change in population size

Evolutionary dynamics

Shift in the trait distribution

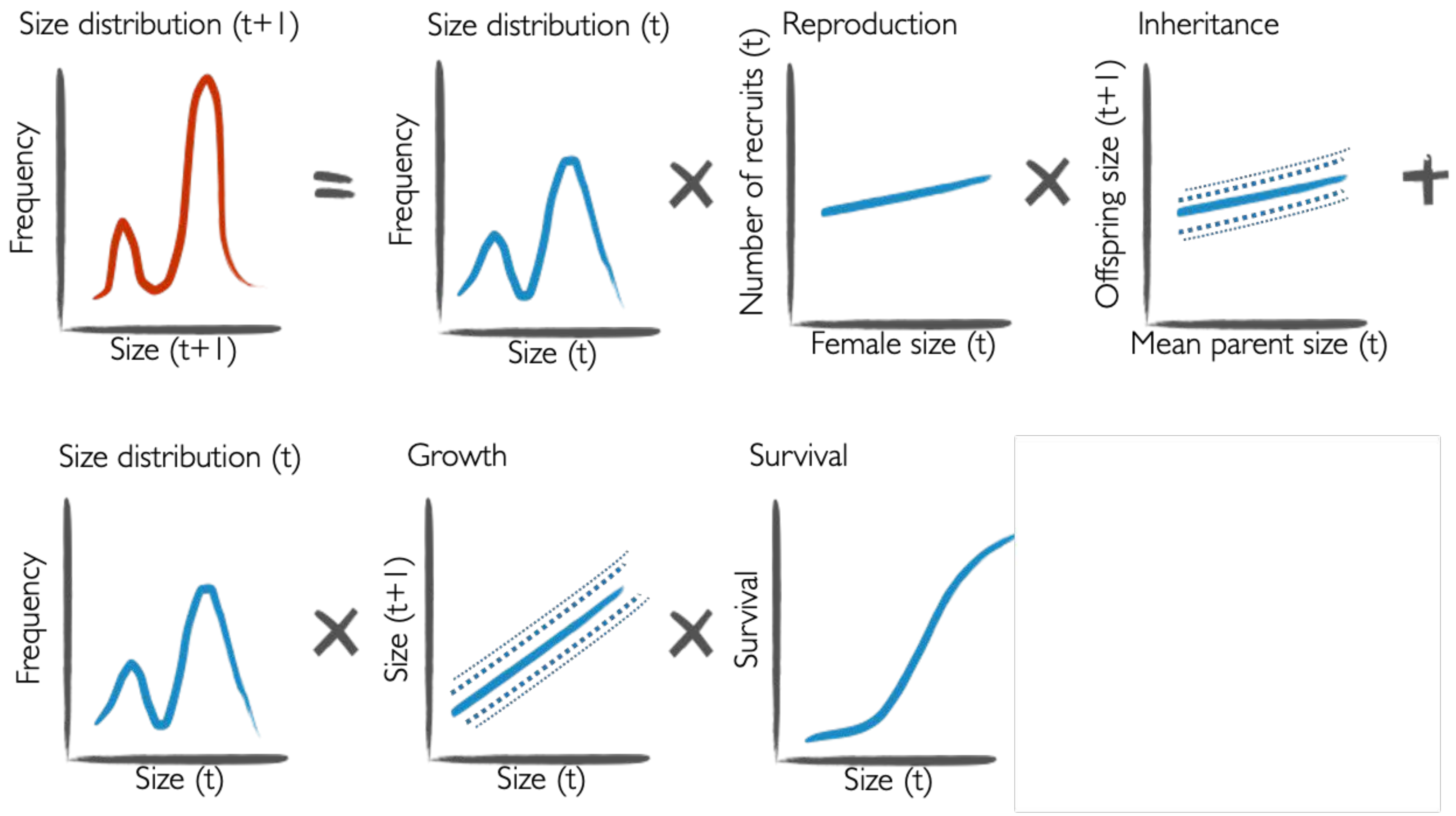
IPMs

explore feedbacks between ecology and evolution

Easterling et al. 2000, Childs et al. 2003, Ellner and Rees 2006, Coulson et al. 2010

Building an (old school) IPM

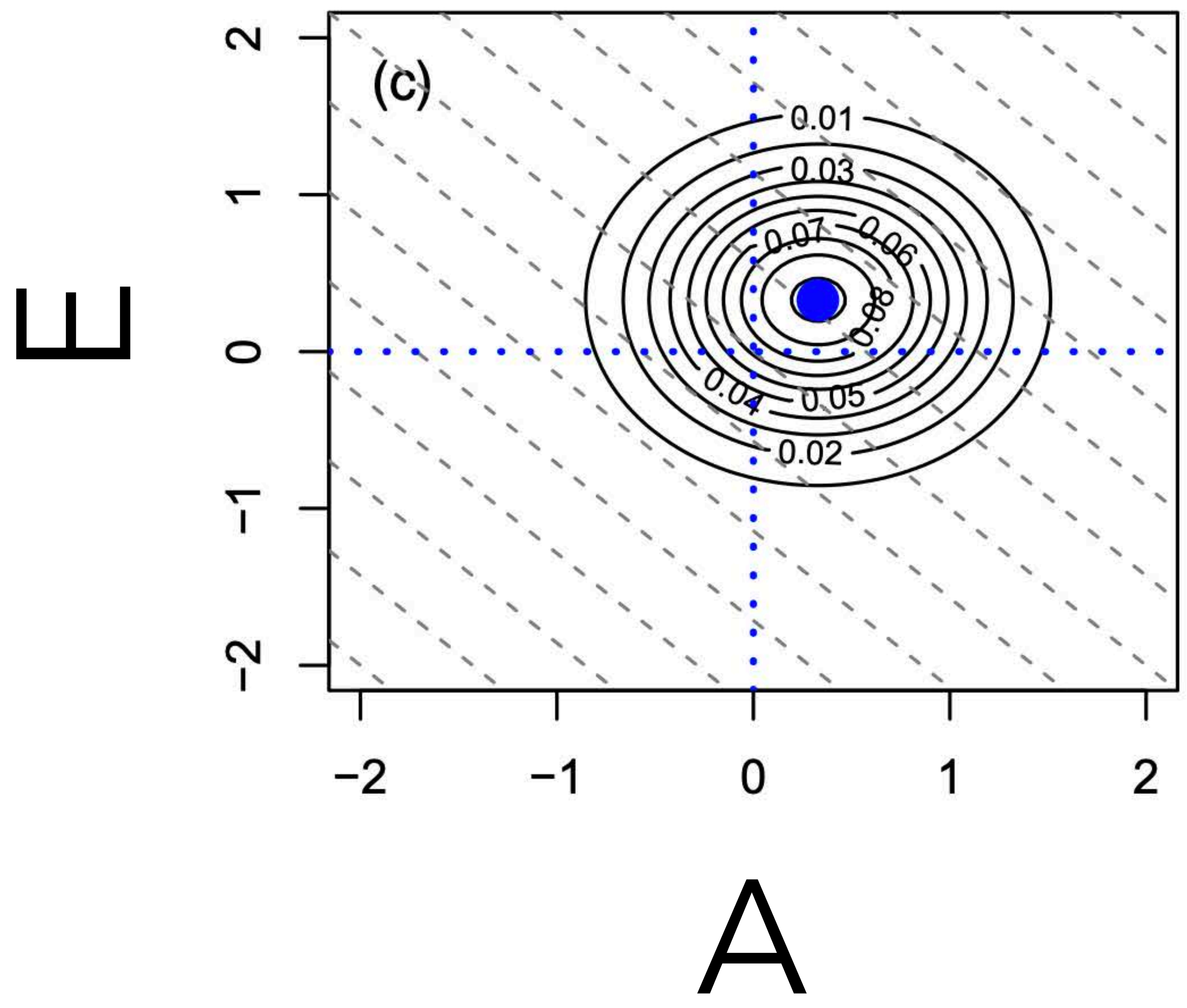
Multiply (and sum) vital rates functions of the trait to obtain a projection kernel



Easterling et al. 2000, Childs et al. 2003, Ellner and Rees 2006, Coulson et al. 2010

Extensions towards EE (evolutionary explicit) IPMs

quantitative genetic inheritance: partitioning of the phenotype into genetic and environmental components (each trait is decomposed into a bivariate distribution $z_i = A_i + E_i$)



- higher accuracy of projections of trait change
- almost identical projections of population dynamics
- contribution of micro-evolution & phenotypic plasticity

BUT

more complex to parameterize and require detailed pedigree information

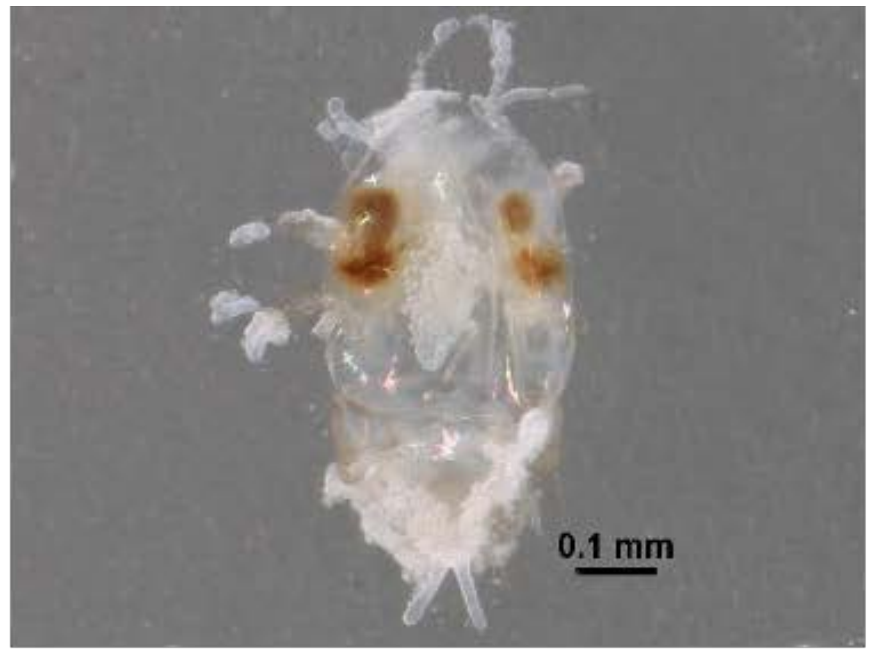
+ rely on assumptions about distributions

Childs et al. 2016, Rees & Ellner 2019, Simmonds et al. 2020, Coulson et al. 2020

Multiple traits and organisms considered

(review Vindenes and Langangen 2015)

rustic cactus
plant volume (F, G)



Rhizoglyphus robini
size (S, F, G)

Great tit
Hatch date

columbian ground squirrel
body mass (S, F, Mating)

Pike
size (S, F, G)

Big horn sheep
Horn size