Fisher's adaptive landscape across environments

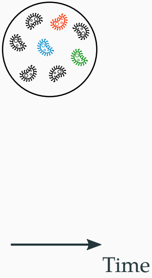
Evolutionary rescue and resistance in asexual populations

Yoann Anciaux

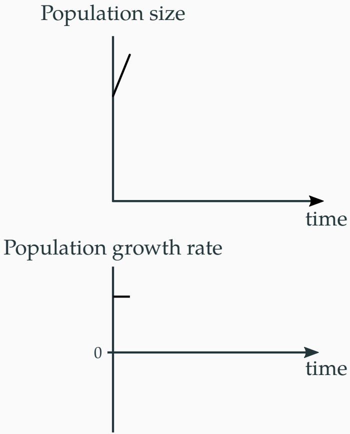
October 29, 2018

Bioinformatic research center Aarhus, Danemark.

Eco-evolutionary dynamics



Dynamics



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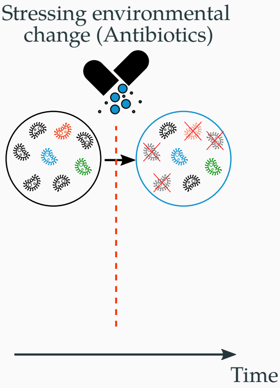

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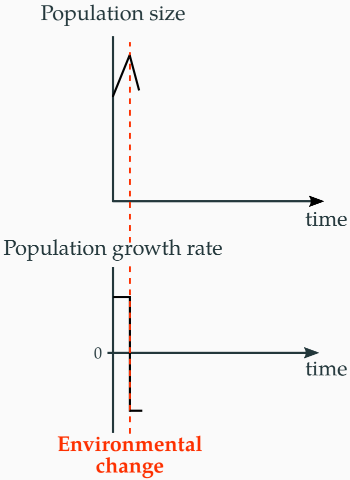

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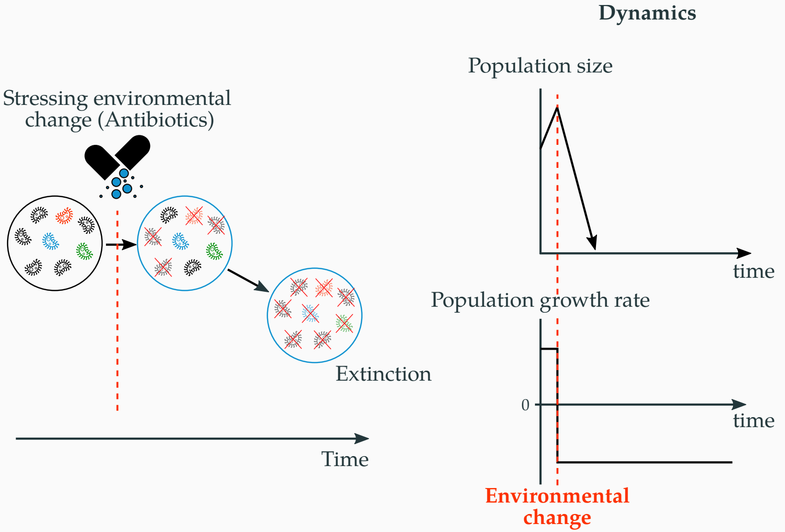

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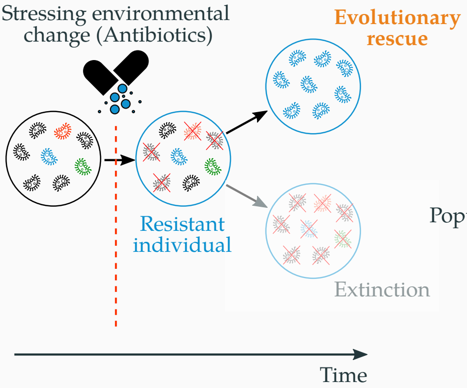

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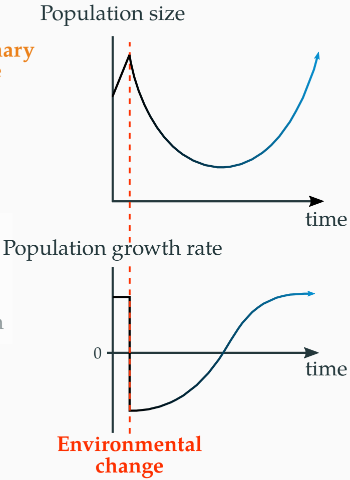
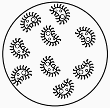
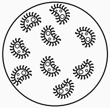


Genetic basis of evolutionary rescue



Genetic basis of Evolutionary rescue

Width



Genetic basis of Evolutionary rescue

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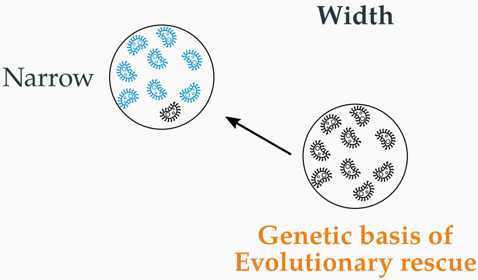

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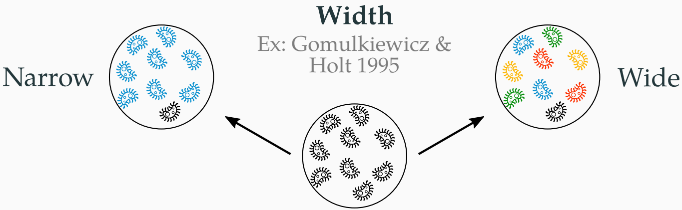


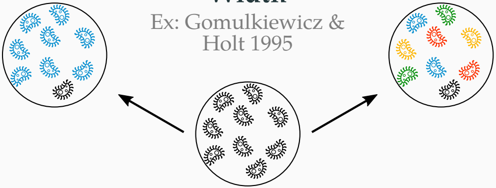
Genetic basis of Evolutionary rescue

Genetic basis of evolutionary rescue

Width

Ex: Gomulkiewicz & Holt 1995

Narrow

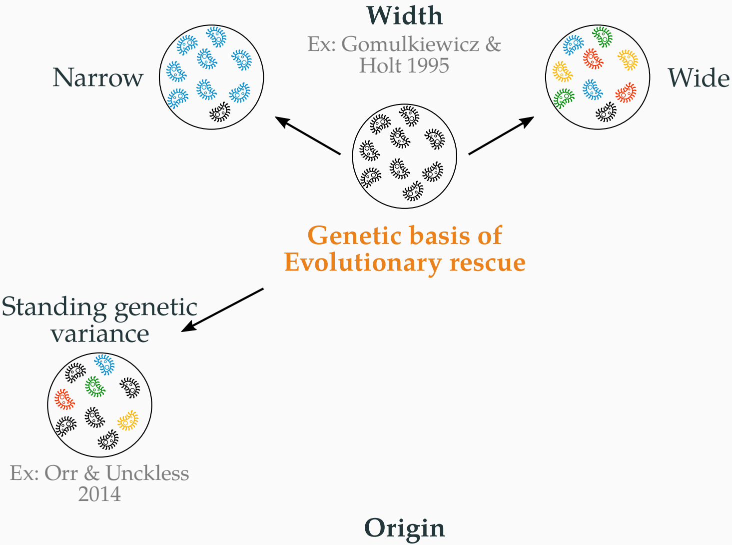


Wide

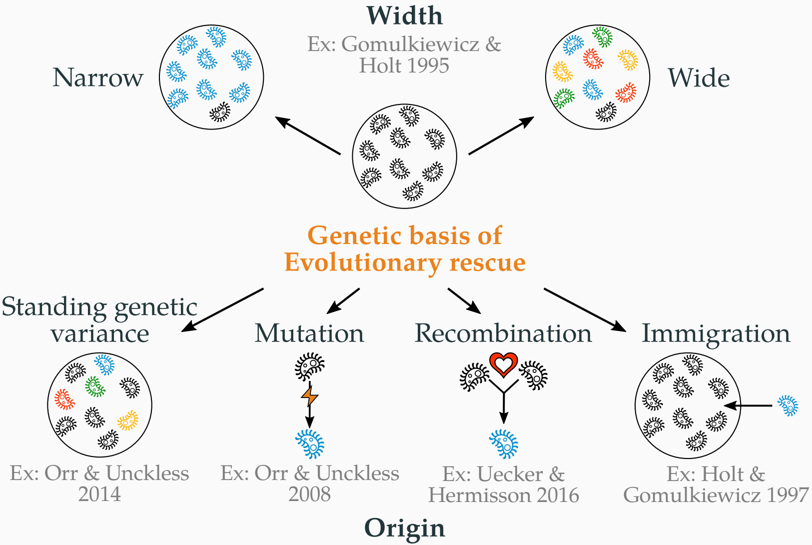
Genetic basis of Evolutionary rescue

Origin

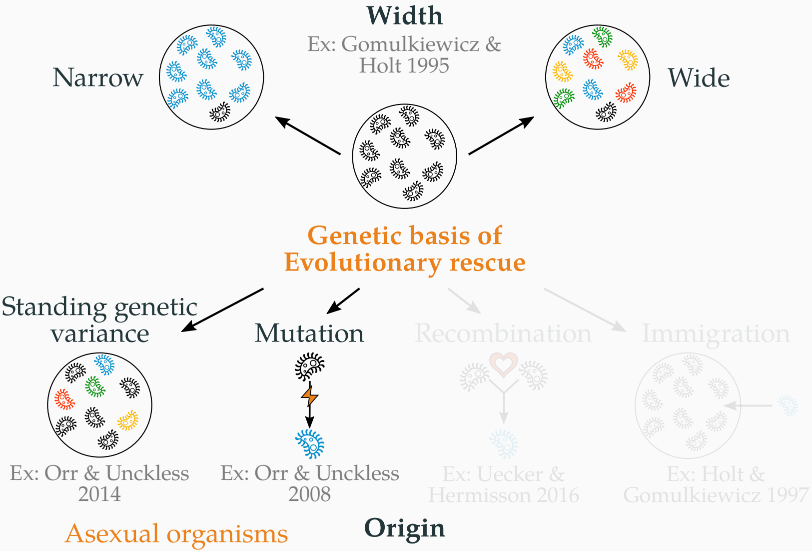
Genetic basis of evolutionary rescue



Genetic basis of evolutionary rescue



Genetic basis of evolutionary rescue



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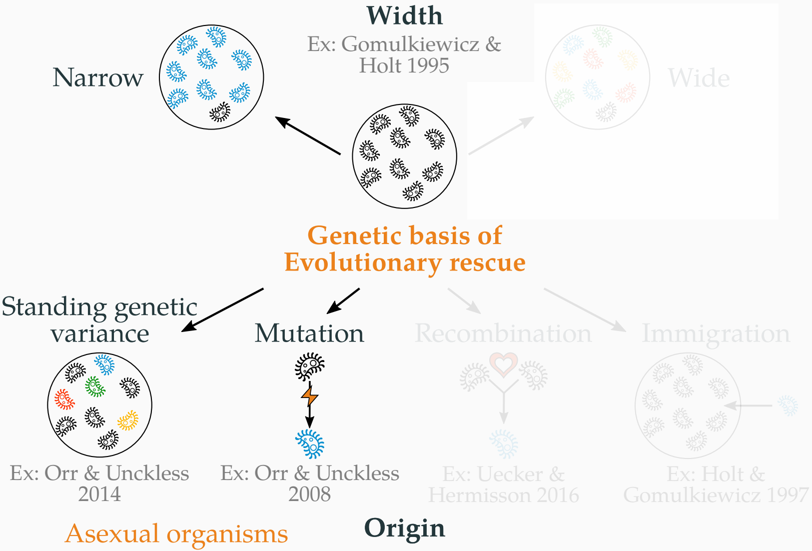
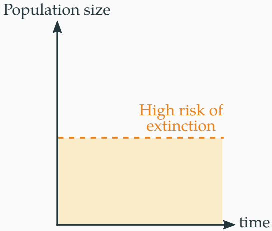


Model of evolutionary rescue from mutation



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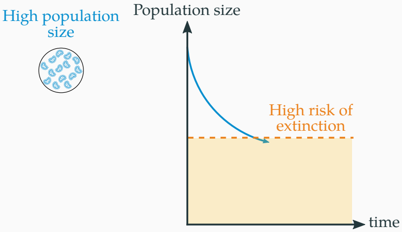

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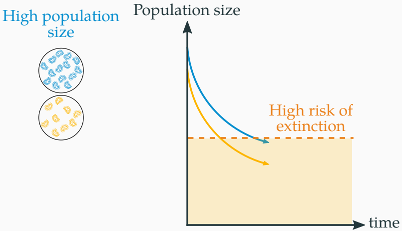

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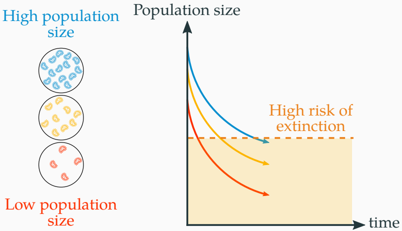

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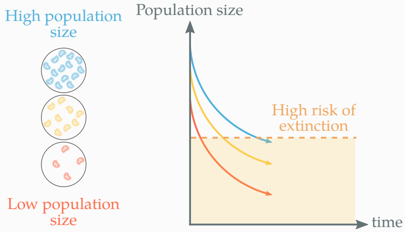

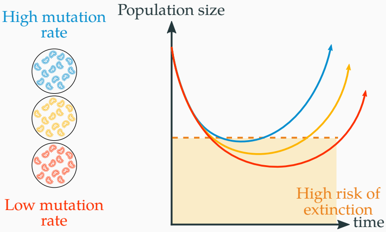

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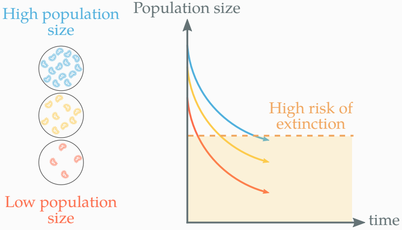

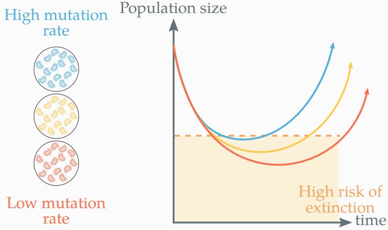

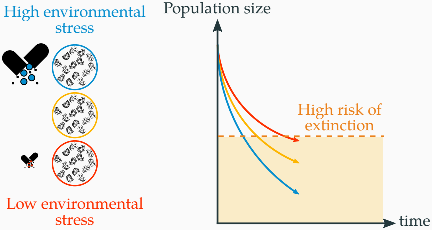

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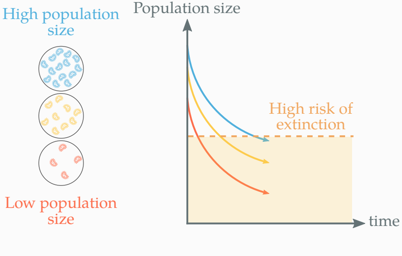
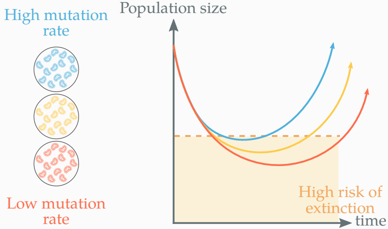
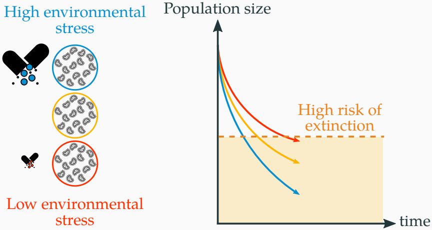






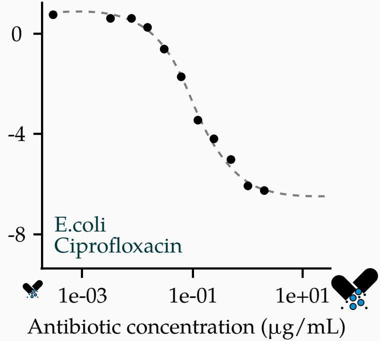
Effect of environmental change on **demography**

BUT

Fixed probability
of apparition of resitant mutations
across environments

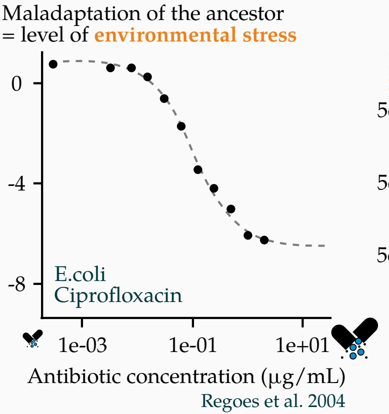
Model of evolutionary rescue from mutation

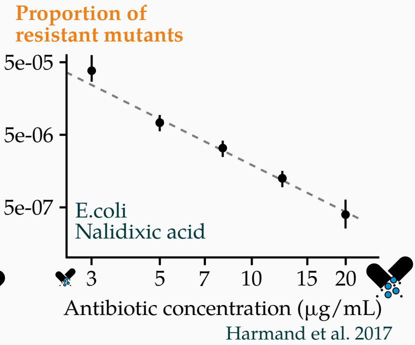
Maladaptation of the ancestor
= level of **environmental stress**



Regoes et al. 2004

Model of evolutionary rescue from mutation





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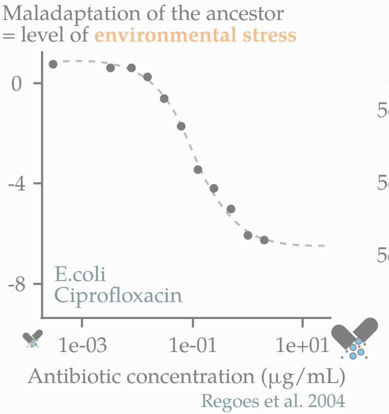
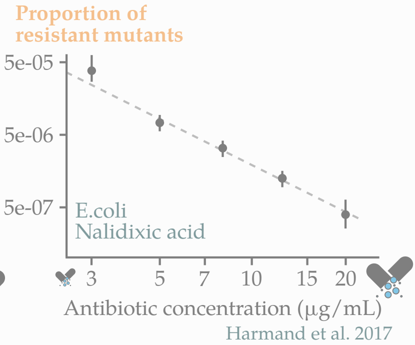
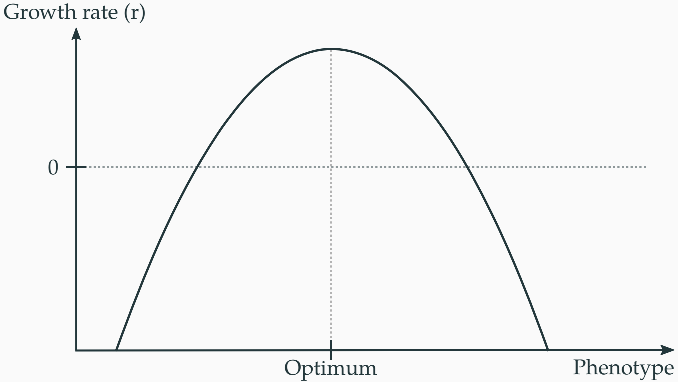




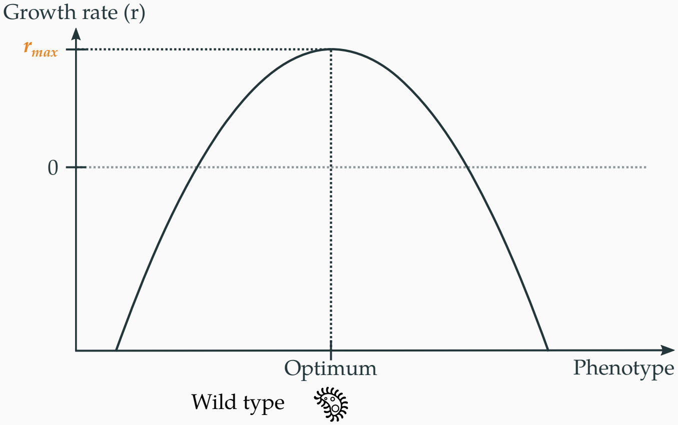
Derive ER models for asexual organisms integrating a **dependence between the environmental and the genetic contexts**

Fisher's Geometric Model



Fisher's Geometric Model

r_{max} : Maximal growth rate reachable in an environment.



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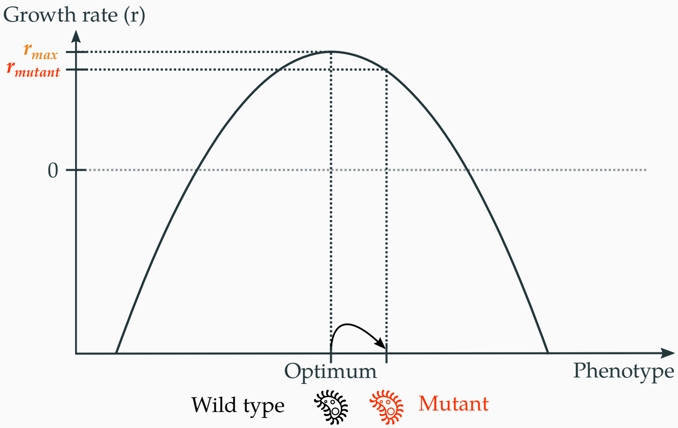
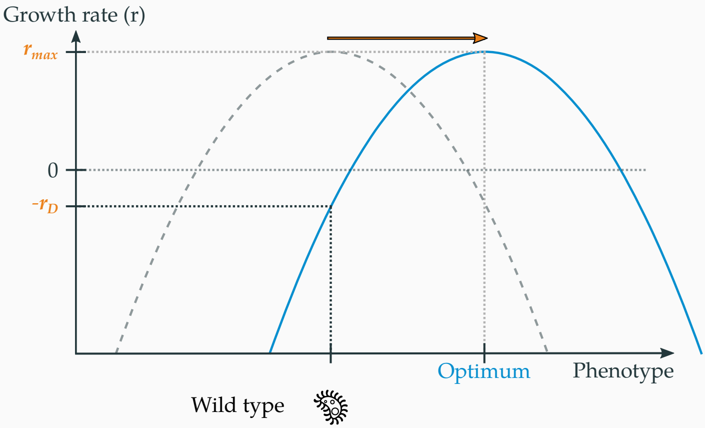


Fisher's Geometric Model

r_{max} : Maximal growth rate reachable in an environment.

r_D : Decay rate of the wild type in the stressing environment.



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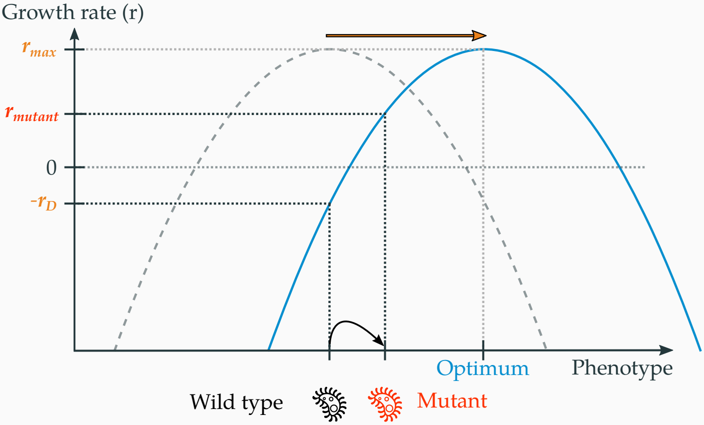

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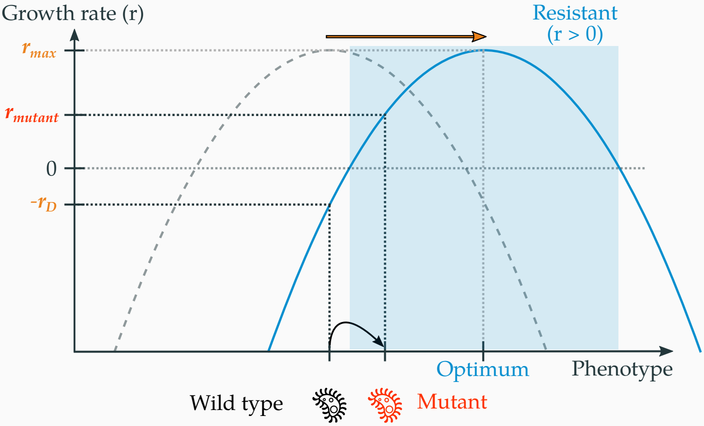

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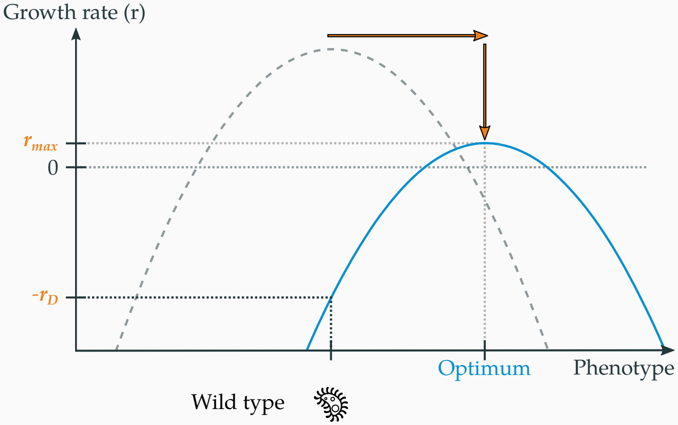

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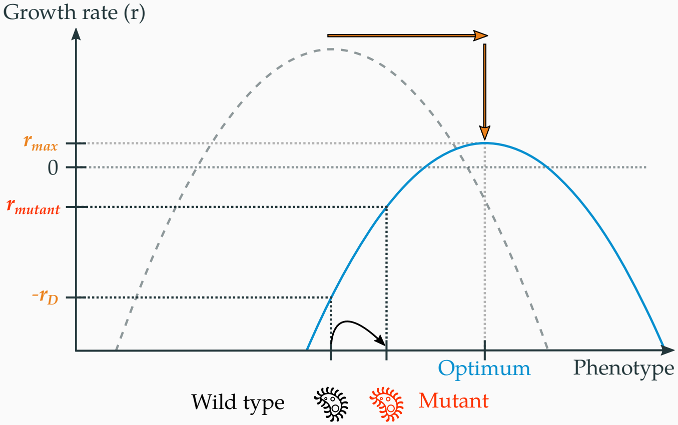

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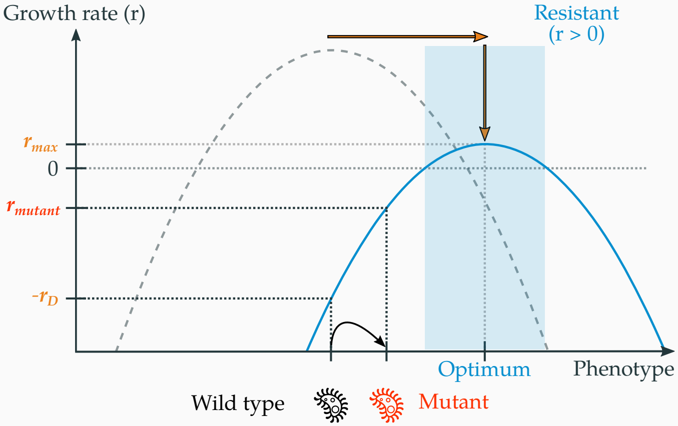

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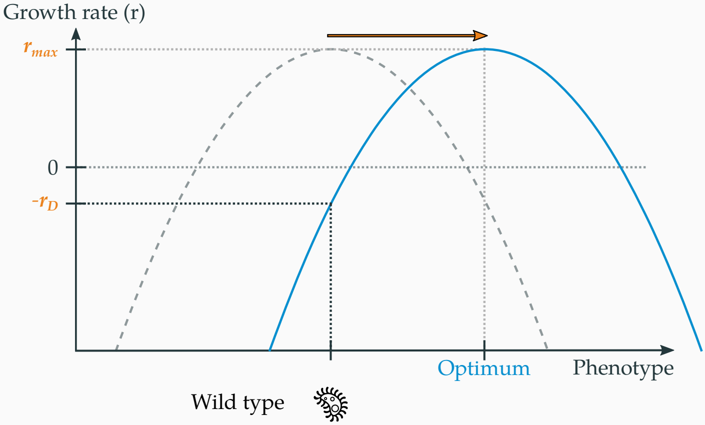

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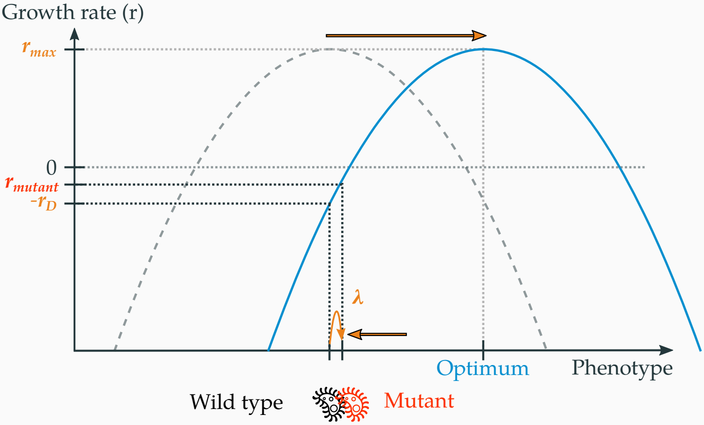
λ : Variance of mutation effects on phenotype



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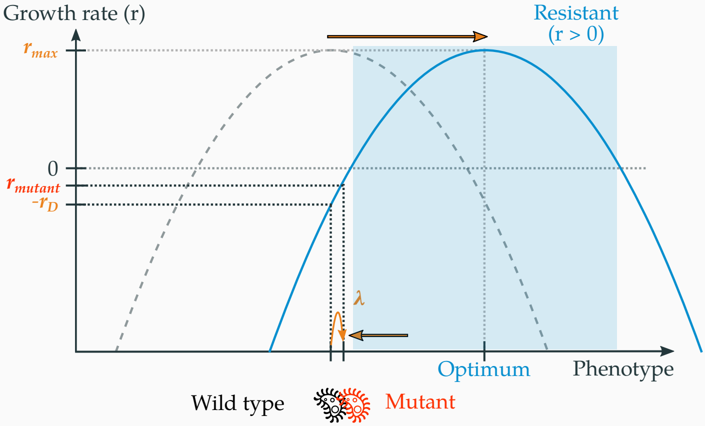

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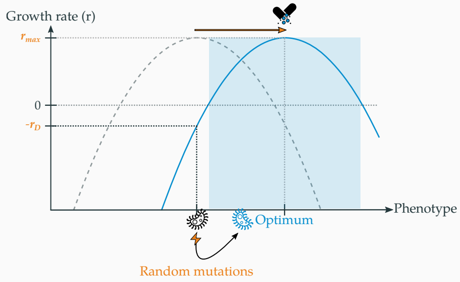

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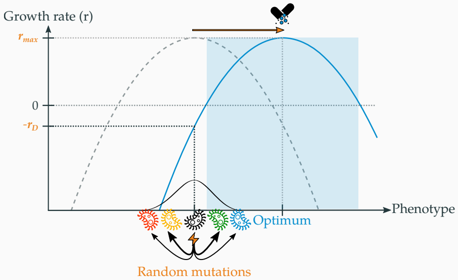

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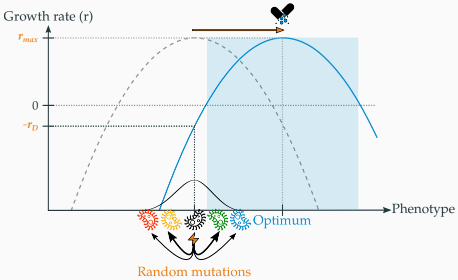

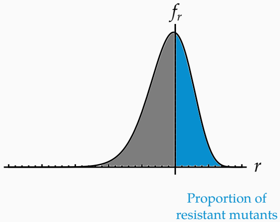

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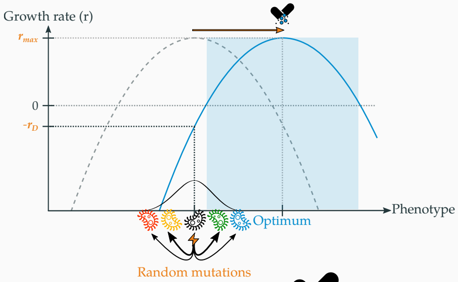

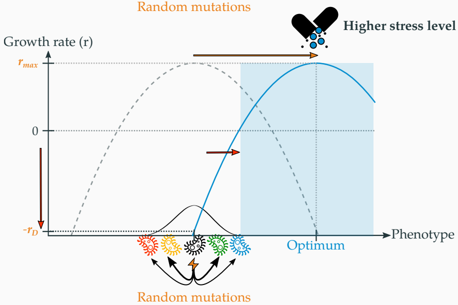

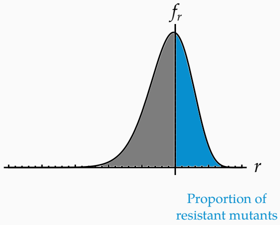

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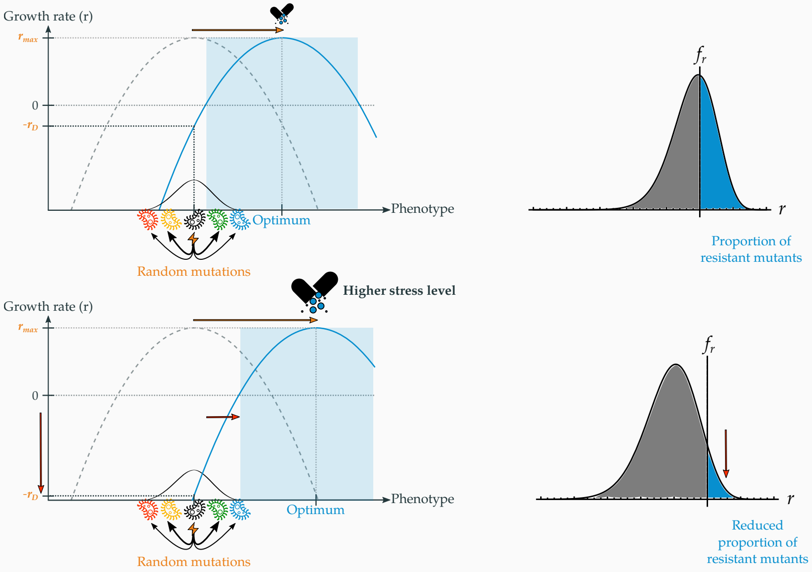
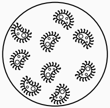


Mutation regimes

Rescue from a narrow genetic basis



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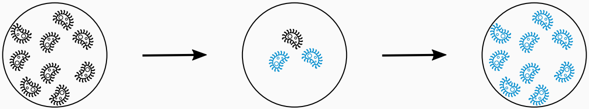

Mutation regimes

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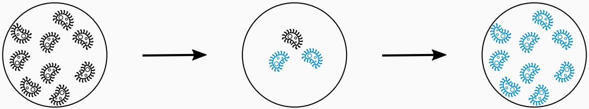


Low mutation rate regime

Stochastic demography

Stochastic evolution

Prediction of evolutionary rescue probabilities

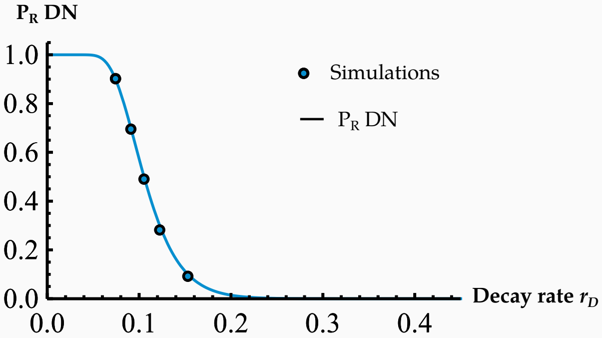
Probability of evolutionary rescue against stress

Exact numeric
solve

Probability of evolutionary rescue against stress

Exact numeric
solve

$$\mathrm{P_R\,DN} = f(U, r_D, r_{max}, \lambda, n)$$



Probability of evolutionary rescue against stress

Exact numeric
solve

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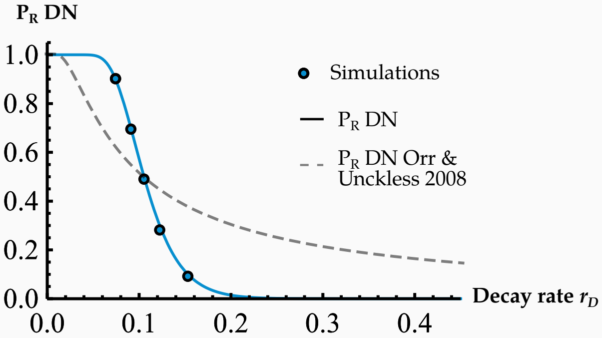


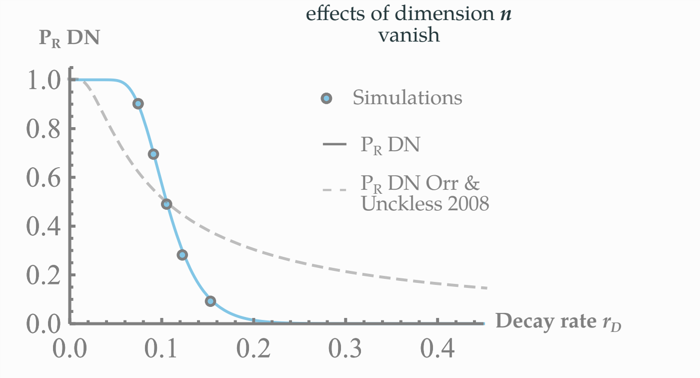
Probability of evolutionary rescue against stress

Exact numeric solve

Weak mutations effects approximation

$$\mathrm{P_R\,DN} = f(U, r_D, r_{max}, \lambda, n) \xrightarrow{\lambda \ll r_{max}}$$

effects of dimension ***n*** vanish



Probability of evolutionary rescue against stress

Exact numeric solve

Weak mutations effects approximation

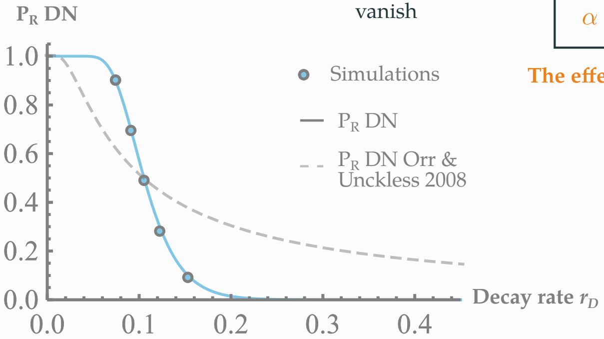
Approximated analytical closed form

$$\mathrm{P_R\,DN} = f(U, r_D, r_{max}, \lambda, n) \xrightarrow{\lambda \ll r_{max}} \mathrm{P_R\,DN} = f(U, \alpha)$$

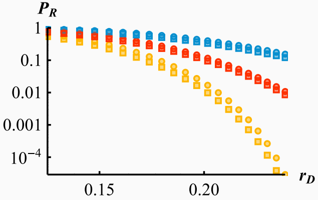
effects of dimension ***n*** vanish

$$\boxed{\alpha \approx \frac{r_D^2}{4\, r_{max}\, \lambda}}$$

The effective stress level



The effective stress level (α)

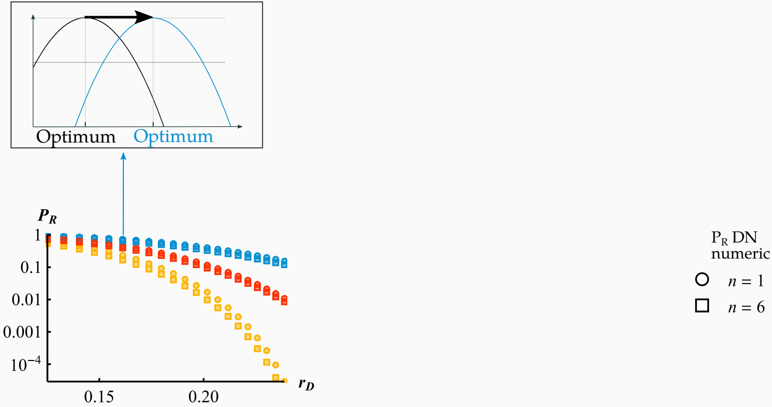


P_R DN
numeric

○ $n = 1$
□ $n = 6$

The effective stress level (α)

Change in r_D



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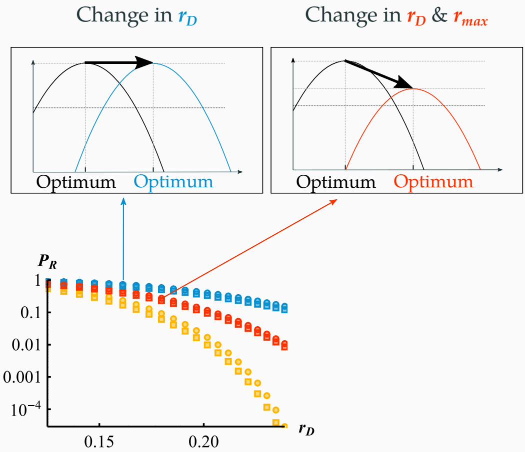

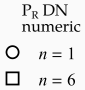

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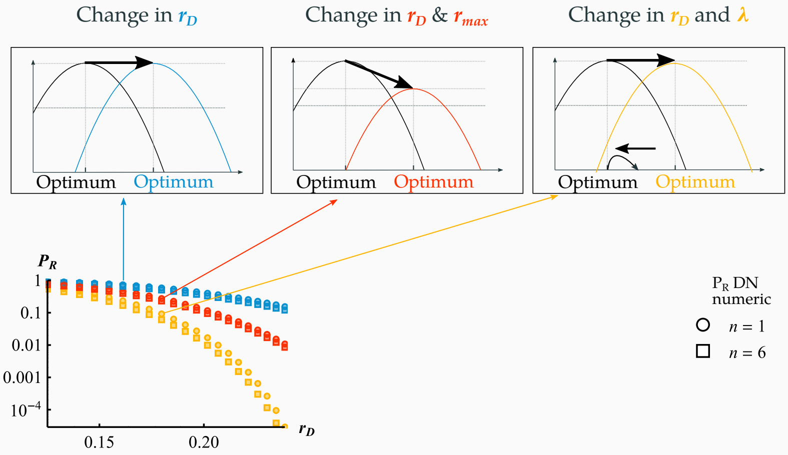
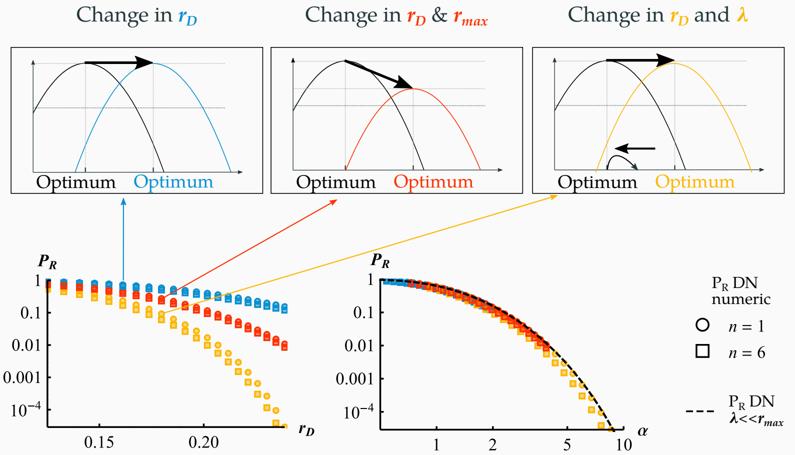
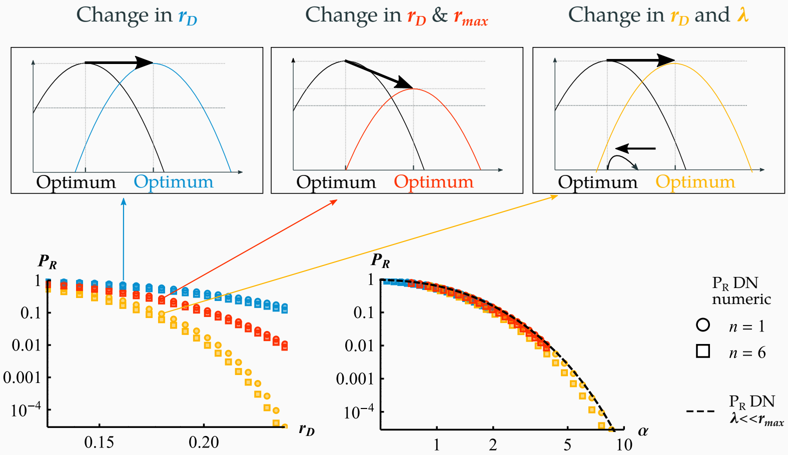


The effective stress level (α)

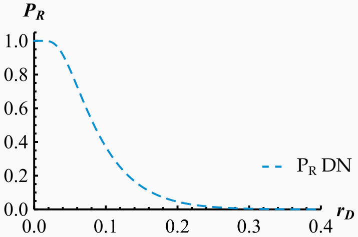


The effective stress level (α)

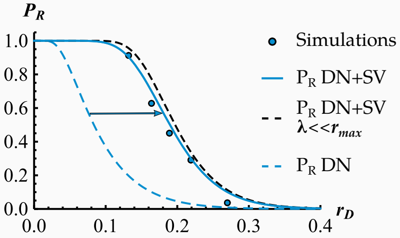


α summarizes the effect on the ER probability of **all the different scenarios** of stressing environmental change

Proportion of ER from standing variance

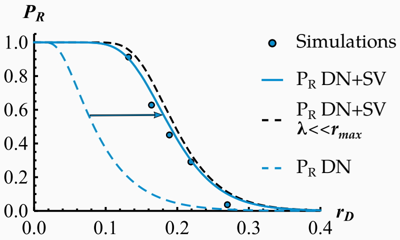


Proportion of ER from standing variance

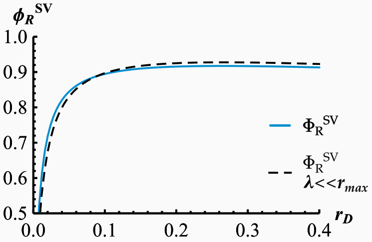


Population with standing genetic variance can withstand **higher stress**

Proportion of ER from standing variance

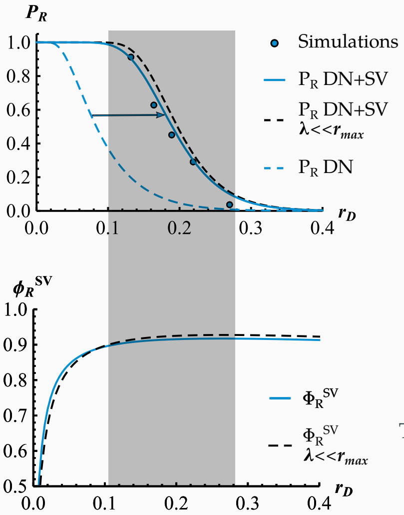


Population with standing genetic variance can withstand **higher stress**



ER is **more likely** from SV than from DN mutations

Proportion of ER from standing variance



Population with standing genetic variance can withstand **higher stress**

ER is **more likely** from SV than from DN mutations

The **proportion of ER from standing** variance is roughly constant with r_D

Summary

Sharper drop of ER probability with **context-dependence**

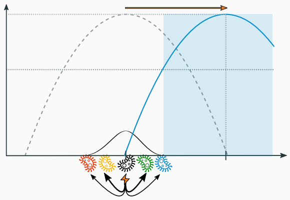
Multiple stress effects from the context dependence can be **summarized in α**

Proportion of rescue from standing variance always **higher** than from de novo mutations and **roughly stable with r_D**

Fitness accross environments and genotypes

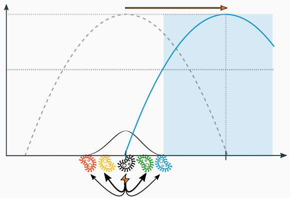
Landscape parametrization

Parametrized fitness landscape

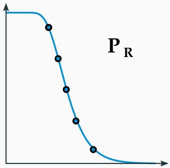


Landscape parametrization

Parametrized fitness landscape

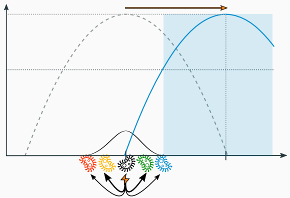


Quantitative predictions
on eco-evolutionary dynamics
across environments

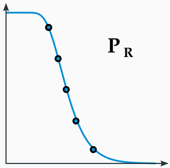


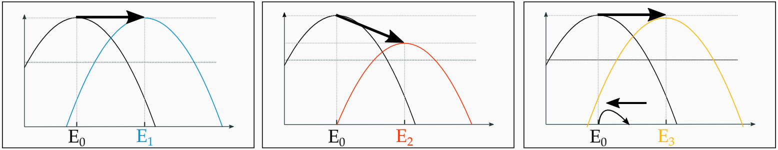
Landscape parametrization

Parametrized fitness landscape

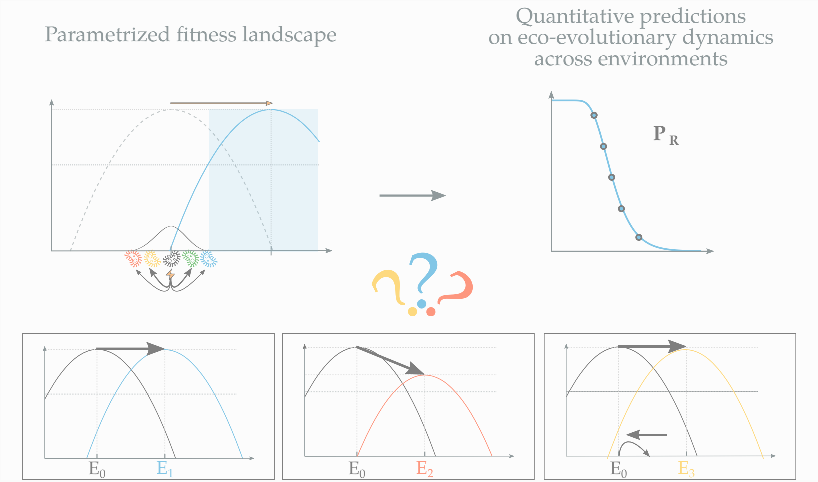


Quantitative predictions
on eco-evolutionary dynamics
across environments





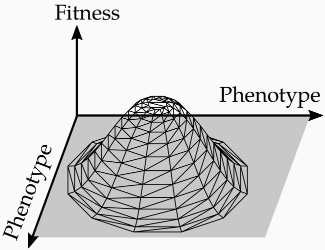
Landscape parametrization



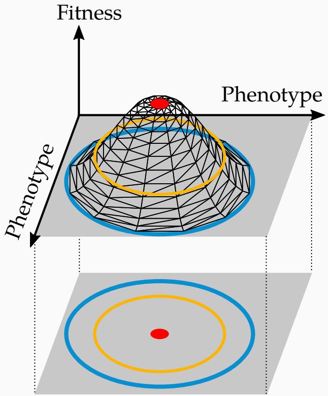
How to **parametrize** the landscape across environments ?
How to **predict fitness changes** across environments ?

Landscape parametrization

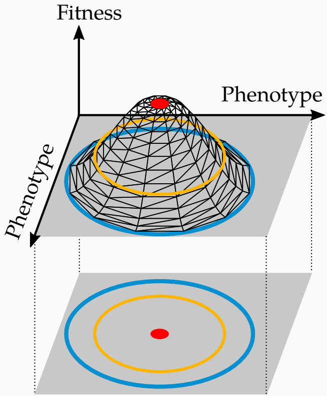
Landscape parametrization

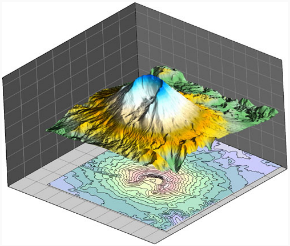


Landscape parametrization

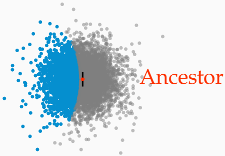


Landscape parametrization

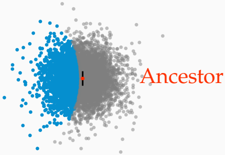


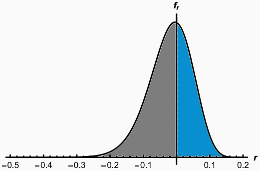


Landscape parametrization



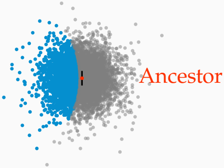
Landscape parametrization

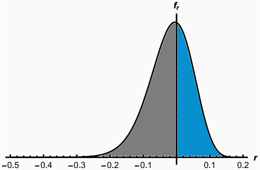




Distribution of fitness effects
(DFE)

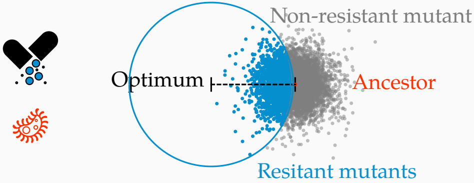
Landscape parametrization

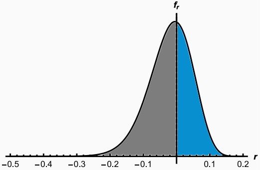




Distribution of fitness effects (DFE)

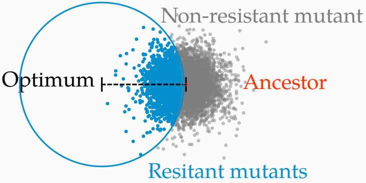
Landscape parametrization

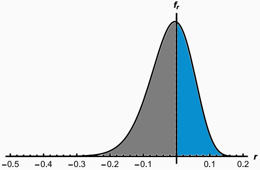




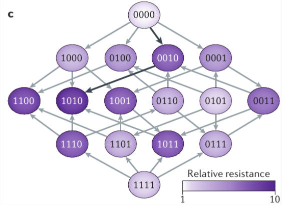
Distribution of fitness effects (DFE)

Landscape parametrization

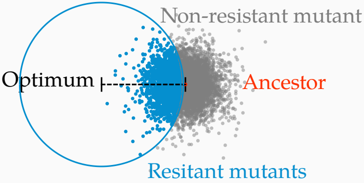


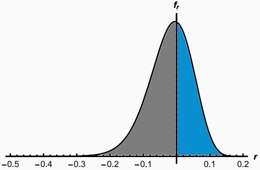


Distribution of fitness effects (DFE)

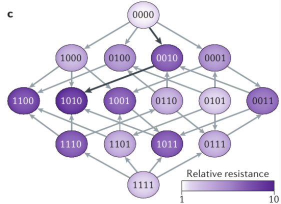


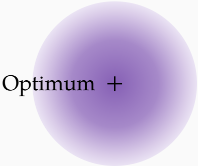
Landscape parametrization



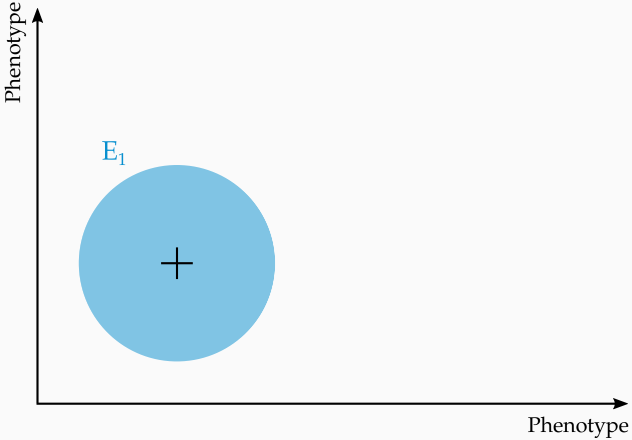


Distribution of fitness effects (DFE)

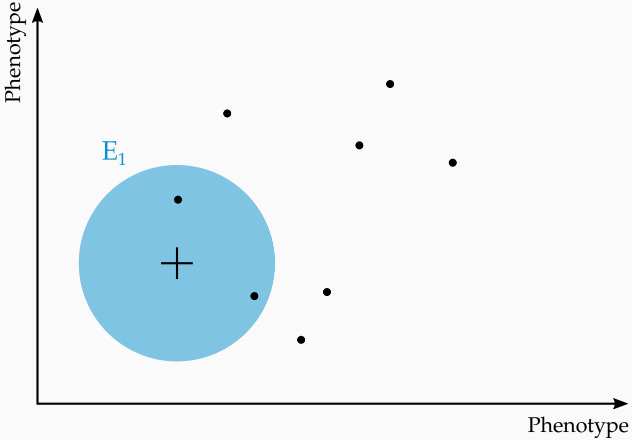




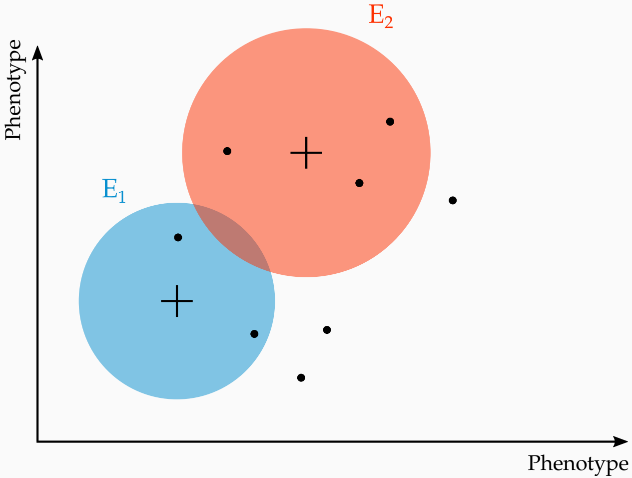
Mapping across environments and genotypes



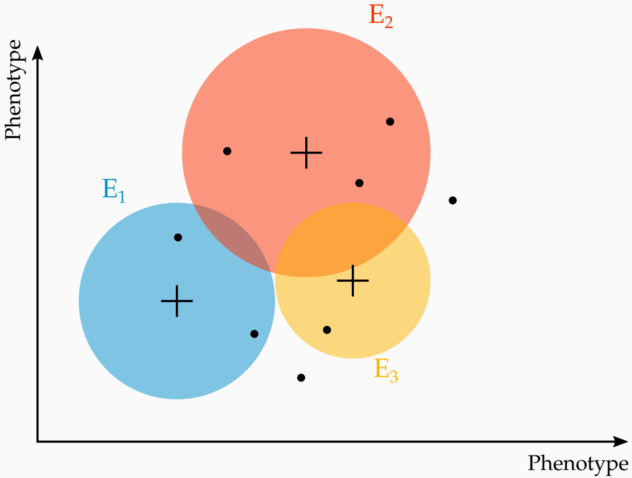
Mapping across environments and genotypes



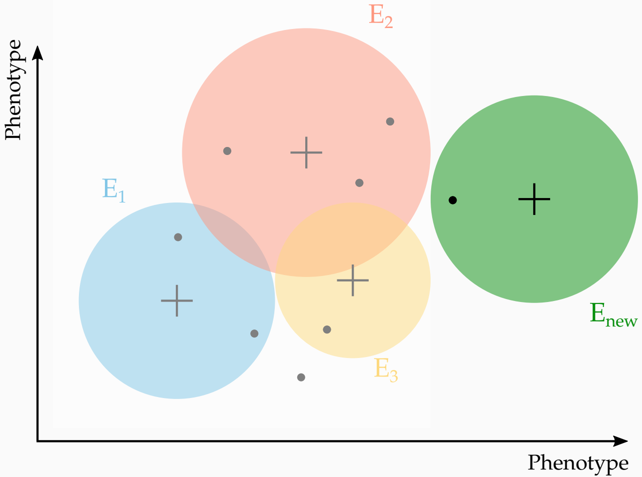
Mapping across environments and genotypes



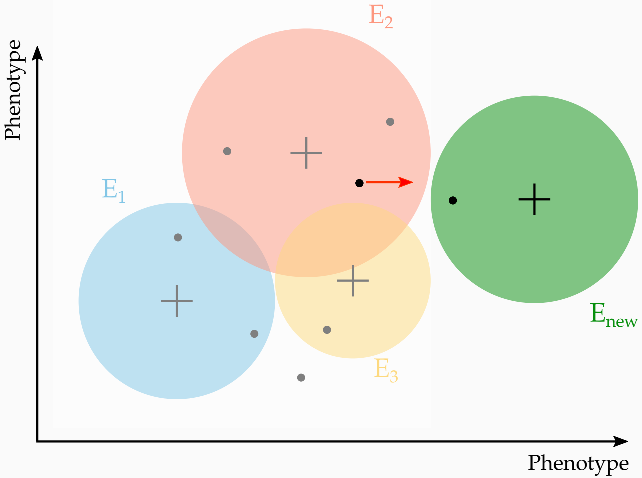
Mapping across environments and genotypes



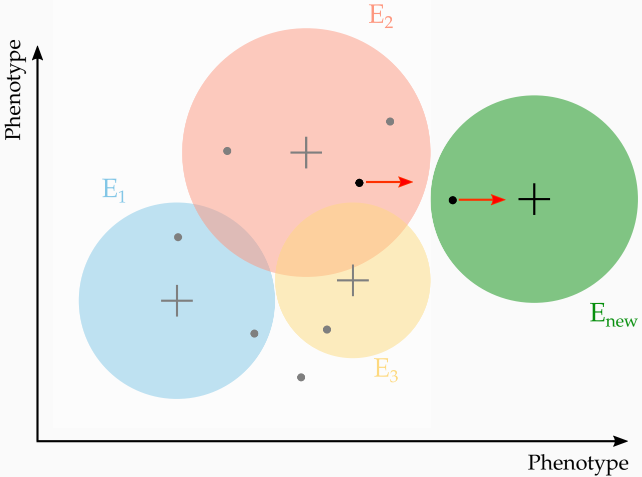
Mapping across environments and genotypes



Mapping across environments and genotypes

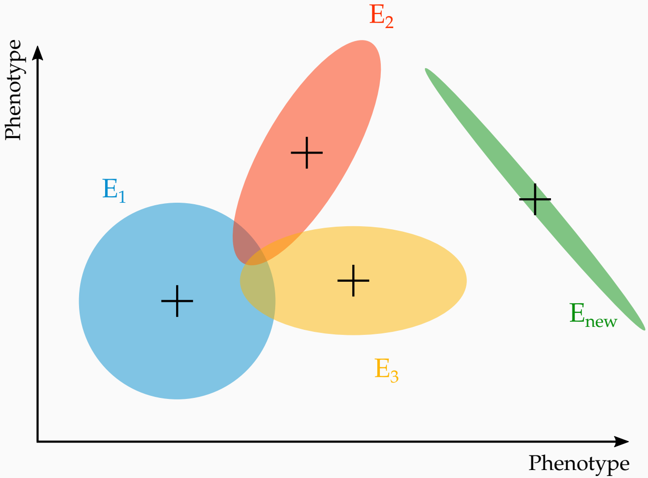


Mapping across environments and genotypes

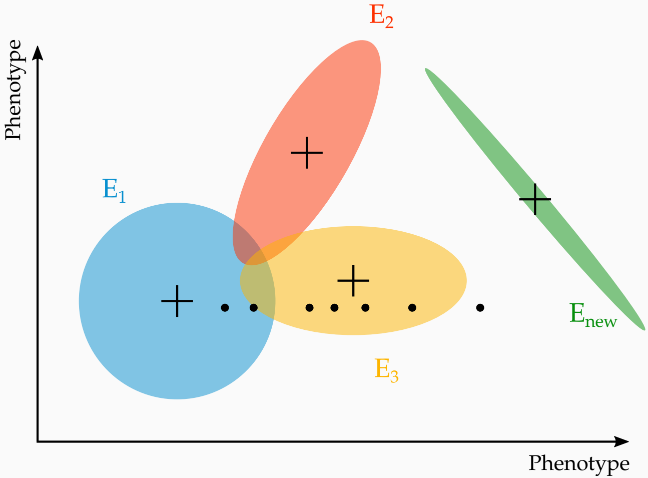


Prediction of fitness **across environments** and **genotypes**

Mapping across environments and genotypes



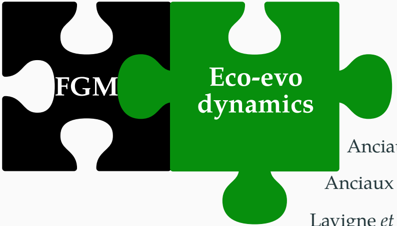
Mapping across environments and genotypes



Anisotropy and **partial pleiotropy**

Conclusions and Perspectives

Conclusions and Perspectives



Anciaux *et al.* (2018)

Anciaux *et al.* (in prep)

Lavigne *et al.* (in review)

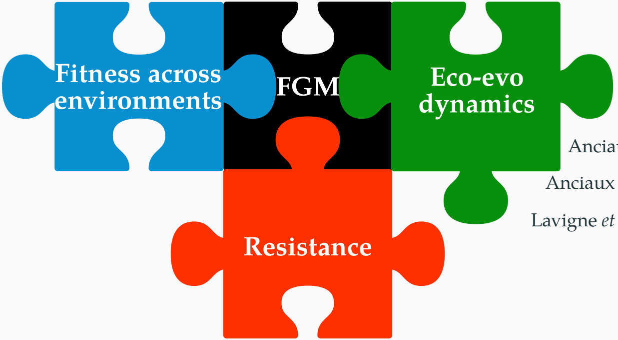
Conclusions and Perspectives

Anciaux *et al.* (2018)

Anciaux *et al.* (in prep)

Lavigne *et al.* (in review)

Conclusions and Perspectives



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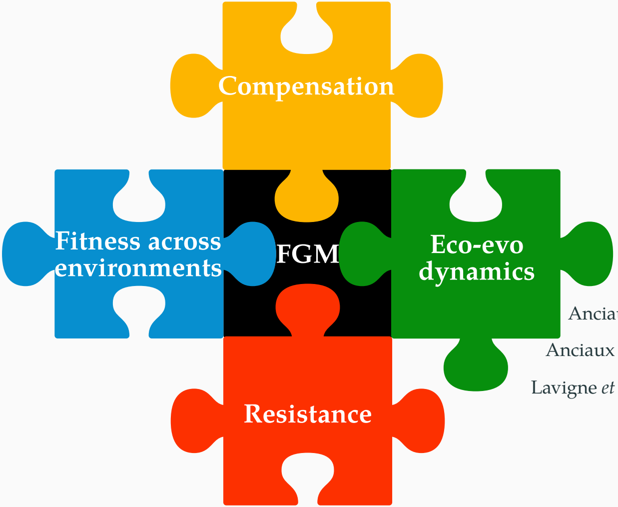
Conclusions and Perspectives



Anciaux *et al.* (2018)

Anciaux *et al.* (in prep)

Lavigne *et al.* (in review)

THANK YOU !

Rescue project

Guillaume Martin

Ophélie Ronce

Lionel Roques

Amaury Lambert

Luis-Miguel Chevin

Resistance across environment project

Thomas Bataillon

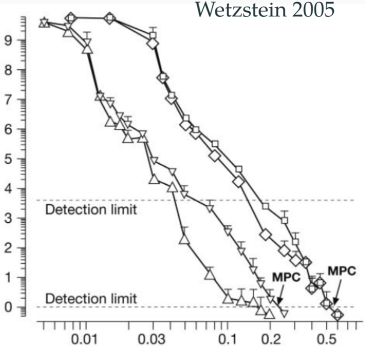
Claudia Bank

Appendix

Available data

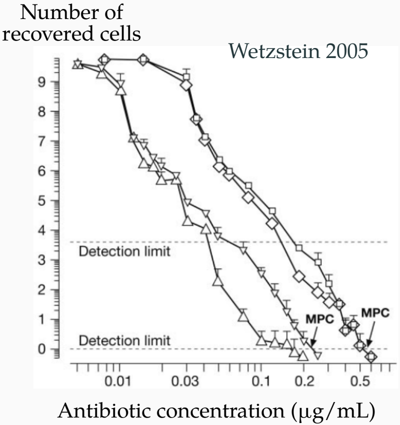
Number of
recovered cells

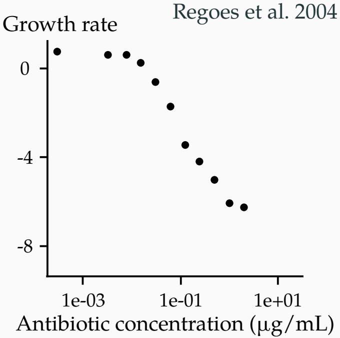
Wetzstein 2005



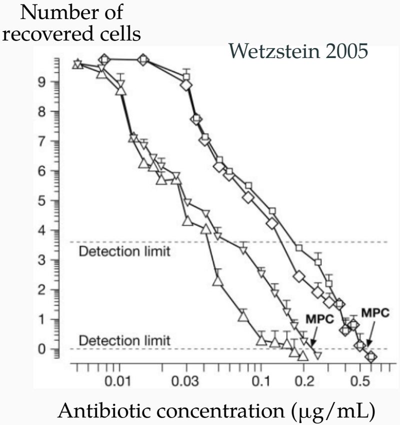
Antibiotic concentration (μg/mL)

Available data

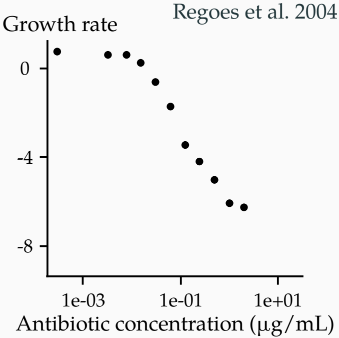




Available data

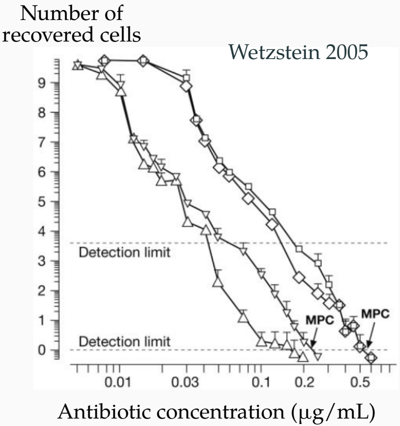


E.coli ATCC8739
Pradofloxacin
Medium USP



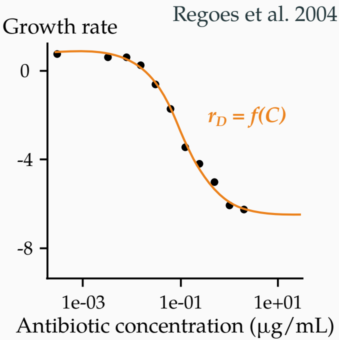
E.coli CAB1
Ciprofloxacin
Medium LB

Available data



E.coli ATCC8739
Pradofloxacin
Medium USP

Relationship between **antibiotic concentration C** and **decay rates r_D**

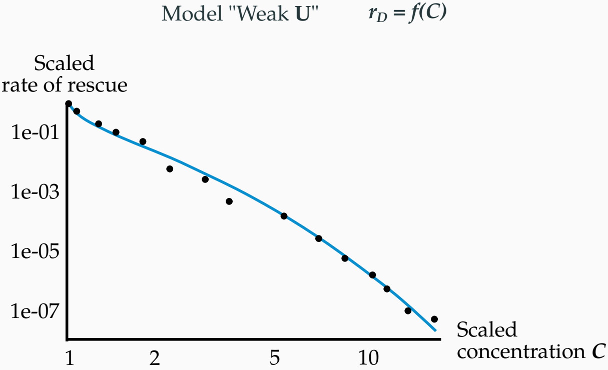


E.coli CAB1
Ciprofloxacin
Medium LB

Available data

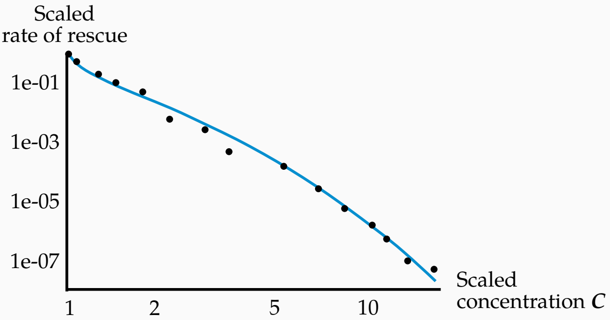
Model "Weak **U**" $\boldsymbol{r_D = f(C)}$

Available data



Available data

Model "Weak **U**" $r_D = f(C)$



The model combining the "Weak U" model and the function $r_D = f(C)$
has too many parameters.

The model gives a better visual fit than a model without context-dependence