Some thoughts and challenges about minimum viable populations and extinction

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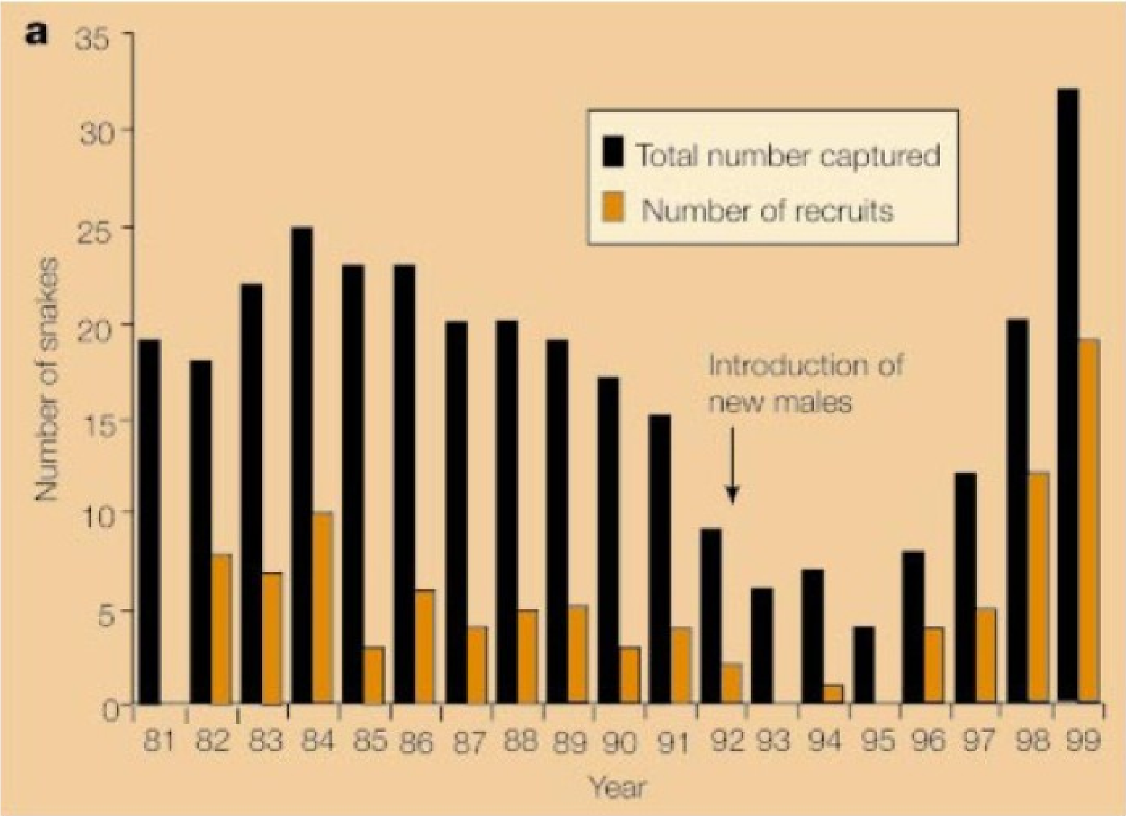
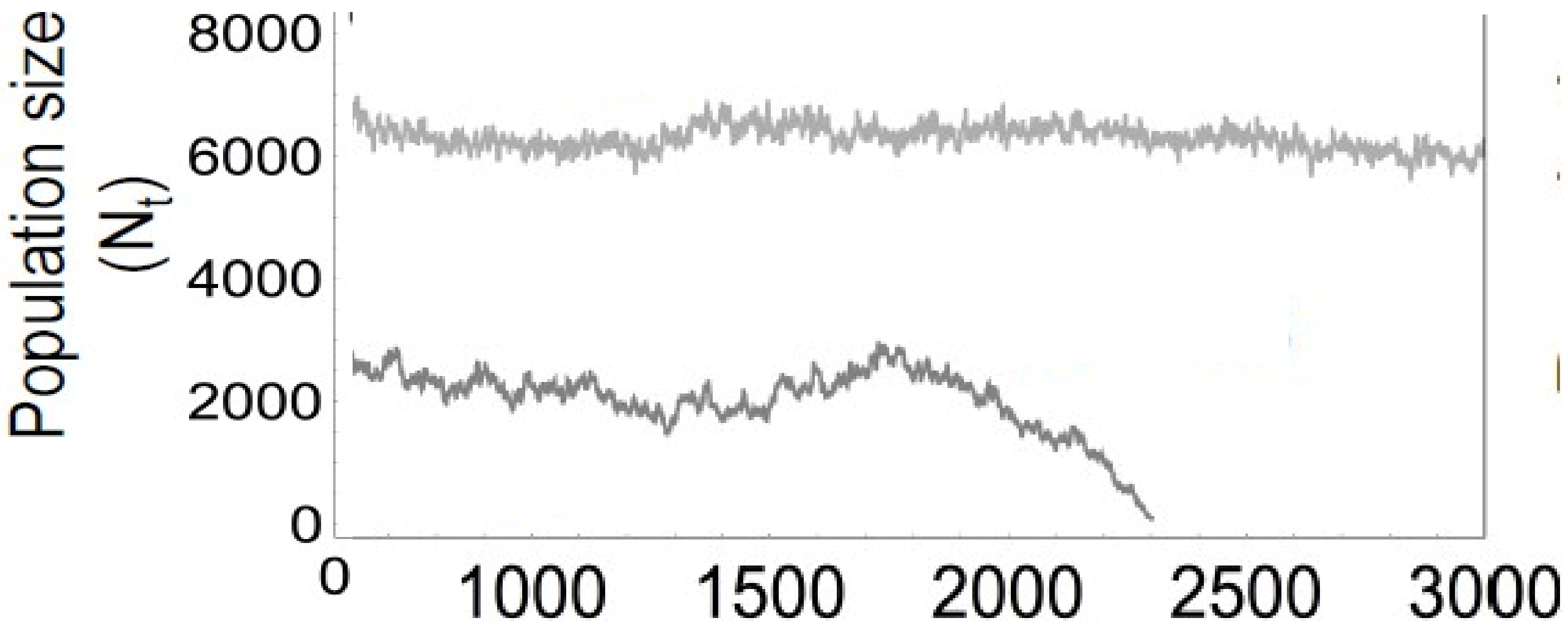
Angers, SMEEG 2013.

Minimum Viable Population:
A major question in fundamental and applied ecology

- Why and how often populations and species go extinct?
- Which species are in danger, degree of danger (IUCN Red List, etc.) ?
- Arbitrage of resources sharing for the conservation of biodiversity
- Management guides for ecological engineering

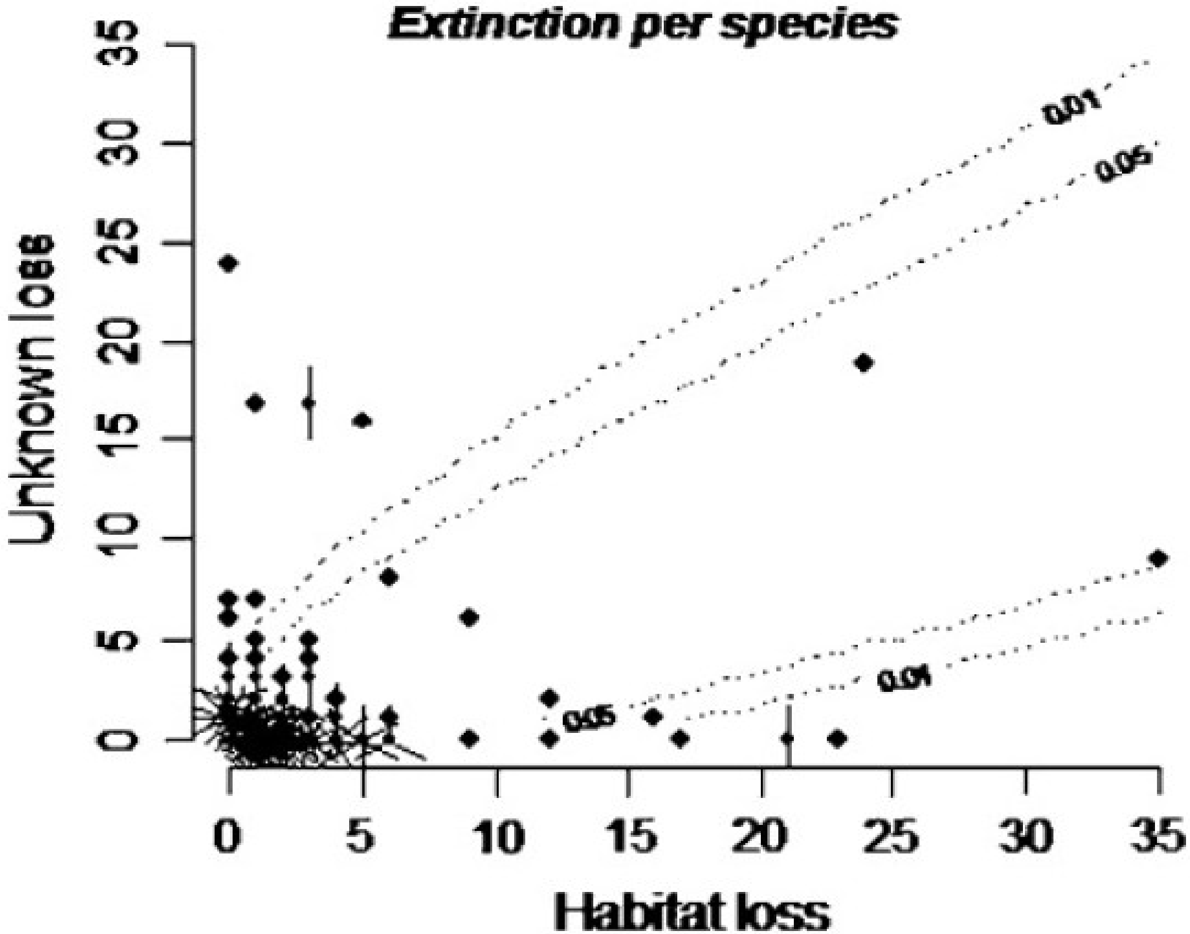


Madsen et al. 1999



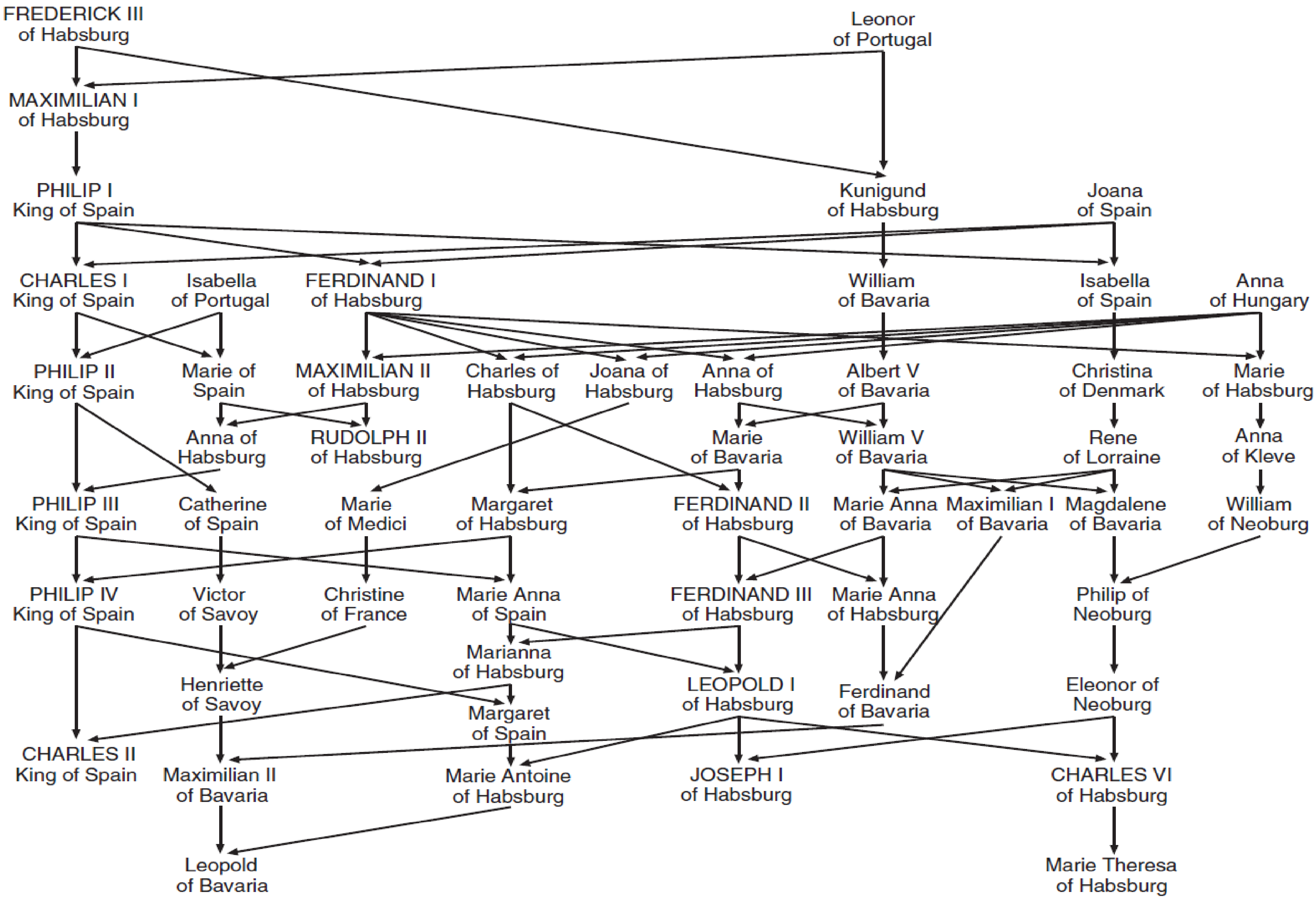
- Environmental (stochastic) change
- Demographic stochasticity
- Genetic stochasticity

Habitat loss and extinction



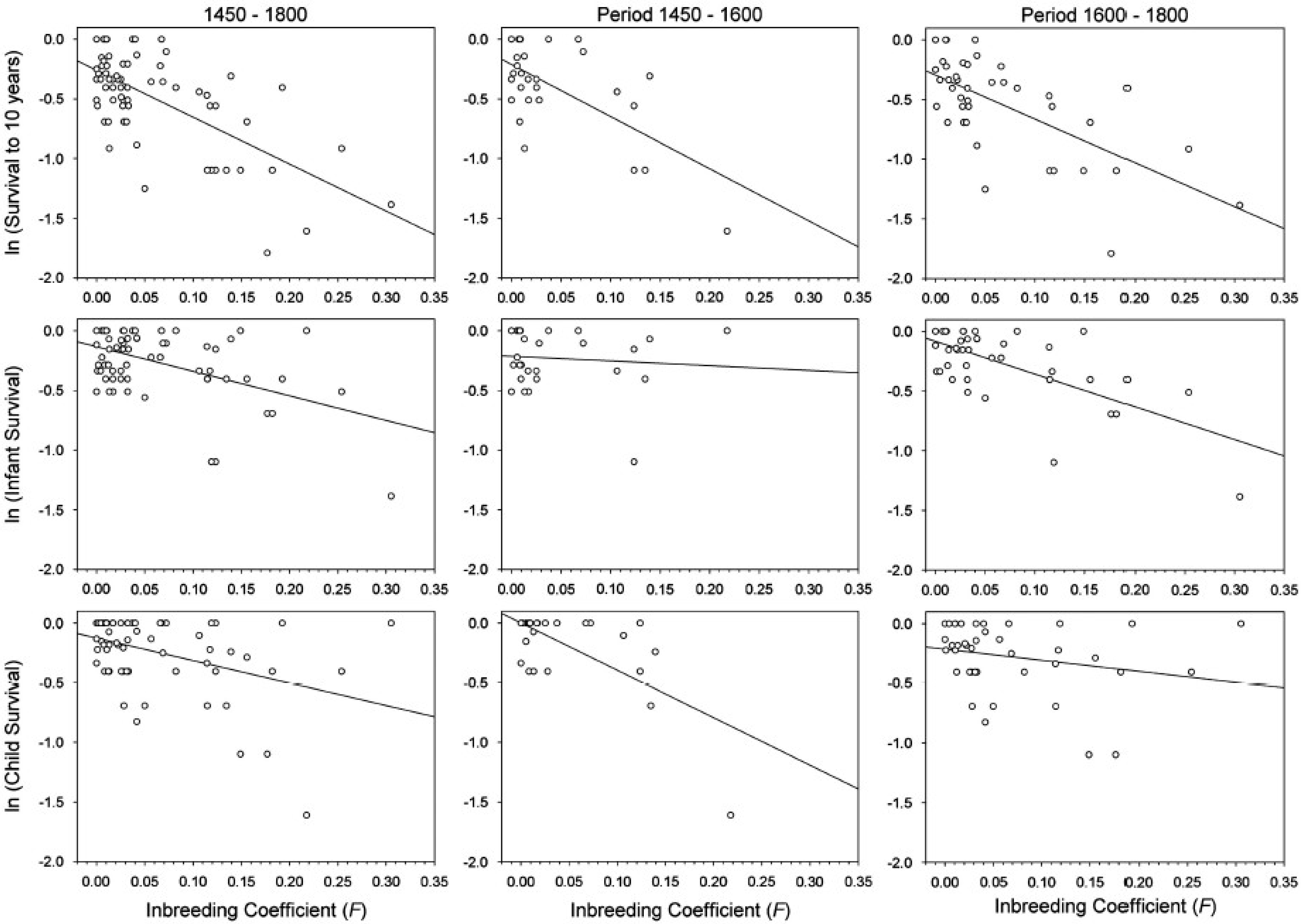
Bonelli et al. 2011

Inbreeding depression and extinction: the Habsburg dynasty



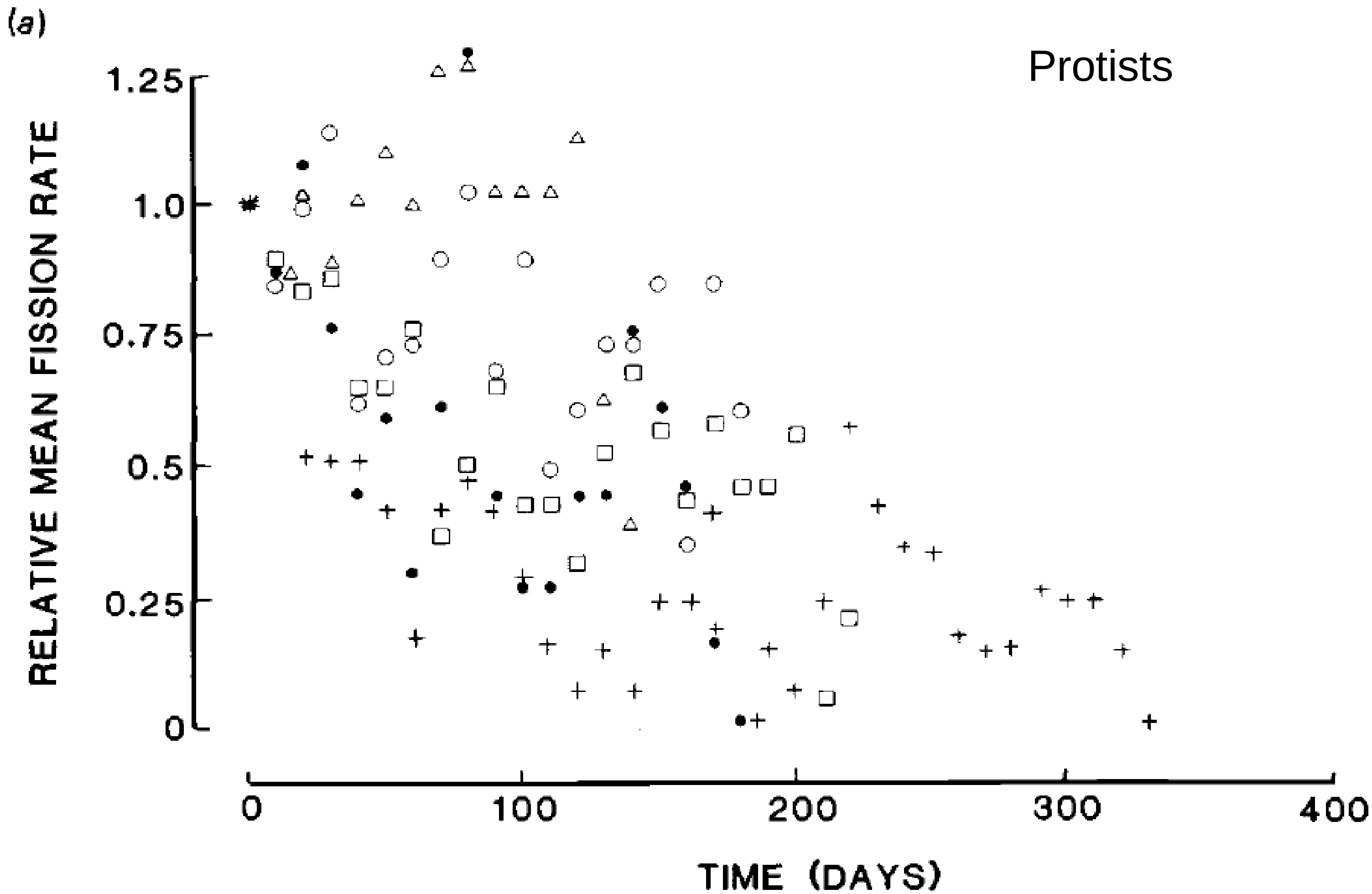
Ceballos and Alvarez 2013

Inbreeding depression and extinction: the Habsburg dynasty



Ceballos and Alvarez 2013

Fixation of deleterious mutations and extinction



Bell 1989

But only in very small populations? (Lynch 1995, Coron et al. 2013)

Most species are not driven to extinction before genetic factors impact them

Derek Spielman*†, Barry W. Brook‡, and Richard Frankham*§¶‖

PNAS | October 19, 2004 | vol. 101 | no. 42 | 15261–15264

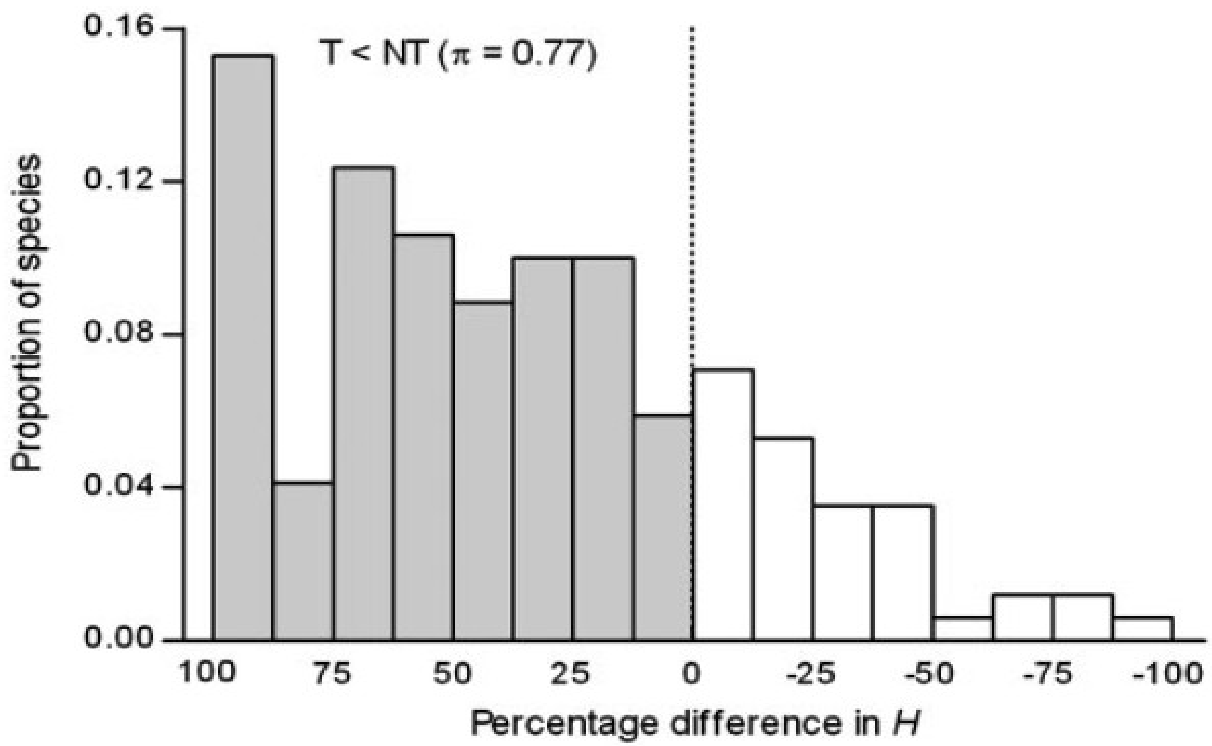


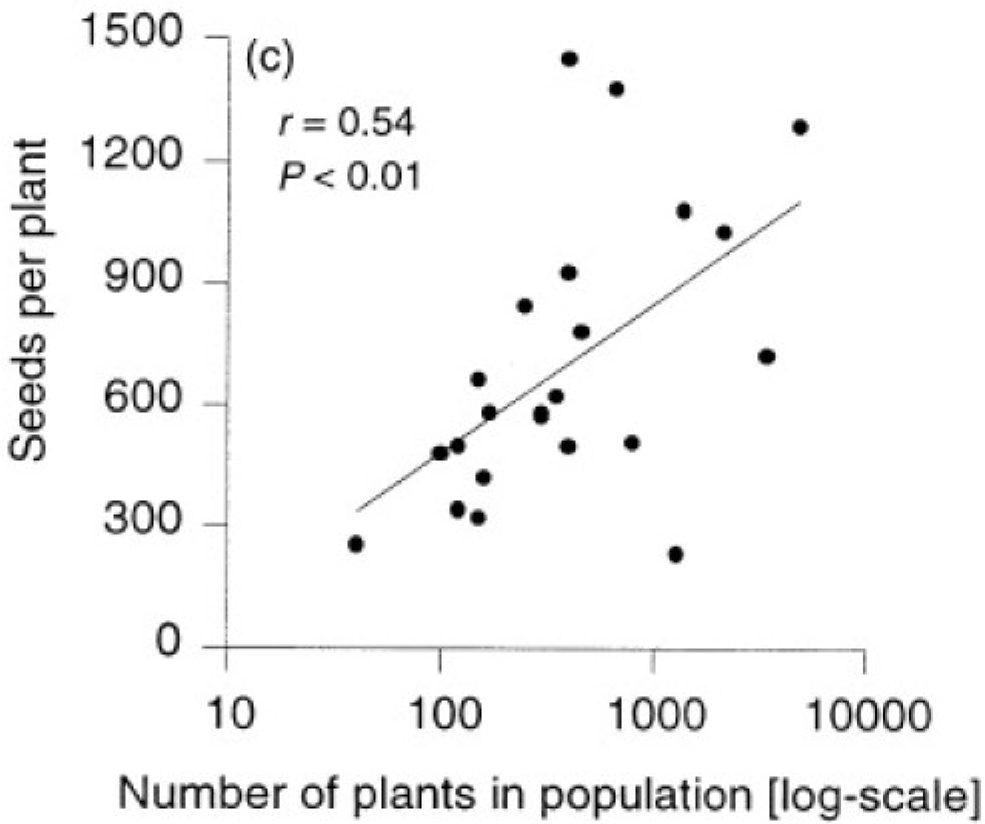
Fig. 1. Distribution of percentage differences in heterozygosity (H) between threatened (T) and taxonomically related nonthreatened taxa (NT). π is the proportion of taxa for which T $<$ NT, indicated by the shaded bars.

A school of red herring: reply to Frankham *et al.*

Ian G. Jamieson[1] and Fred W. Allendorf[2] *TREE 2013*

We believe that Frankham *et al*. place excessive weight on inbreeding depression in very large populations and the potential risk of extinction associated with reduced selection response in future environments.

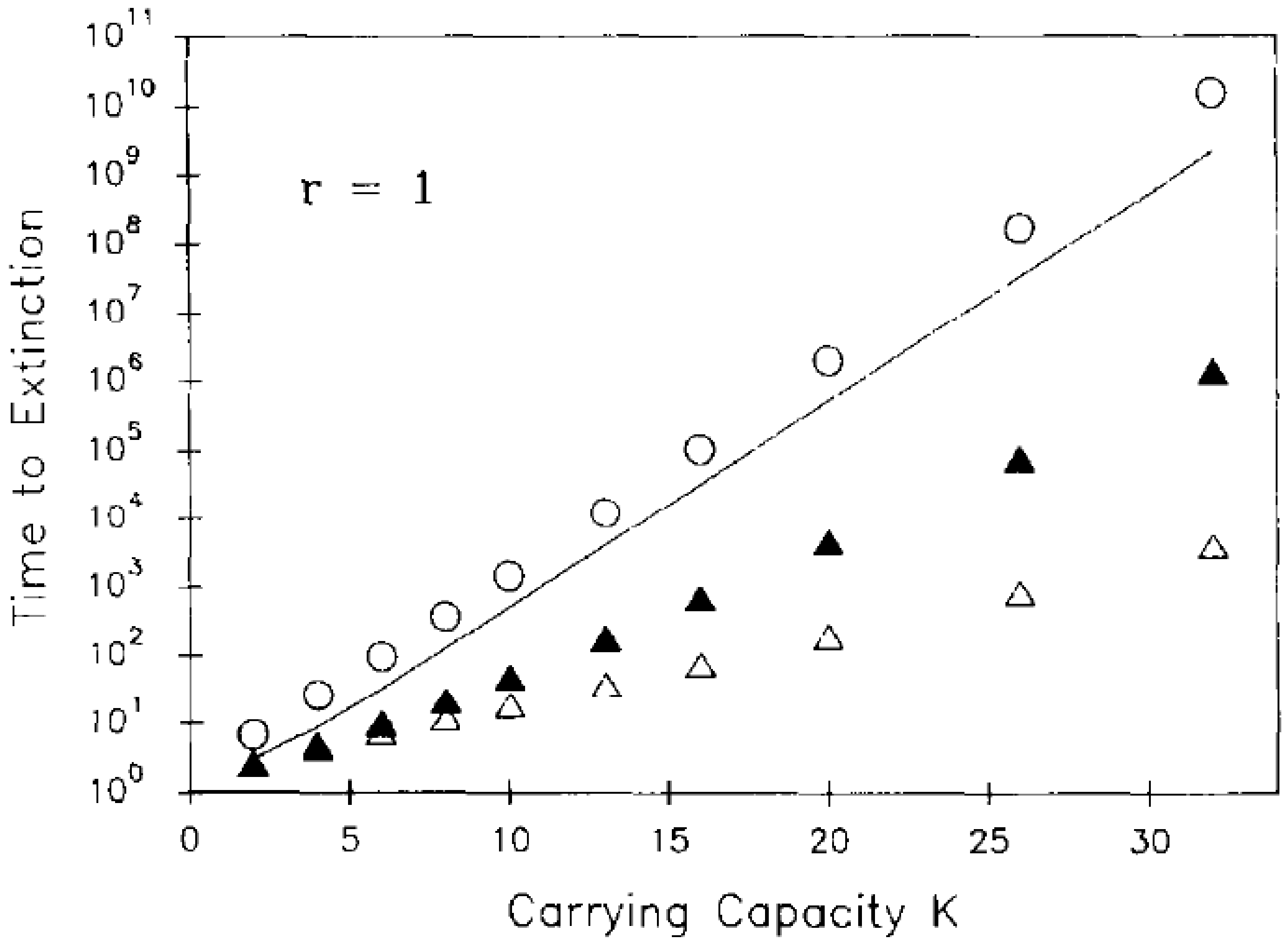
Correlation between reproductive rate and population size, cause or consequence?



Fischer and Matthies 1998
Gentianella germanica

The rules of the dozens/hundreds: demographic stochasticity

$$N(t+1) = F(N(t)),$$



Nc >10-100

Gabriel and Bürger (1992)

The rules of the dozens/hundreds: genetic stochasticity (Franklin 1989)

Ne >50-500

Ne = effective population size = inverse of the coalescent rate

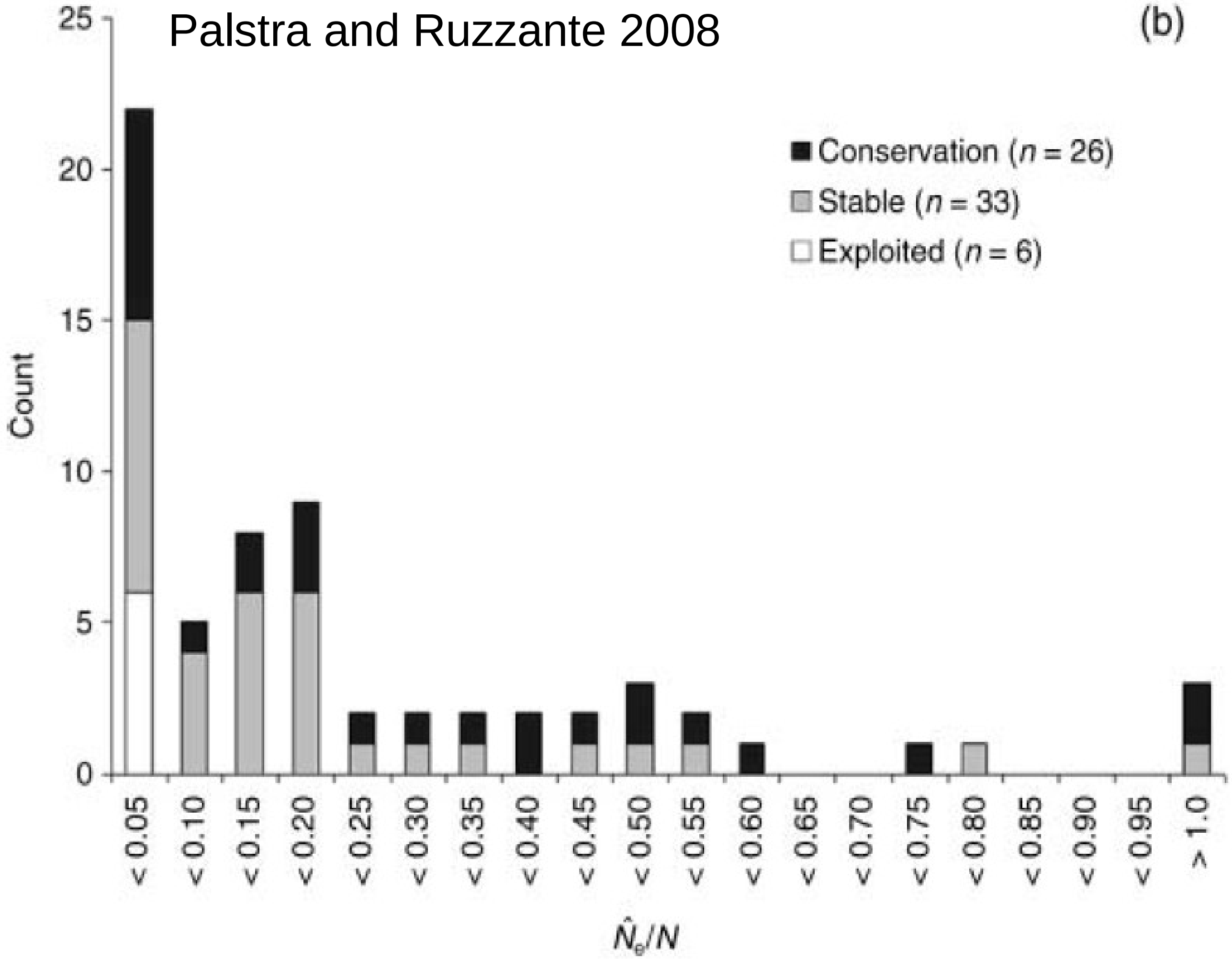
- Ne > 50 to avoid extinction because of deleterious mutations in the short-term

(rule-of-thumb from empirical knowledge of animal breeders)

- Ne > 500 to allow for fast enough adaptation in changing environment

(from classical population genetics and quantitative genetics, estimated for a neutral trait and the number of bristle in *Drosophila*)

The rules of the dozens/hundreds : Ne *vs*. Nc

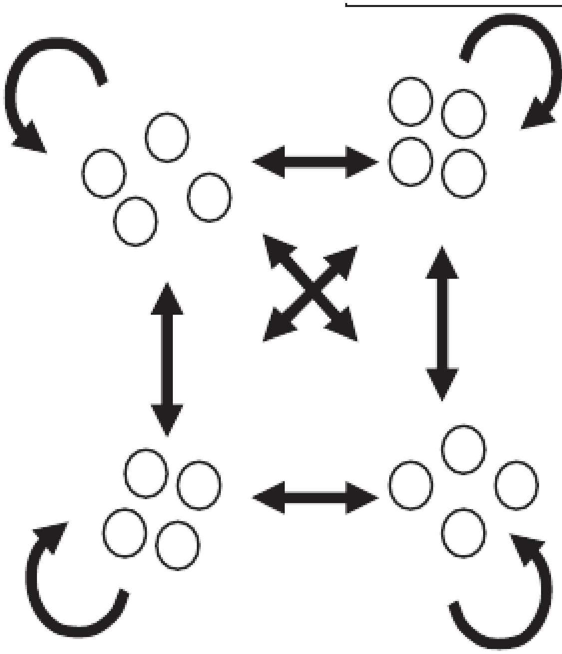


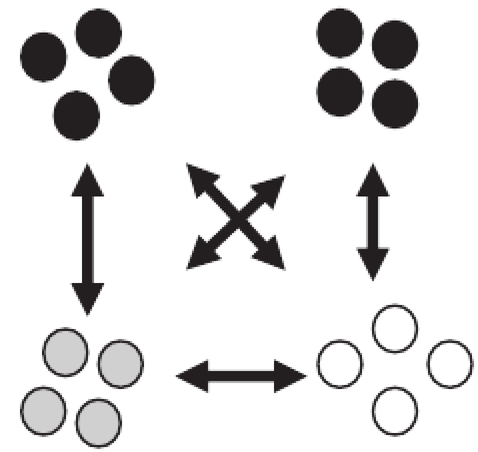
→ Rule of the Nc >500-5000?

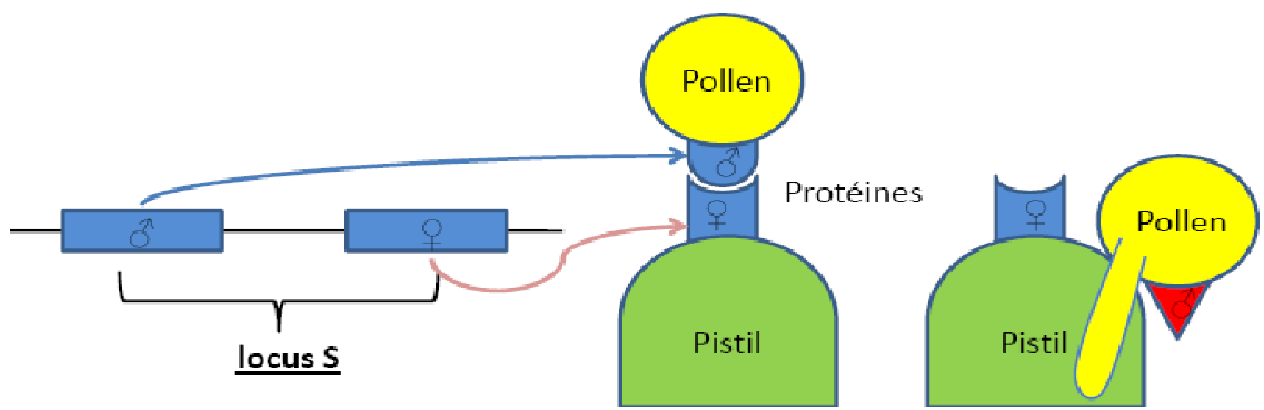
Synthesis and questions

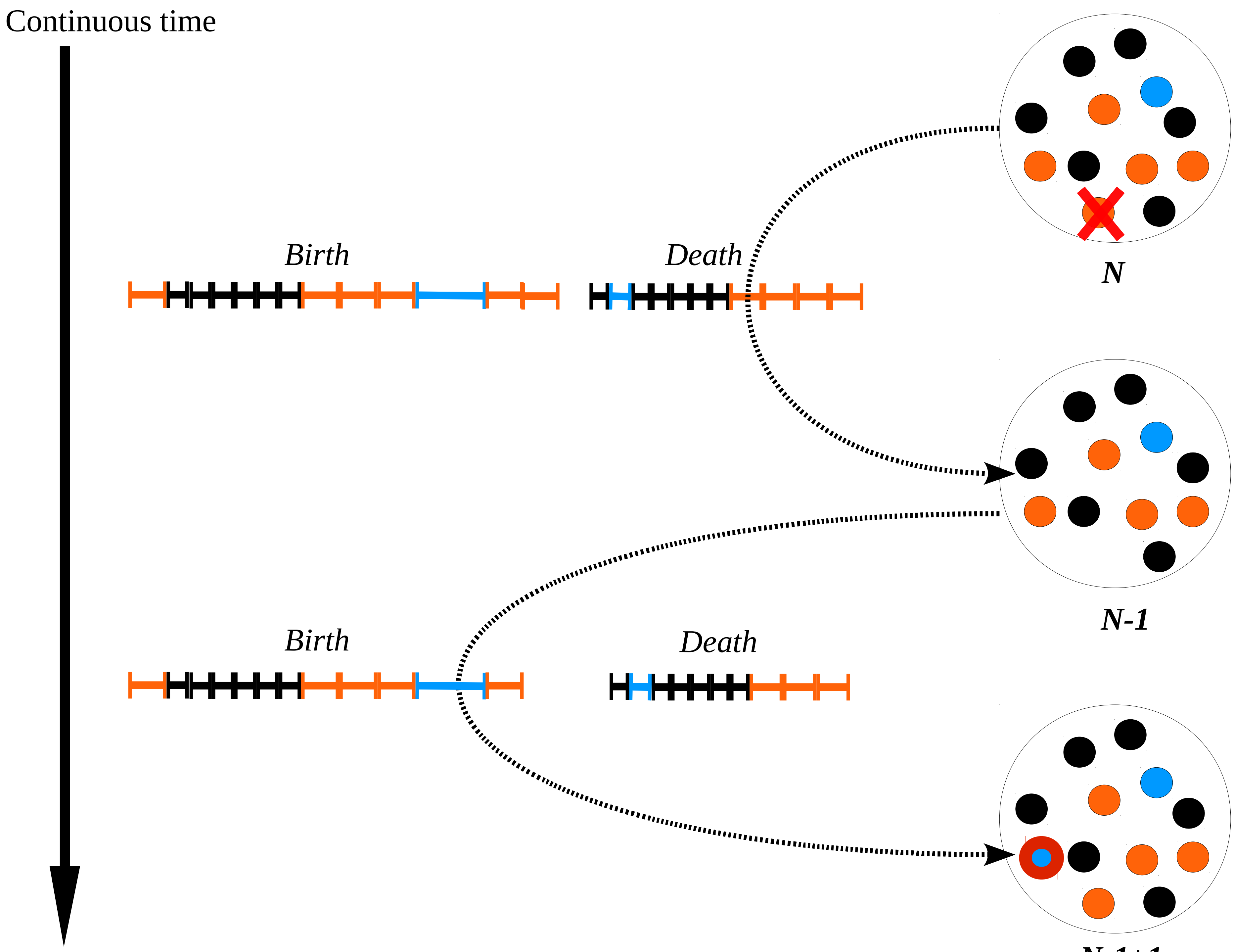
- A fundamental problem where stochastic models are necessary
- Reliability of the 10-100 and 50-500 rules?
- What about the interaction between Ne and Nc?
- Can we get rid of the (sterile) controversy?
- Which tool for ecological engineering?

First example: viability of self-incompatible plants populations and the importance of ***Nc*** *(with V.C. Tran)*








Continuous time
Birth
Death
N
N-1
Birth
Death
N-1+1

Sexual reproduction, mendelian segregation, self-incompatibility

$$r_{uv} = r \left[\frac{1}{2} \sum_{u'} \left(N_{uu'} p^{vv}_{uu'} + N_{vv} p^{uu'}_{vv} \right) + \frac{1}{2} \sum_{v'} \left(N_{uu} p^{vv'}_{uu} + N_{vv'} p^{uu}_{vv'} \right) + \frac{1}{4} \sum_{u' \neq u} \sum_{v' \neq v} \left(N_{uu'} p^{vv'}_{uu'} + N_{vv'} p^{uu'}_{vv'} \right) \right], \qquad u \neq v$$

$$r_{uu} = r \left[\frac{1}{2} \sum_{u'} N_{uu'} p^{uu'}_{uu'} + \frac{1}{2} \sum_{v'} N_{uu} p^{uv'}_{uu} + \frac{1}{4} \sum_{u' \neq u} \sum_{v' \neq u} N_{uu'} p^{uv'}_{uu'} \right] .$$

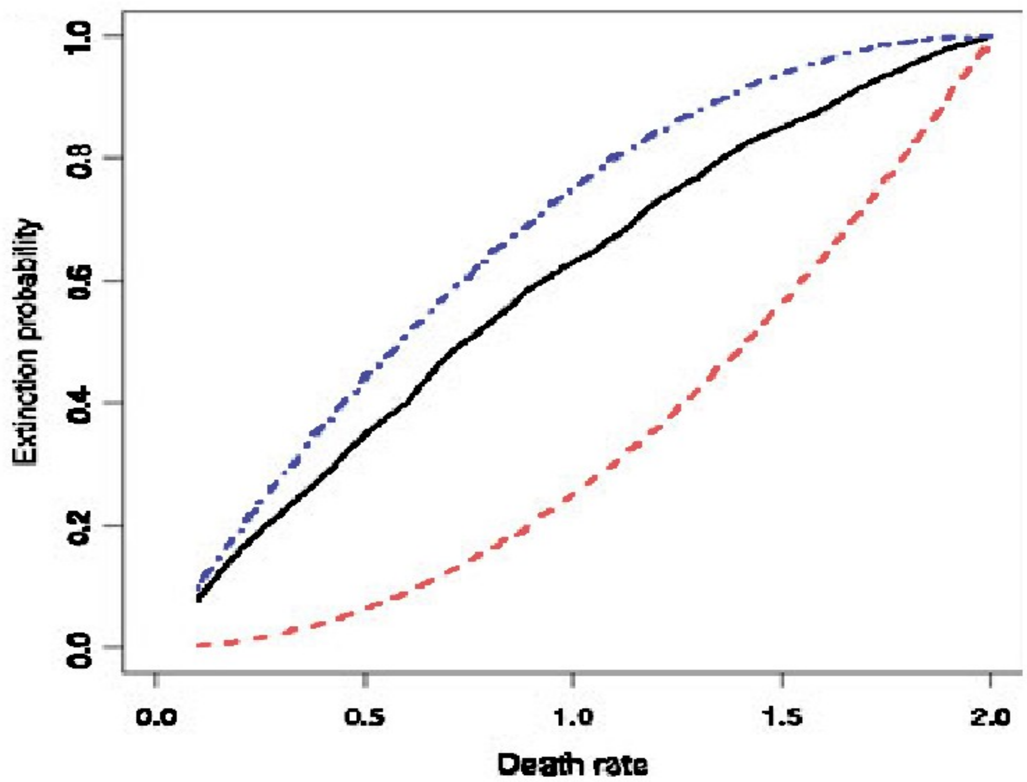
$$N^t_{uv} = N^0_{uv} + \int_0^t \left(r_{uv}(Z_s) - q N^s_{uv} \right) ds + M^t_{uv}$$

(Billiard et Tran. 2012)

Most simple case: distyly

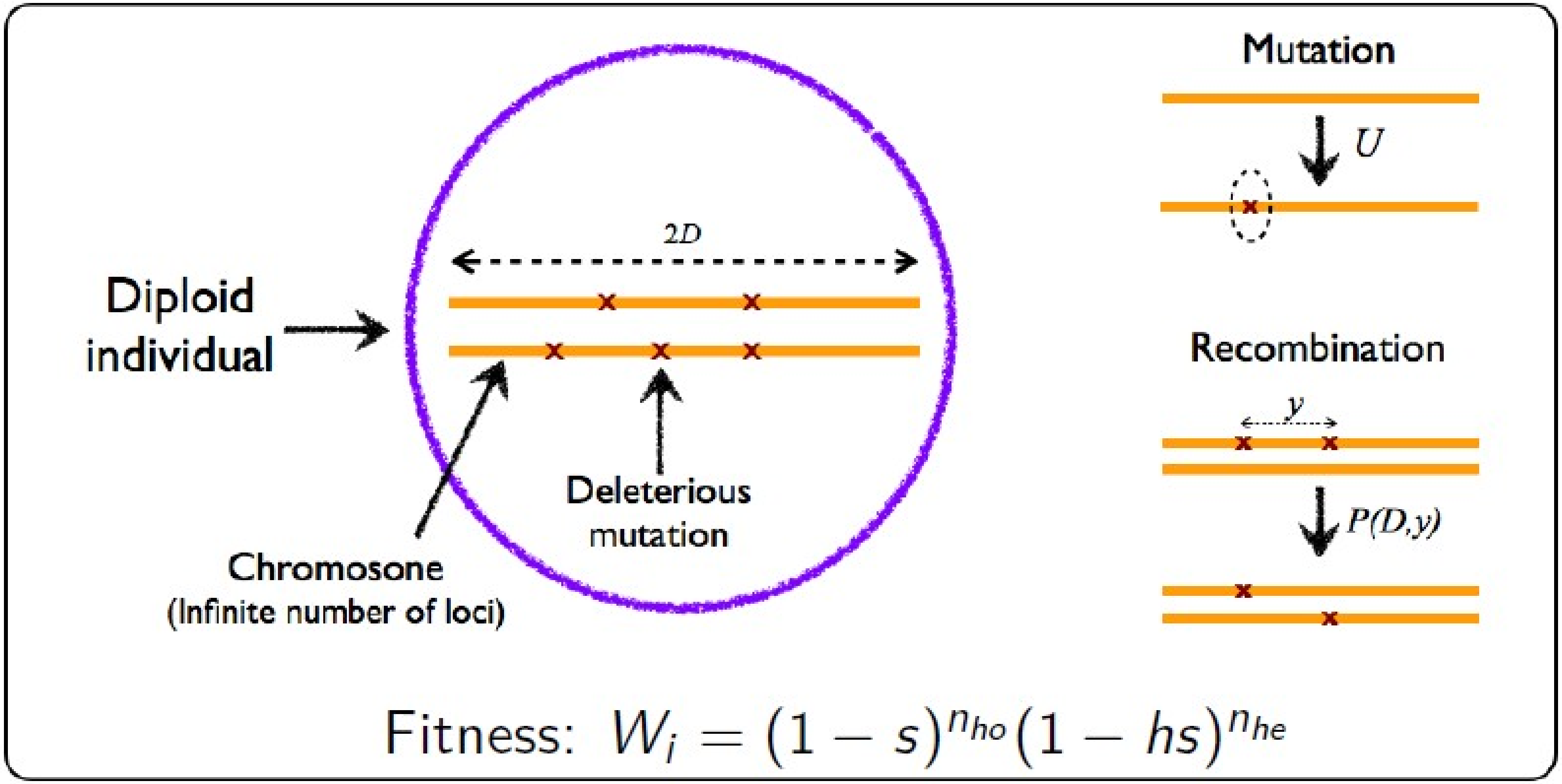
Probability of extinction

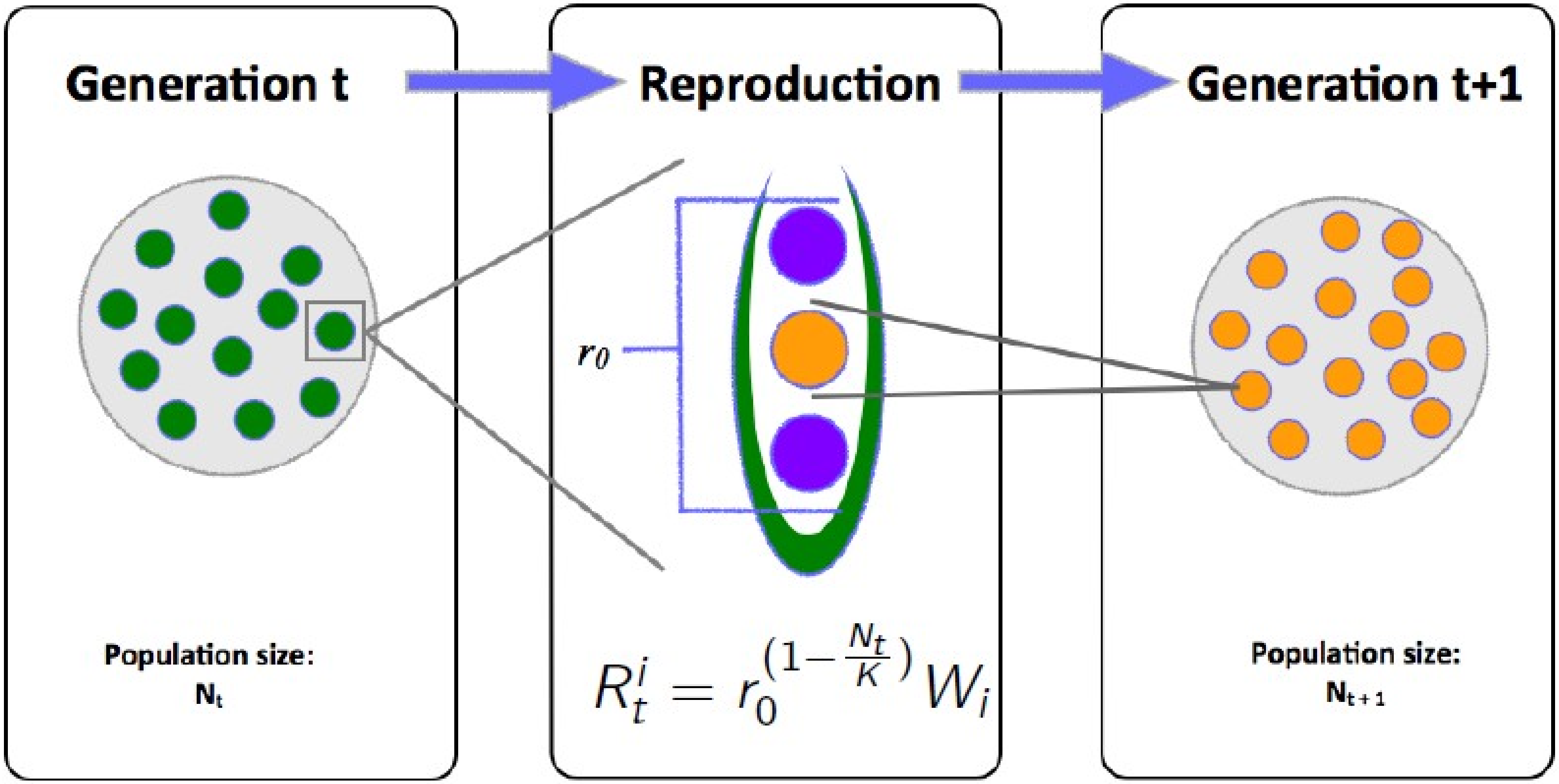
$$\left(\frac{q}{r}\right)^{i+j} \leq \xi_{i,j} \leq \left(\frac{q}{r}\right)^{i} + \left(\frac{q}{r}\right)^{j} - \left(\frac{q}{r}\right)^{i+j}$$



(Billiard et Tran. 2012)

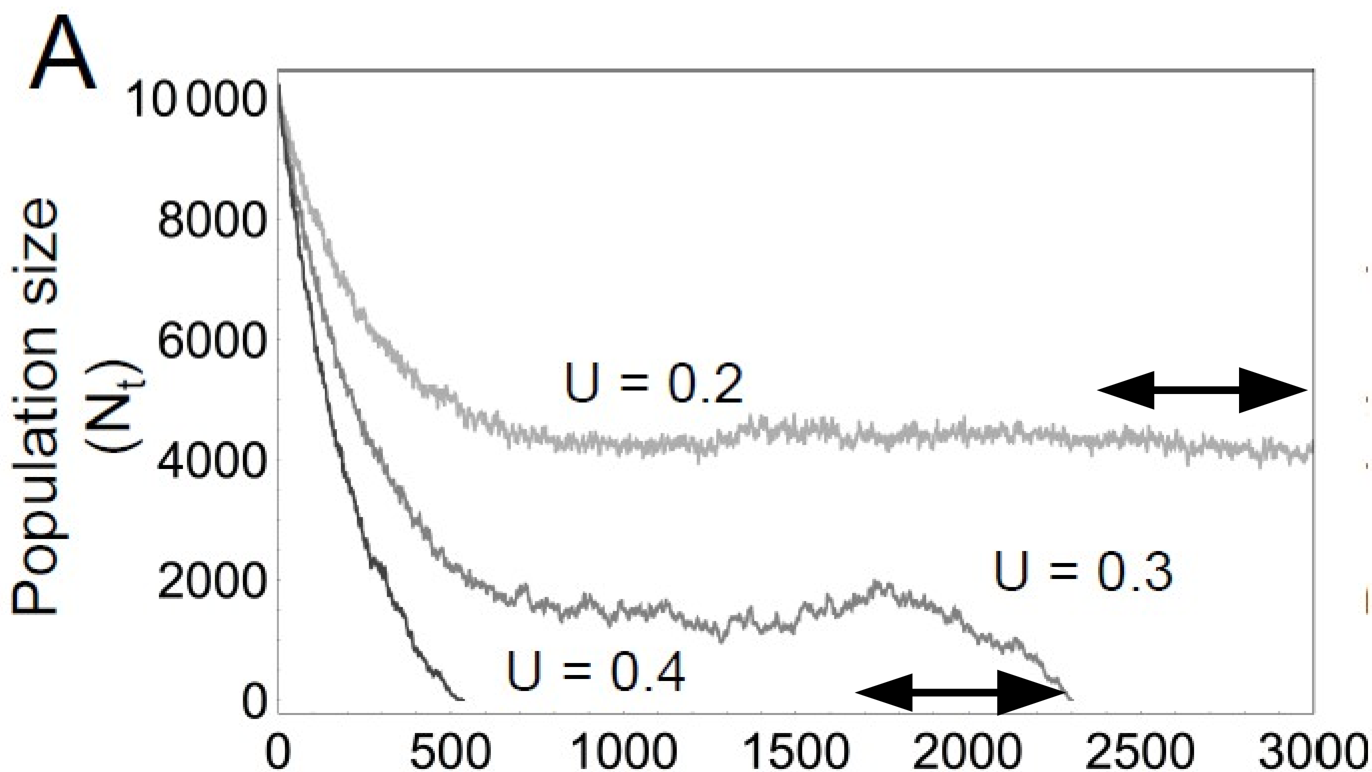
Second example: viability of population with deleterious mutations and the importance of ***Ne*** *(with D. Abu Awad)*

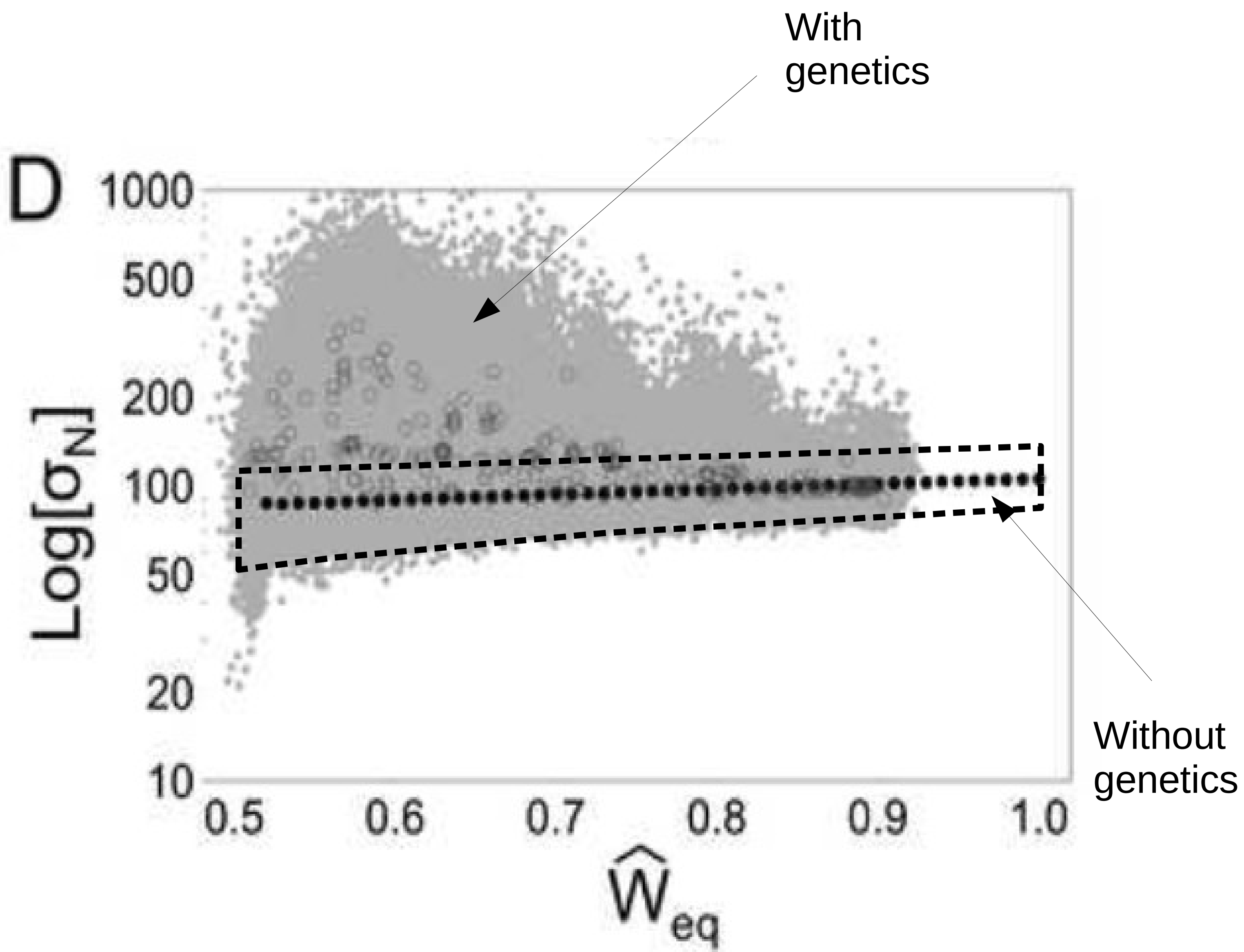




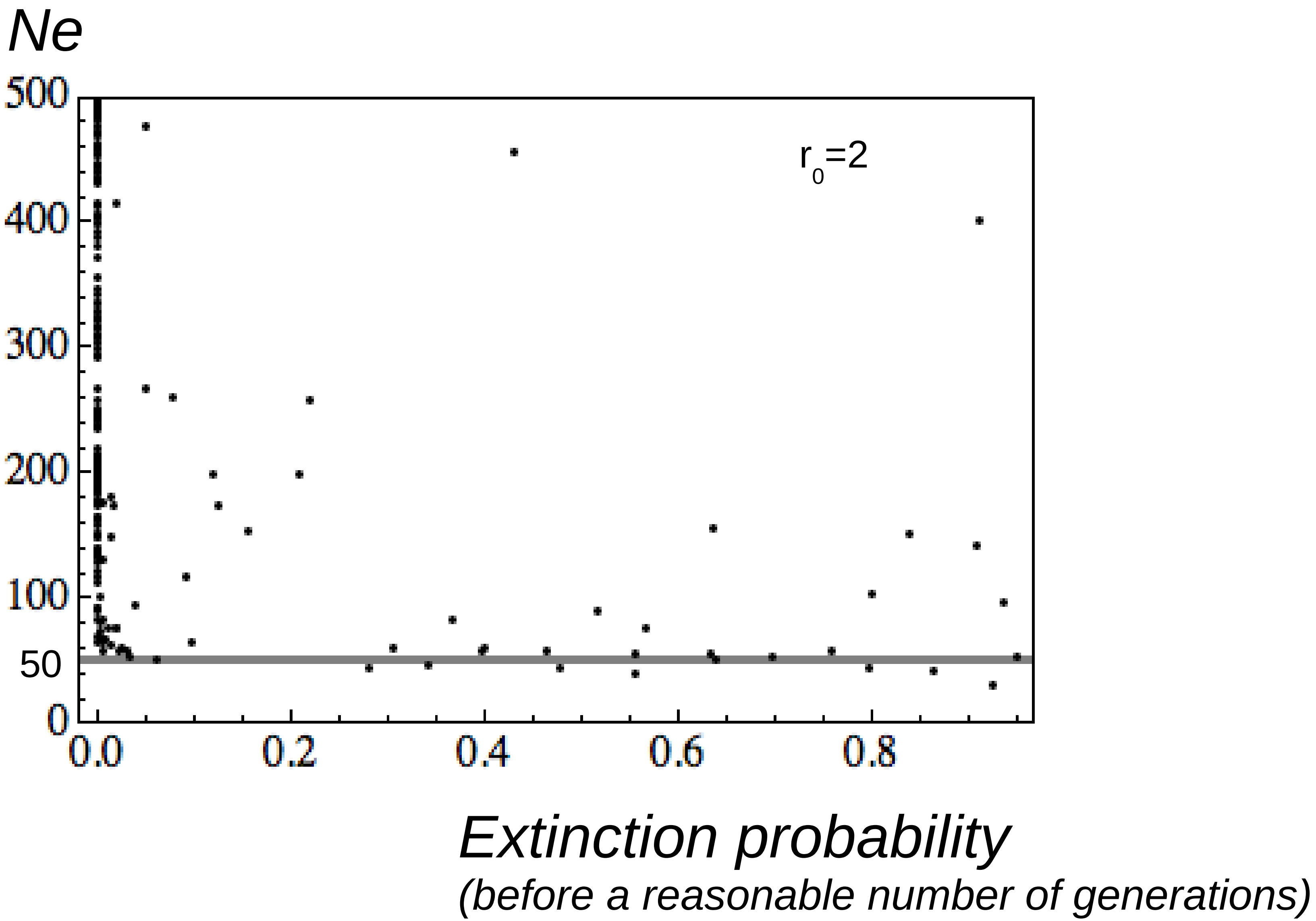
Generation t
Reproduction
Generation t+1
r_0
Population size:
N_t
$R_t^i = r_0^{(1-\frac{N_t}{K})} W_i$
Population size:
N_{t+1}

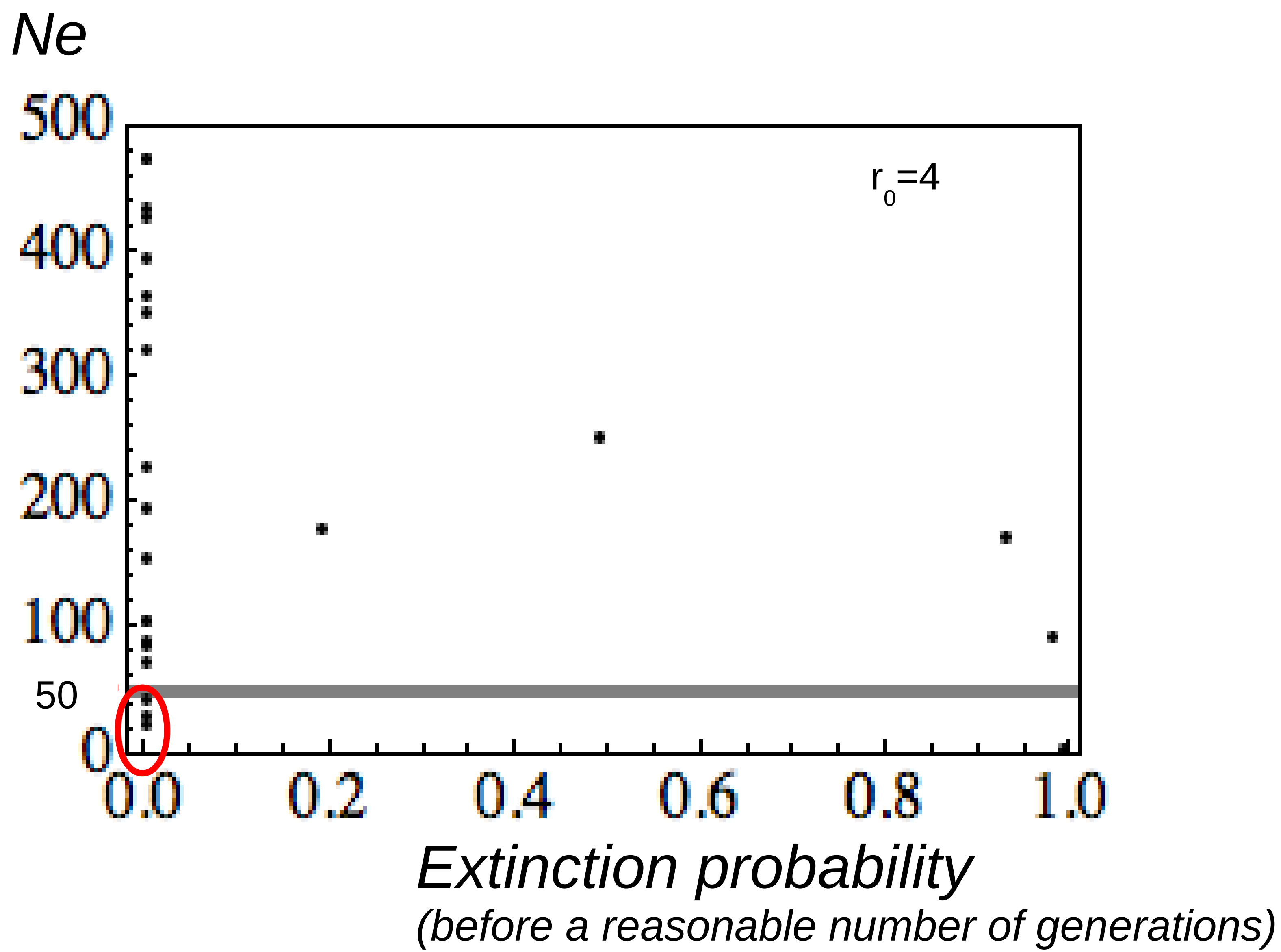
- Initially mutation-free individuals
- K = 10000 (Large populations)
- 1000 replicas
- Simulations stopped at equilibrium (mutation-selection balance or extinction)

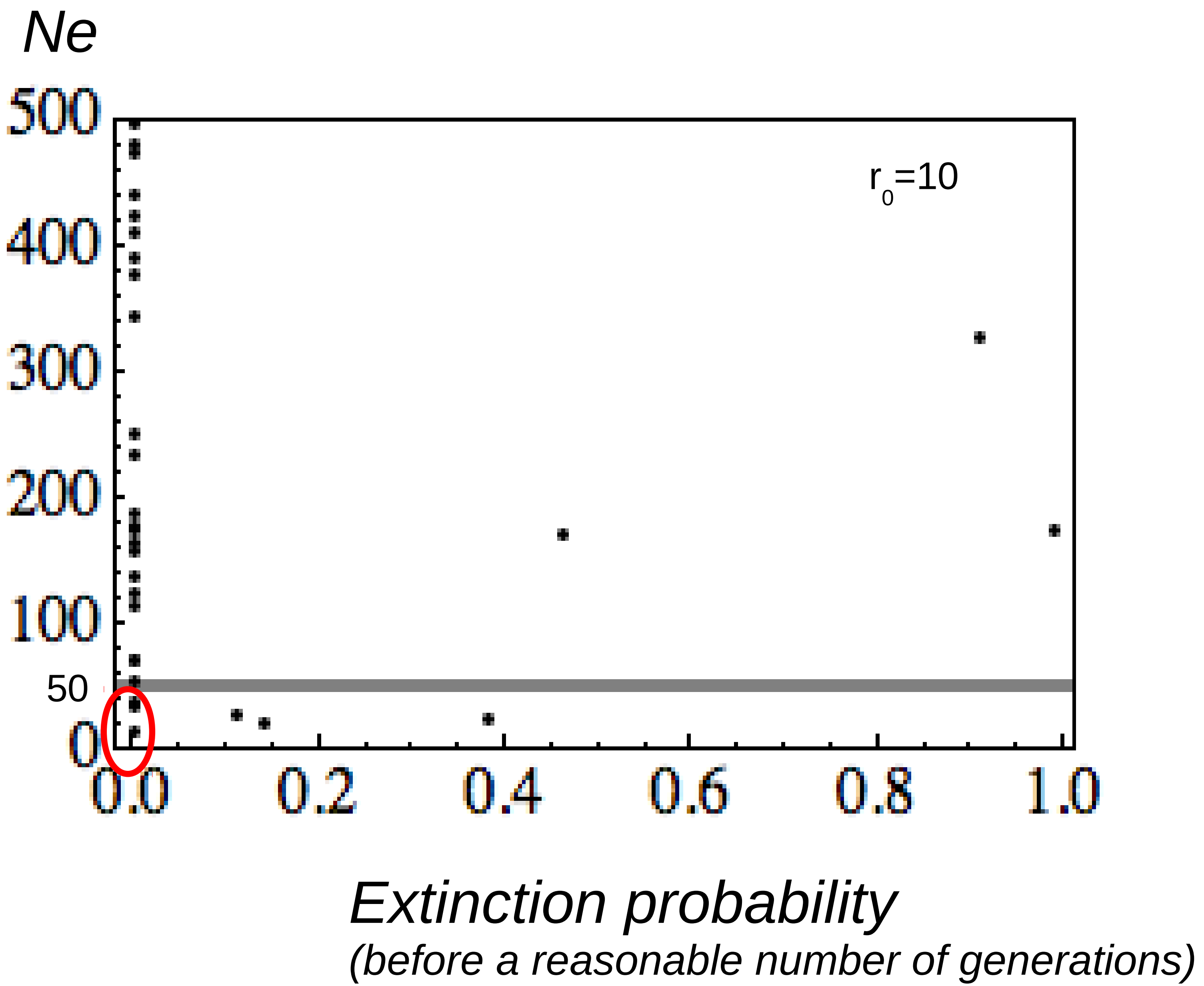


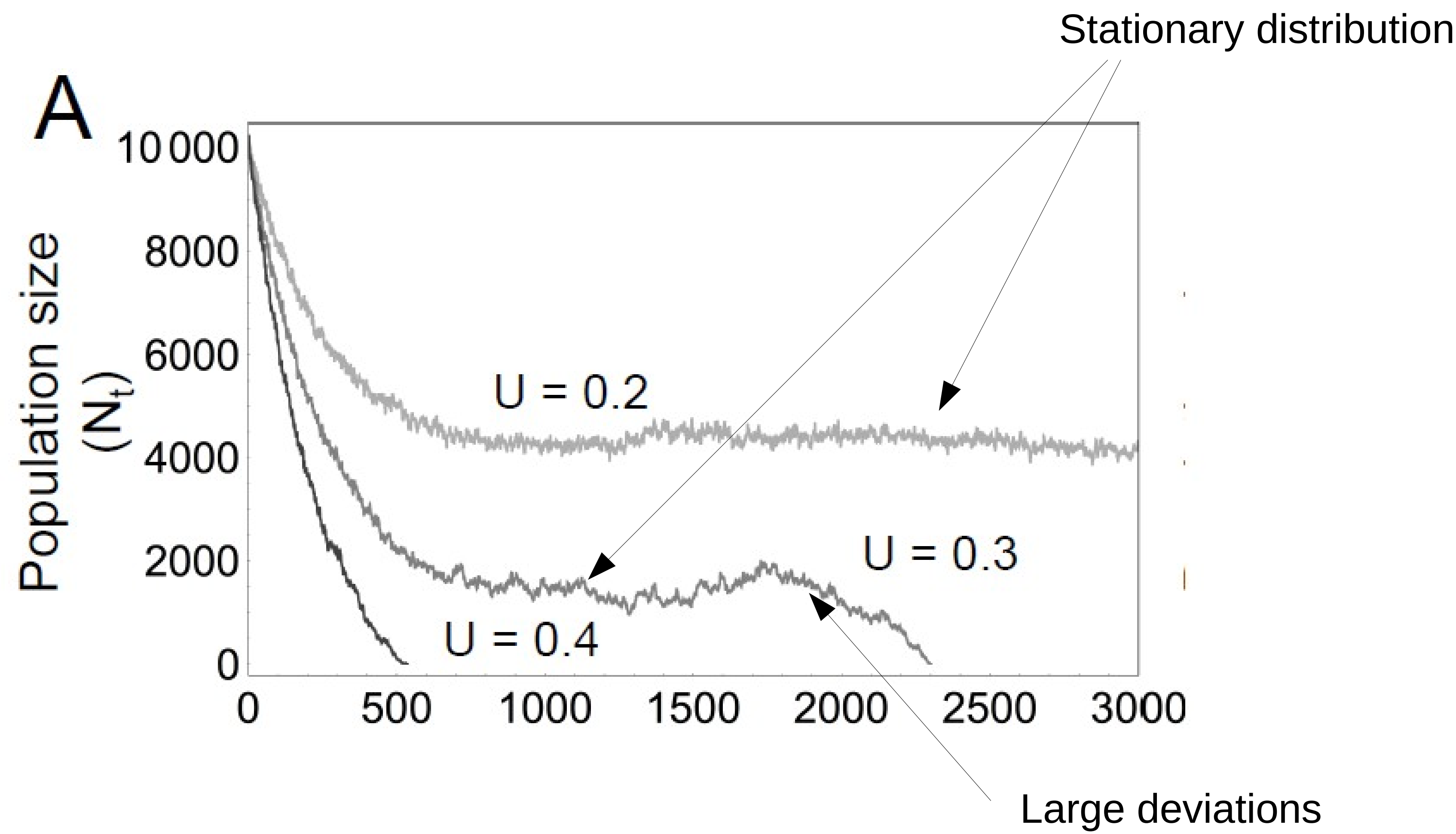


With
genetics
D
1000
500
200
100
50
20
10
Log[σN]
0.5
0.6
0.7
0.8
0.9
1.0
Ŵeq
Without
genetics


Ne
500
400
300
200
100
50
0
0.0
0.2
0.4
0.6
0.8
r0=2
Extinction probability
(before a reasonable number of generations)


Ne
500
400
300
200
100
50
0
r_0=4
0.0
0.2
0.4
0.6
0.8
1.0
Extinction probability
(before a reasonable number of generations)


Ne
500
400
300
200
100
50
0
r0=10
0.0
0.2
0.4
0.6
0.8
1.0
Extinction probability
(before a reasonable number of generations)


Stationary distribution
A
10 000
8000
6000
4000
2000
0
Population size
(N_t)
U = 0.2
U = 0.3
U = 0.4
0
500
1000
1500
2000
2500
3000
Large deviations

Synthesis and challenges

- 10-100 and 50-500 rules do not work here... interaction between Nc, Ne and reproductive rate

→ Reconciling Ne and demographic models

- Time to get rid of the demography *vs*. environment *vs*. genetics controversy?

→ A better question: what is the viability of a population for a given demographic, environmental et genetics state ?

- Difficult to have predictions with both genetics and demography

→ A general framework is needed (e.g. PVA)

- Difficult to have predictions with both genetics and demography

→ A general framework is needed (e.g. PVA)

- But what depth for the microscopic modelling?

e.g. Competition for resources:

- interaction between *n* individuals by pairs
- equal sharing between *n* individuals
- a single individual among *n* gets all the resources?