Basic demographic models

$N_{t+1} = \lambda \cdot N_t$ discrete variation (e.g. semelparous populations)

$dN/dt = r \cdot N$ continuous variation (iteroparous populations)

Where r is the “intrinsic” per capita rate of increase of the population

In this case

$r > 0$ Positive growth
$r < 0$ Negative growth
$r = 0$ Stability only

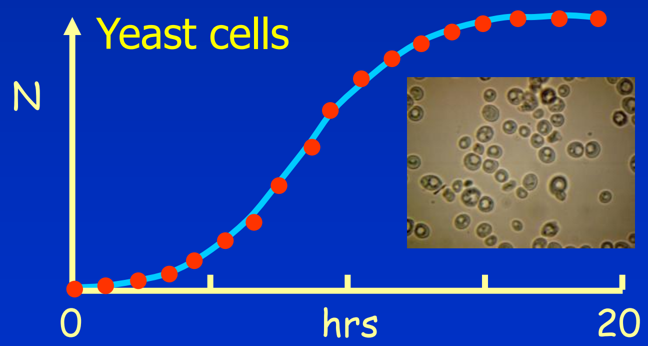
Are basic models of population growth complete ?

$N_{t+1} = \lambda \cdot N_t$ discrete

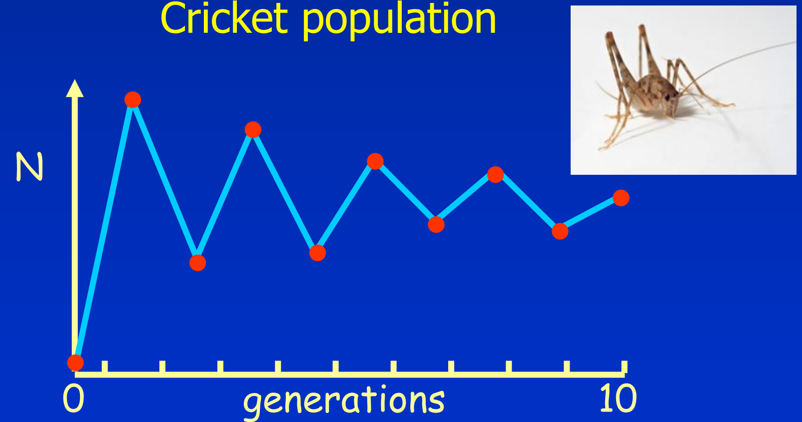
$dN/dt = r \cdot N$ continuous

Are the predictions of these DM coherent with real pops ?

NOT, or at least NOT ALLWAYS



Cricket population



We conclude that the basic DM models are NOT COMPLETE because they are not able to explain demographic homeostasis

MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

We can imagine two classes of mechanisms:

1) Population growth depends on environmental conditions such as climate

$$r \text{ or } \lambda = f\,(C)$$

2) Population growth depends on the availability of resources (food, refugia etc)

$$r \text{ or } \lambda = f\,(R)$$

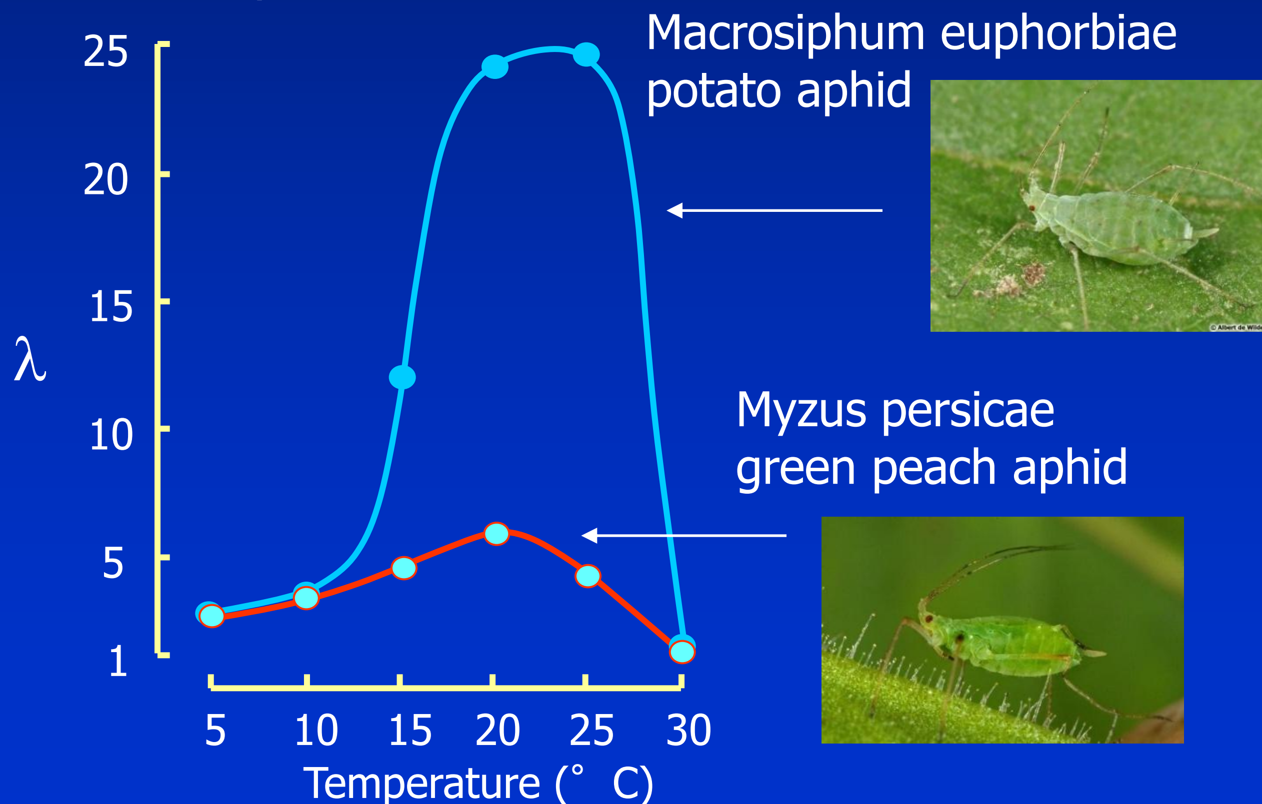
We have already considered an implicit for of dependence of λ on environmental factors (environmental stochasticity in probabilistic Models

We can now try to make this explicit by measuring the effect of different conditions' levels on the rate of increase of the population

MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

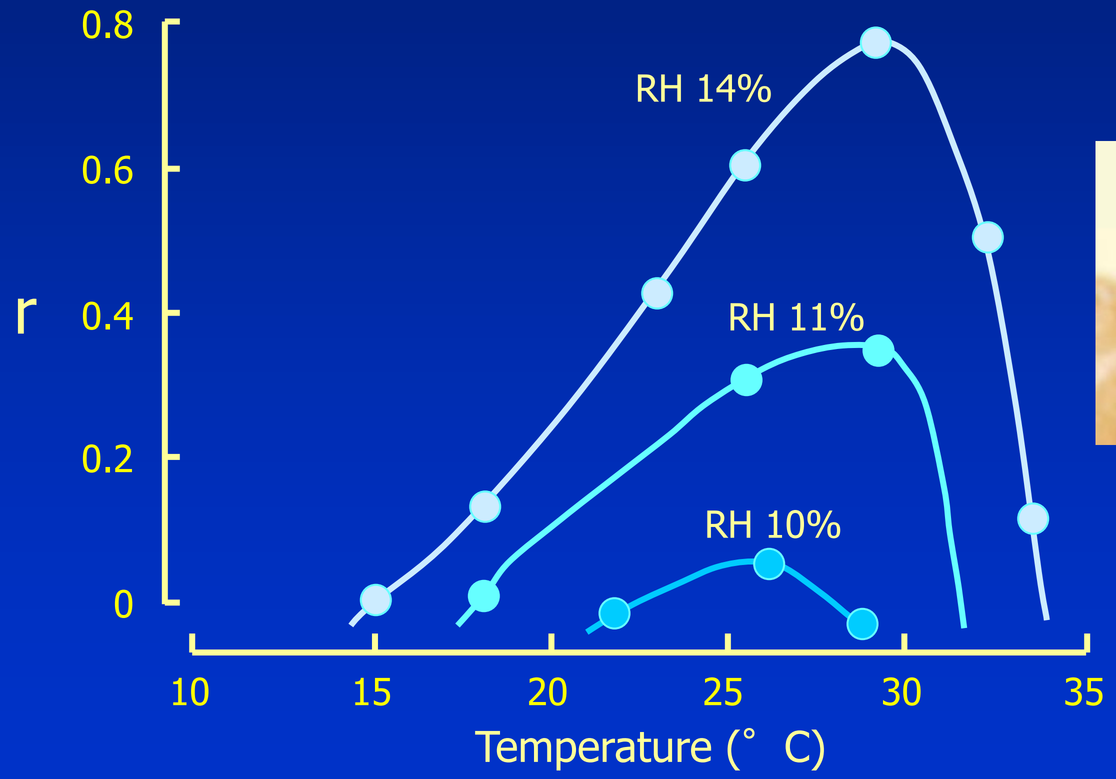
How to assess $\lambda = f(C)$?

Autoecological experiments in the field or under controlled conditions measuring the variation of lambda or its components (mortality and fertility) when conditions do vary



MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

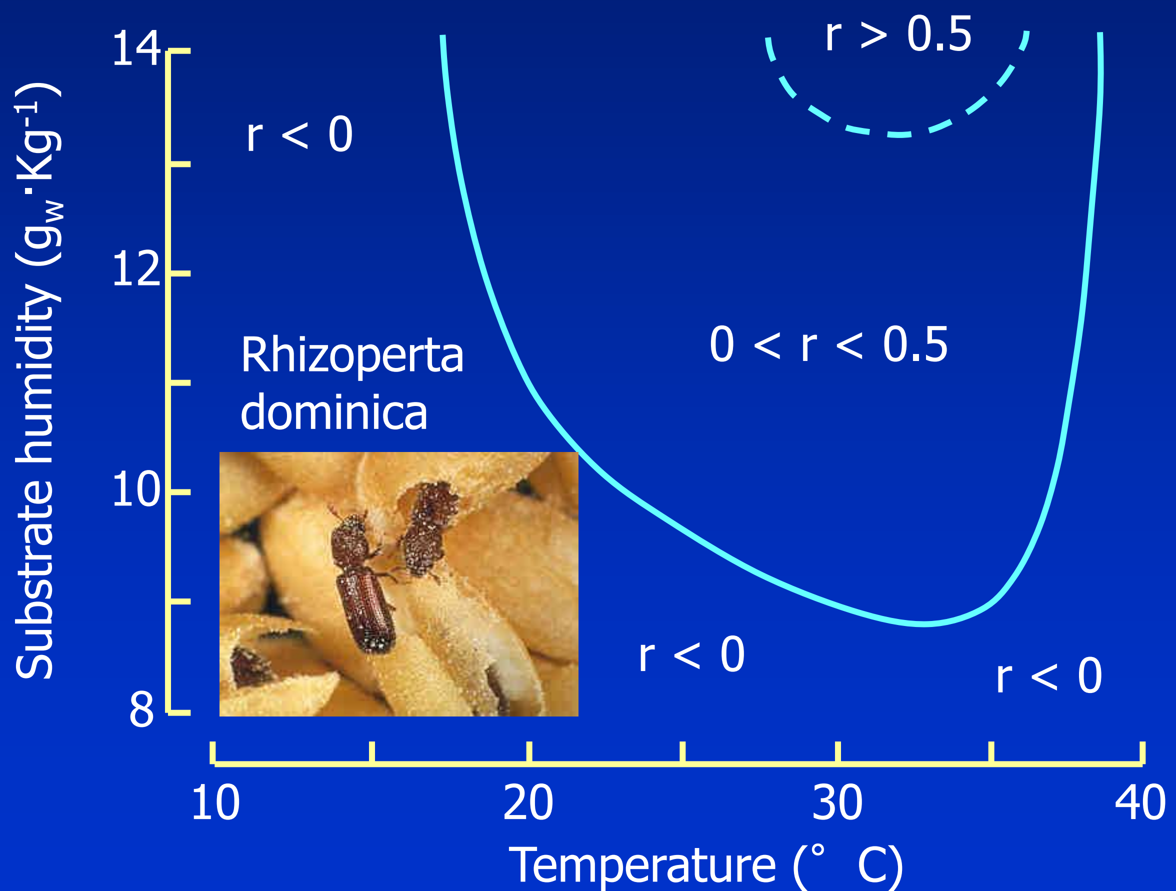
Dependance of instantaneous growth rate on two conditions: temperature and relative humidity



Calandra oryzae
The rice weevil

MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

Dependance of instantaneous growth rate on two conditions: temperature and substrate (weath) humidity



MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

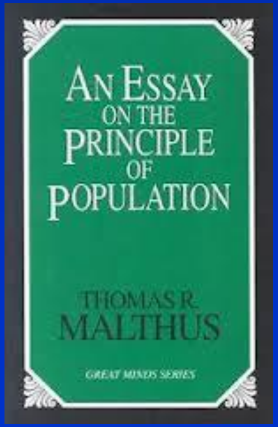
In general, this kind of information is important for planning defence strategies against crop pests, or to assess optimal conditions for farming

On the euristic side, dependence of rate of increase from environmental conditions can explain fluctuations of natural populations, but does not explain homeostasis

As an alternative, dependence of the rate of increase from resorces can be considered

This is the Thomas R. Malthus' hypothesis:

Populations do grow exponentially, but ……
they stop growing under shortage of resources



MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

The availability of the resorces can depend on fluctuations in habitat productivity (climate, nutrients etc.), but in a constant environment it depends on the number of individuals using them (negative density dependence)

So the negative dependence of growth on per-capita resources availability

$$\lambda = f\,(R)$$

becames in fact the negative dependence of growth on population density, due to INTRASPECIFIC COMPETITION

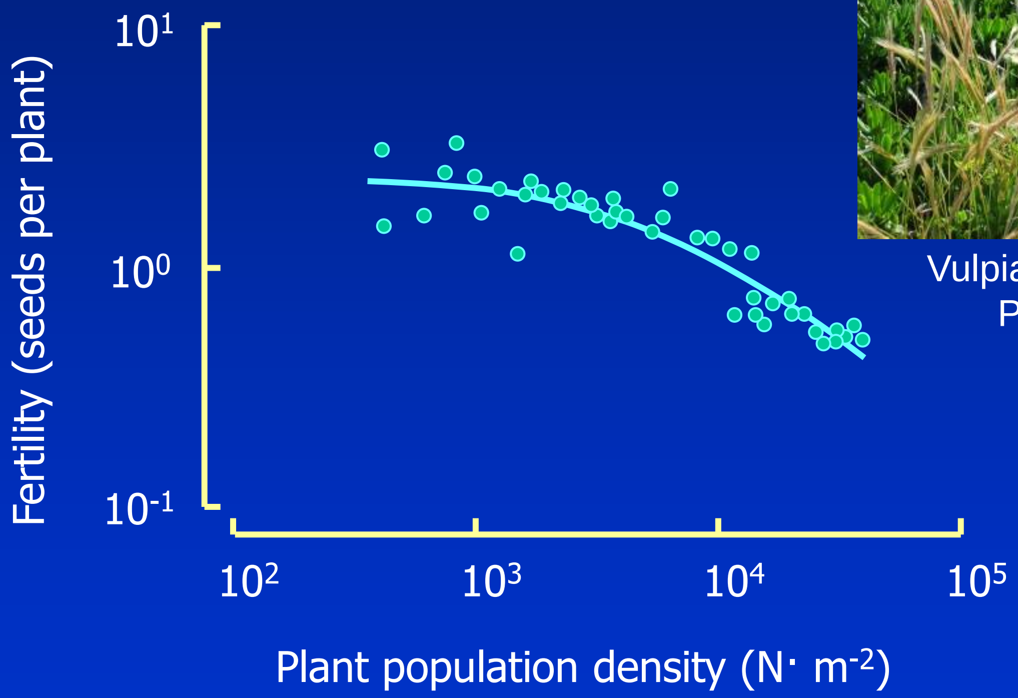
$$\lambda = f\,(N)$$

This is why we speak in general of density dependent models of population dynamics

But what about the experimental evidence for density-dependence?

MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

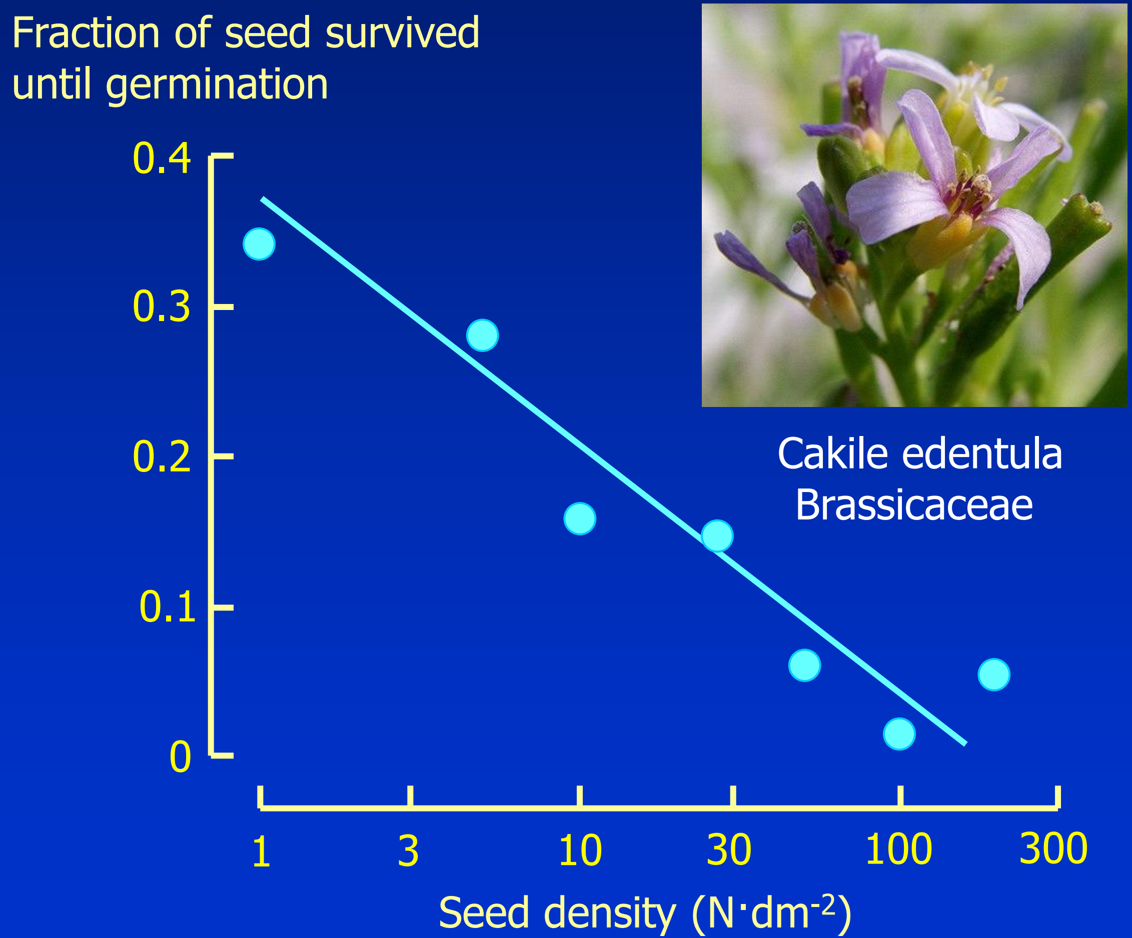
Negative density dependence of growt rate (or of its components) is a common phenomenon in many different organisms



Vulpia fasciculata
Poaceae

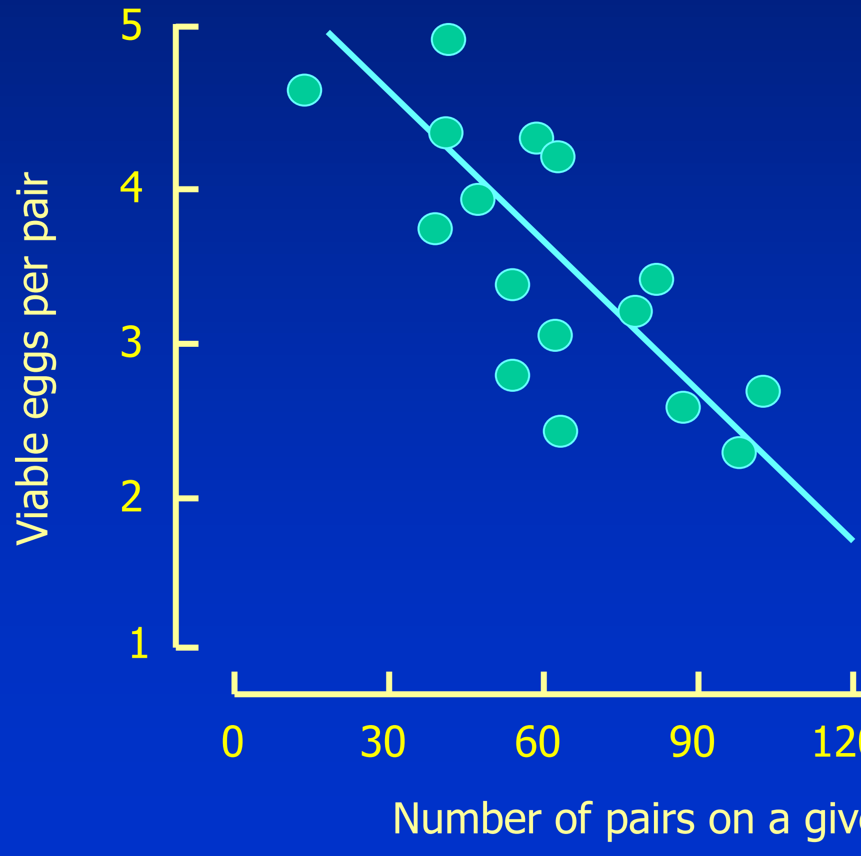
MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

Negative density dependence of growt rate (or of its components) is a common phenomenon in many different organisms



MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

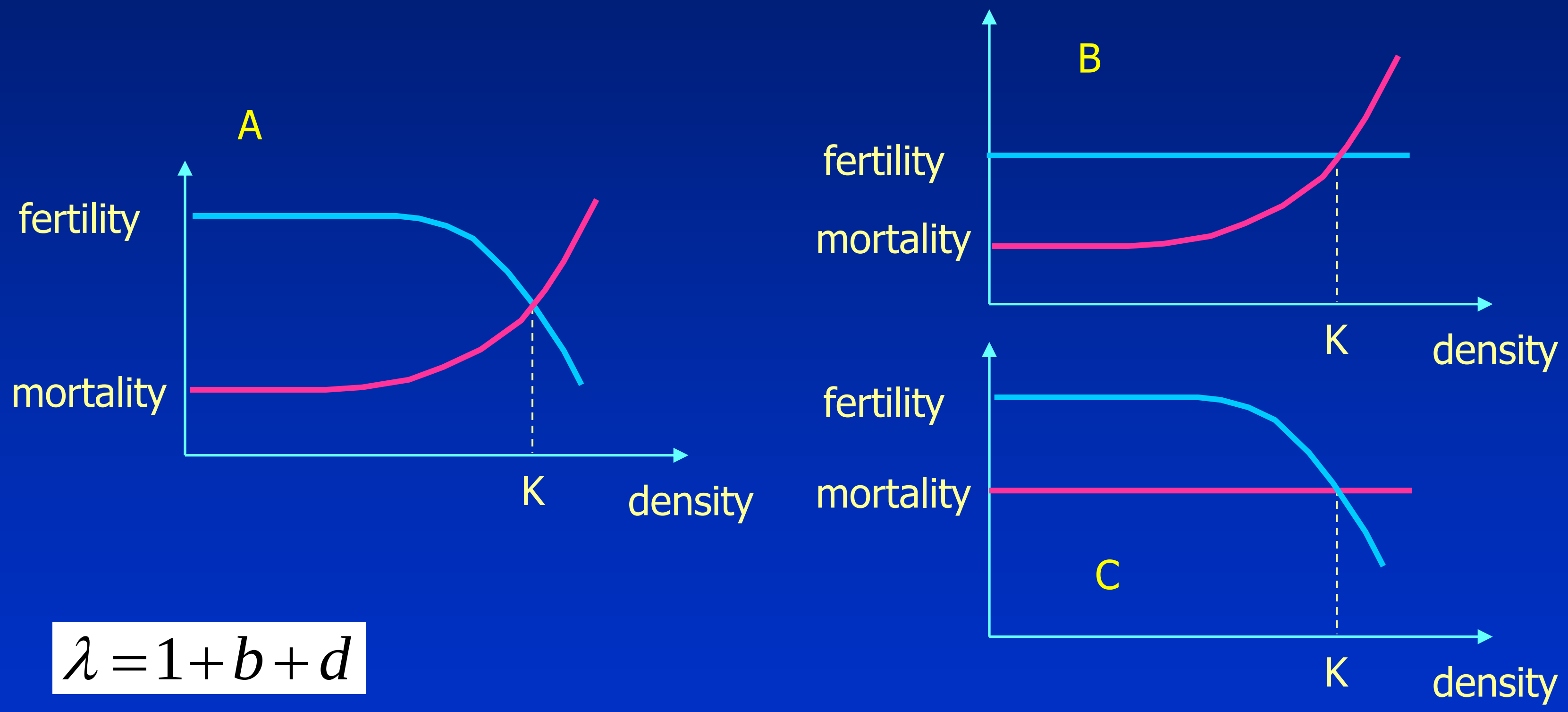
Negative density dependence of growt rate (or of its components) is a common phenomenon in many different organisms



Great tit (*Parus major*)

MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

Negative density dependence of growt rate (or of its components) is a common phenomenon in many different organisms



$$\lambda = 1 + b + d$$

In a density-dependence scenario there is a density value (K) corresponding to which fertility and mortality rate have exactly balanced values to produce null growth (equilibrium density)

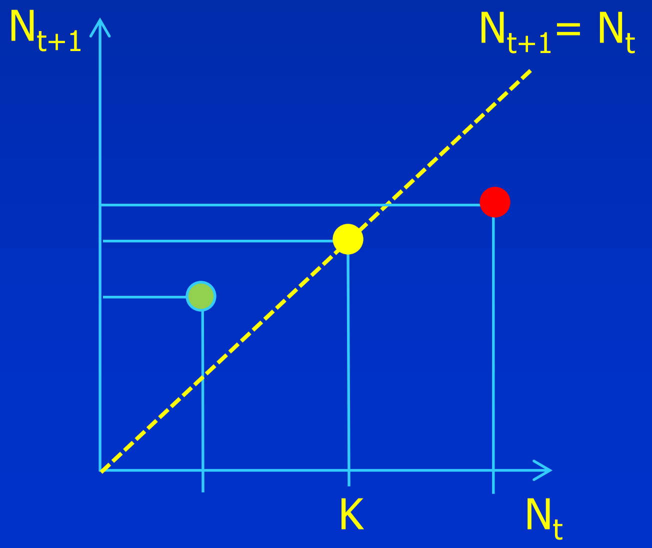
MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

The population grows with a maximum potential growth rate (λ_{max} or r_{max}) only when population density is so low that competition for resources is null

As its size approaches a critical value (K) its growth reduces;
when its size reaches K the growth stops;
when its size exceeds K, its growth becomes negative

K is thus an equilibrium density since, for $\lambda_{max} > 1$

- if $N_t < K$ then $N_{t+1}/N_t > 1$
- if $N_t = K$ then $N_{t+1}/N_t = 1$
- if $N_t > K$ then $N_{t+1}/N_t < 1$



MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

In the continuos growth scenario we have the equivalent idea

if $N < K$ then $dN/dt > 0$

if $N = K$ then $dN/dt = 0$

if $N > K$ then $dN/dt < 0$

We can formalize this "malthusian" idea by the following "logistic eqn"

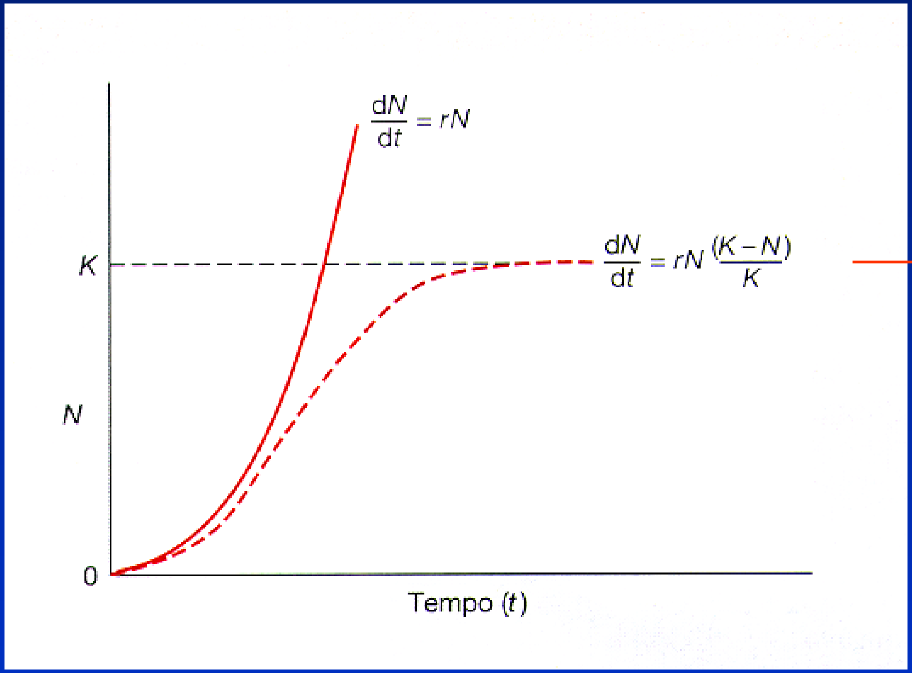
$$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right)$$

rN → Exponential growth

$\left(\frac{K-N}{K}\right)$ → Regulation

MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

Exponential vs. logistic growth



Equilibrium density

also called

Carrying capacity
(of that population in a given habitat)

RATE OF INCREASE OF POPULATIONS

A) Total rate of increase (recruitment)

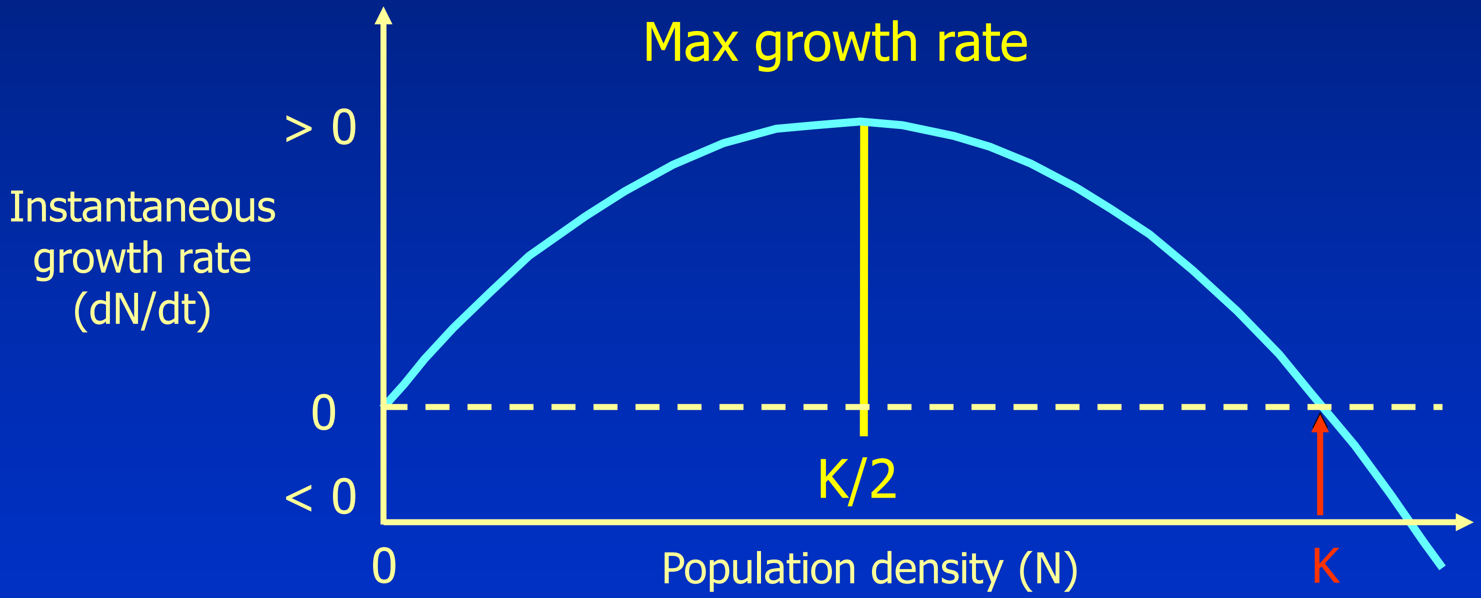
Discrete: $N_{t+1} - N_t$
Continuous: dN/dt

B) Per capita rate of increase i.e. how the single (average) individual contributes to the population growth

Discrete: $(N_{t+1} - N_t) / N_t$
Continuous: $dN/N \cdot dt$

GENERAL PREDICTIONS OF THE LOGISTIC MODEL

2) Increase at the level of the population (recruitment)



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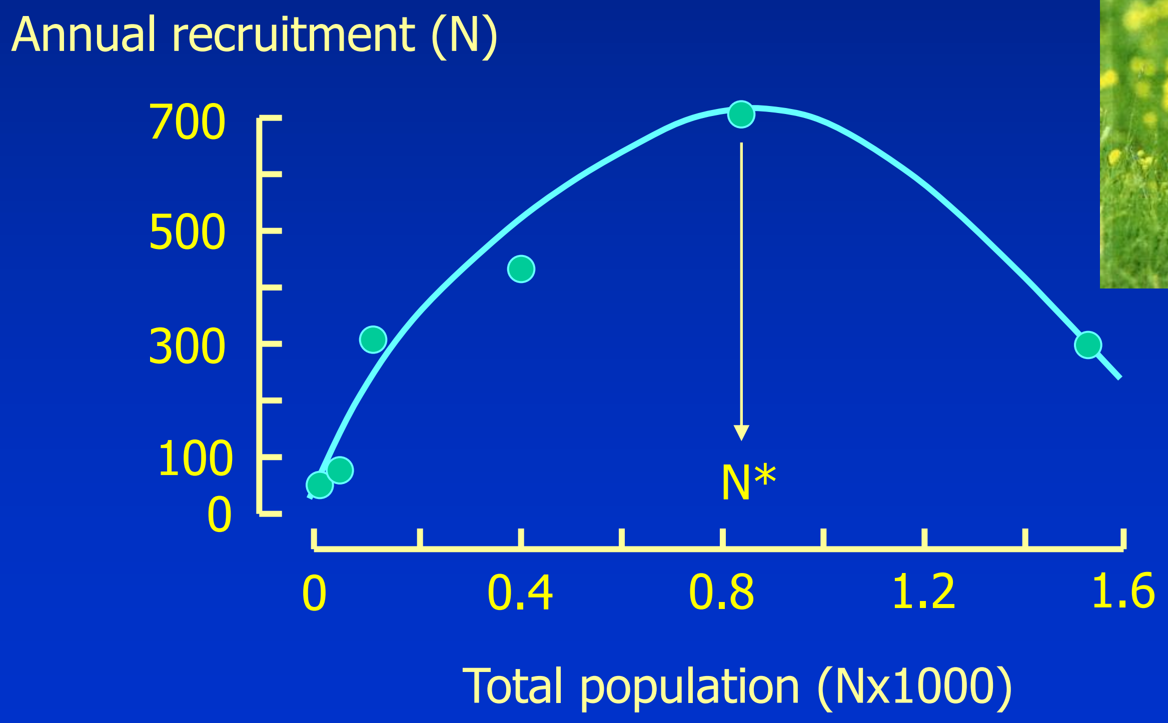
RECRUITMENT ACCORDING TO A LOGISTIC PATTERN

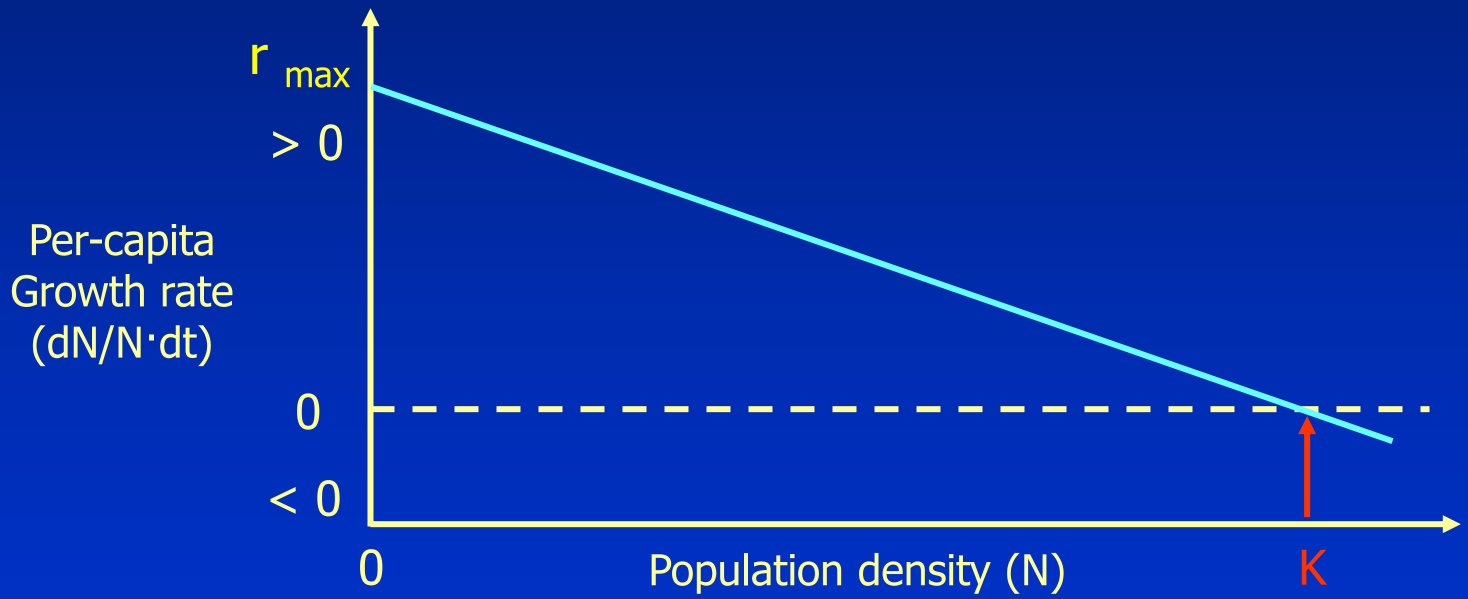
Agreement of observational data (pheasant's recruitment in UK) with the general predictions of the logistic model



Pheasant

GENERAL PREDICTIONS OF THE LOGISTIC MODEL

1) Rate of increase at the level of the single individual



MECHANISMS ALLOWING DEMOGRAPHYC HOMEOSTASIS

Negative density-dependence (competition) in a discrete-growth population

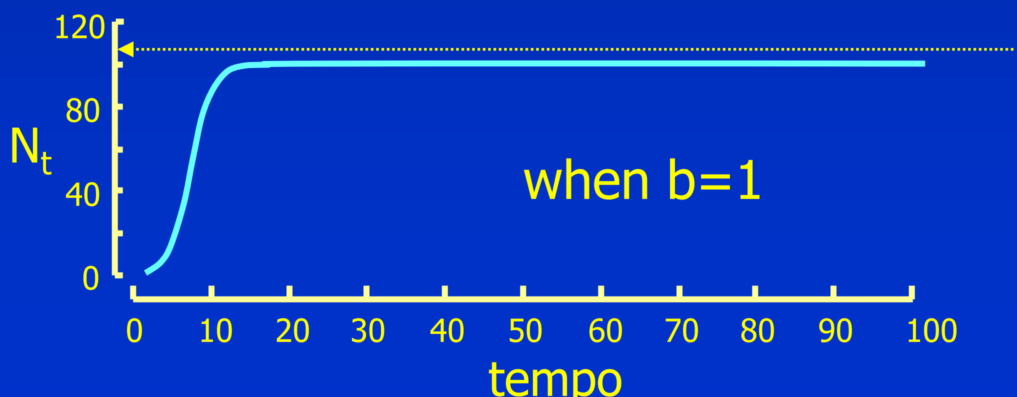
The Maynard-Smith and Slatkin eqn.

$$N_{t+1} = \frac{N_t \cdot \lambda}{1 + (a \cdot N_t)^b}$$

Potential growth

Per-capita effect of competition

Variation of the per-capita effect with density



Carrying capacity

$$K = \frac{(\lambda - 1)^{1/b}}{a}$$

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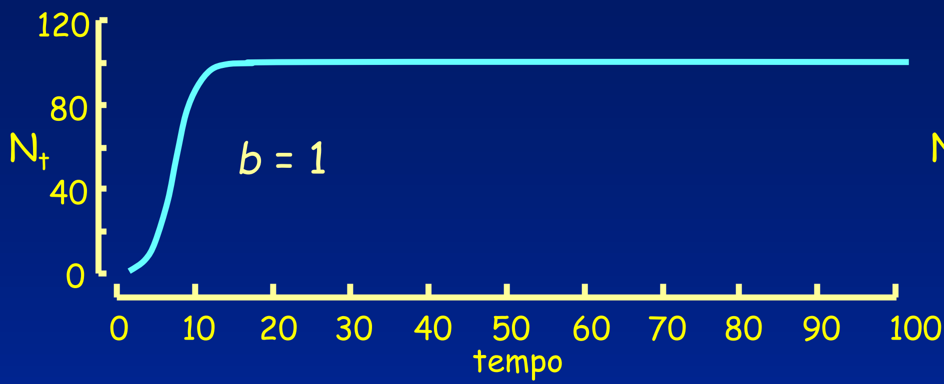
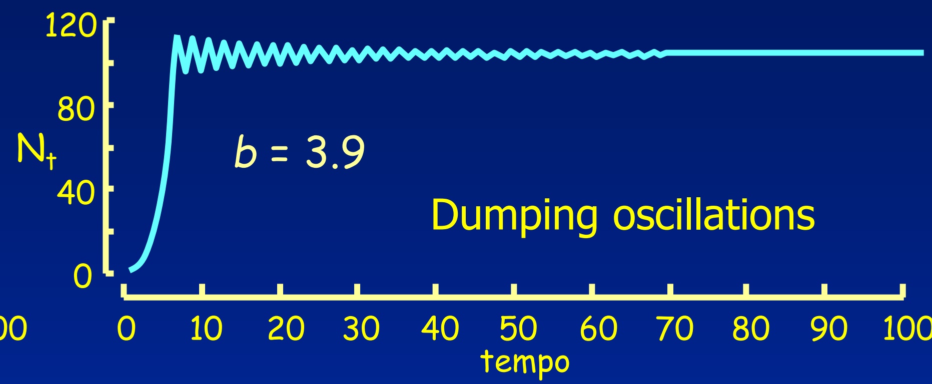
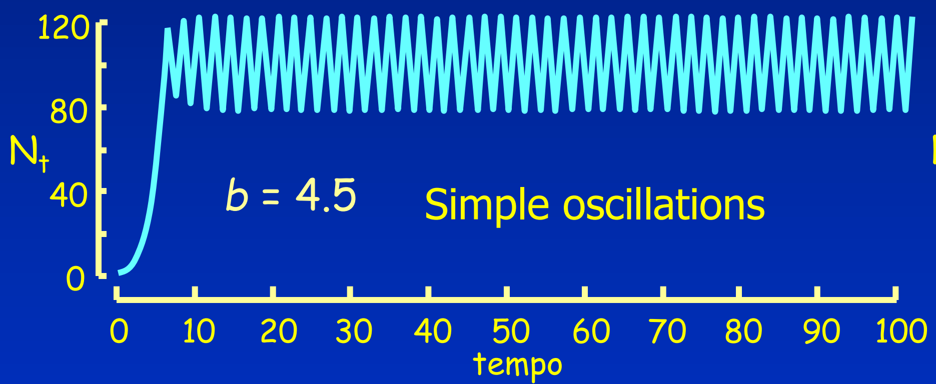
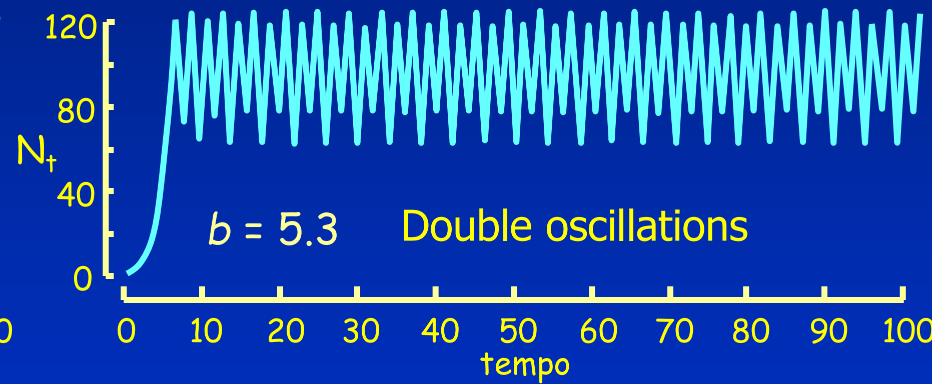
PREDICTIONS OF MS & S EQN. WHEN b>1

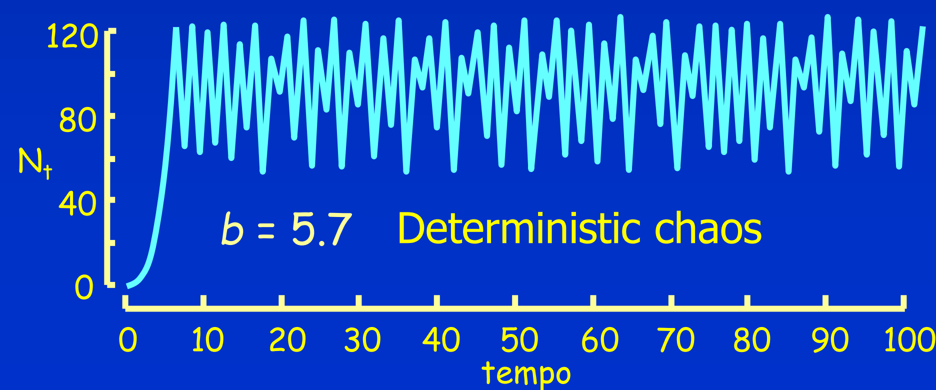








Intraspecific competition alone is able to generate such different dynamics



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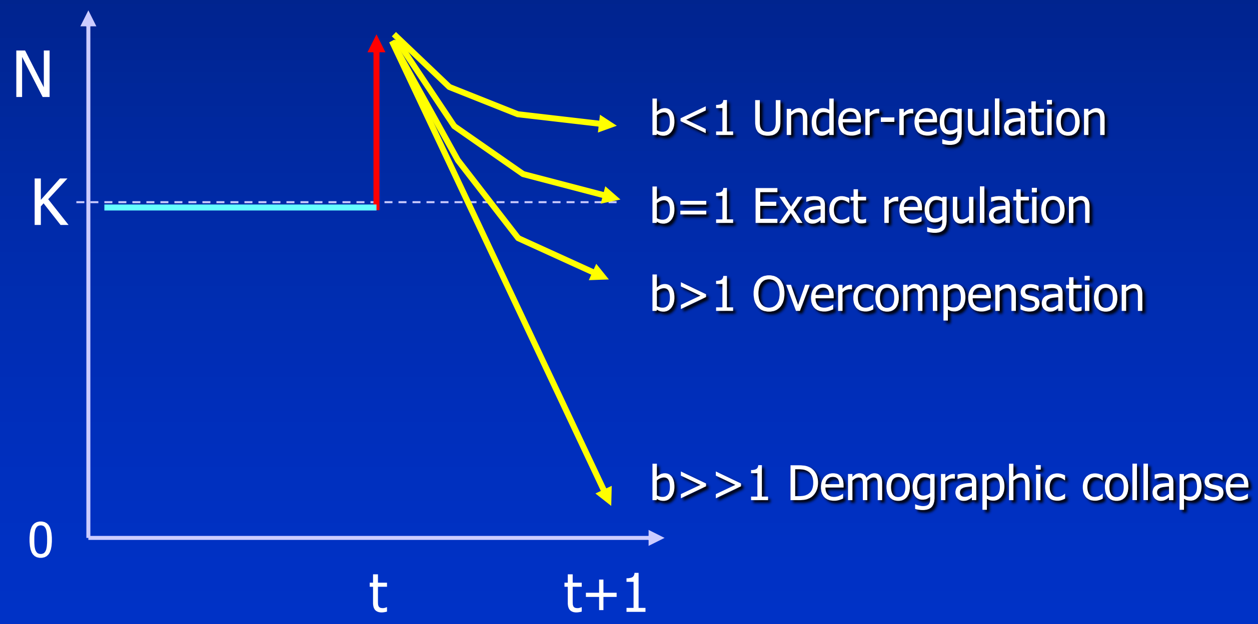
PREDICTIONS OF MS & S EQN.

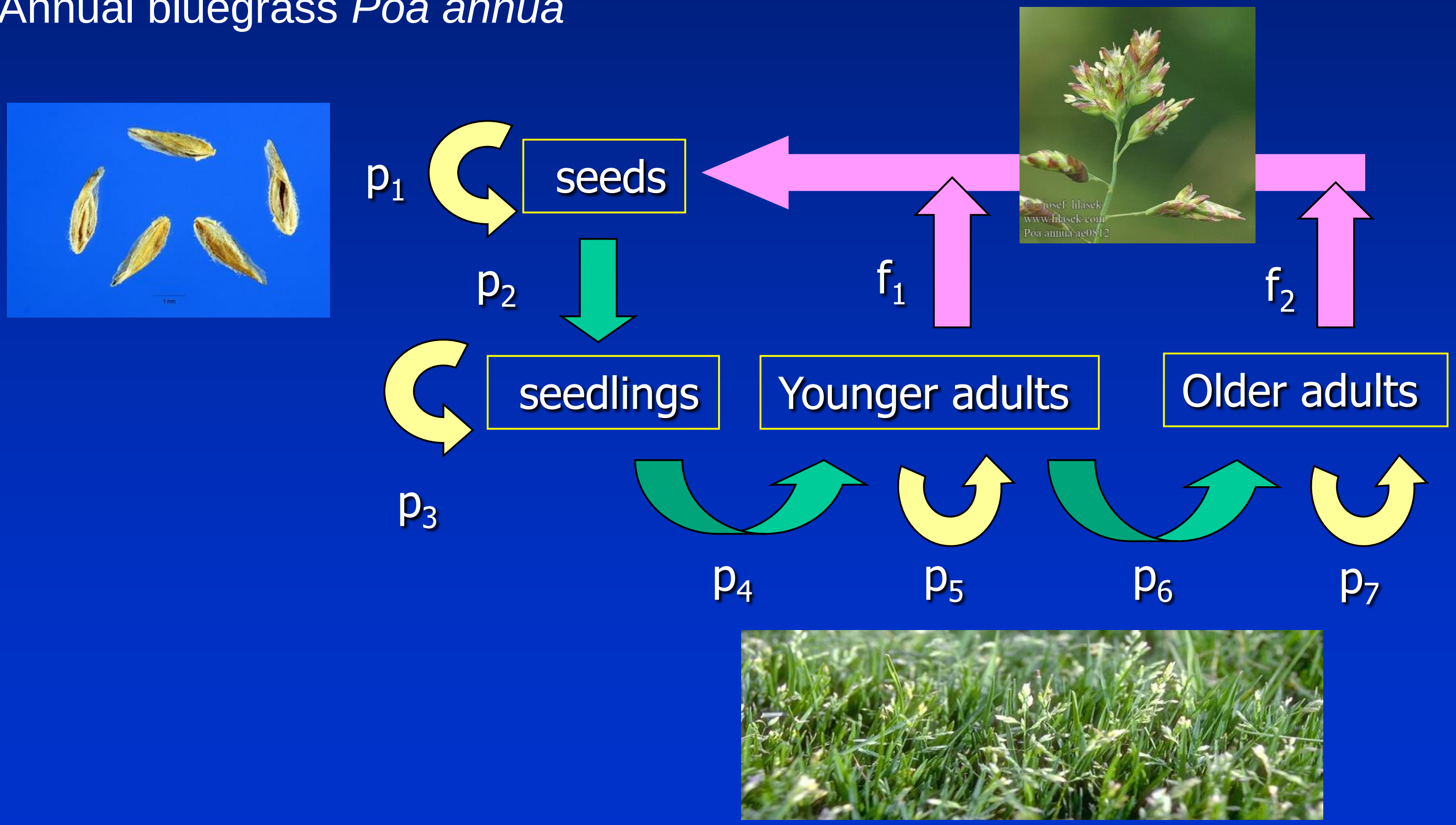
What happens when the carrying capacity is exceeded (immigration, exhagerate introduction of specimens, resources fluctuation)



Life table data and DM of structured populations

Age specific mortality rate, growth rate and relative fertility determine the dynamics of single classes and of the whole population

Annual bluegrass *Poa annua*

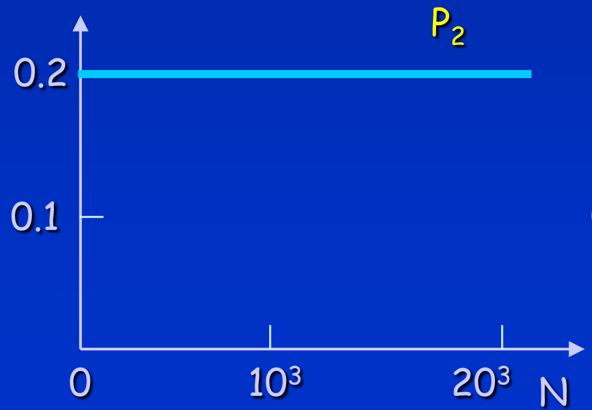


DENSITY DEPENDENCE AND HOMEOSTASIS IN STRUCTURED POPs

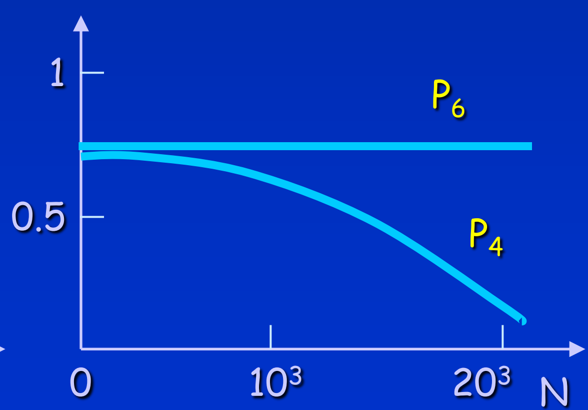
Transition probabilities may depend on density

It is enough that some or even only one coefficient do vary with density for producing a density dependent regulation of the whole population

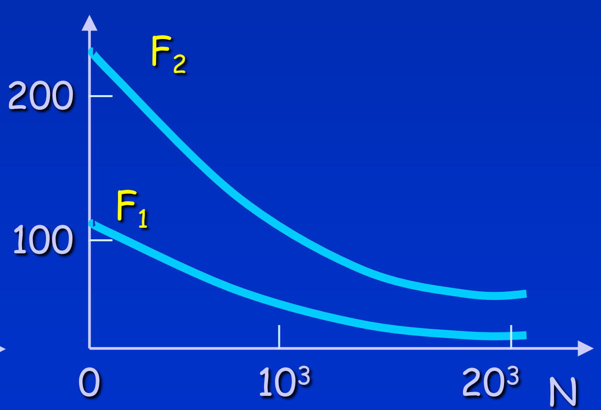
Seed "destiny"



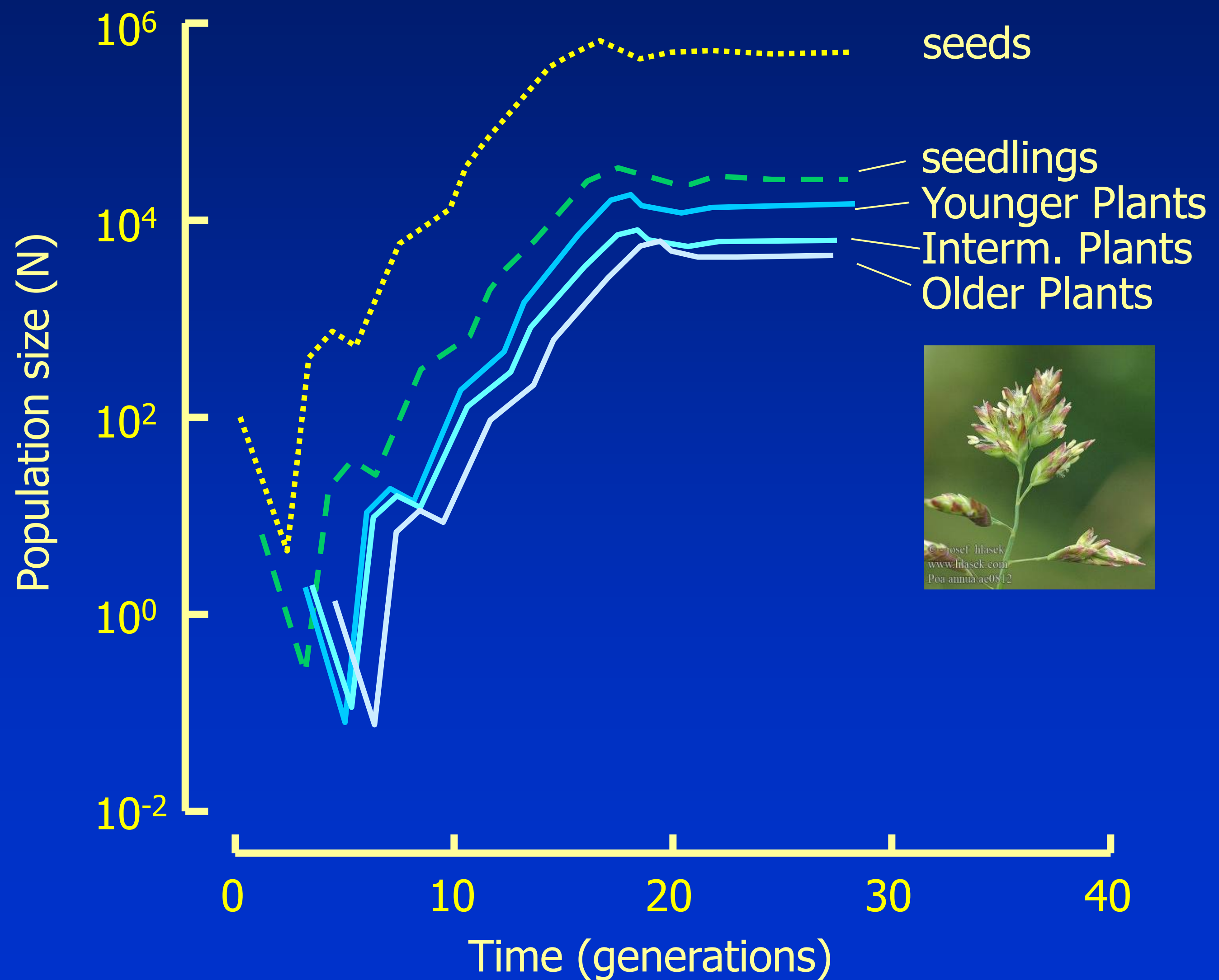
Ageing and growing



Fertility

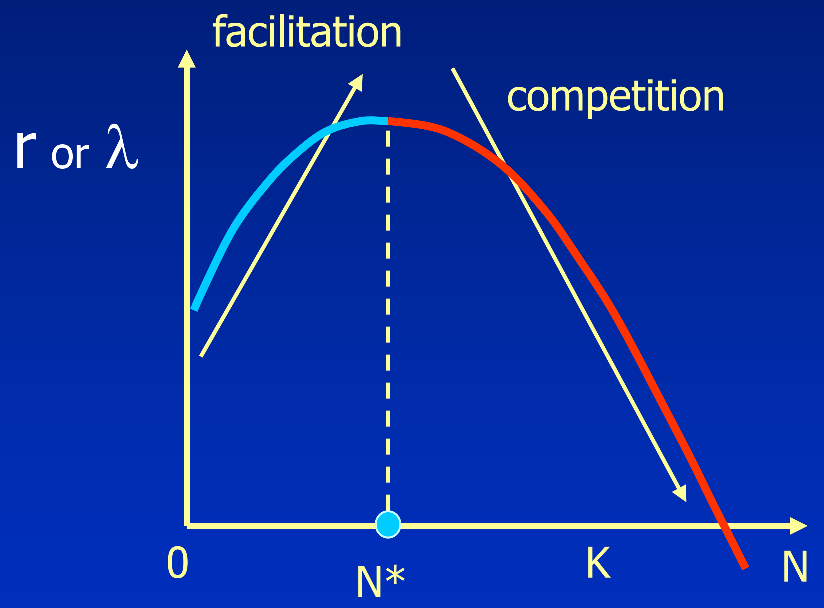


DENSITY DEPENDENCE AND HOMEOSTASIS IN STRUCTURED POPs



COMPETITION AND MUTUAL FACILITATION

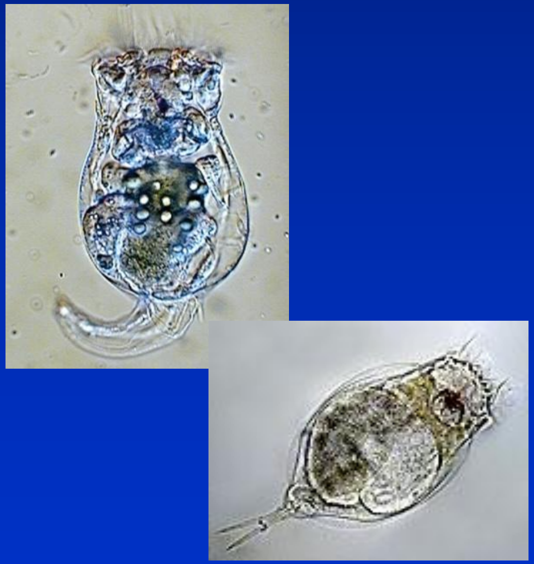
Density dependence can
be negative at higher density
(competition)
but positive at lower density
(mutual facilitation)

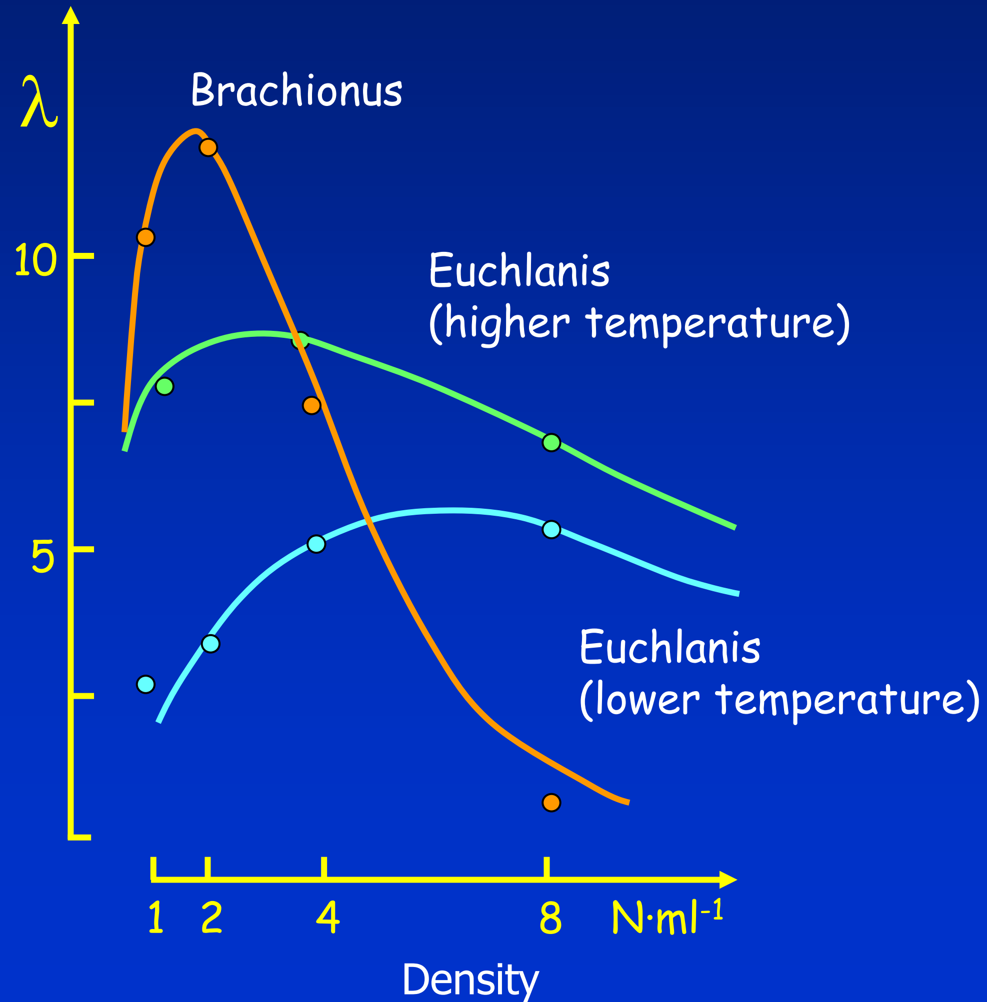


COMPLEX DENSITY DEPENDENCE

In many cases density-dependence is more complex than expected if it would be generated only by competition

Rotifera





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ALLEE EFFECT

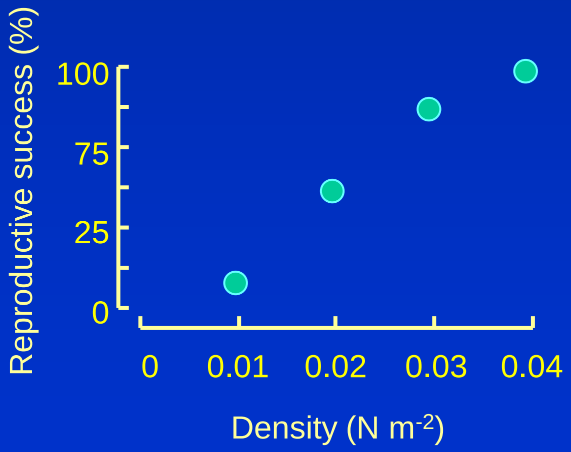
Allee effect can be due to many different processes through which fertility is increased and/or mortality is reduced as population density Increases:

1) Probability to find a sexual partner may be difficult at low densitiy and increases as density increases

2) Increased density may facilitate cooperation in searching for resources or for a better manipulation of them

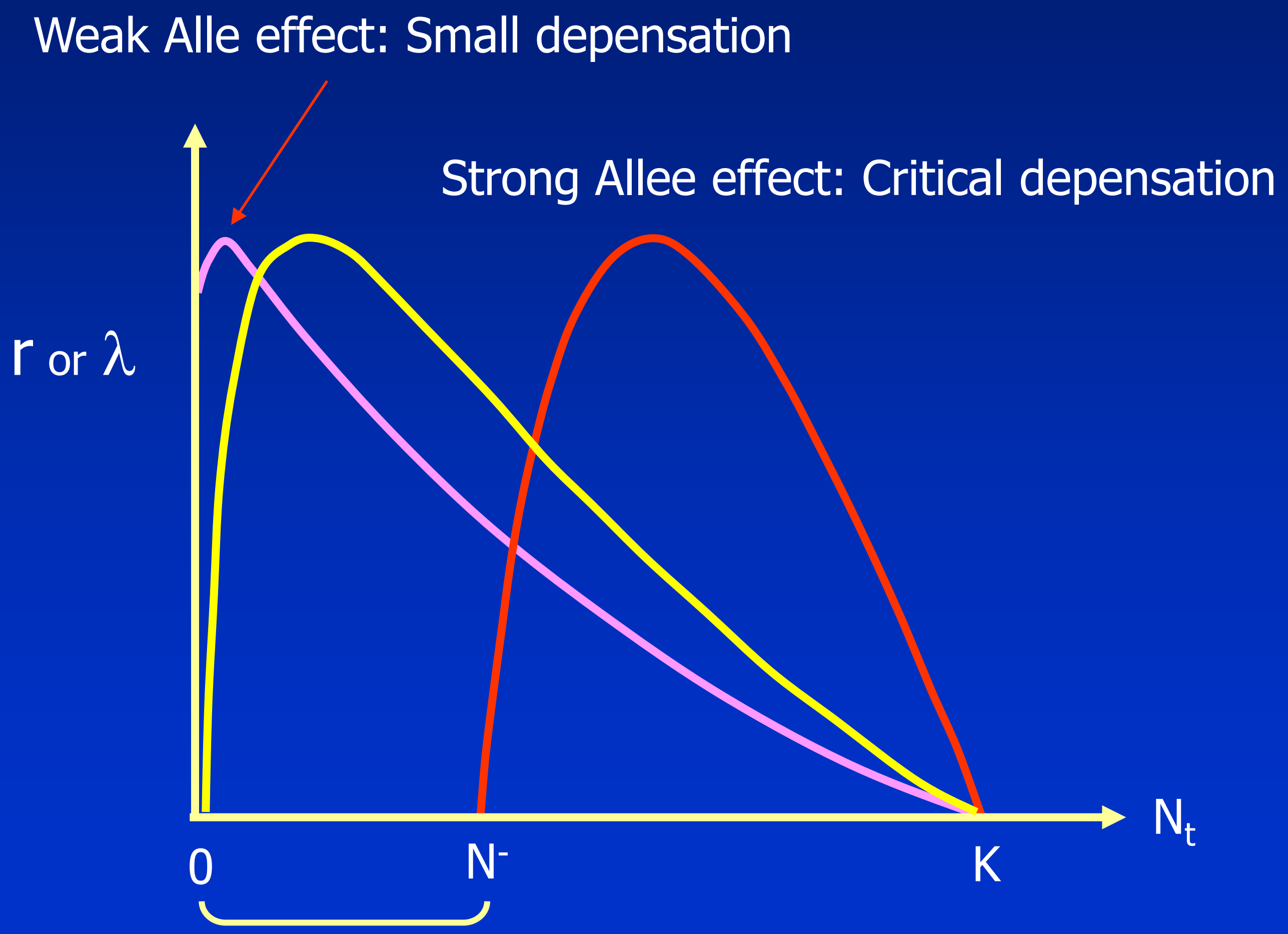
3) Increased density may facilitate interindividual help in avoiding predators, by confusing them or by actively defending against their attacks (mobbing in birds)

Allee effect (reproductive success) in Alca torda



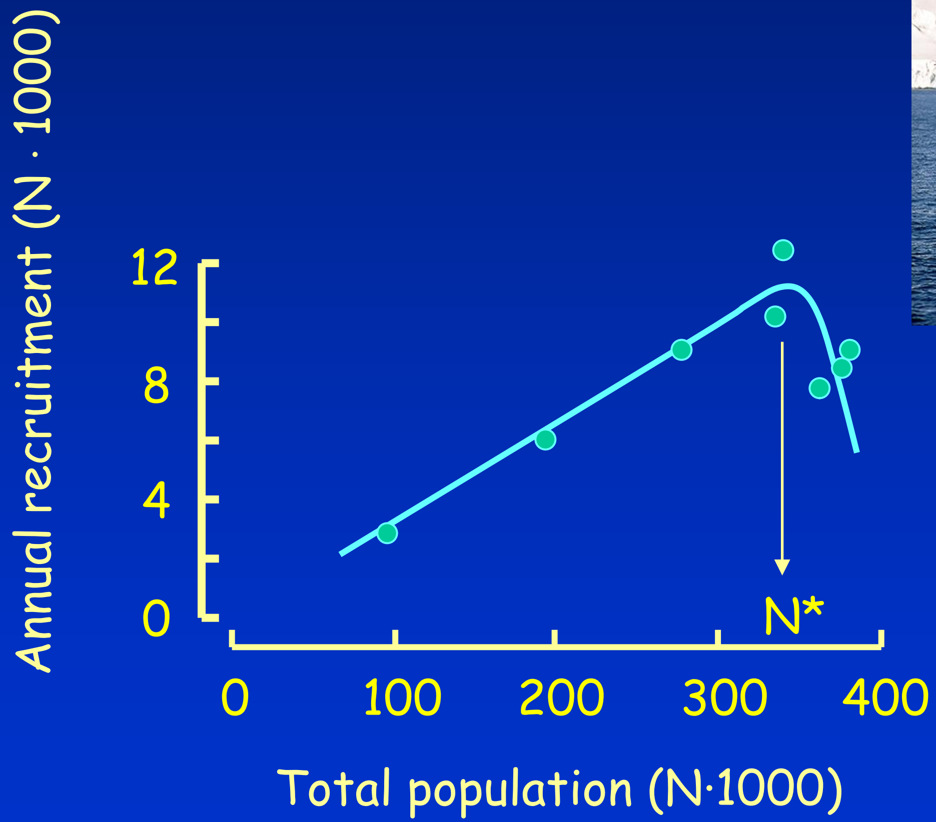
ALLEE EFFECT AND DEPENSATION

Interaction between competition and facilitation
generates “depensation” (e.g. lower growth at lower densities)



ALLEE EFFECT AND DEPENSATION

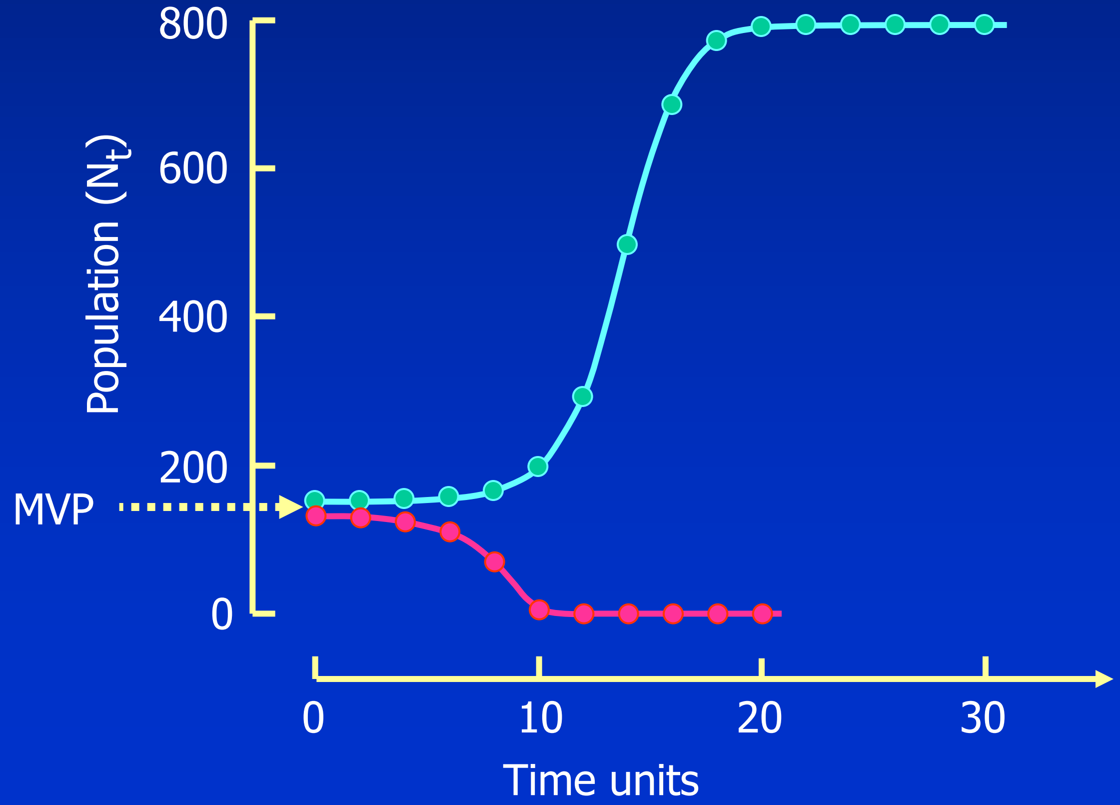
Antarctic whales recruitment affected by depensation



THE EFFECT OF CRITICAL DEPENSATION

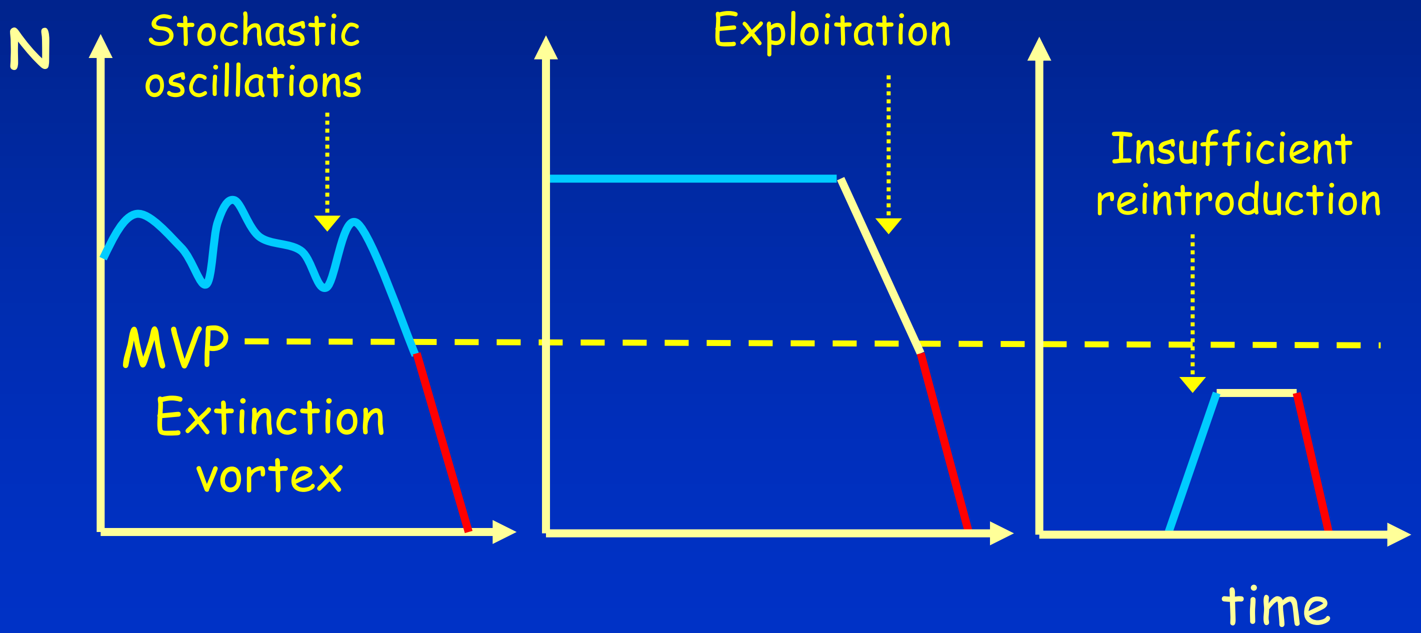
The Minimum Viable Population (MVP)

Due to depensation there is a threshold density (Minimum Viable Population) below which there is not growth even if lambda max is greater than 1



THE EFFECT OF CRITICAL DEPENSATION

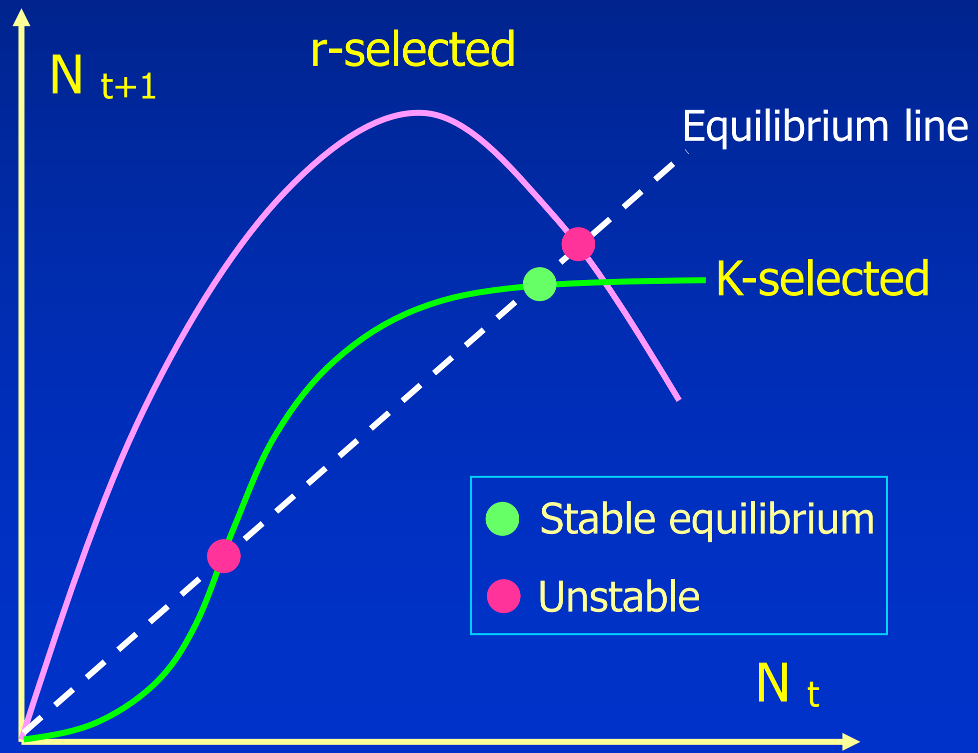
The importance of knowing the Minimum Viable Population (MVP) for conservation and managing of natural populations



DENSITY DEPENDENCE IN r- AND K-SELECTED POPULATIONS

In r-selected populations (unstable environments) growth rate is high at lower-medium density (high r), but besides a given density there is a rapid decrease and overcrowding is followed by population crash

In K-selected populations (stable environments) growth rate is low at lower density (depensation) but the population remains stable when reaches the carrying capacity



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DEMOECOLOGY AND EXPLOITATION POLICIES

Exploitation of natural biotic resources (fishing, forest harvesting etc.) require to combine economical and ecological needs:

A) To give the maximum short term gain compatible with long term exploitability of the resource (sustainability)

A) To guarantee the persistence of population density enough to minimize future risk of extinction (conservation)

Empirism does not work

The only way to obtain policies able to generate acceptable policies combining these two needs is to know the demography of the exploited resources and to use models for predicting future density under different exploitation pressures

DEMOECOLOGY AND EXPLOITATION POLICIES

Two basic strategies: fixed quota and constant effort

A) Fixed quota

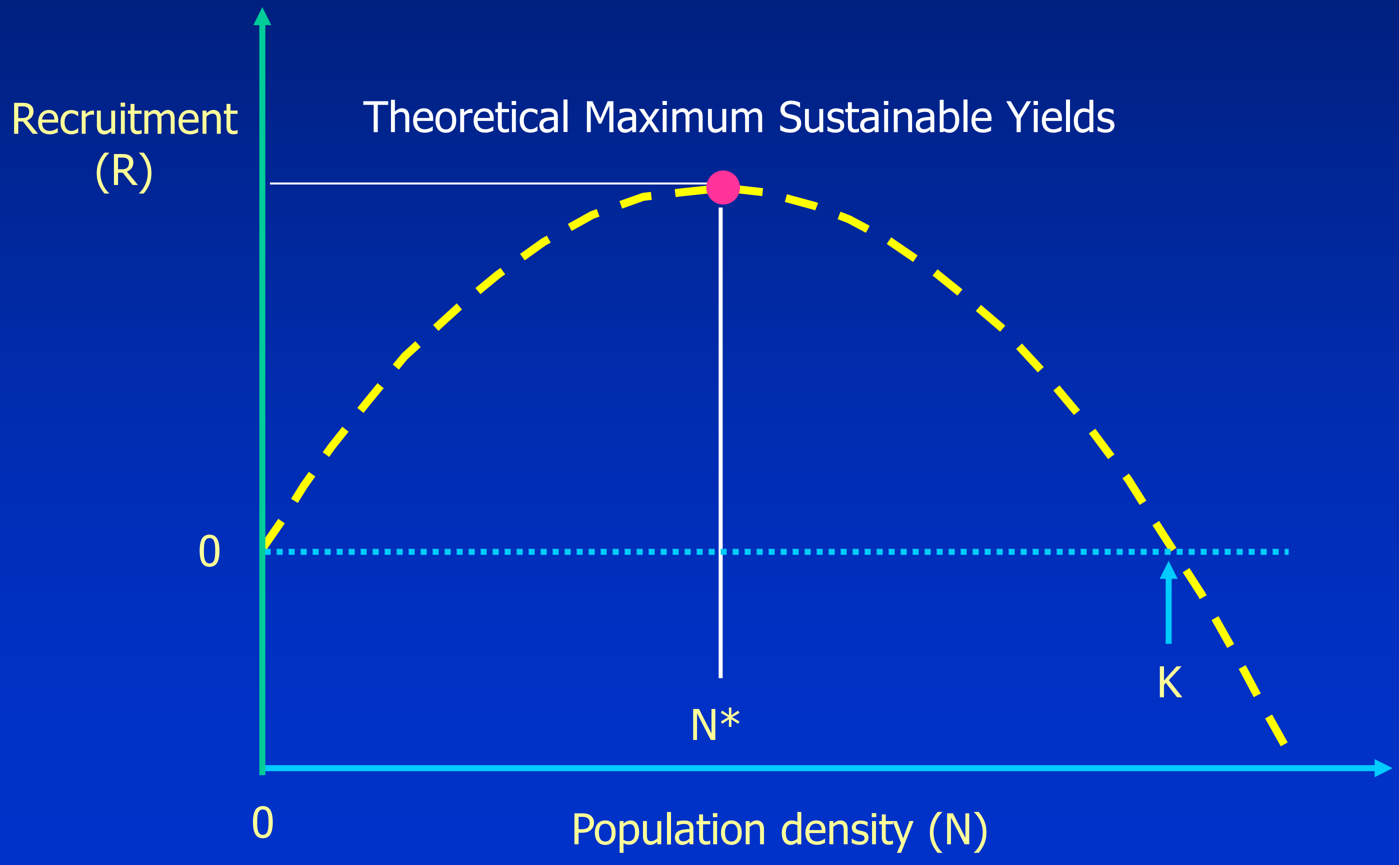
Recruitment: number or biomass reproduced by the population in a given interval of time (e.g. one year)

$$N_{t+1} = N_t + R(N_t) - Q$$

Extraction of a fixed quota (number, biomass)

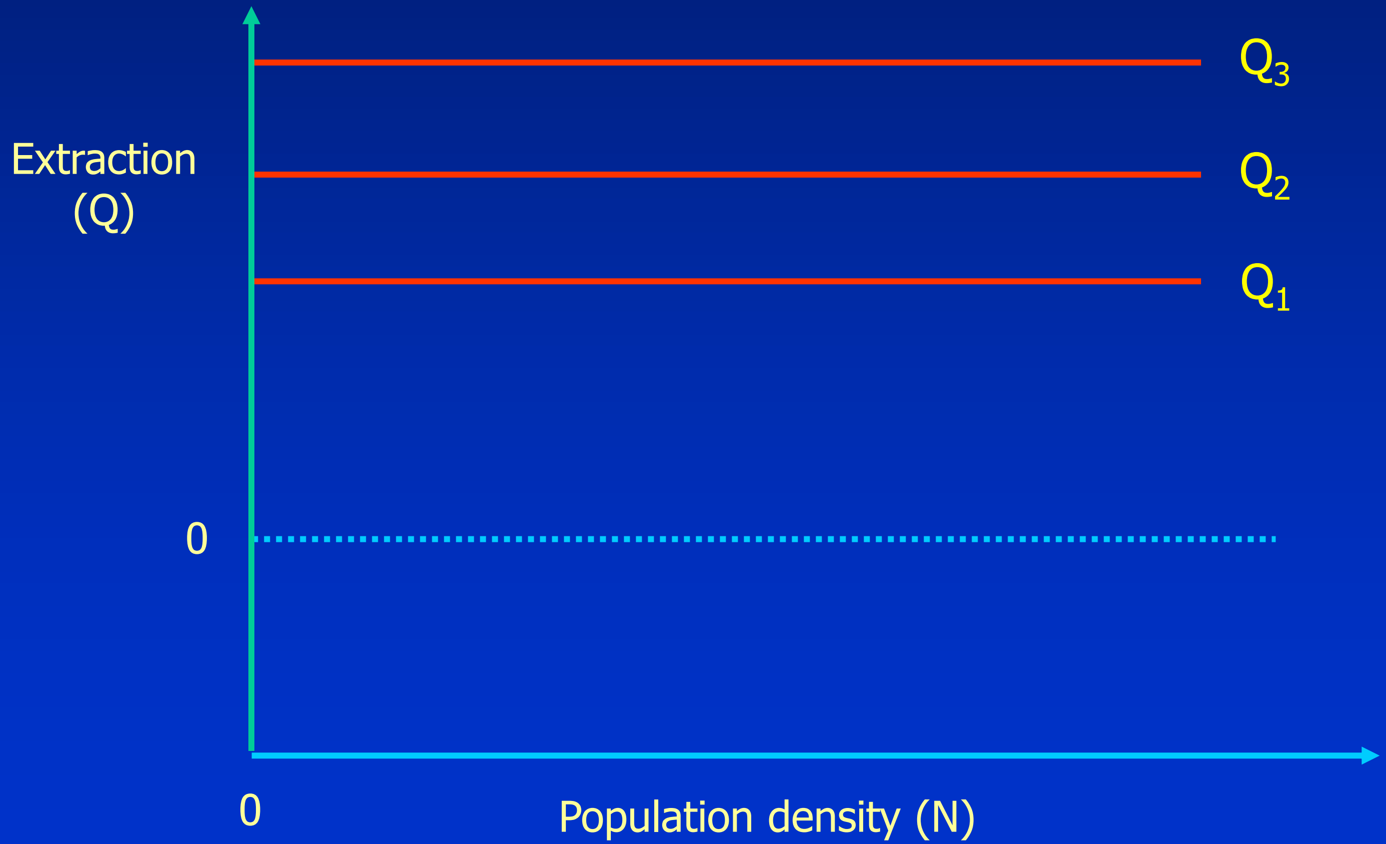
DEMOECOLOGY AND EXPLOITATION POLICIES

Recruitment curve in case of a density dependent regulation



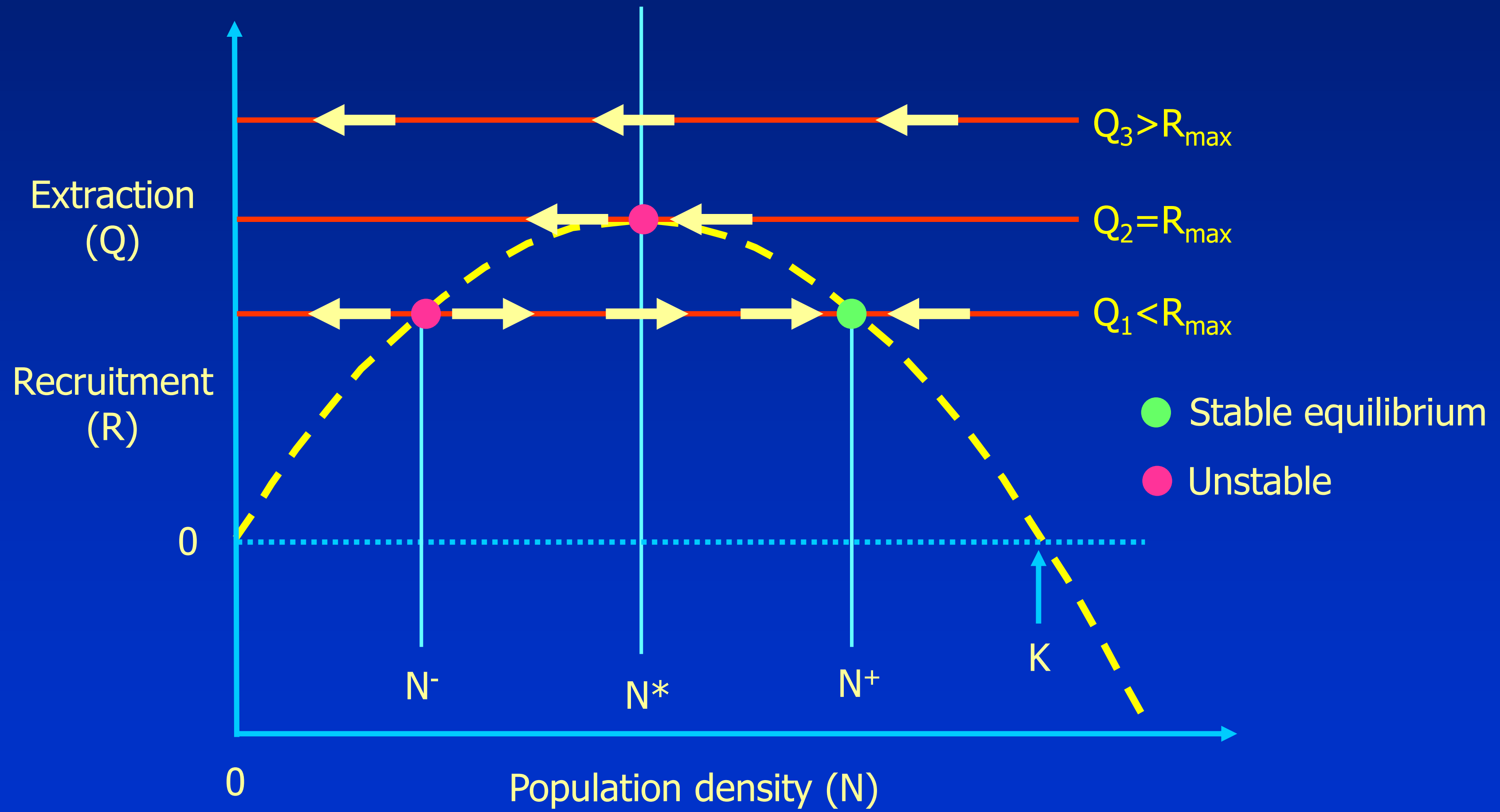
DEMOECOLOGY AND EXPLOITATION POLICIES

Extraction of constant quota of resources (diffent values)



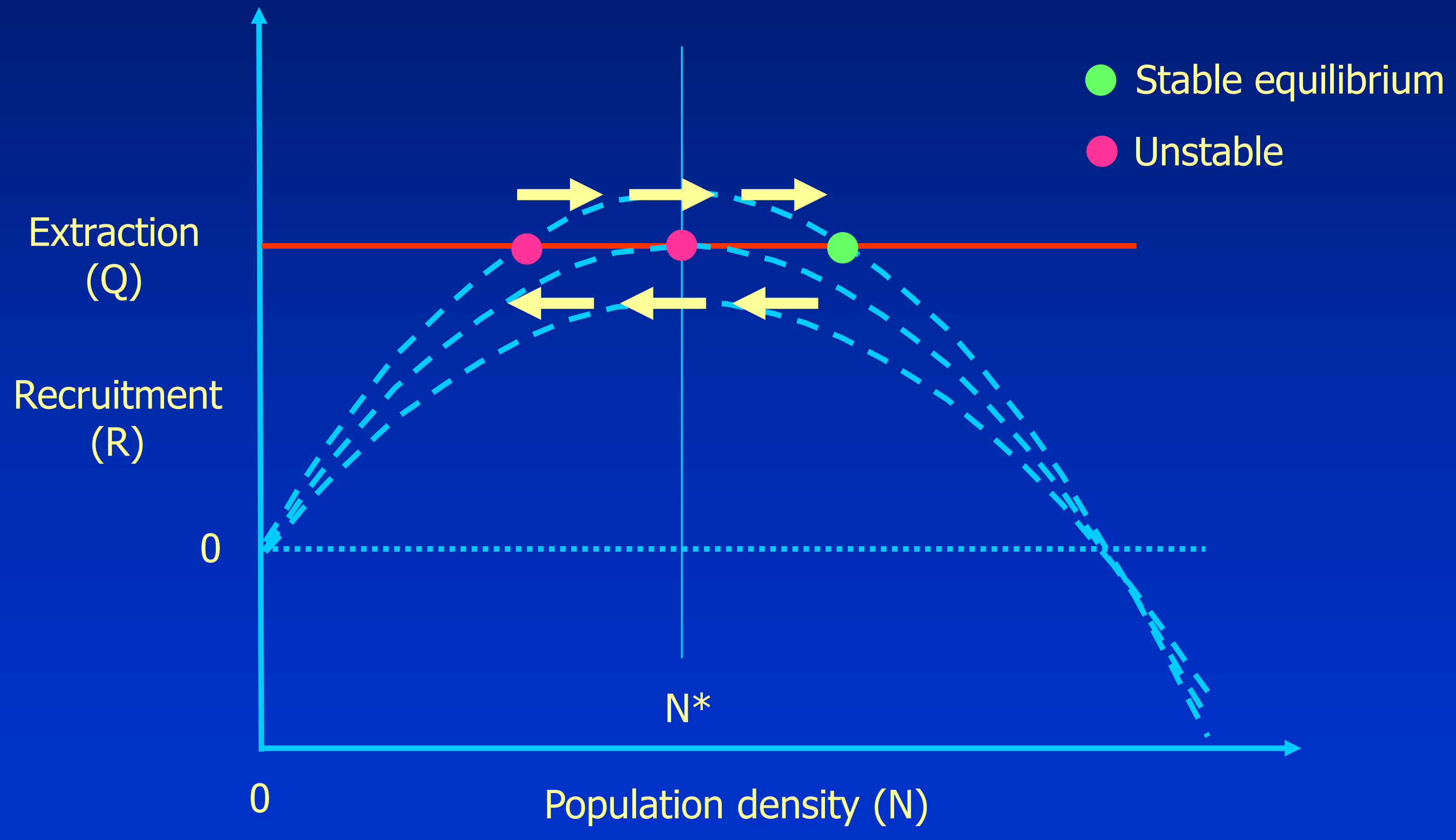
DEMOECOLOGY AND EXPLOITATION POLICIES

Overlapping logistic recruitment and constant quota



DEMOECOLOGY AND EXPLOITATION POLICIES

Problems with fixed quota exploitation: stochasticity of recruitment



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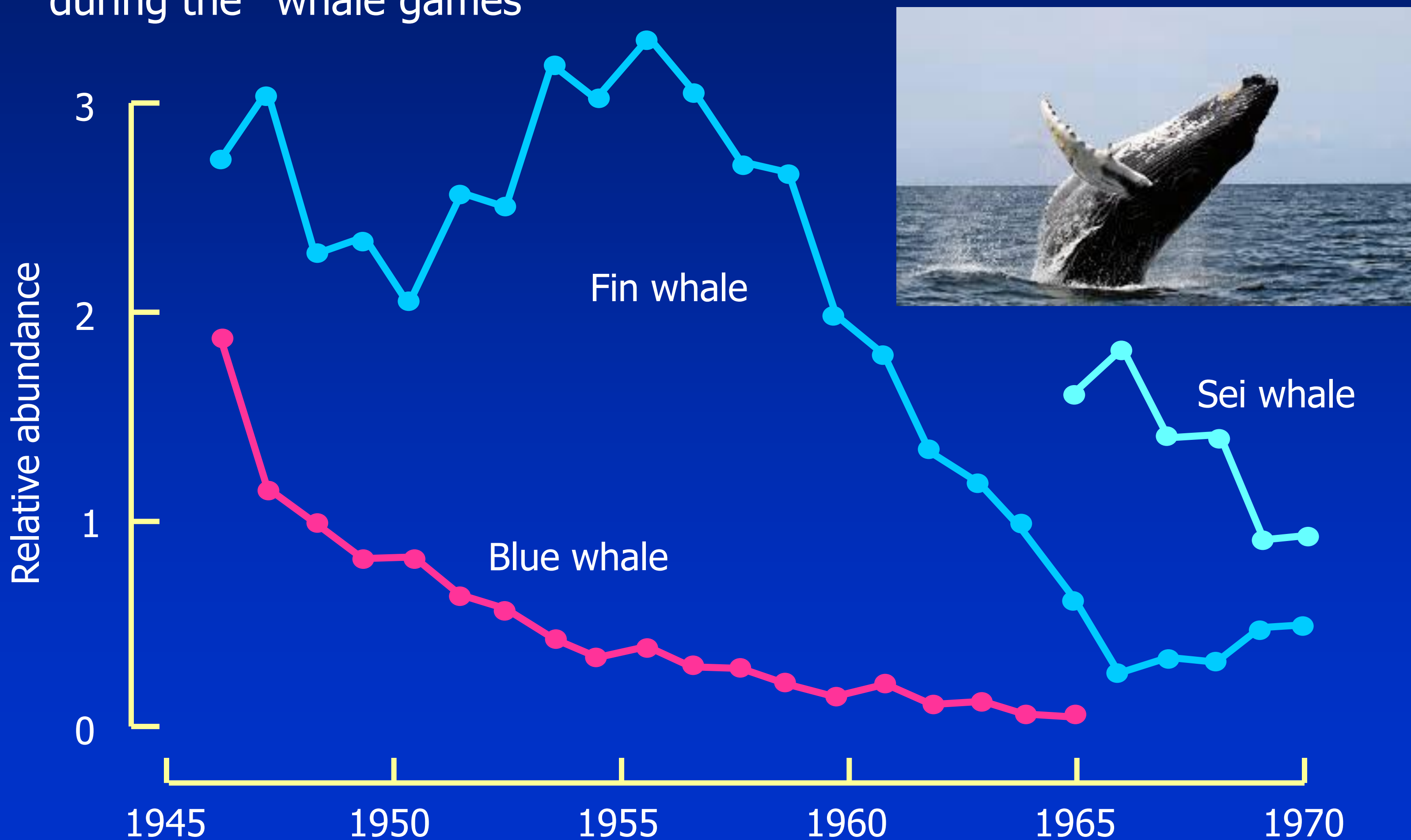
DEMOECOLOGY AND EXPLOITATION POLICIES

Problems with fixed quota exploitation: reduction of whale populations during the “whale games”



DEMOECOLOGY AND EXPLOITATION POLICIES

B) Constant effort

Exploitation effort includes: number of extraction items, their characteristics time of operation etc. (e.g. number of fishing vessels, total length of nets, kind of nets and trawling devices allowed, total number of vessels' days)

Recruitment: number or biomass reproduced by the population in a given interval of time (e.g. one year)

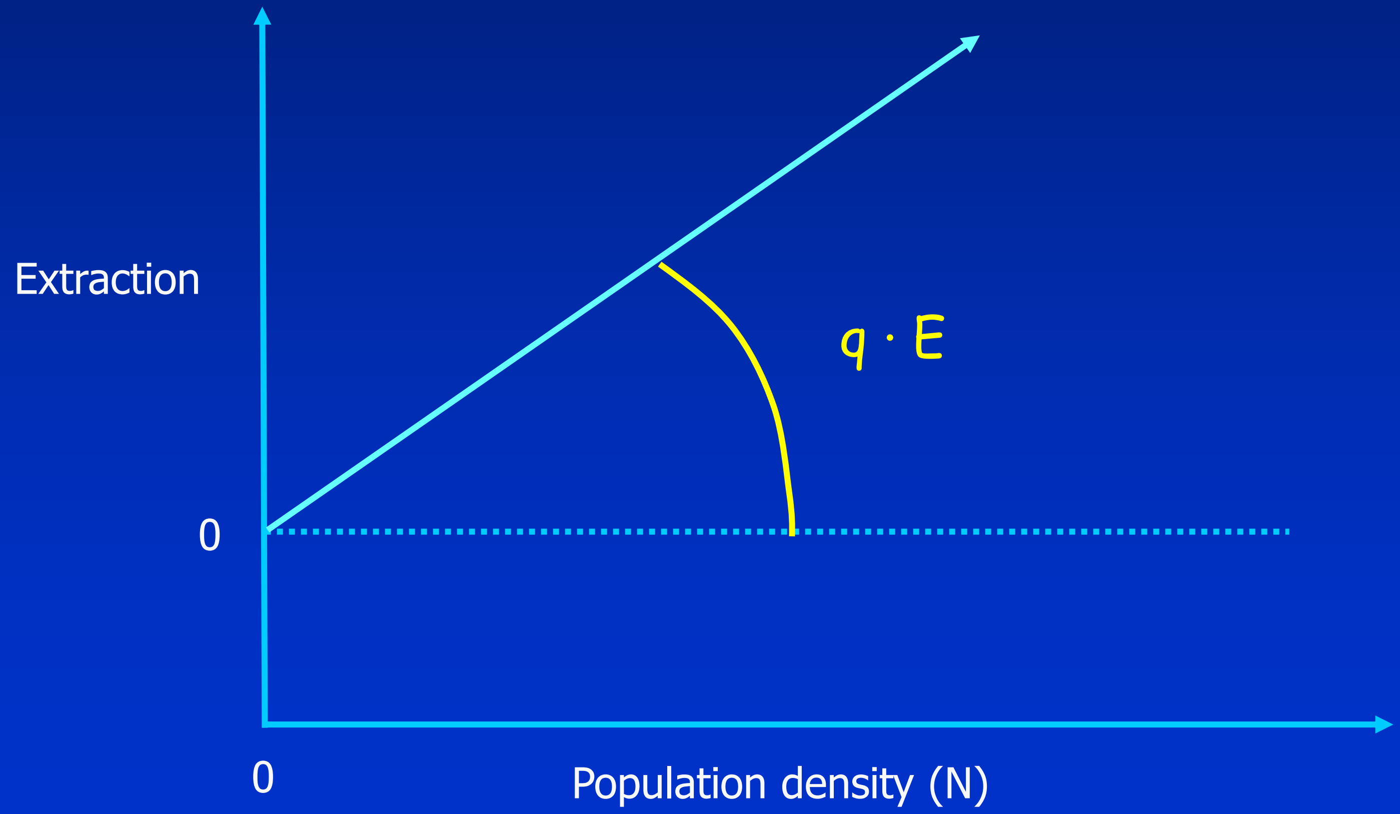
$$N_{t+1} = N_t + R(N_t) - q \cdot E(N_t)$$

Characteristics of extraction devices

Number of extraction devices / days operation

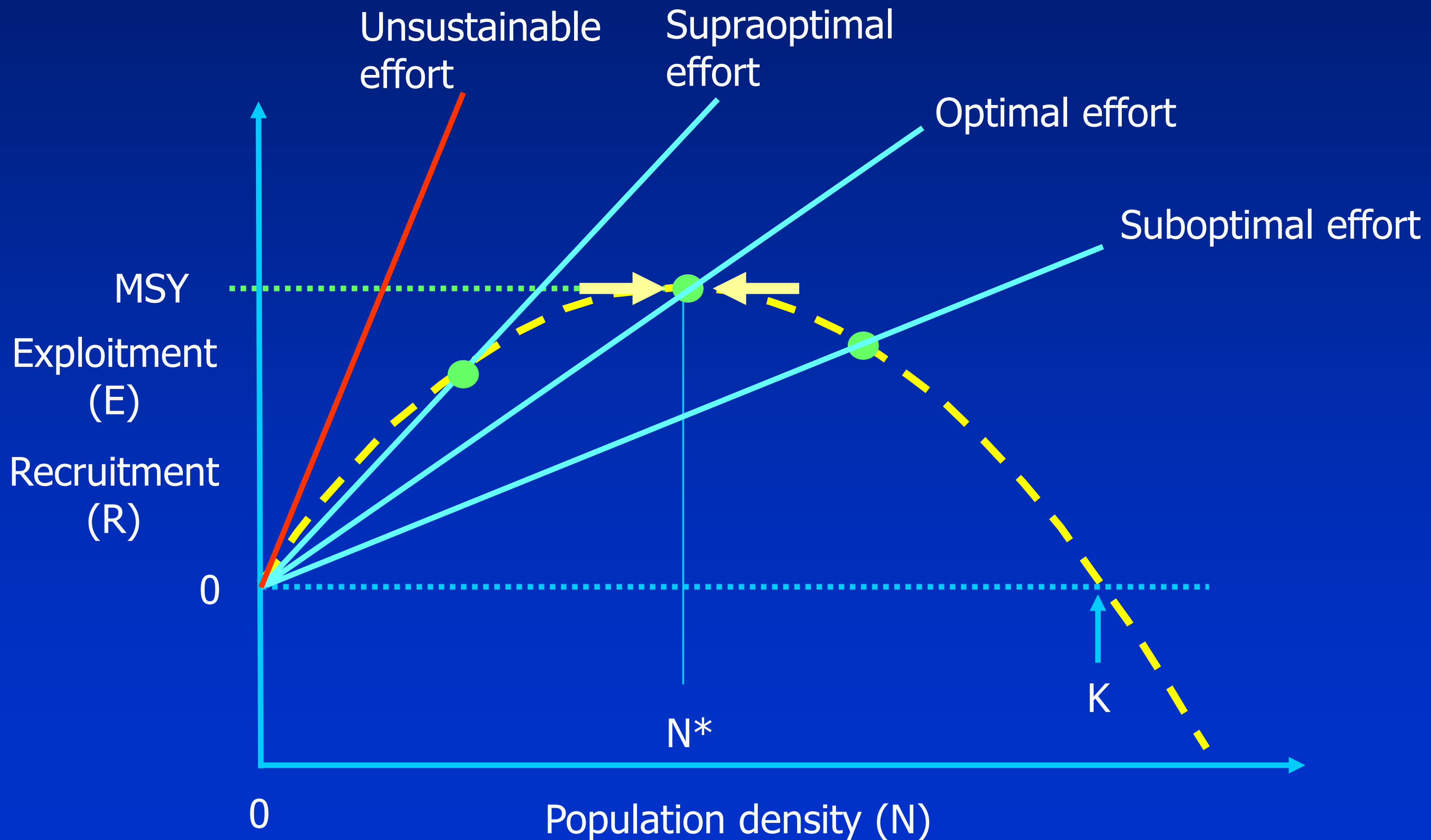
DEMOECOLOGY AND EXPLOITATION POLICIES

With constant effort the amount of resource actually extracted is proportional to the population density (regulated exploitement)



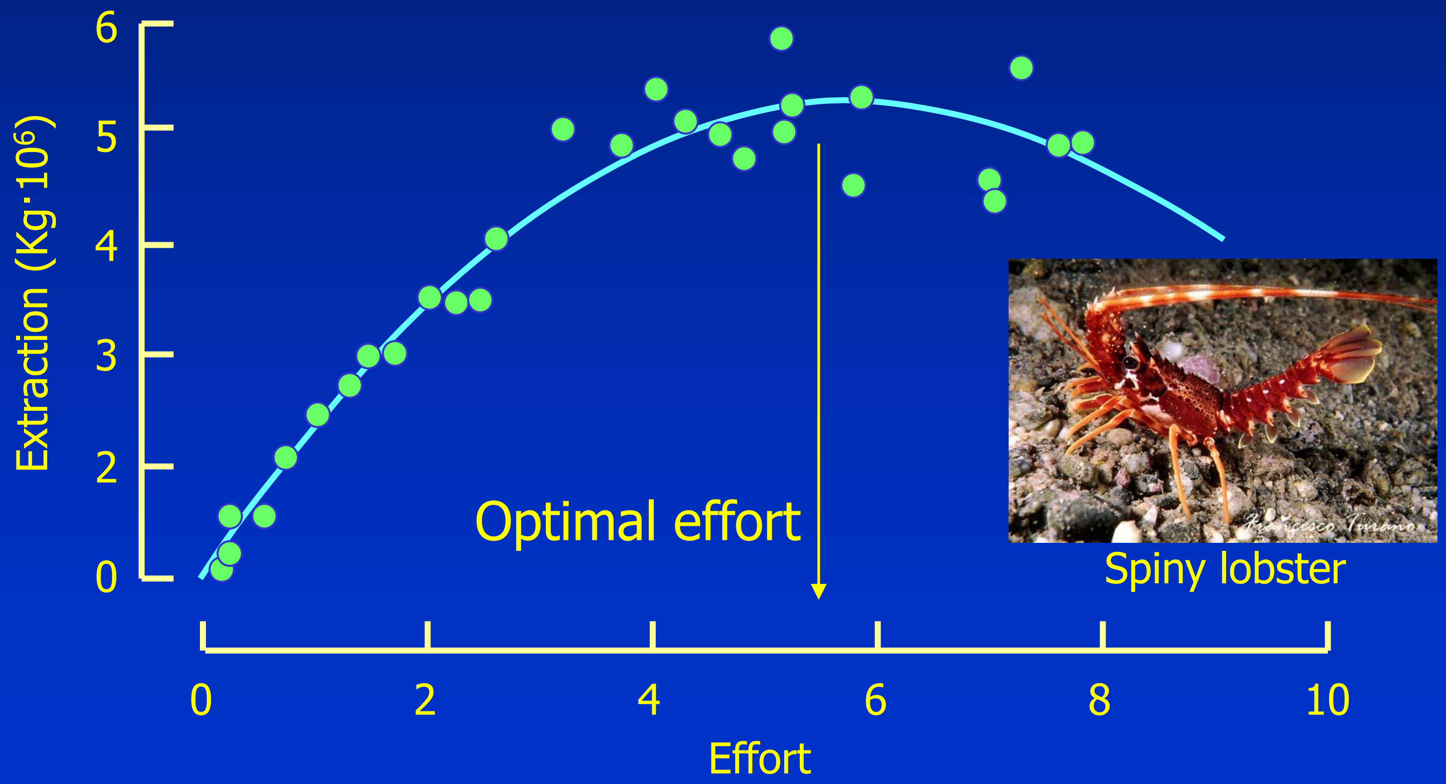
DEMOECOLOGY AND EXPLOITATION POLICIES

Effects of constant-effort policies and Maxymum Sustainable Yield



DEMOECOLOGY AND EXPLOITATION POLICIES

Under “constant effort” exploitment, the yield is maximum for a given (optimal) effort value. Greater effort release lower yields



DEMOECOLOGY AND EXPLOITATION POLICIES

Constant effort may be dangerous in case of depensation