

# DEMOGRAPHIC EFFECTS OF BIOLOGICAL INTERACTIONS BETWEEN DIFFERENT SPECIES

Species do not exist alone in the habitat

Different populations from different species do interact within the same habitat

Interactions between members of different species do affect the demography of the natural populations

Demoeology of interactions start by considering simple binary systems (e.g. systems composed by just two populations of two different species)

Which kind of interactions?

Depending on the “sign” (positive, negative or null) of the effect of pop A on pop B and viceversa, we can distinguish 9 theoretical interactions

# DEMOGRAPHIC EFFECTS OF BIOLOGICAL INTERACTIONS BETWEEN DIFFERENT SPECIES

		Demographic effect of A on B		
		+	-	0
Demographic effect of B on A	+	++ mutualism	+- predation	+0 commensalism
	-	-+ predation	-- competition	-0 amensalism
	0	0+ commensalism	0- amensalism	00 No interaction

# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION



# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

Interspecific competition occurs when members of two different species having similar ecological niche and prophyte (trophic level) live together in the same area/environment they inevitably and share a given set of resources (trophyc, homeostatic and even reproductive)

Interspecific competition may be accomplished by different “methods”:

- A) By means of “exploitation” i.e. by better exploiting the resources
- B) By means of “interference” i.e. by impeding the other pop to access the resources:

Biochemical-physiological interaction

(emission of chemical signals, poisoning etc.)

Morphological interaction

(e.g. overgrowth, overshadowing etc.)

Behavioural interaction

(emission of postural or vocal signals, fighting etc.)



# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

Interspecific competition: why does it matter?

## ECOLOGICAL INTEREST

Packaging of populations having similar conditional and trophic niche in the same community

Dynamic substitution of species in terrestrial biomes

Perturbation of natural communities following biological invasions of alien species

## ECONOMICAL INTEREST

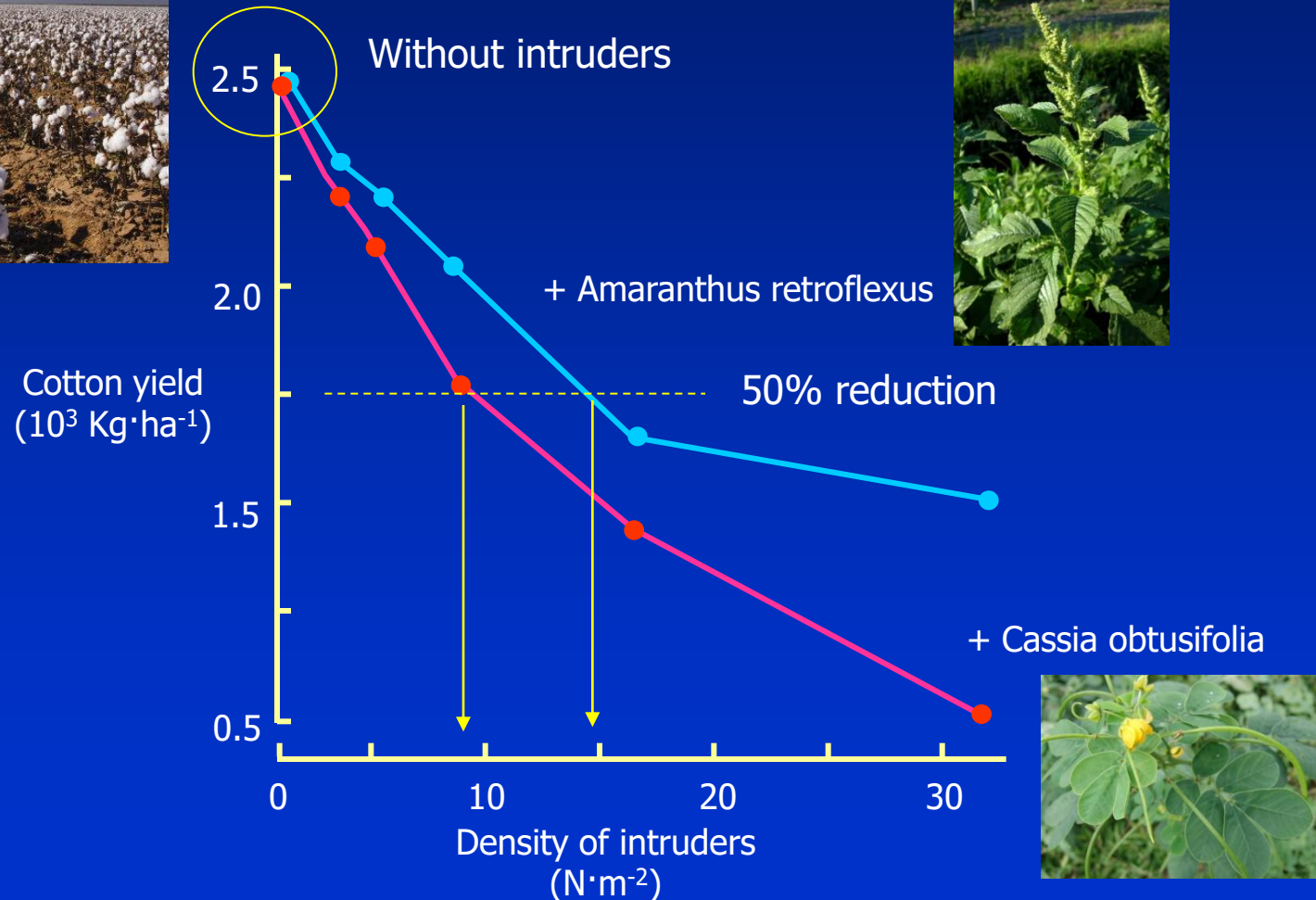
Economic cost of “invading” species in agroecosystems

Possibility to use competition in biological control of “pests”



# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

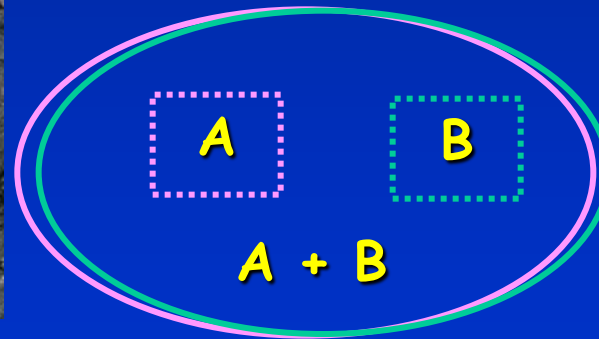
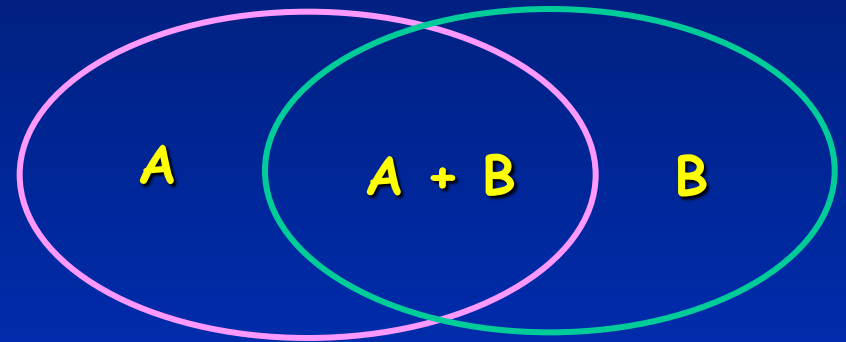
Economic cost of competition. Example: reduction of cotton yield



# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

Demographic effects of interspecific competition can be assessed in the wild by studying parapatric populations or by introducing experimental manipulation of density in experimental plots (fencing)

Natural “experiment”  
Parapatric distribution



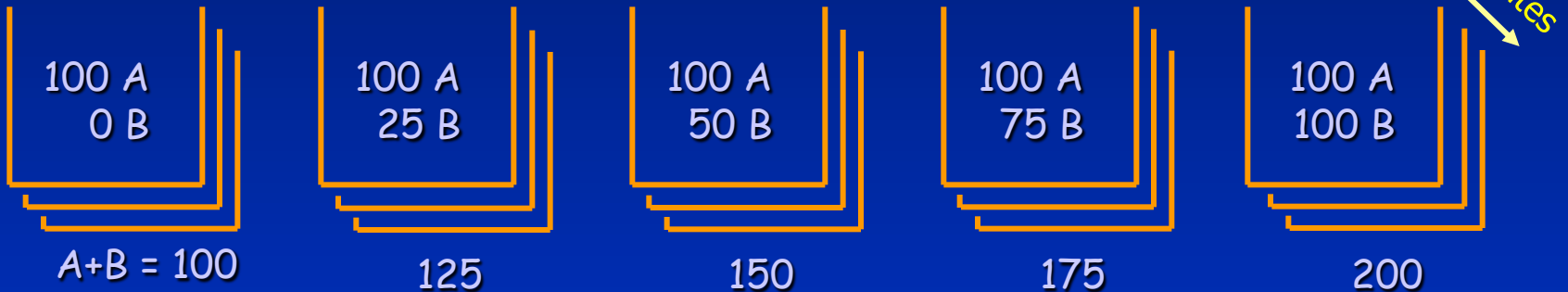
Experimental manipulation in the wild  
Fencing-out

# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

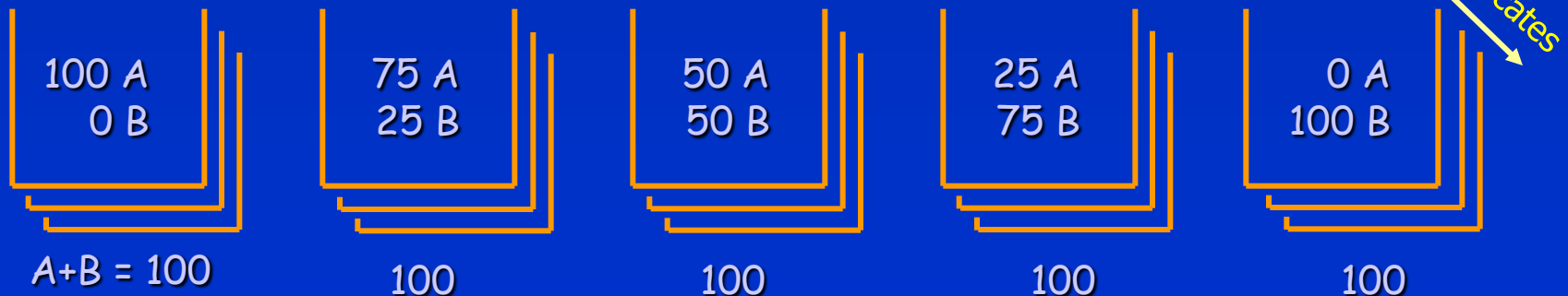
Experimental protocols: input combinations of densities



Additive protocol: density of species A invariant, species B increasing from 0



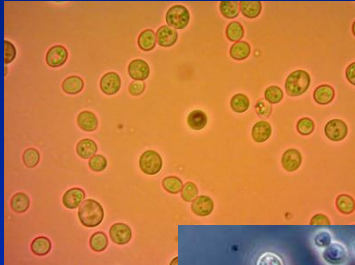
Substitutive (replacement) protocol: Species A decreasing, species B increasing



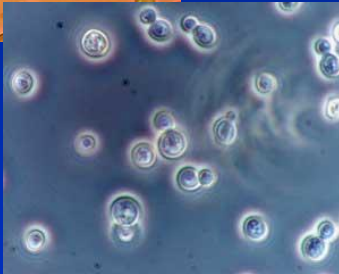


# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

Gause's "free-running"  
experiments  
on yeast cultures

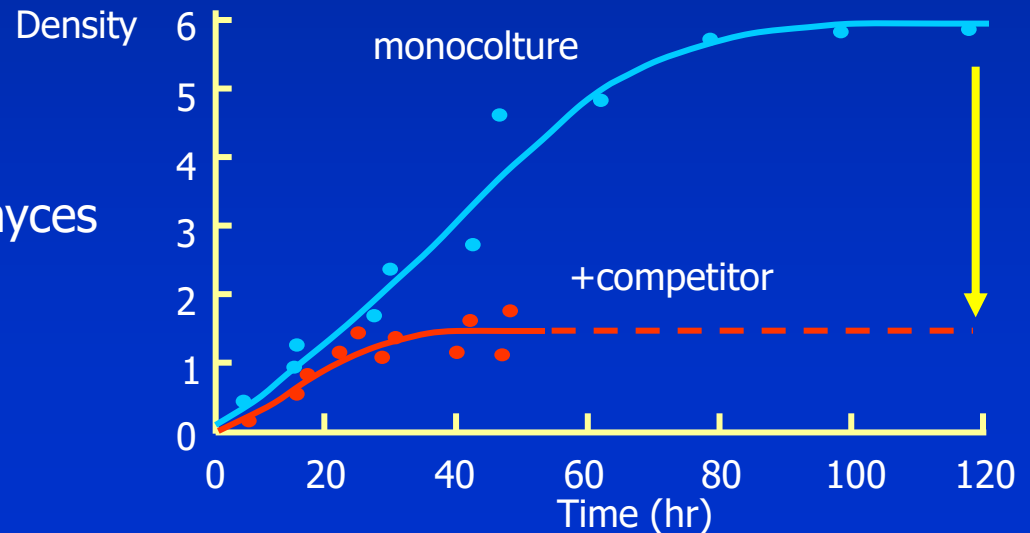
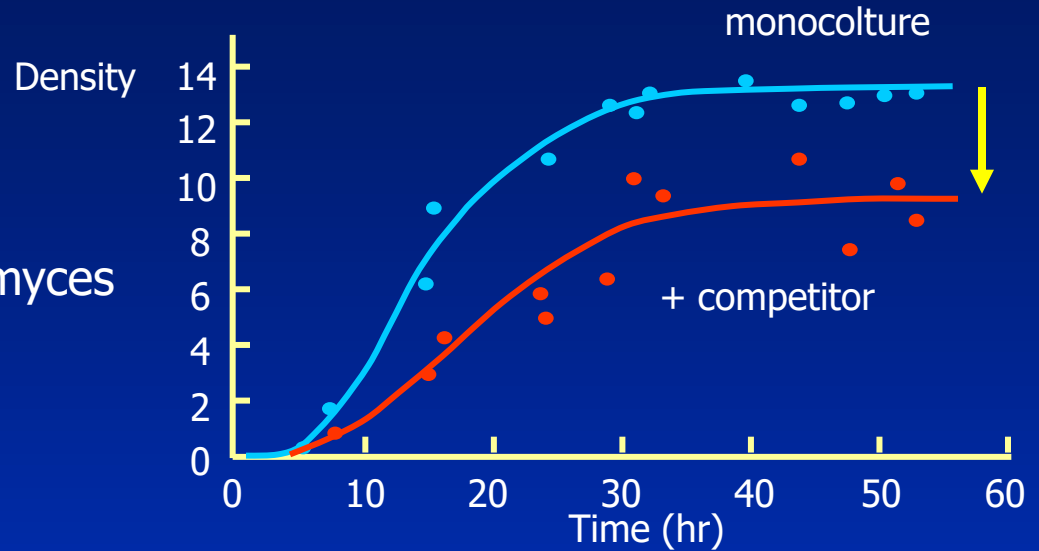


Saccharomyces



Schizzosaccharomyces

Asymmetric reduction of K



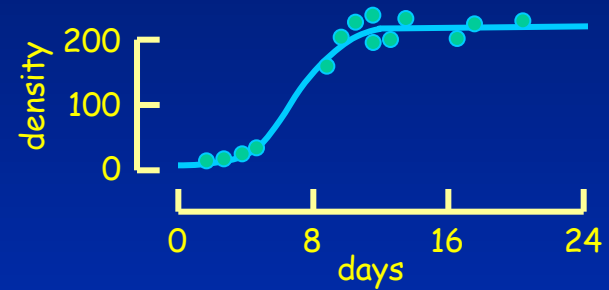
# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

Gause's "free-running" experiments  
on protozoans (*Paramecium* spp.)

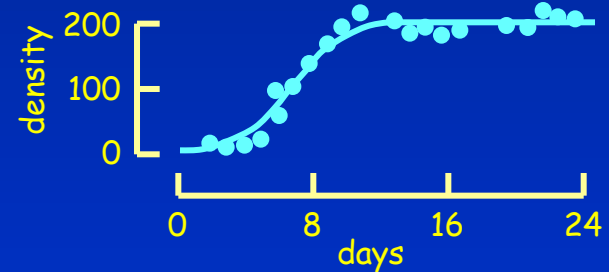
logistic growth in monoculture



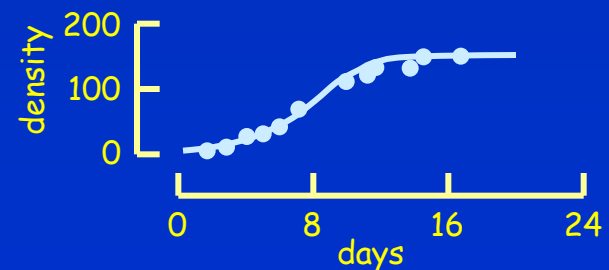
*P. aurelia*



*P. caudatum*



*P. bursaria*

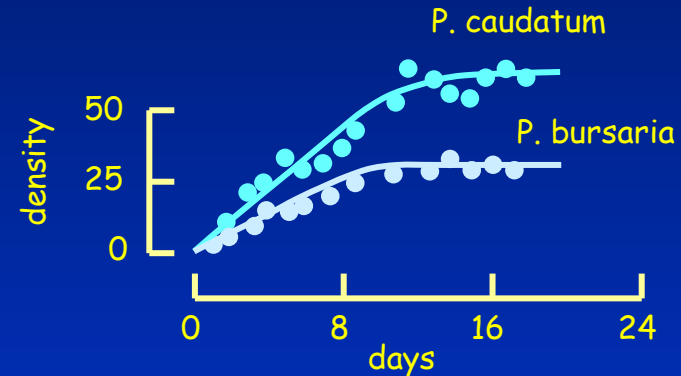
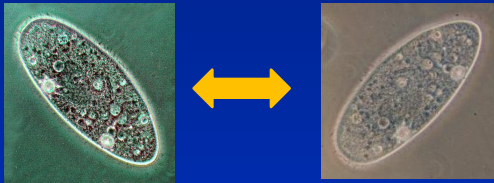


# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

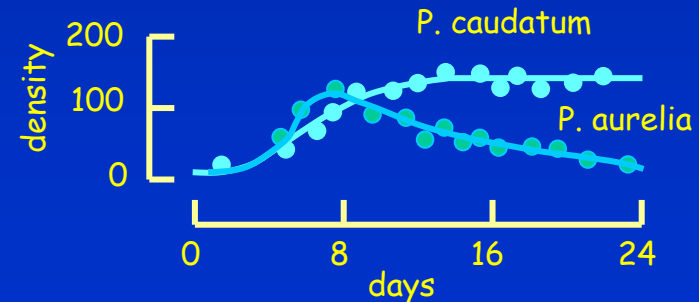
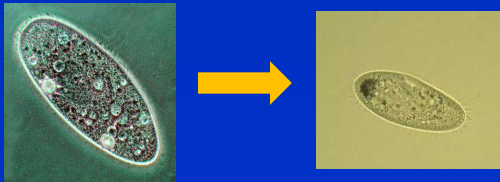
Gause's "free-running" experiments  
on protozoans (*Paramecium* spp.)

growth in mixed culture

*P. caudatum* vs. *P. bursaria*  
**Stable coexistence**



*P. caudatum* vs. *P. aurelia*  
**Competitive exclusion**

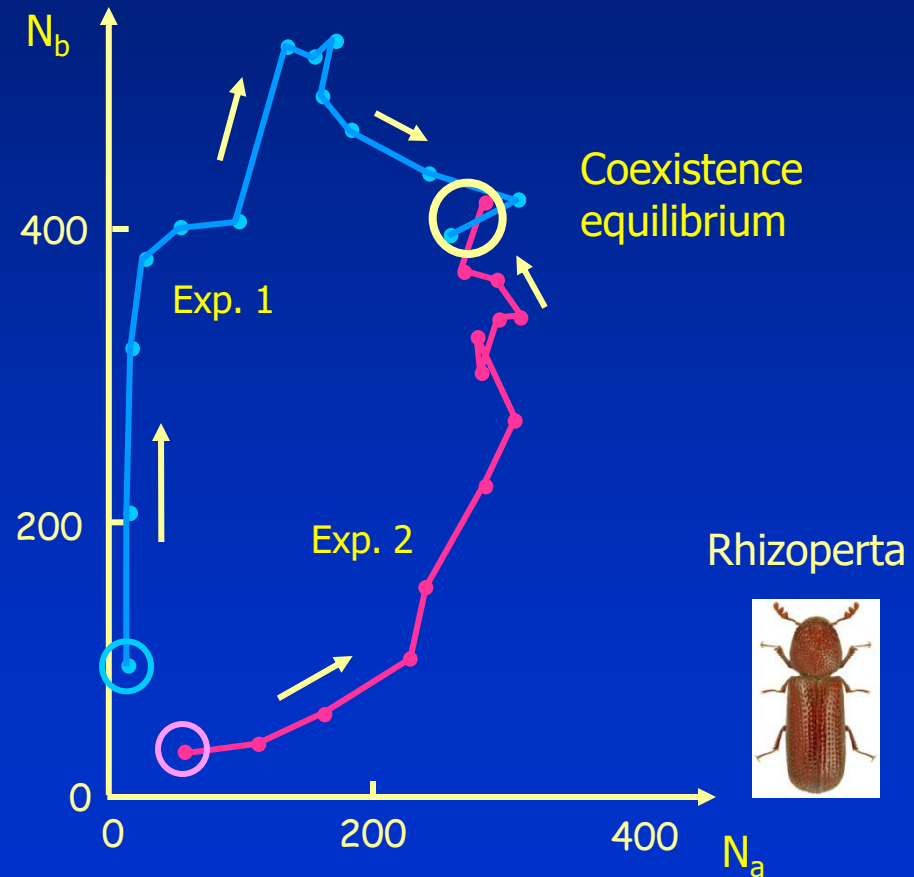


# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

Free running experiments on a couple of competing species of Coleoptera plotted in the “phase plane”  $N_a - N_b$

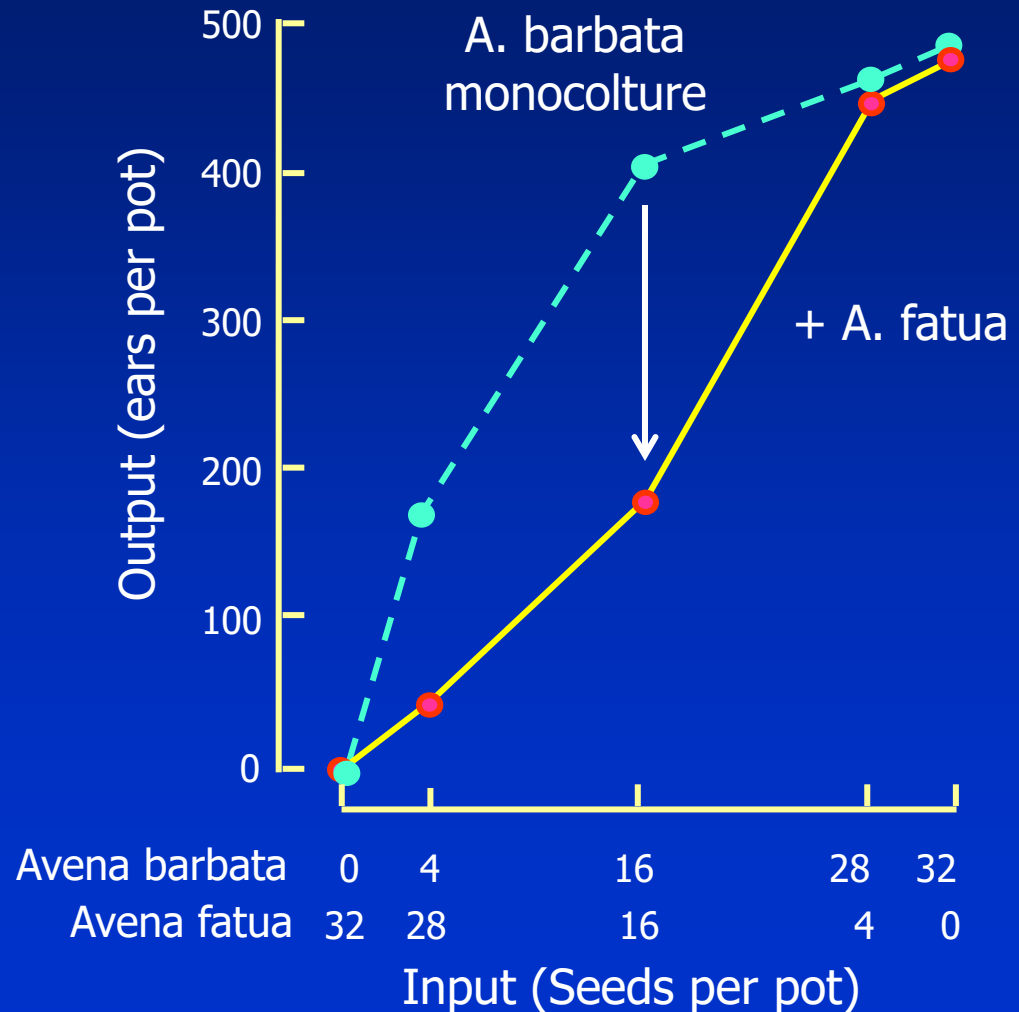
In the phase plane  
each point represents  
a combination of densities  
of the two populations  
and a segment represents  
a variation of densities

Oryzaephilus



# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

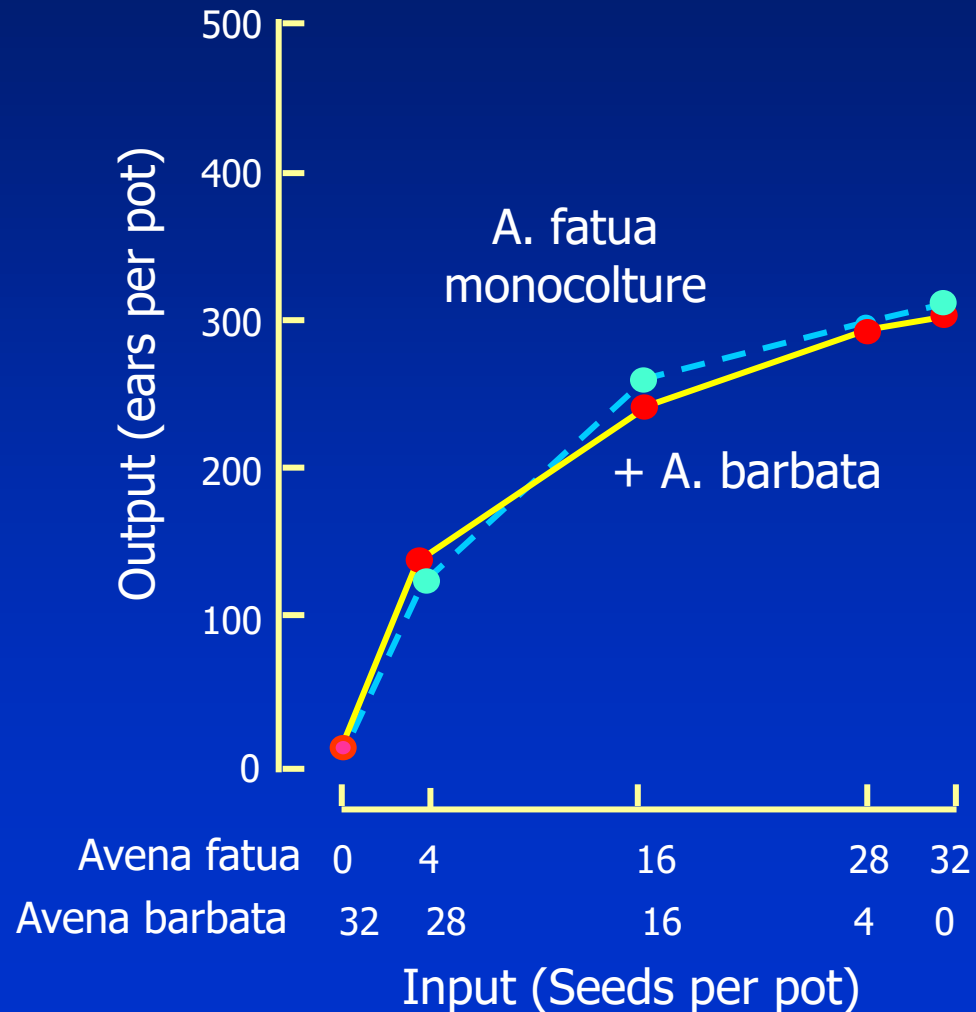
De Witt's substitutive (replacement) experiments on two *Avena* spp.





# DEMOGRAPHIC EFFECTS OF INTER-SPECIFIC COMPETITION

De Witt's substitutive (replacement) experiments on two *Avena* spp.



# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

How to design a model for interspecific competition?

- 1) Parsimony: start from the model of intraspecific competition and add inter-specific interactions
- 2) Completeness: the model must be able to predict different outcomes (exclusion or coexistence) when changing values of the parameters. The model must be able to reproduce symmetric and asymmetric outcomes

Design two linked equations, one for each species, each including competition of species a on b and viceversa

The model of Alfred Lotka and Vito Volterra

$\alpha_{a,b}$  = competition “strength” of b on a

$\alpha_{b,a}$  = competition “strenght” of a on b

$$\frac{dN_a}{dt} = N_a r_a \frac{(K_a - N_a - \alpha_{a,b} \cdot N_b)}{K_a}$$

$$\frac{dN_b}{dt} = N_b r_b \frac{(K_b - N_b - \alpha_{b,a} \cdot N_a)}{K_b}$$

# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

Which are the basic predictions of L-V model ?

$$\frac{dN_a}{dt} = N_a r_a \frac{(K_a - N_a - \alpha_{a,b} \cdot N_b)}{K_a}$$

$$\frac{dN_a}{dt} = 0 \quad \text{when} \quad N_a r_a \frac{(K_a - N_a - \alpha_{a,b} \cdot N_b)}{K_a} = 0$$

i.e. when  $r_a = 0$  or when  $(K_a - N_a - \alpha_{a,b} \cdot N_b) = 0$

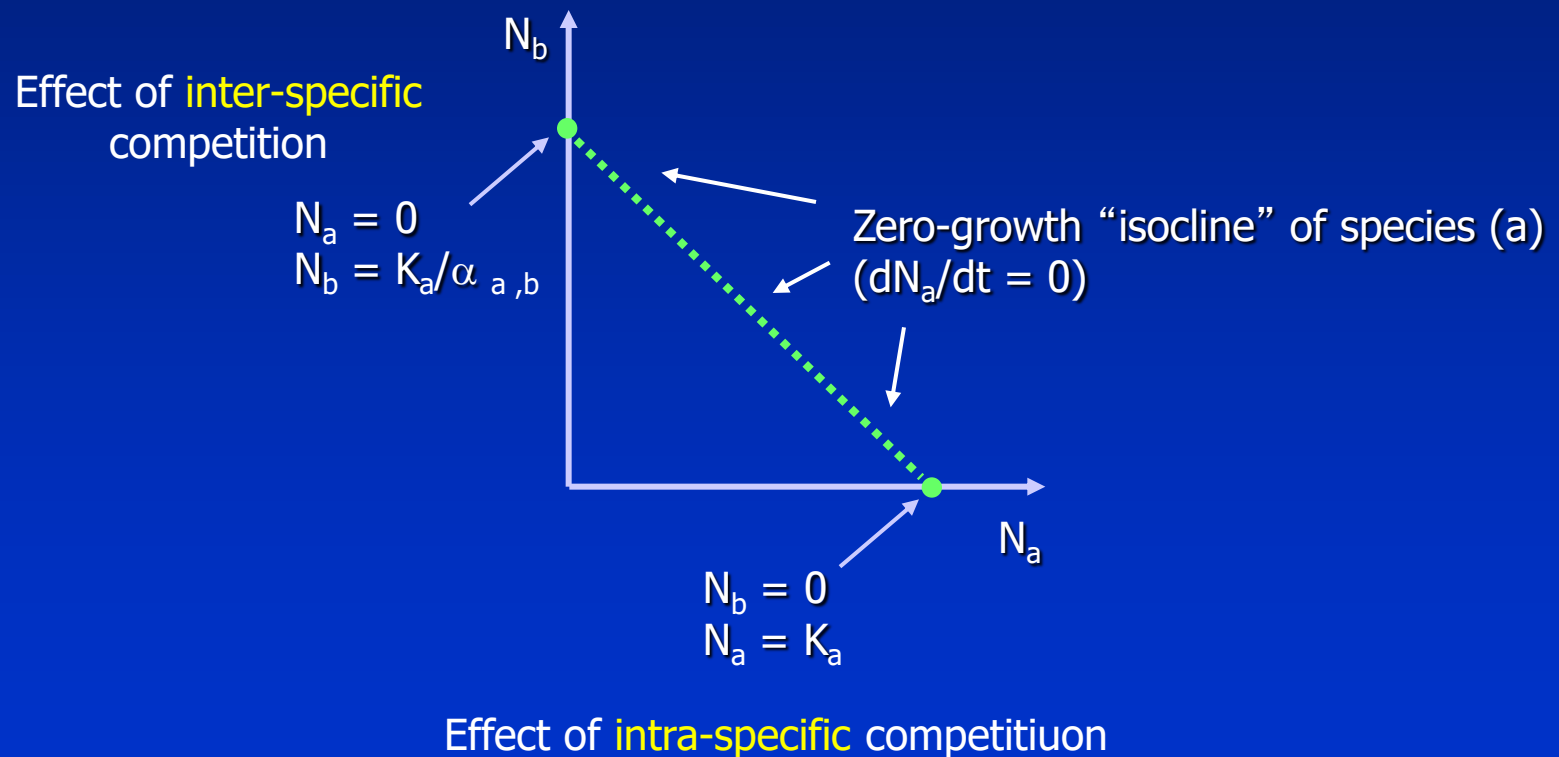


if  $N_b = 0$ , this happens when  $N_a = K_a$   
(pure intra-specific competition)

if  $N_a \rightarrow 0$ , this happens when  $\alpha_{a,b} \cdot N_b = K_a$ , i.e. when  $N_b = K_a / \alpha_{a,b}$   
(pure inter-specific competition)

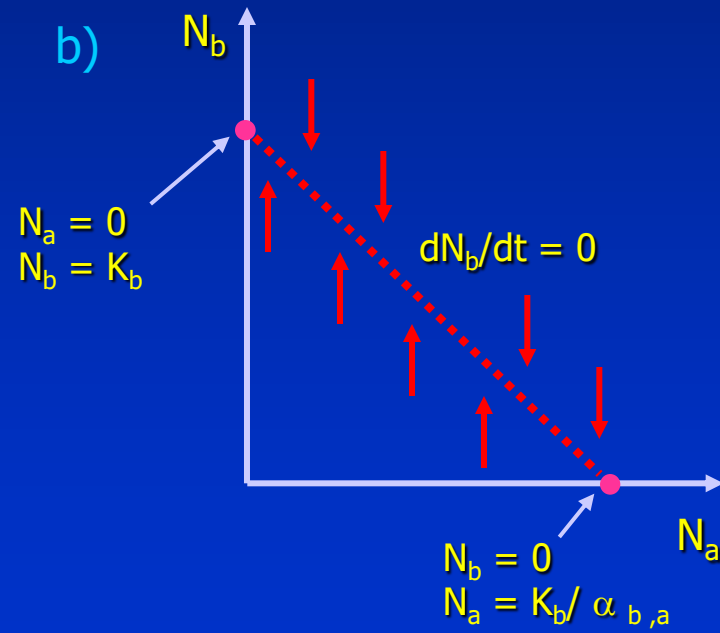
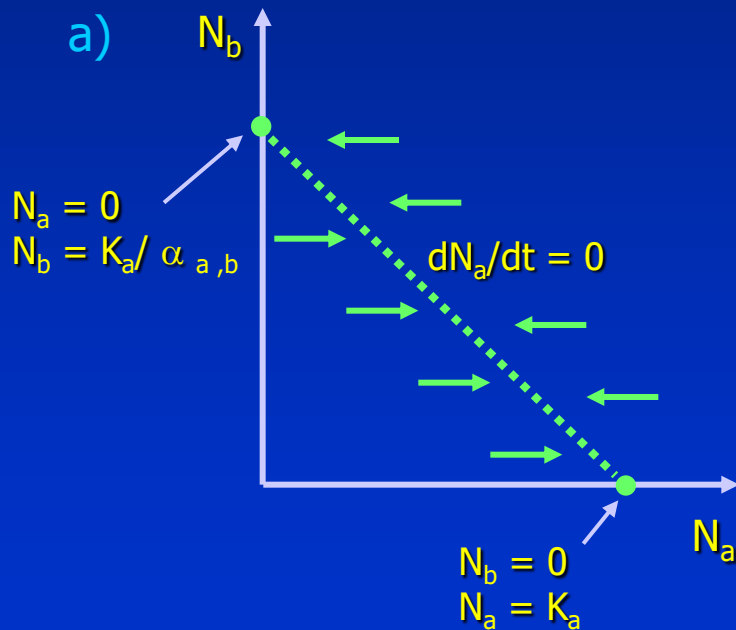
# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

Equilibrium densities in the L-V model. The phase plane of species (a)



# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

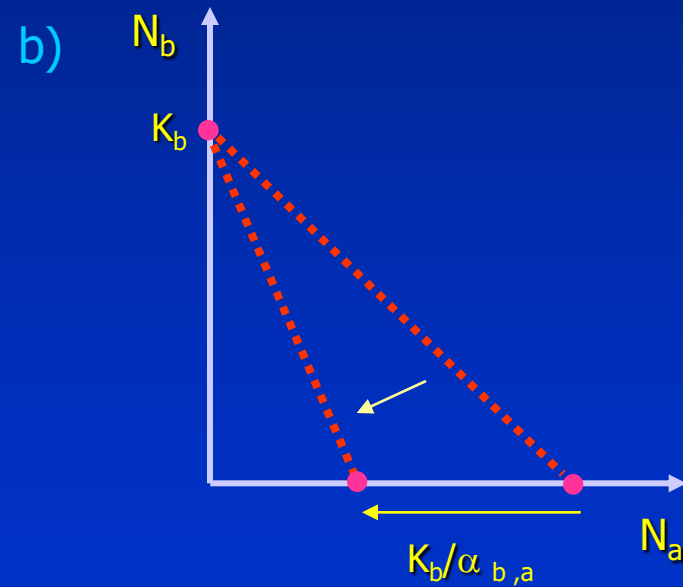
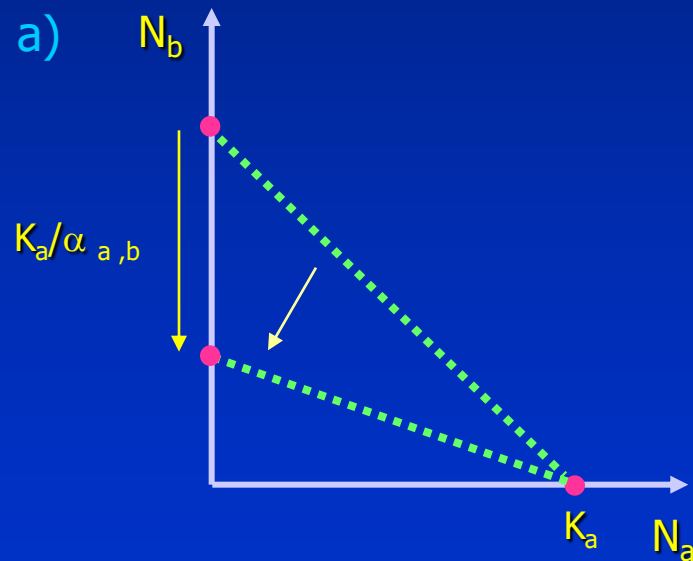
Equilibrium densities of the two species in the L-V model





# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

Equilibrium densities in the L-V model. The effect of increasing  $\alpha$  values (strength of inter-specific competition)



# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

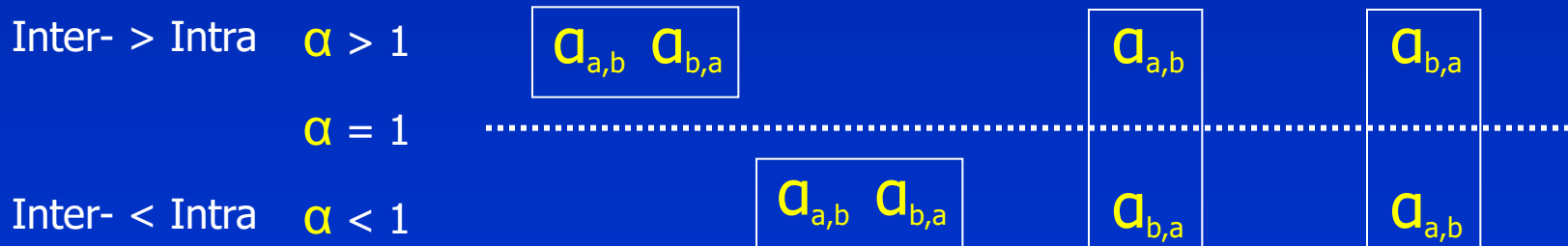
The predicted outcome of competition under L-V models depends on the relative position of the zero growth isoclines of the two species in the common phase-plane

This in turn depends on the values of the critical parameters for intra- and interspecific competition:

Species (a):  $K_a$ ,  $K_a / \alpha_{a,b}$

Species (b):  $K_b$ ,  $K_b / \alpha_{b,a}$

In particular, regarding the alphas the situation of the two species can be as follows

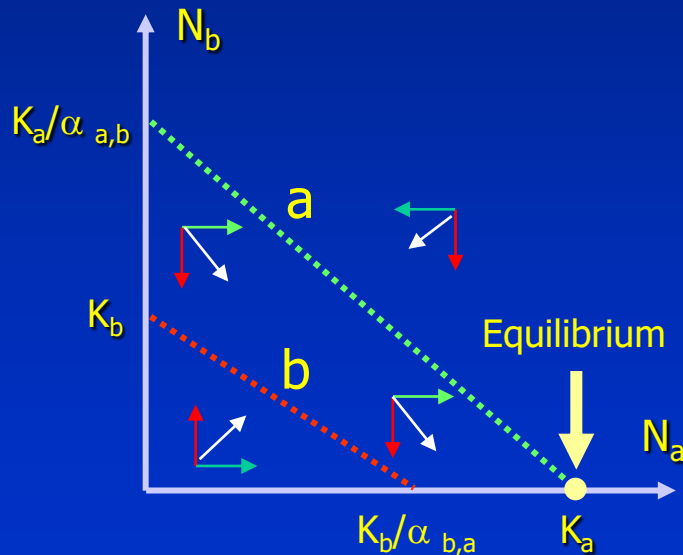


# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

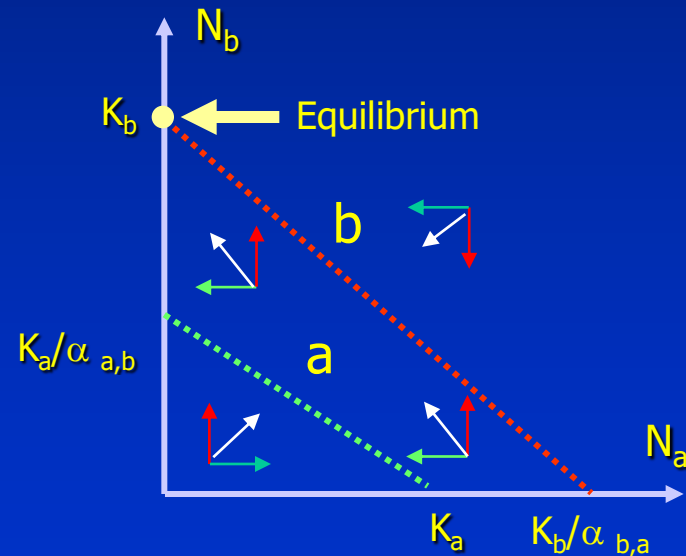
## Predictions of the L-V model

### Case I – Competitive exclusion independent from initial densities

This occurs when one species (overcompetitor) is less constrained than the other both with respect to intra- and inter-specific competition



Species (a) overcompetitor on (b)



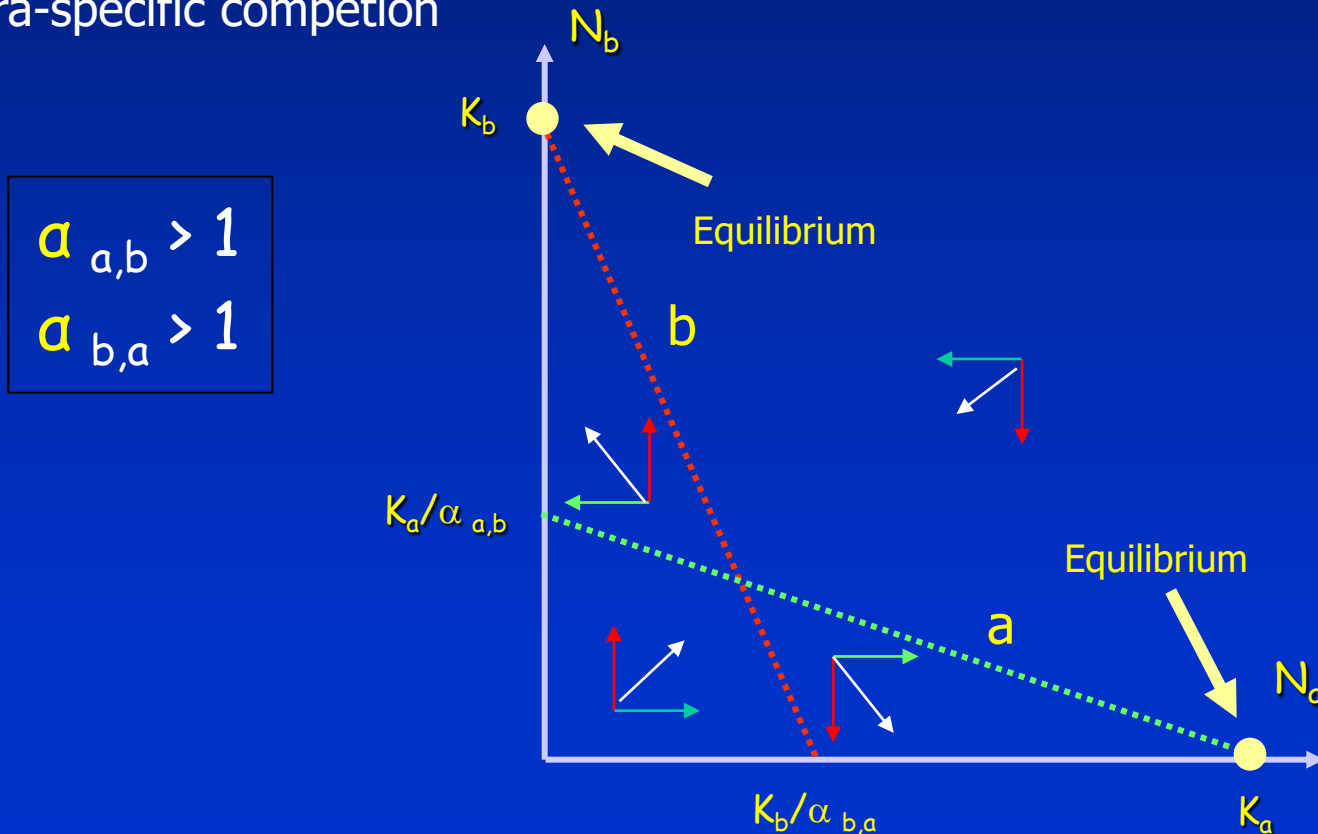
Species (b) overcompetitor on (a)

# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

## Predictions of the L-V model

### Case II – Competitive exclusion dependent from initial densities

This occurs when both species are more constrained by inter- than by intra-specific competition

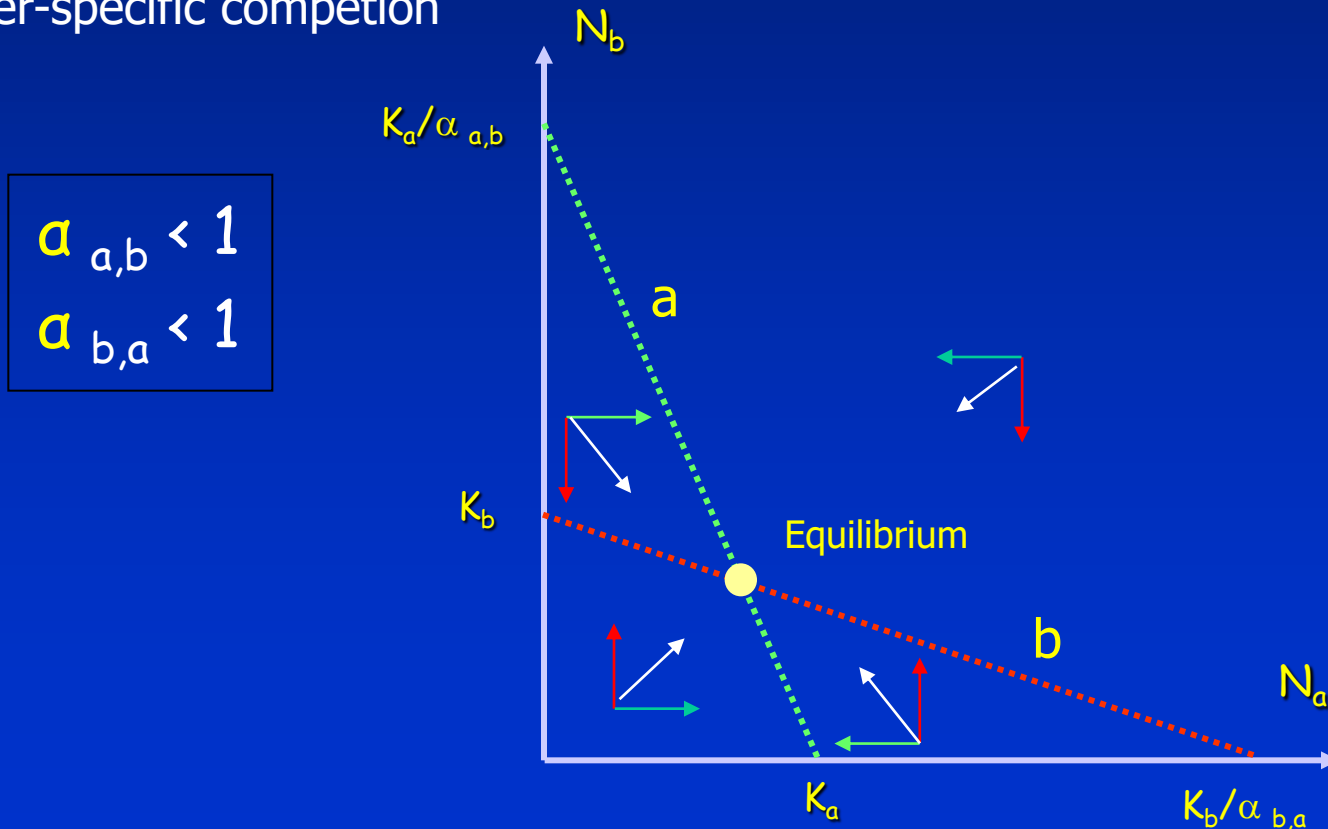


# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

Predictions of the L-V model

Case III – **Stable coexistence**

This occurs when both species are more constrained by intra- than by inter-specific competition





# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

How to assess the alpha coefficients according to the L-V models ?

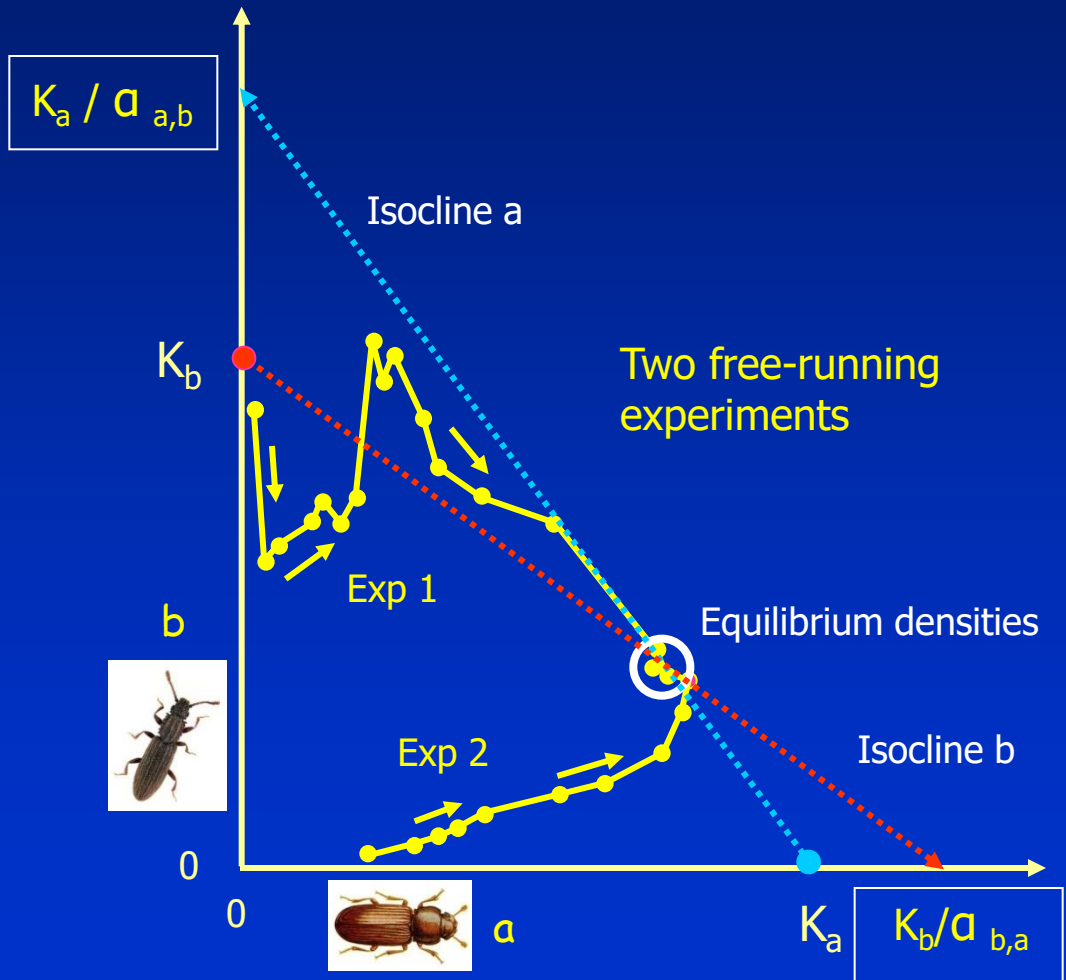
From the equilibrium densities of two competing species in stable coexistence, knowing the carrying capacity of each species in monoculture ( $K_a$ ,  $K_b$ )

Growth of species a is limited by density of species b

$$N_b = K_a / \alpha_{a,b} \text{ hence } \alpha_{a,b} = N_b / K_a$$

Growth of species b is limited by density of species a

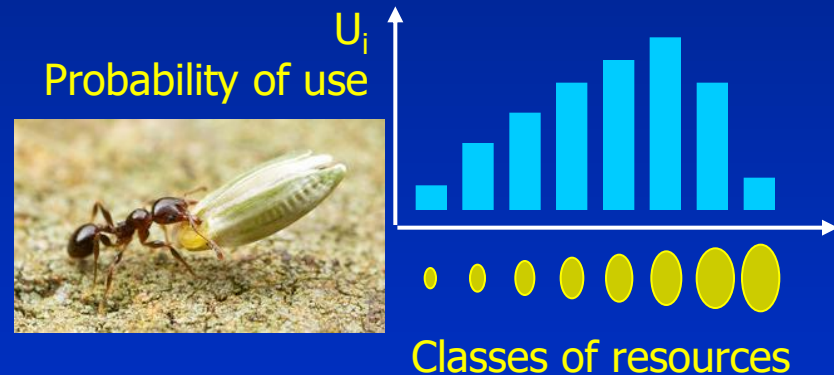
$$N_a = K_b / \alpha_{b,a} \text{ hence } \alpha_{b,a} = N_a / K_b$$



# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

Interspecific competition can be assessed by obtaining the “trophic niche” of two or more species having similar trophic habits

- 1) Offer to individuals of two species (a and b, independently), a set of R different resources equally represented (e.g. seeds of different size “offered” to two species of ants)
- 2) Register the frequency of choices toward each class of items (i) made by each of the two species (how many individuals made their first choice on each class of seeds)
- 3) Normalize the frequency distribution to the total of individuals tested to obtain probabilities of resource use (U)

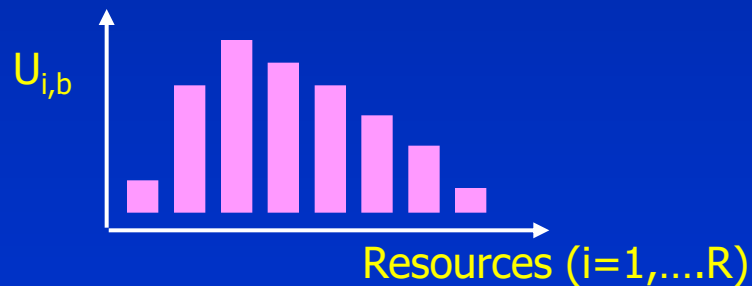


# DEMOGRAPHIC MODELS OF INTER-SPECIFIC COMPETITION

Assessment of “trophic niche overlap” between two species



Species (a)



Species (b)



# PLASTICITY OF RESOURCES USE IN COMPETING SPECIES

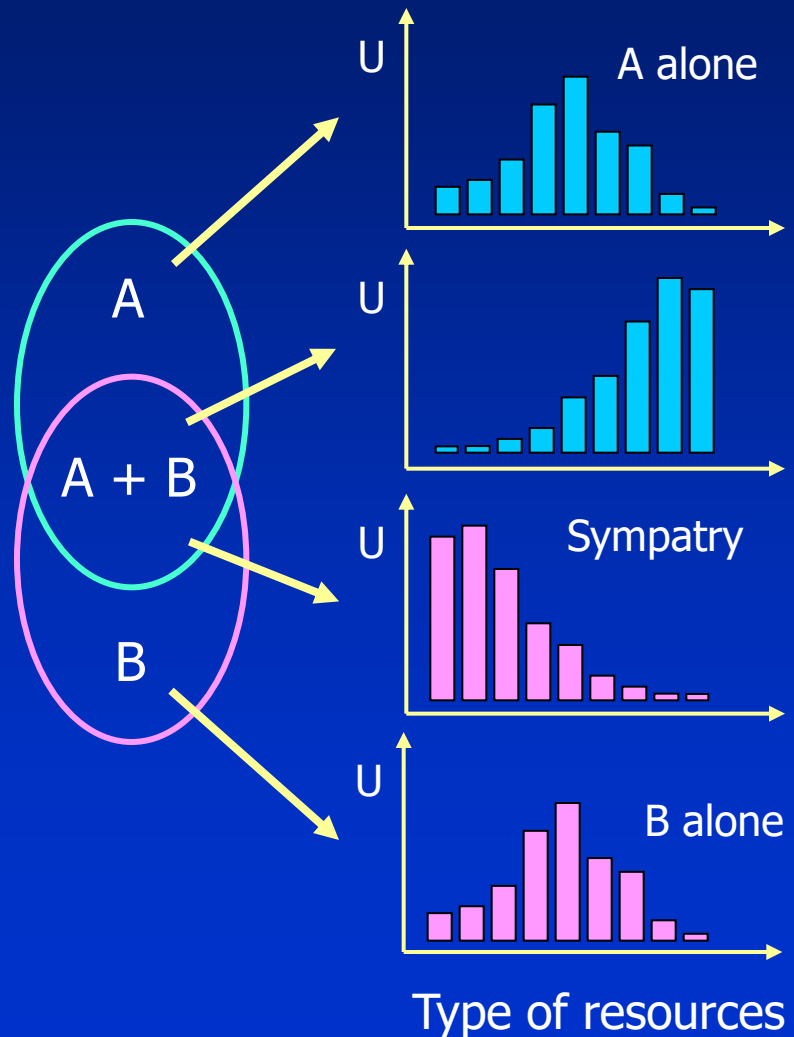
Trophic niche shift (niche apportionment)

Allopatric populations  
have similar trophic niches

Sympatric populations  
have different trophic niche

Niche shift can be based on:

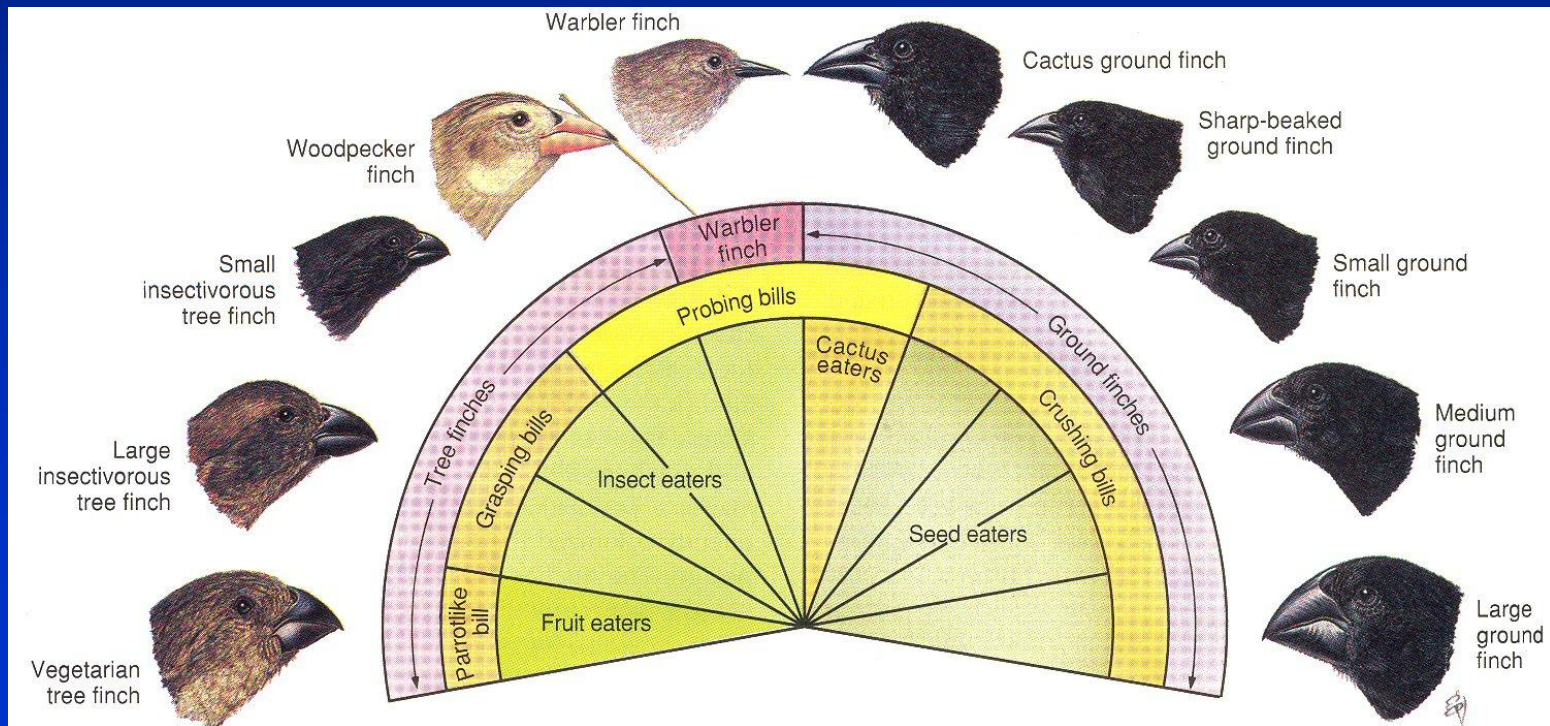
- 1) Individual behavioural plasticity
- 2) Selection at the level of population



# PLASTICITY OF RESOURCES USE IN COMPETING SPECIES

## Trophic niche shift (niche apportionment)

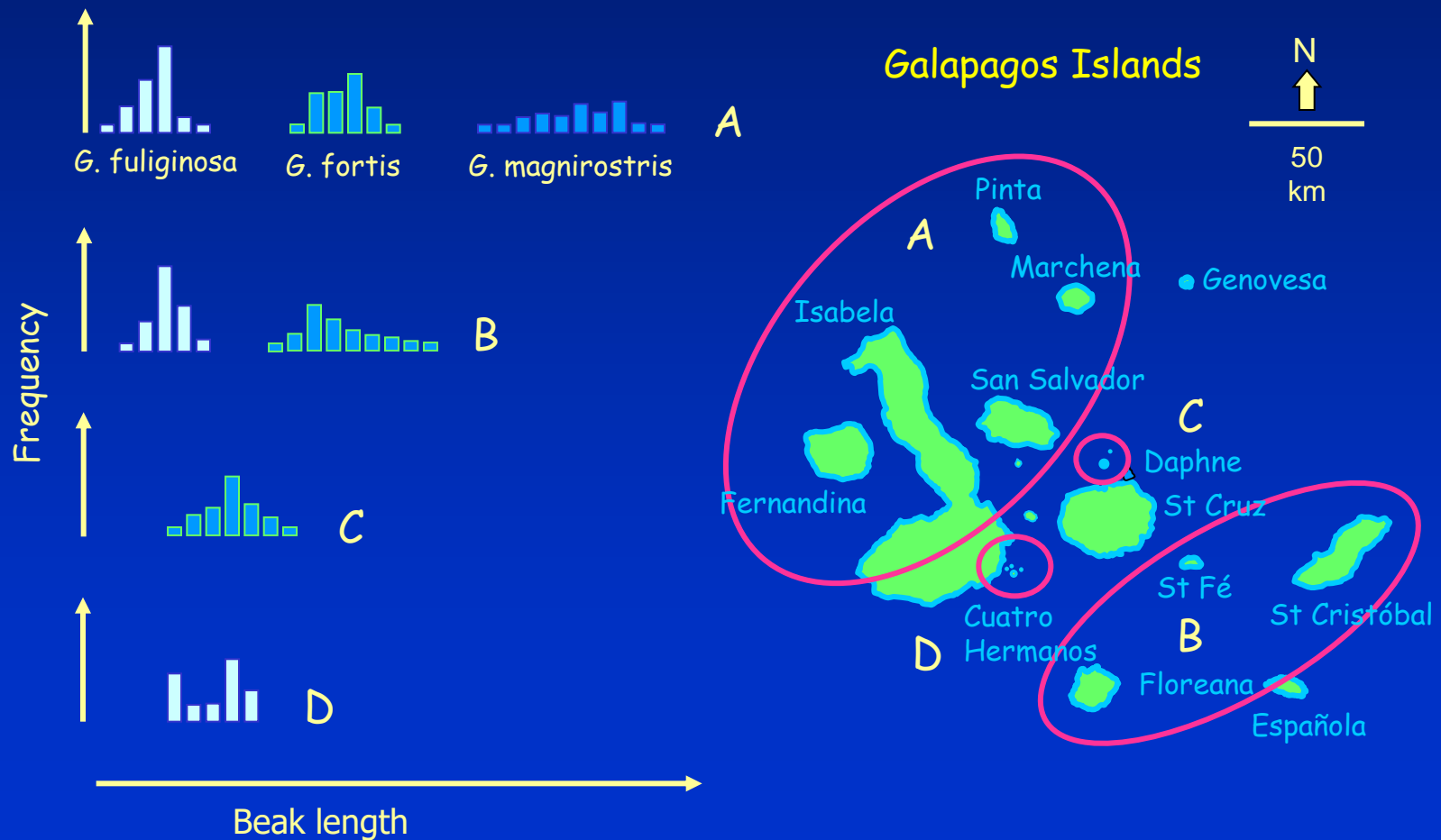
The different species of Galapagos' finches have different trophic niches. The differences are both between species and between the populations of the same species. This can be assessed from the beak morphology.





## PLASTICITY OF RESOURCES USE IN COMPETING SPECIES

Trophic niche shift (niche apportionment) occurs when two or more species are in sympatry



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The meaning of the word “predation” is manifold in ecology

Predation *sensu stricto* occurs when a population (the predator) gains materials/energy from killing and consuming individuals of a second populations (the prey). The process of predation *s.s.* thus involve subtraction of individual from one population (increasing the mortality rate of the prey) and demographic growth of the predator (increase of survival and fertility)

Other forms of “- +” interactions include:

Parasitoidism, when a species (parasitoid) lays its eggs into the body of larvae or adults of a second species (host/prey) which are then consumed by larvae during their development, eventually leading to the their death

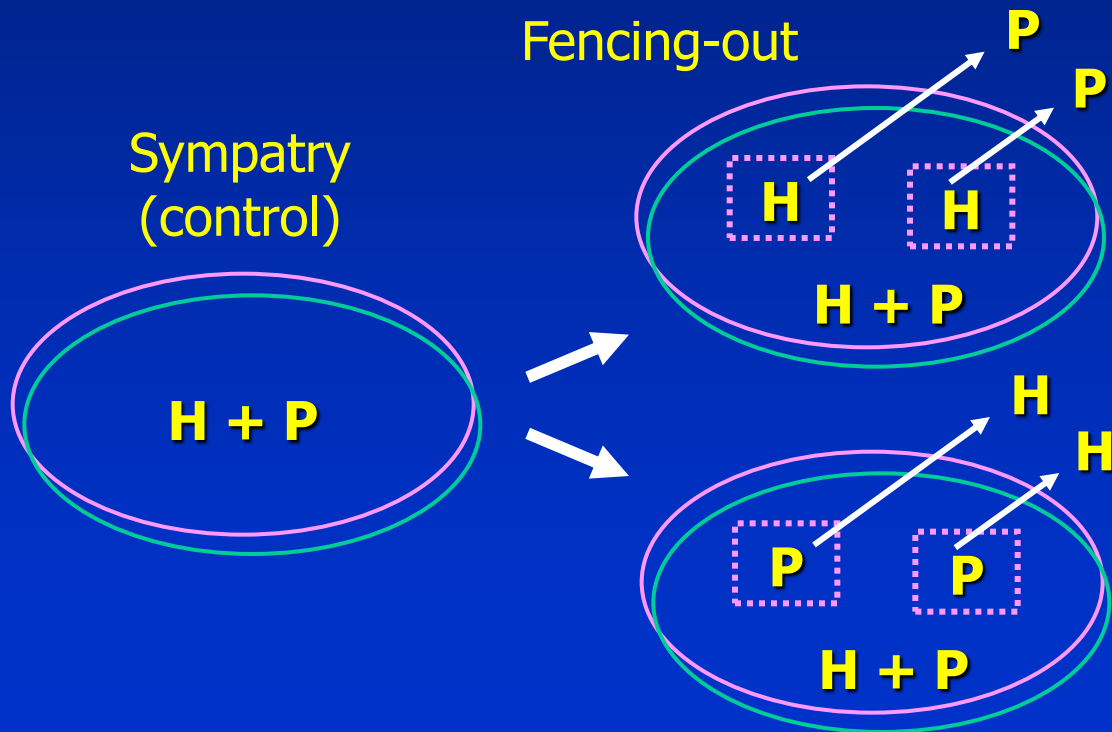
Destructive herbivory, when the consumption of parts or products of a species by a consumer (e.g. browsing, grazing, sucking) leads to death or decrease of fertility/survival of the consumed population

When a consumer utilizes parts (or products) of another species without impairing its survival/fertility the interaction can be classified as commensalism (+ 0)

# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

How to study empirically the demography of predation ?

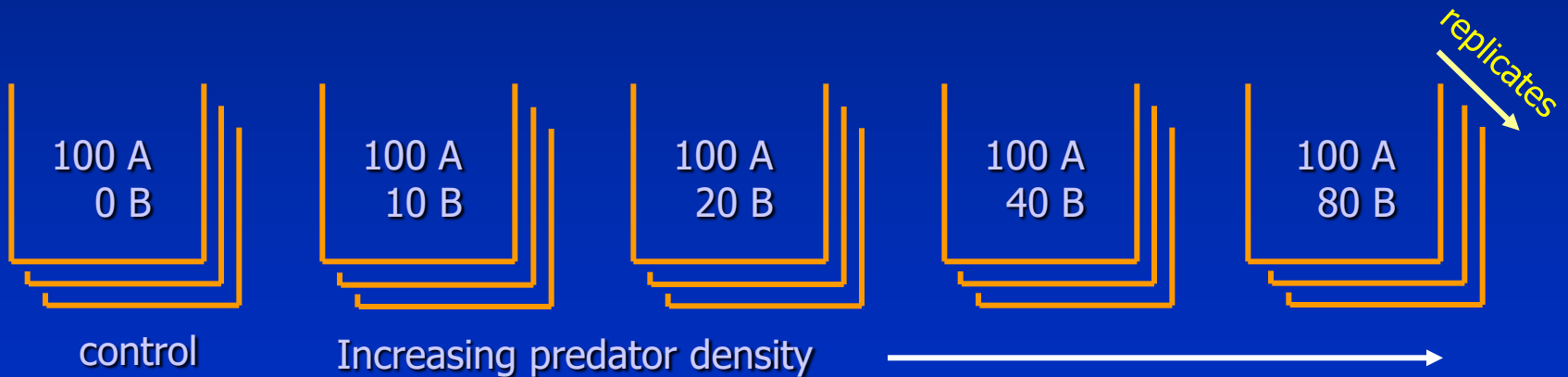
Similar to competition, demographic effect of predation can be assessed by changing prey-predator densities in the field, by using fencing-out or fencing-in experiments



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

How to study empirically the demography of predation ?

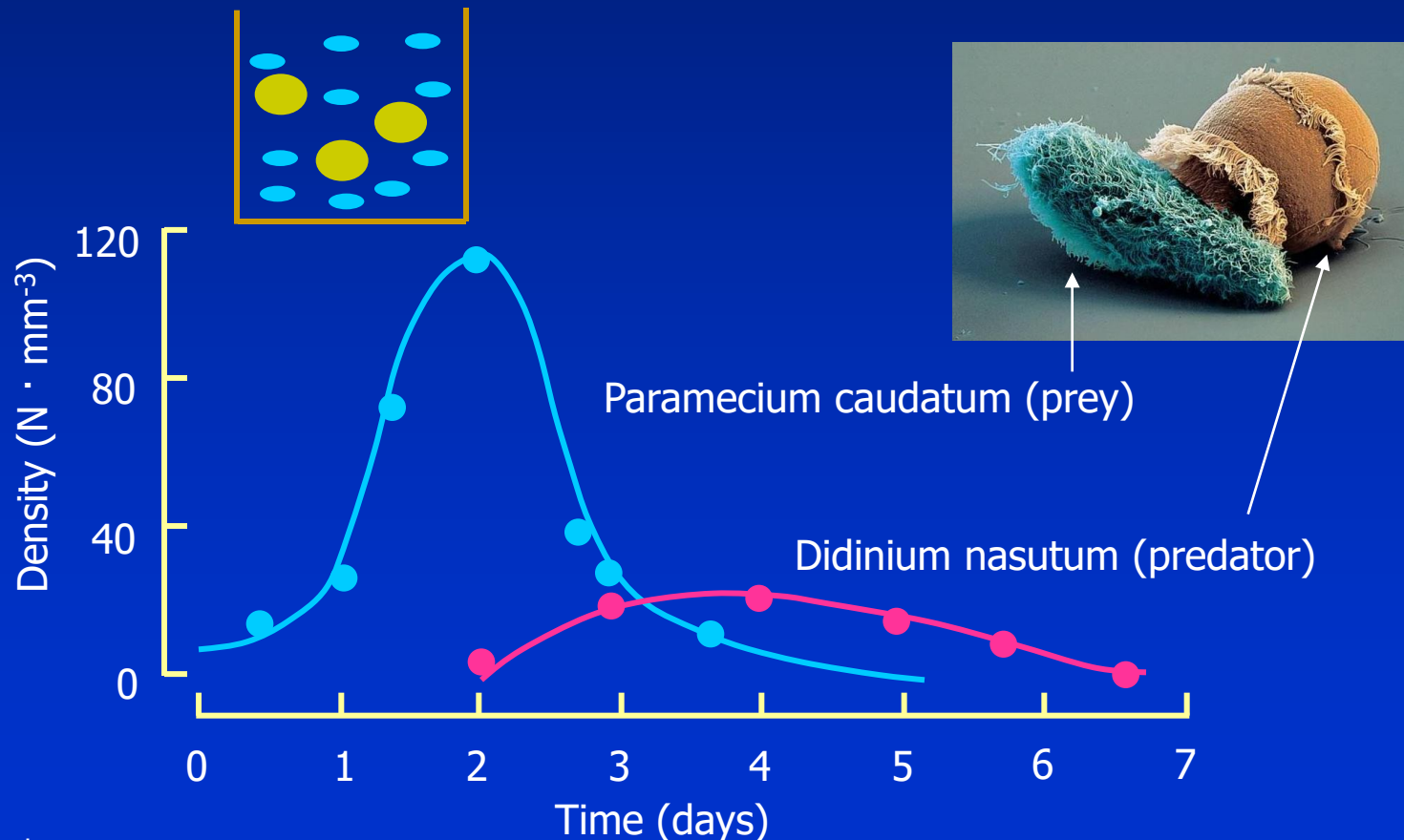
Similar to competition, demographic effect of predation can be performed in the laboratory, by experiments where different densities of the prey and the predator are set as initial conditions



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

Gause's free-running experiments on a couple of protozoan species

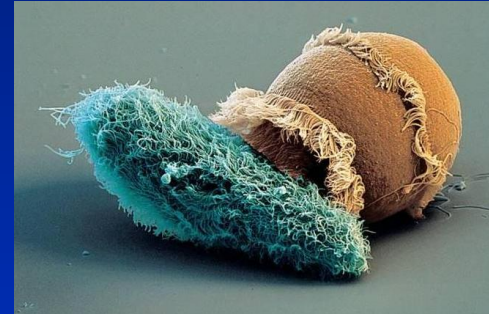
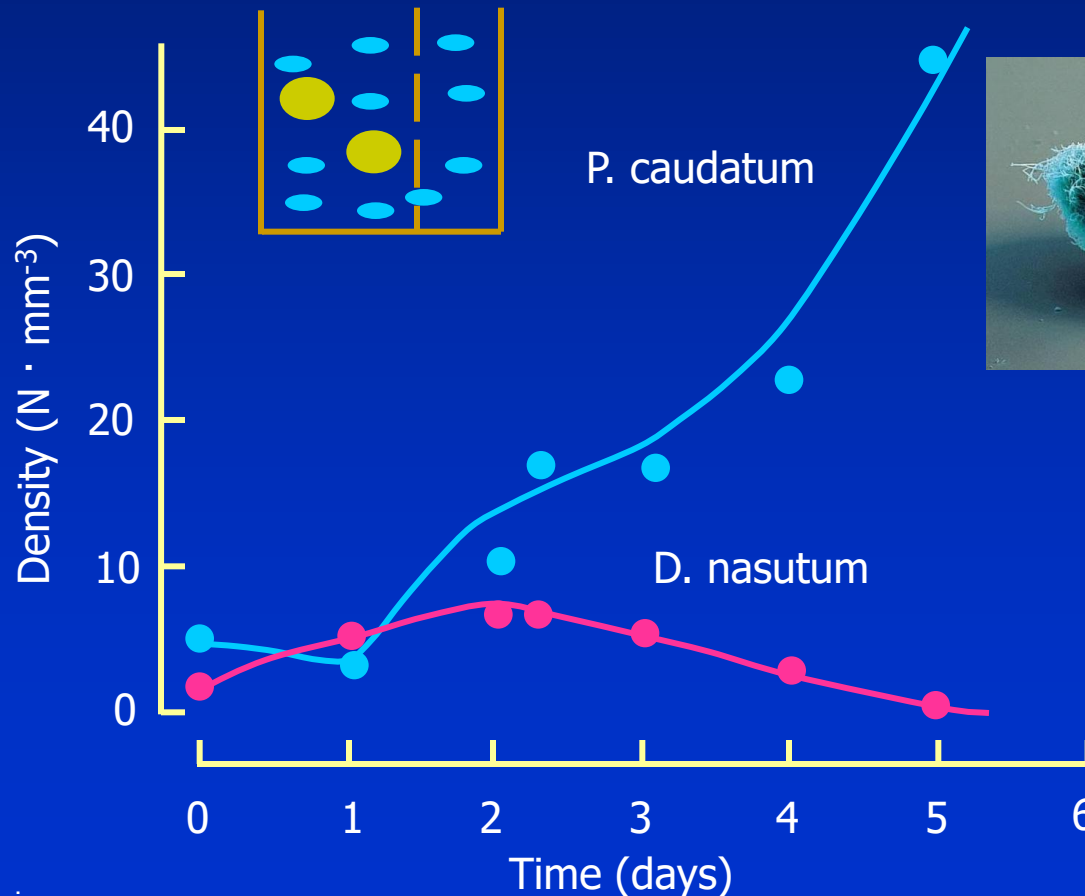
1) Closed, homogeneous environment:  
one single demographic growth followed by extinction of both prey and its predator



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

Gause's free-running experiments on a couple of protozoan species

2) Closed environment, but refugia accessible to the prey:  
extinction of the predator after one cycle, prey growing to its carrying capacity

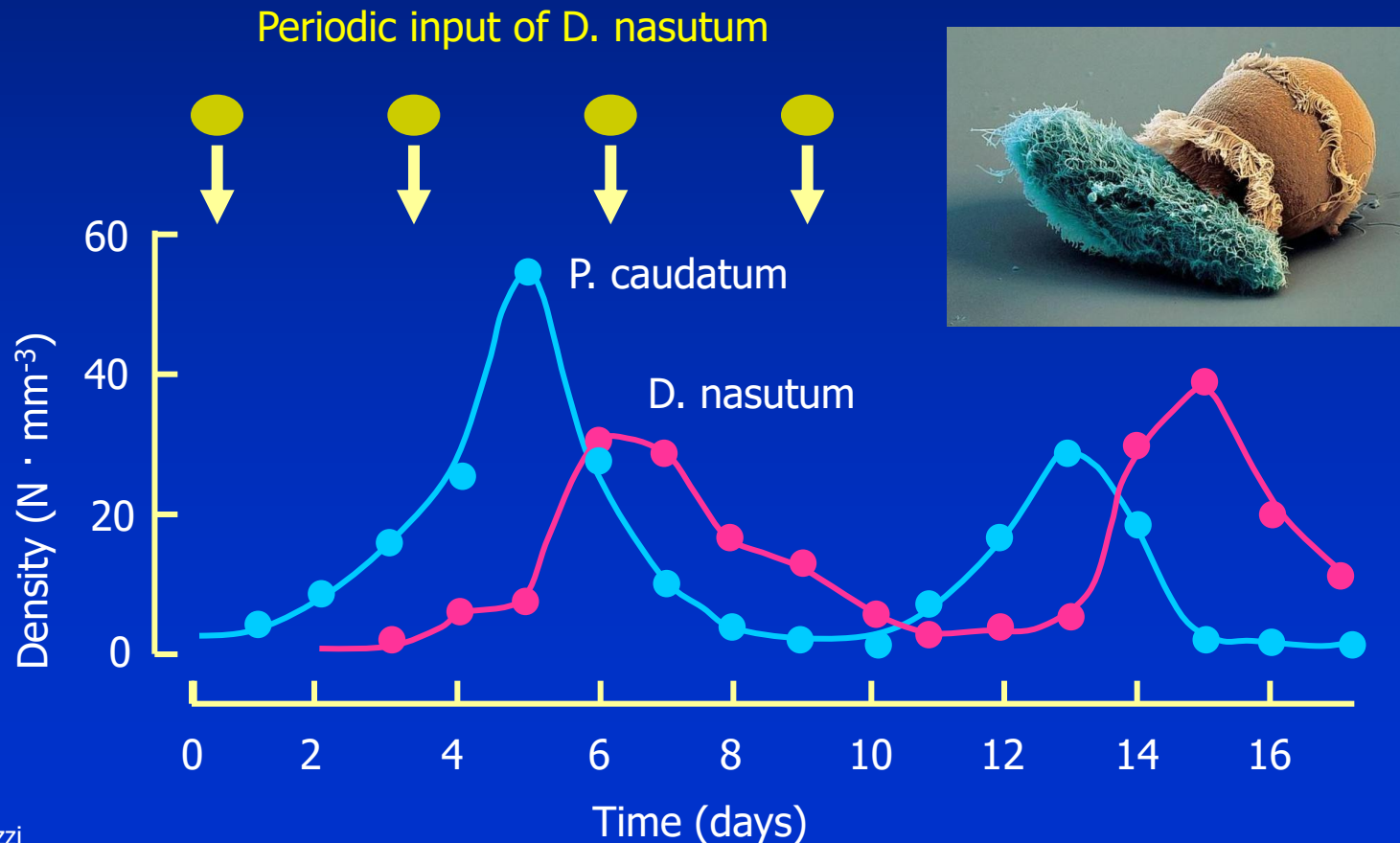




# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

Gause's free-running experiments on a couple of protozoan species

3) Open environment, periodic immigration of the predator:  
demographic cycles with predator's increase-decrease shifted with respect to the prey





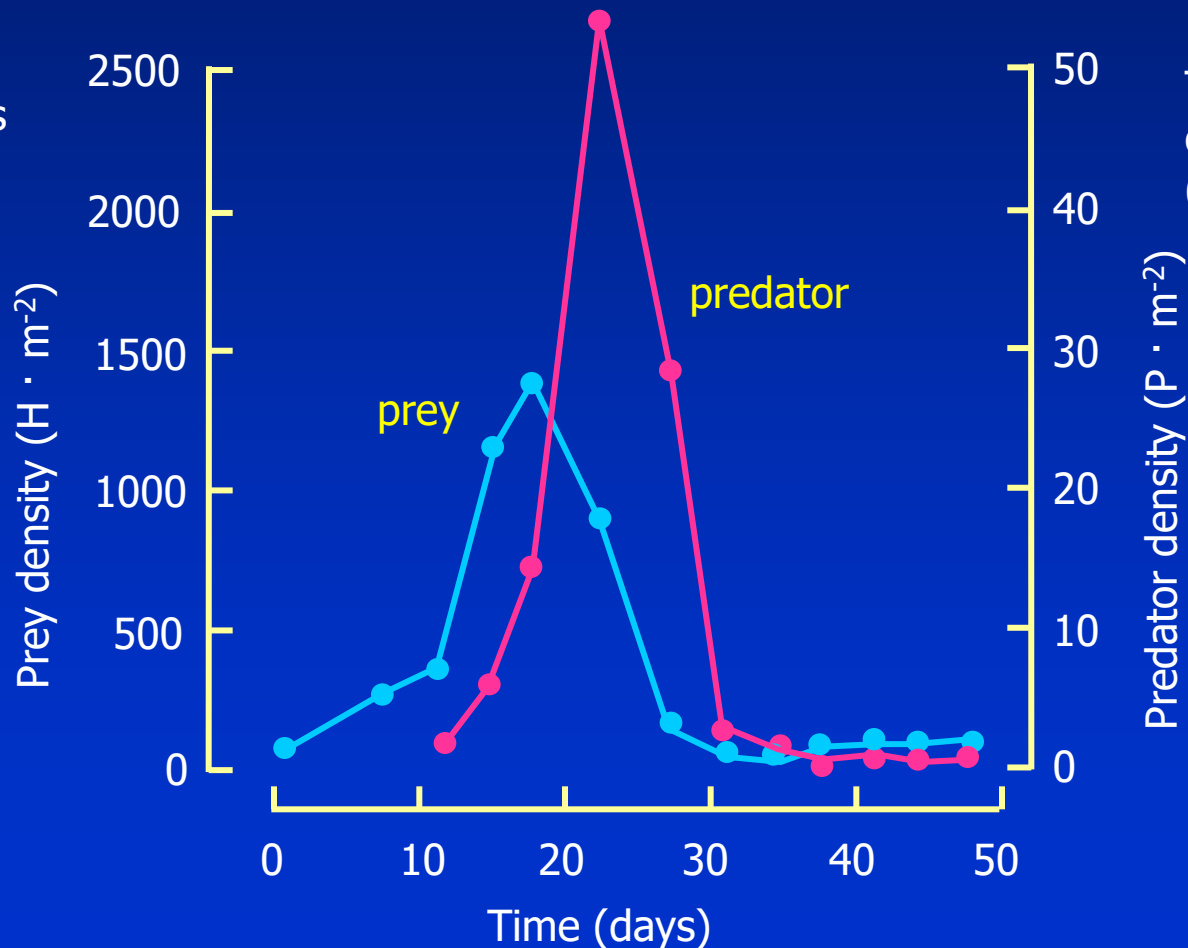
# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

Huffaker's free-running experiments on a couple of mites (Acari)

1) Homogeneous environment:

One demographic cycle, followed by extinction of the predator

*Eotetranychus sexmaculatus*  
(prey)



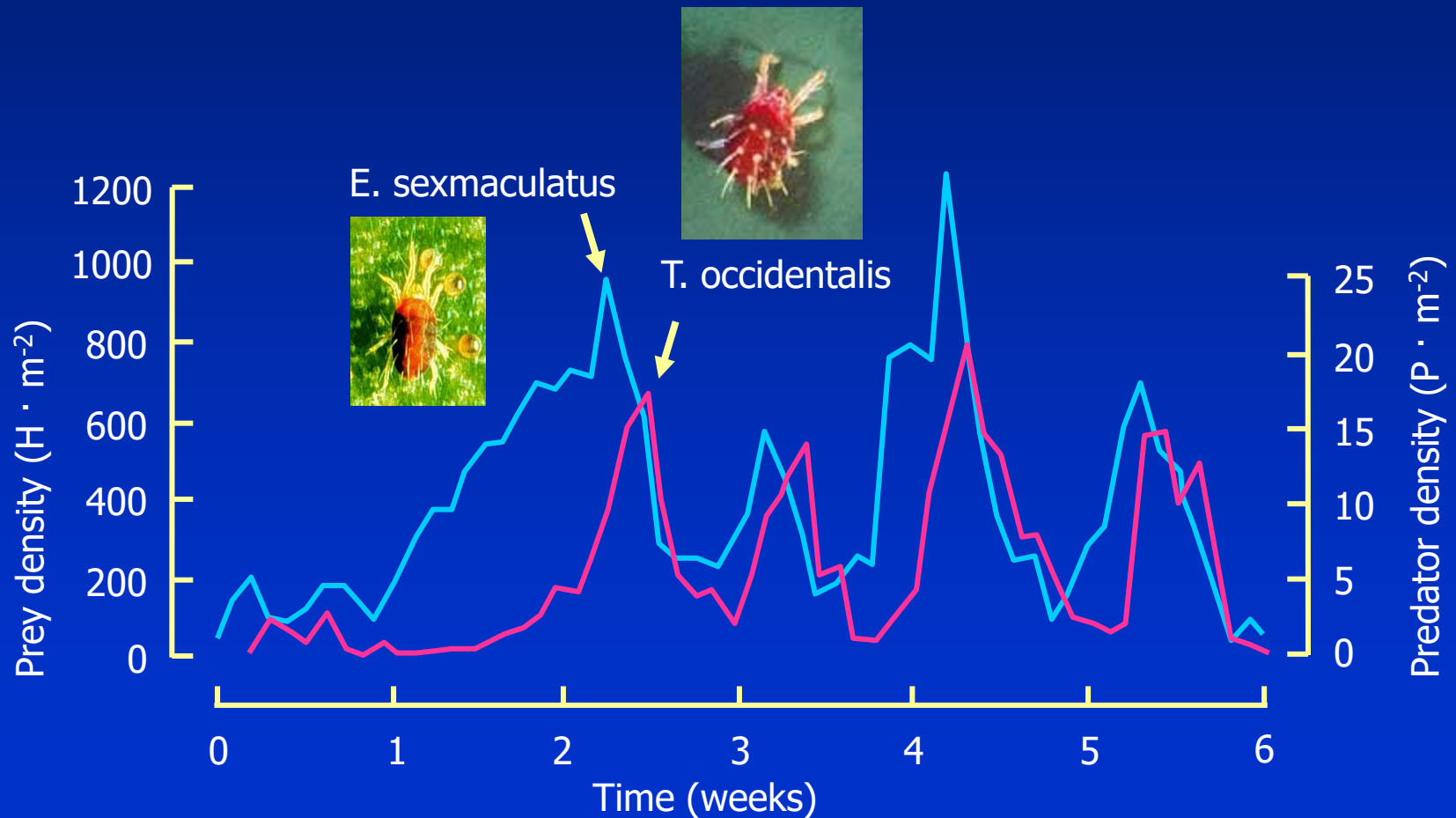
*Typhlodromus occidentalis*  
(predator)



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

Huffaker's free-running experiments on a couple of mites (Acari)

2) Partitioned environment:  
Sustained demographic cycles

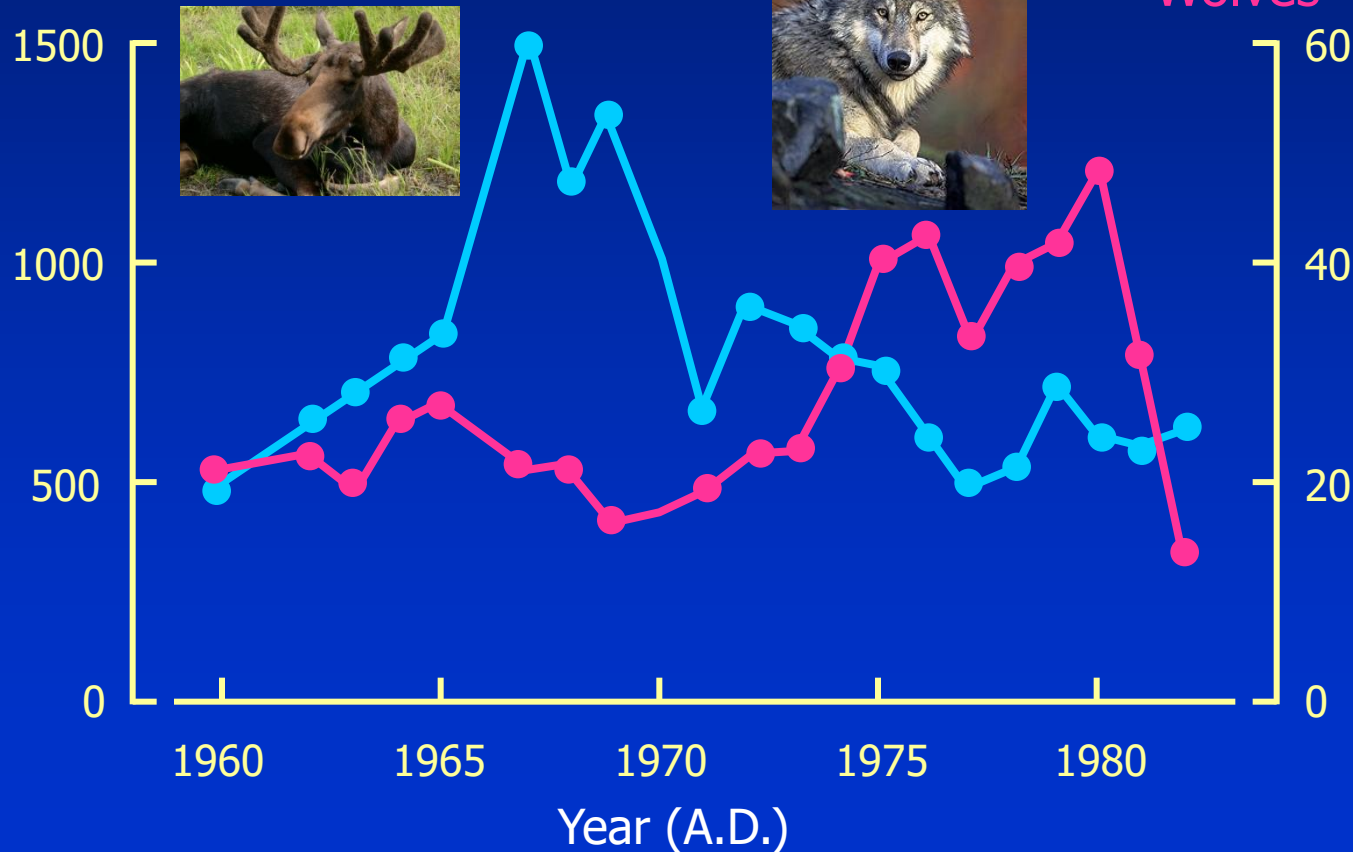


# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

Isle Royale “free-running experiment” on wolves and moose

Demographic cycles

Moose



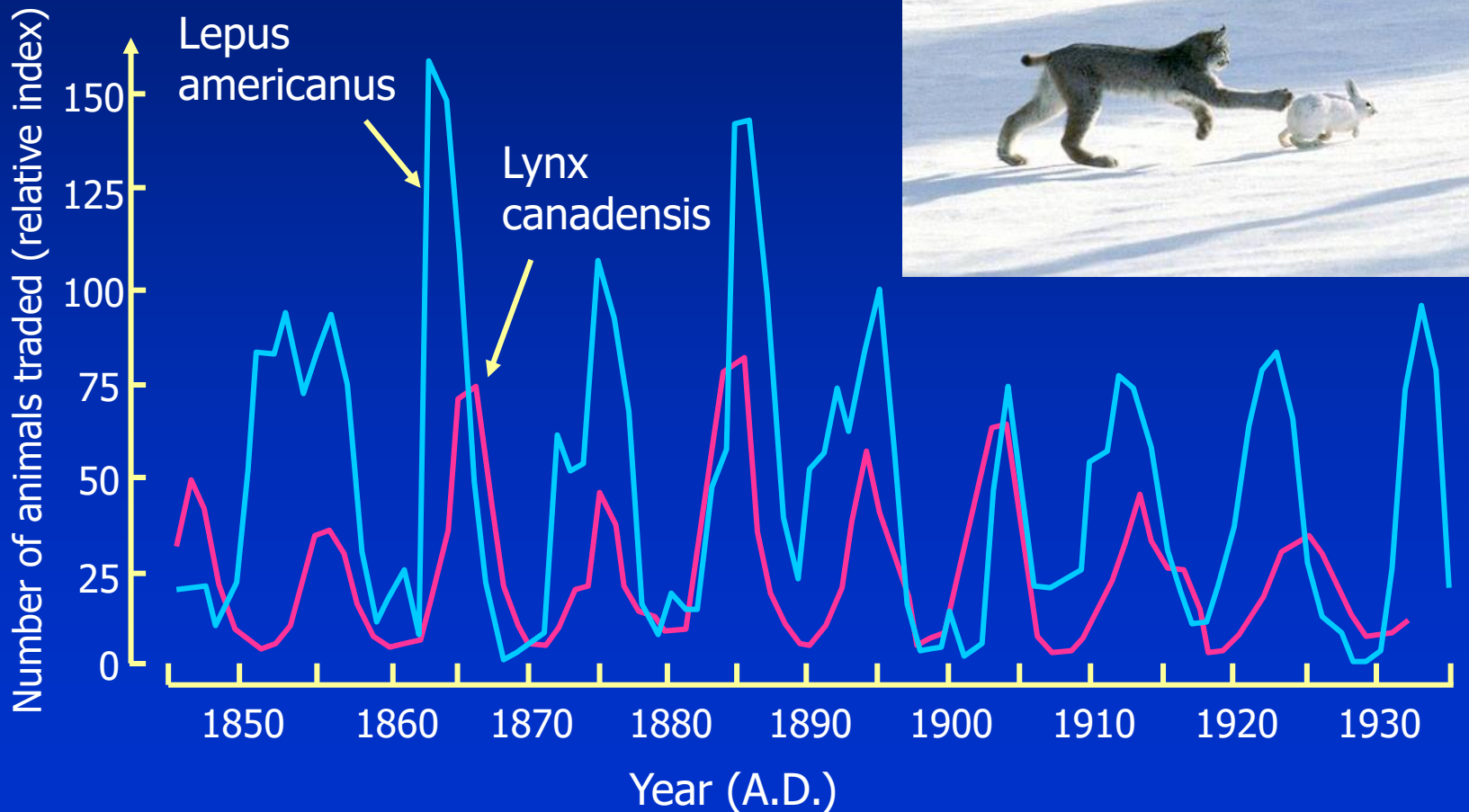
Wolves



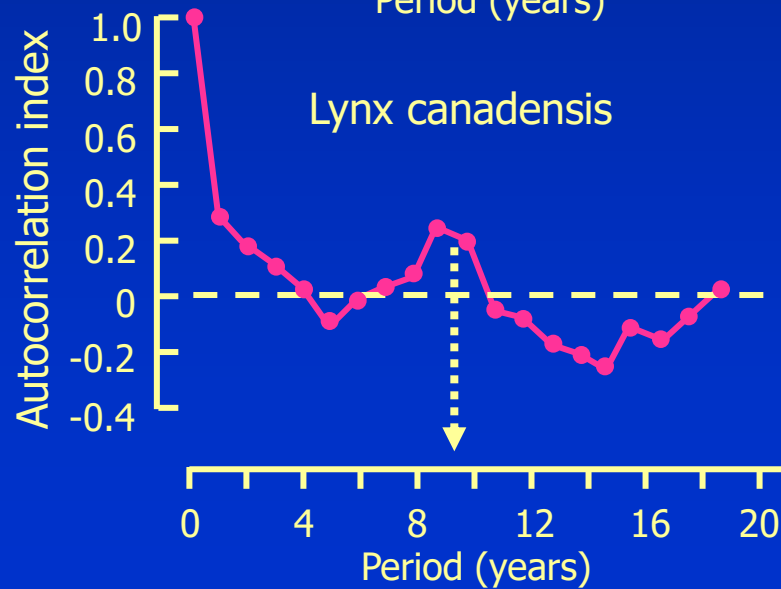
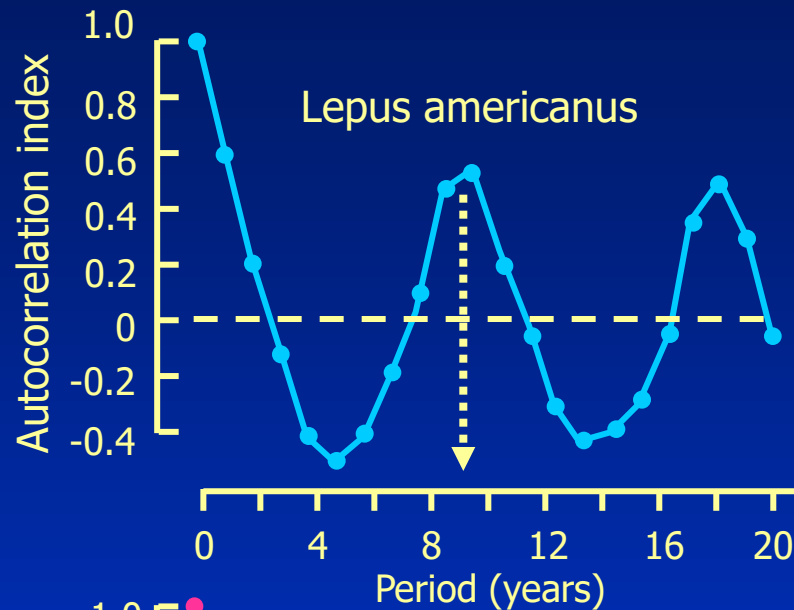
# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

Hudson Bay “free-running experiment” on lynx and hare in North America

Demographic cycles



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

How to design a model for interspecific competition?

- 1) Parsimony: two species linked by an exclusive interaction not dependent from external constraints (homogeneous space, no climatic fluctuations, no other interactions)
- 2) Completeness: the model must be able to predict different outcomes (exclusion or coexistence) when changing values of the parameters. The model must be able to reproduce demographic cycles

Design two linked equations, one for each species, each including predation of species a on b

The model of Alfred Lotka and Vito Volterra

Prey	$\frac{dH}{dt} = f(H) - g(H, P)$
Predator	$\frac{dP}{dt} = e \cdot g(H, P) - m(P)$

Generic equations

$f(H) = r \cdot H$
$g(H, P) = a \cdot H \cdot P$
$m(P) = \mu \cdot P$

Specific assumptions

# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The original model of Alfred Lotka and Vito Volterra

$$\frac{dH}{dt} = r \cdot H - a \cdot H \cdot P$$

$$\frac{dP}{dt} = b \cdot H \cdot P - \mu \cdot P$$

$a$  = search/hunt efficiency of the predator  
(or prey detectability)

$b$  =  $a$  by a coefficient of biomass/energy transfer  
from prey to predator  
(metabolic efficiency of the predator)

$\mu$  = mortality rate of the predator by starvation

Prey stability

$$\frac{dH}{dt} = 0 \quad \text{if} \quad r \cdot H = a \cdot H \cdot P$$

Prey zero growth isocline



$$P = \frac{r}{a}$$

Predator stability

$$\frac{dP}{dt} = 0 \quad \text{if} \quad b \cdot H \cdot P = \mu \cdot P$$

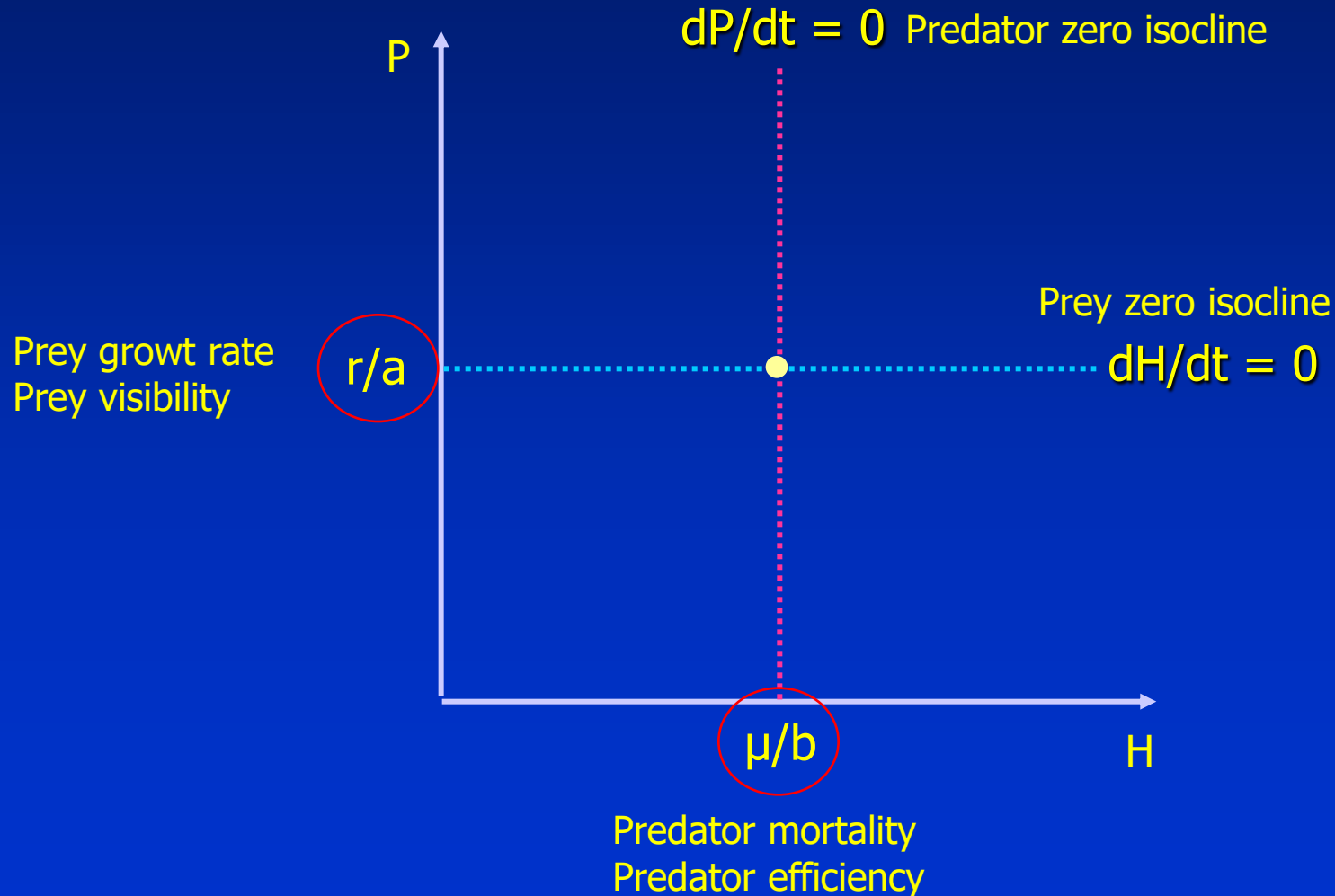
Predator zero growth isocline



$$H = \frac{\mu}{b}$$

# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The original model of Alfred Lotka and Vito Volterra

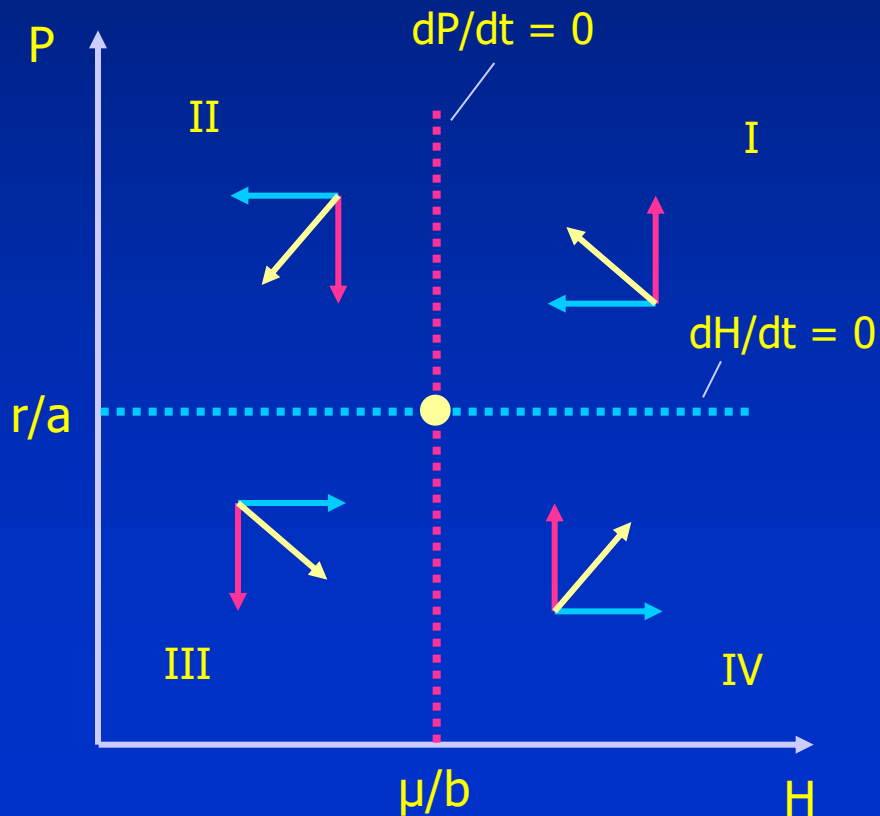




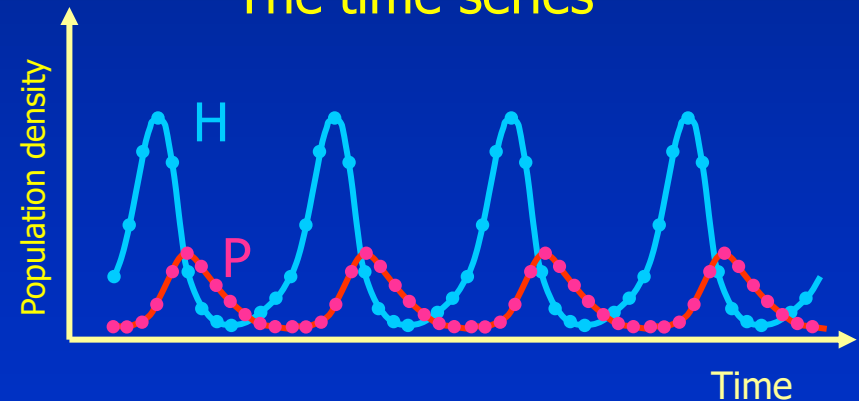
# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The predictions of the original model of Alfred Lotka and Vito Volterra

## The phase-plan

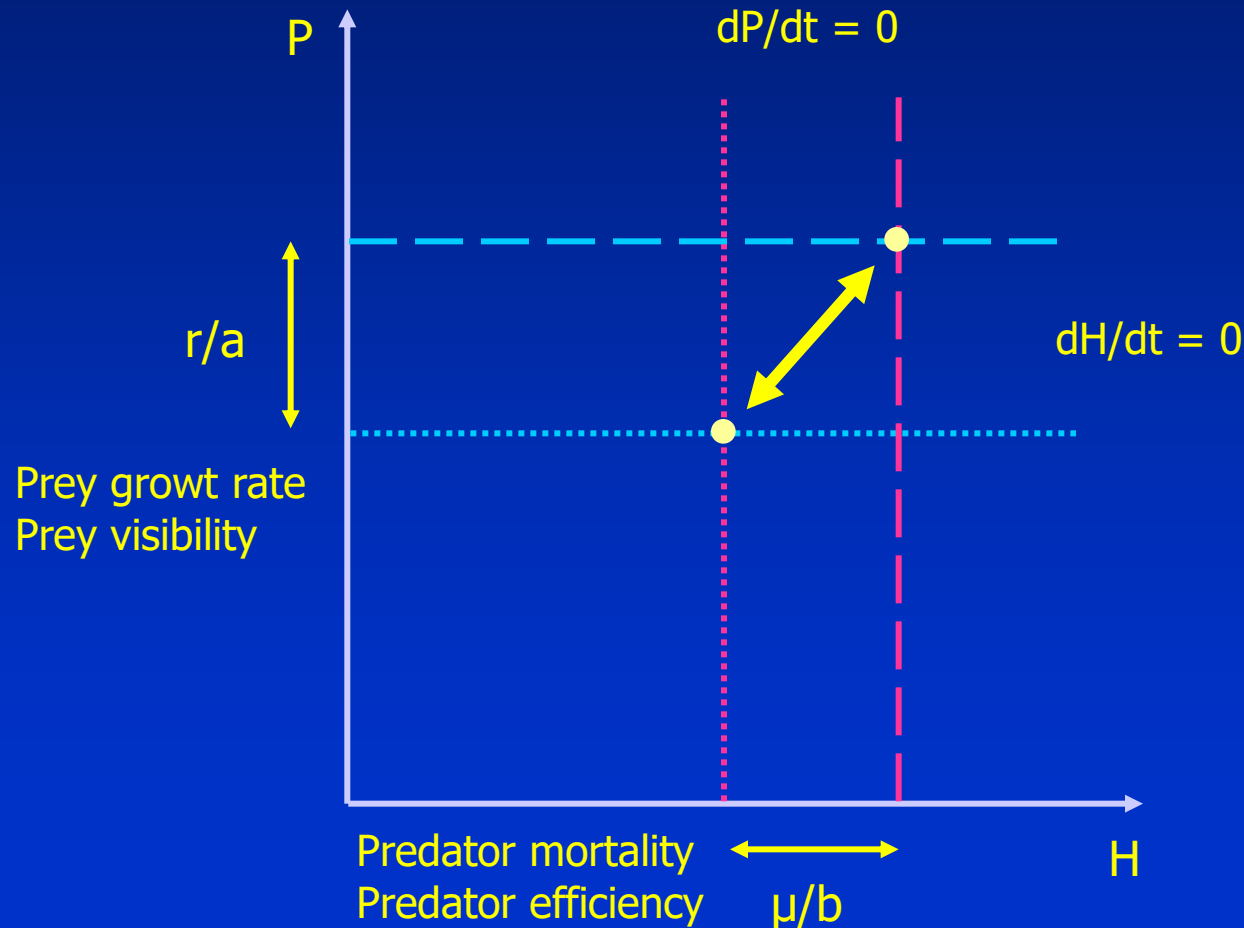


## The time series



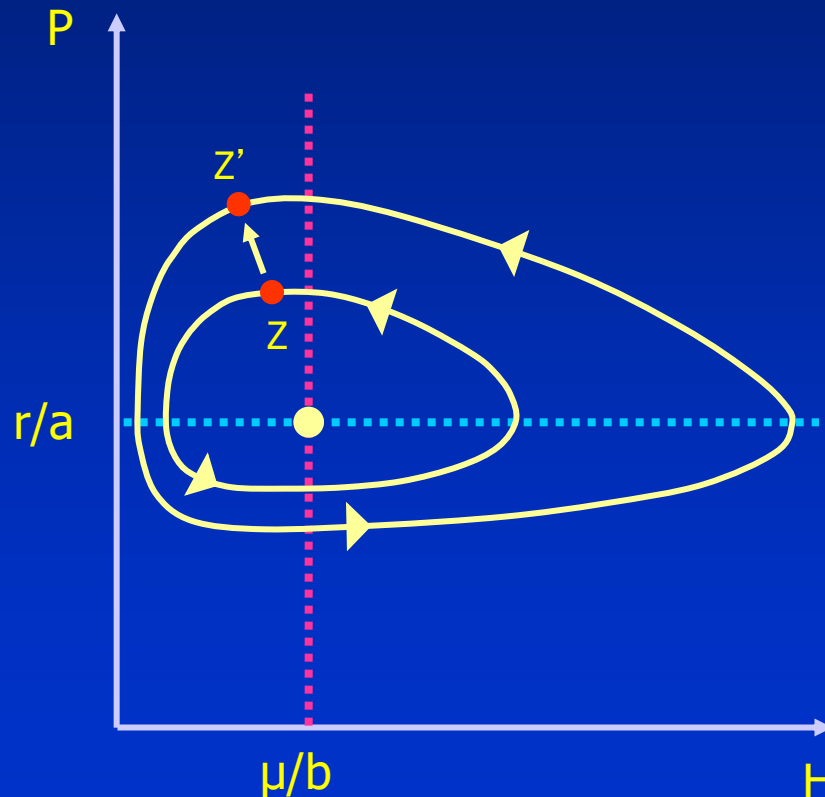
# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The effect of changing the biological characteristics of the predator and the prey in the original model of Alfred Lotka and Vito Volterra



## DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The instability of the original model of Alfred Lotka and Vito Volterra: a variation in the density of the two species (from  $Z$  to  $Z'$ ) is followed by a new cyclic pattern



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The effect of prey visibility (predation avoidance)

Extraction function



$$g(H, P) = a \cdot H \cdot P$$

The whole population is exposed  
(standard model)

A)  $g(H, P) = a \cdot (H - s \cdot H) \cdot P$

A fraction ( $s$ ) of the population  
avoid the predation  
(es. mimetismo criptico)

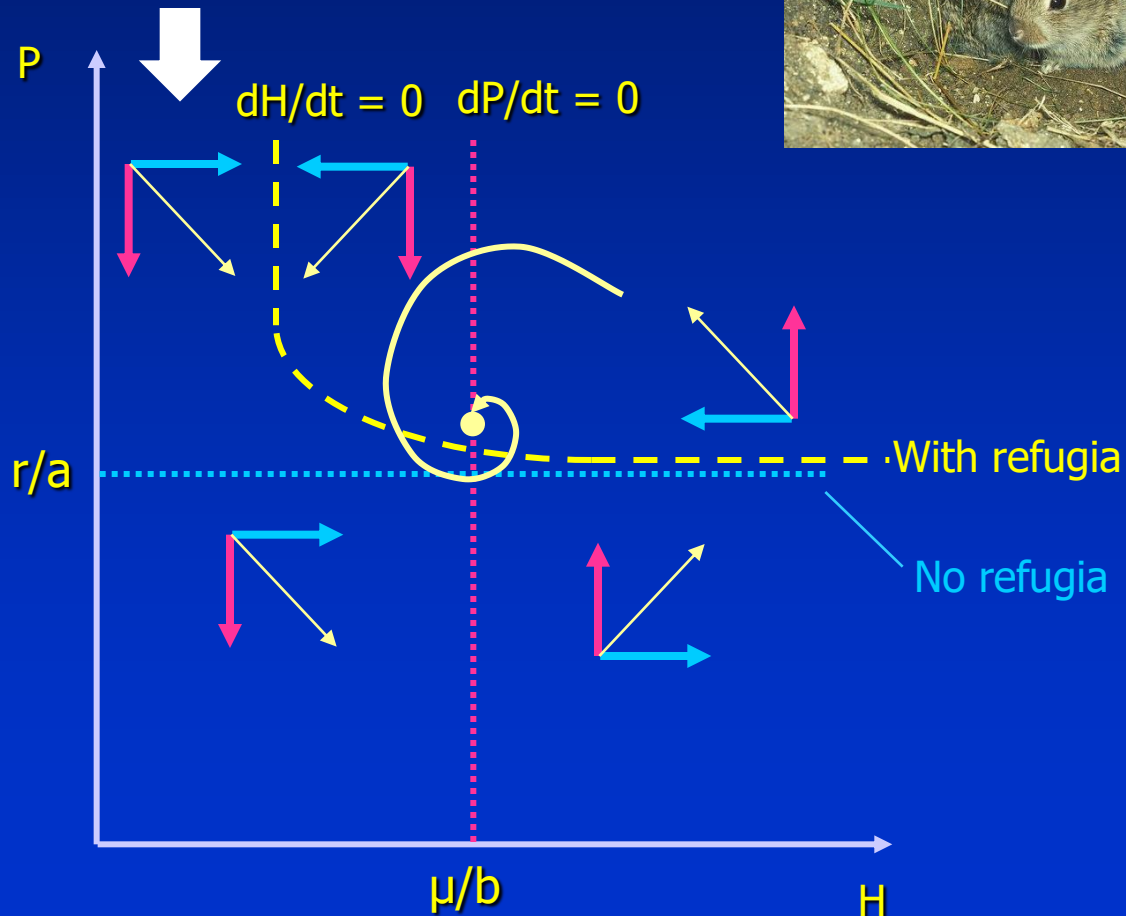
B)  $g(H, P) = a \cdot (H - H^-) \cdot P$

A constant number of preys ( $H^-$ )  
avoid the predation  
(es. refugia)

# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The effect of predation avoidance

Protected prey population



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

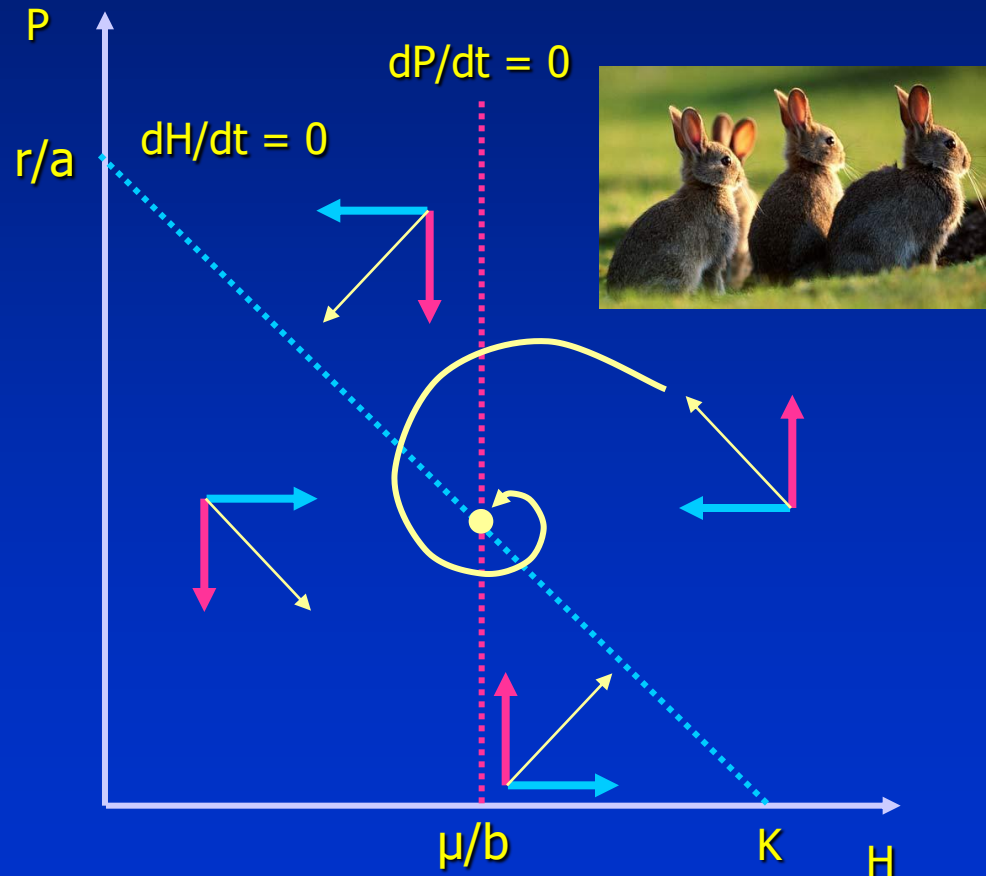
The effect of intraspecific competition in the prey

$$f(H) = r \cdot H$$

Unlimited growth  
(standard model)

$$f(H) = r \cdot H \left( 1 - \frac{H}{K} \right)$$

Intraspecific competition  
in the prey



# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

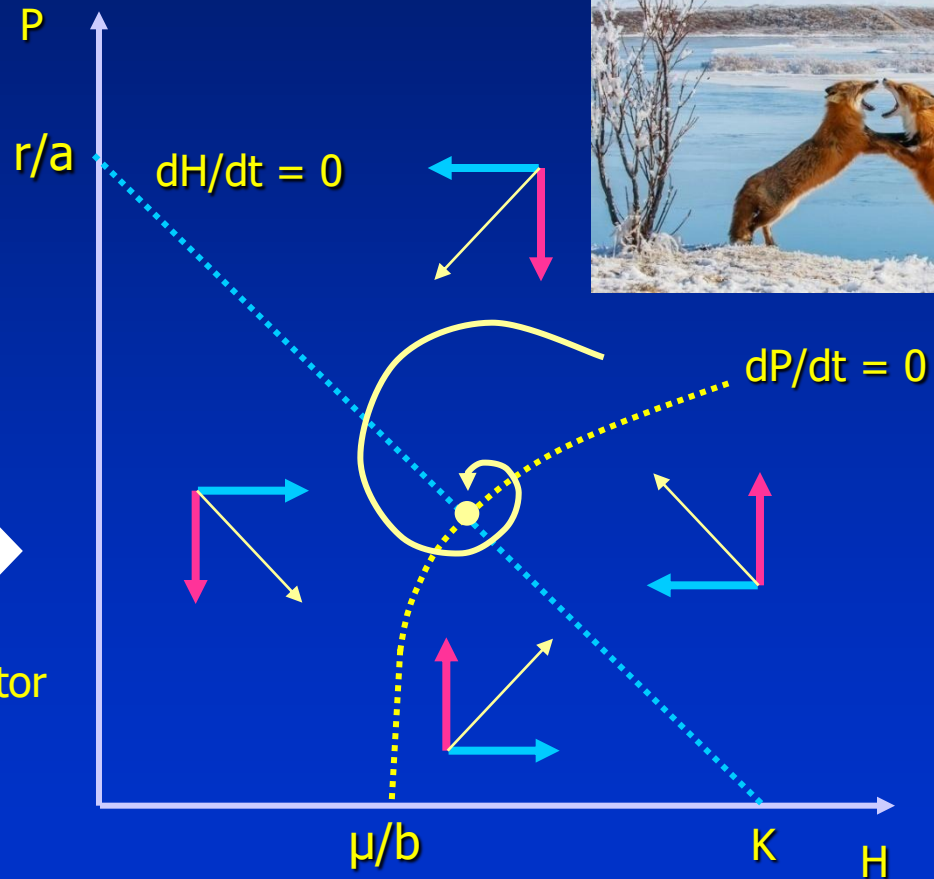
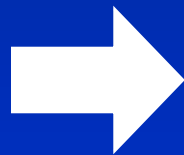
The effect of intraspecific interference in the predator

$$g(H, P) = a \cdot H \cdot P$$

Extraction function  
in the standard model

$$g(H, P) = \frac{H}{P^i}$$

Mutual interference in the predator  
 $i$  = interference coefficient

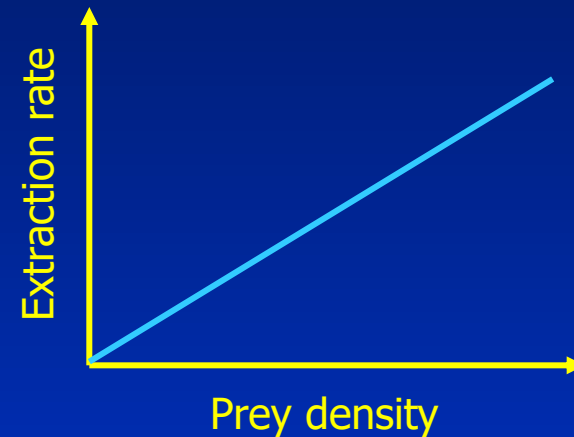


# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The effect of type II functional response

Resources extraction in the standard model

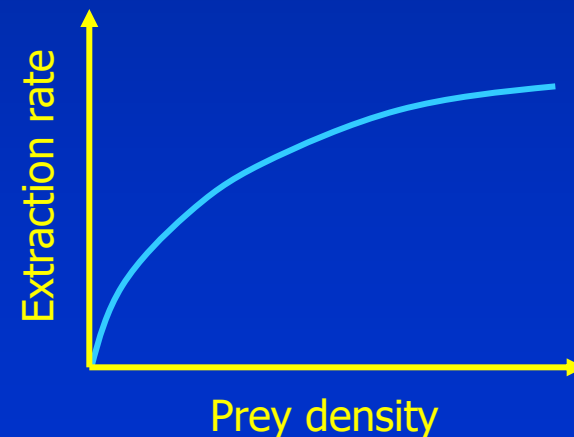
$$g(H, P) = a \cdot H \cdot P$$



Type II functional response

$$g(H, P) = \frac{a \cdot H \cdot P}{1 + a \cdot H \cdot T_h}$$

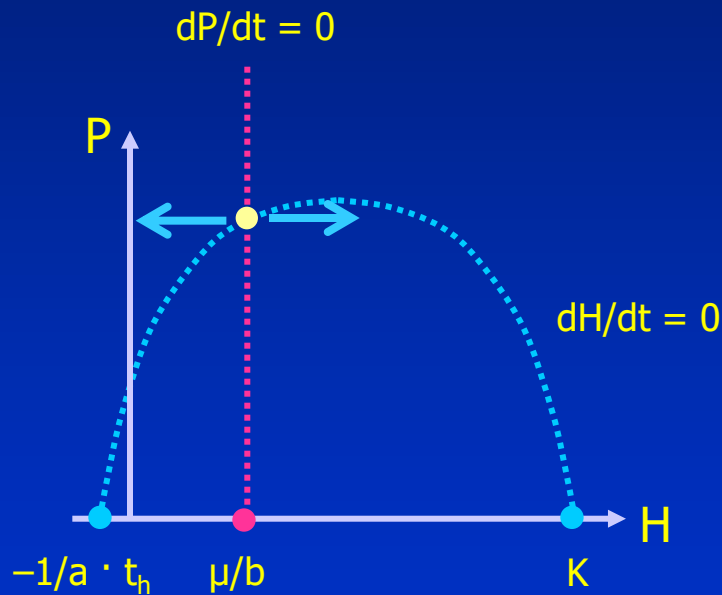
Handling time



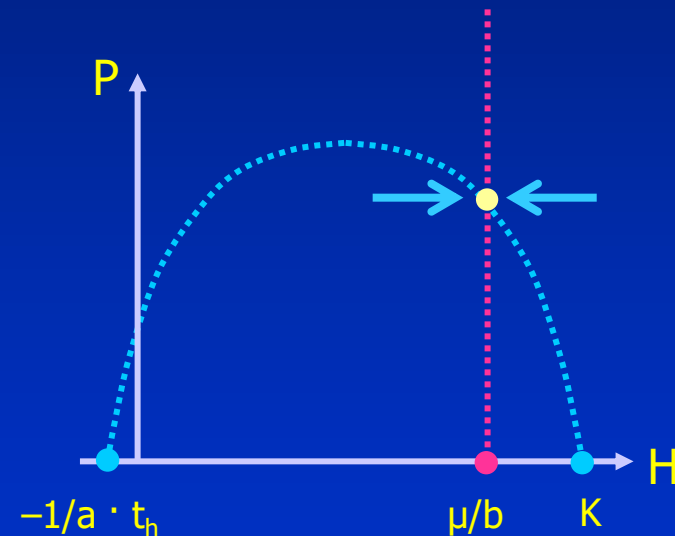


# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The effect of type II functional response depends on the characteristics of the predator



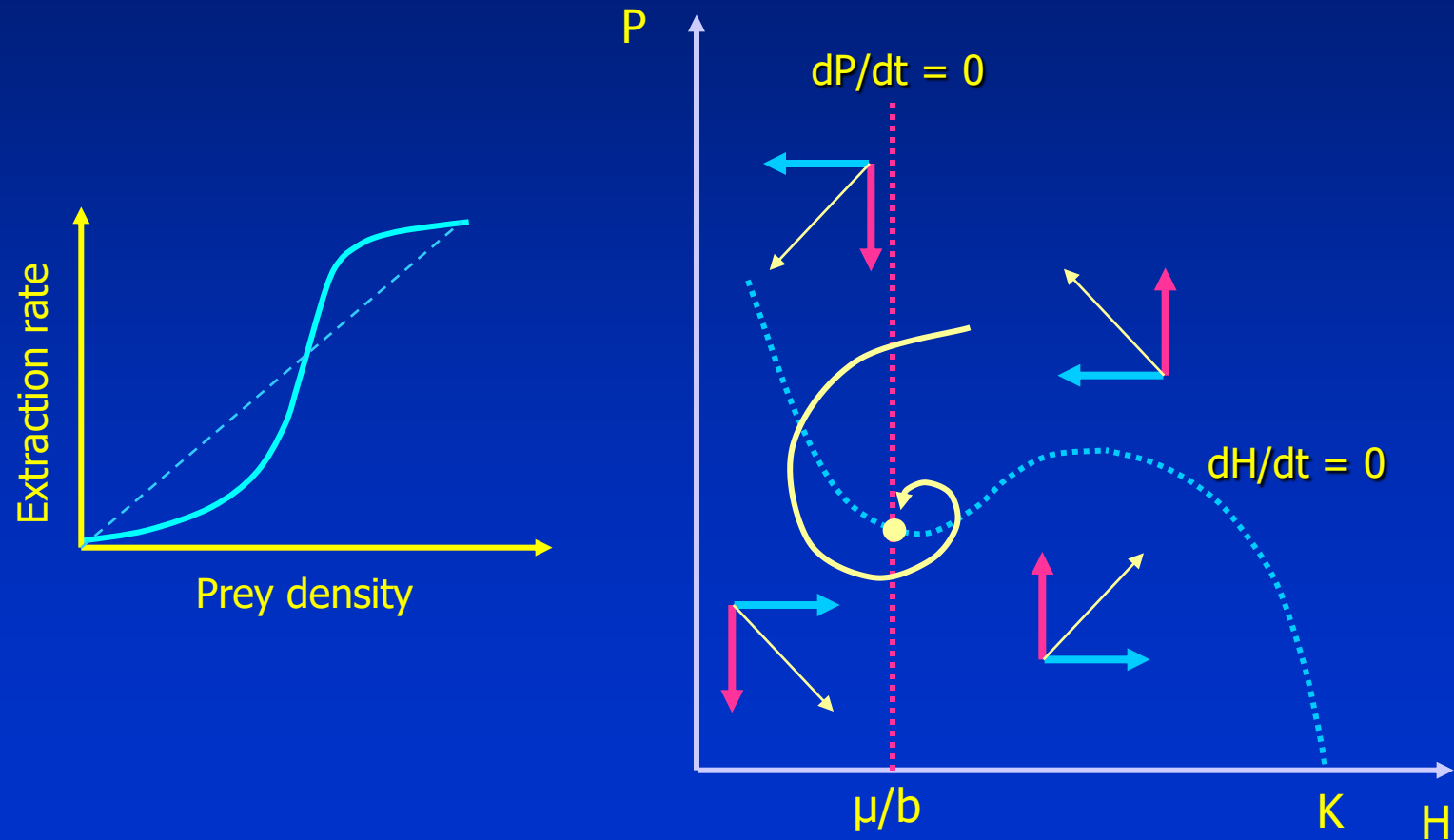
Higher efficiency predator  
Unstable equilibrium



Lower efficiency predator  
Stable equilibrium

# DEMOGRAPHIC EFFECTS OF PREY-PREDATOR INTERACTIONS

The effect of type III (switching) functional response



# DEMOGRAPHIC EFFECTS OF HERBIVORY

Herbivory is a form of consumption in which an organism principally obtains energy/biomolecules by eating primary producers such as plants, algae, phytoplankton and photosynthesizing procariotes, or their parts or products

Such wide definition includes:

Grazers: eating parts of the stem and leaves of the vascular plants (e.g. herbs)

Browsers: eating leaves or shots of vascular plants (e.g. shrubs, trees)

Frugivores

Granivores

Xylofages

Root eaters

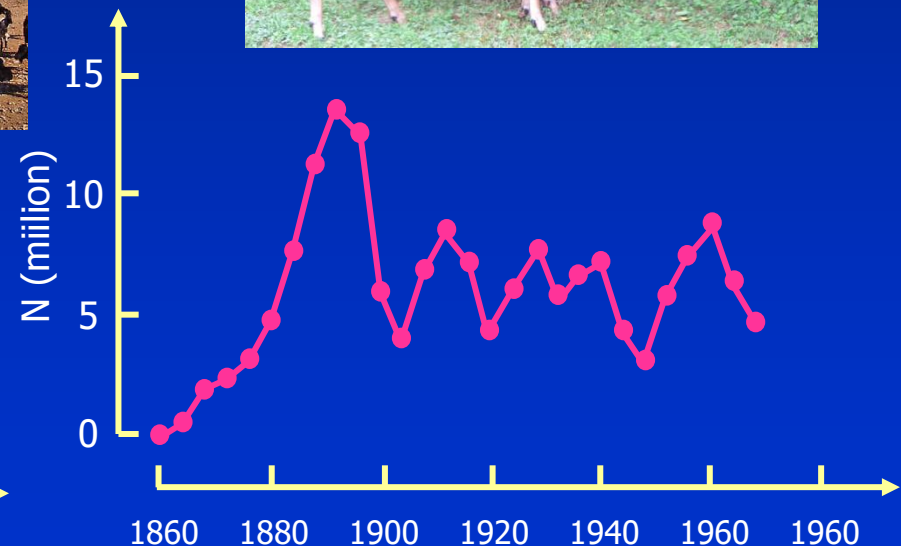
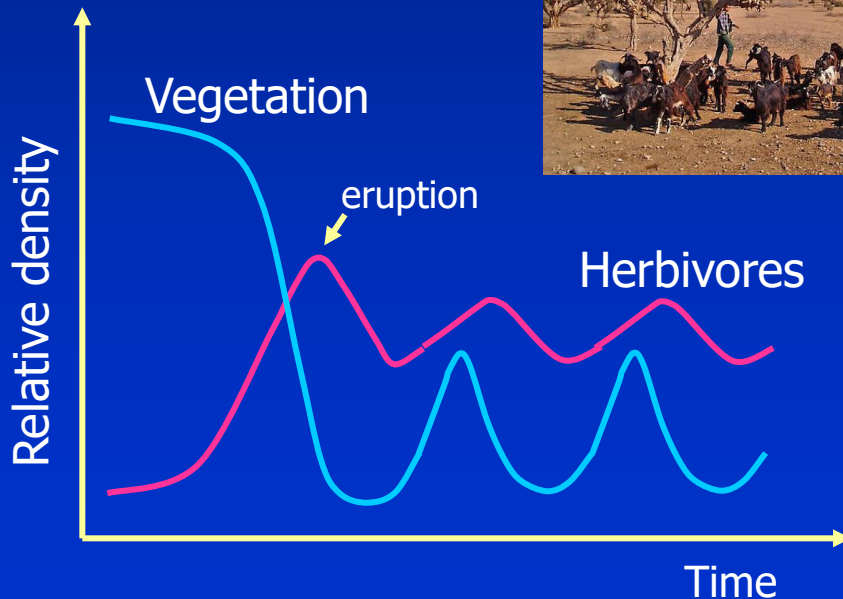
Nectarivores

Palinivores



# DEMOGRAPHIC EFFECTS OF HERBIVORY

In the case of “destructive” grazing-browsing  
co-dynamics of herbivores and their resources  
Can be described and predicted by using  
prey-predator models



# DEMOGRAPHIC EFFECTS OF NON-DESTRUCTIVE HERBIVORY

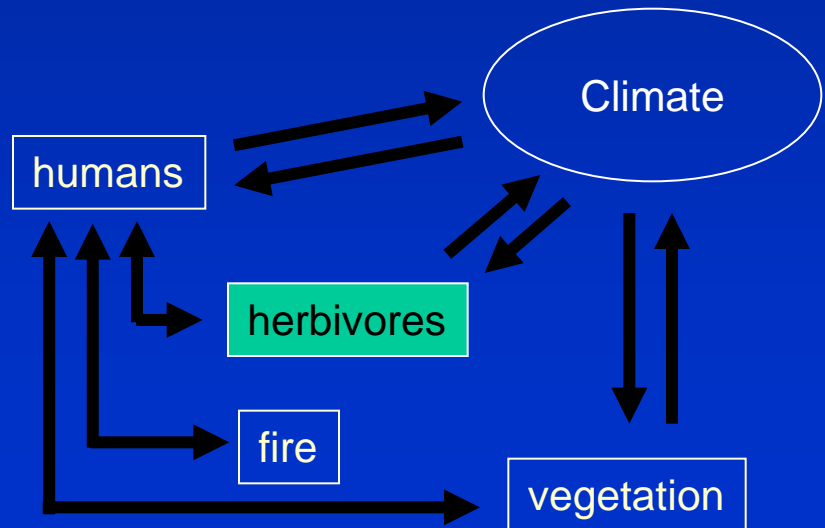
Grazing and browsing are generally conservative and regulative (i.e. individual plants are not eliminated, and their regrowth can be stimulated by g-b)

Frugivore may favour seed dispersal

Nectarivores and palinivores facilitate fertilization by impollination

The demoecological role of herbivory cannot be understood without considering herbivore-plants coevolution

Herbivores have often a role of “Ecosystem Engineers”, being at the core of ecological interactions and feedbacks

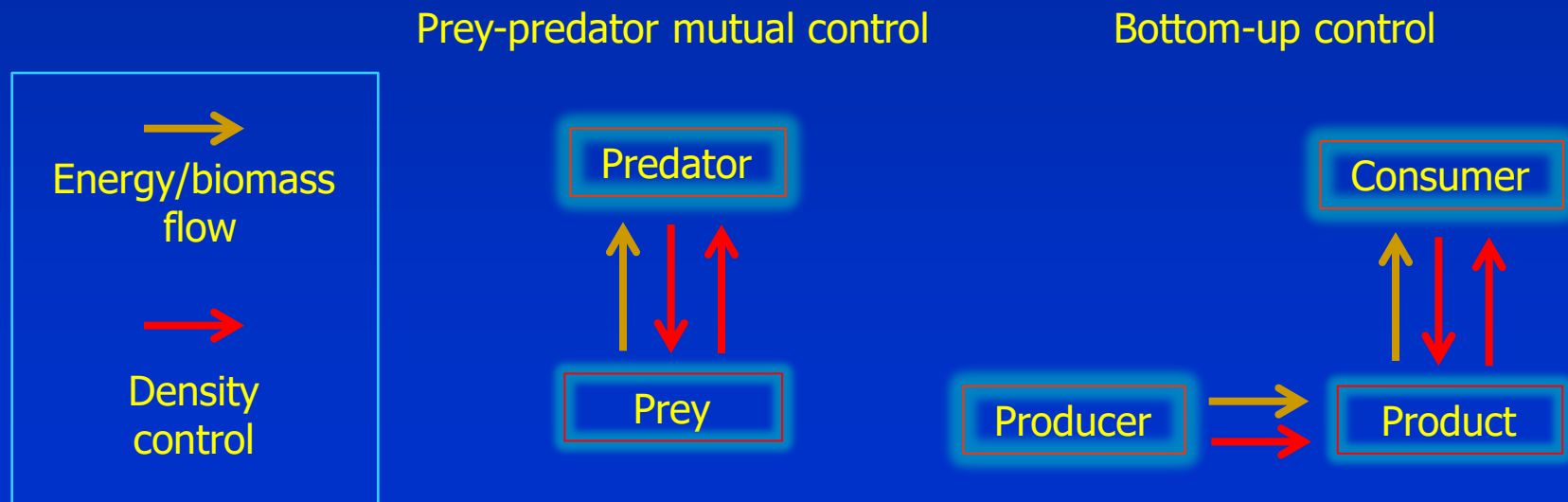


# FROM HERBIVORY TO COMMENSALISM AND SAPROPHITISM

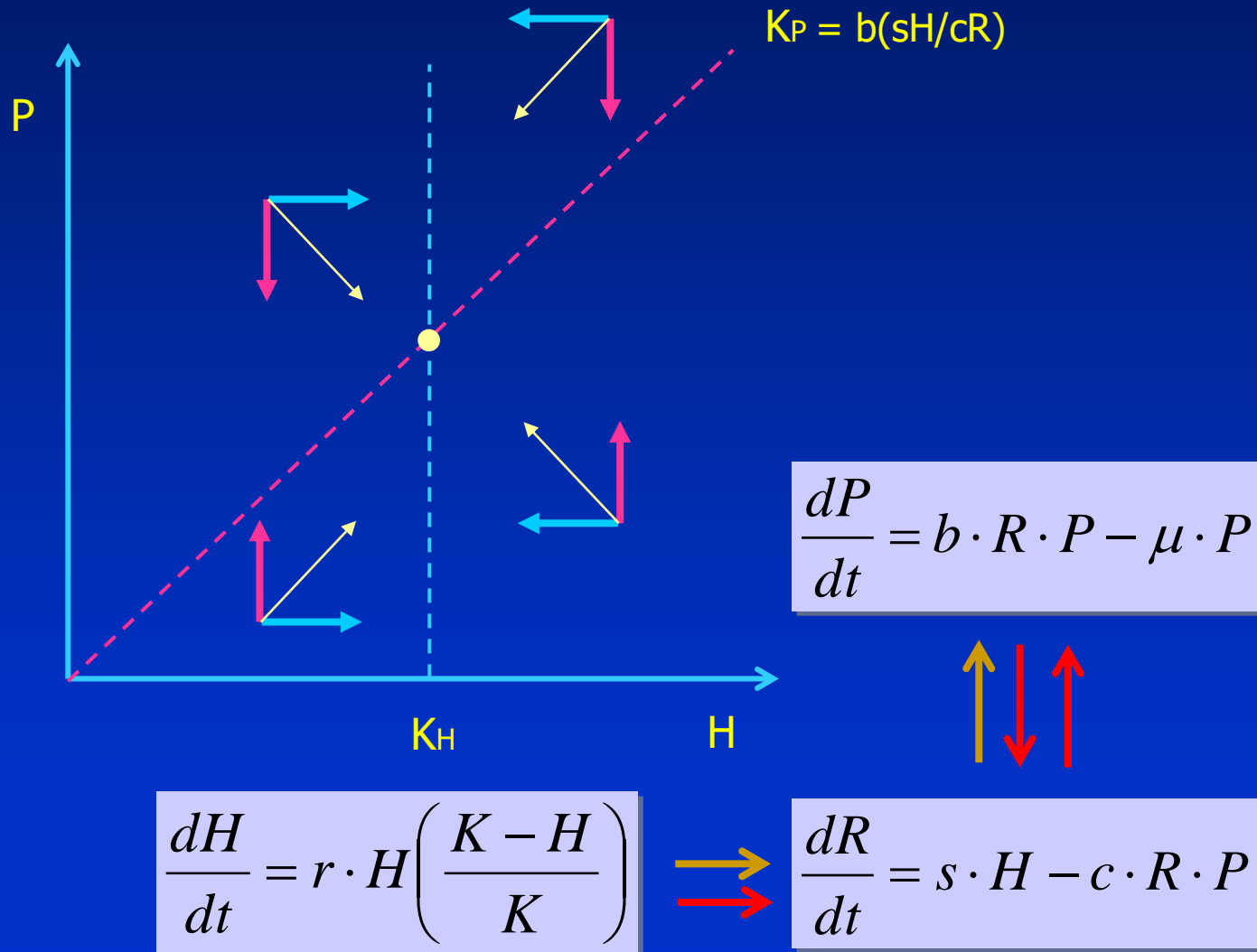
When the consumer takes food/energy from parts or products of individuals of a second species, this can lead to a +0 interaction called commensalism

The same occurs when the consumer utilizes dead individuals or part of individuals of a second species, which is currently called saprophitism

In both cases the density of exploited population can control the density of exploiter, but not the contrary. This leads to asymmetric, bottom-up demographic regulation along the food chain



# BOTTOM-UP DEMOGRAPHIC CONTROL OF “+0” RELATIONSHIPS





# TOP PREDATOR CONTROL OF COMMUNITIES

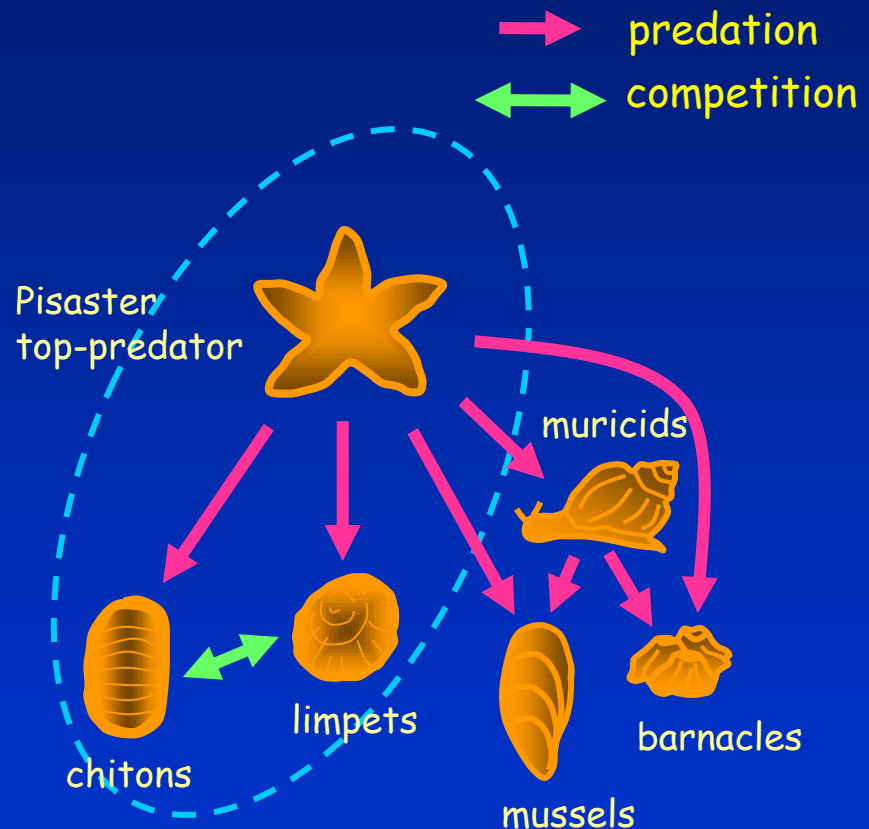
A simplified picture of the intertidal community along the rocky shores of North-Western America

The echinoderm *Pisaster ochraceus* is a top predator preying on different species of the community, including grazing molluscs (chitons and limpets) which compete for microalgae

*Pisaster* has a shifting behaviour, preferring more dense species

This has the benefit to regulate the competition between species (e.g. chitons and limpets)

If *Pisaster* is removed from the shore competitive exclusion occurs between the other species and the demographic equilibria among them are broken



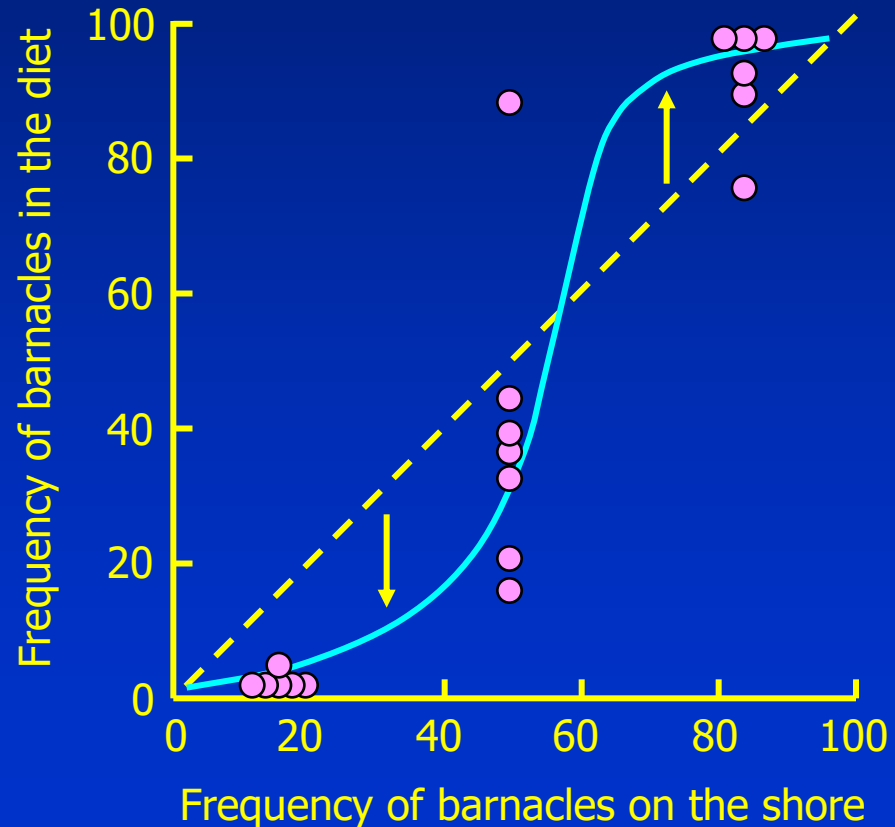


# TOP PREDATOR CONTROL OF COMMUNITIES

## The density-dependent, shifting predation of *Pisaster*

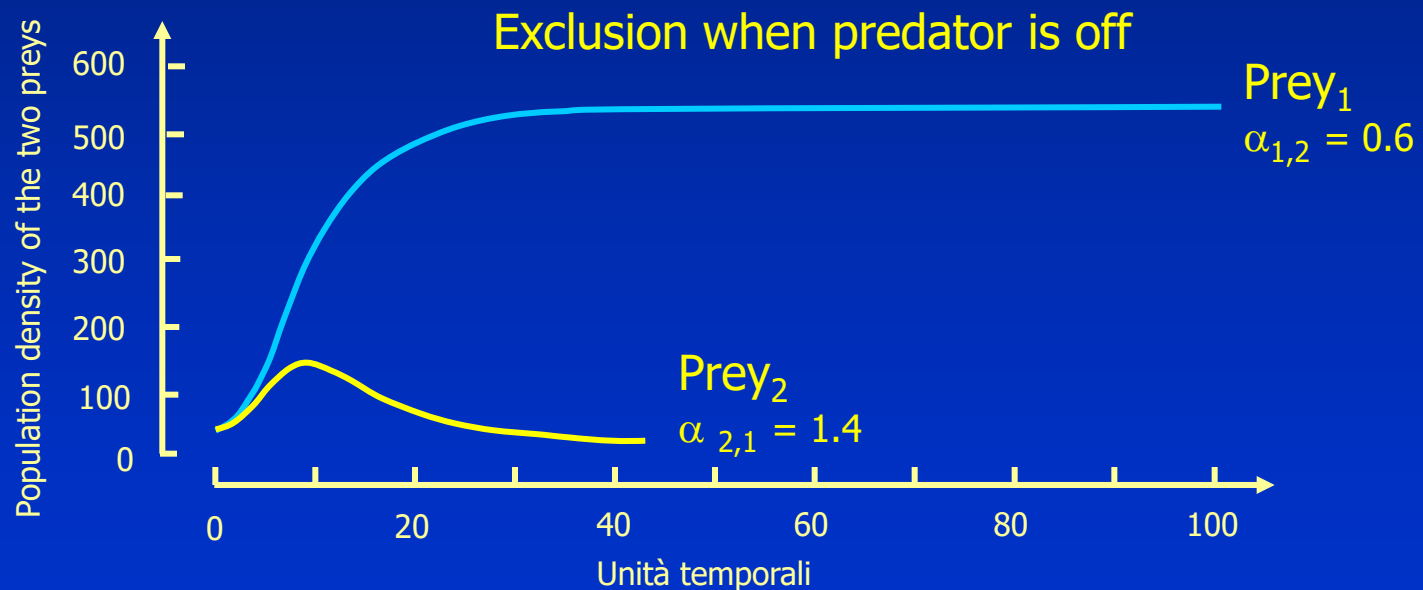
The frequency of attacks toward a given prey (e.g. barnacles) is not linearly related to their abundance on the shore.

Instead, *Pisaster* does neglect a prey if it is relatively unfrequent  
But strongly concentrates its attacks on it when it is relatively abundant



# TOP PREDATOR CONTROL OF COMMUNITIES

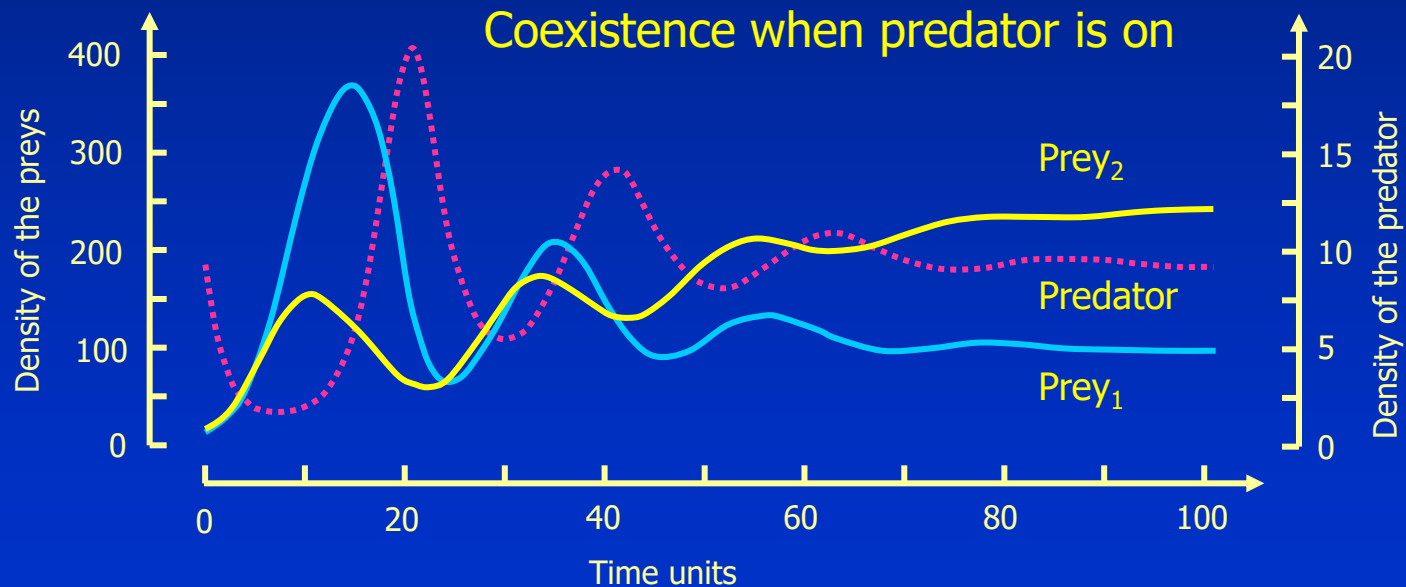
If the simulation is repeated including only the two competing species (without the predator) competitive exclusion is evident, displacing one of the two species (undercompetitor) from the habitat



# TOP PREDATOR CONTROL OF COMMUNITIES

A simulation using L-V model of the dynamics of two competing species one of which (Prey<sub>2</sub>) is made overcompetitor on the other (Prey<sub>1</sub>) by assigning opportune values of alfa ( $a_{2,1} = 1.4$ ;  $a_{1,2} = 0.6$ ).

The model includes a third species (Predator) assumed to have a switching predation pattern, according to the density of each prey



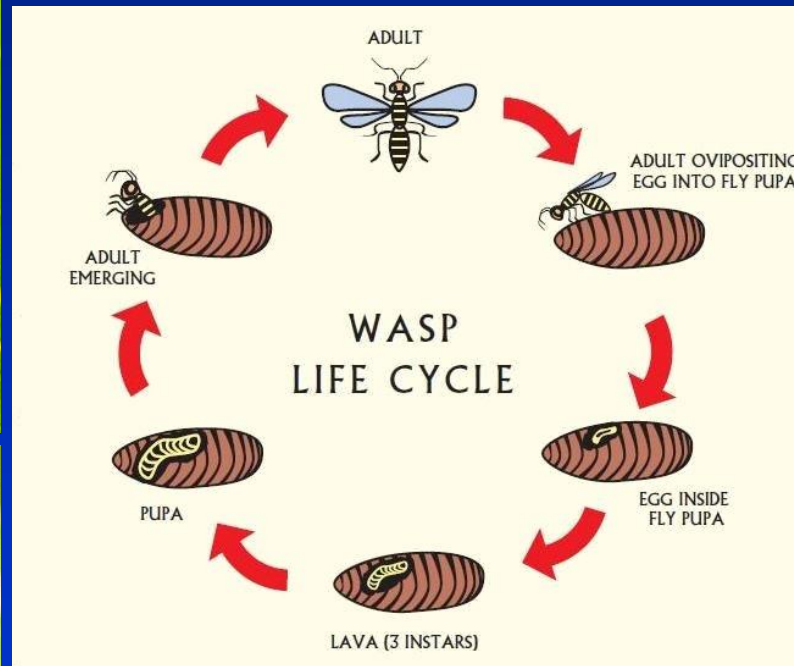
# TOP PREDATOR CONTROL OF COMMUNITIES

## The special case of the parasitoids

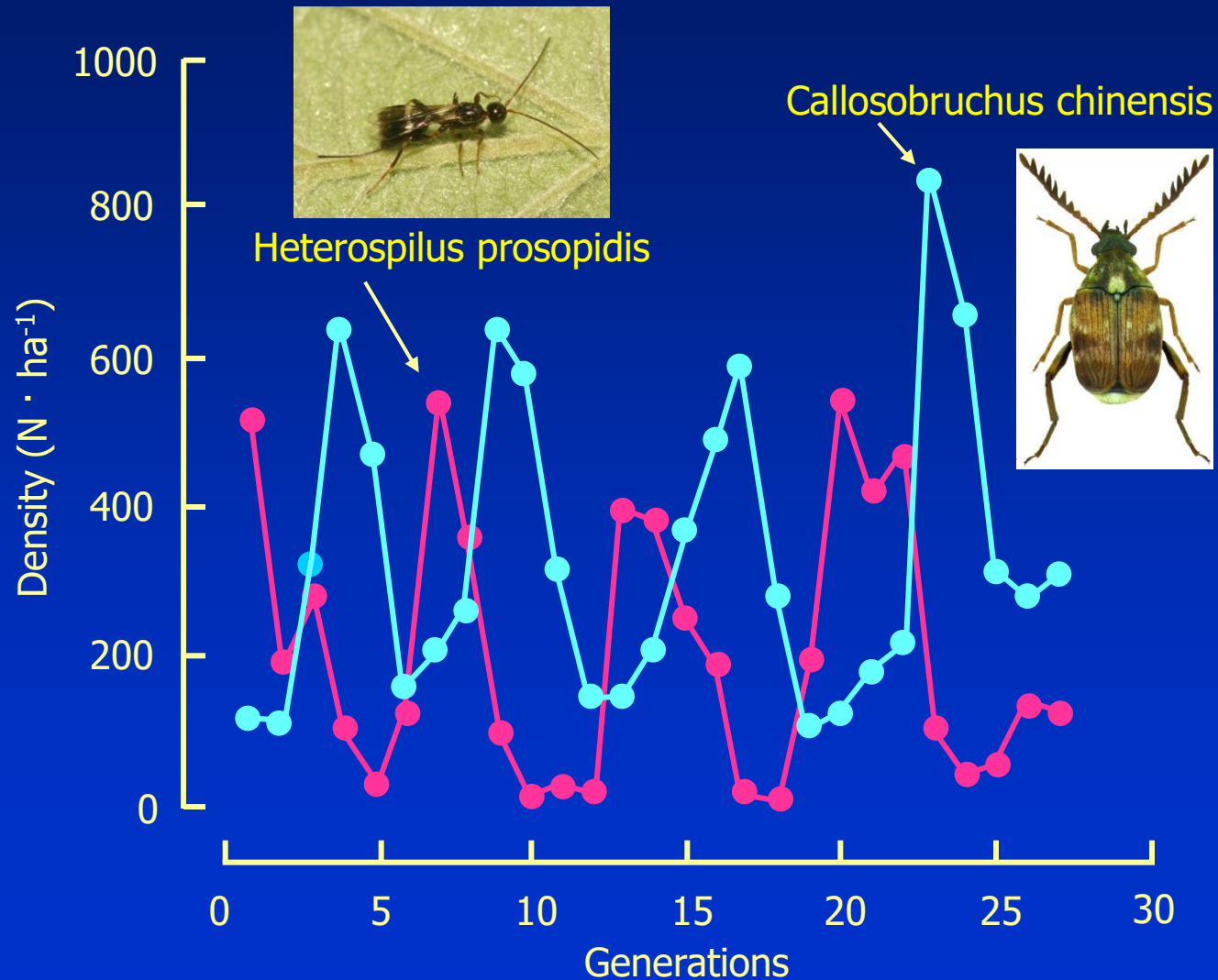
20% of Insects (particularly Mymenoptera Ichneumonidae)

But also Diptera and Coleoptera

Host-preys: other Hymenoptera, Coleoptera, Diptera, Araccnida, Gastropoda



# HOST-PARASITOID CO-DYNAMICS



# HOST-PARASITOID CO-DYNAMICS

The standard Nicholson & Bailey discrete-time model



Host dynamics

$$H_{t+1} = H_t \cdot \lambda \cdot f(H_t, P_t)$$

Host finite rate of growth

Probability for the host of NOT being attacked



Parasitoid dynamics

$$P_{t+1} = c \cdot H_t [1 - f(H_t, P_t)]$$

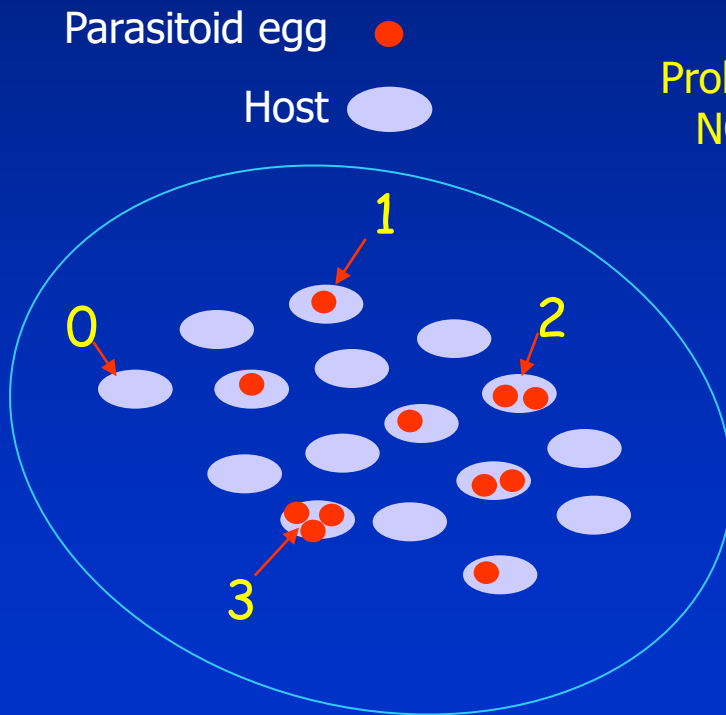
Hatching rate of parasitoid  
(n. newborns per host attacked)

Probability for the host of being attacked

# HOST-PARASITOID CO-DYNAMICS

The standard Nicholson & Bailey model

Random attack: Poisson distribution



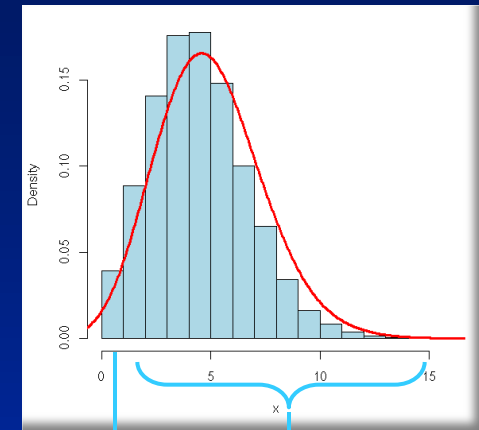
Probability for the host  
NOT being attacked

$$p_0 = e^{-s \cdot P_t}$$

Search efficiency  
of the parasitoid

Probability for the host  
of being attacked (1,.....)

$$p_{1 \rightarrow \infty} = 1 - e^{-s \cdot P_t}$$



# HOST-PARASITOID CO-DYNAMICS

The standard Nicholson & Bailey discrete-time model



Host dynamics

$$H_{t+1} = H_t \cdot \lambda \cdot e^{-s \cdot P_t}$$



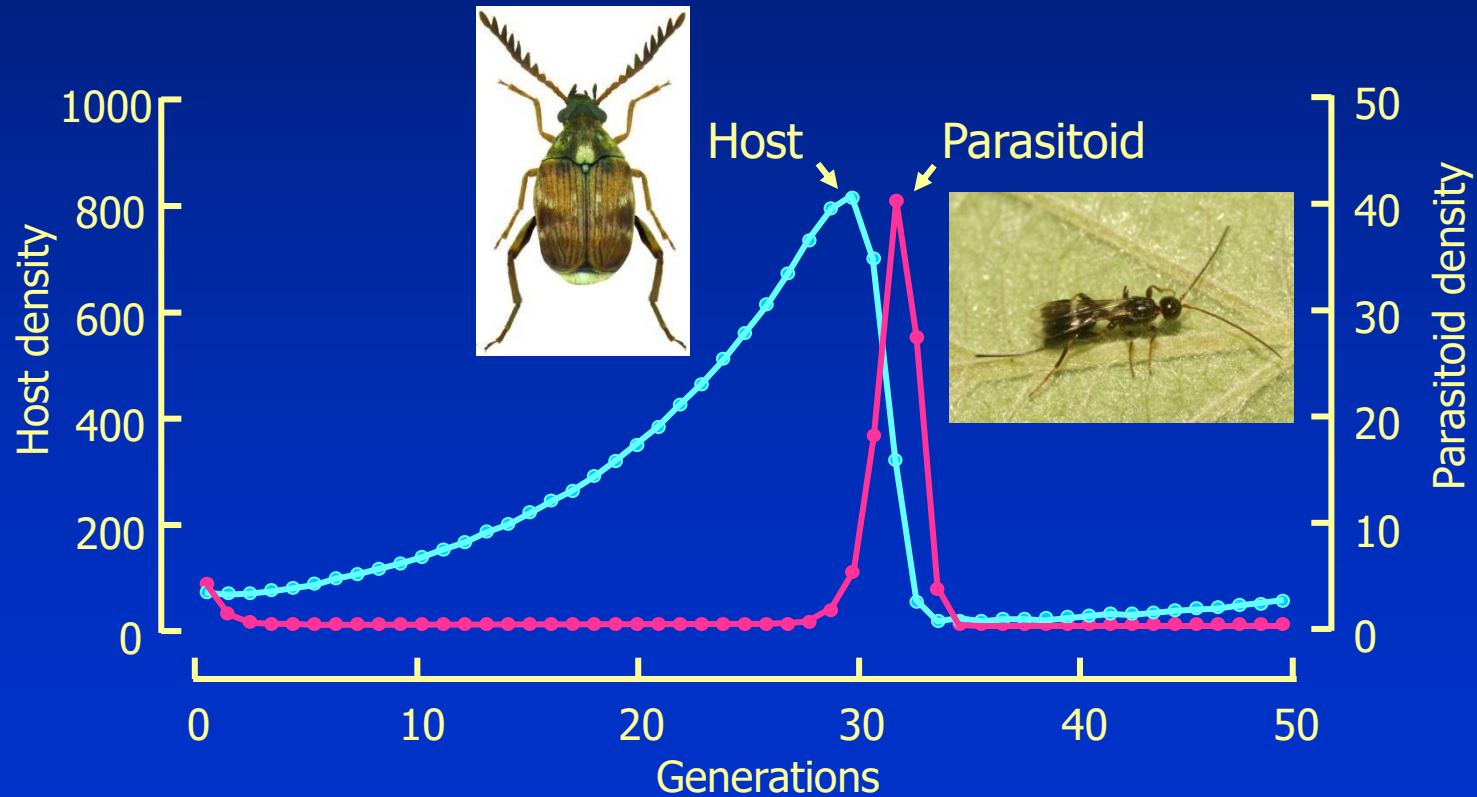
Parasitoid dynamics

$$P_{t+1} = c \cdot H_t \cdot \left(1 - e^{-s \cdot P_t}\right)$$



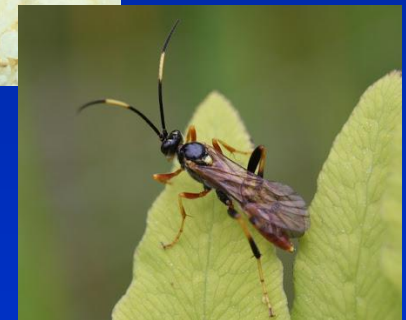
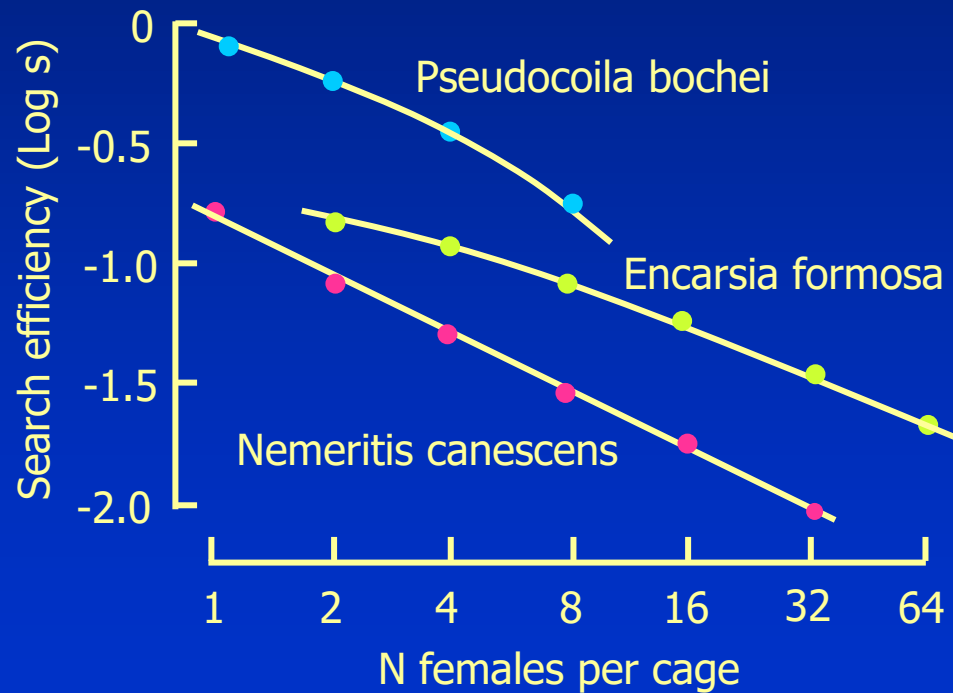
# HOST-PARASITOID CO-DYNAMICS

The standard Nicholson & Bailey discrete-time model



# HOST-PARASITOID CO-DYNAMICS

Interference within the parasitoid population



# HOST-PARASITOID CO-DYNAMICS

Interference within the parasitoid population

Hassel & Varley Eqn  $\longrightarrow$   $s = Q \cdot P^{-i}$

Interference coefficient

Maximum potential efficiency

Nicholson & Bailey  
with mutual interference

$$H_{t+1} = H_t \cdot \lambda \cdot e^{-Q \cdot P_t^{1-i}}$$
$$P_{t+1} = c \cdot H_t \cdot \left( 1 - e^{-Q \cdot P_t^{1-i}} \right)$$

# HOST-PARASITOID CO-DYNAMICS

Competition within the host population

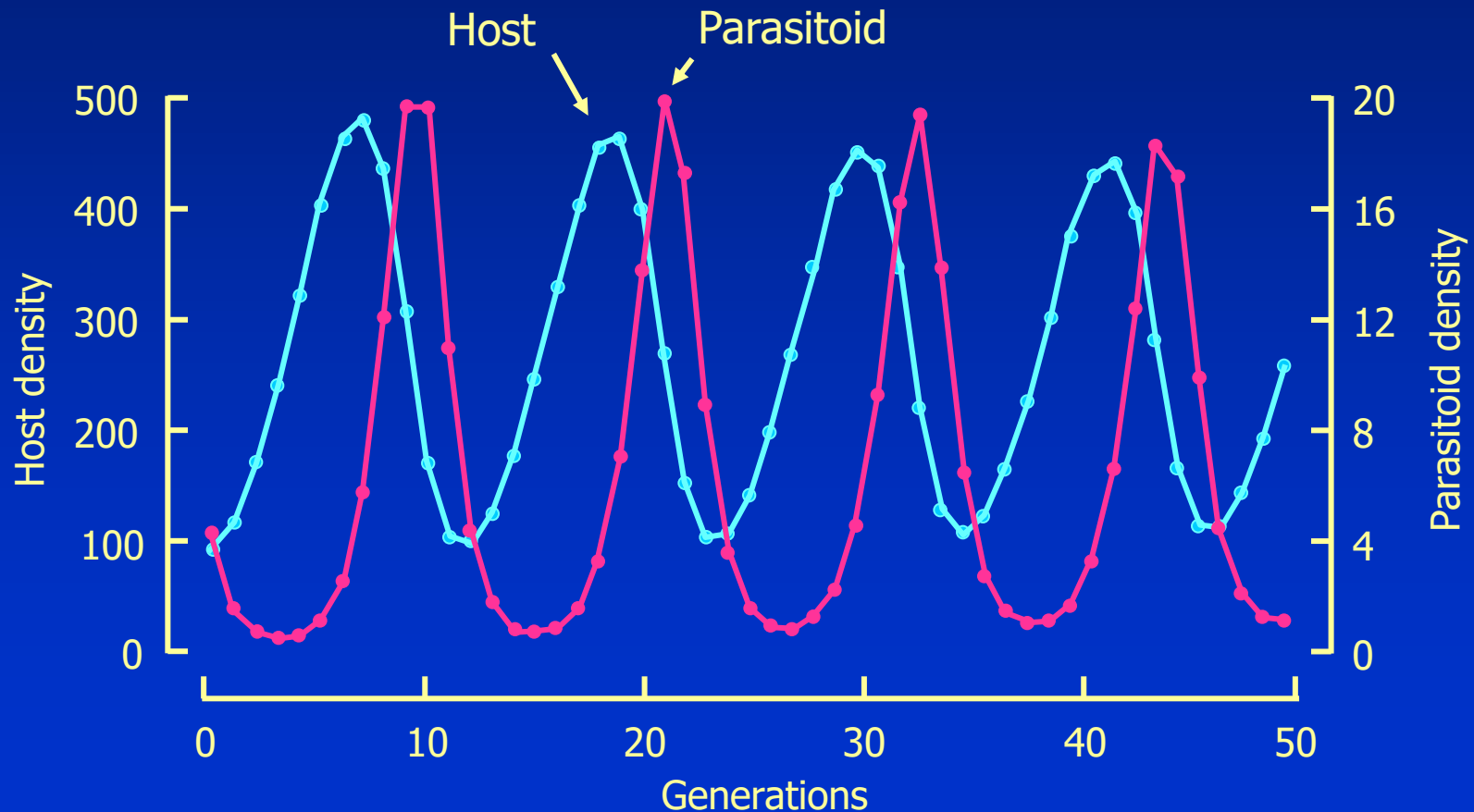
Host dynamics

$$H_{t+1} = H_t \cdot \lambda \cdot \left( \frac{1}{1 + a \cdot H_t} \right) e^{-sP_t}$$

Intraspecific competition  
(e.g. Maynard Smith & Slatkin)

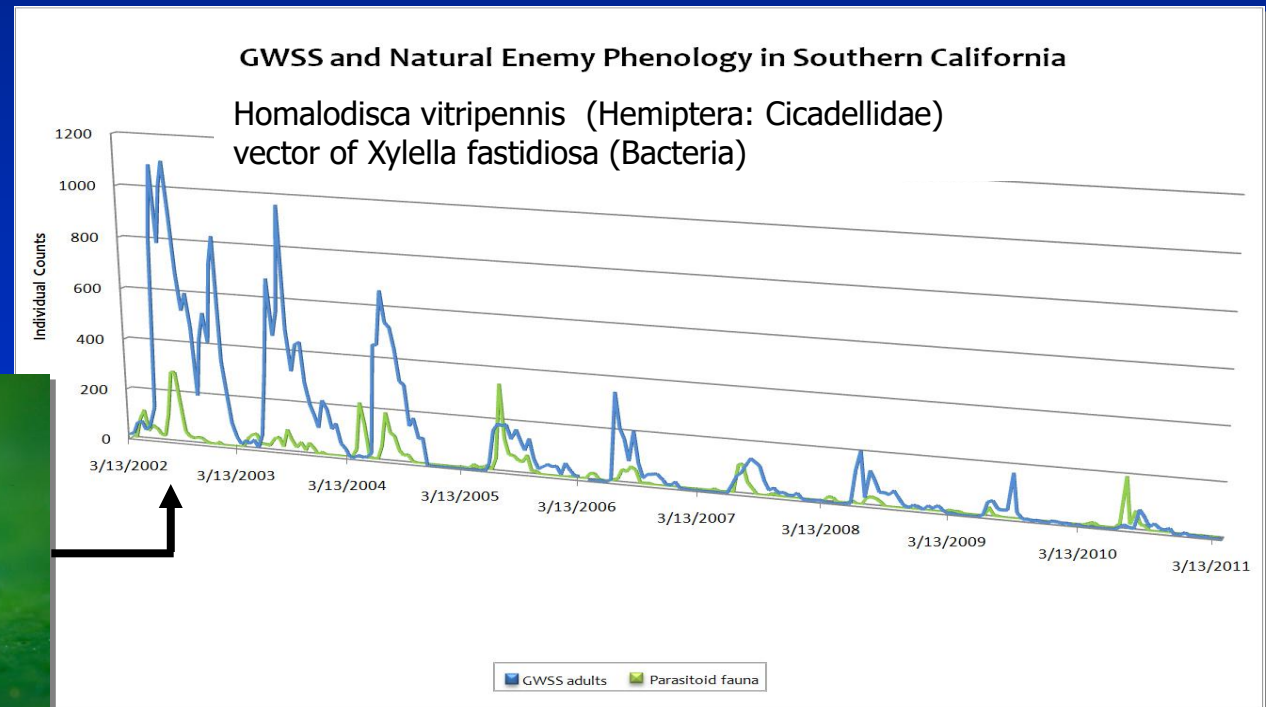
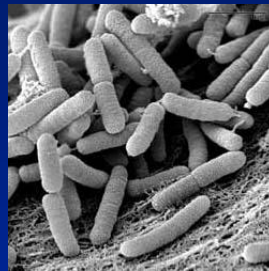
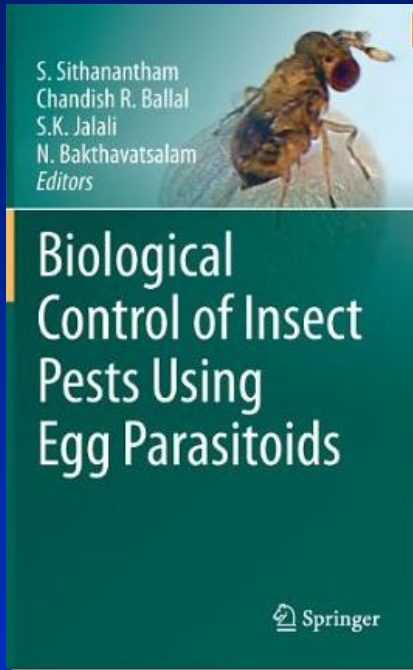
# HOST-PARASITOID CO-DYNAMICS

Simulation with implemented N & B model (interference+competition)



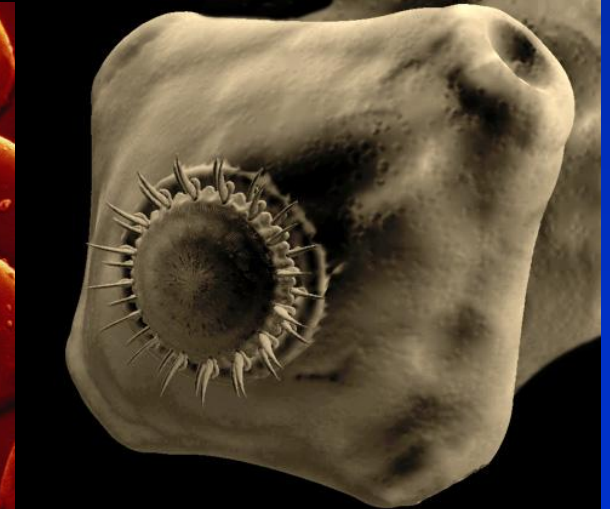
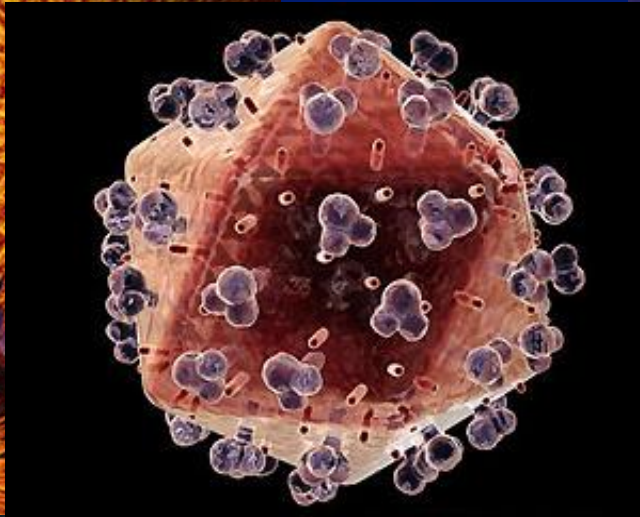
# HOST-PARASITOID CO-DYNAMICS

Use of parasitoids in the biological control of pests





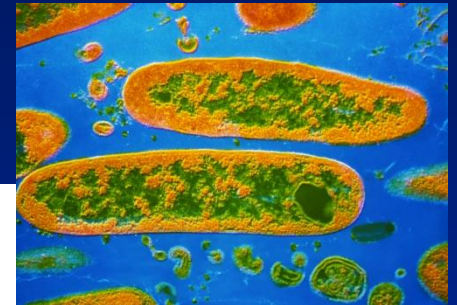
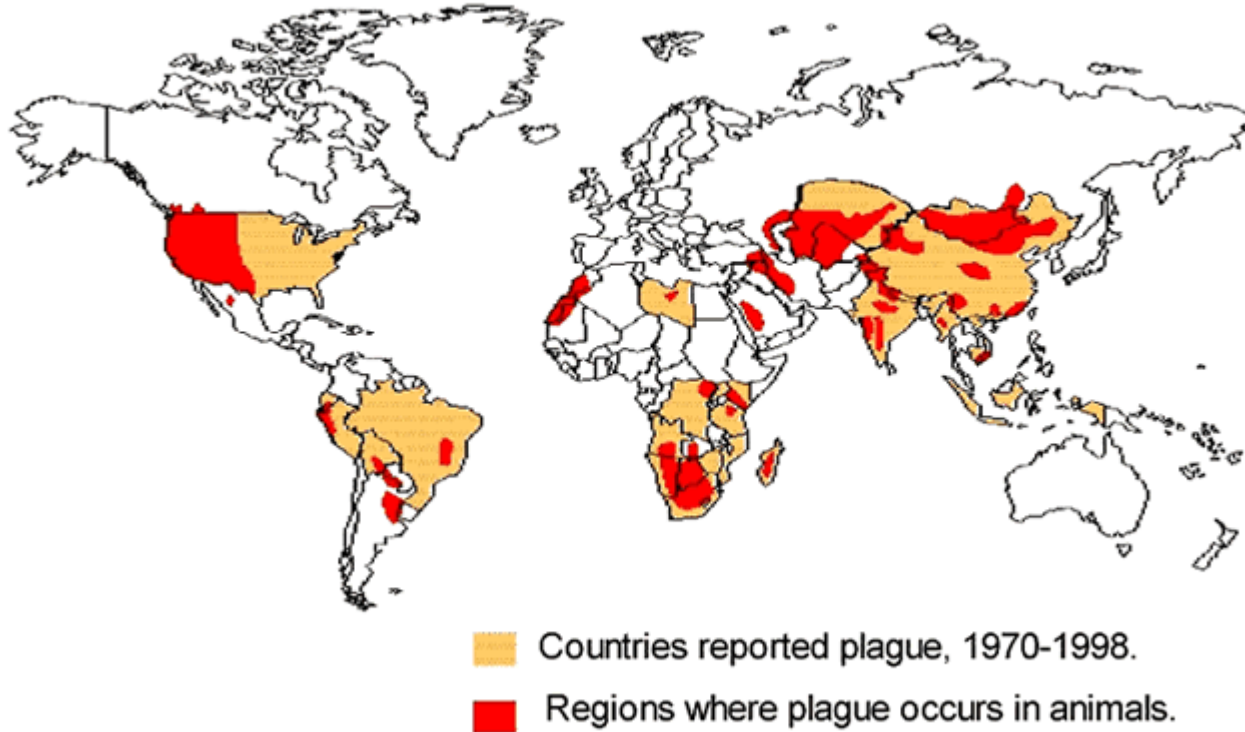
# PARASITE EFFECTS OVER HOST DEMOGRAPHY



# PARASITE EFFECTS OVER HOST DEMOGRAPHY

The present day plague distribution on the planet

World Distribution of Plague, 1998

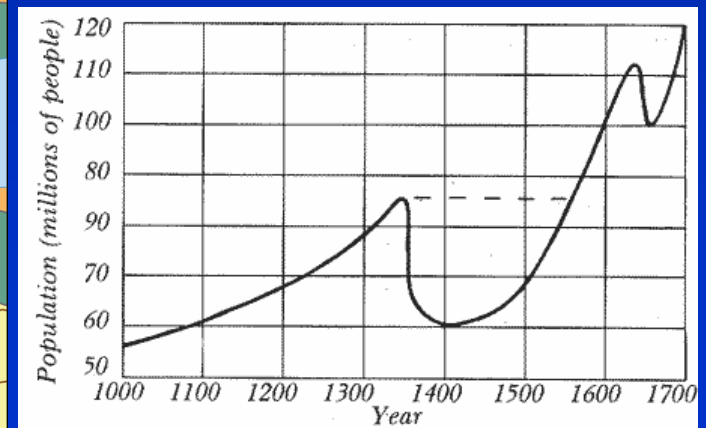
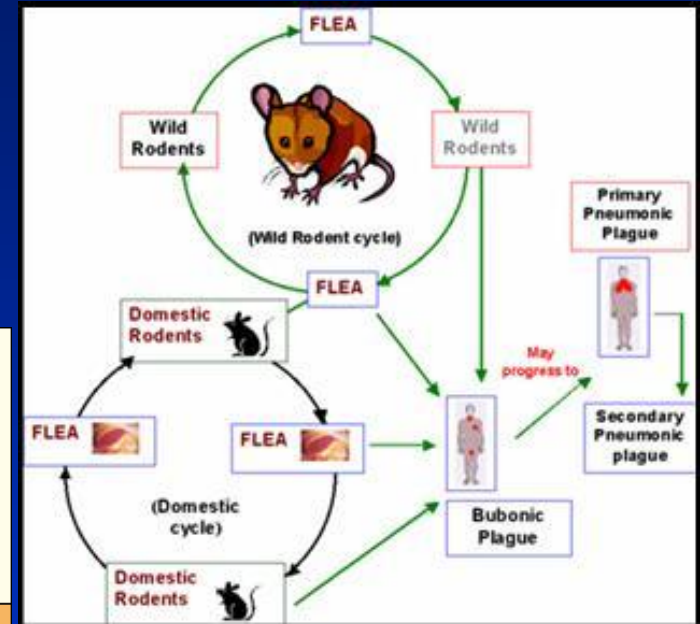
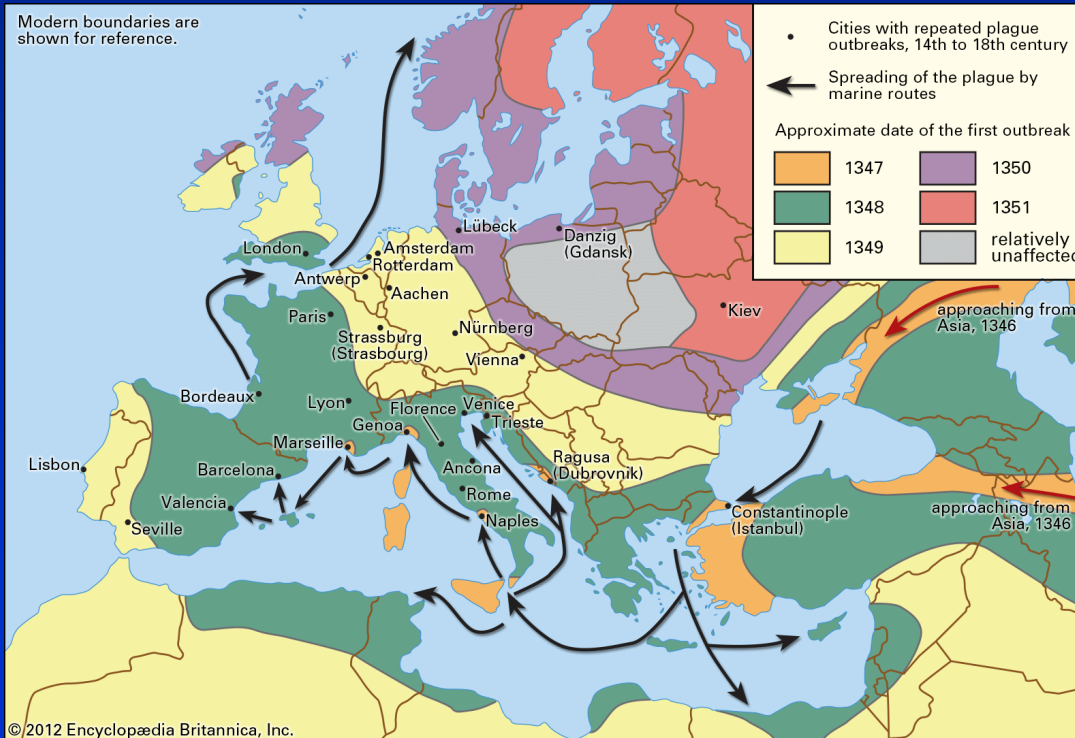




# PARASITE EFFECTS OVER HOST DEMOGRAPHY

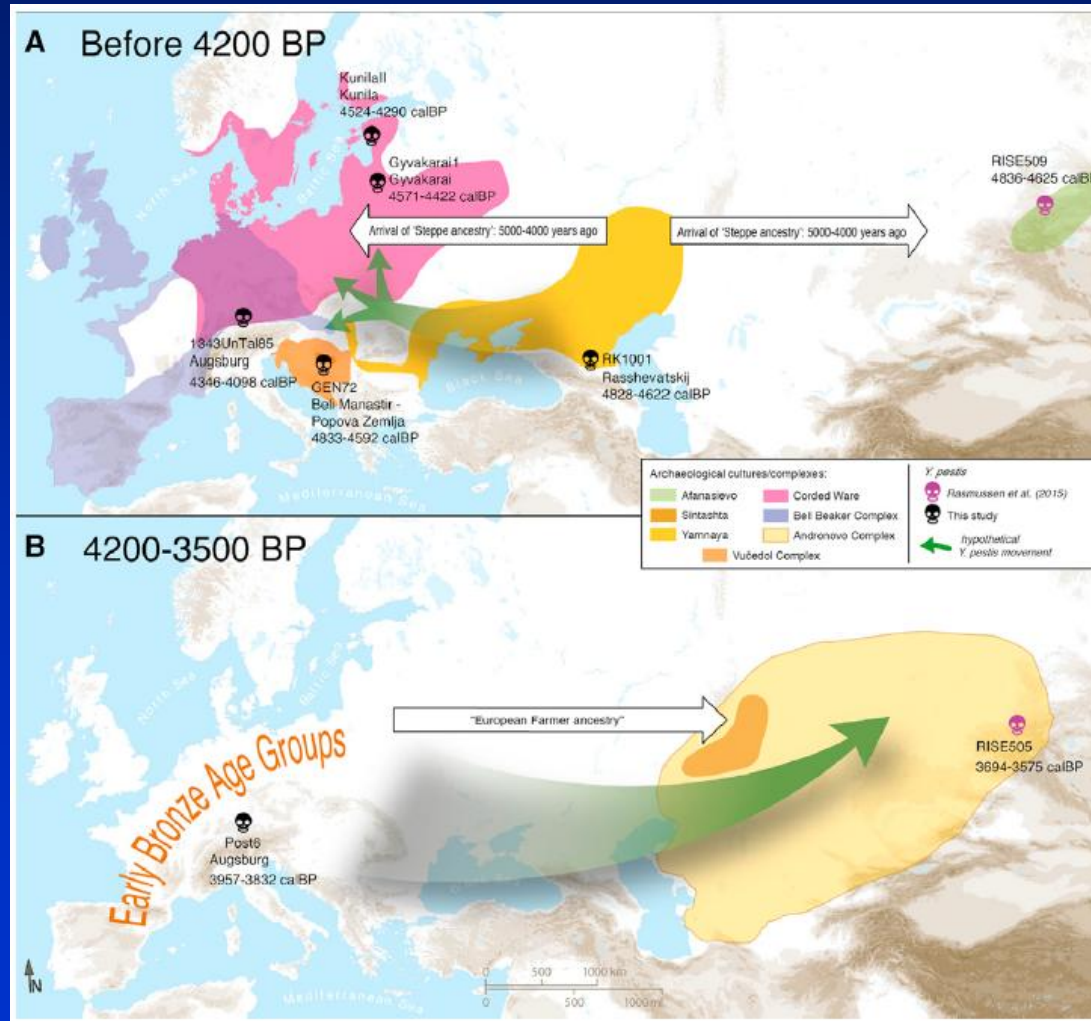
## The black plague in Europe (1347-1350)

The Black Death originated in or near China and spread into Western Eurasia. It may have reduced world population from an estimated 450 down to 350 million by the year 1400. In Europe 20-35 million died



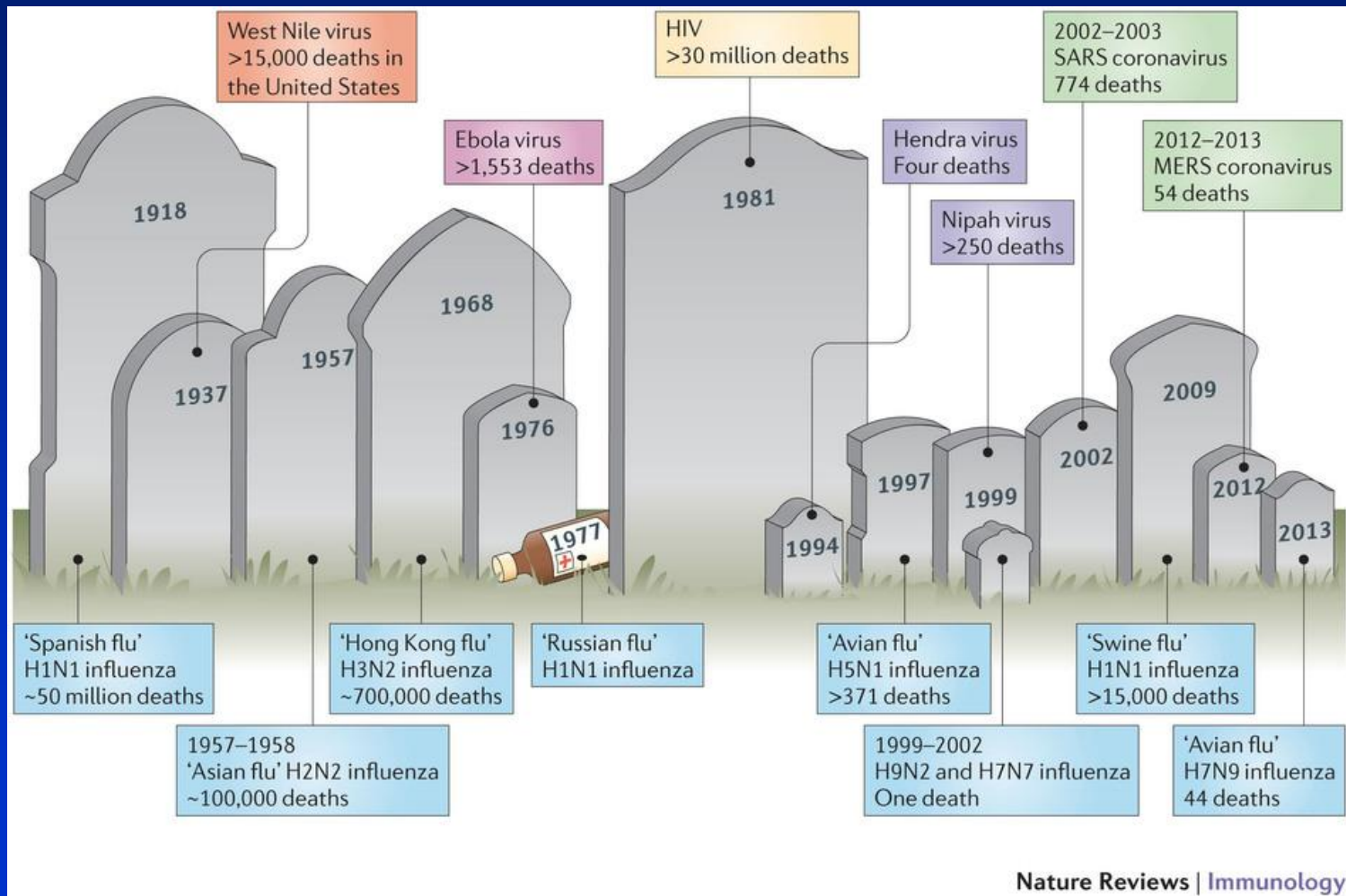
# PARASITE EFFECTS OVER HOST DEMOGRAPHY

## Late Neolithic and Early Bronze Age spread of black plague in Eurasia



# PARASITE EFFECTS OVER HOST DEMOGRAPHY

The impact of recent infection diseases on human populations





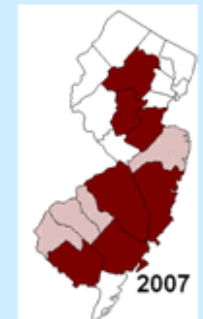
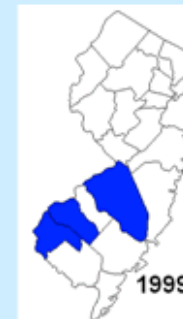
# PARASITE EFFECTS OVER HOST DEMOGRAPHY

## Epizootic Hemorrhagic Disease (EHD)

A disease of white-tailed deer (*Odocoileus virginianus*) caused by an infection of a virus from the genus *Orbivirus*, transmitted by biological vectors (in N America the midge, *Culicoides variipennis*)

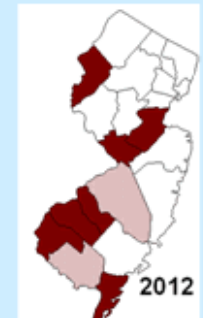
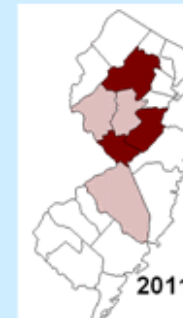


## EHD Outbreaks in New Jersey



EHDV-1

EHDV-2

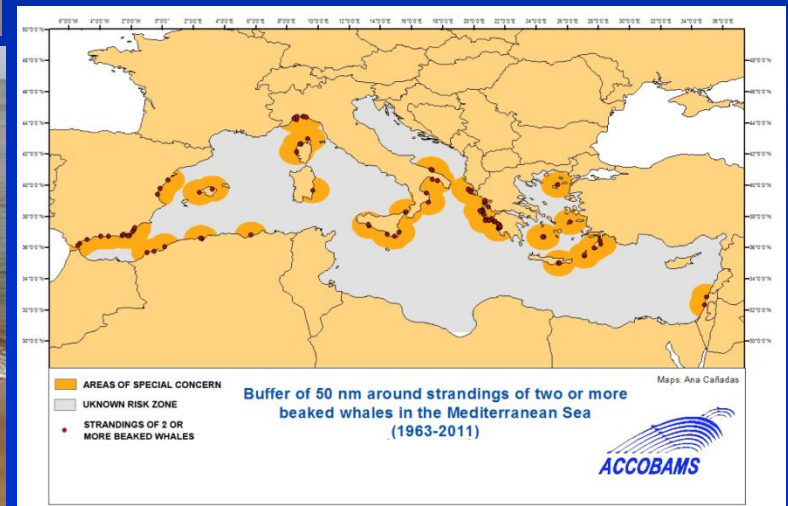
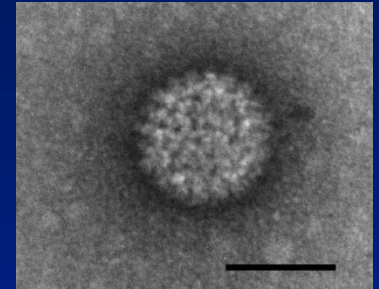


# PARASITE EFFECTS OVER HOST DEMOGRAPHY

Epizootic diseases in marine mammals due to Paramyxoviruses

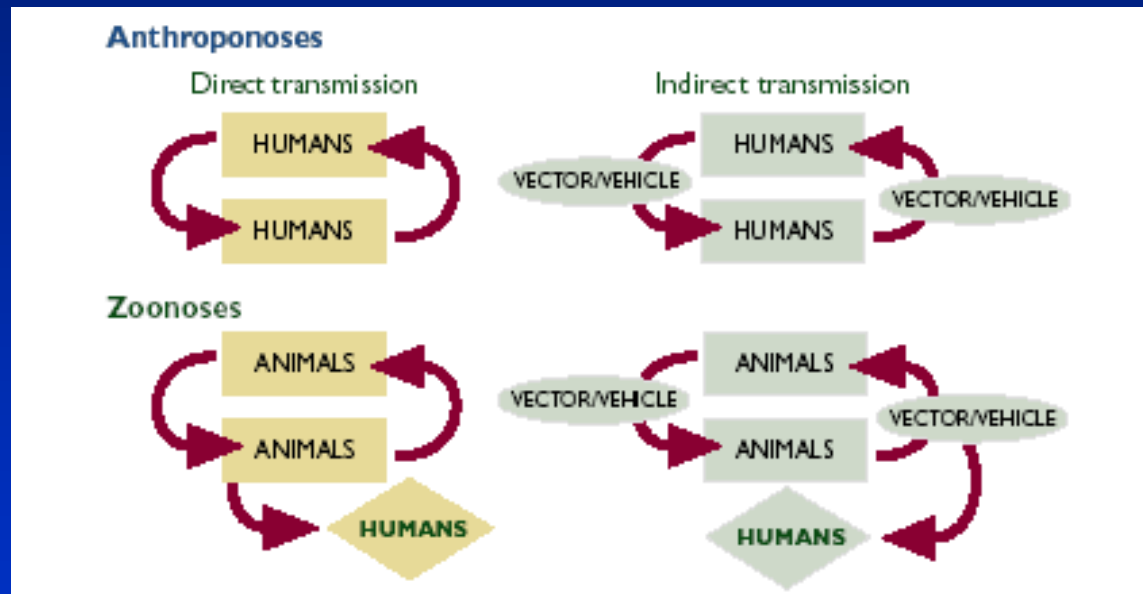
Phocine distemper virus

Cetacean morbillivirus



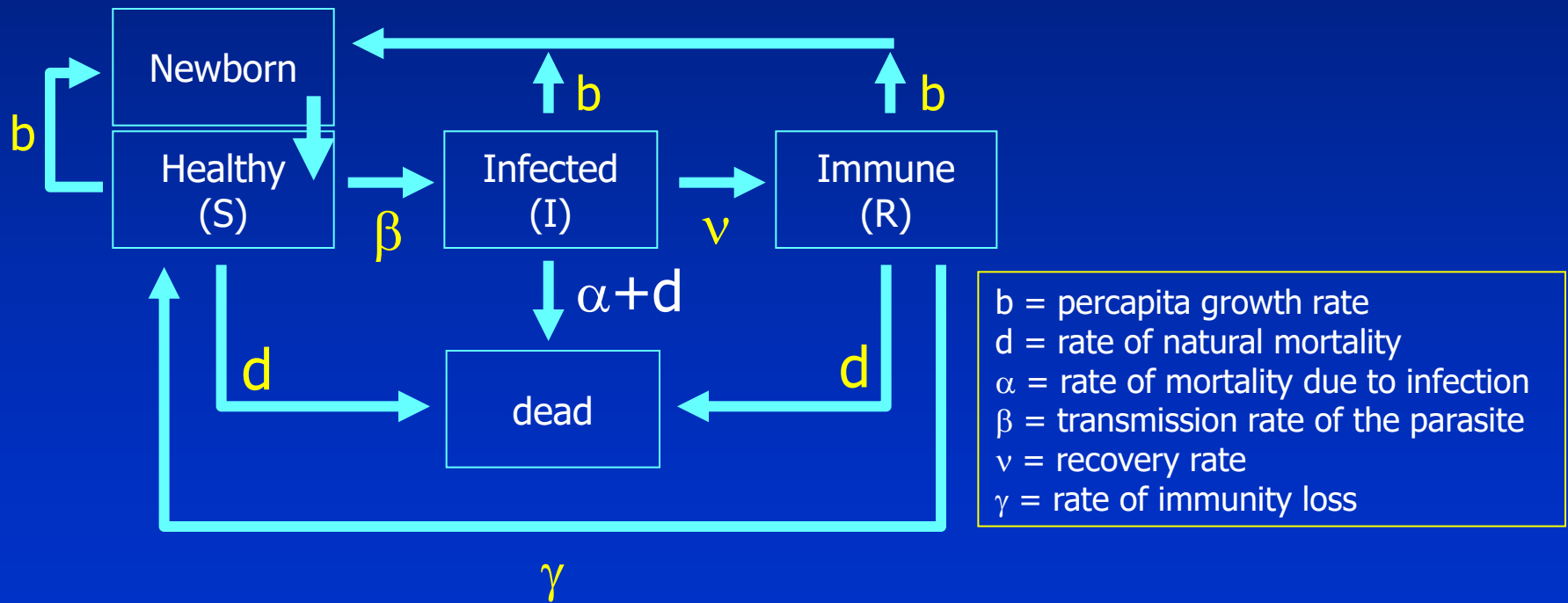
# PARASITE EFFECTS OVER HOST DEMOGRAPHY

## Anthroponoses and Zoonoses



# MICROPARASITE EFFECTS OVER HOST DEMOGRAPHY

The Anderson & May approach



# MICROPARASITE EFFECTS OVER HOST DEMOGRAPHY

The Anderson & May approach

$$\frac{dS}{dt} = b \cdot (S + I + R) - d \cdot S - \beta \cdot S \cdot I + \gamma \cdot R$$

Healthy - Susceptible

$$\frac{dI}{dt} = \beta \cdot S \cdot I - (\alpha + d + \nu) \cdot I$$

Infected

$$\frac{dR}{dt} = \nu \cdot I - (d + \gamma) \cdot R$$

Recovered - Immune

From the above eqns, by posing  $r = b - d$   
we obtain the predicted dynamics  
of the whole population

$$\frac{dN}{dt} = r \cdot (S + I + R) - \alpha \cdot I$$

$b$  = percapita growth rate  
 $d$  = rate of natural mortality  
 $\alpha$  = rate of mortality due to infection  
 $\beta$  = transmission rate of the parasite  
 $\nu$  = recovery rate  
 $\gamma$  = rate of immunity loss



# MICROPARASITE EFFECTS OVER HOST DEMOGRAPHY

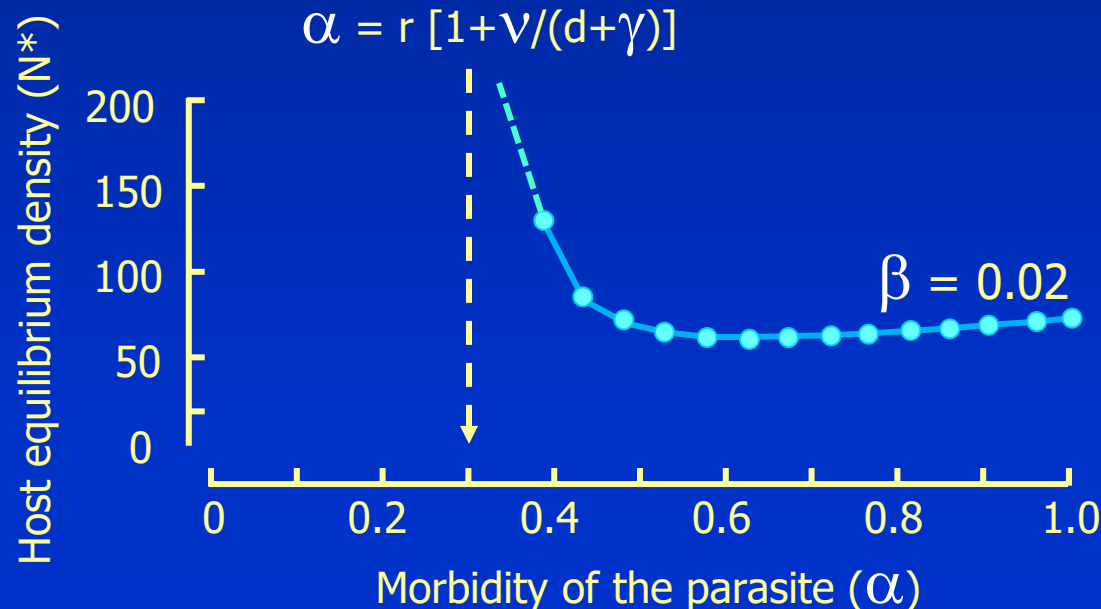
## The Anderson & May approach

When the rate of mortality is so that:

$$\alpha > r \cdot \left( 1 + \frac{v}{d + \gamma} \right)$$

$b$  = percapita growth rate  
 $d$  = rate of natural mortality  
 $r = b - d$   
 $\alpha$  = rate of mortality due to infection  
 $\beta$  = transmission rate of the parasite  
 $v$  = recovery rate  
 $\gamma$  = rate of immunity loss

Then, the infection does regulate the host population at a stable density  $N^*$  which depends on the transmission rate

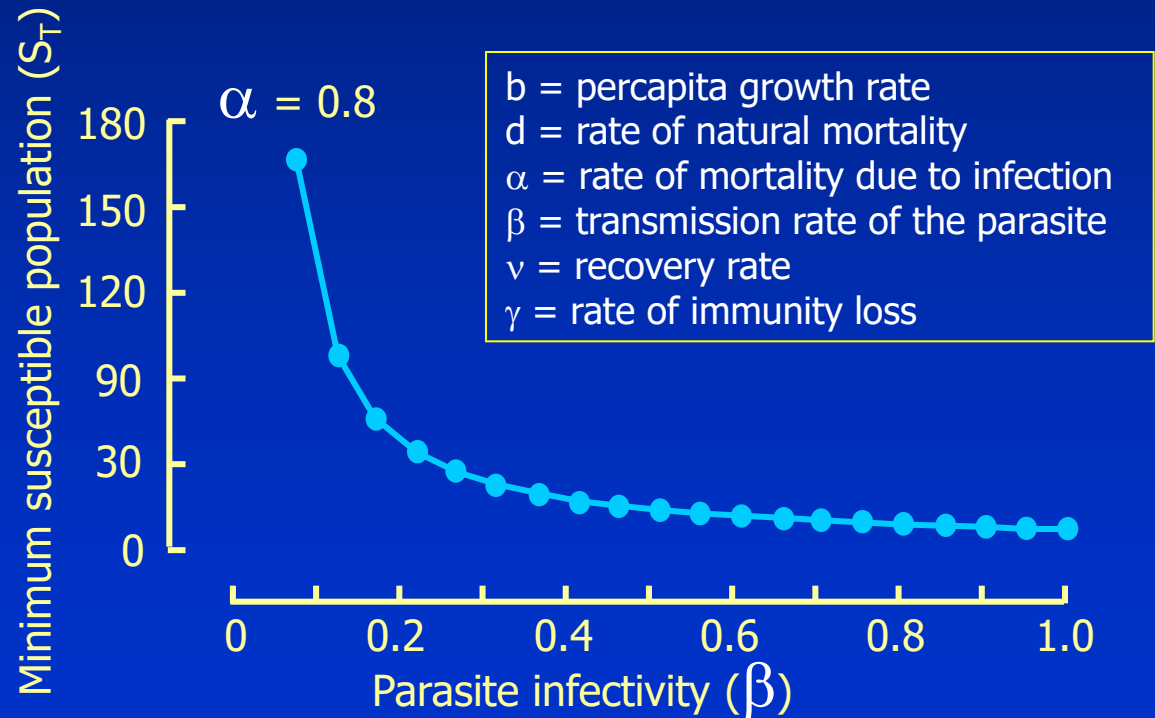


# MICROPARASITE EFFECTS OVER HOST DEMOGRAPHY

## The Anderson & May approach

The A & M model predicts the minimum susceptible host population ( $S_T$ ) necessary to keep the microparasite infection in an endemic form, which depends on  $\alpha$ ,  $\beta$ ,  $\nu$  and  $d$

$$S_T = \frac{\alpha + d + \nu}{\beta}$$



# MICROPARASITE EFFECTS OVER HOST DEMOGRAPHY

## The Anderson & May approach

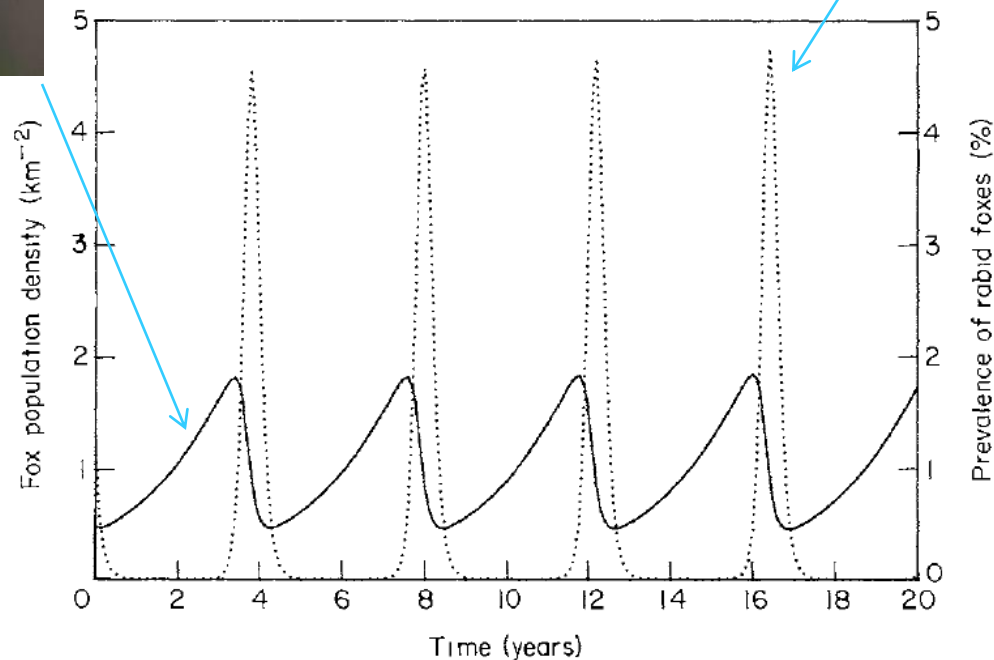
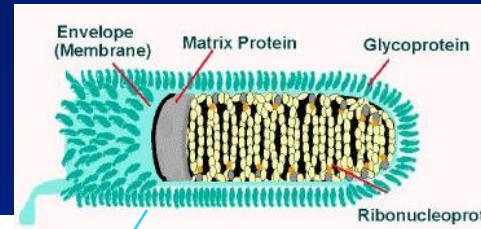


FIG. 3. Oscillatory fluctuations in total fox population density and the density of rabid foxes generated by a simple model of the interaction between the rabies virus and its host population (see Anderson *et al.* 1981). Parameter values; disease-free carrying capacity,  $10 \text{ km}^2$ ,  $r=0.5 \text{ year}^{-1}$ ,  $\beta=80 \text{ year}^{-1}$ ,  $\sigma=13 \text{ year}^{-1}$ ,  $\alpha=73 \text{ year}^{-1}$ .

# MICROPARASITE EFFECTS OVER HOST DEMOGRAPHY

The Hyman & Stanley (1988) model for HIV

$$\frac{dS(t)}{dt} = \mu(S_0 - S(t)) - \lambda(t)S(t),$$

$$\frac{dI(t)}{dt} = \lambda(t)S(t) - (\gamma + \mu)I(t),$$

$$\frac{dA(t)}{dt} = \gamma I(t) - \delta A(t),$$

$$\frac{dA_T(t)}{dt} = \gamma I(t),$$

$t$  = time,

$S(t)$  = number of susceptible individuals,

$I(t)$  = number of infected individuals without AIDS,

$A(t)$  = number of AIDS cases,

$A_T(t)$  = accumulated number of AIDS cases,

$N(t)$  = number of susceptible and infected individuals without AIDS,

$\mu$  = death rate of individuals without AIDS,

$\delta$  = death rate of individuals with AIDS,

$\gamma$  = rate of developing AIDS of infected individuals,

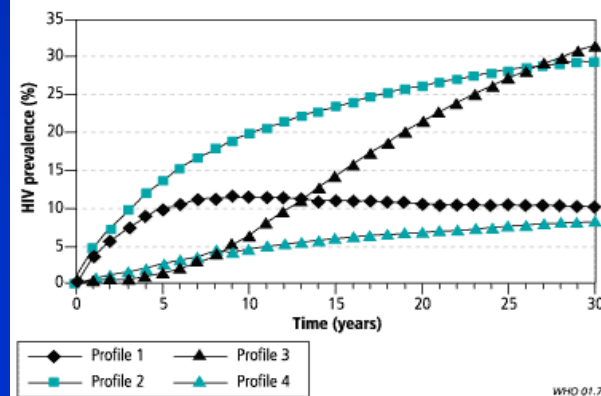
$i$  = probability of infection from a sexual contact with an infected,

$c$  = average number of contacts between sexual partners,

$r$  = average number of new sexual partners per year, and

$S_0$  = population size before the AIDS virus was introduced.

Fig. 2. Baseline projections of HIV prevalence in adult population (15–49 years) for four sexual behaviour profiles (see Table 1)



## METAPOPULATION ECOLOGY

Classical demoecology refers to populations evenly distributed in a structureless habitat, however:

Real populations have often complex spatial distributions consisting of different local populations connected in a network

Local populations occupy portions of ecologically suitable patches (conditions/resources) interspersed by a matrix of unsuitable habitats

Connection between local populations is based on mobility of individuals (and genes) from one population to other population

Ecological corridors maintain the connectivity of the system

Such network of interconnected local populations is called a metapopulation

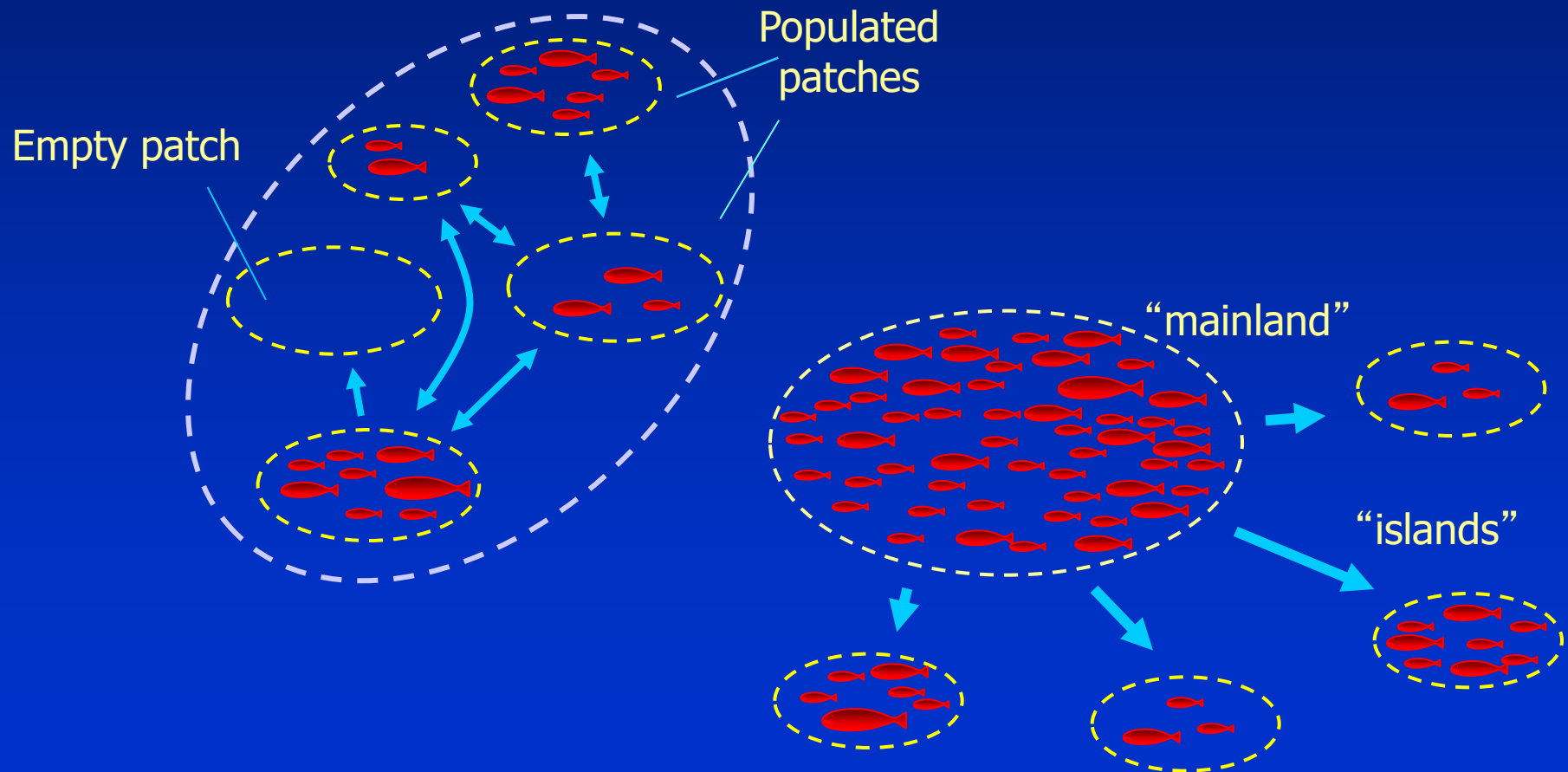
# METAPOPULATION ECOLOGY

Some good reasons to consider metapopulation approach in demoeology

- Many (if not most) natural populations are in effect metapopulations
- Metapopulations reveal emerging properties with respect to the single populatons of the network
- Metapopulation approach opens new horizons to the conservation and restoration strategies, e.g. local vs global conservation
- Metapopulation approach is the basis for restoration strategies e.g. design of natural reserves (one large vs many small)
- Habitat fragmentation due to human activities (e.g. deforestation, building of infrastructures) create metapopulation structures: which consequences for the long term species/populations survival?

# METAPOPULATION ECOLOGY

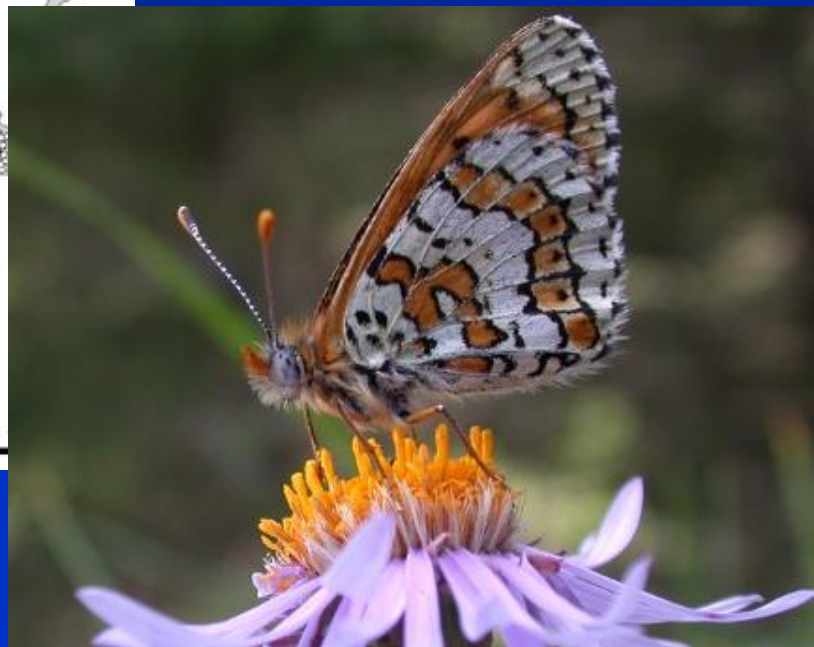
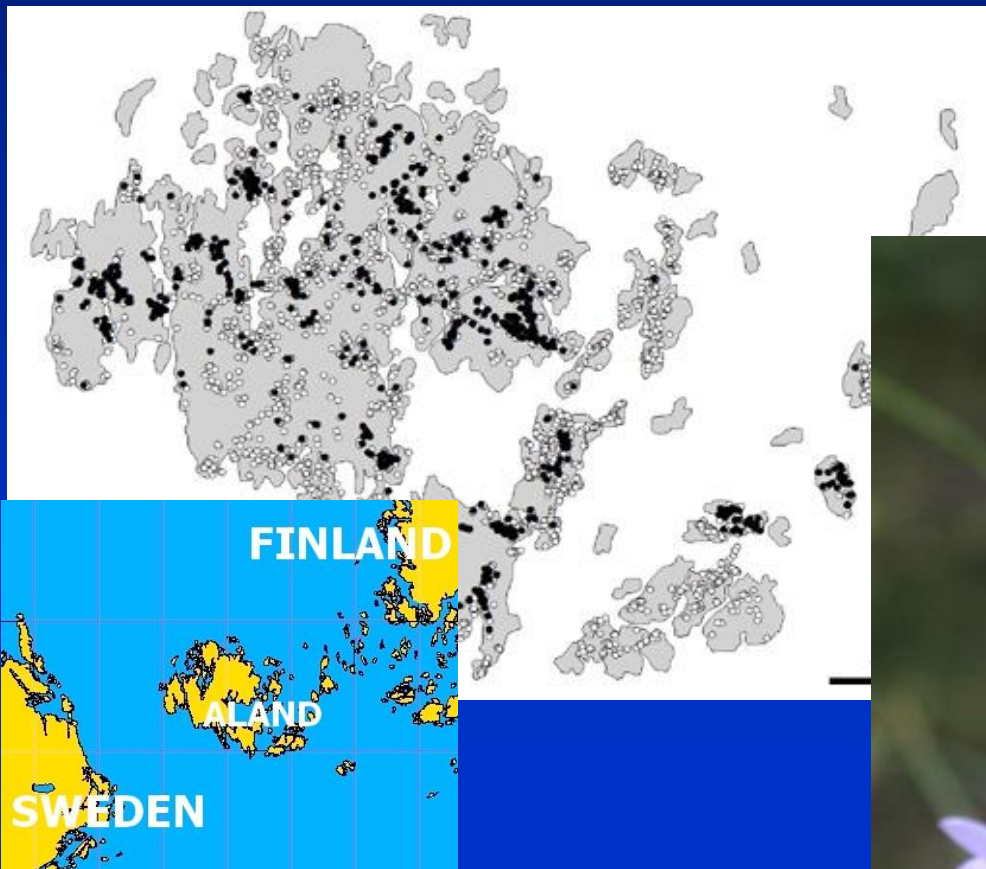
## Different arrangements of metapopulations



# METAPOPULATION ECOLOGY

Glainville Fritillary butterfly (*Melitaea cinxia*) in the Aland Islands

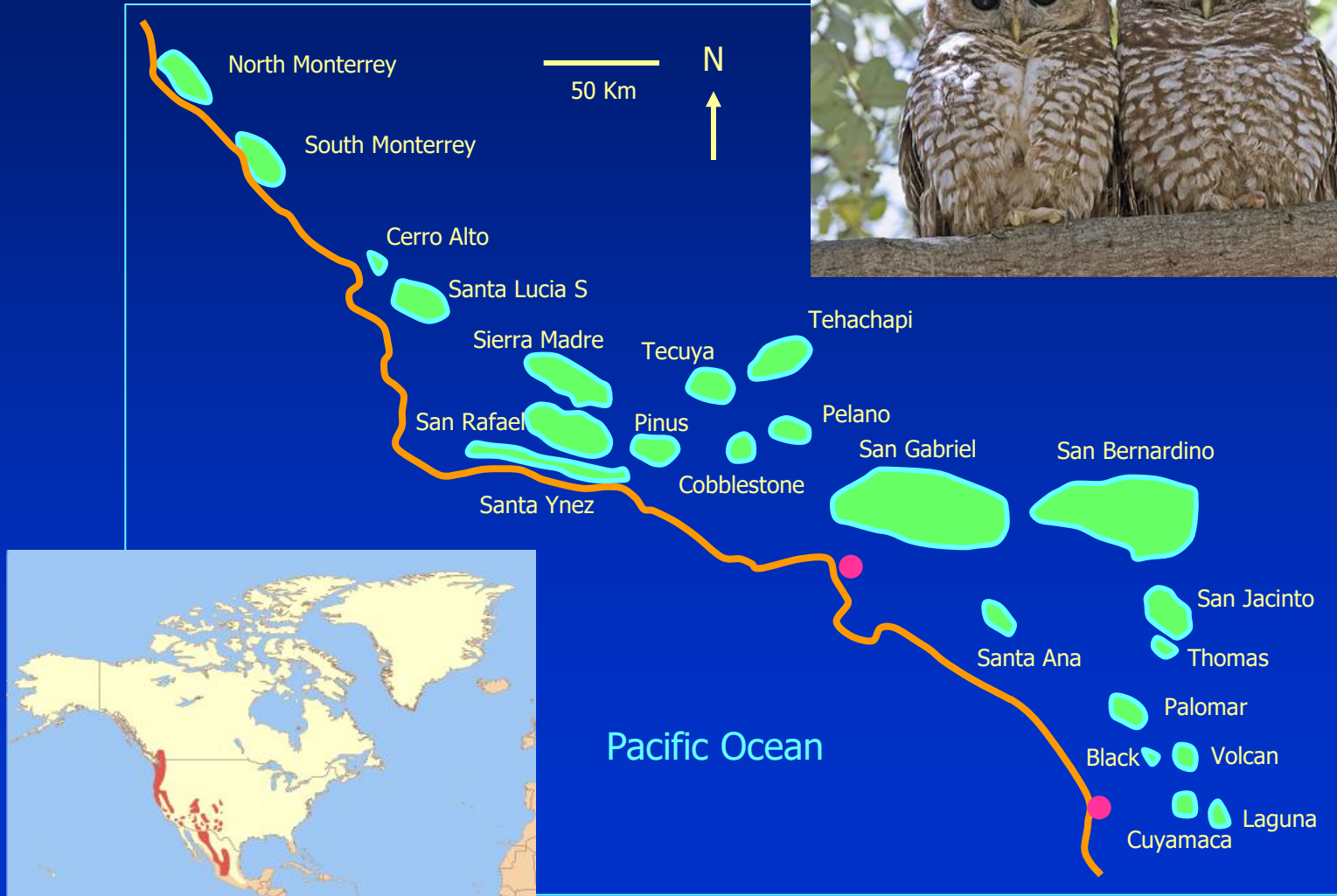
Metapopulation structure – Ilkka Hanski





# METAPOPULATION ECOLOGY

## California Spotted Owl (*Strix occidentalis*)

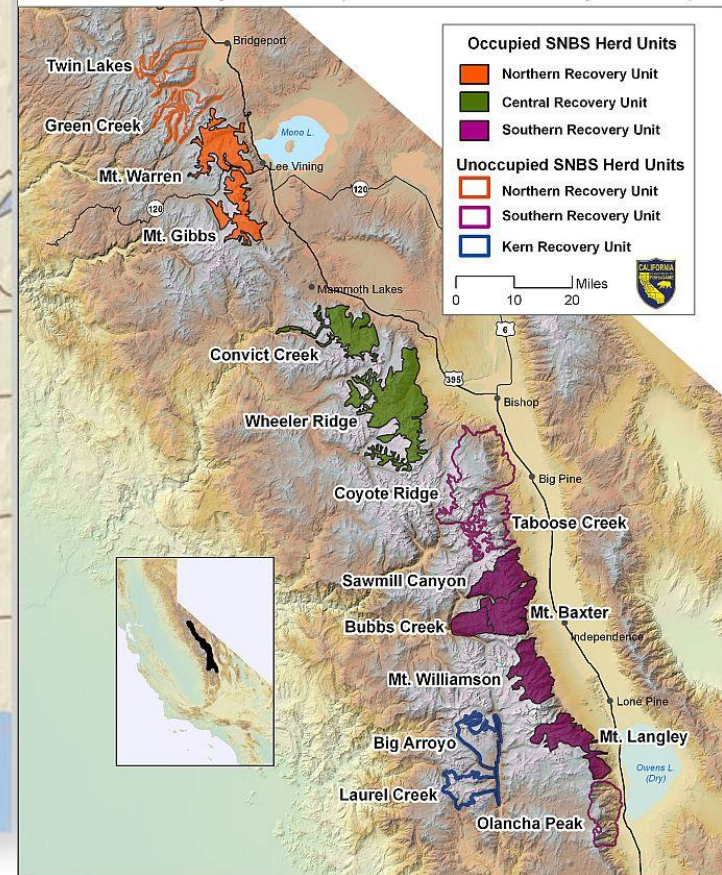


# METAPOPOPULATION ECOLOGY

## Bighorn Sheeps (*Ovis canadensis*)



Sierra Nevada Bighorn Sheep Herd Unit & Recovery Unit Map



# METAPOPULATION DYNAMICS

The spatially implicit Levins model (patch dynamics)

$$\frac{dP}{dt} = c \cdot P \cdot (1 - P) - e \cdot P$$

Local populations extinction rate

New patches colonization rate

$$\frac{dP}{dt} = (c - e) \cdot P \cdot \left( 1 - \frac{P}{1 - \frac{e}{c}} \right)$$

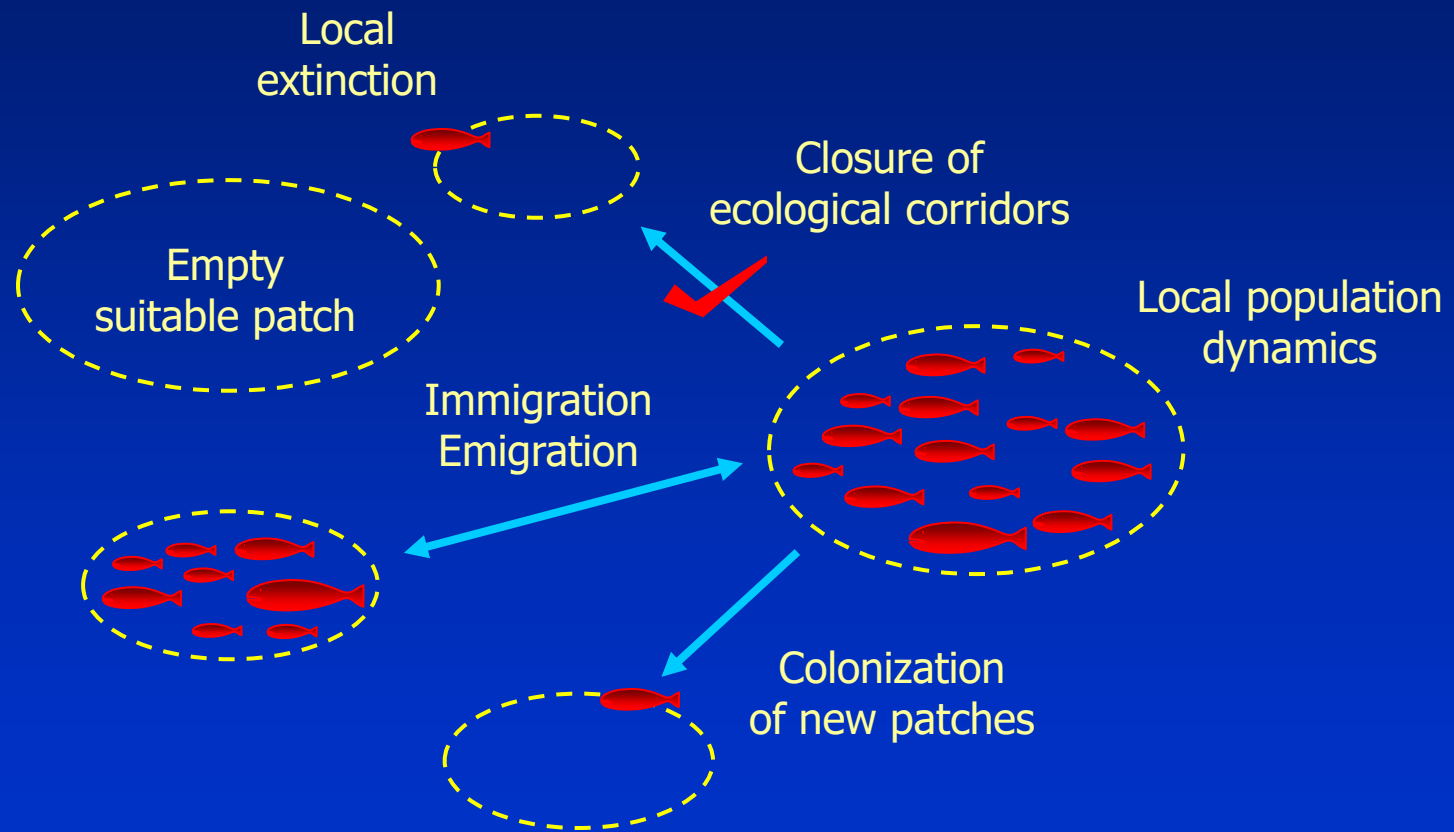
“carrying capacity”  
of the metapopulation

$$P^* = 1 - e/c$$

The metapopulation persists only if  $c/e > 1$

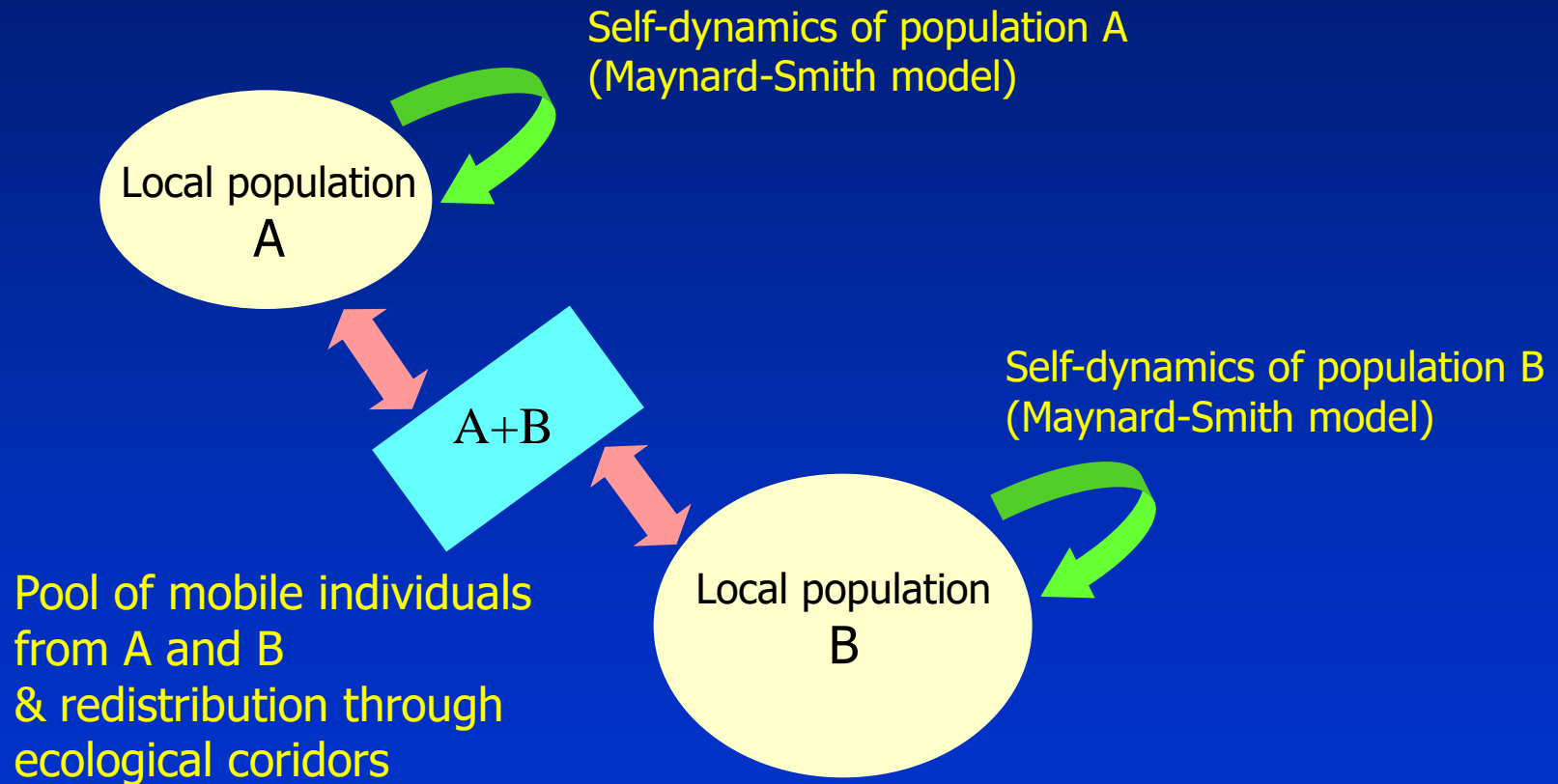
# METAPOPULATION DYNAMICS

## Spatially explicit models



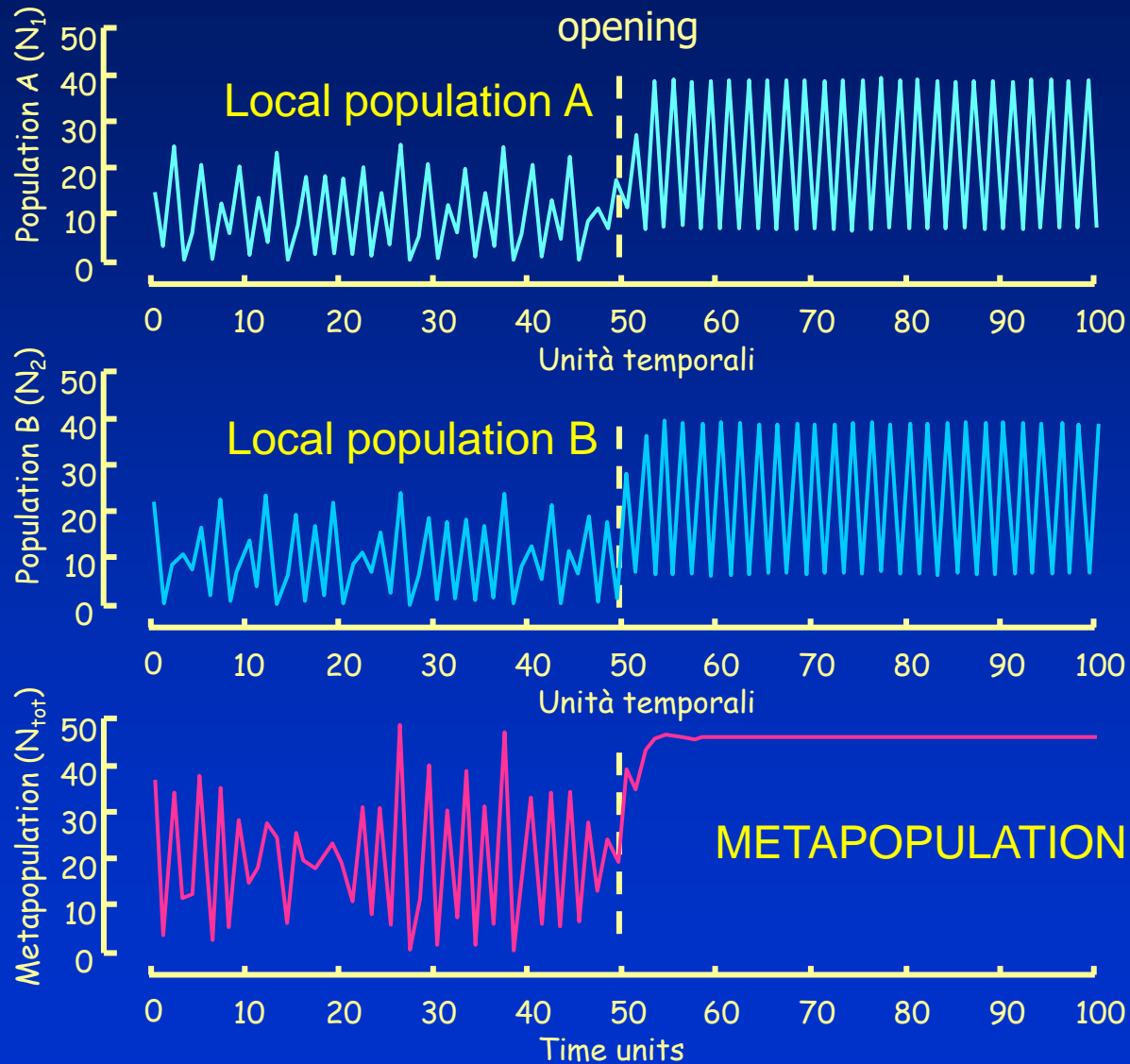
# METAPOPULATION DYNAMICS

The spatially explicit Hanski model: source-sink populations





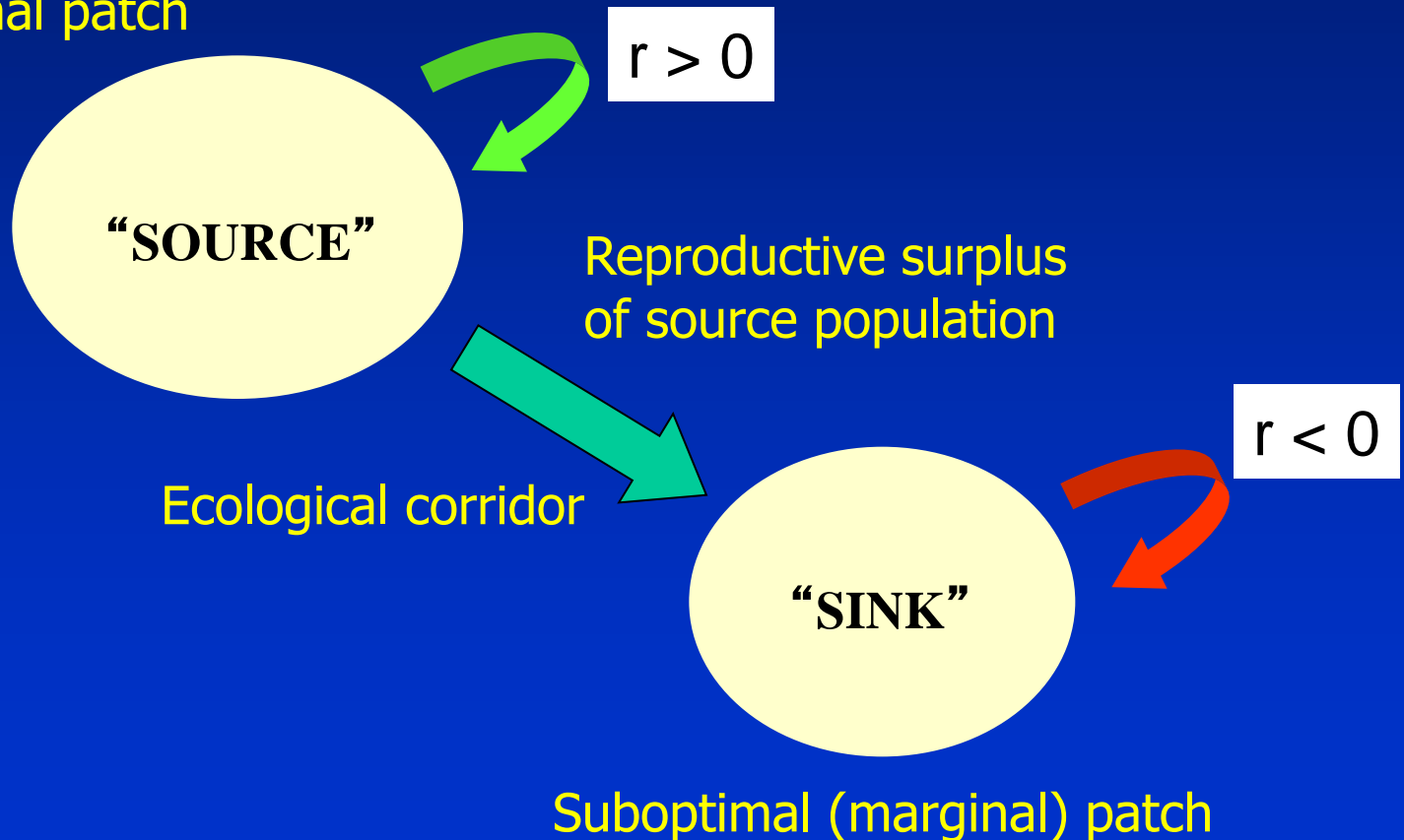
# METAPOPULATION DYNAMICS



# METAPOPULATION DYNAMICS

The spatially explicit Hanski model: source-sink populations

Optimal patch





# METAPOPULATION DYNAMICS

## The rescue effect

Reduction of Local  
Extinction  
(stochasticity & inbreeding)

