

Intraspecific Interactions

“Populační ekologie živočichů“

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Density-dependent growth

- ▶ includes all mechanisms of population growth that change with density
 - population structure is ignored
 - extrinsic effects are negligible
 - response of λ and r to N is immediate

- ▶ λ and r decrease with population density either because natality decreases or mortality increases or both
 - negative feedback of the 1st order

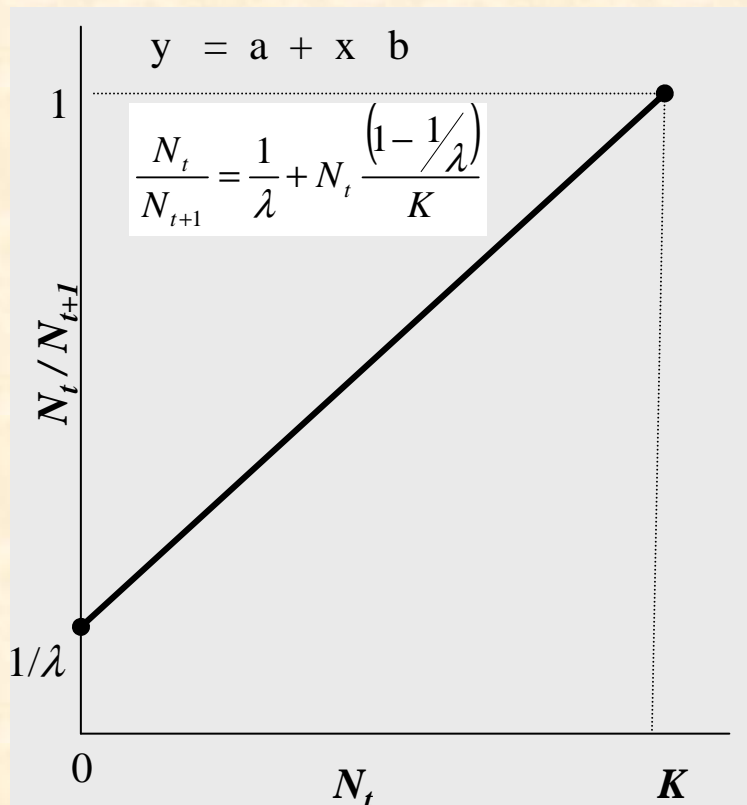
- ▶ K .. carrying capacity
 - upper limit of population growth where $\lambda = 1$ or $r = 0$
 - is a constant

Discrete (difference) model

- there is linear dependence of λ on N

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

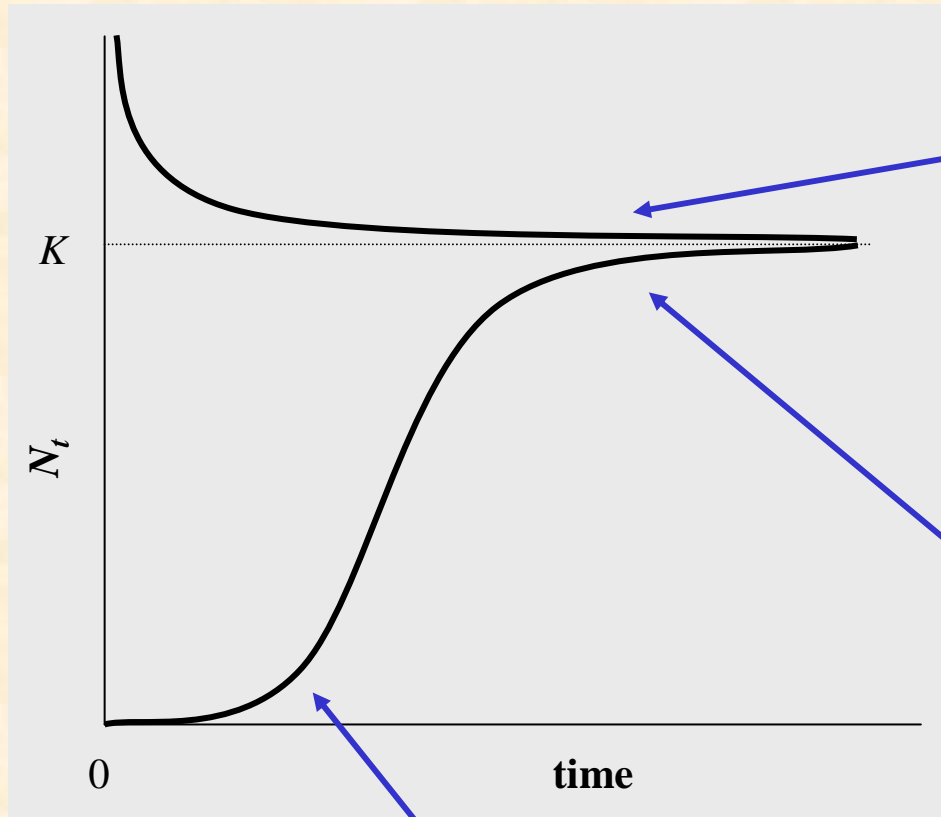
$$\frac{N_t}{N_{t+1}} = \frac{1}{\lambda}$$



$$N_{t+1} = \frac{N_t \lambda}{1 + \frac{(\lambda - 1)N_t}{K}}$$

if $a = \frac{\lambda - 1}{K}$ then

$$N_{t+1} = \frac{N_t \lambda}{1 + a N_t}$$



when $N_t > K$ then

$$\frac{\lambda}{1 + aN_t} < 1$$

- population returns to K

when $N_t \rightarrow K$ then

$$\frac{\lambda}{1 + aN_t} \approx 1$$

- density-dependent control
- S-shaped (sigmoid) growth

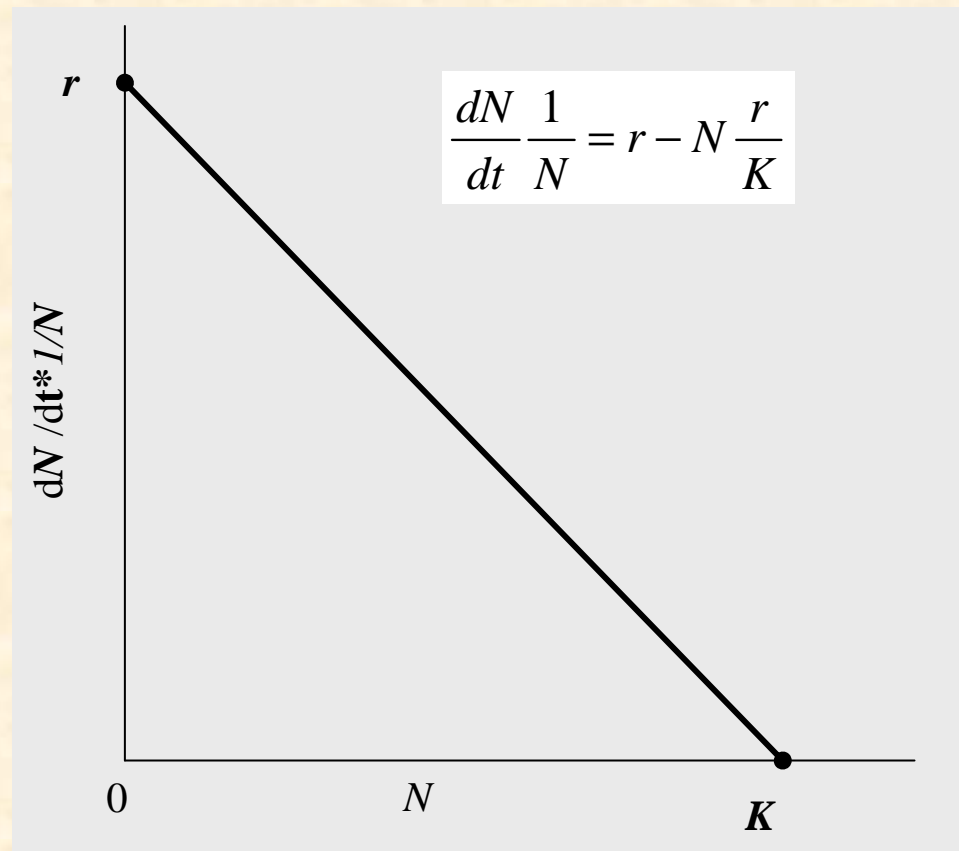
when $N_t \rightarrow 0$ then

$$\frac{\lambda}{1 + aN_t} \approx \lambda$$

- no competition
- exponential growth

Continuous (differential) model

- ▶ logistic growth
- ▶ first used by Verhulst (1838) to describe growth of human population
- there is linear dependence of r on N



$$\frac{dN}{dt} \frac{1}{N} = r - N \frac{r}{K}$$

$$\frac{dN}{dt} = Nr \rightarrow \frac{dN}{dt} \frac{1}{N} = r$$

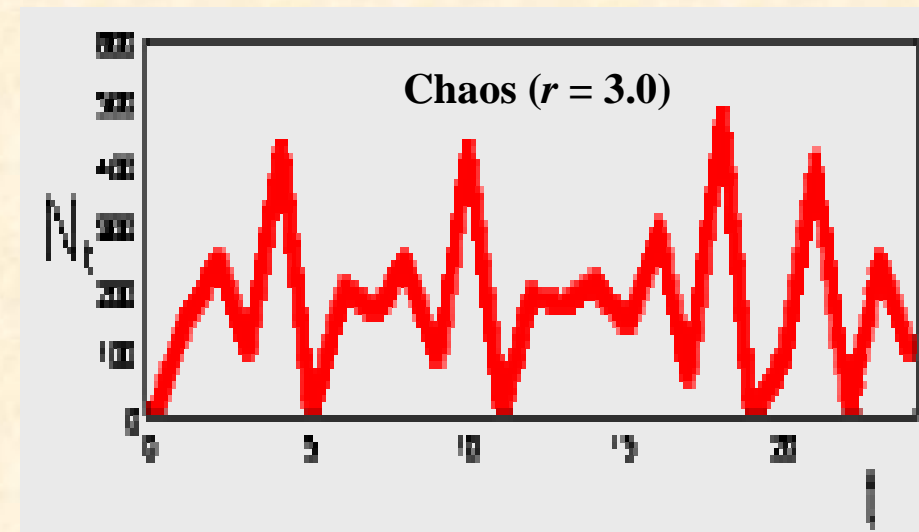
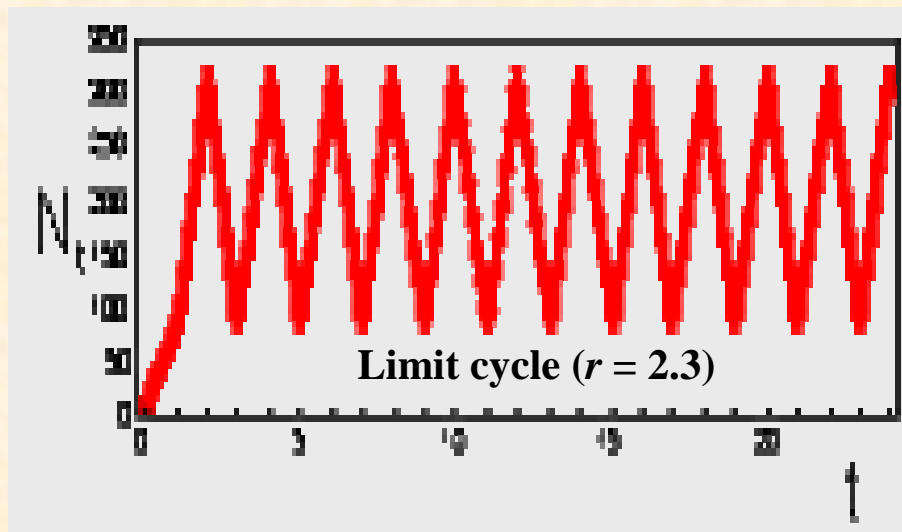
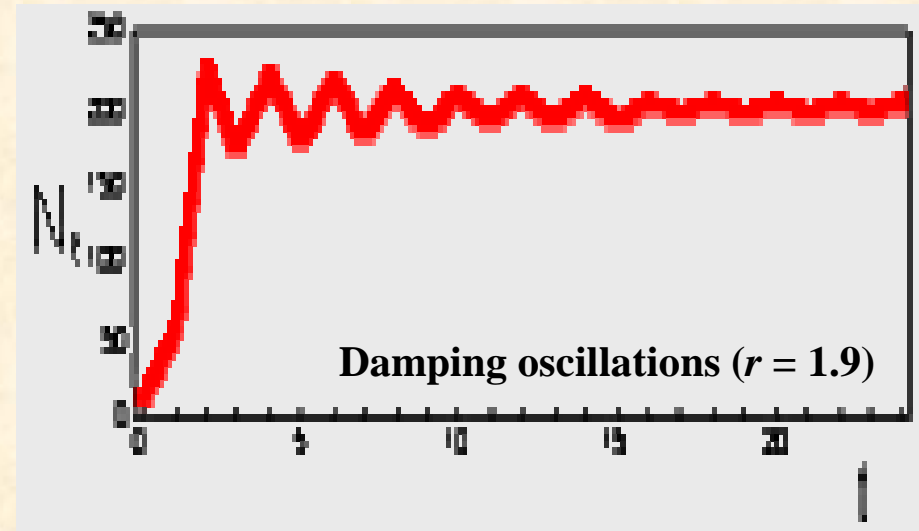
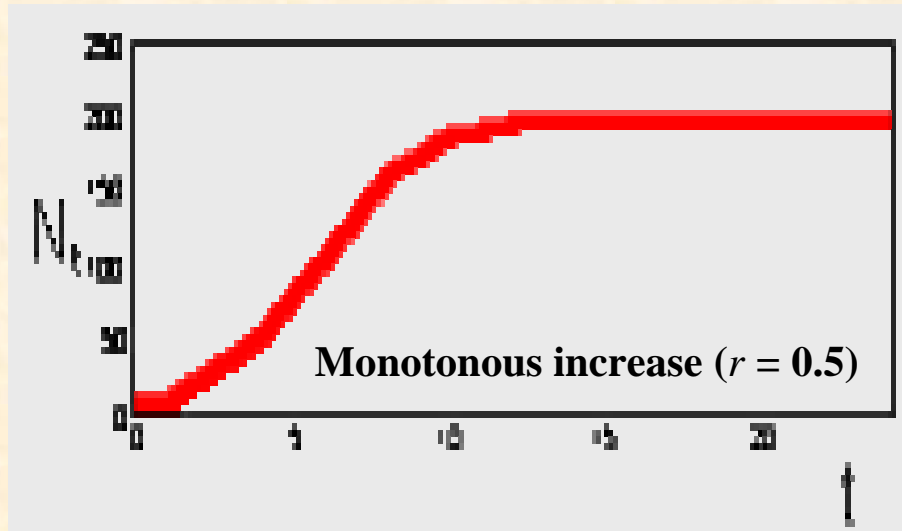
- when $N \rightarrow K$ then $r \rightarrow 0$

$$\frac{dN}{dt} = Nr \left(1 - \frac{N}{K} \right)$$

Solution of the differential equation

$$N_t = \frac{KN_0}{(K - N_0)e^{-rt} + N_0}$$

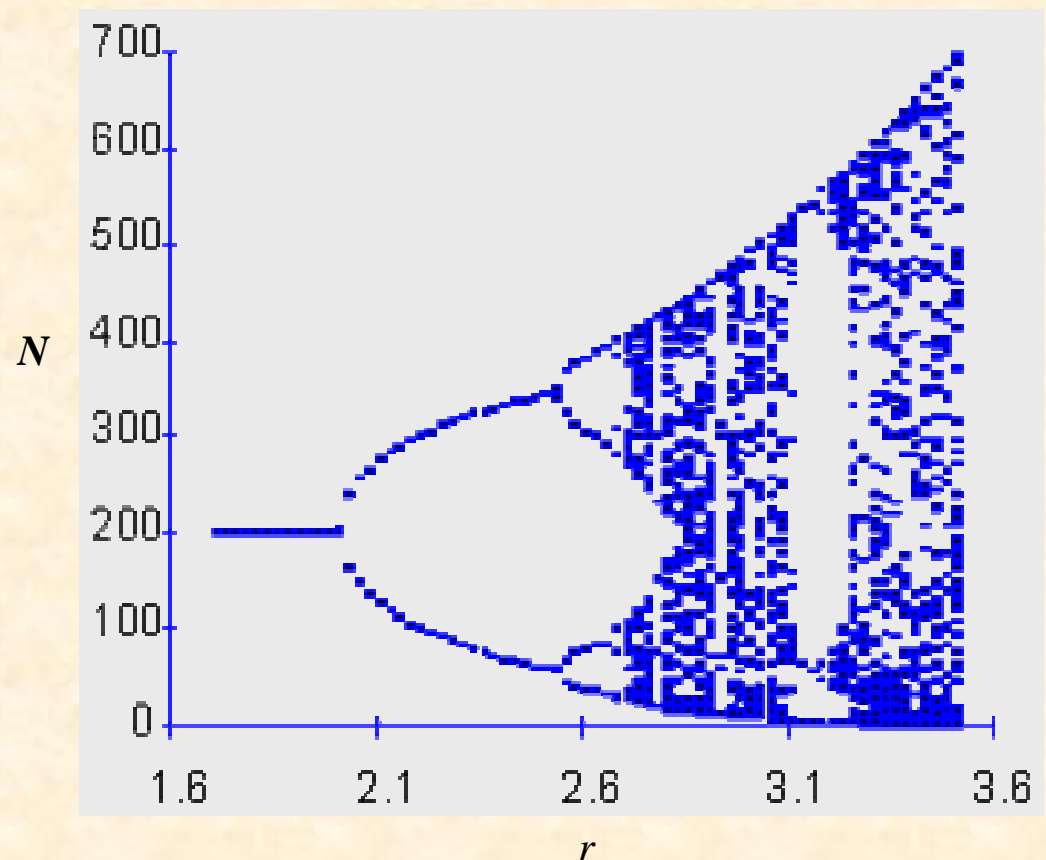
Examination of the logistic model



Model equilibria

1. $N = 0$.. unstable equilibrium
2. $N = K$.. stable equilibrium .. if $0 < r < 2$
 - ▶ “Monotonous increase” and “Damping oscillations” has a stable equilibrium
 - ▶ “Limit cycle” and “Chaos” has no equilibrium

- $r < 2$.. stable equilibrium
- $r = 2$.. 2-point limit cycle
- $r = 2.5$.. 4-point limit cycle
- $r = 2.692$.. chaos
 - ▶ chaos can be produced by deterministic process
 - ▶ density-dependence is stabilising only when r is rather low



Observed population dynamics

a) yeast (logistic curve)

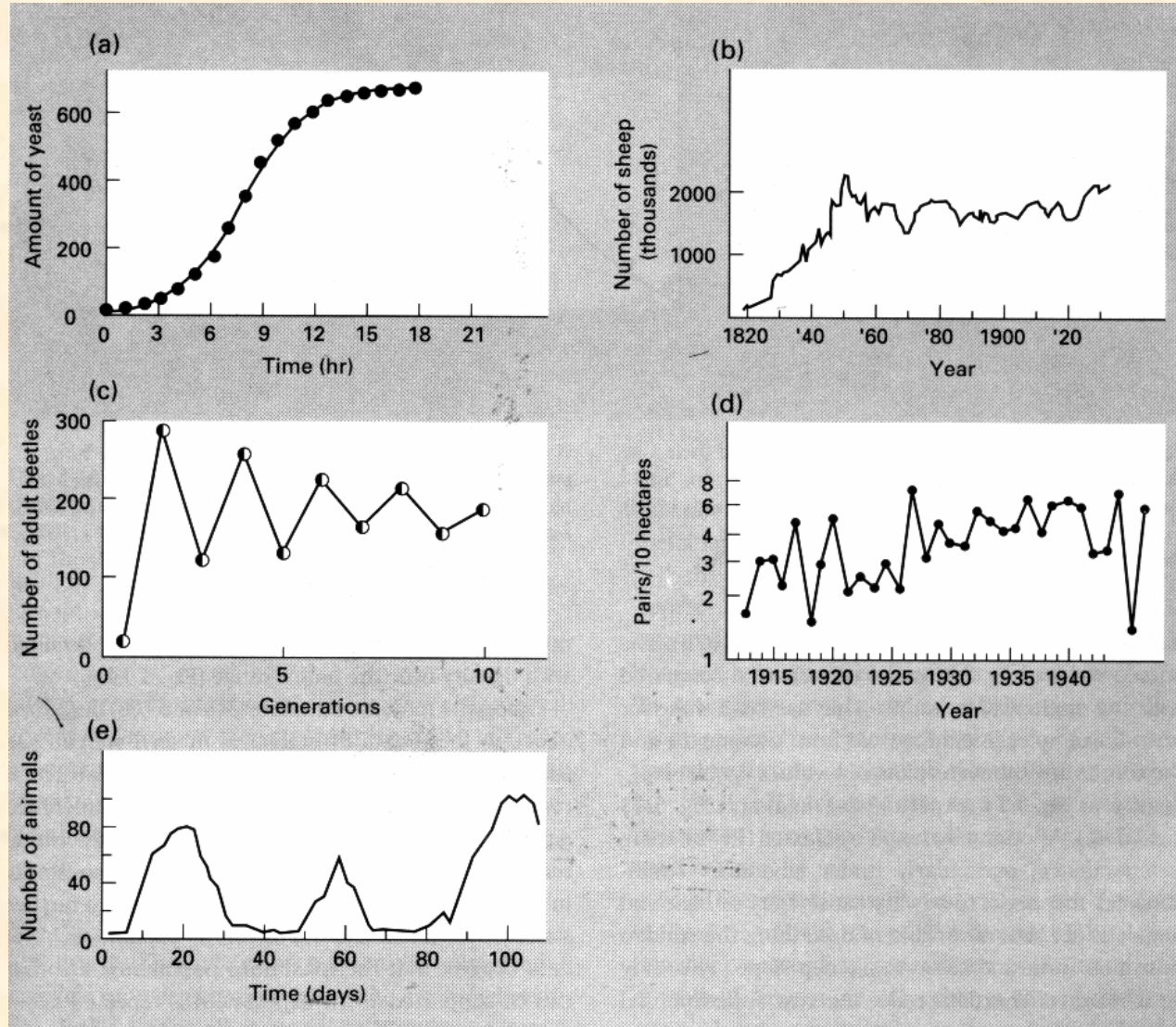
b) sheep (logistic curve with oscillations)

c) *Callosobruchus* (damping oscillations)

d) *Parus* (chaos)

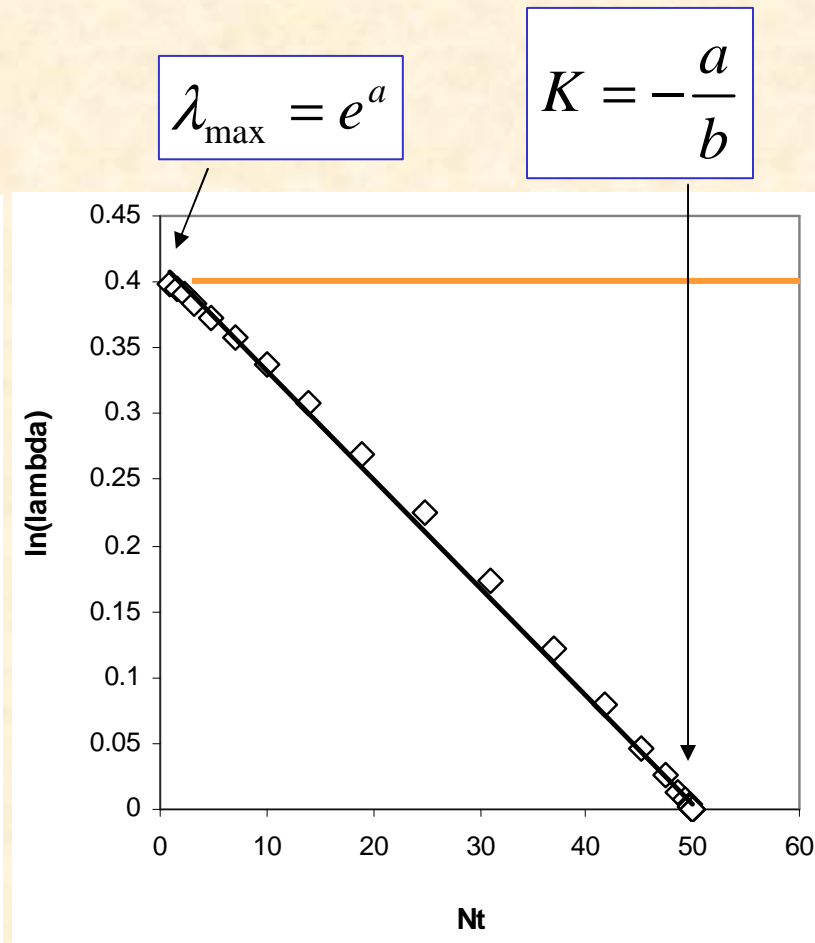
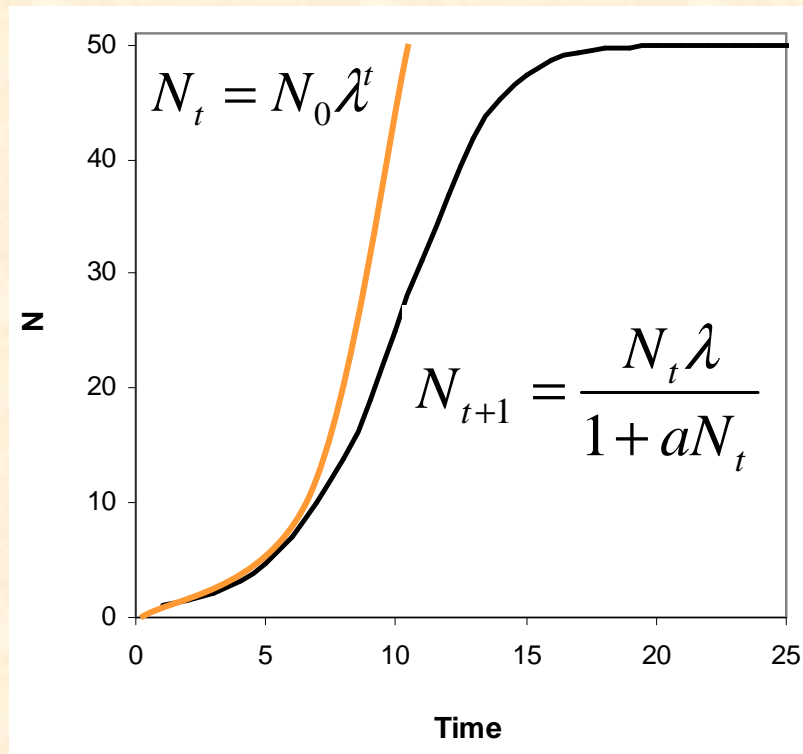
e) *Daphnia*

▶ of 28 insect species in one species chaos was identified, one other showed limit cycles, all other were in stable equilibrium



Evidence of DD

- ▶ in case of density-independence λ is constant – independent of N
- ▶ in case of DD λ is changing with N : $\ln(\lambda) = a - bN_t$
- ▶ plot $\ln(\lambda)$ against N_t
- ▶ estimate λ and K



General logistic model

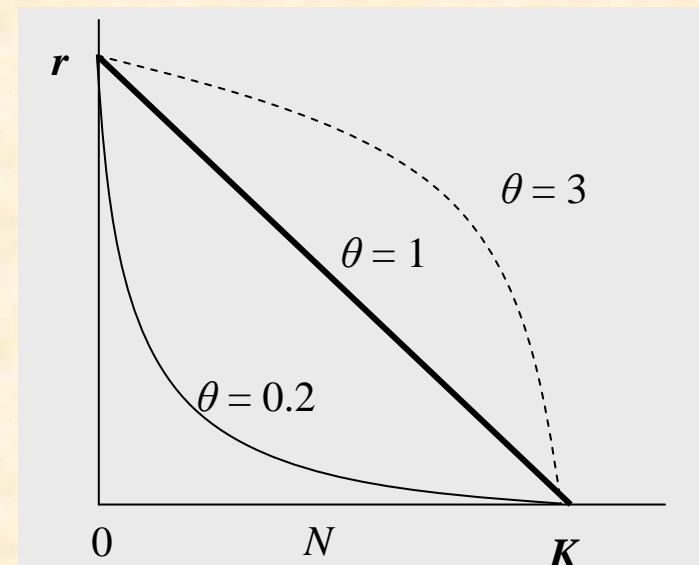
- ▶ Hassell (1975) proposed general model for DD
- r is not linearly dependent on N

$$N_{t+1} = \frac{N_t \lambda}{(1 + aN_t)^\theta}$$

$$\frac{dN}{dt} = rN \left(1 - \left(\frac{N}{K} \right)^\theta \right)$$

where θ .. the strength of competition

- ▶ $\theta \gg 1$.. scramble competition (over-compensation), strong DD, leads to fluctuations around K
- ▶ $\theta = 1$.. contest competition (exact compensation), stable density
- ▶ $\theta < 1$.. under-compensation
- weak DD, population will return to K



Models with time-lags

- ▶ species response to resource change is not immediate (as in case of hunger) but delayed due to maternal effect, seasonal effect, predator pressure
- ▶ appropriate for species with long generation time where reproductive rate is dependent on the past (previous generations)
- ▶ time lag (d or τ) .. negative feedback of the 2nd order

discrete model

$$N_{t+1} = \frac{N_t \lambda}{1 + aN_{t-d}}$$

continuous model

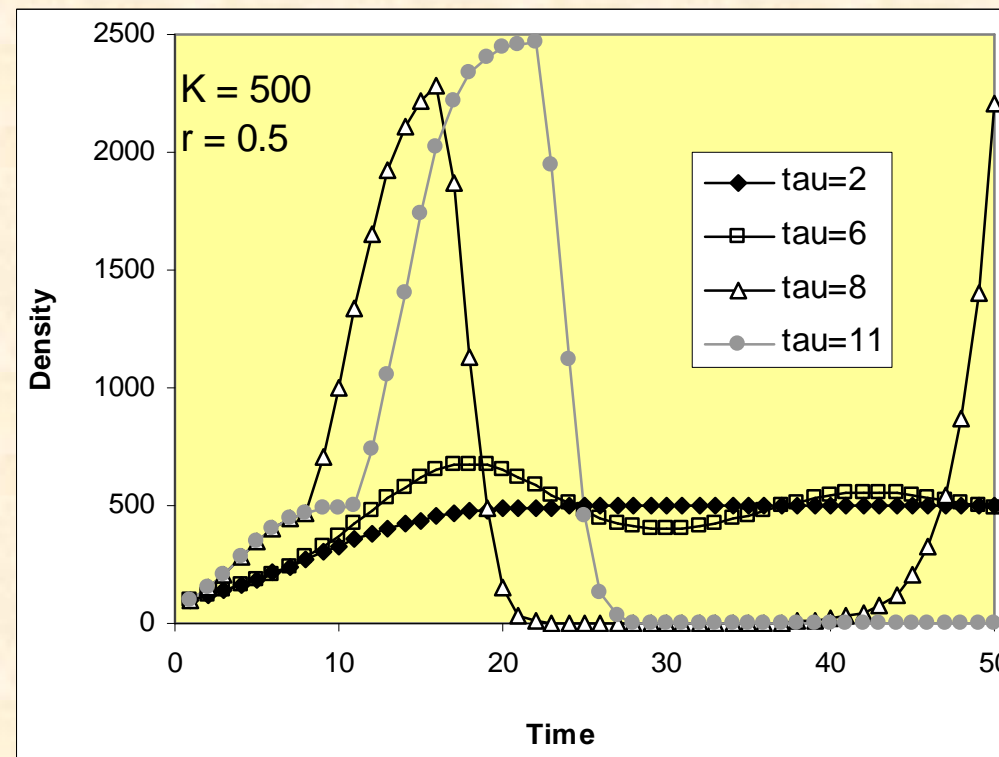
$$\frac{dN}{dt} = N_t r \left(1 - \frac{N_{t-\tau}}{K} \right)$$

- ▶ many populations of mammals cycle with 3-4 year periods
- ▶ time-lag provokes fluctuations of certain amplitude at certain periods
- ▶ period of the cycle in continuous model is always 4τ

Solution of the continuous model:

$$N_{t+1} = N_t e^{r \left(1 - \frac{N_{t-\tau}}{K} \right)}$$

- $r \tau < 1 \rightarrow$ monotonous increase
- $r \tau < 3 \rightarrow$ damping fluctuations
- $r \tau < 4 \rightarrow$ limit cycle fluctuations
- $r \tau > 5 \rightarrow$ extinction

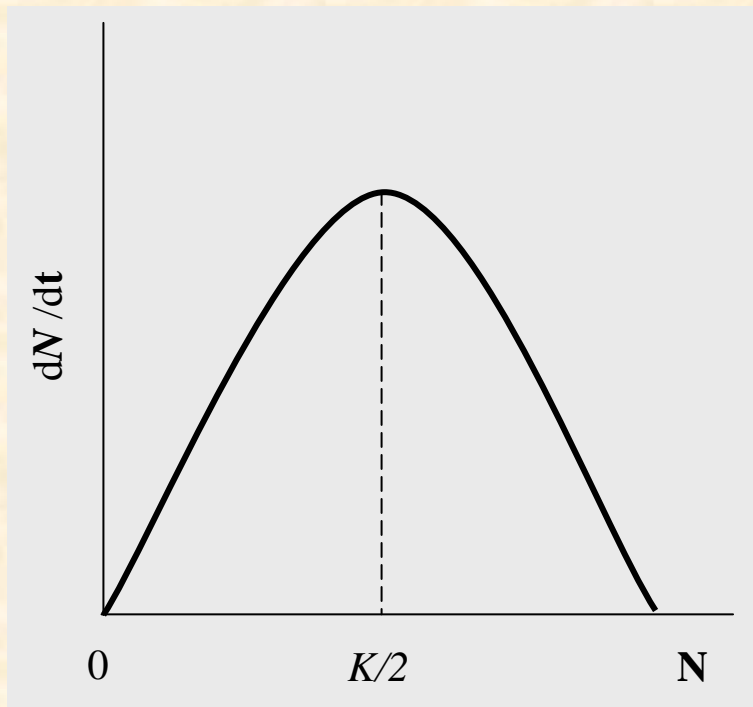


Harvesting

► Maximum Sustainable Harvest (MSH)

- to harvest as much as possible with the least negative effect on N
- ignore population structure
- ignore stochasticity

$$\frac{dN}{dt} = Nr \left(1 - \frac{N}{K} \right) = 0$$



local maximum: $N^* = \frac{K}{2}$

Amount of MSH (V_{\max}):
at $K/2$:

$$\text{MSH} = \frac{rK}{4}$$

► Robinson & Redford (1991)

- Maximum Sustainable Yield (MSY)

$$\text{MSY} = a \left(\frac{\lambda K - K}{2} \right)$$

where $a = 0.6$ for longevity < 5
 $a = 0.4$ for longevity $= (5, 10)$
 $a = 0.2$ for longevity > 10

► Surplus production (catch-effort) models

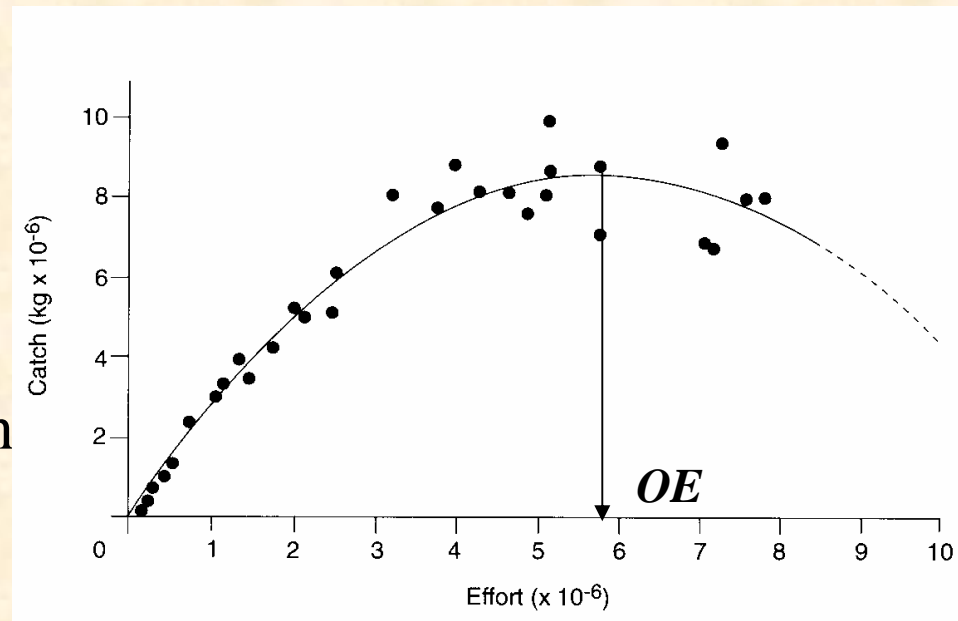
- when r , λ and K are not known

- effort and catch over several years is known

- Schaefer quadratic model

$$\text{catch} = \alpha + \beta E + \gamma E^2$$

- local maximum of the function identifies optimal effort (OE)



Alee effect

▶ individuals in a population may cooperate in hunting, breeding – positive effect on population increase

▶ Allee (1931) – discovered inverse DD

- genetic inbreeding – decrease in fertility

- demographic stochasticity – biased sex ratio

- small groups – cooperation in foraging, defence, mating, thermoregulation

▶ K_2 .. extinction threshold,

- unstable equilibrium

▶ population increase is slow at low density but fast at higher density

$$\frac{dN}{dt} = Nr \left(1 - \frac{N}{K_1} \right) \left(\frac{N}{K_2} - 1 \right)$$

