Populations

“Populační ekologie živočichů“

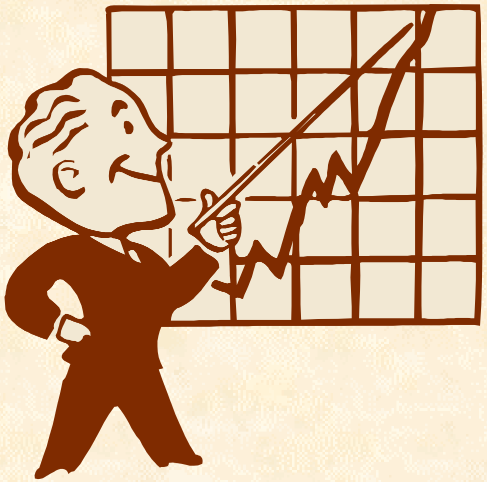
Stano Pekár

Population Ecology

- a major sub-field of ecology which deals with description and the dynamics of populations within species, and the interactions of populations with environmental factors

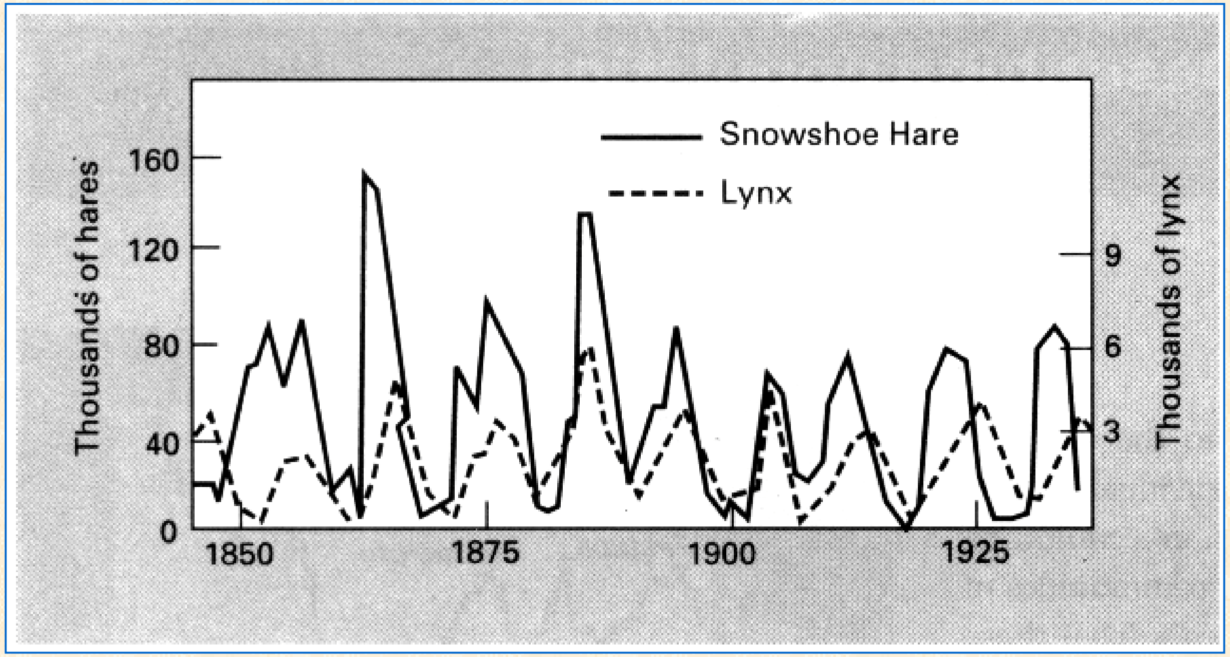
- expanding field (Price & Hunter 1995):
  - populations 52 %, communities 9 %, ecosystems 10 %

- main focus on
  - **Demography** = description of populations that gave rise to **Life-history theory**
  - **Population dynamics** = describe the change in the numbers of individuals in a population



‣ populations of member species may show a range of dynamic patterns in time and space

‣ central question: “WHAT DOES REGULATE POPULATIONS?“



Change in abundance of *Lynx* and *Lepus* in Canada

‣ density independent factors, food supply, intraspecific competition, interspecific competition, predators, parasites, diseases

Utilization

1. Conservation biology

- World Conservation Union (IUCN) uses several criterions (population size, generation length, population decline, fragmentation, fluctuation) to assess species status

- by means of Population viability analysis (PVA) estimates the extinction probability of a taxon based on known life history, habitat requirements, threats and any specified management options

Saiga tatarica

critical: 50% probability of extinction within 5 years

endangered: 20% probability of extinction within 20 years

vulnerable: 10% probability of extinction within 100 years

2. Biological control

- to assess ability of a natural enemy to control a pest

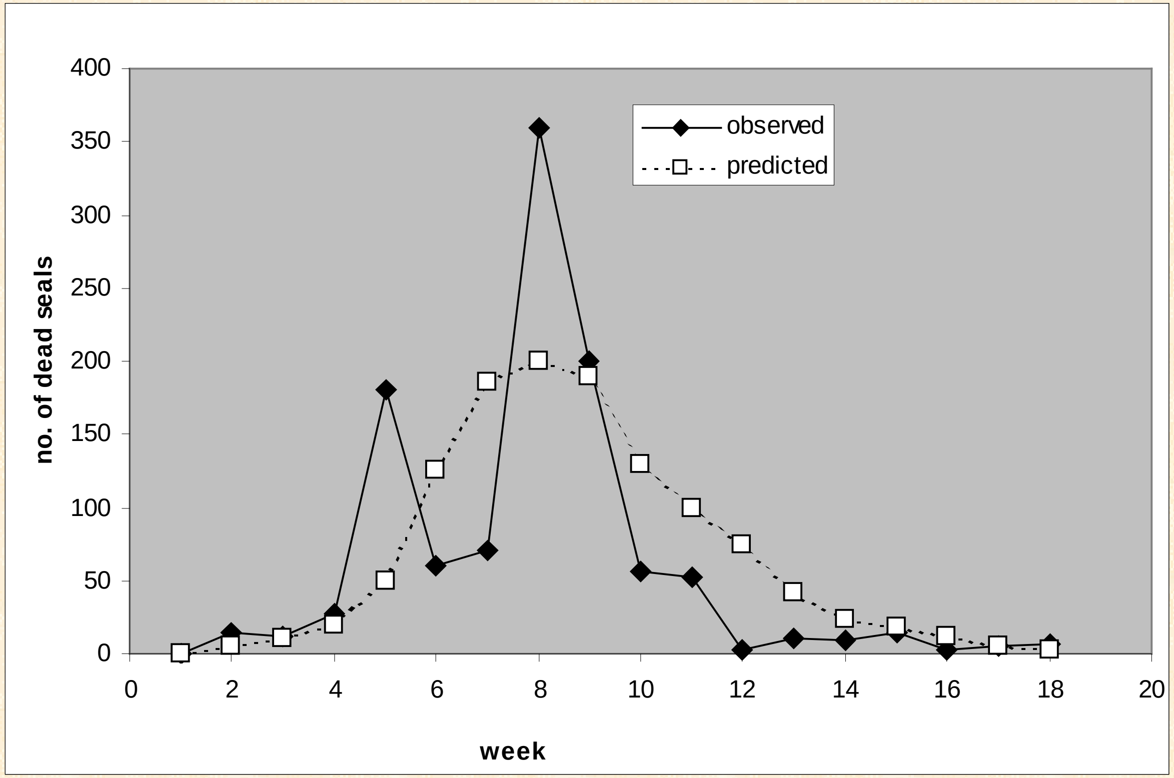
Rodolia cardinalis (Coccinellidae) eating *Icerya purchasi* (Hemiptera)

- in 1880 *Icerya purchasi* was causing infestations so severe in California citrus groves that growers were burning their trees
- in winter 1888-1889 *Rodolia cardinalis* and *Cryptochaetum* were introduced into California from Australia, growers took the initiative and applied the natural enemies themselves
- by fall 1889 the pest was completely controlled
- *Rodolia cardinalis* has been exported to many other parts of the world
- the interest of growers and the public in this project was due to its spectacular success: the pest itself was showy and its damage was obvious and critical; the destruction of the pest and the recovery of the trees was evident within months

3. Epidemiology

- to predict the diffusion of a disease and to plan a vaccination
- phocine distemper virus was identified in 1988 and caused death of 18 000 common seals in Europe
- during 4 months the disease travelled from Denmark to the UK
- the population of common seals in the UK declined by about half

Grenfell et al. (1992)



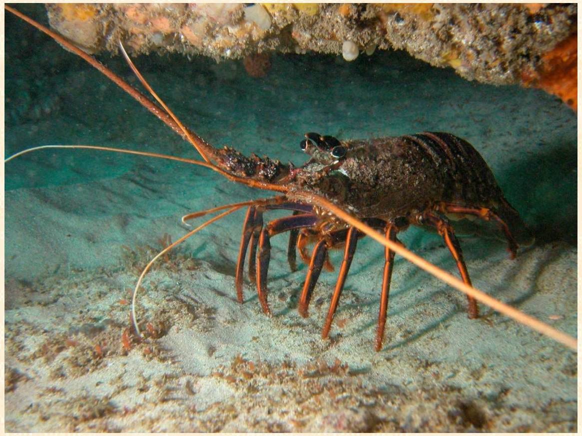
Observed and predicted epidemic curves for virus in common seals in the UK

4. Harvesting

‣ to predict maximum sustainable harvest in fisheries and forestry but also used to regulate whale or elephant hunting

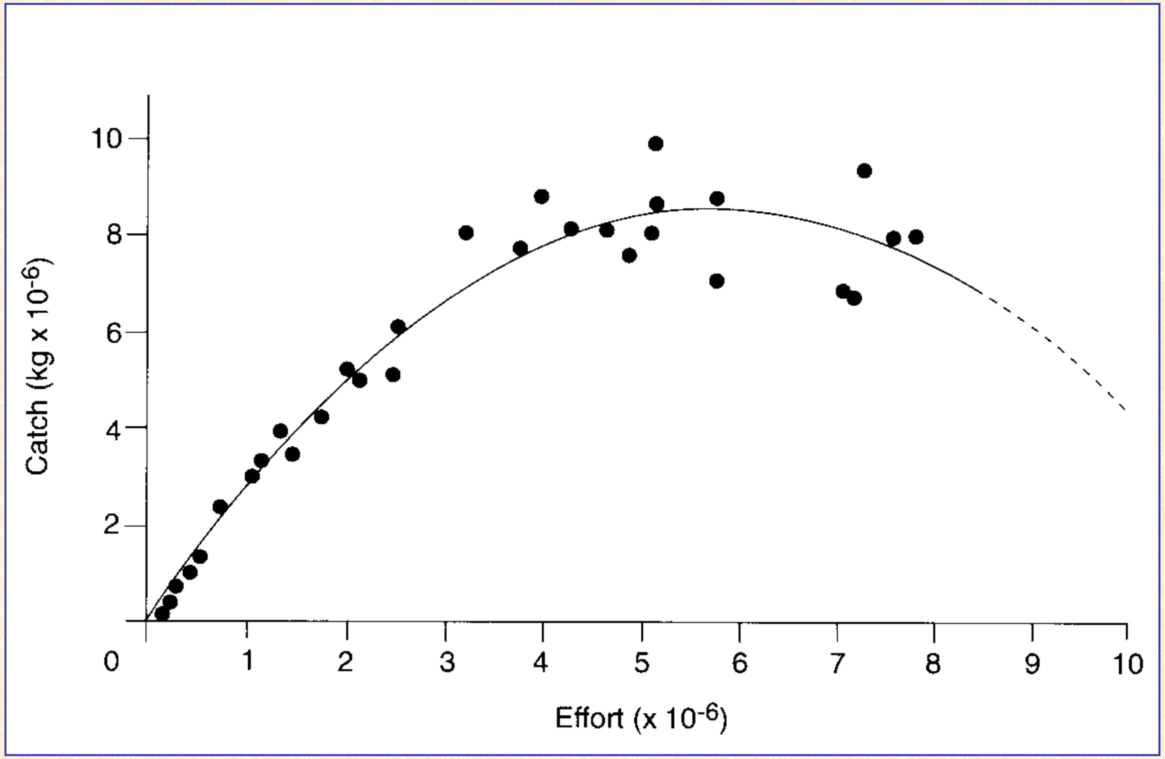
‣ when population is growing most rapidly (*K*/2) then part of population can be harvested without causing extinction

Relationship between capture and fishing effort

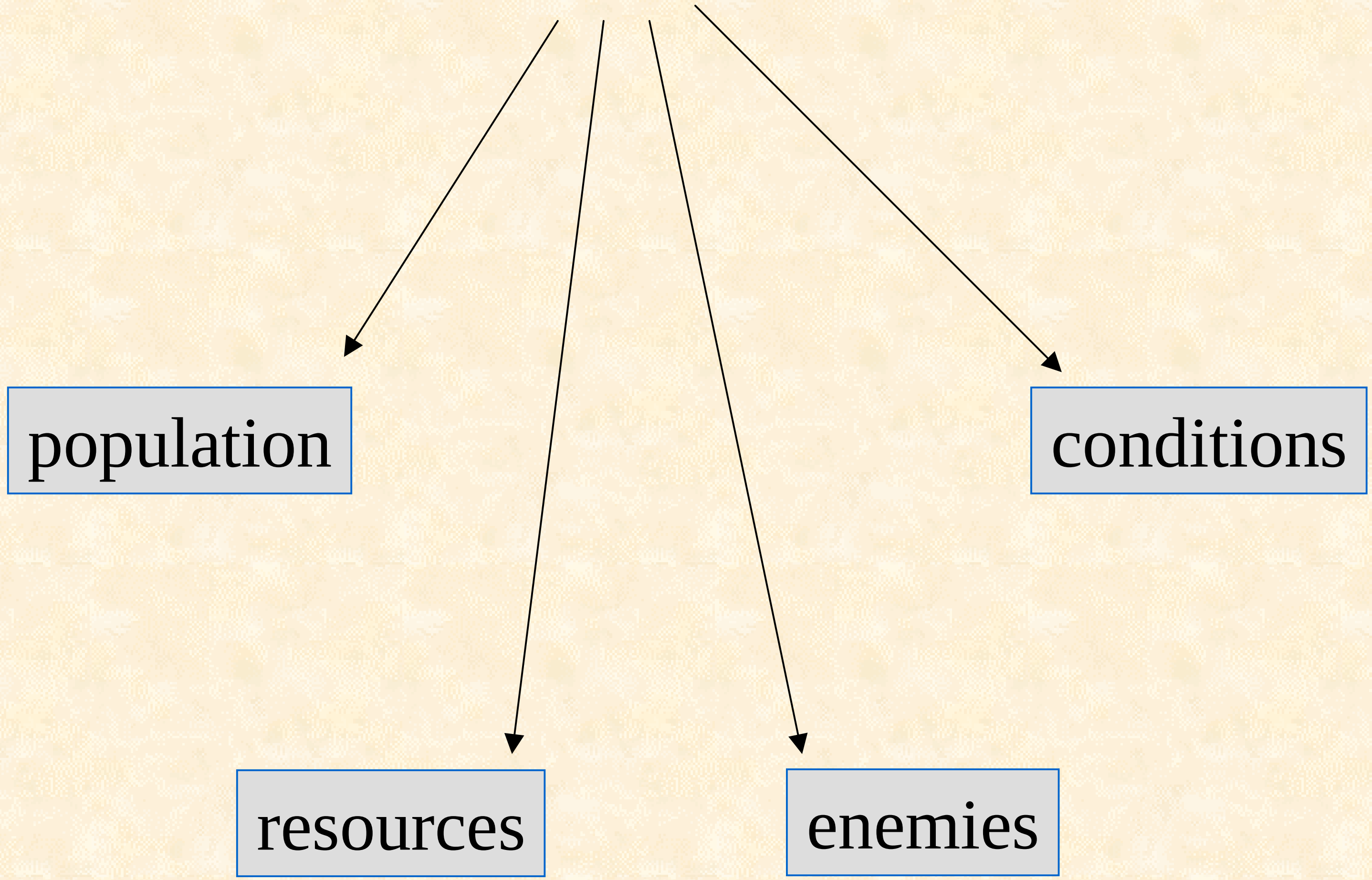


Panulirus cygnus

Beddington (1979)



Population + environment = population system



Population

- molecules → organels → cells → tissues → organs → organ systems → organisms → **populations** → communities → ecosystem → landscape → biosphere
- a group of organisms of the same species that occupies a particular area at the same time and is characterised by an average characteristic (e.g., mortality)
- characteristics:

Individual	→	**Population**
Developmental stage		Stage structure
Age		Age structure
Size		Size structure
Sex		Sex ratio
Territorial behaviour		Spatial distribution

Events & Processes

Event – an identifiable change in a population

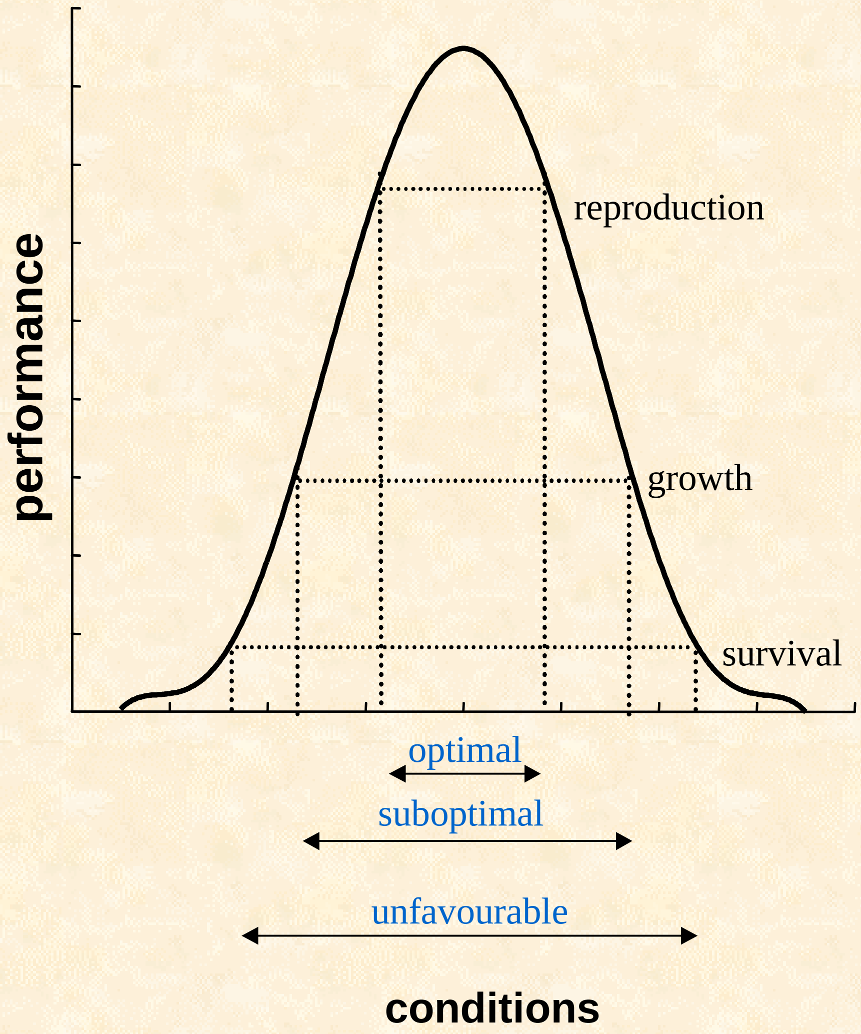
Process – a series of identical events

- ***rate*** of a process – number of events per unit time

Event	**Process**
Birth [inds]	Natality (birth rate)
Death [inds]	Mortality (mortality rate)
Increment [gram]	Growth (growth rate)
Increment [number]	Population increase (rate of increase)
Acquisition of food [gram]	Consumption (consumption rate)

Conditions

- inherent characteristics of the evironment (pH, salinity, temperature, moisture, wind speed, etc.)
- not modified by populations
- not consumed by population
  $\Rightarrow$ no feedback mechanisms
  $\Rightarrow$ do not regulate population size
- limit population size



Resources

- any entity whose quantity is reduced (food, space, water, minerals, oxygen, sun radiation, etc.)
- modified (reduced) by populations
- defended by individuals (interference competition)
- regulate population size
- non-renewable resources - space

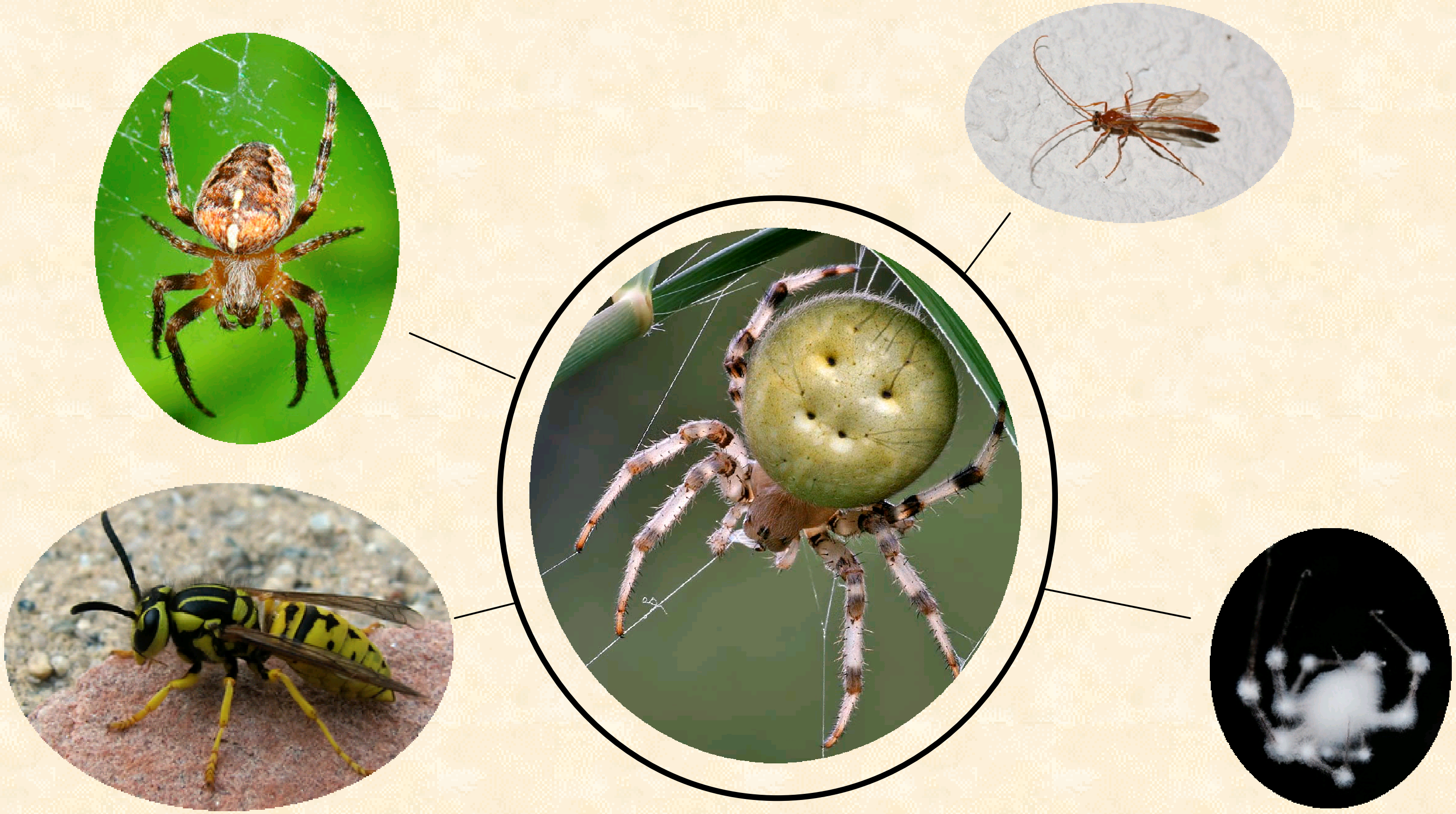
Renewable resources

- regeneration centre outside the population system $\Rightarrow$ no effect of the consumer (e.g., oxygen, water)

- regeneration centre inside of the population system $\Rightarrow$ influenced by the consumer (e.g., prey)

Enemies

- competitors, predators, parasites, pathogens
- negative effect on the population
- top-down regulation of the population



Population Estimates

Absolute

- number of individuals per unit area
- number of individuals per unit of habitat (leaf, plant, host)
- sieving, sweeping, extraction, etc.

Relative

- number of individuals
- trapping, fishing, pooting

Capture-recapture method

Assumptions:

- marked individuals are not affected and marks will not be lost
- marked animals become mixed in the population
- all individuals have same probability of capture
- capture time must be short

Closed population

- population do not change over sampling period - no death, births, immigration, emigration

Petersen-Lincoln estimator:

N - number of individuals in population

a - total number of marked individuals

r - total number of recaptured marked individuals

n - total number of individuals recaptured

$$N = \frac{an}{r}$$

Variance: $v = \dfrac{a^2 n(n-r)}{r^3}$

Open population

- changes due to death, births, immigration, emigration
- at least 3 sampling periods

Stochastic Jolly-Seber method

N_i - estimate of population on day

a_i - number of marked individuals on day i

n_i - total number of individuals captured on day i

r_i - sum of recaptured marked individuals on day i

Z_i - sum of marked individuals before day i

R_i - sum of all marked individuals on day i

$$N_i = \frac{M_i n_i}{r_i} \quad \text{where} \quad M_i = \frac{a_i Z_i}{R_i} + r_i$$

Population Growth

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Ecological Models

- aim: to simulate (predict) what can happen
- models are tested by comparison with observed dynamic

- realistic models - complex (many parameters), realistic, used to simulate real situations
- strategic models - simple (few parameters), unrealistic, used for understanding of model behaviour

- a model should be:

1. a satisfactory description of diverse systems
2. an aid to enlighten aspects of population dynamics
3. a system that can be incorporated into more complex models

- deterministic models - everything is predictable
- stochastic models - including random events

▸ <u>discrete models:</u>

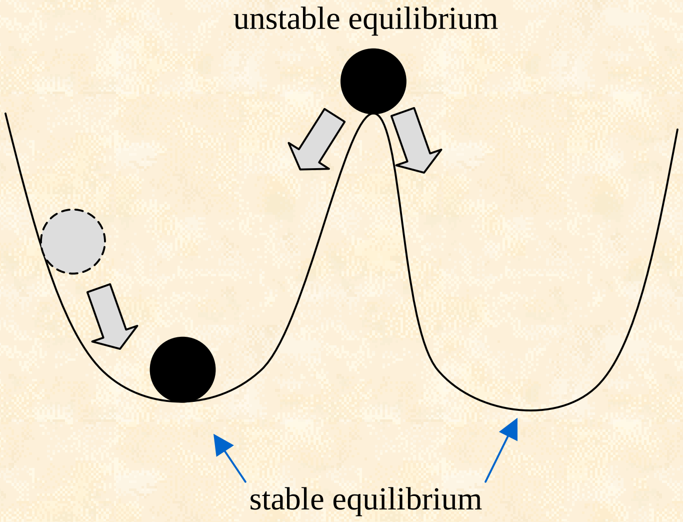
- time is composed of discrete intervals or measured in generations
- used for populations with synchronised reproduction (annual species)
- modelled by difference equations

▸ <u>continuous models:</u>

- time is continual (very short intervals) thus change is instantaneous
- used for populations with asynchronous and continuous overlapping reproduction
- modelled by differential equations

STABILITY

▸ stable equilibrium is a state (population density) to which a population will move after a perturbation



Population processes

- focus on rates of population processes

- number of cockroaches in a living room increases:

- influx of cockroaches from adjoining rooms → immigration [***I***]
- cockroaches were born → birth [***B***]

- number of cockroaches declines:

- dispersal of cockroaches → emigration [***E***]
- cockroaches died → death [***D***]

Blatta orientalis

$$N_{t+1} = N_t + I + B - D - E$$

- population increases if $I + B > E + D$

- rate of increase is a summary of all events ($I + B - E - D$)

- growth models are based on ***B*** and ***D***
- spatial models are based on ***I*** and ***E***

Density-independent Population Growth

Assumptions:

- immigration and emigration are ignored
- all individuals are identical
- reproduction is asexual
- resources are infinite

Discrete (difference) model

- for population with discrete generations (annual reproduction)
- if births and deaths do not depend on population size
- exponential (geometric) growth
- Malthus (1834) realised that any species can potentially increase in numbers according to a geometric series

N_0 .. initial density
b .. birth rate (per capita)
d .. death rate (per capita)

$$\Delta N = bN_{t-1} - dN_{t-1}$$

$$N_t - N_{t-1} = (b-d)N_{t-1}$$

$$N_t = (1+b-d)N_{t-1}$$

where $1+b-d = \lambda$

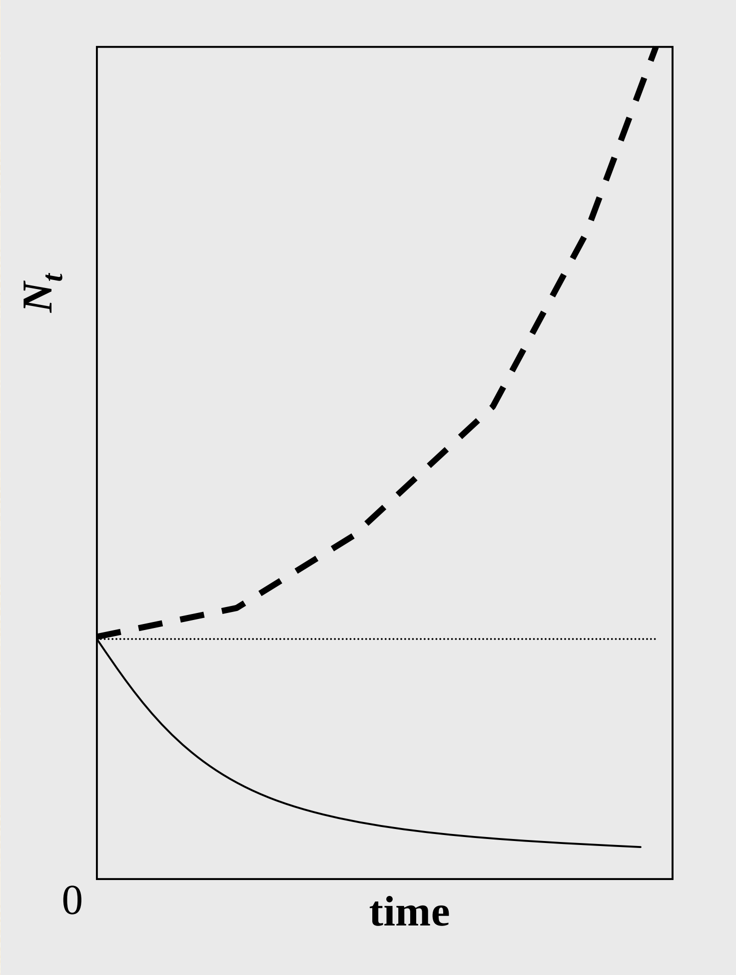
$$N_t = N_{t-1}\lambda$$

- population number in generations ***t*** is equal to

$$N_2 = N_1\lambda = N_0\lambda\lambda$$

$$\boxed{N_t = N_0\lambda^t}$$

$\lambda < 1$ .. population declines
$\lambda > 1$ .. population increases
$\lambda = 1$ .. population does not change



- number of individuals is multiplied each time - the larger the population the larger the increase

λ = finite growth-rate, per capita rate of growth
λ = 1.23 .. 23% increase

R ..average of finite growth rates

$$R = \left(\prod_{i=1}^{t}\lambda_i\right)^{\frac{1}{t}} = (\lambda_1\lambda_2\ldots\lambda_t)^{\frac{1}{t}}$$

Continuous (differential) model

- populations that are continuously reproducing
- when change in population number is permanent

$$N_t = N_0 \lambda^t$$

$$\ln(N_t) = \ln(N_0) + t\ln(\lambda)$$

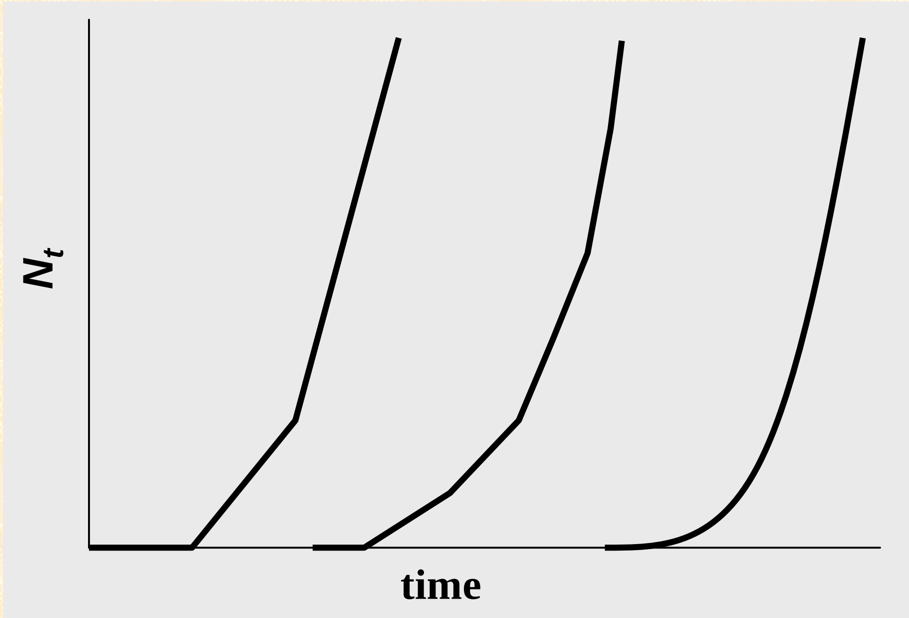
$$\ln(N_t) - \ln(N_0) = t\ln(\lambda)$$

$$\frac{dN}{dt}\frac{1}{N} = \ln(\lambda)$$

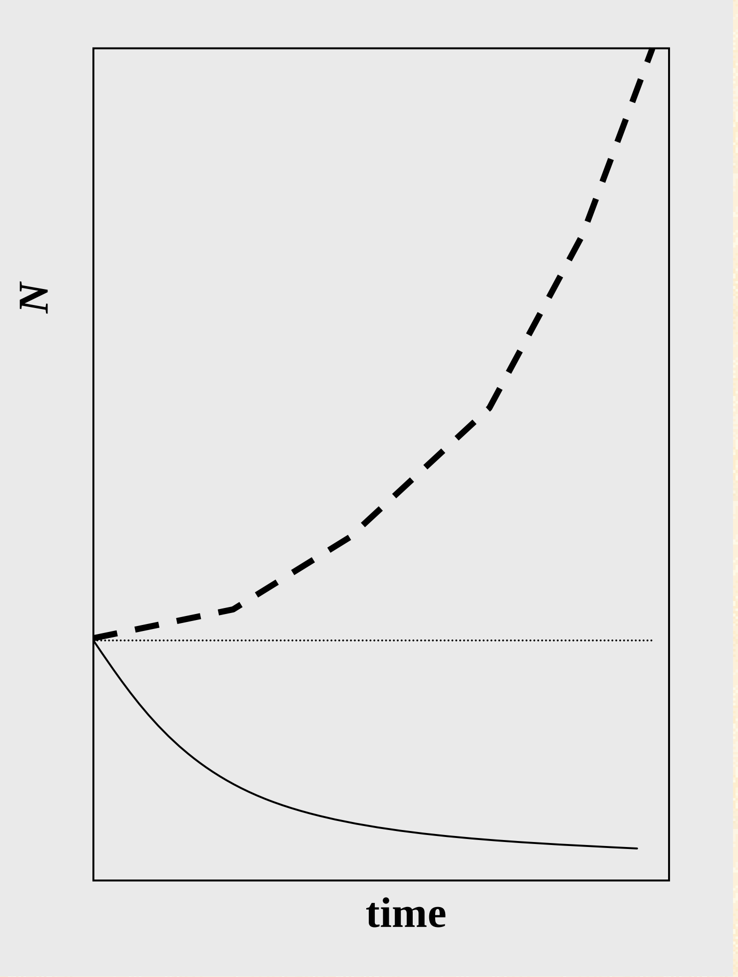
$$\frac{dN}{dt} = N\ln(\lambda)$$

if $r = \ln(\lambda)$ $\boxed{\frac{dN}{dt} = Nr}$

Comparison of discrete and continuous generations



r - intrinsic rate of natural increase,
instantaneous per capita growth rate



$r < 0$ .. population declines
$r > 0$ .. population increases
$r = 0$ .. population does not change

Solution of the differential equation:

- analytical or numerical

▸ at each point it is possible to determine the rate of change by differentiation (slope of the tangent)

▸ when t is large approximated by the exponential function

$$\frac{dN}{dt} = Nr$$

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

$$\int_0^T \frac{1}{N} dN = \int_0^T r dt$$

$$\ln(N_T) - \ln(N_0) = r(T - 0)$$

$$\ln\left(\frac{N_T}{N_0}\right) = rT$$

$$\frac{N_T}{N_0} = e^{rT}$$

$$\boxed{N_t = N_0 e^{rt}}$$

- doubling time: time required for a population to double

$$\boxed{t = \frac{\ln(2)}{r}}$$

r versus λ

$$N_t = N_0 \lambda^t \qquad N_t = N_0 e^{rt}$$

$$\lambda^t = e^{rt}$$

$$\boxed{r = \ln(\lambda)}$$

- r is symmetric around 0, λ is not

$r = 0.5$ ... $\lambda = 1.65$

$r = -0.5$ ... $\lambda = 0.61$

Cvičení z Populační ekologie

S. Pekár

podzim 2011

evropský sociální fond v ČR
EVROPSKÁ UNIE
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY
OP Vzdělávání pro konkurenceschopnost
UNIVERSITAS MASARYKIANA BRUNENSIS
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Excercise 1

Cockroaches were captured using traps with baits for 4 consecutive days. Each day the specimens were marked and released.

1. Estimate population density assuming closed population.
2. Estimate population density assuming open population.
3. Estimate average population size for both closed and open populations.

Capture				**Recapture day**		
Day	**ni**	**ai**	**1**	**2**	**3**	**ri**
1	60	58				
2	125	123	15			15
3	154	150	5	38		43
4	189	187	9	20	45	
Ri				58	45	
Zi+1			14	20		

$Z_2 = 14, Z_3 = 20$ $R_2 = 58, R_3 = 45$ $r_2 = 15, r_3 = 43$

Excercise 2

Population density of the true bugs *Coreus marginatus* was recorded for 10 years. Here are the densities:

160, 172, 188, 154, 176, 185, 168, 194, 170, 169

- Does population increase or decrease?
- What is the average population growth (R)?
- Project population for another 10 years using R and $N_0 = 90$.
- Simulate population growth for the next 20 years using observed finite-growth rates.

Excercise 3

Population density of the mite *Acarus siro* was recorded every 3 days during 28 days. The following densities were found:

165, 145, 139, 125, 105, 101, 88, 81, 73, 69

- What is the intrinsic rate of increase (*r*) and what was the initial density ?
- How long it takes for a population to decrease to half size?
- Project population growth for another 5 weeks using estimated *r* and $N_0 = 69$.
- What would be the estimated rate if you know the initial and final density?