Spatial Ecology

"Populační ekologie živočichů"

Stano Pekár

Spatial ecology - describes changes in spatial pattern over time

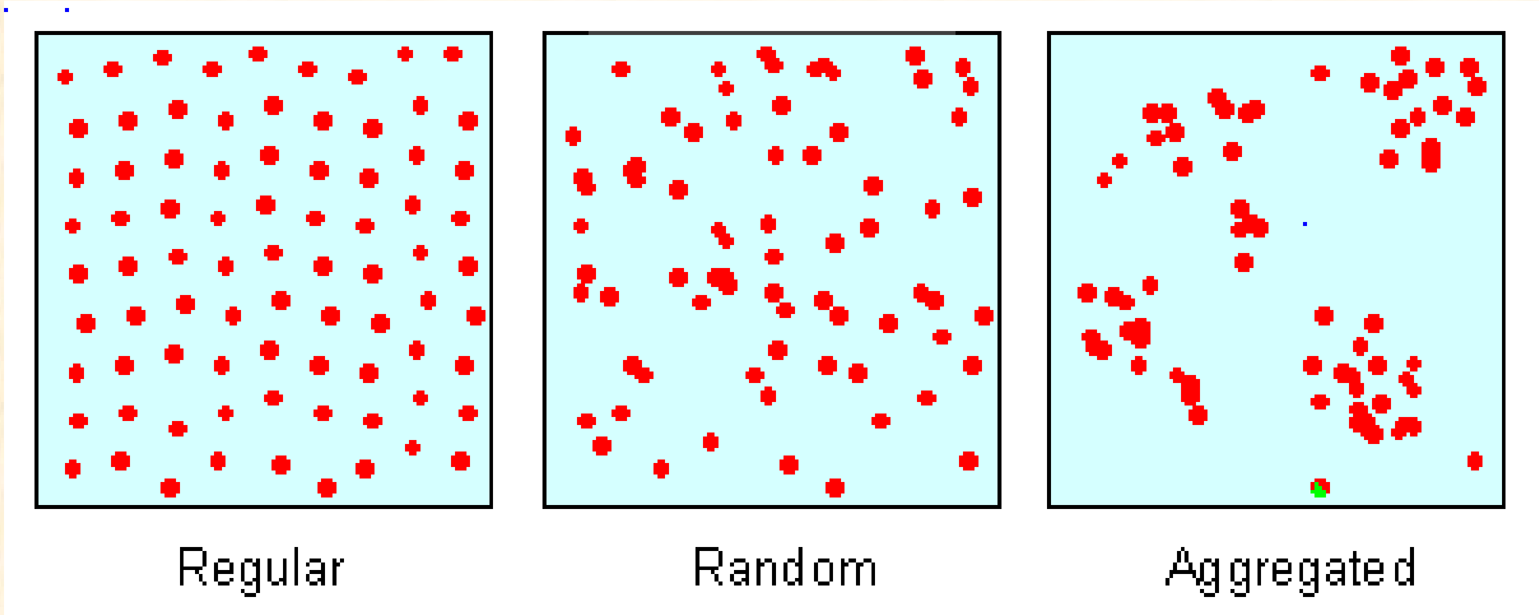
- processes - colonisation / immigration and local extinction / emigration

- local populations are subject to continuous colonisation and extinction
- wildlife populations are fragmented

Metapopulation - a population consisting of many local populations (sub-populations) connected by migrating individuals with discrete breeding opportunities (not patchy populations)

Distribution of individuals

- population density changes also in space
- for migratory animals (salmon) seasonal movement is the dominant cause of population change
- movement of individuals between patches can be density-dependent
- distribution of individuals have three basic models:



- most populations in nature are aggregated (clumped)

Regular distribution

- described by hypothetical discrete uniform distribution

$$P(x) = \frac{1}{n}$$

n .. is number of samples
x .. is category of counts (0, 1, 2, 3, 4, ...)

- all categories have similar probability

- mean: $\mu = \frac{1}{2}(n+1)$

- variance: $\sigma^2 = \frac{1}{12}(n^2 - 1)$

- for regular distribution: $\boxed{\mu > \sigma^2}$

Random distribution

- described by hypothetical Poisson distribution

$$P(x) = \frac{\mu^x e^{-\mu}}{x!}$$

μ .. is expected value of individuals
x .. is category of counts (0, 1, 2, 3, 4, ...)

- probability of x individuals at a given area usually decreases with x
- observed and expected frequencies are compared using χ^2 statistics
- for random distribution: $\boxed{\mu = \sigma^2}$

Aggregated distribution

- described by hypothetical negative binomial distribution

$$P(x) = \left(1 - \frac{\mu}{k}\right)^{-k} \frac{(k+x-1)!}{x!(k-1)!} \left(\frac{\mu}{\mu+k}\right)^{x}$$

μ .. is expected value of individuals
x .. is category of counts (0, 1, 2, 3, 4, ...)
k .. degree of clumping, the smaller k ($\rightarrow 0$) the greater degree of clumping

- approximate value of k: $$k \approx \frac{\mu^2}{\sigma^2 - \mu}$$

- for aggregated: $\boxed{\mu < \sigma^2}$

Coefficient of dispersion (CD)

$$\boxed{CD = \frac{s^2}{\bar{x}}}$$

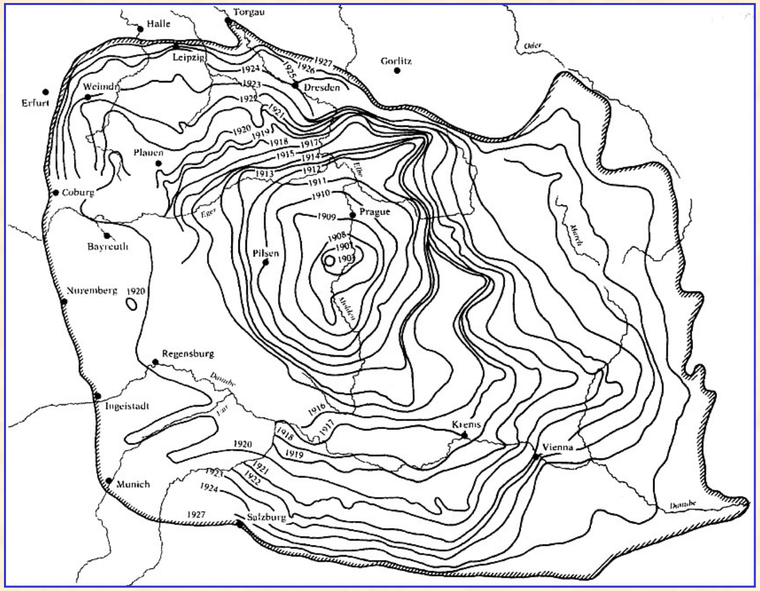
CD < 1 … uniform distribution
CD = 1 … random distribution
CD > 1 … aggregated distribution

Dispersal

- **Geographic range** - radius of space containing 95% of individuals
- **expansion** – increase in geographic range
- individual makes blind **random walk**
- random walk of a population undergoes **diffusion** in space
- diffusion (Brownian motion) model in 2dimensional space:

$$\frac{\partial N}{\partial t} = D\left(\frac{\partial^2 N}{\partial x^2} + \frac{\partial^2 N}{\partial y^2}\right)$$

Elton 1958

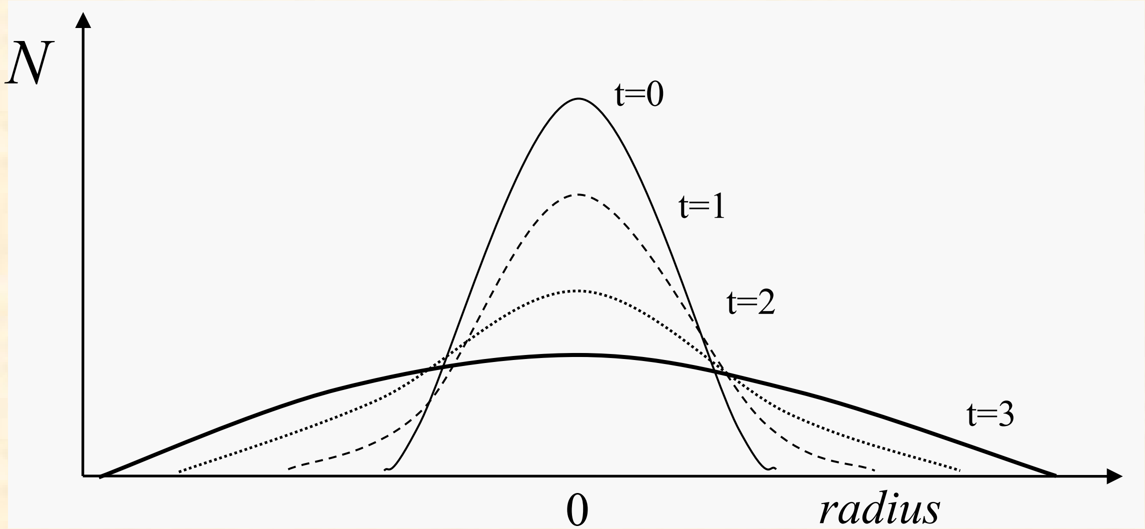


Spread of muskart in Europe

- radial distance moved in a random walk is related to $\sqrt{time}$

D .. diffusion coefficient (distance^2/time)

Pure dispersal



• Diffusion model
- solved to 2dimensional Gaussian distribution

$$N(\rho,t)=\frac{N_0}{4\pi Dt}\exp\left(\frac{-\rho^2}{4Dt}\right)$$

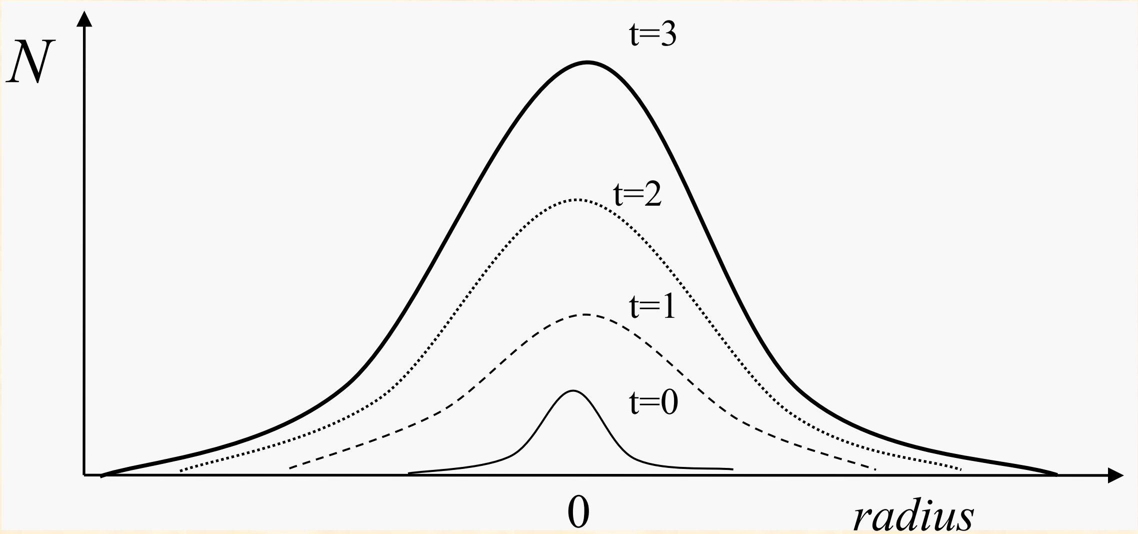
$$\boxed{\rho=\sqrt{4Dt}}$$

$$\boxed{D=\frac{\rho^2}{4t}}$$

- assuming all individuals are dispersers
- range expanses linearly with time
- no reproduction

N_0 .. initial density
ρ .. radial distance from point of release (range)

Dispersal + population growth



- Skellam‘s model
- includes diffusion and exponential population growth

r .. intrinsic rate of increase

$$N(\rho,t)=\frac{N_0}{4\pi Dt}\exp\left(rt-\frac{\rho^2}{4Dt}\right)$$

c - expansion rate [distance/time]

$$\boxed{c=2\sqrt{rD}}$$

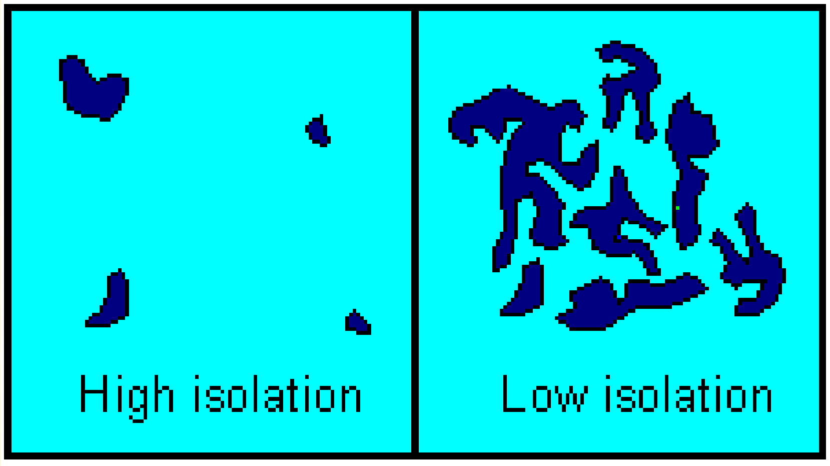
Skellam 1951

Metapopulation ecology

- types of spatially distributed populations:

- Source-sink (mainland-island), panmictic (clumped), nonequilibrium (fragmented), metapopulation

- the degree of isolation may vary depending on the distance among patches



- unlike growth models that focus on population size, metapopulation models concern persistence of a population - ignore fate of a single sub-population and focus on fraction of sub-population sites occupied

- Metapopulation assumptions:
  - Suitable habitat is in discrete patches
  - Population is reproductively active
  - Subpopulations have high risk of extinction
  - Subpopulations are not too isolated such that recolonization is likely
  - Dynamic are not synchronised across subpopulations
  - All patches are alike for extinction and colonization

- Levins (1969) distinguished between dynamics of a single population and a set of local populations which interact via individuals moving among populations

- Hanski (1997) developed the theory - suggested *core-satellite* model

Levin‘s model

- assumptions

- sub-populations are identical in size, distance, resources, etc.
- extinction and colonisation are independent of p
- many patches are available
- natality and mortality is ignored

p .. proportion of patches occupied
m .. colonisation (immigration) rate - proportion of open sites colonised per unit time
e .. extinction (emigration) rate - proportion of sites that become unoccupied per unit time

$$\frac{\mathrm{d}p}{\mathrm{d}t} = mp(1-p) - ep$$

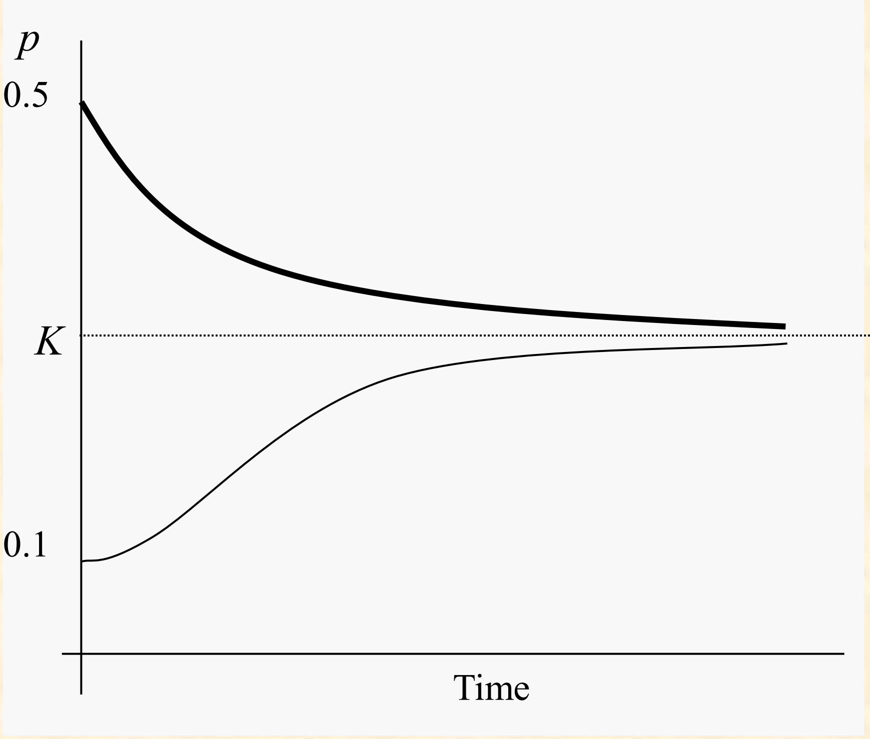
Levin (1969)

- equilibrium is found for $\dfrac{\mathrm{d}p}{\mathrm{d}t} = 0$

$$p^* = \frac{m - e}{m} = 1 - \frac{e}{m}$$

- sub-populations will persist ($p^* > 0$) only if colonisation is larger than extinction ($m > e$)
- Equilibrium state will always include empty patches if if $e > 0$

- K ..is fraction of patches
- defined by balance between m and e



- metapopulations are found in insects, *Daphnia*, frogs, birds

- rescue-effect model, incidence model