

# Spatial Ecology

*“Populační ekologie živočichů“*

Stano Pekár

**Spatial ecology** - describes changes in spatial pattern over time

- ▶ processes - colonisation / immigration and local extinction / emigration

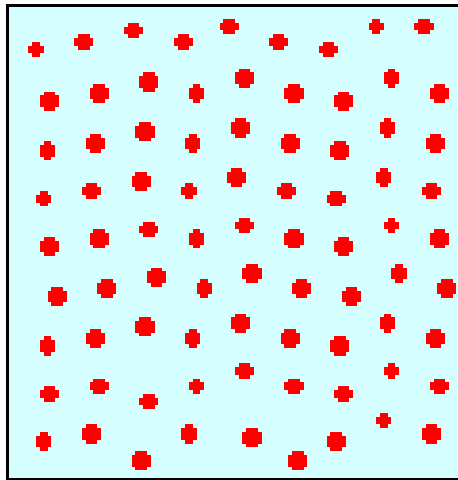
- ▶ local populations are subject to continuous colonisation and extinction

- ▶ wildlife populations are fragmented

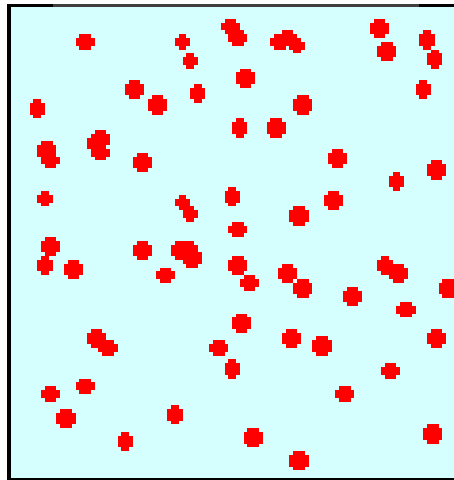
**Metapopulation** - a population consisting of many local populations (sub-populations) connected by migrating individuals with discrete breeding opportunities (not patchy populations)

# Distribution of individuals

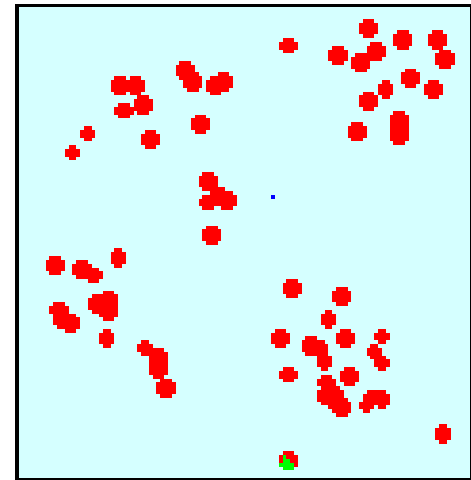
- ▶ population density changes also in space
- ▶ for migratory animals (salmon) seasonal movement is the dominant cause of population change
- ▶ movement of individuals between patches can be density-dependent
- ▶ distribution of individuals have three basic models:



Regular



Random



Aggregated

- ▶ 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:  $\mu > \sigma^2$

# Random distribution

- ▶ described by hypothetical Poisson distribution

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

$\mu$  .. 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  $\chi^2$  statistics
- ▶ for random distribution:  $\mu = \sigma^2$

# Aggregated distribution

- ▶ described by hypothetical negative binomial distribution

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

$\mu$  .. 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:

$$\mu < \sigma^2$$

## Coefficient of dispersion (CD)

CD < 1 ... uniform distribution

CD = 1 ... random distribution

CD > 1 ... aggregated distribution

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

# Dispersal

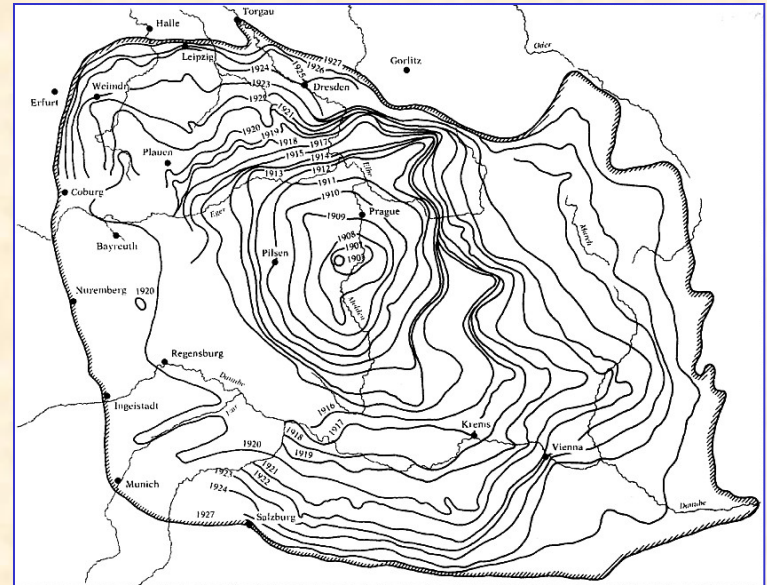
- **Geographic range** - radius of space containing 95% of individuals
- **expansion** – increase in geographic range
- individual makes blind **random walk**
- random walk of a population undergoes **diffusion** in space
- diffusion (Brownian motion) model in 2dimensional space:

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

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

$D$  .. diffusion coefficient  
(distance<sup>2</sup>/time)

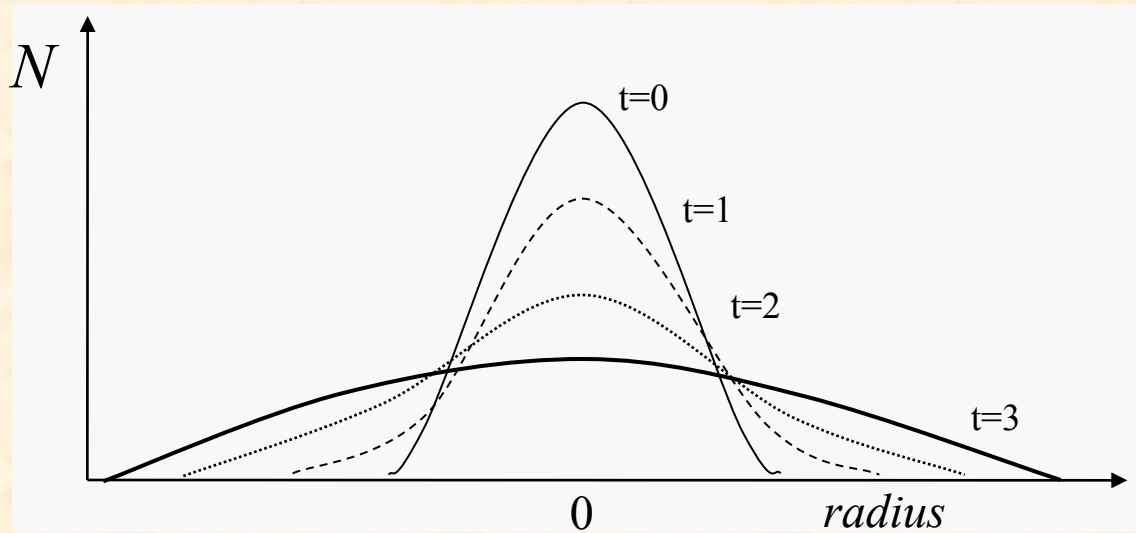
Elton 1958



Spread of muskard in Europe



# Pure dispersal



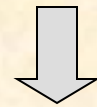
- assuming all individuals are dispersers
- range expands linearly with time
- no reproduction

$N_0$  .. initial density

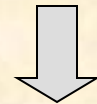
$\rho$  .. radial distance from point of release (range)

- Diffusion model
- solved to 2dimensional Gaussian distribution

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



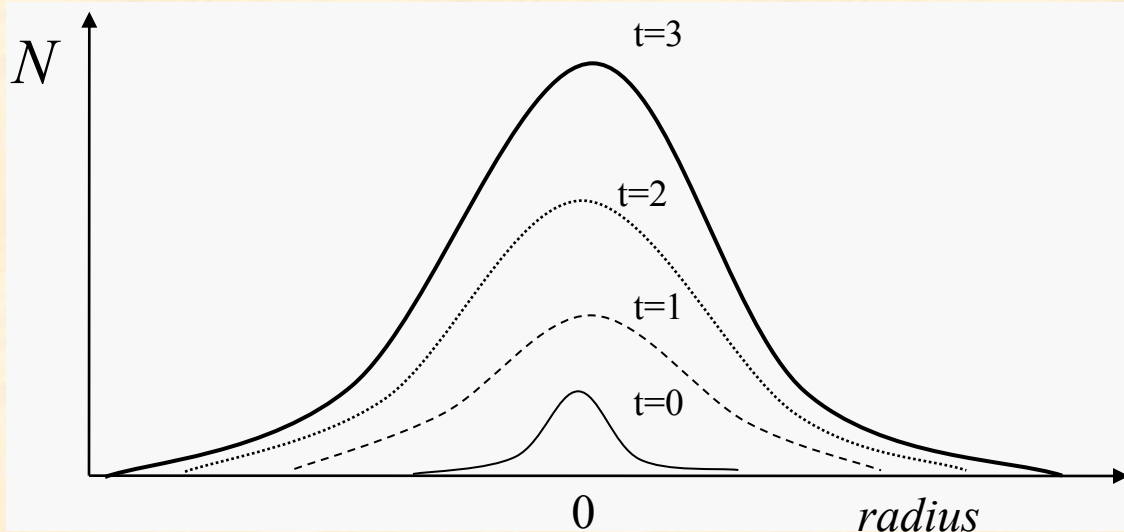
$$\rho = \sqrt{4Dt}$$



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



# Dispersal + population growth



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

$r$  .. intrinsic rate of increase

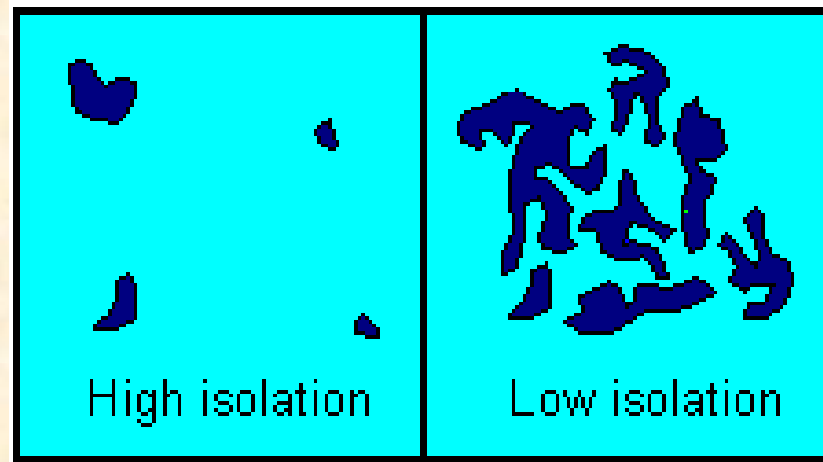
$$N(\rho, t) = \frac{N_0}{4\pi Dt} \exp\left(rt - \frac{\rho^2}{4Dt}\right)$$

$c$  - expansion rate [distance/time]

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

# 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
- Dynamics 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

$$\frac{dp}{dt} = mp(1 - p) - ep$$

▶ equilibrium is found for  $\frac{dp}{dt} = 0$

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

- sub-populations will persist ( $p^* > 0$ ) only if colonisation is larger than extinction ( $m > e$ )

- Equilibrium state will always include empty patches if  $e > 0$

-  $K$  ..is fraction of patches

- defined by balance between  $m$  and  $e$

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

▶ rescue-effect model,  
incidence model

