Tanjona Ramiadantsoa
(with materials from Atte Molainen)

Metapopulation

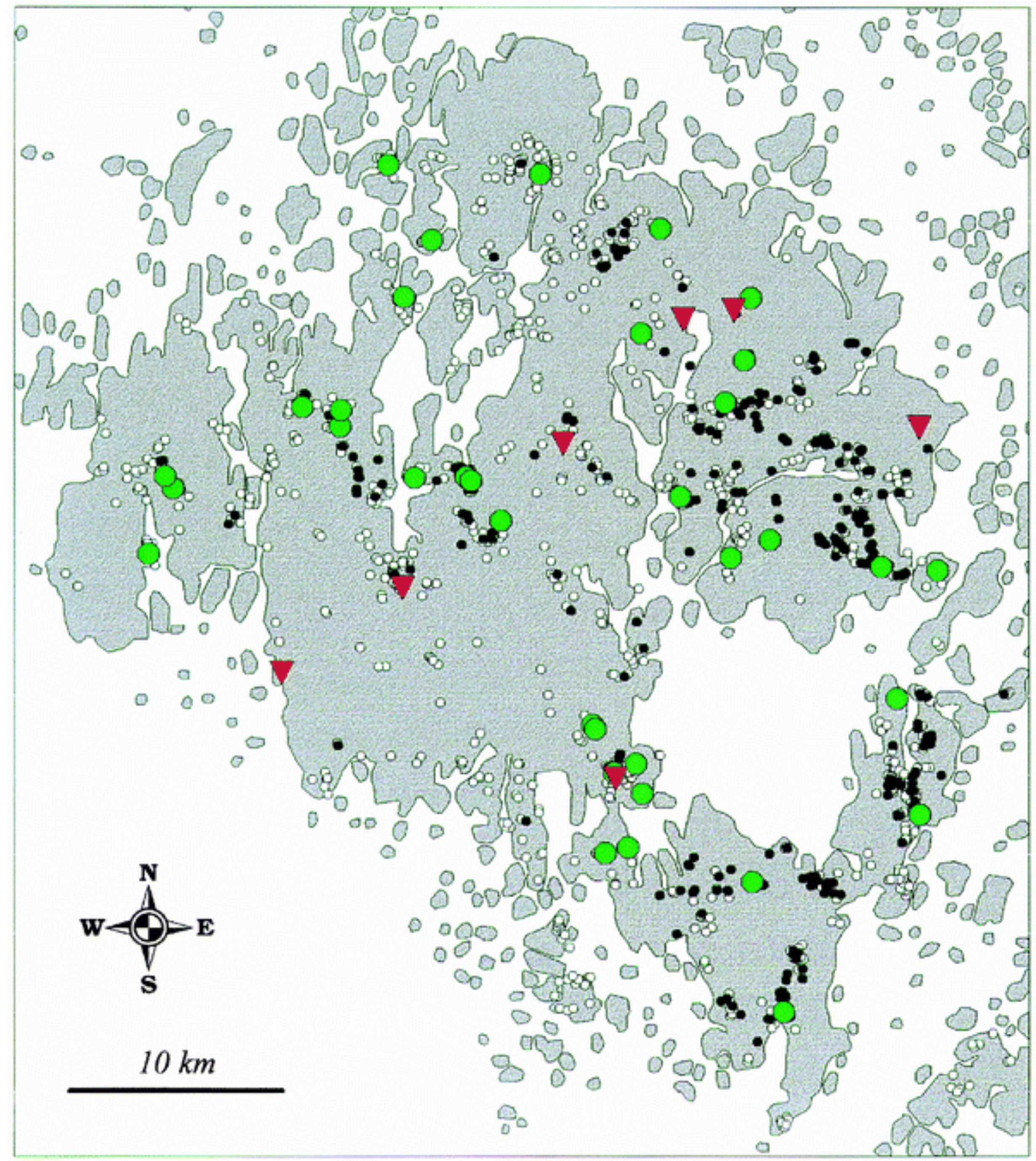
Ilkka Hanski
1953-2016

Model system for metapopulation

Glanville fritillary butterfly
Melitaea cinxia

Model system for metapopulation

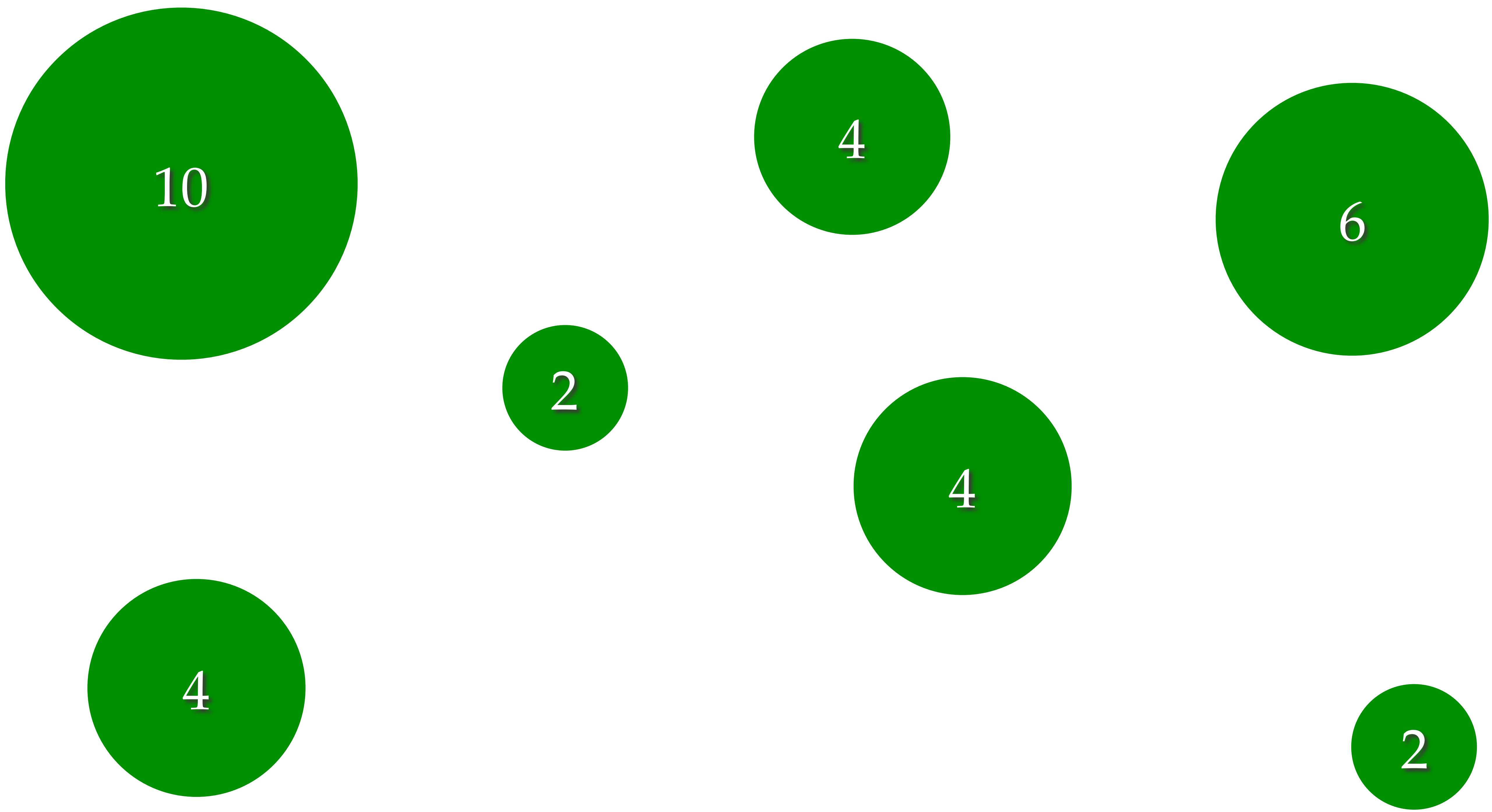
Glanville fritillary butterfly
Melitaea cinxia



Saccheri et al. 1998

Metapopulation game

Those numbers are the number of individuals a patch can support



Players

- Butterfly (14 males and 14 females)
- Predator (1)
- Parasitoid (2)
- Patch controller (7)

Rules

- Your goal is to mate as many times as possible!!!
  - You can only mate within a patch
  - You can only mate with an individual of the opposite sex
  - **You have to leave the patch to mate again with the same individual**
  - Individuals have different allele (denoted by a letter)
    - If you mate with an individual of the same allele, you get **one point (inbreeding)**
    - If you mate with an individual with different allele, you get **three points (outbreeding)**

Final rules

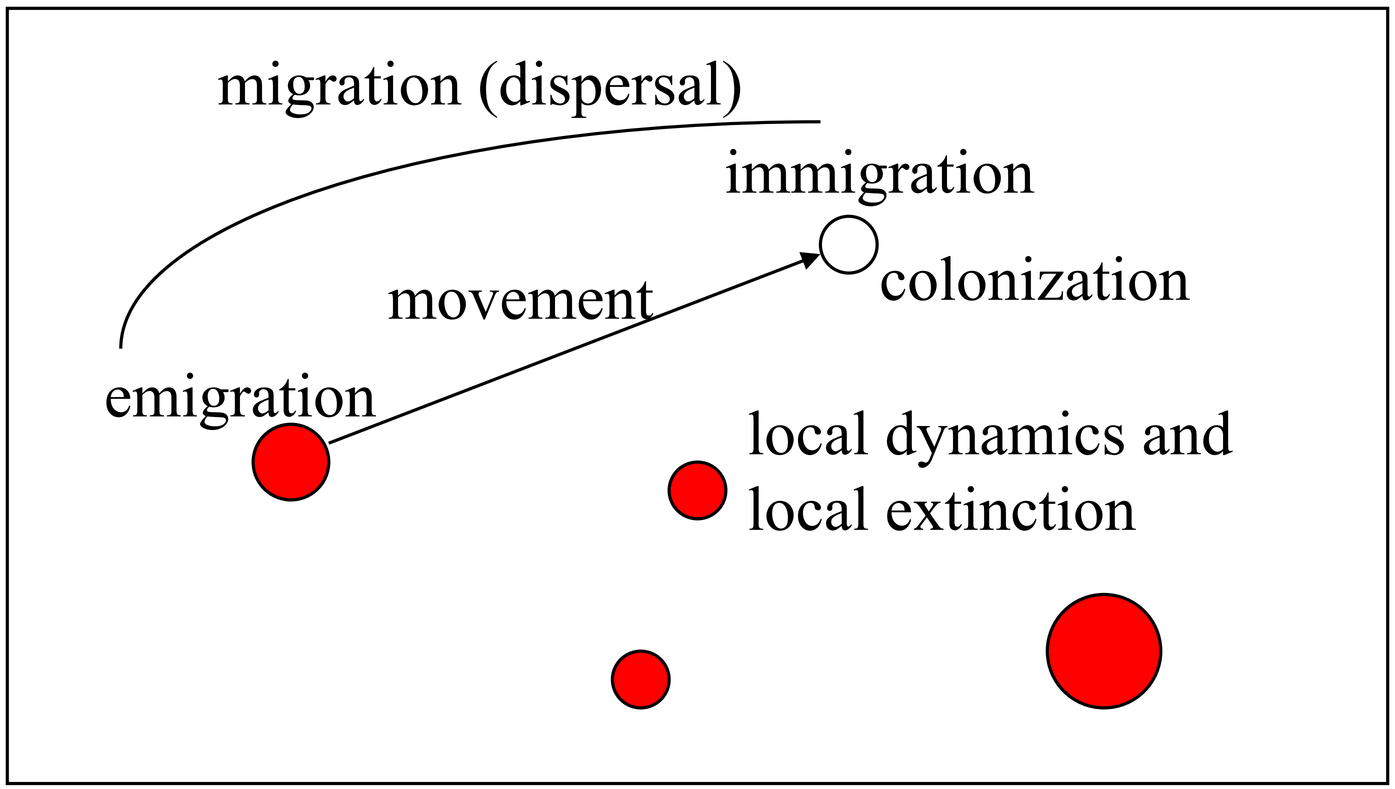
- The **predator** resides in the matrix
  - If you get caught by the predator, you are out of the game
- The **parasitoids** reside in the matrix
  - If you get caught by the parasitoid, you lose one point
- Patch can be **temporarily unsuitable (stochasticity)**, it can be
  - Local: the patch controller raises the hand and you have the leave the patch
  - Global: all the patches are unavailable and you have to leave all of them

Let’s go and play

Many processes

species interactions regional stochasticity rescue effect

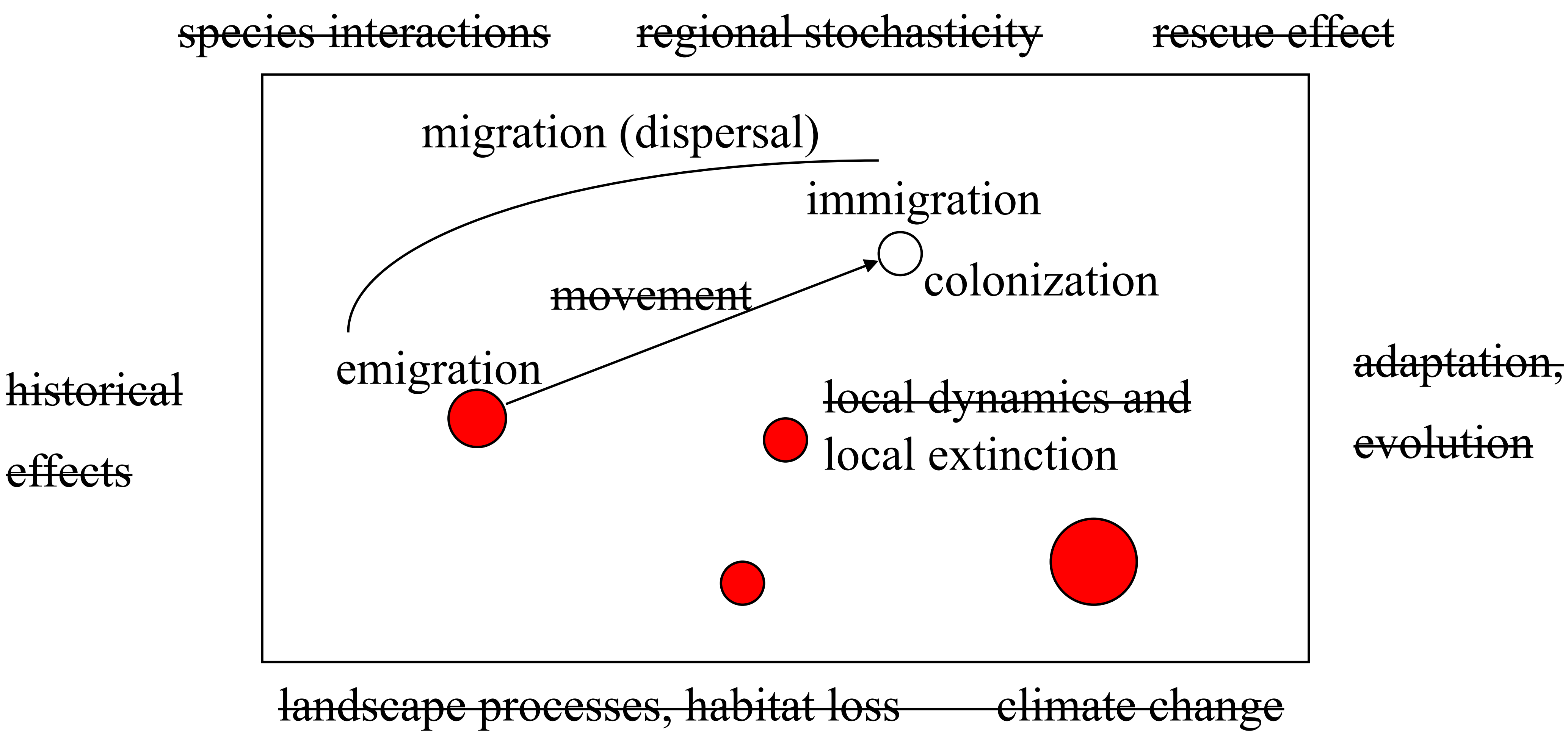
historical effects



adaptation, evolution

landscape processes, habitat loss climate change

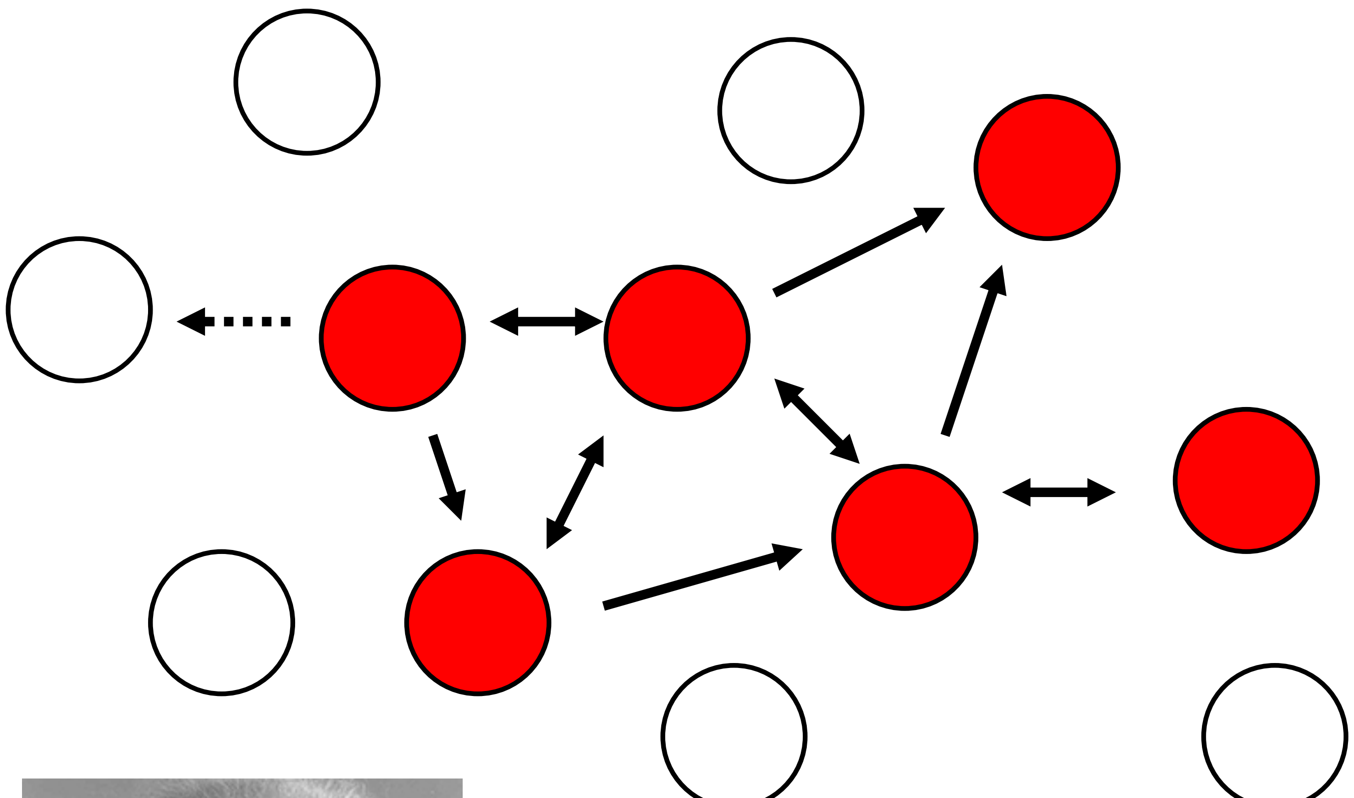
Simplify

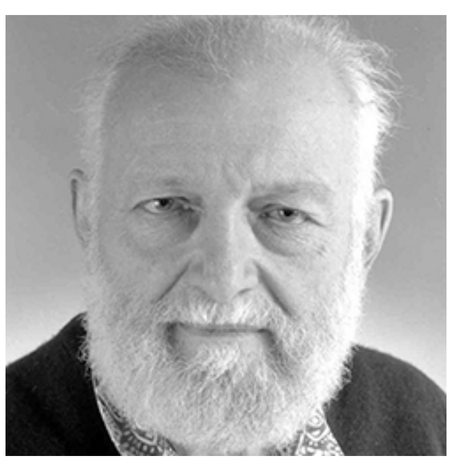


~~species interactions~~
~~regional stochasticity~~
~~rescue effect~~
migration (dispersal)
immigration
colonization
~~movement~~
emigration
~~historical~~
~~effects~~
~~local dynamics and~~
local extinction
~~adaptation,~~
~~evolution~~
~~landscape processes, habitat loss~~
~~climate change~~

Levins' metapopulation (1969)

"A set of population connected by migration"



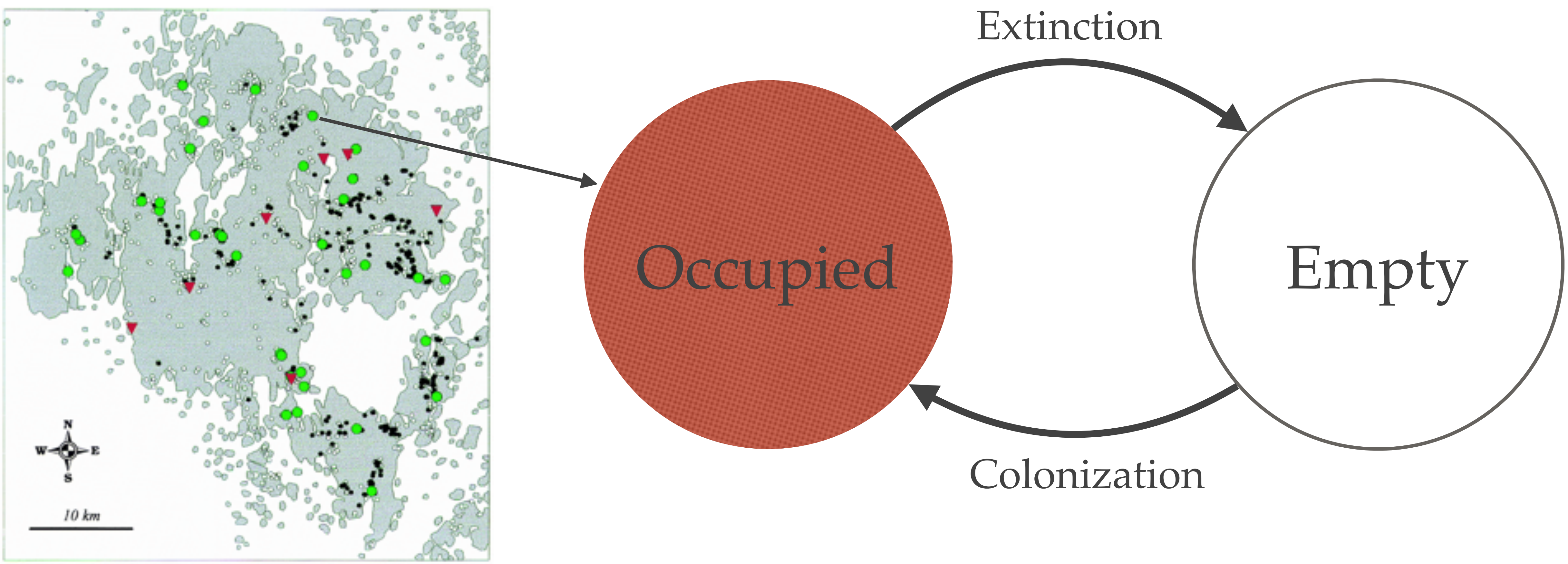


Richard Levins

Interested in whether the patch is empty or occupied (occupancy model)

Response:
fraction of patches occupied

A simple model



Levins' deterministic model

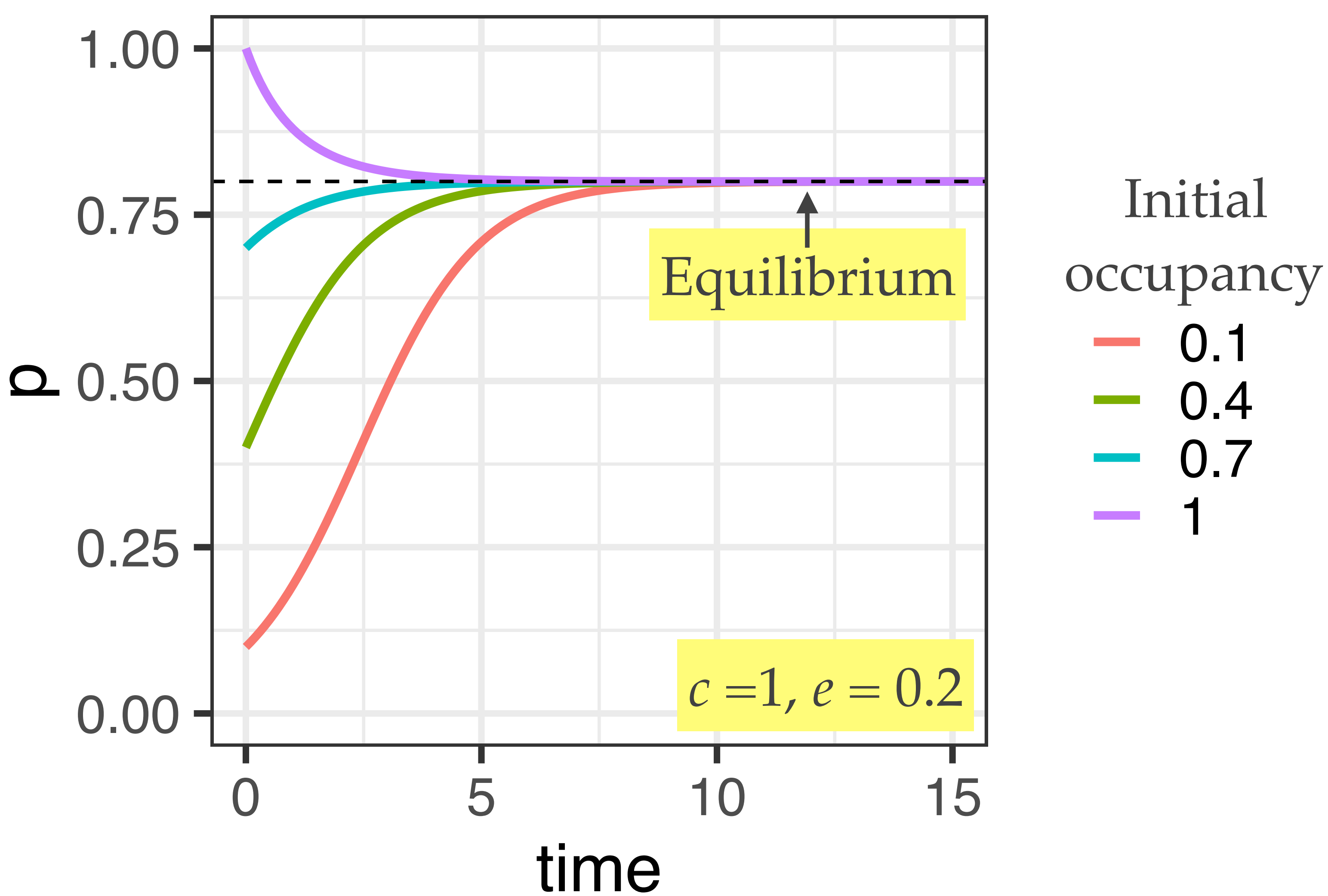
- Spatially implicit
  - All patches have the same quality -> **same probability of going extinct (e)**
  - Distances among patches don't matter -> **same probability of being colonized (c)**
- *p*: **faction of patches occupied**

$$\frac{dp}{dt} = \overbrace{cp\underbrace{(1-p)}_{\text{Fraction of empty patch}}}^{\text{Become occupied}} - \overbrace{ep}^{\text{Become extinct}}$$

Dynamic and equilibrium

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

Solution with different initial conditions



$$\frac{dp}{dt} = 0$$

$$\Leftrightarrow$$

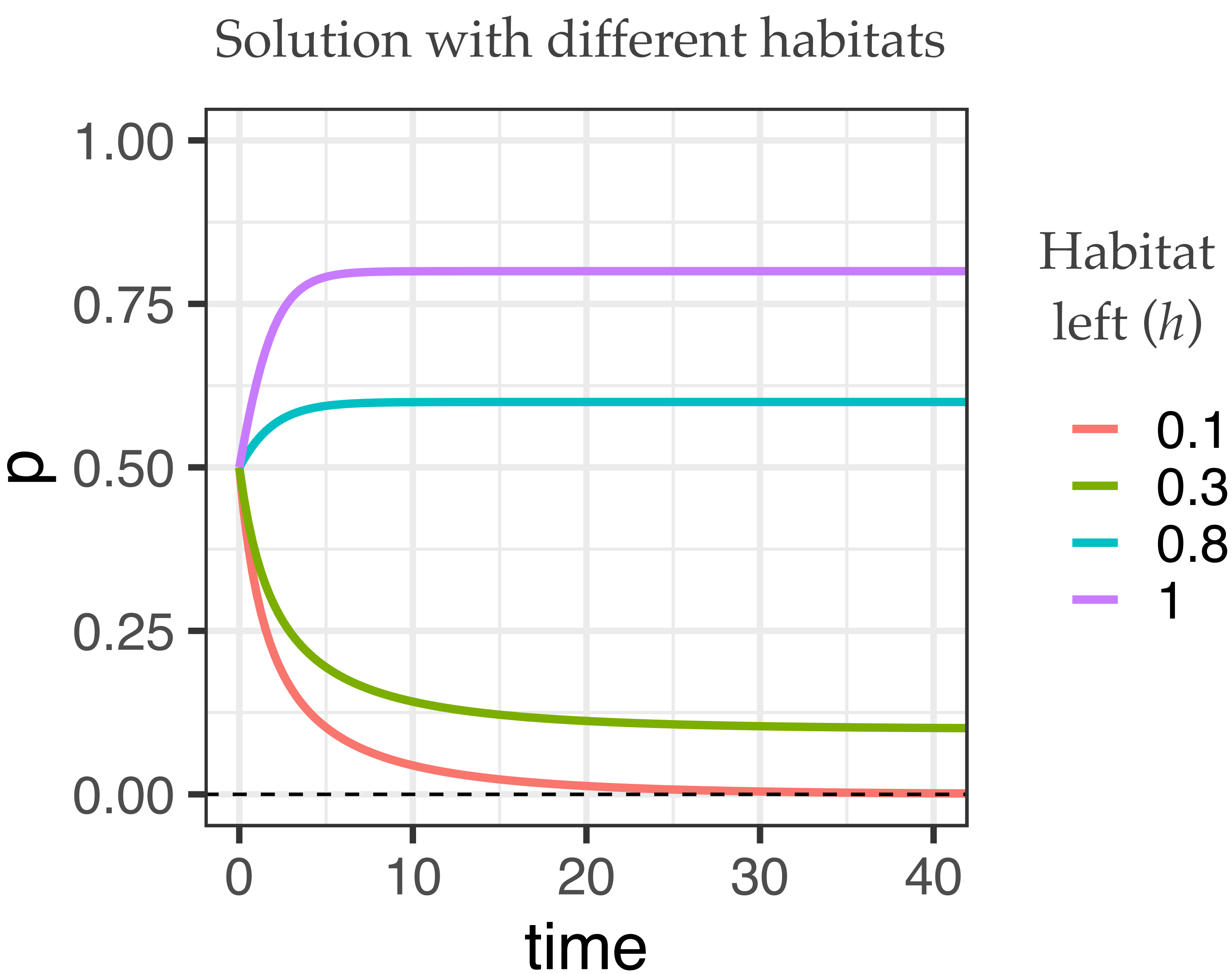
$$cp(1-p) - ep = 0$$

$$\Leftrightarrow$$

$$p^* = 0 \text{ or } p^* = 1 - \frac{e}{c}$$

Adding habitat loss (h)

$$\frac{dp}{dt} = cp(h - p) - ep$$



The new equilibrium is

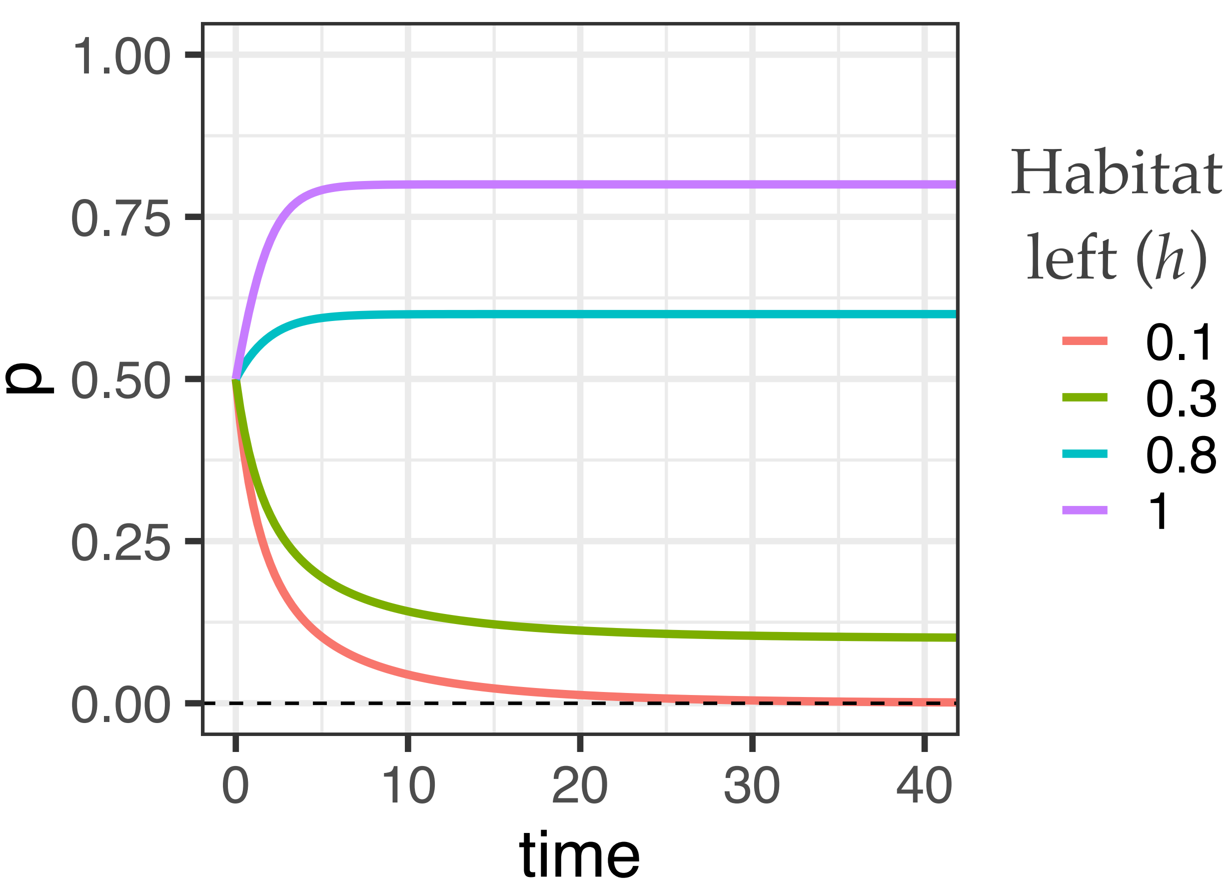
$$p* = 1 - \frac{e/c}{h}$$

Persistence if $p* > 0$, i.e.,

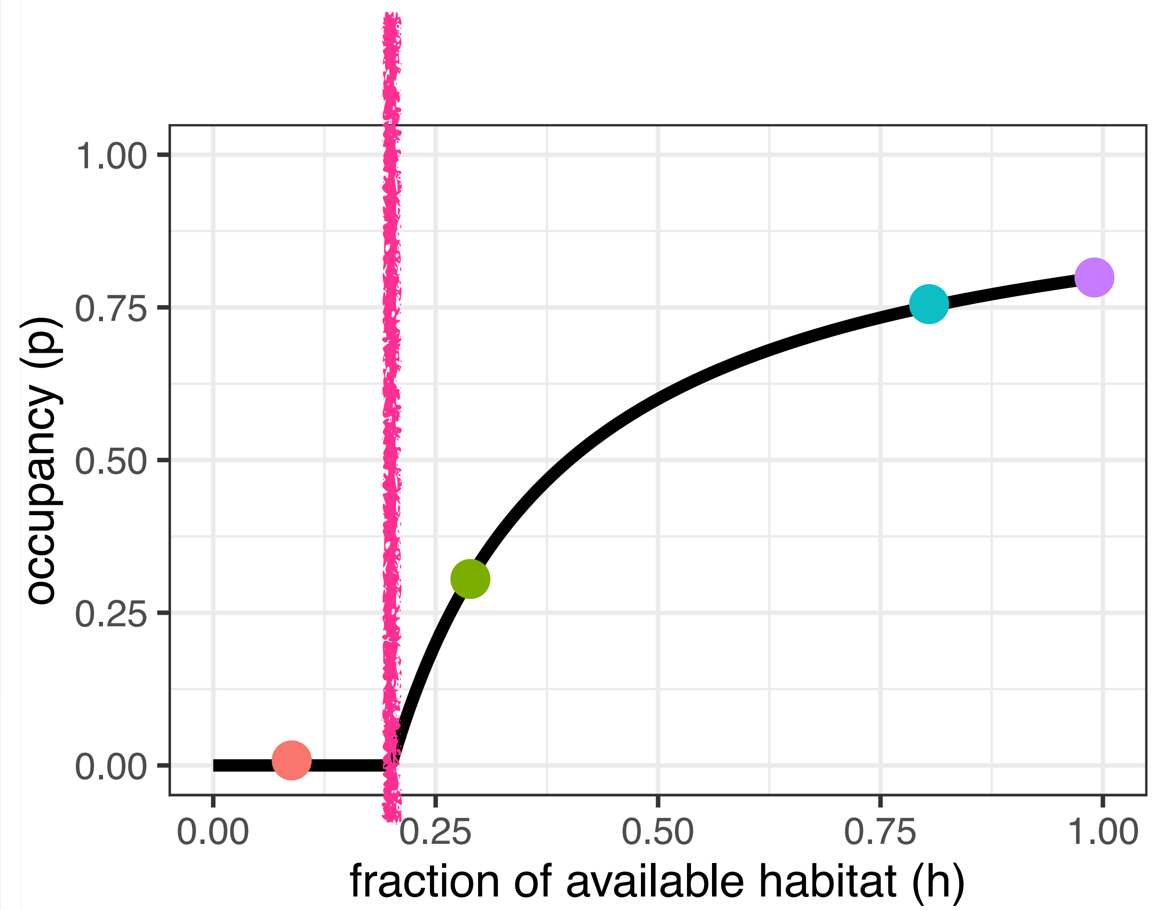
$$h > \frac{e}{c}$$

Extinction threshold

Solution with different habitats



Extinction threshold = the root

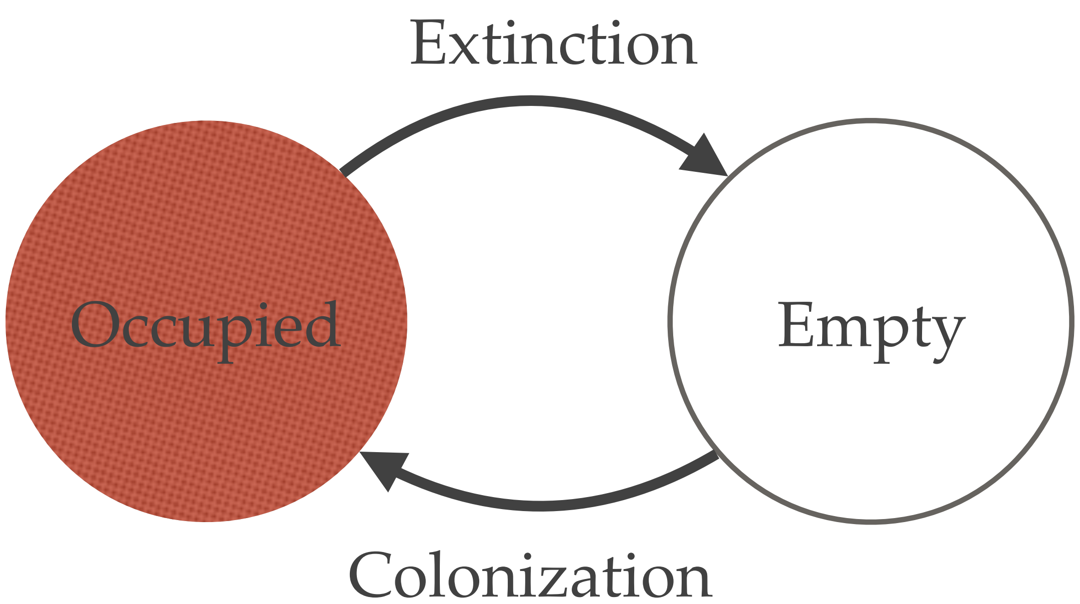


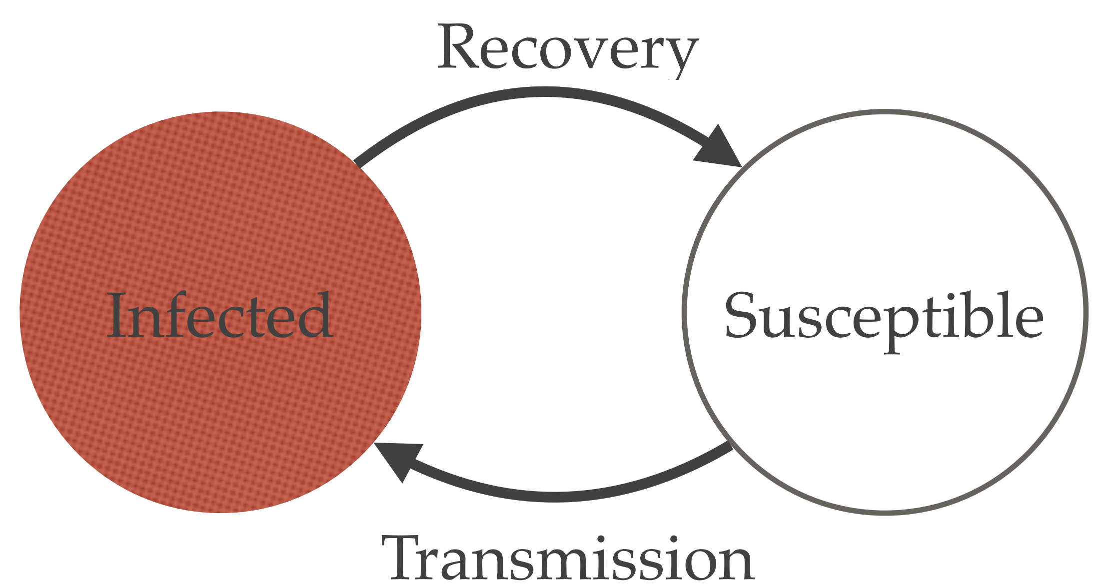
Extinction threshold: $h = \frac{e}{c}$

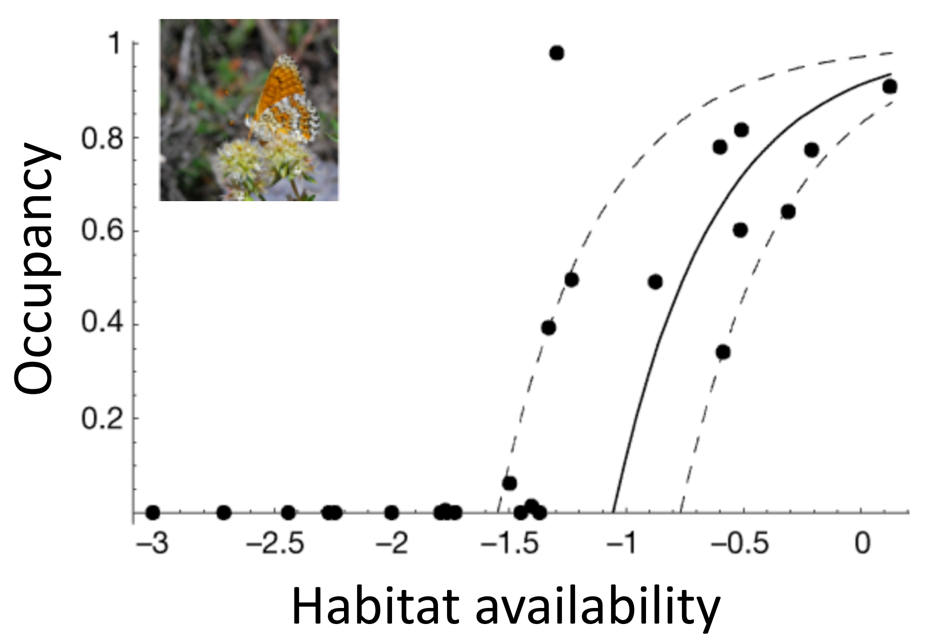
Ecology vs. Epidemiology

Ecology ~ Epidemiology

Ecology ~ Epidemiology

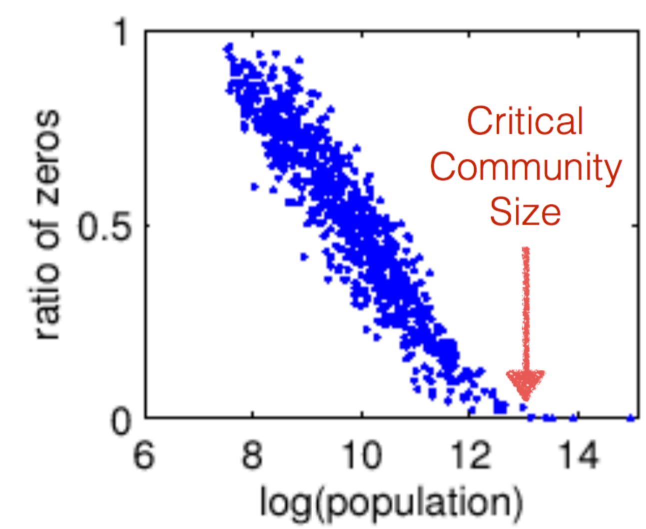






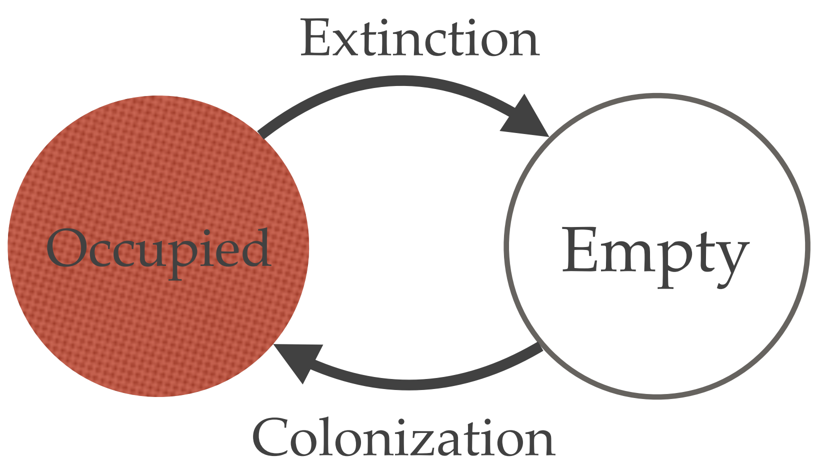
Hanski & Ovaskainen, 2000, *Nature*

Smaller cities go extinct more often



Grenfell et al., 2001, *Nature*

Metapopulation ~ Epi SIS

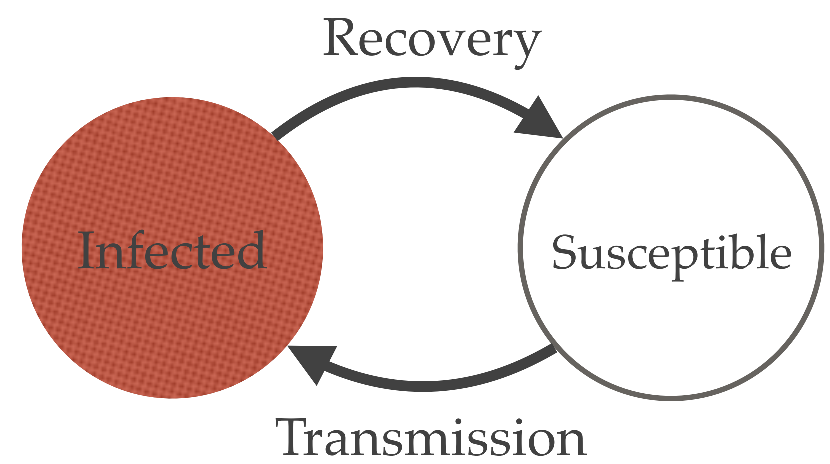


- The fraction of occupied patch at equilibrium is

$$p^* = 1 - \frac{\text{extinction rate}}{\text{colonization rate}} = 1 - \frac{e}{c}$$

- If h is the fraction of suitable patches, the metapopulation goes extinct if

$$h < \frac{e}{c}$$



- The fraction of infected individuals at equilibrium is

$$p^* = 1 - \frac{\text{recovery rate}}{\text{transmission rate}} = 1 - \frac{\gamma}{\beta}$$

- If $h = 1 - p_c$ is the fraction of unvaccinated individuals, the disease is eradicated if

$$h < \frac{\gamma}{\beta} = \frac{1}{R_0}$$