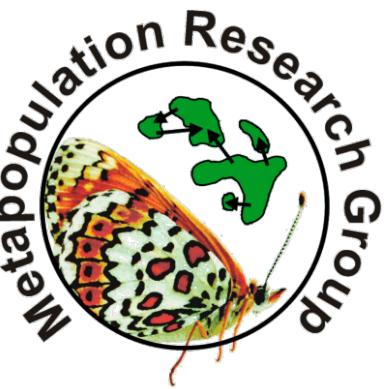




Department of
Integrative Biology
UNIVERSITY OF WISCONSIN-MADISON



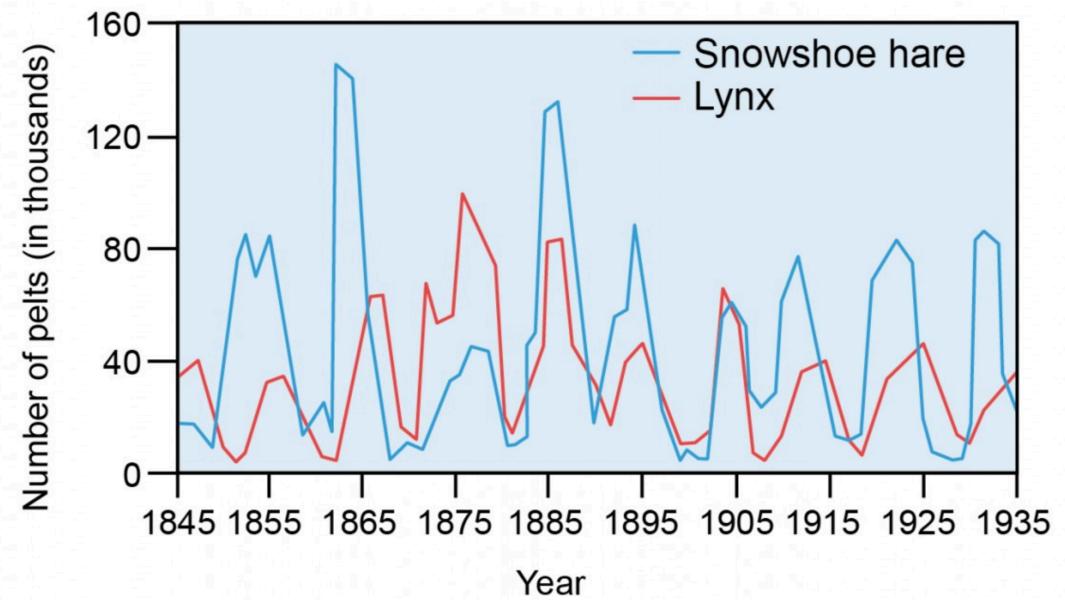
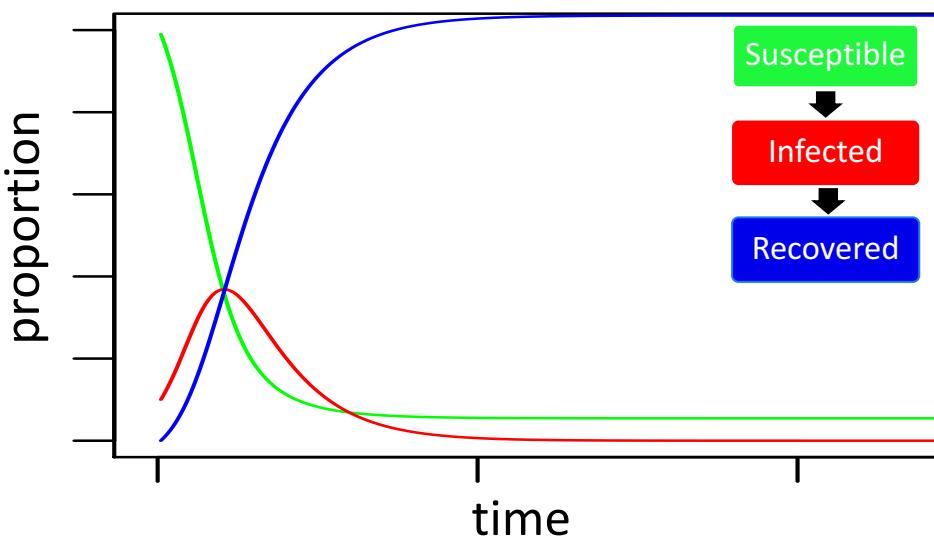
Spatial mechanistic models

Tanjona Ramiadantsoa

with materials from Atte Molainen

Previously

- Variable of interest is population size through time

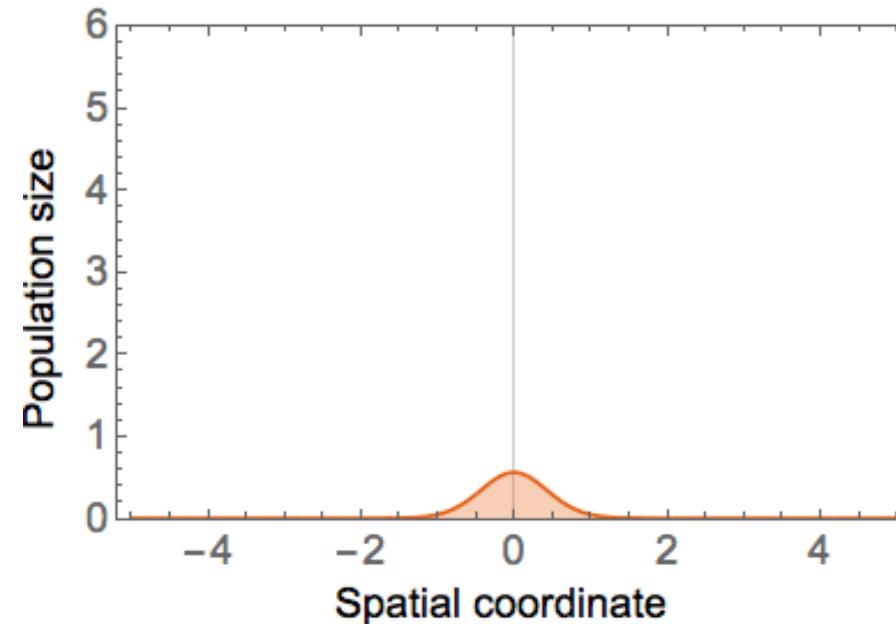


Spatial model

- Now, we are interested in population size **both through time and through space**

Spatial model

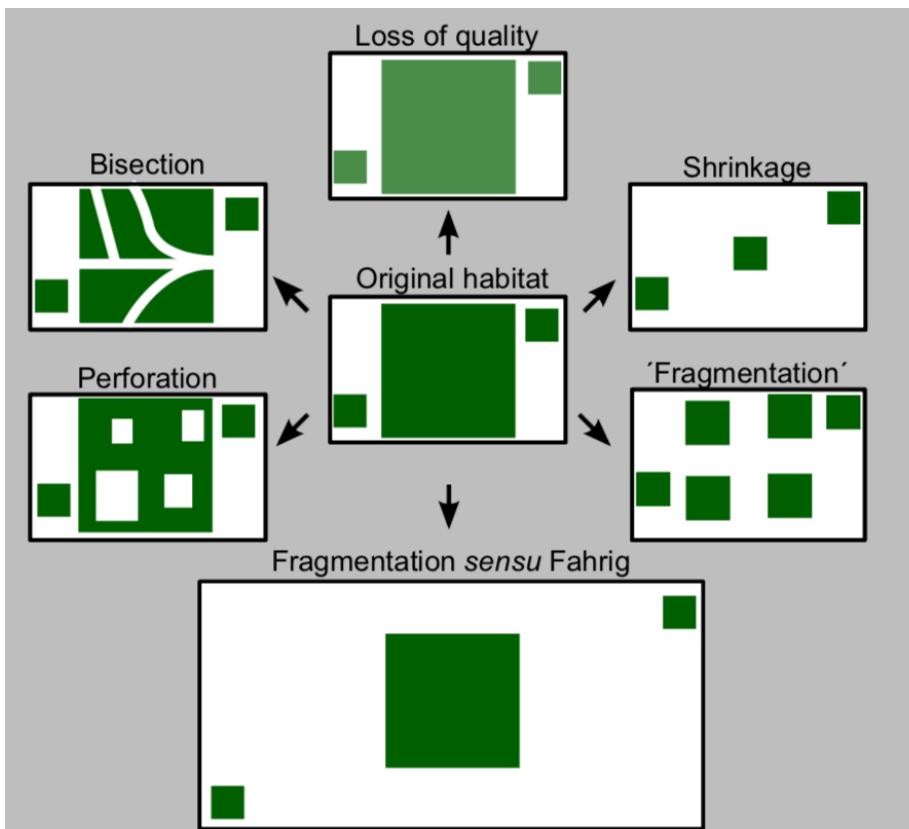
- Now, we are interested in population size **both through time and through space**



Spatial model

Two necessary additions

Landscape structure



Dispersal



Outline

- Metapopulation paradigm
- Levins' (spatially implicit) metapopulation model
- Spatially realistic metapopulation model
- Software demonstration: SPOMSIM

Outline

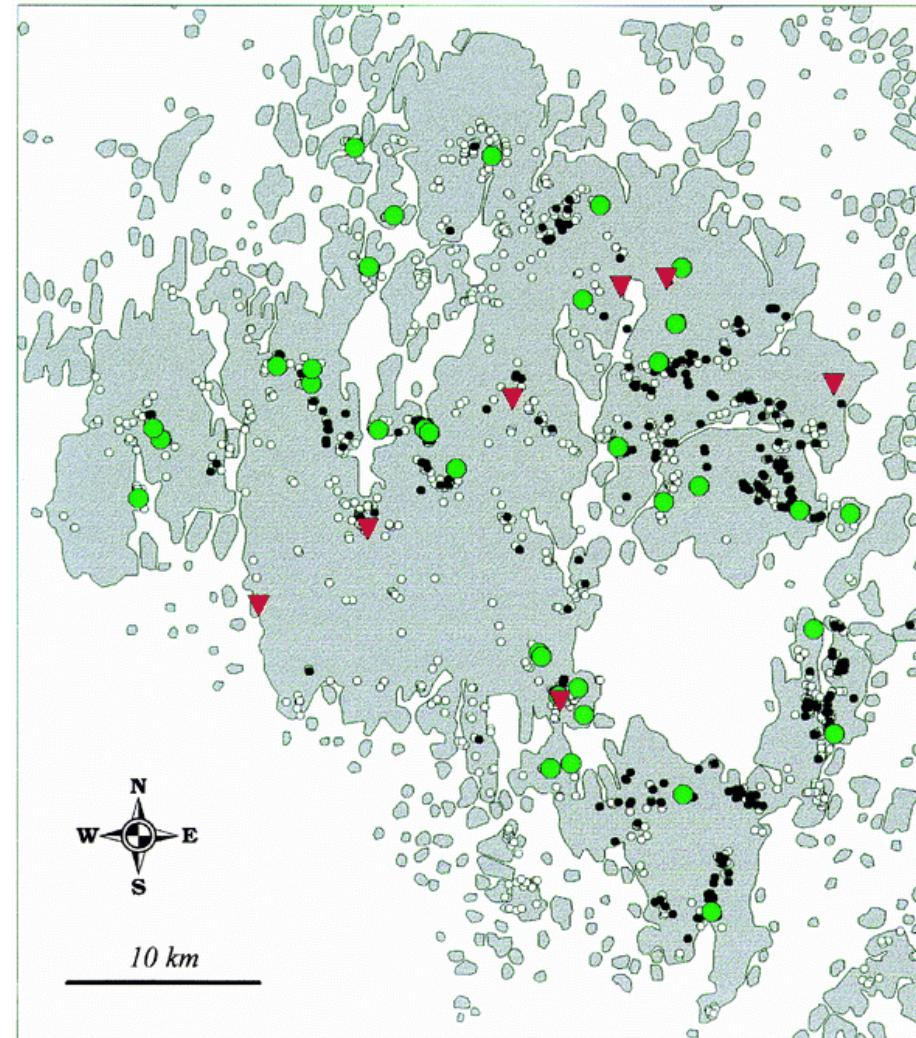
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Model system for metapopulation

Glanville fritillary butterfly
(*Melitaea cinxia*)

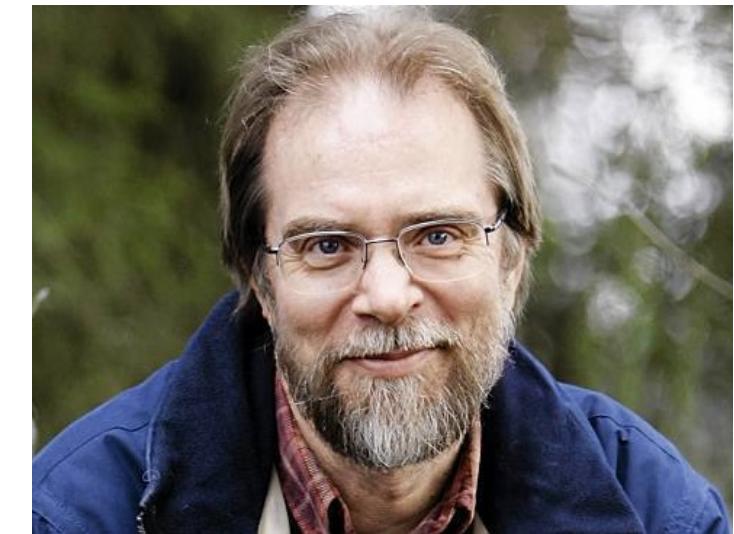


Photo: Hannu Aarnio

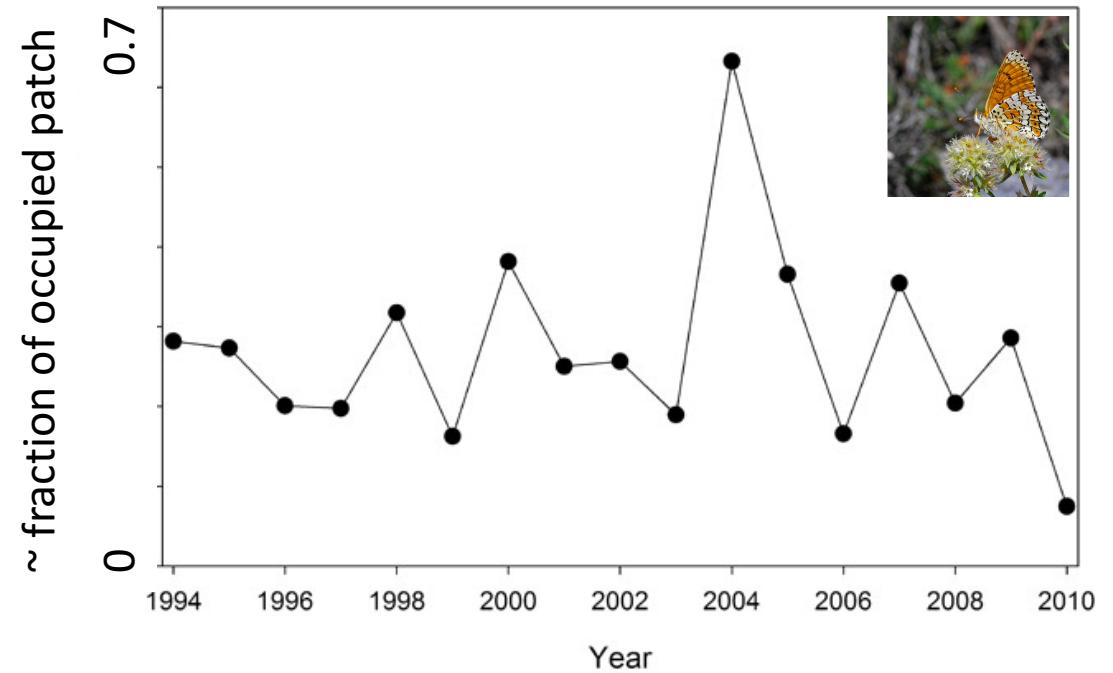
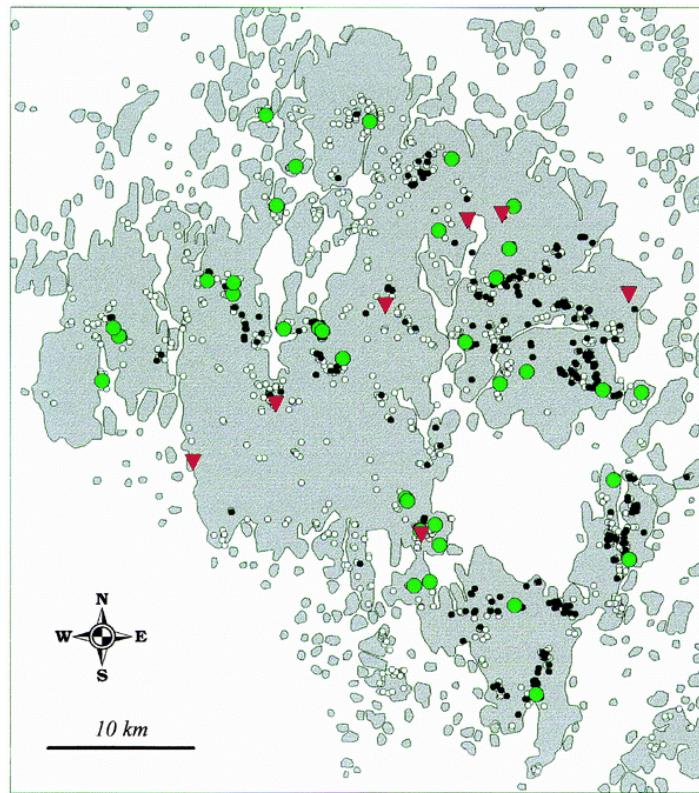


Saccheri et al. 1998

Ilkka Hanski



Metapopulation dynamics



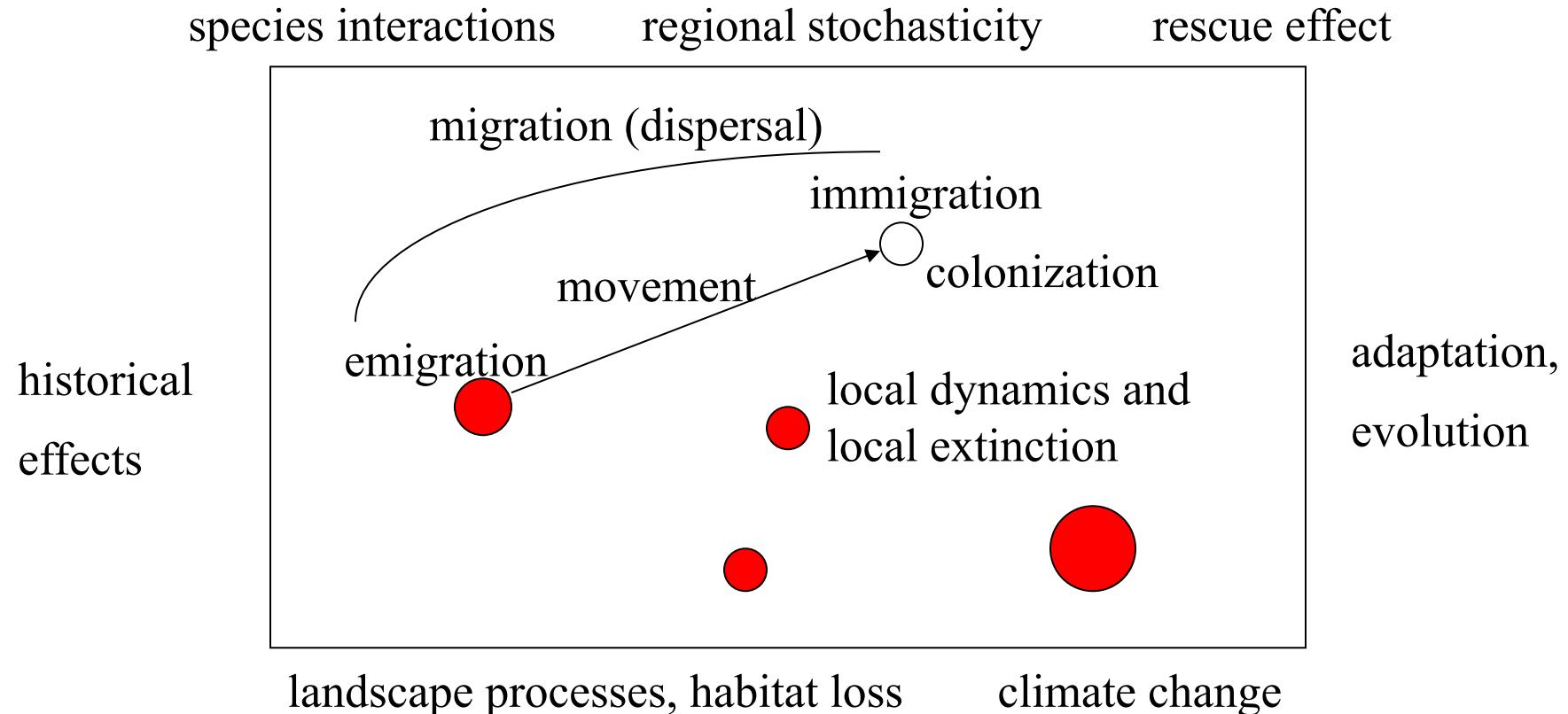
Hanski 2011

Metapopulation paradigm

Historically, ecologists mainly focus on local processes

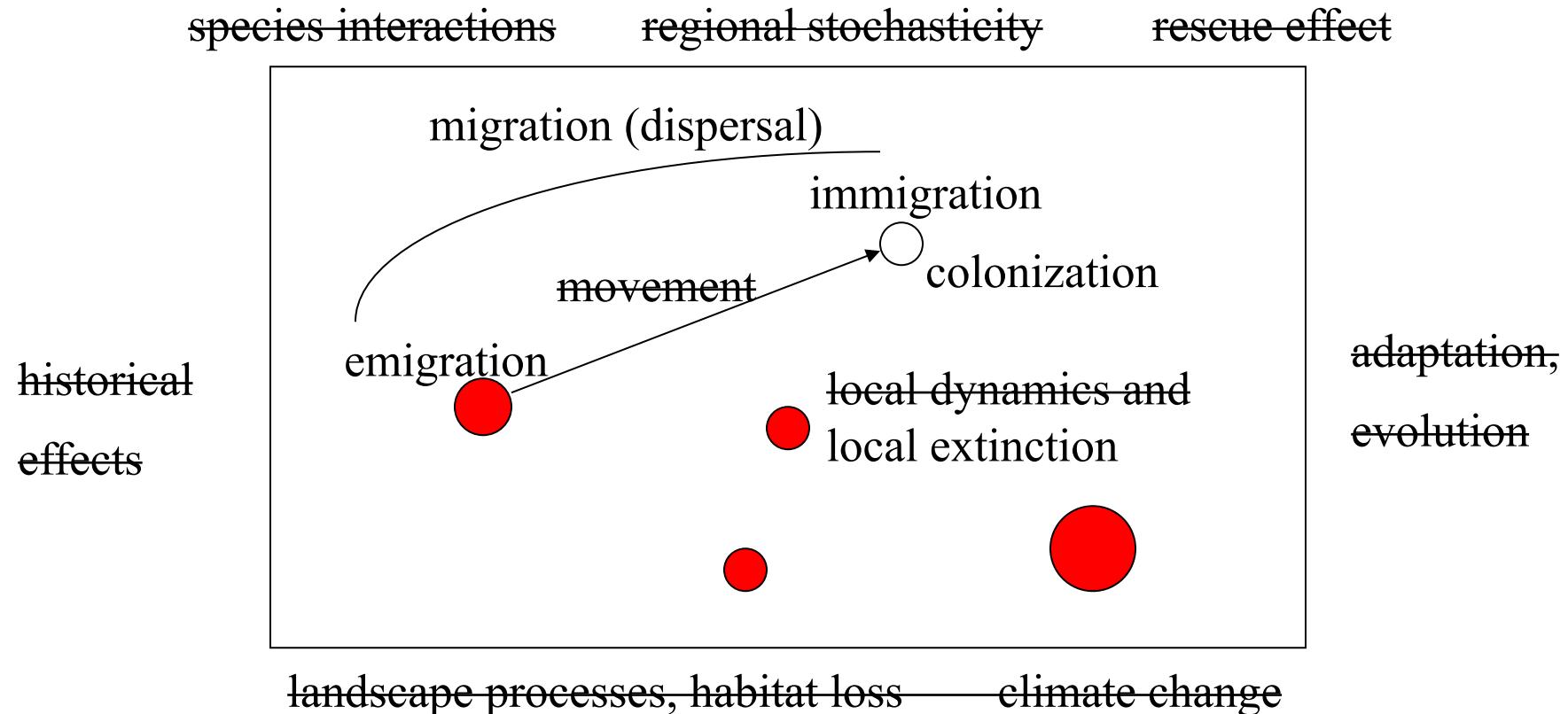
Metapopulation paradigm

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Metapopulation paradigm

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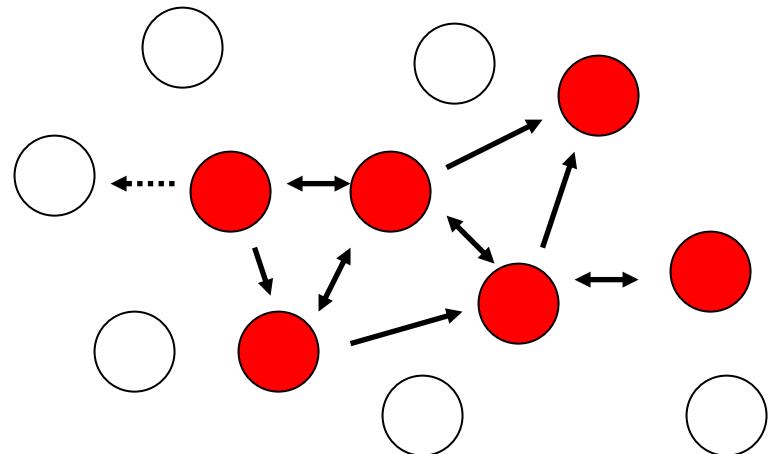
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The concept of metapopulation (Levins 1969)



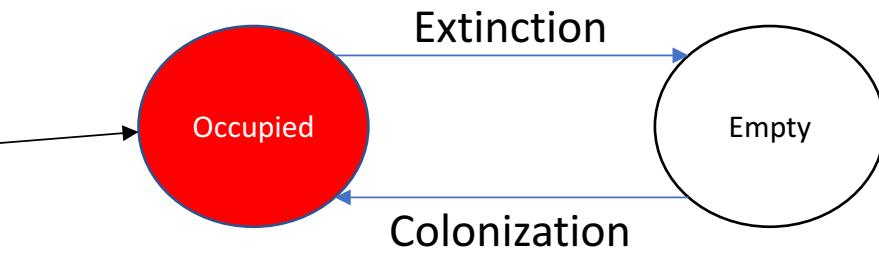
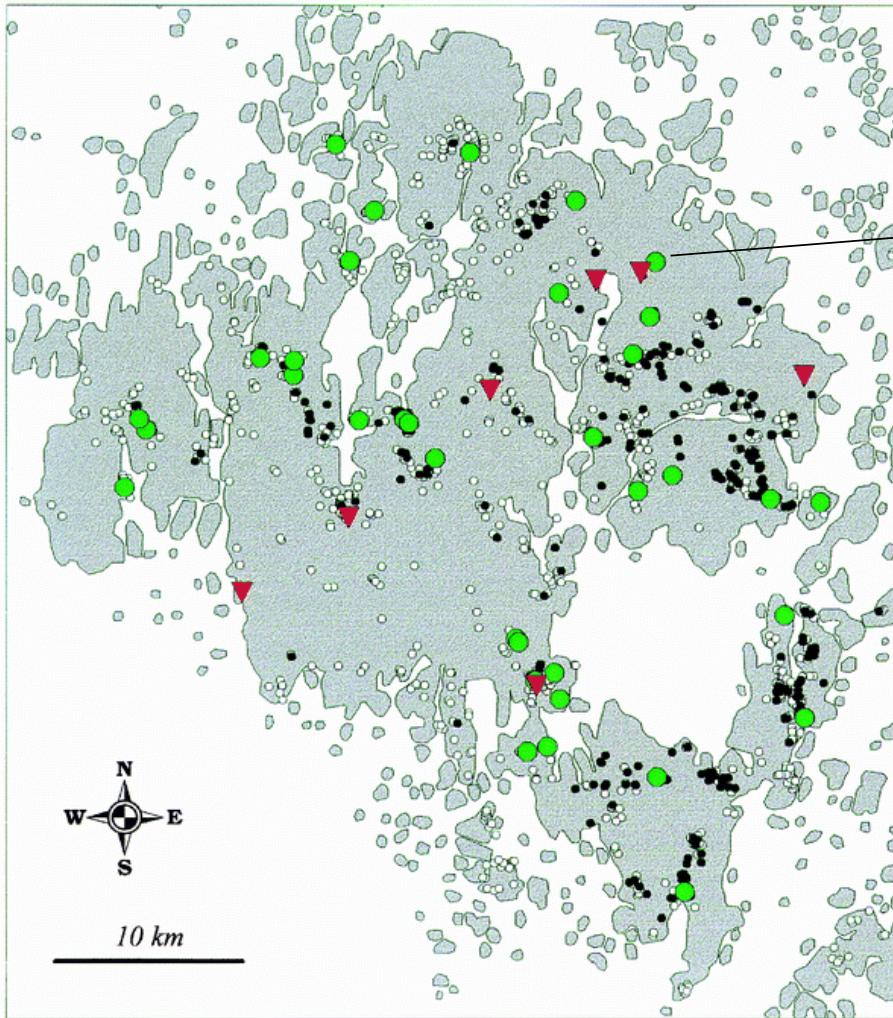
Richard Levins



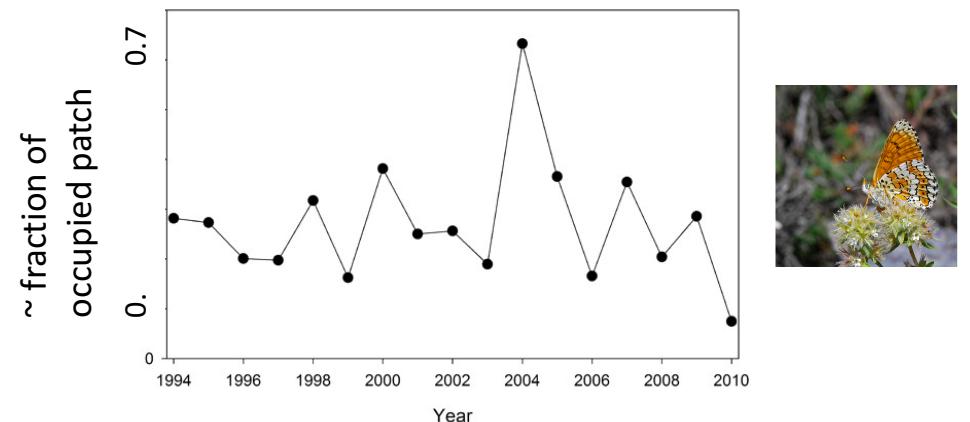
⇒ We only ask whether the patch is empty or occupied (occupancy model)

“a set of local populations connected by migration”

Conceptual model



We are interested in the fraction of occupied patch p



Levins' (spatially implicit) deterministic model

Spatial implicit model

- 1- All patches have the same probability of going extinct
- 2- All patches are equidistant to each other
- 3- Infinitely many patches (removes stochasticity)

Let p the fraction of occupied patch in the landscape

- Extinction happens at a rate e
- Colonization happens at a rate cp

$$\frac{dp}{dt} = \underbrace{cp(1-p)}_{\text{All colonizations}} - \underbrace{ep}_{\text{All extinctions}}$$

Empty patches

Levins' (spatially implicit) deterministic model

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Let p the fraction of occupied patch in the landscape

- Extinction happens at a rate e
- Colonization happens at a rate cp

- Equilibria

$$\frac{dp}{dt} = 0 \Leftrightarrow cp(1-p) - ep = 0$$
$$\Leftrightarrow p^* = 0 \text{ or } p^* = 1 - \frac{e}{c}$$

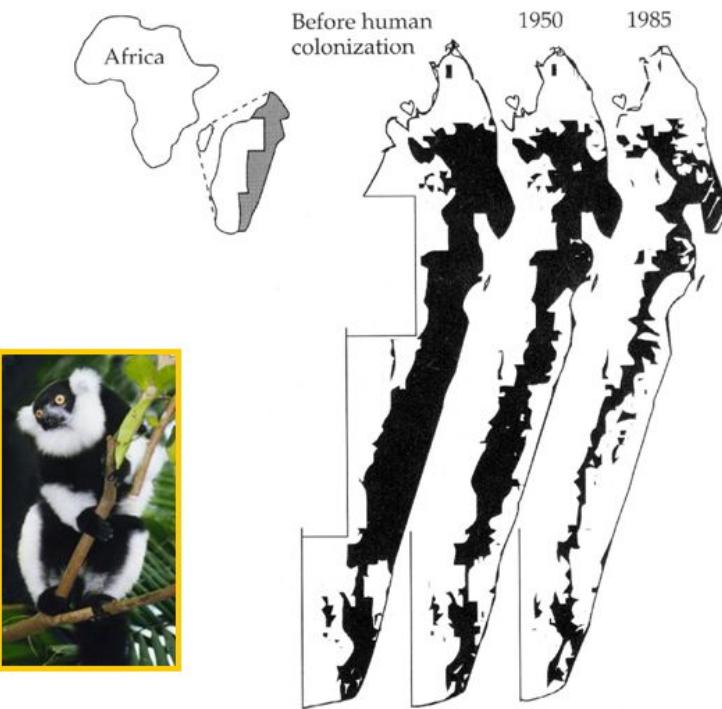
- Persistence if $p^* > 0$, i.e.

$c > e$ (does it make sense?)

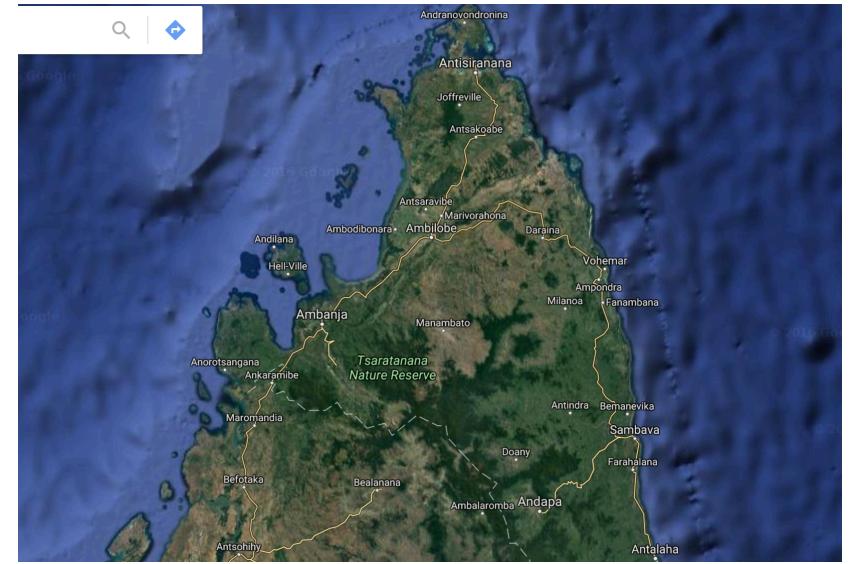
$$\frac{dp}{dt} = \underbrace{cp}_{\text{All colonizations}} \underbrace{(1-p)}_{\text{Empty patches}} - \underbrace{ep}_{\text{All extinctions}}$$

Habitat destruction and extinction threshold

DEFORESTATION AND HABITAT FRAGMENTATION IN MADAGASCAR



Extent of eastern rainforest



Habitat destruction and equilibrium

- If we destroy the habitat, so that **h fraction remains**, the remaining part available for colonization is $h - p$

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

- The new equilibrium is

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

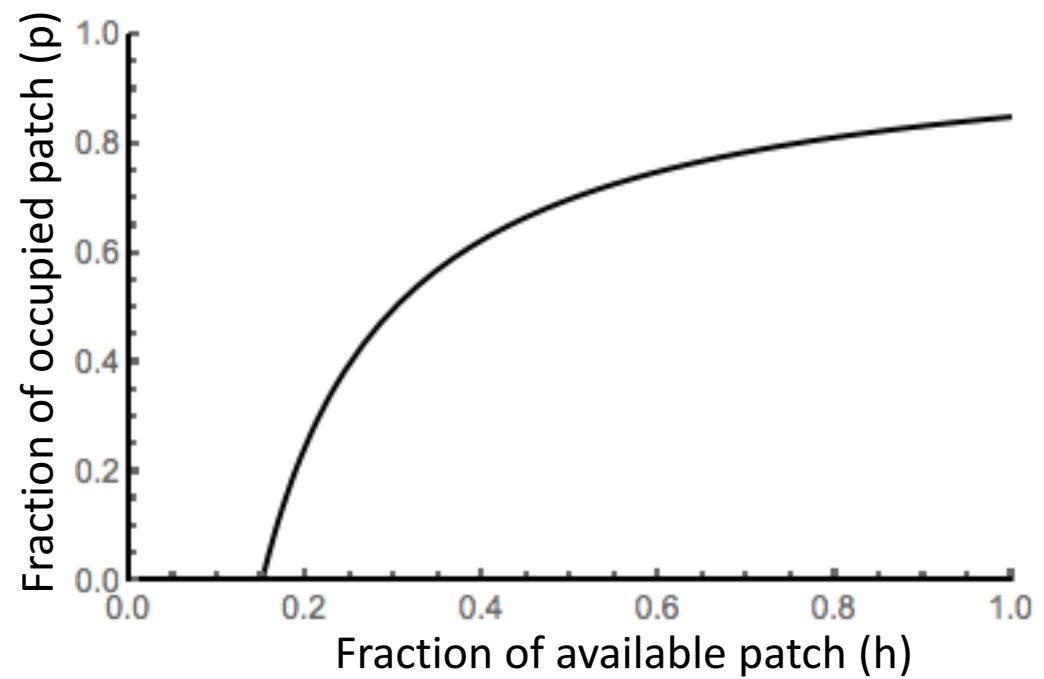
Habitat destruction and equilibrium

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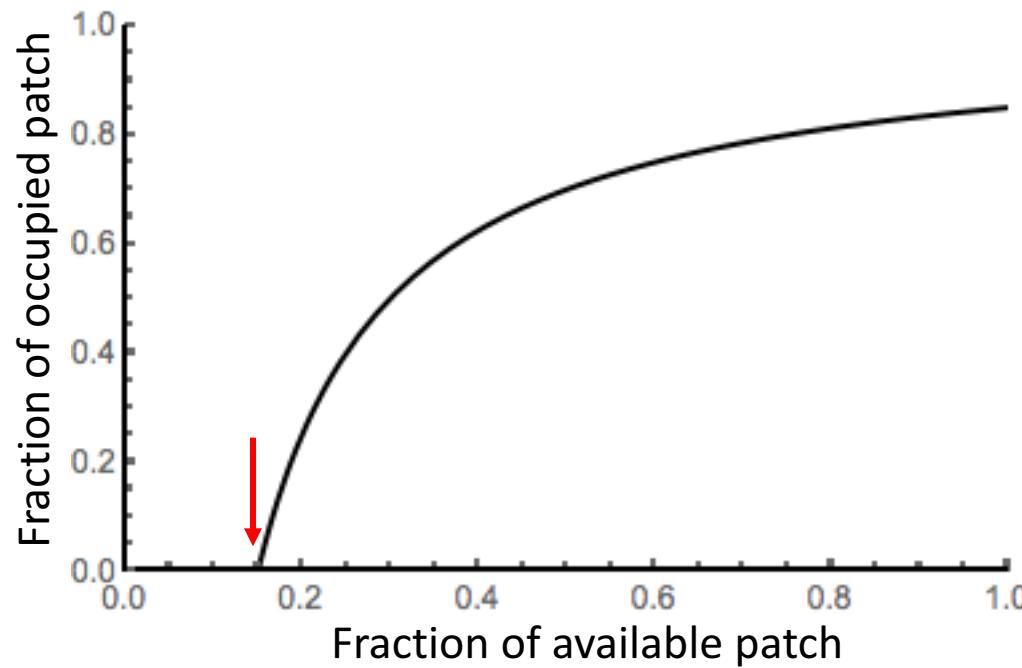
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Habitat destruction and extinction threshold



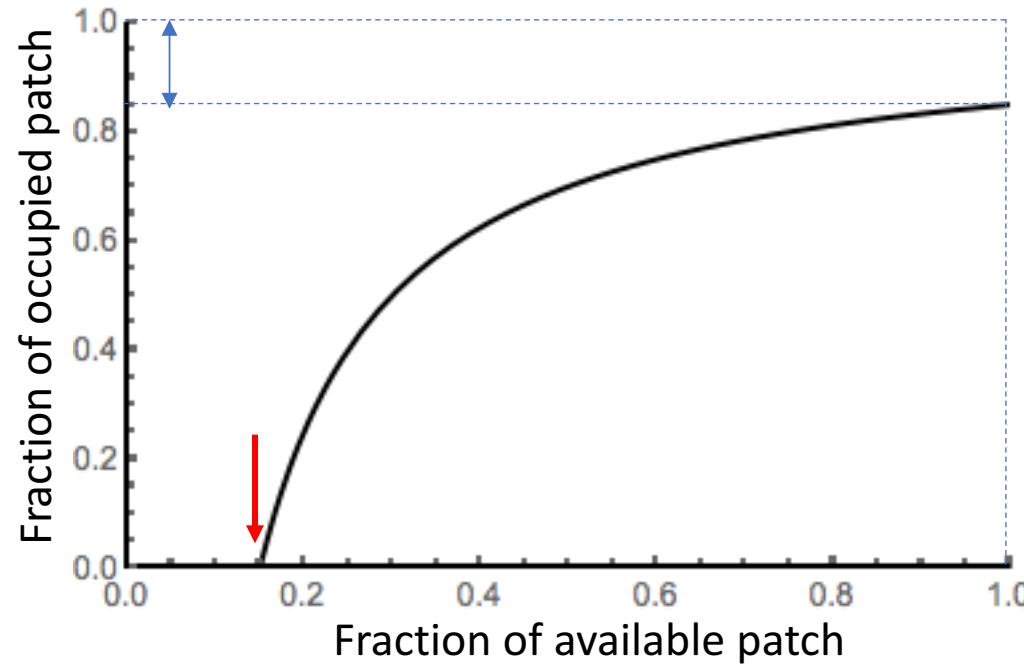
The extinction threshold (↓) is the minimum amount of habitat necessary for the persistence of the metapopulation

$$p^* = 1 - \frac{e/c}{h} > 0$$

i.e.

$$h > e/c$$

Habitat destruction and extinction threshold



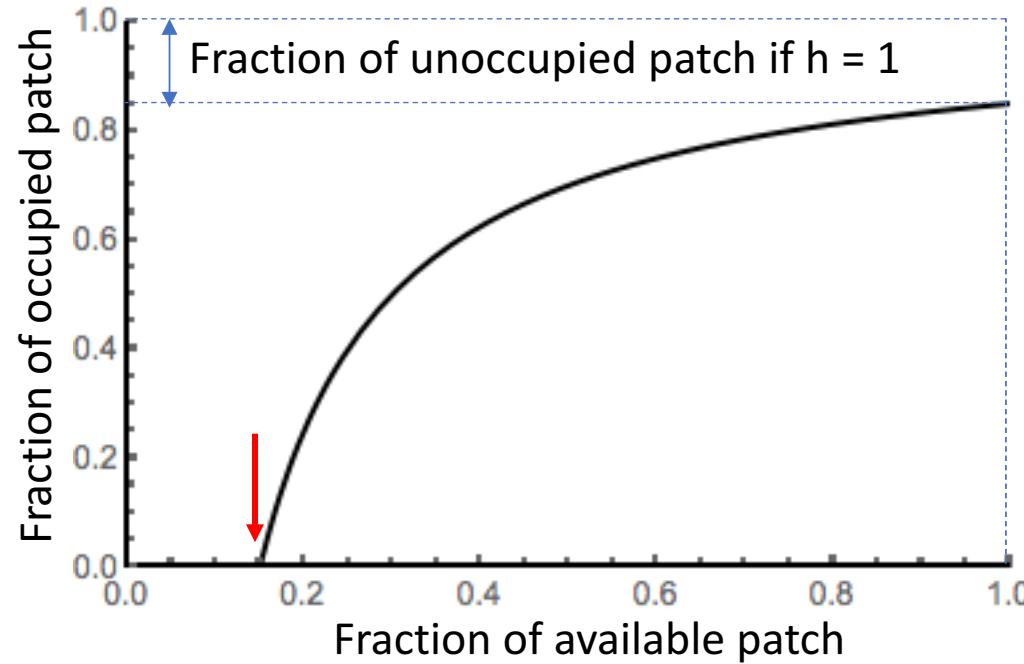
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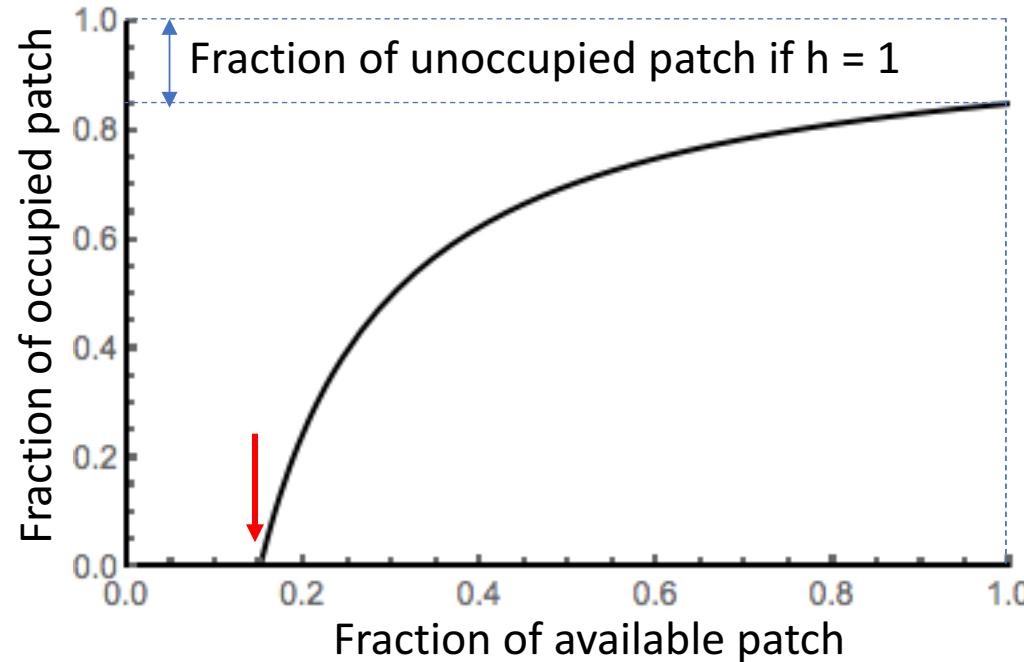
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Habitat destruction and extinction threshold



The extinction threshold (\downarrow) is the minimum amount of habitat necessary for the persistence of the metapopulation

$$p^* = 1 - \frac{e/c}{h} > 0$$

i.e.

$$h > e/c$$

The extinction threshold = the fraction of unoccupied patch at equilibrium when all patches are available

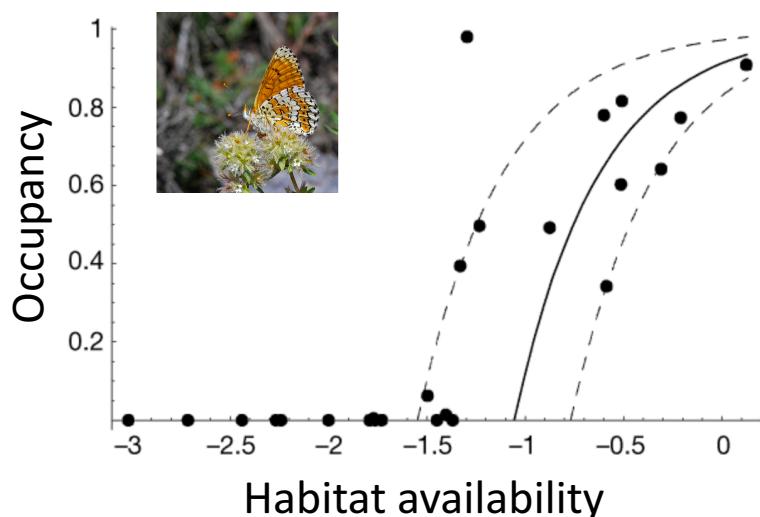
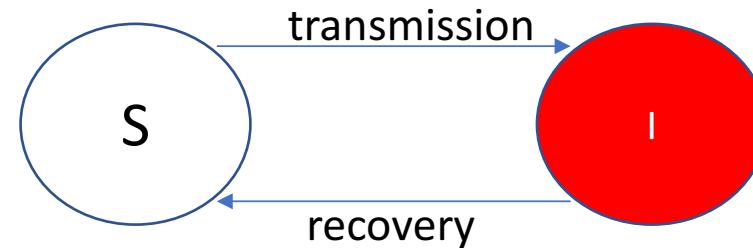
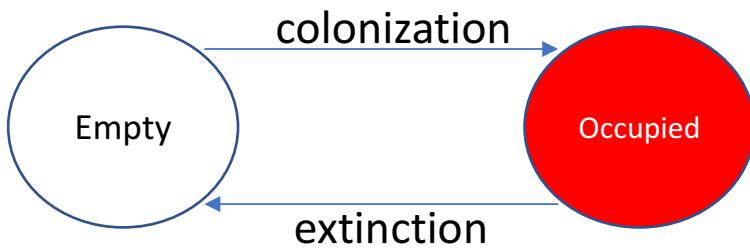
Ecology vs. Epidemiology



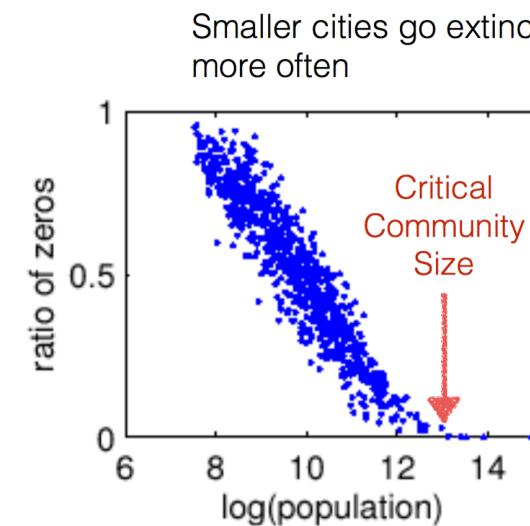
Ecology ~ Epidemiology



Metapopulation ~ Epidemiology: SIS



Hanski & Ovaskainen, 2000, *Nature*



Grenfell et al., 2001, *Nature*

Metapopulation ~ Epidemiology: SIS

Metapopulation

- 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

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

SIS

- 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 individual, the disease is eradicated if

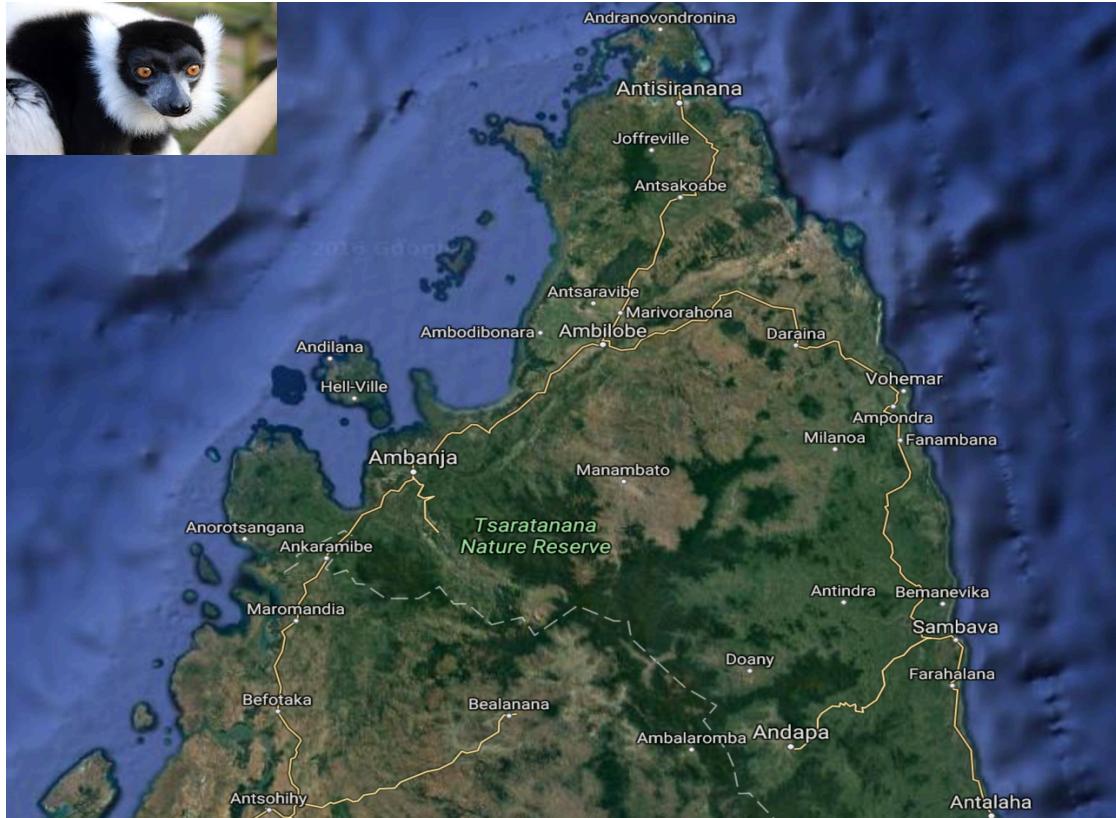
$$h < \frac{\gamma}{\beta} = \frac{1}{R_0}$$

Outline

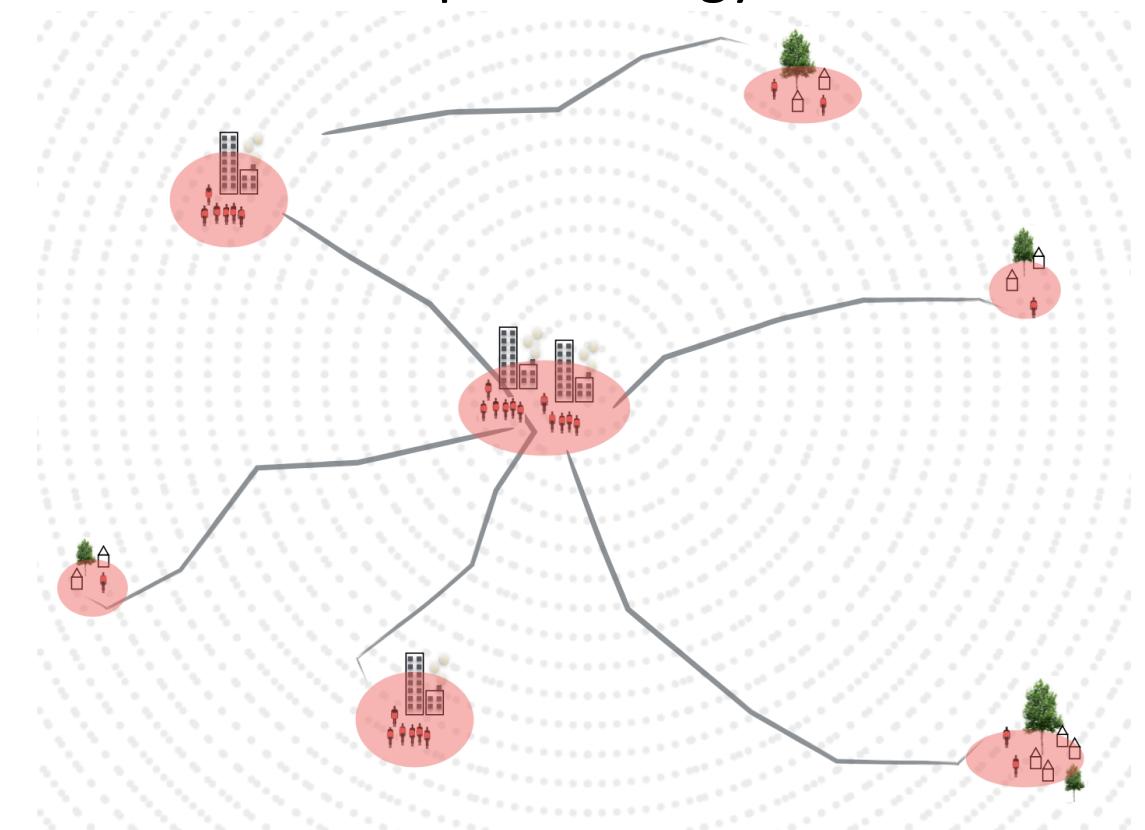
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- **Spatially realistic metapopulation model**
- Software demonstration: SPOMSIM

Spatially realistic metapopulation model

Ecology

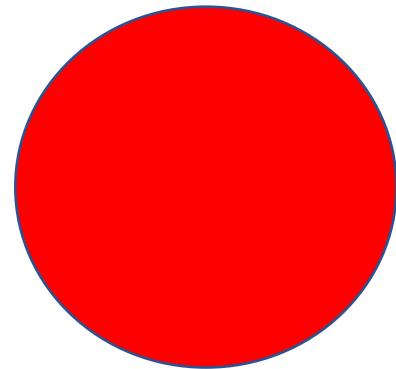


Epidemiology



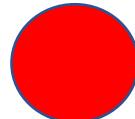
Extinction as a function of patch size

Large patch => large population size



=> Low probability of extinction

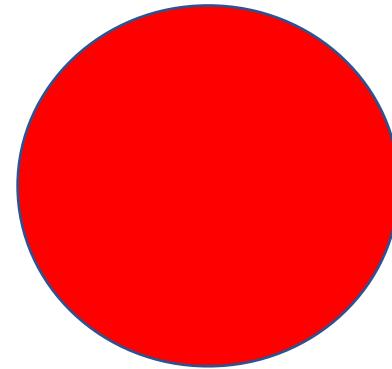
Small patch => small population size



=> High probability of extinction

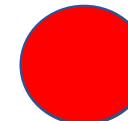
Recovery as a function of human 'condition'

Strong person => ...



=> Quick recovery

Weak person => ...

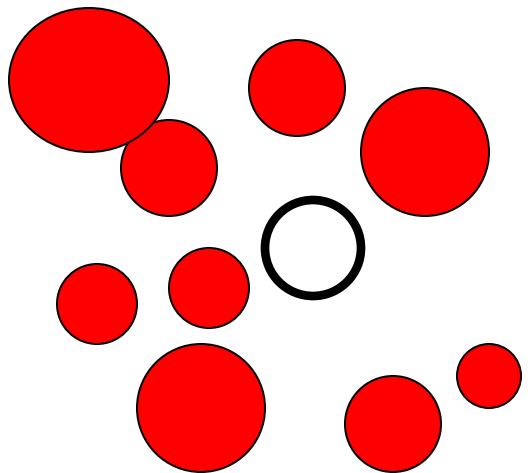


=> Slow recovery

Ecology

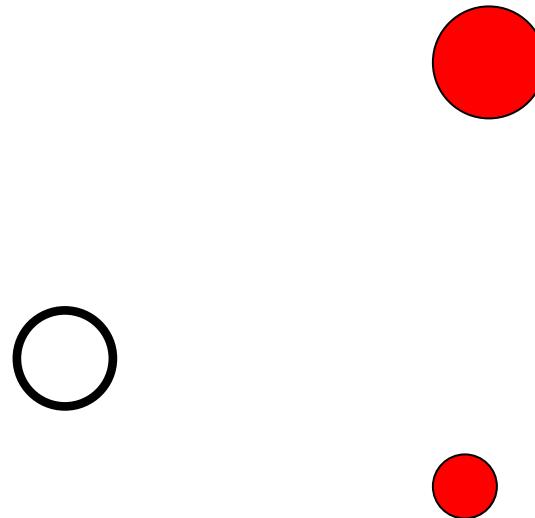
Colonization of an empty patch:
general idea = scales with *connectivity*. Heuristically:

Well-connected focal patch
(many close-by occupied
neighbours)



⇒ **High** probability of
being colonized

Poorly connected
focal patch

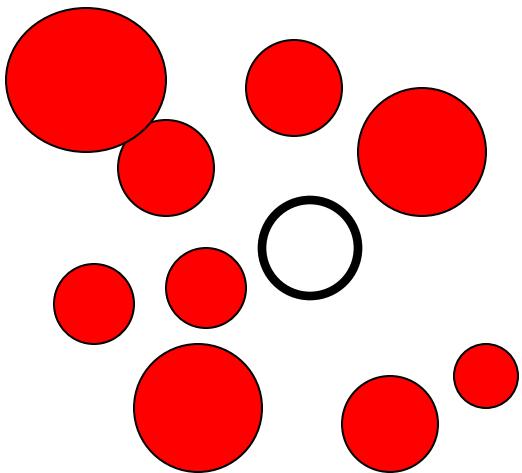


⇒ **Low** probability of
being colonized

Epidemiology

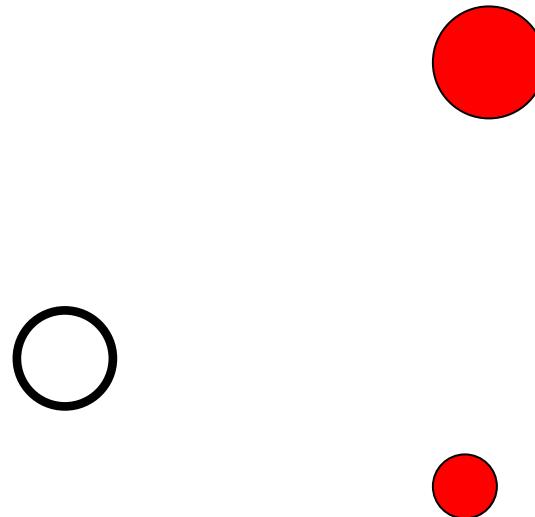
Infection of an healthy person:
general idea = scales with *connectivity*. Heuristically:

Well-connected focal healthy
person
(many sick persons close-by)



⇒ **High** probability of
being infected

Poorly connected
focal health person



⇒ **Low** probability of
being infected

A little bit of math: functional forms

Extinction (recovery) probability

- Assume patch i of size A_i is occupied, the probability of local extinction is

$$prob_e(A_i) = 1 - e^{-e/A_i}$$

A little bit of math: functional forms

Extinction (recovery) probability

- Assume patch i of size A_i is occupied, the probability of local extinction is

$$prob_e(A_i) = 1 - e^{-e/A_i}$$

Colonization (transmission) probability

- Assume patch i of size A_i is empty, the probability of local colonization is

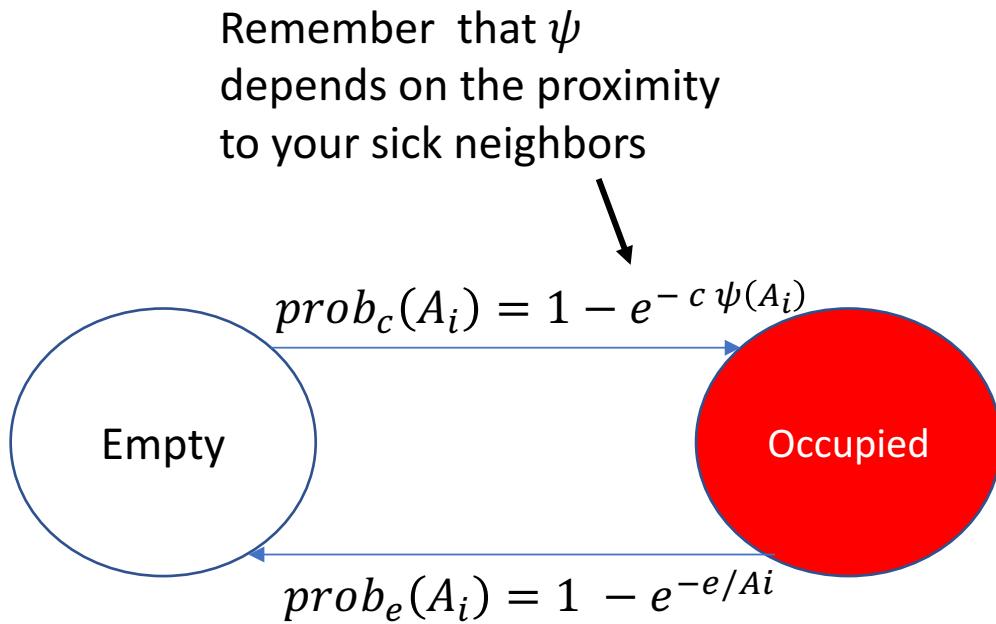
$$prob_c(A_i) = 1 - e^{-c \psi(A_i)}$$

- $\psi(A_i)$ represents the connectivity of the patch i

$$\psi(A_i) = A_i \sum_{A_j \in source} A_j e^{-\kappa d_{ij}}$$

- $e^{-\kappa d_{ij}}$ is called a dispersal kernel

Simulation



'for' loop for each time step

- If patch 1 is empty, it has a probability $prob_c(A_1)$ to be colonized for next year
- If patch 1 is occupied, it has a probability $prob_e(A_1)$ to go extinct for next year

Repeat that procedure for all the patches in the system and we get the next state of the metapopulation



Extinction threshold in the realistic model

- In the Levins' model, the equilibrium was

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

Extinction threshold in the realistic model

- In the Levins' model, the equilibrium was

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

- In the realistic model, we have a similar relationship

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

- λ_M summarizes the role of dispersal, landscape structure, and the dominant eigenvalue of a something called “landscape” matrix.
- λ_M is called the **metapopulation capacity**

Outline

- Metapopulation paradigm
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- Spatially realistic metapopulation model
- **Software demonstration: SPOMSIM**

SPOMSIM: Stochastic Patch Occupancy Model Simulation



Available online at www.sciencedirect.com



Ecological Modelling 179 (2004) 533–550

**ECOLOGICAL
MODELLING**

www.elsevier.com/locate/ecolmodel

**SPOMSIM: software for stochastic patch occupancy
models of metapopulation dynamics**

Atte Moilanen*

*Department of Biological and Environmental Sciences, Metapopulation Research Group, University of Helsinki,
PO Box 65 (Viikinkaari 1), Helsinki FIN-00014, Finland*

Received 7 July 2003; received in revised form 29 March 2004; accepted 29 April 2004

SPOMSIM: Stochastic Patch Occupancy Model Simulation

The screenshot shows a web browser window for the URL cbig.it.helsinki.fi. The page is titled "C-BIG Conservation Biology Informatics Group" and features a logo of a stylized bird or flame. Below the title, it says "University of Helsinki, Department of Biosciences". A navigation bar at the top includes links for HOME, PEOPLE, CONTACT INFO, RESEARCH, PUBLICATIONS, SOFTWARE (which is highlighted in blue), and OUTREACH.

The main content area has a heading "Other Software SPOMSIM and RSW2". Under "SPOMSIM", there is a link to download the software: [Download SpomSim: spomsetup.exe](#). A description of the software follows: "SPOMSIM 1.0 . Software for the analysis of SPOMs, Stochastic Patch Occupancy Models of metapopulation dynamics. Includes e.g SPOM definition, simulation, parameter estimation, patch system editing, reserve network design etc." To the right of this section is a sidebar with a "Software" section containing links to Zonation and RobOff, and an "Other software" section containing links to More on RSW2, Components of RSW2, and RSW2 References.

Below the SPOMSIM section is another heading, "RSW2 – Reserve Selection with Weights", with a download link: [Download RSW2](#). A detailed description of the RSW2 program is provided: "RSW2 is a program for solving maximum coverage -type reserve selection problems, where one seeks to maximize conservation value obtained with a limited budget. The novelty in this program is that the conservation value of a reserve network is not merely the number of species represented in it, but is derived using several optional features that make conservation planning more realistic. These include differential species weights according to their conservation priority, continuous benefit functions for species representation, refinements for site size based on the species-area relationship and combining quantitatively site value (replacement cost (by christina at dhead)) with urgency of protection (vulnerability). The software calculates replacement costs for

Conclusions

Spatial models are needed when:

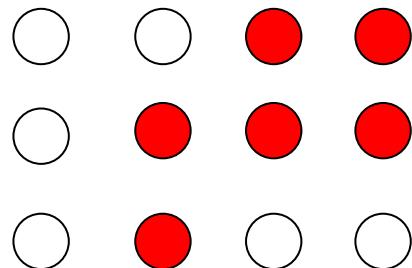
- the question involves both the distribution and abundance of a species/disease
- When dispersal and landscape structure are important processes

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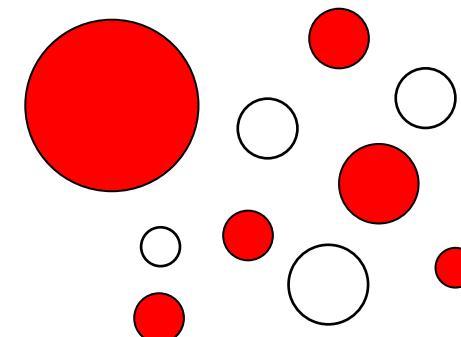
Spatially implicit: homogenous



$$\text{Habitat quality} > \frac{\text{extinction rate}}{\text{colonization rate}}$$

$$\text{Susceptible} > \frac{\text{recovery rate}}{\text{transmission rate}}$$

Spatially realistic: heterogeneous

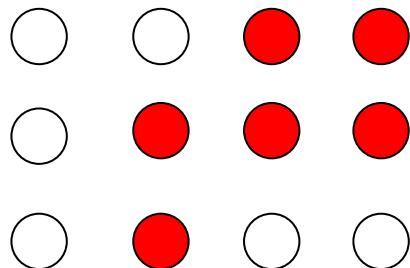


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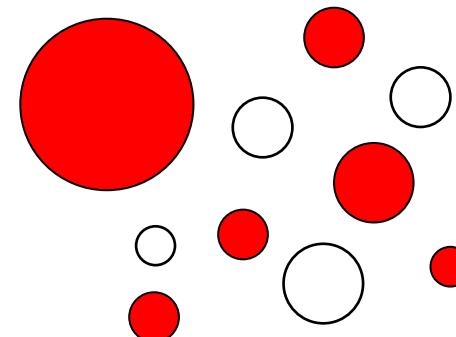
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Metapopulation theory helps to understand dynamics of population in a fragmented landscape