BIOL 410 Population and Community Ecology

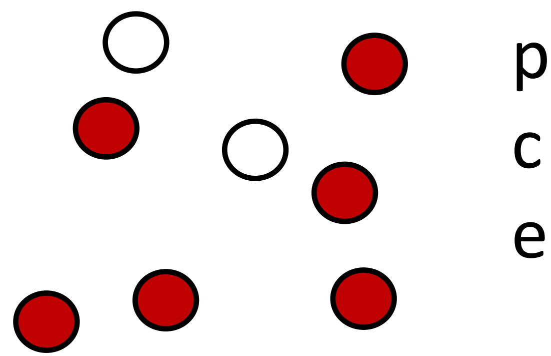
Incidence function model

Stochastic patch occupancy model

Metapopulation and patch occupancy

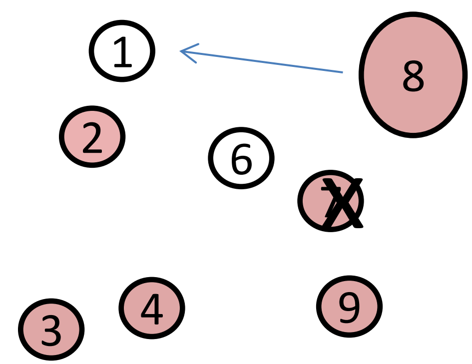
- Levin's classic metapopulation

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



- Patch occupancy model
  - State of individual patches

Time	Patch	occupancy
1	6	1
2	7	0
3	8	1



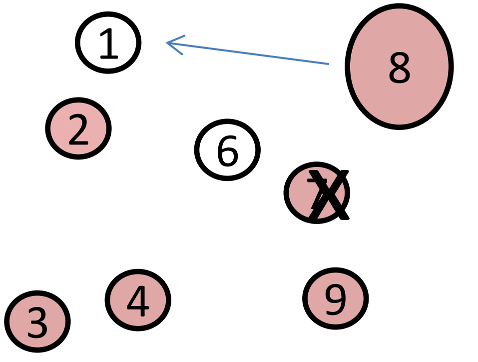
Patch occupancy models

- Why?
  - Develop fundamental theory (distribution, occurrence, extinction, connectivity)
  - Facilitate qualitative/ quantitative predictions for conservation
    - Evaluate the effects of fragmentation and habitat loss
    - Reserve network design
    - Metapopulation viability analysis
    - Study the feasibility of reintroduction

Patch occupancy

- Occupied, not occupied

- Local dynamics and extinction
- Emigration
- Movement
- Immigration
- Colonization



Factors affecting local dynamics and local extinction

- Population size (density)
- Emigration
- Immigration
- Population growth rate
- Species interactions

- Patch
  - Size
  - Quality (food, breeding)

- Stochastic factors
  - Environmental stochasticity
  - Demographic stochasticity
  - Catastrophes
  - Genetics
  - Human influence

- Habitat loss

Factors affecting emigration

- Patch
  - Size
  - Quality
  - Shape
  - Edge quality

- Population density

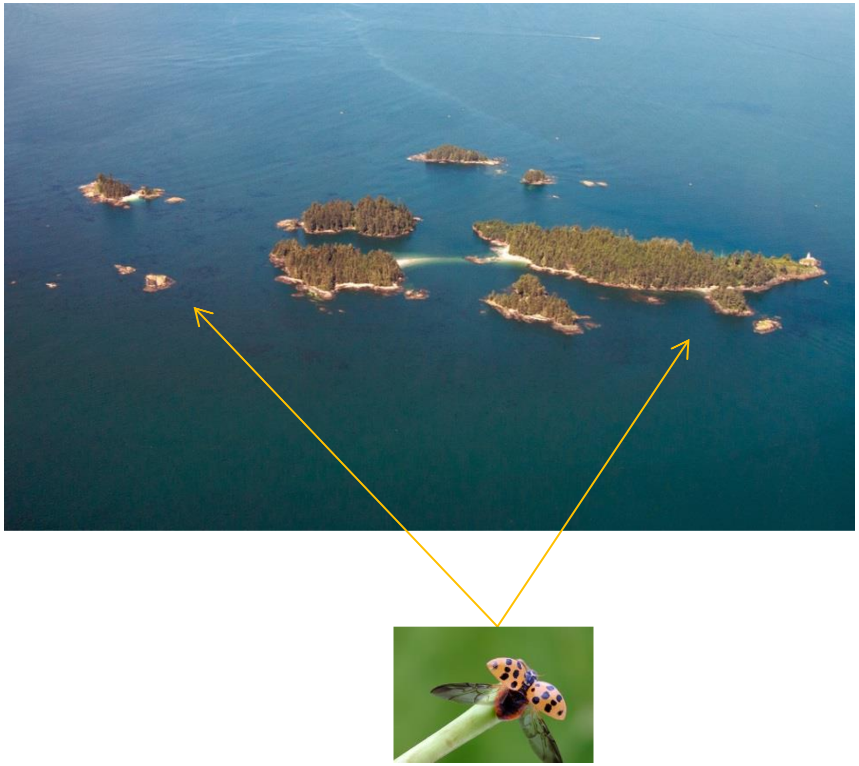
Factors affecting movement

- The habitat matrix
  - habitat types
  - "texture" of habitat patterns
  - Distance between patches
- Behaviour of the species
  - Habitat specific movement and mortality rates
  - Edge effects
  - Species perceptual ability
  - Dispersal cues (conspecific attraction etc.)

Connectivity

Factors affecting immigration

- Patch detection ability of the species
  - Active vs. passive
- Patch
  - Size
  - Shape
  - Boundary quality
  - Quality
- Population size/desntiy



Factors affecting colonization

- Number of immigrants
- Patch quality
- Population density (possible Allee effects etc.)

Marmot

Factors affecting all metapopulation processes

- Species interactions
  - Predation, competition, mutualism etc.

- Regional stochasticity
  - Spatially correlated environmental stochasticity
    - Caused by weather, disease, etc.
    - Caused by correlation in local dynamics / migration
    - Can have strong impact on metapopulation persistence

Glanville fritillary butterfly

1993: 250 populations (occupied patches)
1994: 130 populations
Decline due to larval mortality resulting from dry summer

Stocastic Patch Occupancy Models (SPOMs)

- Basic assumption
  - Local dynamics are very complex to model
    - Ignore local dynamics and only model species presence / absence in habitat patches
  - Kareiva & Steinberg (1997)
    - “the presences / absence assumption is almost necessary in large scale ecological studies”
  - Relatively easy data to collect
  - Original SPOM, Incidence Function Model (IFM)
    - Hanski, 1994

SPOM

Journal of Animal Ecology 1994, **63**, 151–162

A practical model of metapopulation dynamics

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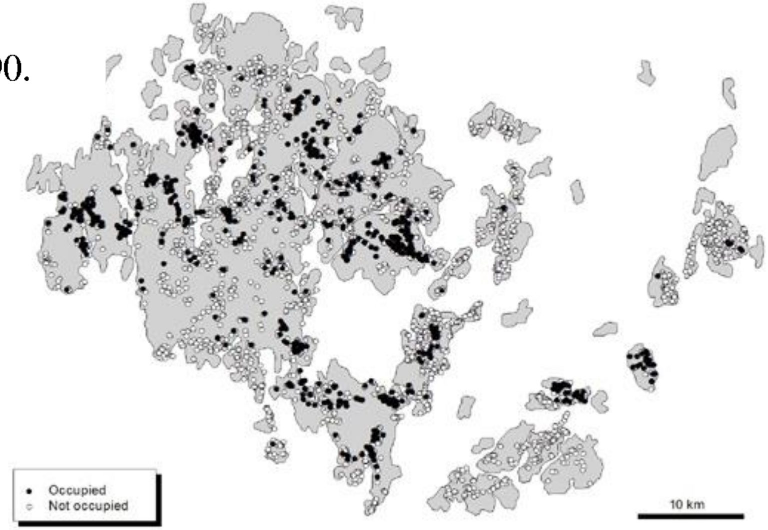
The Quantitative Incidence Function Model and Persistence of an Endangered Butterfly Metapopulation

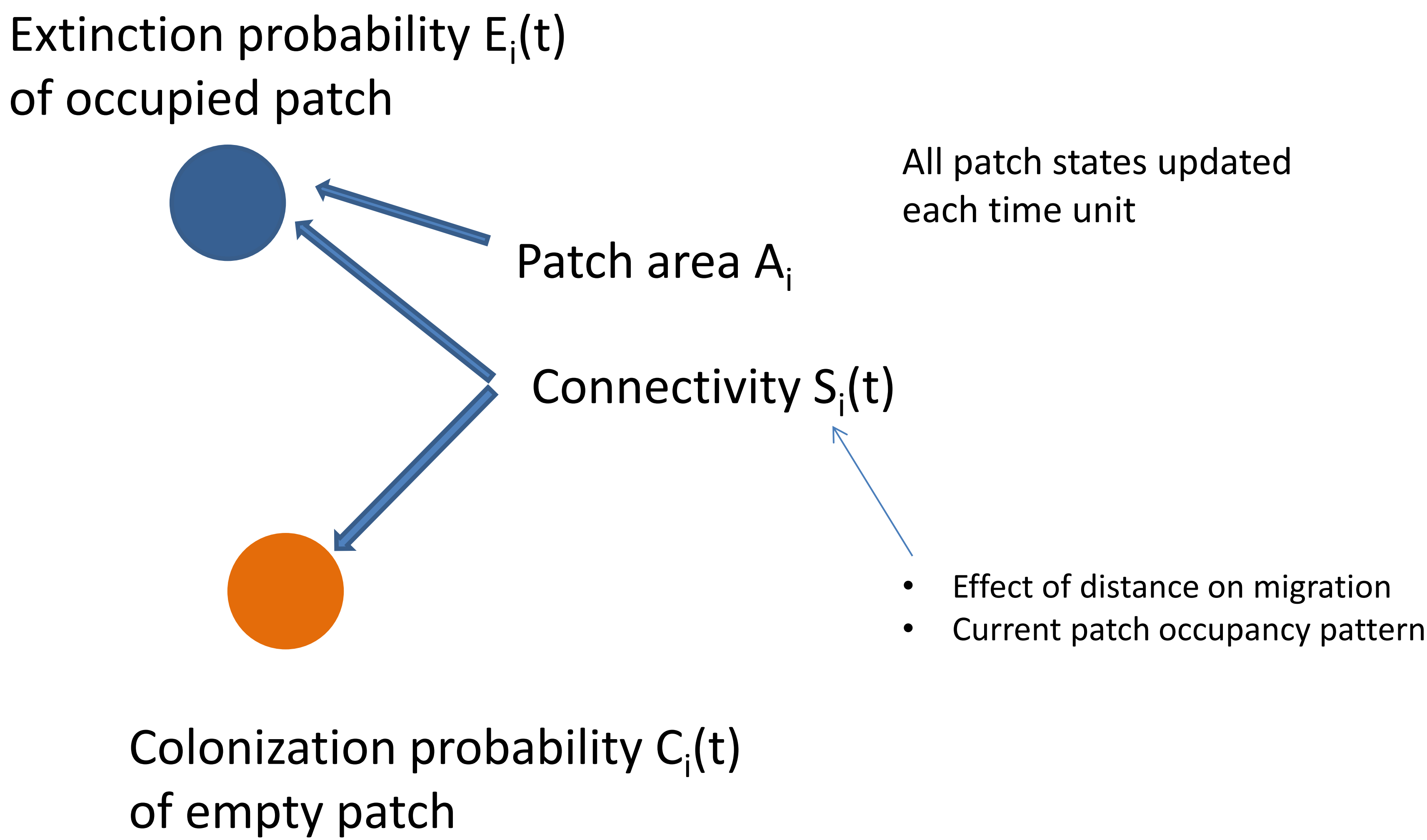
Ilkka Hanski; Atte Moilanen; Timo Pakkala; Mikko Kuussaari

Conservation Biology, Vol. 10, No. 2 (Apr., 1996), 578-590.



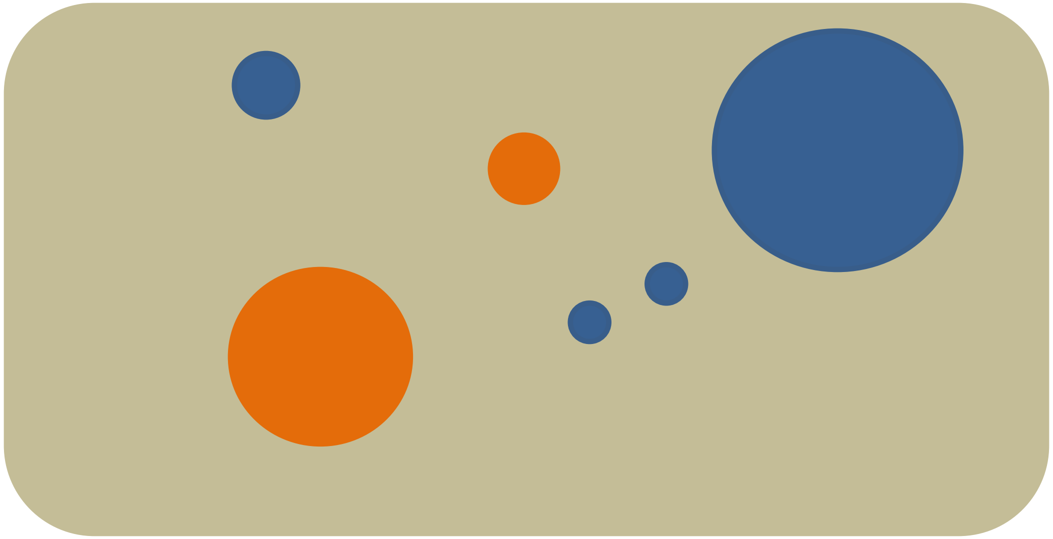
Åland islands Finland

SPOM: general structure



SPOMs: common simplifications

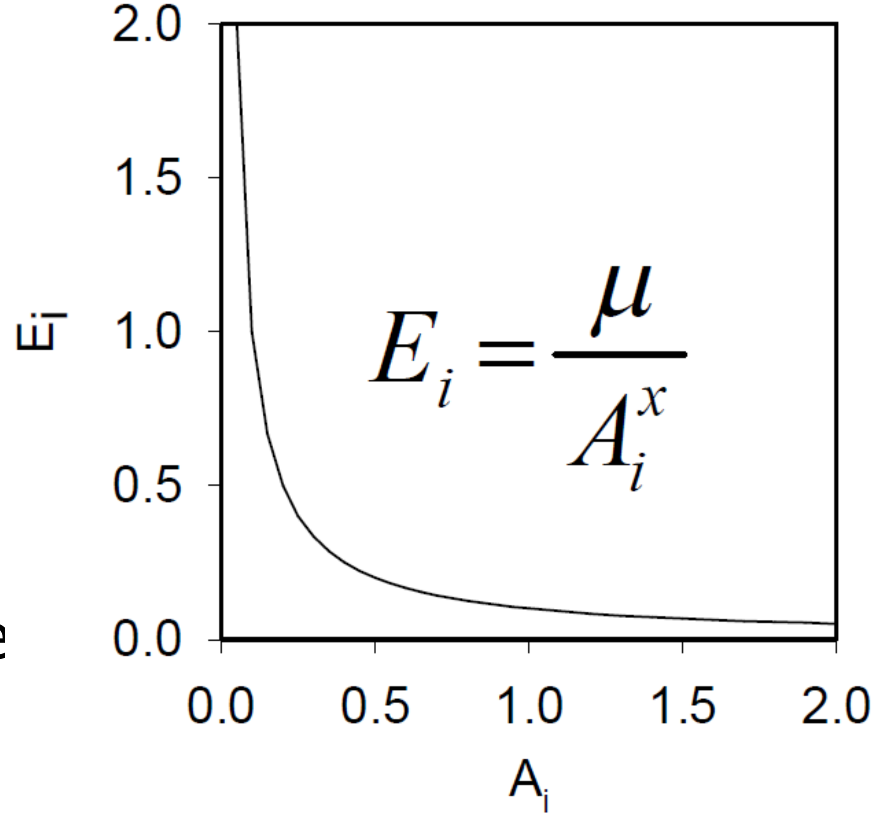
- Patches have sizes but no shape
- Patch quality is constant
- Habitat matrix is uniform quality
- Regional stochasticity is often ignored



Extinction
colonization

Local extinction model: example

- Decreasing function of area
- Ai = area of patch I
- μ and x are parameters
  - μ minimum patch size



Local migration: example

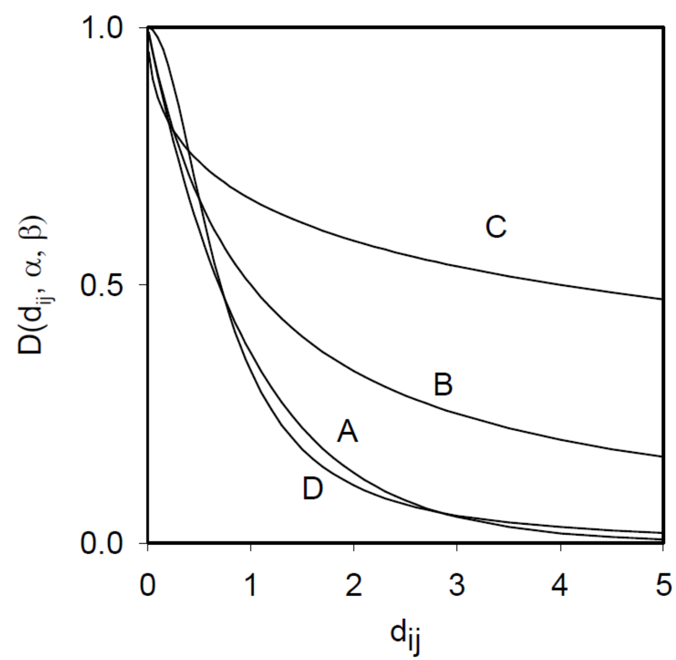
- Migration success decreasing function of distance
- "the dispersal kernel"
- A (negative exponential)

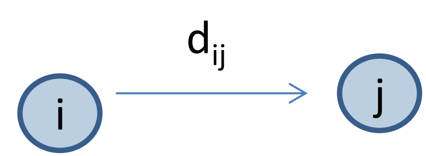
$$D(d_{ij}, \alpha) = \exp(-\alpha d_{ij})$$

- B,C,D (fat tailed)

$$D(d_{ij}, \alpha, \beta) = \frac{1}{1 + \alpha d_{ij}^{\beta}}$$

- d_{ij} = distance from i to j





SPOM: colonization

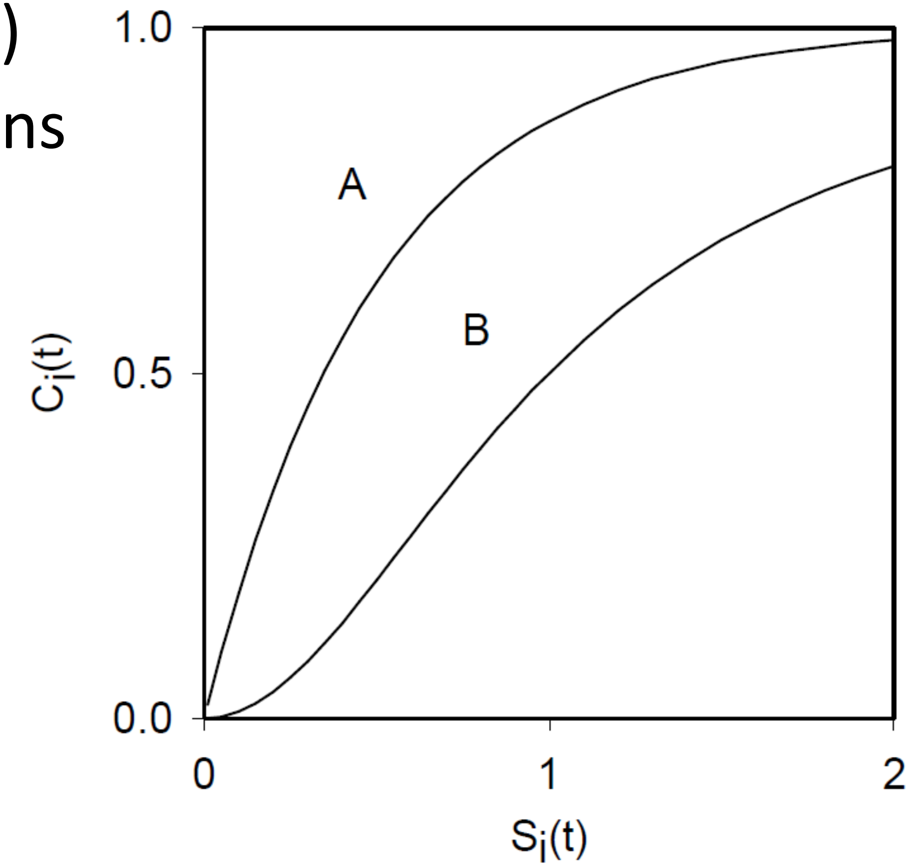
- Colonization probability of patch i, $C_i(t)$=f(connectivity)
- A: independent colonizations

$$C_i(t) = 1 - \exp(-yS_i(t))$$

- B: Alee effects

$$C_i(t) = \frac{[S_i(t)]^2}{[S_i(t)]^2 + y^2}$$

- $S_i(t)$ = connectivity
- y = parameter



SPOMs: regional stochasticity

- Spatial correlation in extinctions and/or colonizations (weather etc.)
- Approaches
  - Synchronous variation in patch areas
    - Bad year A_i decreases, good year A_i increases
    - Modelling alternatives
      - Synchronous over the entire metapopulation
      - Synchronous within patch clusters, different between clusters
      - Synchronous for different habitat patch classes

  - Enormous effect on predicted metapopulation extinction probabilities

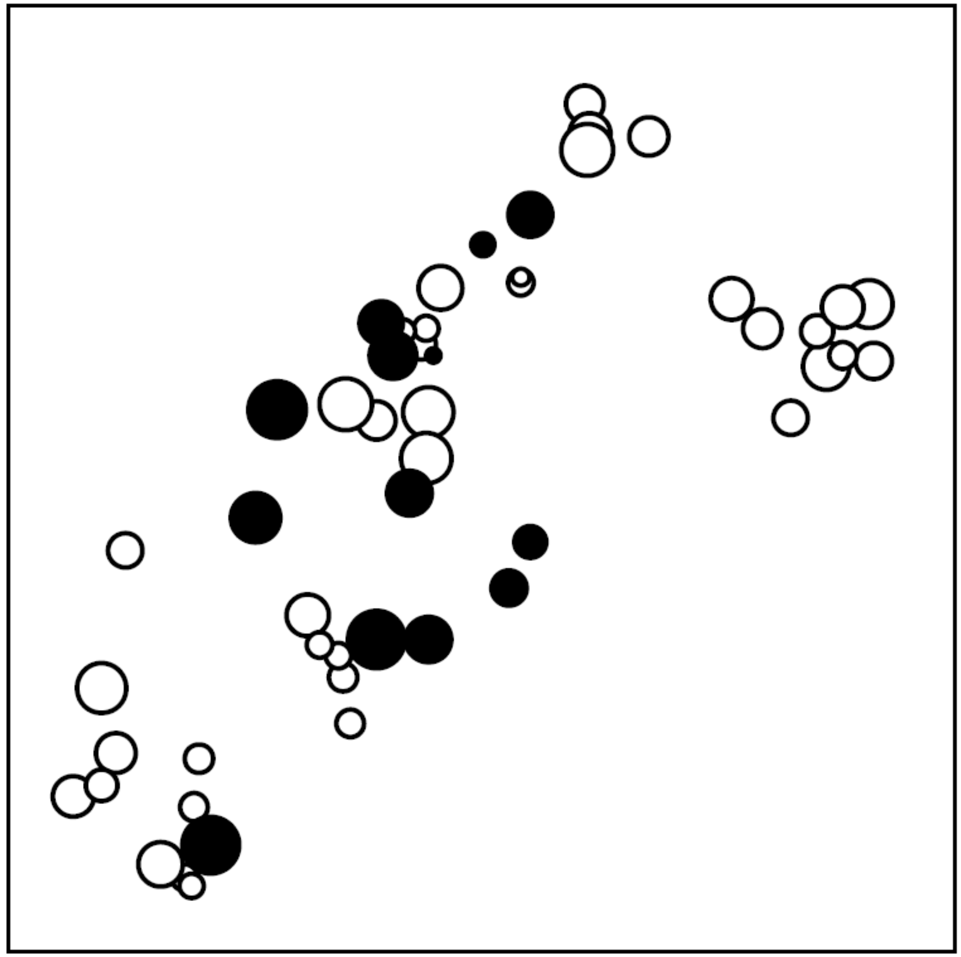
Connectivity in metapopulations

- Connectivity is a critical component of all spatial models

- Many different connectivity measures used in literature
- Most connectivity measures can be classified as
  - Nearest neighbor measures
  - Buffer measures
  - IFM measures

  - Result in large differences in projections and model behaviour

Patch occupancy models

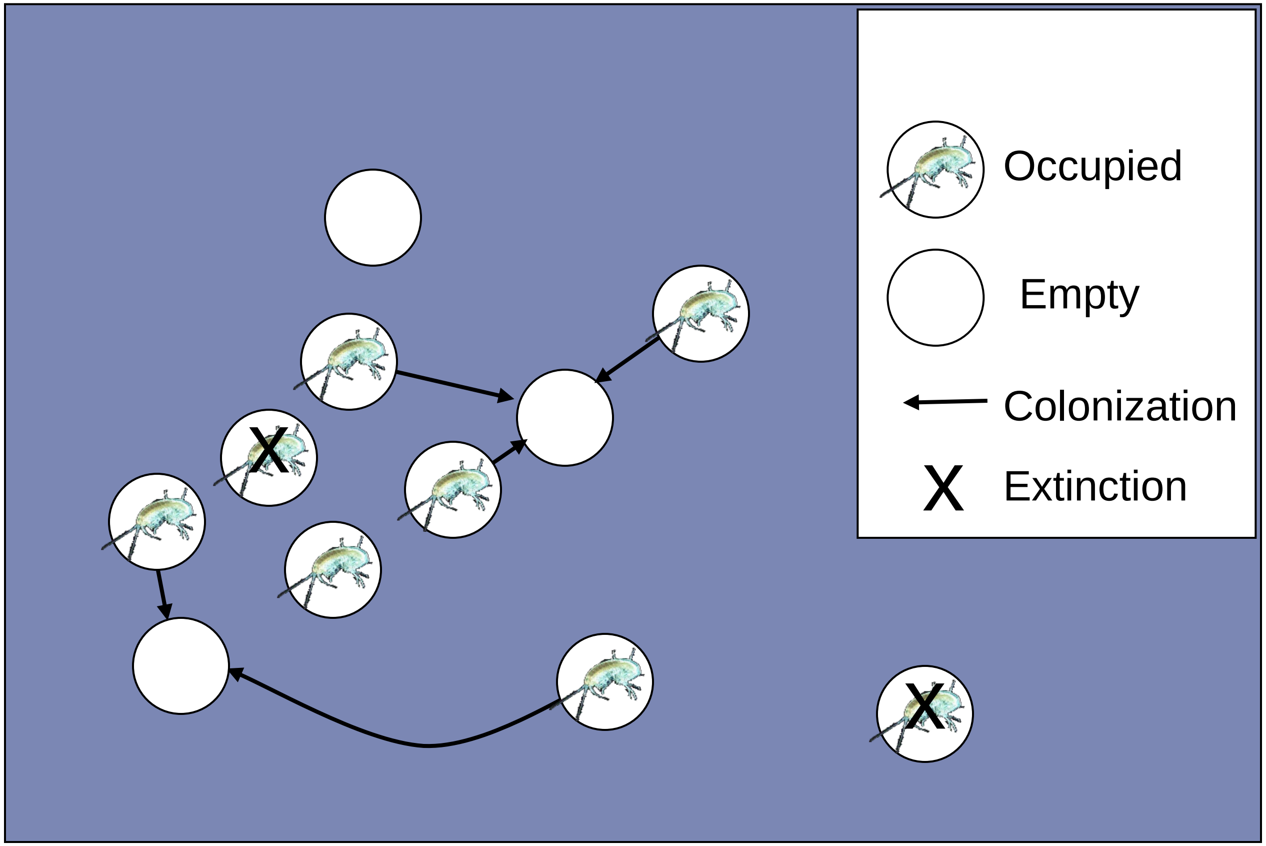


- How to characterize connectivity

Comparing connectivity measures

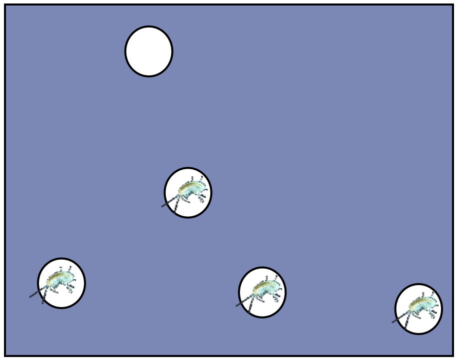
- NN considered poor (base on past performance)
- Best performance of buffer and IFM measures approximately equal
  - Buffer measures sensitive to estimation of buffer radius
  - Inclusion of focal patch size always improves results

Stochastic Patch Occupancy Model



Incidence function model

time t



$$\begin{matrix} X_1(t) \\ X_2(t) \\ X_3(t) \\ X_4(t) \\ X_5(t) \end{matrix} \begin{bmatrix} 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

- Hanski 1994, 1996
- Fist-order linear Markov chain
- The stationary probability of patch i being occupied is given by:

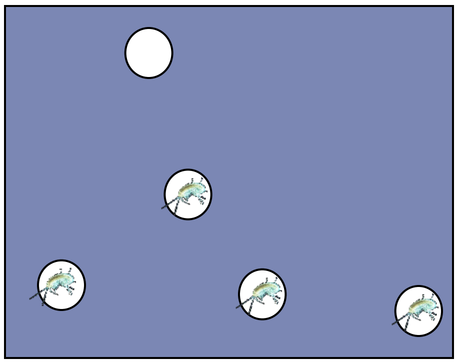
$$J_i = \frac{C_i}{C_i + E_i}$$

$$C_i(t) = \frac{[S_i(t)]^2}{[S_i(t)]^2 + y^2}$$

$$E_i = \frac{\mu}{{A_i}^x}$$

Incidence function model

time t



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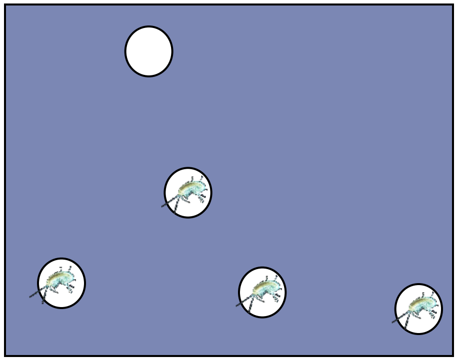
Incidence function model

time t



$$\begin{bmatrix} X_1(t) & 0 \\ X_2(t) & 1 \\ X_3(t) & 1 \\ X_4(t) & 1 \\ X_5(t) & 1 \end{bmatrix}$$

$$C_i(t) = \frac{[S_i(t)]^2}{[S_i(t)]^2 + y^2} \qquad E_i = \frac{\mu}{{A_i}^x}$$

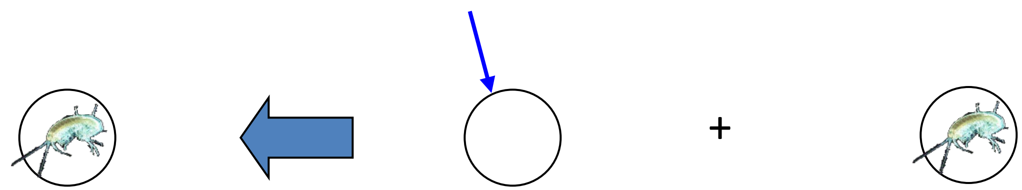
$$J_i = \frac{C_i}{C_i + E_i}$$

- IFM
  - Estimate parameters using maximum likelihood regression (or other)
- Then?
  - Numerically iterate population dynamics
  - Transient dynamics, steady state
  - Importance of patch structure?
  - Importance of individual patches?
  - Likelihood of metapopulation survival

Markov process: conlonization since last observation

Next State X(t+1)

Current State X(t)



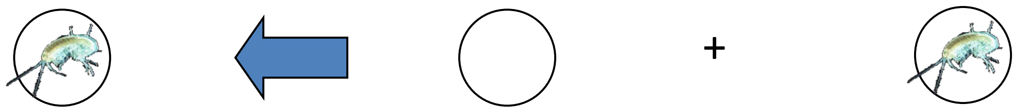
$$\Pr\{X(t+1)=1\}=\big(1-X(t)\big)p_c+X(t)\big(1-p_e\big)$$

1 if not occupied

colonization probability

Markov process: extinction since last observation

Next State X(t+1) Current State X(t)

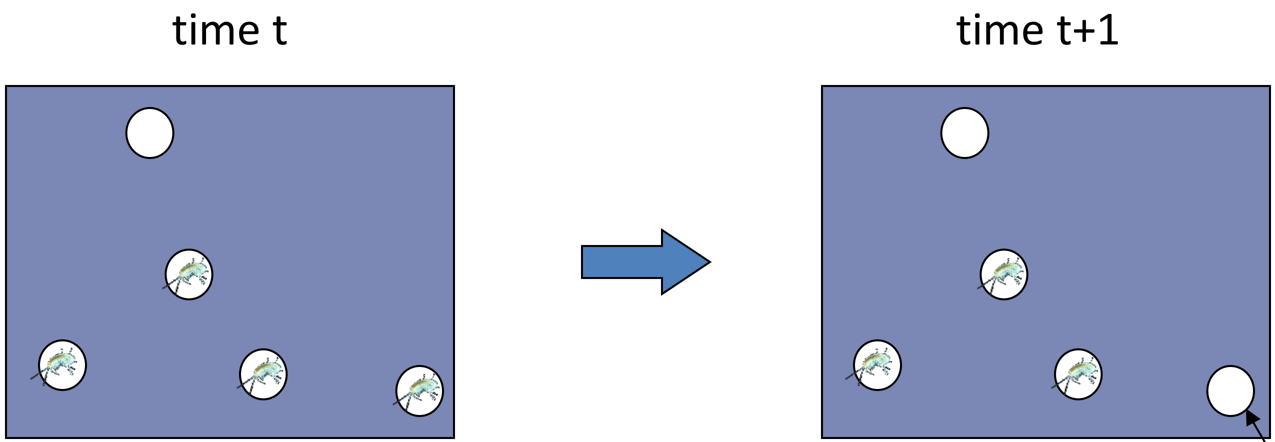


$$\Pr\{X(t+1)=1\}=(1-X(t))p_c+X(t)(1-p_e)$$

1 if occupied

probability of not going extinct

State changes through time



$$\begin{matrix} X_1(t) \\ X_2(t) \\ X_3(t) \\ X_4(t) \\ X_5(t) \end{matrix} \begin{bmatrix} 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \xrightarrow{\text{1 extinction}} \begin{bmatrix} 0 \\ 0 \\ 1 \\ 1 \\ 1 \end{bmatrix} \begin{matrix} X_1(t+1) \\ X_2(t+1) \\ X_3(t+1) \\ X_4(t+1) \\ X_5(t+1) \end{matrix}$$