Metapopulation models

A **metapopulation** is a population of subpopulations linked by dispersal.

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Properties

- Subpopulations occur in discrete habitat patches.
- The landscape "matrix" is not suitable for reproduction.

- Many populations are fragmented.

Motivation

- Many populations are fragmented.
- Metapopulation models can be used to forecast dynamics of fragmented populations.

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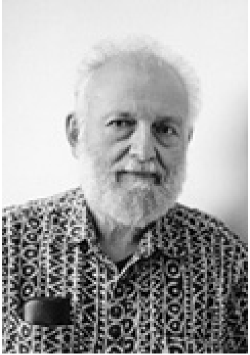
- Metapopulation models can be used to forecast dynamics of fragmented populations.
- Models can be used to identify critical habitat patches or locations for establishing new subpopulations.

Richard Levins



First metapopulation models were parameterized in terms of the proportion of patches occupied.

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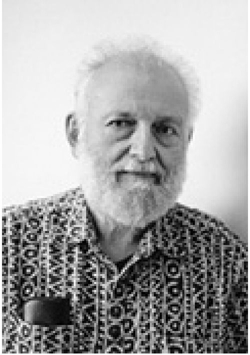
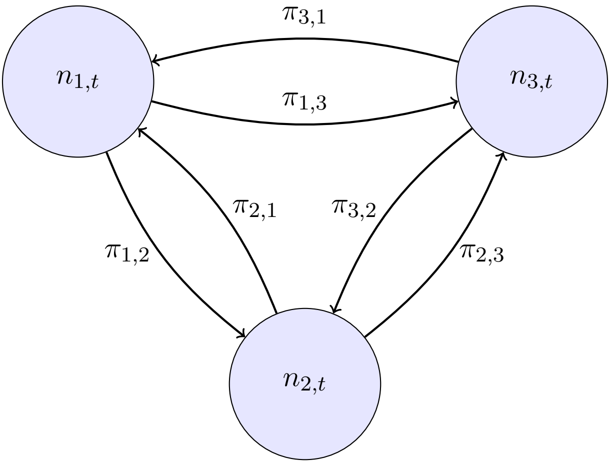


First metapopulation models were parameterized in terms of the proportion of patches occupied.

Modern models are formulated in terms of patch-specific occupancy or abundance.

A simple case with only three subpopulations

$$N_t = n_{1,t} + n_{2,t} + n_{3,t}$$



The movement probabilities ($\pi_{i,j}$) indicate the proportion of individuals moving from patch i to patch j

Building the metapopulation model for the first subpopulation.

$$n_{1,t+1} = n_{1,t}\lambda_1$$

Three components

(1) Geometric growth

Building the metapopulation model for the first subpopulation.

$$n_{1,t+1} = n_{1,t}\lambda_1(1 - \pi_{1,2} - \pi_{1,3}) +$$

Three components

(1) Geometric growth

(2) 1 minus emigration rates

Building the metapopulation model for the first subpopulation.

$$n_{1,t+1} = n_{1,t}\lambda_1(1 - \pi_{1,2} - \pi_{1,3}) + n_{2,t}\lambda_2(\pi_{2,1}) + n_{3,t}\lambda_3(\pi_{3,1})$$

Three components

(1) Geometric growth

(2) 1 minus emigration rates

(3) Immigration from subpopulations 2 and 3

The movement probabilities ($\pi_{i,j}$) represent the outcomes of both immigration and emigration.

What influences these probabilities?

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What influences these probabilities?

Examples

- Habitat quality in the patch of origin
- Habitat quality in the landscape between origin and destination patches
- Habitat quality in the destination patch
- Distance between patches

Source

A patch with $\lambda > 1$. Sources tend to be net exporters of individuals.

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Sink
A patch with $\lambda < 1$. Sinks would go extinct in the absence of immigration.

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A patch with $\lambda < 1$. Sinks would go extinct in the absence of immigration.

Ecological trap
A sink that animals incorrectly perceive as a high quality source.

Can we identify sources, sinks, and traps by estimating patch-specific density (at one point in time)?

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DENSITY AS A MISLEADING INDICATOR OF HABITAT QUALITY

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Abstract: Current methods of evaluating wildlife habitat for management purposes can be arranged in a hierarchy of increasing generality. The most general level is evaluation of wildlife habitat for entire communities on the basis of inferences drawn from vegetational structure. At the base of the hierarchy the high resolution studies, upon which accuracy at the higher hierarchical levels depends, usually assume that habitat quality for a species is positively correlated with the density of the species. If habitat quality for a wildlife species is a measure of the importance of habitat type in maintaining a particular species, habitat quality should be defined in terms of the survival and production characteristics, as well as the density, of the species occupying that habitat. Situations in which habitat quality thus defined is not expected to be positively correlated with density are described, along with the species and environmental characteristics that are most likely to produce these situations. Examples drawn from the literature in which density and habitat quality are not positively correlated are described. The positive correlation of density with habitat quality in specific instances cannot be assumed without supporting demographic data.

J. WILDL. MANAGE. 47(4):893–901

Assignment: Read this paper and be prepared to discuss it.

Occupancy models

Emphasis on stochastic patch-level dynamics

- What is the probability that a patch will be occupied?

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- What is the probability that a patch will be occupied?
- What is the probability that an empty patch will be colonized?
- What is the probability that a subpopulation will go locally extinct?
- What is the probability that the entire metapopulation will go extinct?

Occurrence $(O_{i,t})$
Indicates if patch i occupied at time t

Definitions

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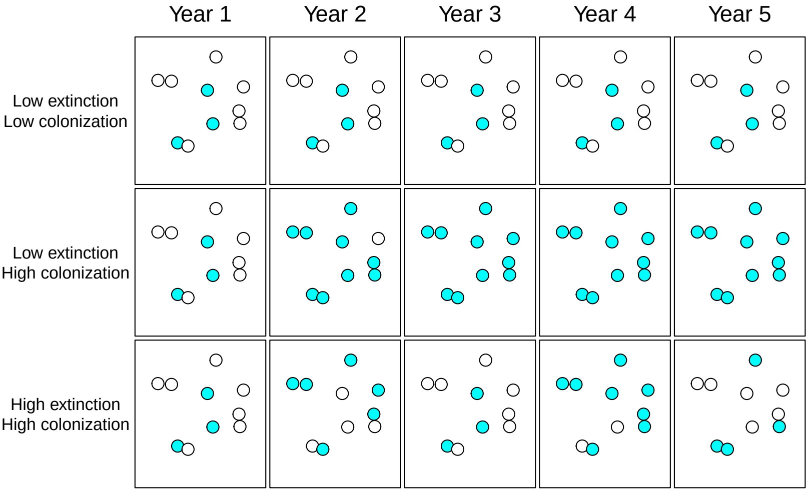
Metapopulation extinction risk
The probability that all subpopulation will go extinct.

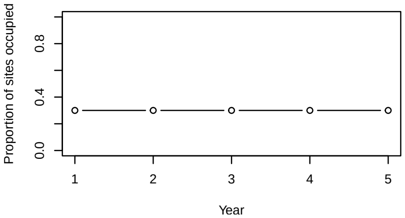
Example



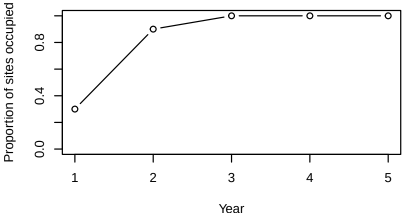
Year 1
Year 2
Year 3
Year 4
Year 5
Low extinction
Low colonization
Low extinction
High colonization
High extinction
High colonization

Example

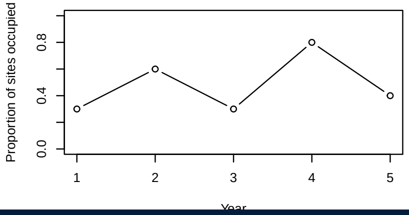
Low extinction
Low colonization



Low extinction
High colonization



High extinction
High colonization



The model

$$\psi_{i,t+1} = O_{i,t}(1-\varepsilon) + (1-O_{i,t})\gamma$$

$O_{i,t}$=1 if patch i is occupied at time t
$O_{i,t}$=0 if patch i is unoccupied at time t
$\psi_{i,t}$ is probability that patch i will be occupied at time t
ε is local extinction probability
γ is colonization probability

$$\psi_{i,t+1} = O_{i,t}(1-\varepsilon) + (1-O_{i,t})\gamma$$

$$O_{i,t+1} \sim \text{Bernoulli}(\psi_{i,t+1})$$

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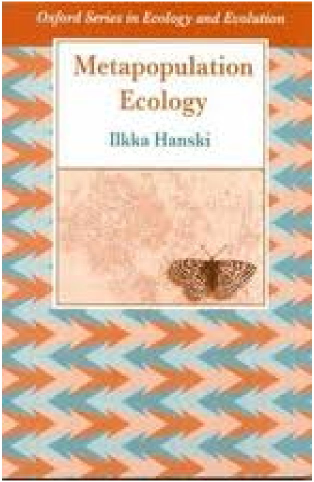
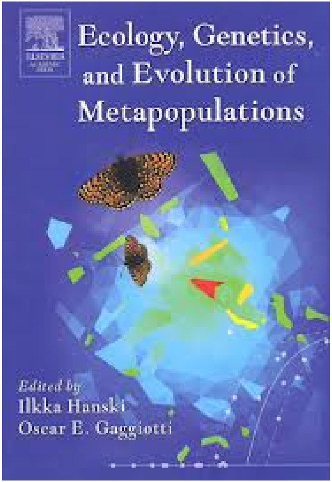
- Abundance doesn't matter
- Patch quality is constant
- Colonization and local extinction probabilities are constant
- Landscape matrix doesn't matter


Oxford Series in Ecology and Evolution
Metapopulation Ecology
Ilkka Hanski


Ecology, Genetics, and Evolution of Metapopulations
Edited by
Ilkka Hanski
Oscar E. Gaggiotti

All else equal...

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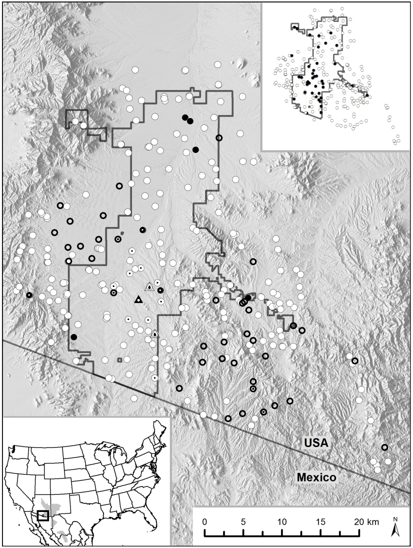
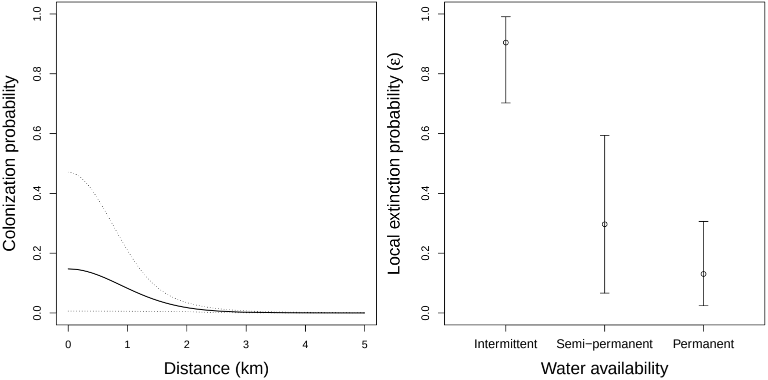
All else equal...

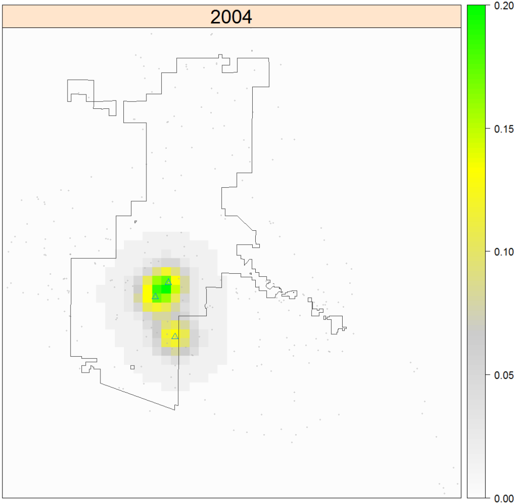
- An unoccupied site should have a higher chance of being colonized if it is close to an occupied site than if it is isolated
- Similarly, isolated sites should have a higher extinction probability than connected sites (rescue effect)
- Connectivity is determined by:
  - Dispersal ability
  - Spatial configuration of sites
  - Landscape resistance to movement


USA
Mexico
0
5
10
15
20 km
N

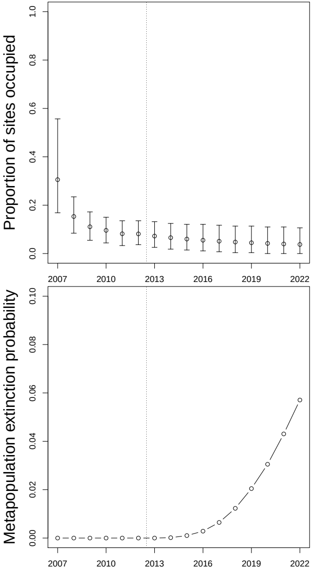
Results


Colonization probability
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
Distance (km)
Local extinction probability (ε)
1.0
0.8
0.6
0.4
0.2
0.0
Intermittent
Semi−permanent
Permanent
Water availability

Results



Results



Proportion of sites occupied
0.0
0.2
0.4
0.6
0.8
1.0
2007
2010
2013
2016
2019
2022
Metapopulation extinction probability
0.00
0.02
0.04
0.06
0.08
0.10
2007
2010
2013
2016
2019
2022

Metapopulation models are widely used to describe the dynamics of fragmented populations.

Model can be formulated in terms of patch-level abundance and/or occupancy.

Modern models are stochastic and spatially explicit.