Metapopulation models

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

Properties

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

MOTIVATION

- Many populations are fragmented
- 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

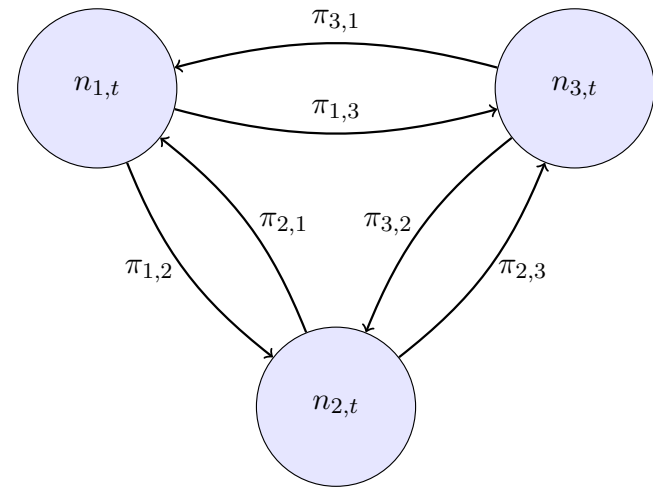---

ORIGINS

Richard Levins

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

Abundance formulation

A simple case with only three subpopulations

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

Abundance and movement

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

Abundance models

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

What influences movement?

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

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

Sources, sinks, and traps

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

Sink
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.

Density and habitat quality

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

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

Occupancy models

Emphasis on stochastic patch-level dynamics
- 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?

DEFINITIONS

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

Occurrence probability (psi=$\psi_{i,t}$)
Probability that site i is occupied at time t
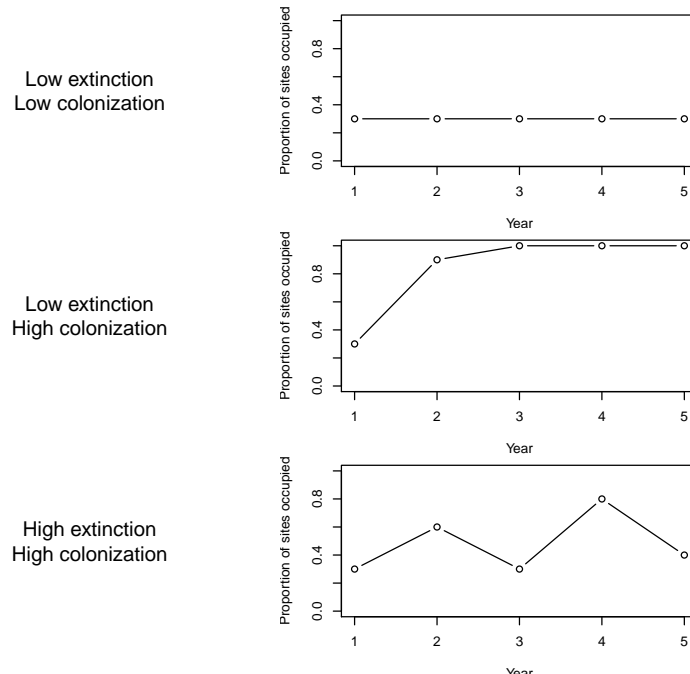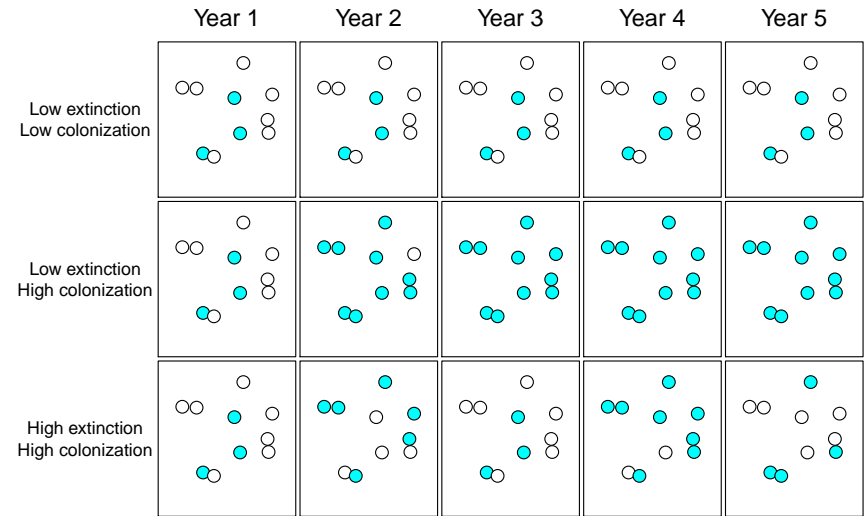
Colonization probability (gamma=γ)
The probability that an unoccupied patch at time t becomes occupied at time $t+1$

Local extinction probability (epsilon=ε)
The probability that an occupied patch at time t becomes unoccupied at time $t+1$

Metapopulation extinction risk
The probability that all subpopulation will go extinct

EXAMPLE

EXAMPLE

THE MODEL

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

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

$O_{i,t}$=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

Assumptions of basic non-spatial model

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

Spatial models

Spatial models
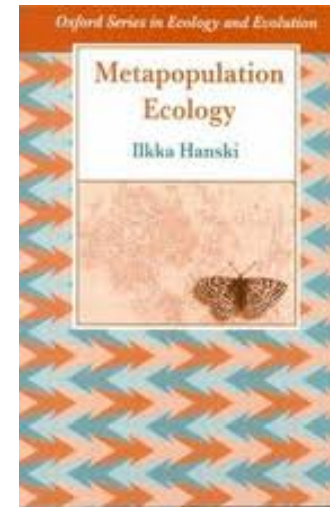
All else equal. . .
- An unoccupied site should have a higher chance of being colonized if it is close to an occupied site than if it is isolated
- Similarly, isolated sites should have a higher extinction probability than connected sites (rescue effect)
- Connectivity is determined by
  - ▶ Dispersal ability
  - ▶ Spatial configuration of sites
  - ▶ Landscape resistance to movement
- Modern models account for all of this

Case study

Results

Results

Results

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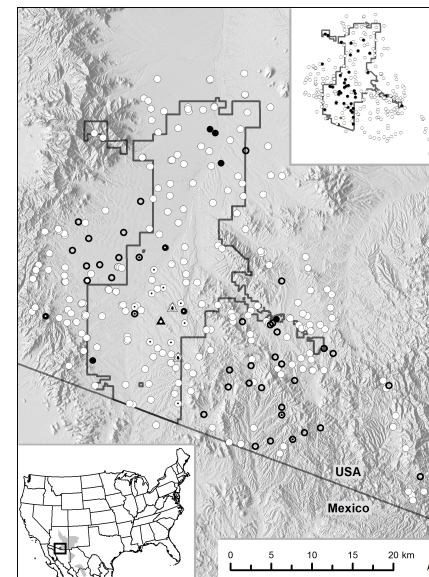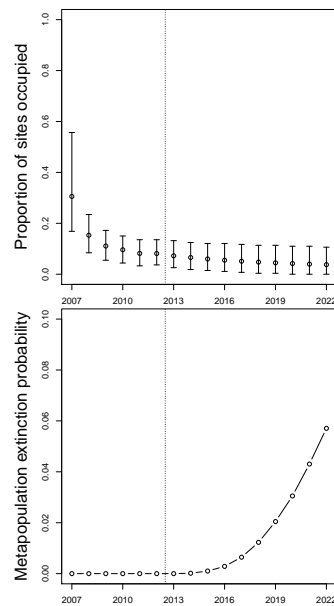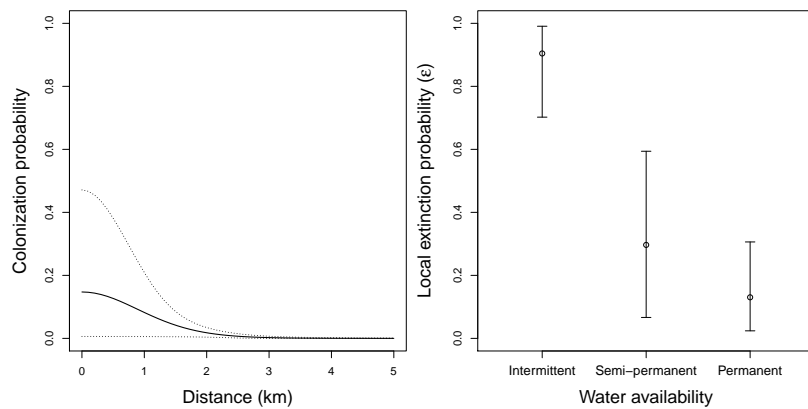
Metapopulation models are widely used to describe the dynamics of fragmented populations

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

Modern models are stochastic and spatially explicit