Modeling Metapopulations

BIO534
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Definitions

Population

- A group of organisms of one species living together

Metapopulation

- "population of populations" (Levins 1970)
- A group of populations linked by immigration and emigration.

Previous models (exponential, logistic) assumed the population was closed (ie no migration). With metapopulation models we are going to open up the population.

Objectives

- Review classic metapopluation models
- Understand their conceptual framework
- Identify their assumptions

Source Sink Dynamics: Concept

Two **patch** model: a **source** population and a **sink** population

Conceptual Diagram

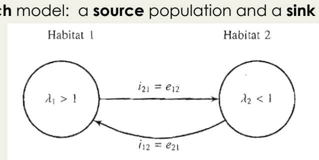


Fig. 4.2: The simplest source-sink model.

Source Population: Has growth rate $\lambda > 1$

Sink Population: Has growth rate $\lambda < 1$

Assumes all excess population production in source habitat **migrates** to the sink habitat

Pulliam 1988

Source Sink Dynamics: Model

Two **patch** model: a **source** population and a **sink** population

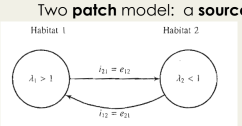


Fig. 4.2: The simplest source-sink model.

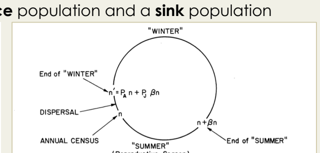


FIG. 1.—An annual census is taken in each habitat or "compartment" in the spring at the initiation of the breeding season (summer). Each individual breeding in the habitat produces β juveniles that are alive at the end of the breeding season. There is no adult mortality during the breeding season; adults survive the nonbreeding (winter) season with probability P_A and juveniles survive with probability P_J.

Two linked, discrete time equations

$$n_1(t+1) = P_A n_1(t) + P_j \beta_1 n_1(t) = \lambda_1 n_1$$

$$n_2(t+1) = P_A n_2(t) + P_j \beta_1 n_2(t) = \lambda_2 n_2$$

$P_A =$ adult survival
$P_j =$ survival of juveniles
$\beta_i =$ reproduction of population i
$\lambda_i =$ per capita growth rate (discrete)

Pulliam 1988

Source Sink Dynamics: Analysis

Two **patch** model: a **source** population and a **sink** population

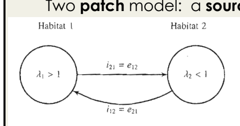


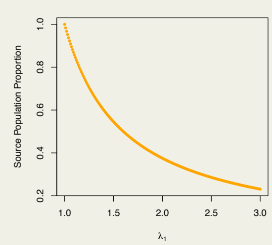
Fig. 4.2: The simplest source-sink model.

Matrix Model Representation

$$\mathbf{A} = \begin{bmatrix} P_A + P_J\beta_1 & M_{12} \\ M21 & P_A + P_J\beta_2 \end{bmatrix}$$

Assume
(1) migration is just from source to sink and
(2) All excess production goes to sink

$$\mathbf{A} = \begin{bmatrix} 1 & 0 \\ \lambda_1 - 1 & \lambda_2 \end{bmatrix}$$



Source population looks like a smaller fraction of the whole population as λ_1 increases

Pulliam 1988

Generalizing

General Model Form

Conceptualization

Habitat, H, is the total number is available sites for a population

p is the fraction or proportion of H that are occupied by a population

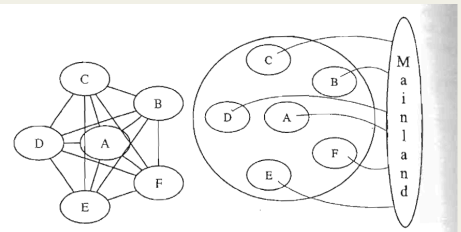
Two general processes affect the rate of change in the proportion of occupied sites:

Colonization and Extinction

Model

$$\frac{dp}{dt} = \text{Colonization}(C) - \text{Extinction}(E)$$

Two Conceptual Models



(a) A closed collection (b) An open collection

Fig. 4.4: Collections of sites. (a) Sites may be recolonized via internal propagule production and dispersal only, or (b) sites may receive immigrants from an outside source that is not influenced by the collection. Each site (A-F) may be a spot of ground potentially occupied by a single plant, or it may be an oceanic island potentially occupied by a butterfly population. Sites may also be colonized via both internal and external sources.

Levins Model

Colonization (internal)

$$C = c_i p(1-p)$$

p is the proportion of sites occupied with a population

c_i is the specific colonization rate, a function of propagule production

(1-*p*) is the proportion of fields that are unoccupied. Space is finite.

Extinction

$$E = ep$$

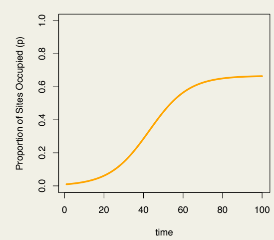
e is the specific extinction rate

c_i and *e* are similar to *b* and *d* in exponential and logistic growth

Model equation

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

Dynamics



Assumptions

- Homogeneous Patches
  - Same size, quality, distance, etc.
- No Spatial Structure
- No time lags
- Constant colonization and extinction rates
- Regional occurrence (p) affects local colonization and extinction rates
  - Most metapopulation models assume that migration is substantial enough to affect local population dynamics.
- Large number of Patches
  - If p gets small, we are assuming the metapopulation will still persist.
- No demographic Stochasticity

Levins model: Equilibriums

When does the metapopulation persist?

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

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

$$c_i p(1-p) = ep$$

$$(1-p) = e/c_i$$

$$p^\star = 1 - e/c_i$$

So… the population persists ($p^*>0$) if $e < c_i$

Propagule Rain Model

Colonization (internal)

$C = c_e(1-p)$

p is the proportion of sites occupied with a population

c_e is the specific colonization rate, a function of propagule rain from a "main land". No internal production

(1-p) is the proportion of fields that are unoccupied. Space is finite.

Extinction

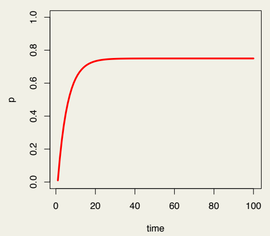
$E = ep$

e is the specific extinction rate

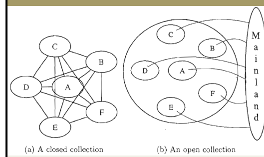
Model equation

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

Dynamics



Combine Levins & Propagule Rain Model

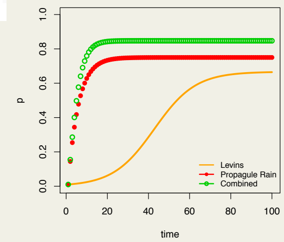


$c_e = 0.15$
$c_i = 0.15$
$e = 0.05$

Model equation

$$\frac{dp}{dt} = (c_i p + ce)(1-p) - ep$$

Dynamics



Hanski: Rescue Effect, Core-Satellite Model

Colonization (internal)

$C = c_i p(1-p)$

p is the proportion of sites occupied with a population

c_i is the specific colonization rate, a function of propagule production

(1-p) is the proportion of fields that are unoccupied. Space is finite.

Extinction

$E = -ep(1-p)$

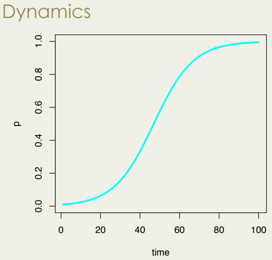
e is the specific extinction rate

E is now a function of the available sites (parabola)

Model equation

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

Dynamics



Levins vs. Hanski

Compare the equilibriums

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

Levins assumes a = 0, Hanksi assumes a = 1

$$p^\star = \frac{c-e}{e-ae}$$

Let K, the carrying capacity be

$$K = H * p^\star$$

In the Hansi model, K fills all of the available habitat
In the Levins model, K only fills a fraction of the total available habitat

Other Steps

- Show correspondence between Levins model and Logistic population growth
  - Use "rescaling" technique
- Habitat Destruction
  - Karieva and Wennergren (1995)
- Core-Satellite Simulation

Alternative Conceptualizations

- Landscape ecology
  - Not a collection of patches, but
  - Continuous space
- Use Grid or Lattice to model space
  - Each grid cell contains copy of model
  - Processes to connect cells
  - Parameters for each cell model
- Hanksi has patch models that account for different patch sizes.

Discussion

- These are still relatively simple models
  - Emphasis on being general, less realism, even less precision
- Their use is primarily one of *synthesis and integration* of existing knowledge. Secondarily, with modification they can be used to test the plausibility of alternative hypotheses and *drive new empirical research*.
- Theoretical models…

Exam

Question 6

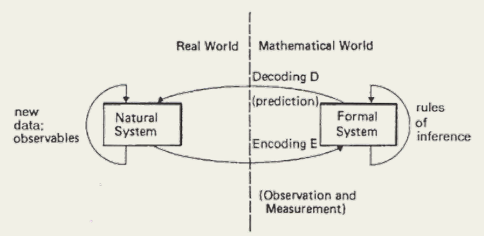


Figure 1.5. The Modeling Relation

Casti, 1992

- 9d
  draw on board
- 11a – distinguishing control function
  - Essential
  - Independent
  - Substitutable

12. Model Use

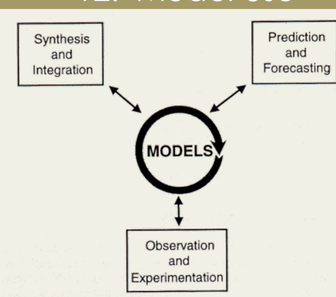


Figure 1.1

Where do the population models we have been studying fall on this graph?