

# Chapter 5 Lecture

## Metapopulation Ecology

Spring 2013

## 5.1 Fundamentals of Metapopulation Ecology

Populations have a spatial component and their persistence is based upon:

**Gene flow** ~ immigrations and emigrations

**Colonization** ~ establishment of new population

**Birth and Death**

**Extinction**

**Ex. History of Krakatau** –illustrates 2 major points?

1)

2)

## 5.2 Background of Spatial Ecology

Most deterministic models **assume** that populations are large and continuous across wide areas of habitat **Realistic?**

### Two approaches to Spatial Ecology

- 1) **Metapopulation approach** – scale of local populations of one species. Habitat either suitable or not suitable.
- 2) **Landscape ecology** – much larger scale at level of community and ecosystem and acknowledges patchiness of habitat. Addresses habitat suitability on a continuous scale.

Both address what fundamental questions concerning population persistence? ?

## 5.2 History of Metapopulation Ecology

**Sewell Wright (1940)** - deme

**Andrewartha and Birch (1954)** – island mainland comparison

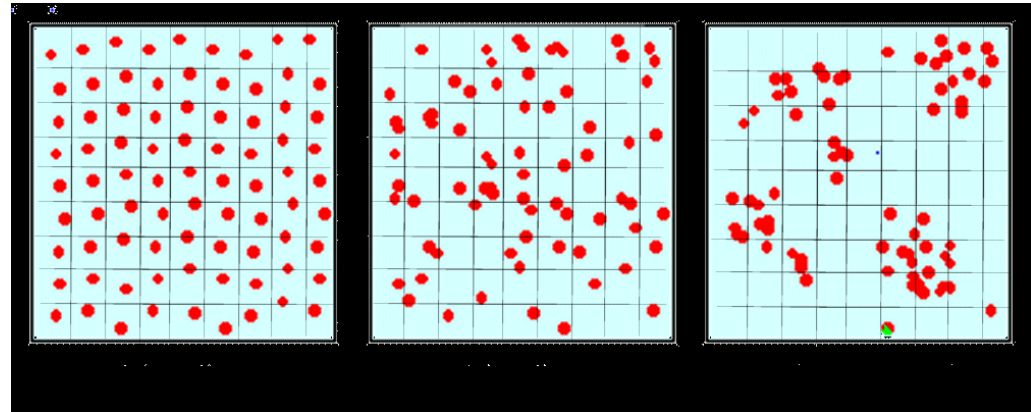
**Levin (1970)** – coined term “metapopulation ecology” and emphasized “local” populations or demes

**Hanski (1999)** – ack. great increase in fragmentation, reserve size

Metapopulation Ecology definition: Regional assemblages of plant and animal species, with long-term survival of the species depending on shifting balance between local extinctions and re-colonizations in the patchwork of fragmented landscapes.

## 5.2 Types of Models for Spatial Ecology

- Lattice Models
- Patch Models
- Incidence Function Models
- Spatial distribution:
  - Clumped
  - Random
  - Regular



Harrison (1994) Types of Metapopulation Dynamics:

- 1) Classic
- 2) Mainland-island
- 3) non-equilibrium
- 4) patchy

## 5.2 Metapopulation Dynamics

Individual organisms normally interact with their local environment

Why is the above statement important?

Relationship between colonizing ability and competitive ability?

Relevance?

# 5.3 MacArthur and Wilson Equilibrium Theory

## 4 Basic Principles:

- 1) Relationship between habitat island area and number of species (species-area curve)
- 2) local extinction a common event, especially on islands
- 3) local island diversity dependent on interaction between island and mainland
- 4) distance of island from mainland will influence  $\sim$ equilibrium # species on island

## 5.3 MacArthur and Wilson Equilibrium Theory

$$S = CA^z$$

Where:

S = number of species on island

A = area of island

C = a constant (y intercept)

z = a constant that is consistent within a taxonomic group and/or types of islands under consideration

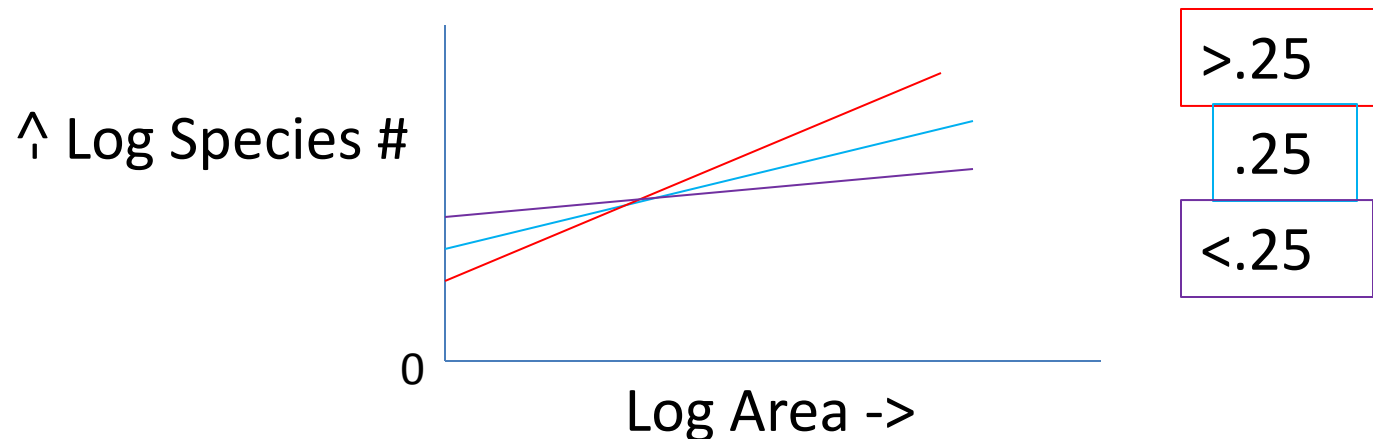
= depends on if **true oceanic islands** (0.2-0.4), **land-bridge islands** (0.1-0.25) or **habitat islands** (>0.26)

$$\text{Log } S = \text{Log } C + z\text{Log}A \quad (\text{eq. 5.1})$$

Equation for straight line with slope = z with Log C = y intercept

# How z value can vary with sampling effort (and timing of sampling)

- Slope of  $.25 = z$ , common for species area curves
- When small areas are sampled (and timing) may include transient species, artificially increasing species # and a subsequent smaller than expected rise in # spp and with increased sampling area ( $<.25$ )
- When islands contain great habitat diversity with semi-isolated unique species encountered as sampling area increased ( $>.25$ )

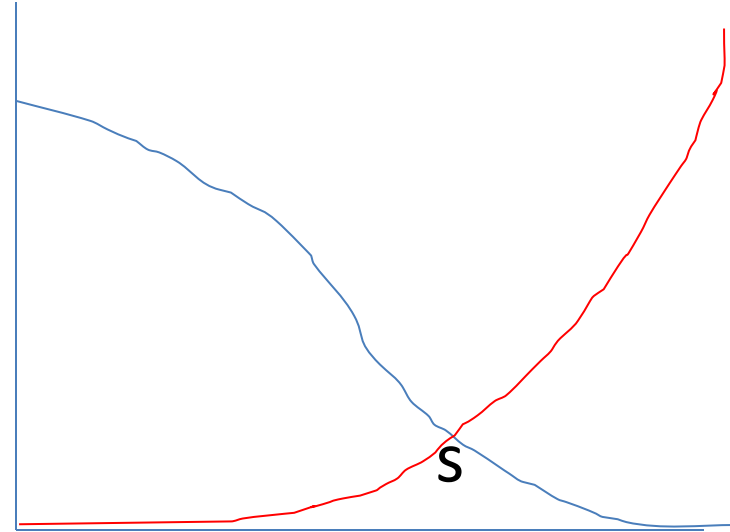


To see how relationship changes with z values above, please visit  
<http://www.mathopenref.com/coordequationps.html>

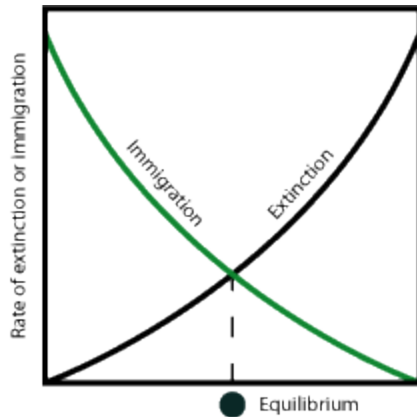
# 5.3 MacArthur and Wilson Equilibrium Theory

See Fig. 5.1 Immigration and extinction curves from island biogeography

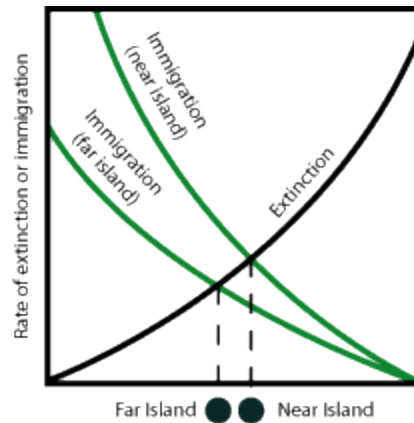
Immigration & extinction rate



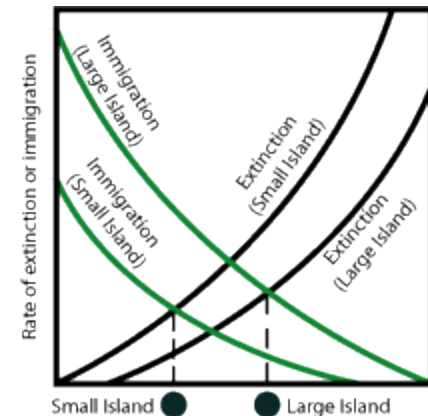
# species ->



Number of species on island



Number of species on island



Number of species on island

# 5.4 Levin's Classic Metapopulation Model

Levin 1969

Eq. 5.2

$$\frac{dP}{dt} = cP(1-P) - \epsilon P$$

(Error in Text)

Rate of change in occupied habitats is a function of:

- 1) Colonization rates ( $c$ )
- 2) Extinction rates ( $\epsilon$ )
- 3) Proportion of patches occupied ( $P$ )

A Deterministic Model based on stochastic events

## 5.4 Levin's Classic Metapopulation Model

Hanski 2001

Eq. 5.3

$$\frac{dP'}{dt} = cP'(T - P') - \varepsilon P$$

If define:

$P'$  as number of occupied habitat fragments

$T$  as total number of habitat patches available

Also a deterministic model based on stochastic events

# 5.4 Levin and Hanski Models

Levin 1969

Eq. 5.2

$$\frac{dP}{dt} = cP(1-P) - \varepsilon P$$

Hanski 2001

Eq. 5.3

$$\frac{dP'}{dt} = cP'(T-P') - \varepsilon P'$$

Assumptions of both models:

- 1) Local populations are identical and behave same way
- 2) Extinctions occur independently, local dynamics are asynchronous
- 3) Colonization spreads across patch network and all equally likely
- 4) All patches equally connected to all other patches

**No** attempt to count numbers/indiv. per patch or quality or size  
Just suitable or not, then called occupied or unoccupied, respectively

# Equilibrium value of $P = \hat{P}$

$$\hat{P} = \frac{c-\varepsilon}{c} = 1 - \frac{\varepsilon}{c} \quad \text{Eq. 5.4}$$

Implies that colonization > extinction must be > 0 or equilibrium proportion of patches occupied = 0

Think of colonization as birth and extinction as death

Then  $c-\varepsilon = \text{growth rate} \sim r$  of logistic equation and

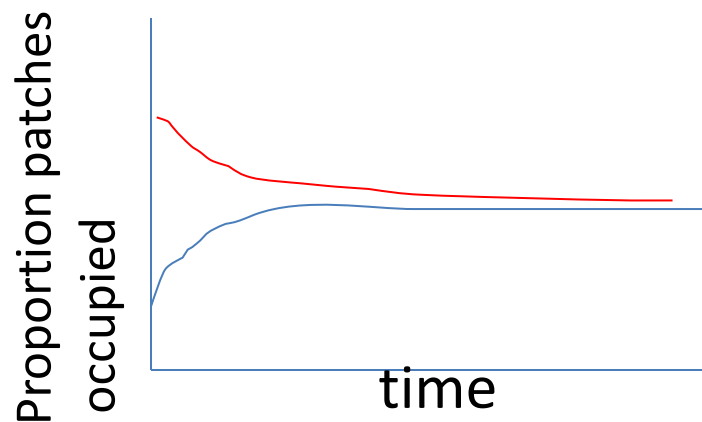
$K = 1 - \varepsilon/c = \text{carrying capacity} \underline{\text{or}} \text{ equilibrium}$

# Levin's model

Eq. 5.5

$$\frac{dP}{dt} = (c - \varepsilon) P \left[ 1 - \frac{P}{1 - \varepsilon/c} \right]$$

**Fig. 5.2** Expected proportion of patches occupied over time with  $P_0 = 0.5$  (**top line**) and  $P_0 = 0.15$  (bottom line) Based on Eq. 5.5



See **Fig. 5.3** dynamic pop effects

## 5.5 Local vs. Metapopulation Extinction

**Table 5.1** (from Hanski 1998)

|                      | Local extinction             | Metapopulation extinction                                       |
|----------------------|------------------------------|-----------------------------------------------------------------|
| Stochastic processes | Demographic                  | Extinction – colonization in Regional processes and interaction |
| Extrinsic causes     | Environmental - Habitat Loss | Habitat loss and fragmentation                                  |

## 5.6 Metapopulation dynamics in 2 local pops

- Ricker equation:
  - $N_{t+1} = N_t e^{r(1-Nt/K)}$  (eq 5.6)
  - From Fig. 2.19 and when  $r$  set  $> 2.69$ , population experienced chaotic behavior
  - See Fig. 5.4 Where 2 populations without emigration are chaotic in their behavior but with 30% migration they act as ONE population and enter into a two-point reliable cycle.
  - See Fig. 5.5 too
- ❖ Thus migration can help stabilize local population dynamics!

## 5.7 Source sink populations

- Source patches =
  - Sink patches =
  - Rescue effect =
  - A pseudo sink population =
- 
- Similarity between source-sink and mainland-island populations?
- 
- Examples?

## 5.8 Non-equilibrium & patchy metapopulations

- Non-equilibrium metapopulation is when:
- Example?
- Patchy metapopulation is when:
- Example?

## 5.9 Spatially realistic models

Most models assume unconditional emigration

– Examples? Realistic?

Pg. 122: **Fig. 5.6**

Shape of dispersal curve of migrants ~ colonists

Emigration usually modeled as a negative exponential

$$C_i = \beta e^{-\alpha d_i}$$

To determine colonizing ability (C) examine:

$\beta$  = number of individuals dispersing

$\alpha$  = dispersal ability of each individual

$d_i$  = distance from source population

## 5.9 Incidence Function Model (IFM) Hanski and colleagues

➤ Long distance dispersal events are important

- Approach to make metapopulation models more realistic
- Stochastic patch model where each patch has two states: presence or absence

IFM includes:

- 1) Finite number of habitat patches
- 2) Patches of different sizes
- 3) Each patch has unique spatial coordinate so that interactions among patches are localized in space

**Parameters can be estimated from field data allowing application to real populations!**

## 5.9 Incidence Function Model (IFM) Hanski and colleagues

### Assumes:

- For a given patch  $i$ , there is a constant prob.,  $C_i$ , of recolonization per unit time
- If patch occupied, there is constant prob.,  $E_i$ , of extinction per unit time
- One event is allowed per unit time
- The long term probability of a patch being occupied is called the incidence of  $J_i$
- (Eq. 5.8) 
$$J_i = C_i / C_i + E_i$$

## 5.9 Incidence Function Model (IFM) Hanski & colleagues

- Extinction probability and size of patch (related to species area curve idea)
- $E_i = e / A^x$  (Eq. 5.10)
- Where **E** and **x** are calculated from field data
- **e** = parameter related to probability of extinction per unit time in a patch of a given size
- **x** = measure of environmental stochasticity
- Many other permutations of this equation taking into account isolation etc. are illustrated in the text book.

## 5.10 Minimum viable **metapopulation** size (MVP)

Introduced by Soule (1980) single pop – replaced now with PVA

$$\text{MVP} = \frac{P^*}{H} > 3 \quad \text{For *metapopulation* to persist!}$$

Where  $\hat{P}$  = fraction of occupied patches at equilibrium

$H$  = total # habitat patches

$T_M$  = long term persistence of metapopulation

❖ More patches  $\rightarrow$  probability{metapop persistence}

Can use to attempt to predict minimum viable population size over a period of time, ex., 100, 1000, or 10,000 yrs.

- Metapop persistence ( $T_M$ ) vs. Local pop persistence ( $T_L$ )

## 5.11 Assumptions & evidence of metapopulations

- 1) Species has local breeding poplns in discrete patches
- 2) No local popln able to persist beyond lifetime of metapop
- 3) Empty habitat patches are common
- 4) Patches are not too isolated to prevent recolonization
- 5) Local dynamics asynchronous to prevent uniform extinctions of all pops
- 6) Metapop dynamics occurring: turnover, extinctions etc.
- 7) Pop size and pop density significantly influenced by migration
- 8) Pop dens, colonization rate, and extinction rates are influenced by patch size and isolation
- 9) Metapops can affect competition, predator-prey, and parasite-host interactions.

# Role of Corridors?

- Supportive field studies – which one did you like?
- Role of spatial dynamics important

Glanville fritillary: *Melitaea cinxia*



[http://felixthecatalog.tim.pagesperso-orange.fr/melitaea\\_cinxia6\\_bis.jpg](http://felixthecatalog.tim.pagesperso-orange.fr/melitaea_cinxia6_bis.jpg)

## Questions?

# Highlights

- Metapopulations and spatial ecology
- MacArthur and Wilson and the equilibrium theory
- Levin ~ classical metapopulation
- Extinction in metapopulations
- Metapopln dynamics of two local poplns
- Source-sink metapoplns & the rescue effect
- Non-equilibrium and patchy metapoplns
- Spatially realistic models
- Examples of metapopulations in nature – assumptions and evidence
- Role of corridors
- Spatial Dynamics Matter!