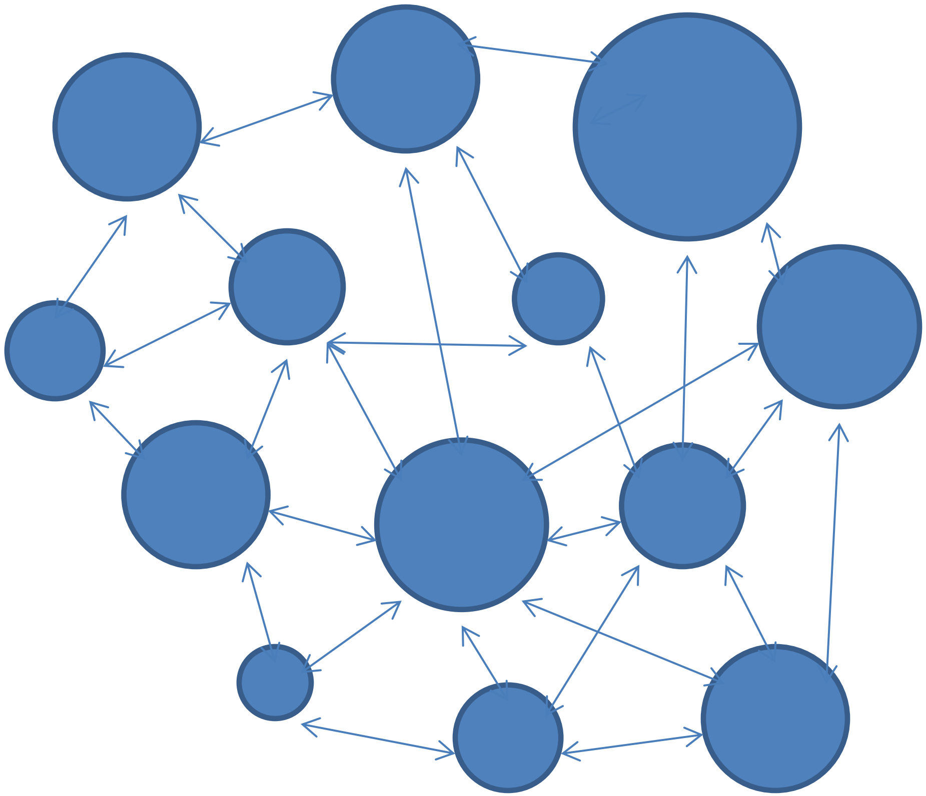
Metapopulations

1. Local (within-patch)
   – Local extinction
2. Metapopulation (regional)
   – Regional extinction

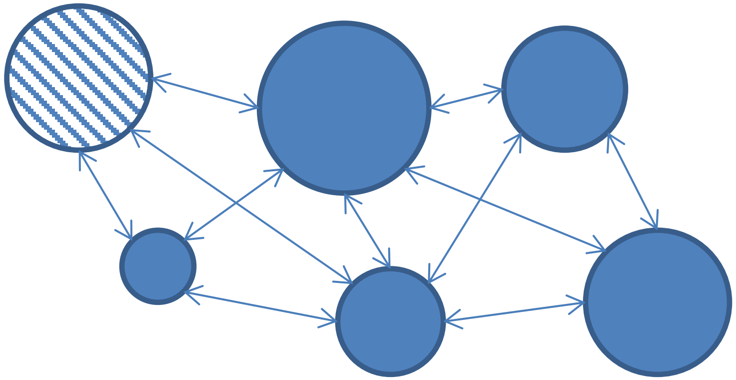
- Shifting mosaic of occupied and unoccupied patches

- How long will regional population persist?
- What are the conditions for persistence?
- What will happen if there is a loss of habitat (reduction in # of patches)?



Local extinction risk

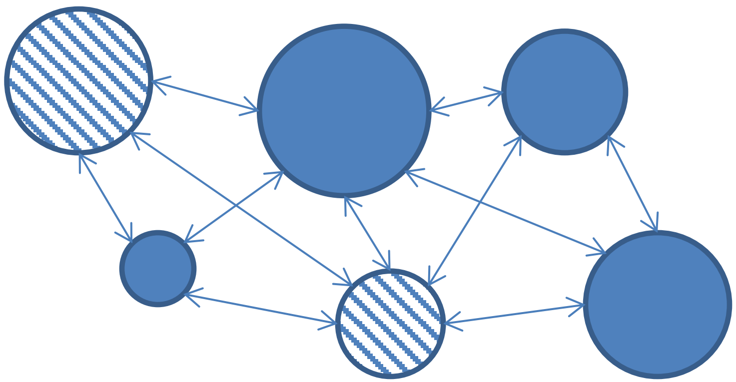
- **Probability of extinction within fixed time period (p_e)**
- **Probability that subpopulation will persist during the same period ($1 - p_e$)**



- **Probability (P) that the subpopulation will persist for a number (n) of time periods (years or decades):**

$$P_n = (1 - p_e)^n$$

Regional extinction risk



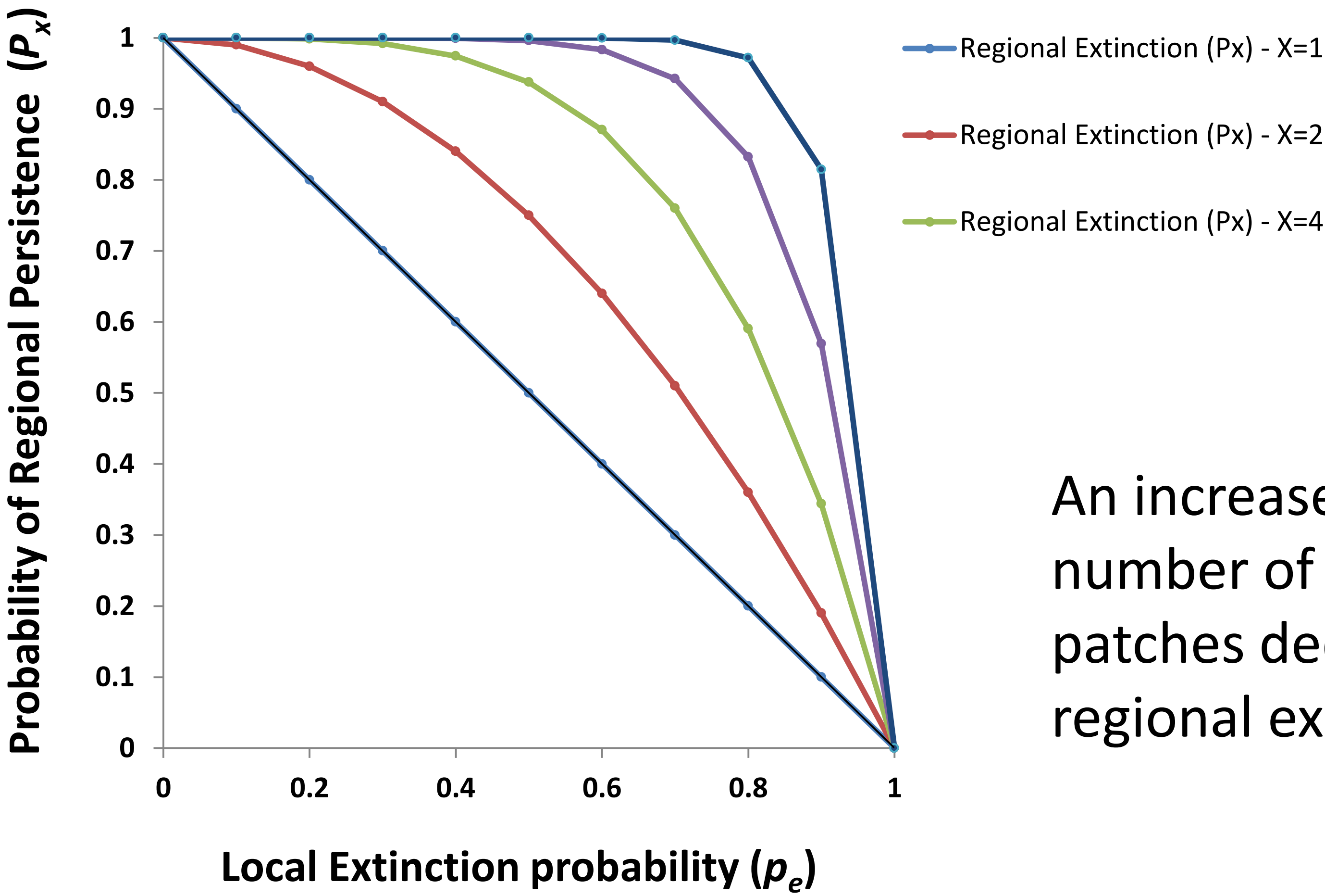
- **Probability that two subpopulations will go extinct**
  - $(p_{e1} \times p_{e2})$
- **Probability that all subpopulations will go extinct**

$$P_{re} = (p_e)^x$$

- **Probability that at least one subpopulation will persist (1 – p(regional extinction))**

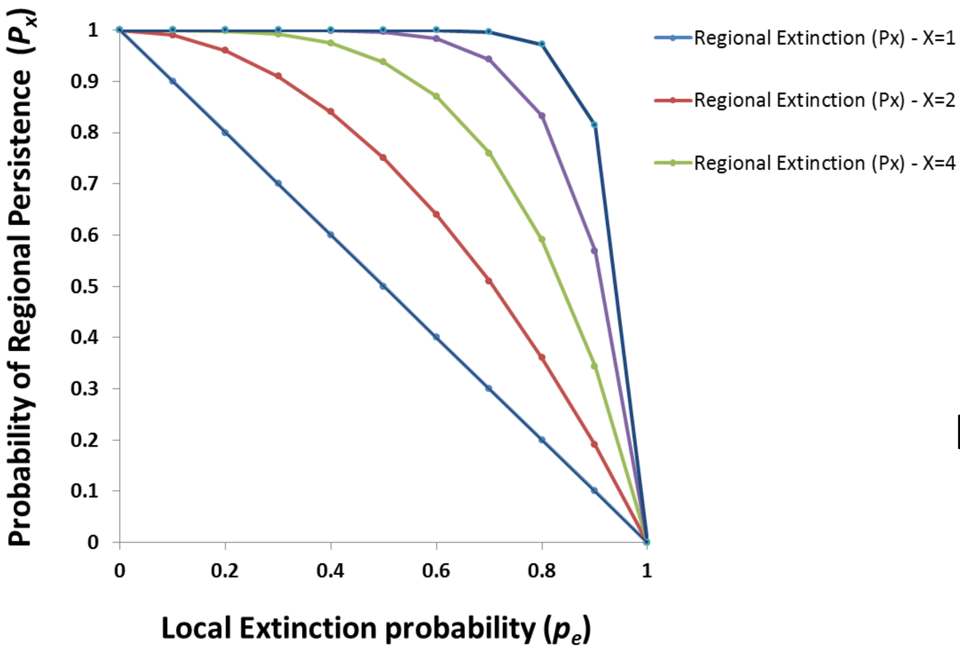
$$P_x = 1 - (p_e)^x$$

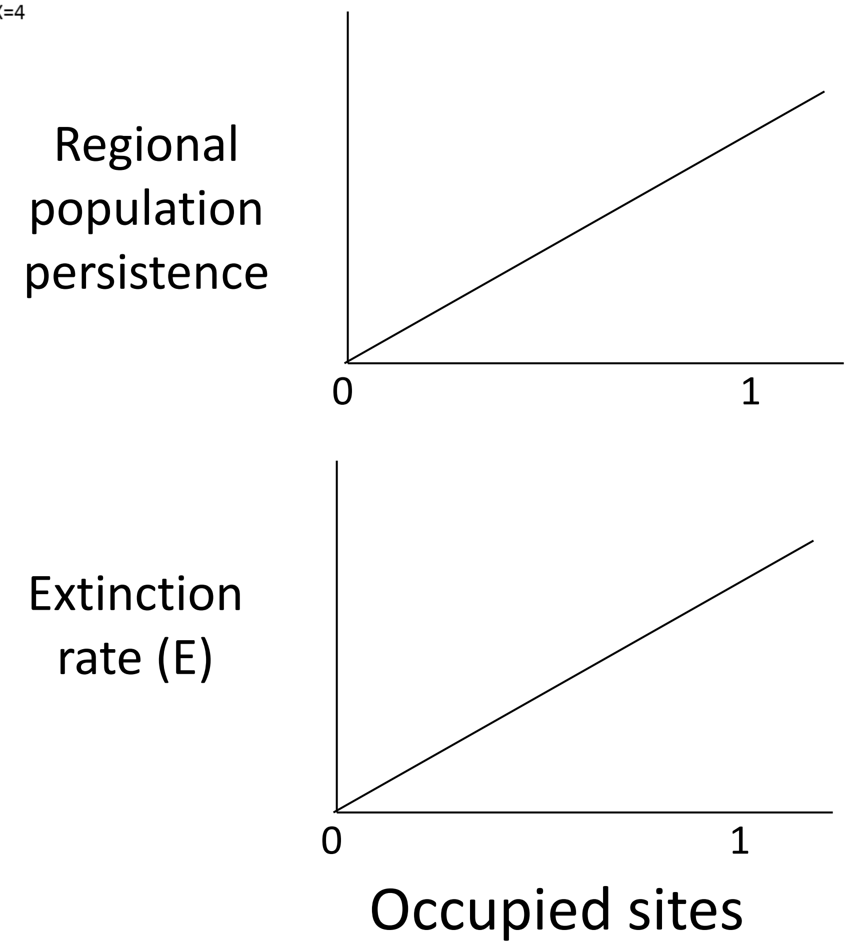
Regional extinction risk



An increased in the number of occupied patches decrease the regional extinction risk.

Regional extinction risk

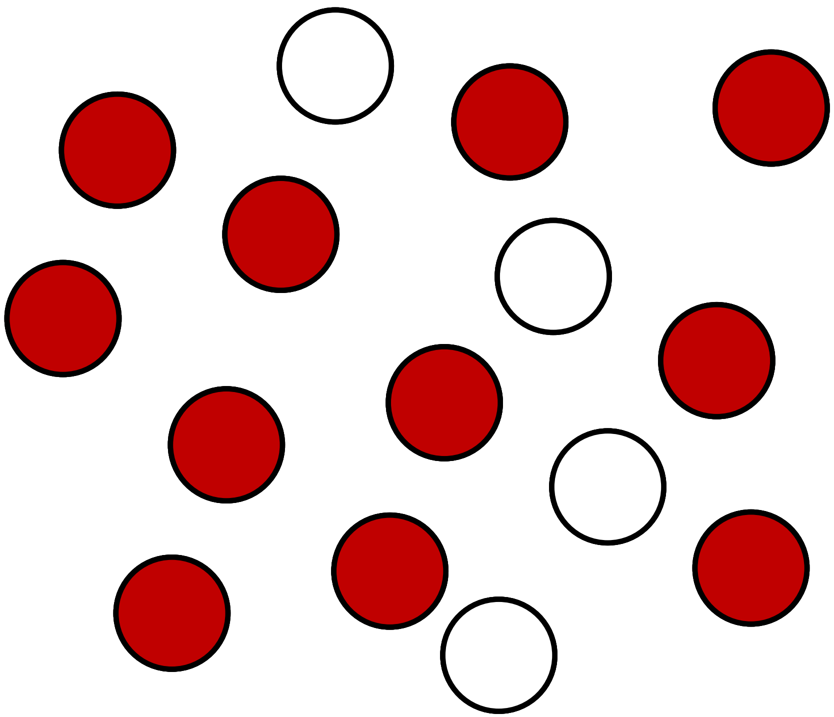




- Regional extinction risk depends on # sites occupied

Site occupancy

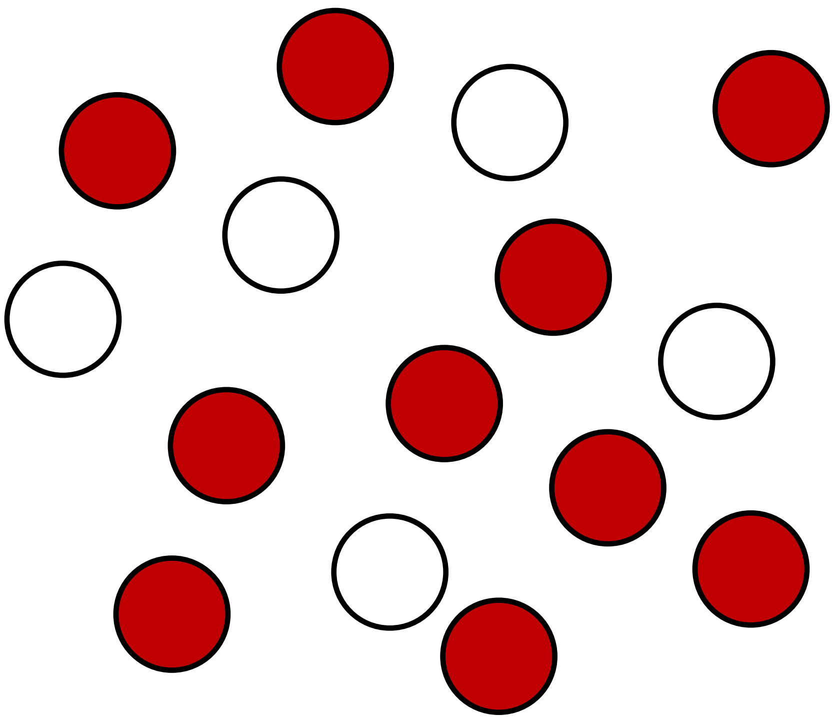
- State of regional (meta) population
- Given by f: fraction of occupied patches



$$f = \frac{11}{15} = 0.73$$

Site Occupancy

- fraction of the sites occupied (*f*) over time (t) is the interplay between immigration rates (I) and extinction rates (E)



$$\frac{df}{dt} = I - E$$

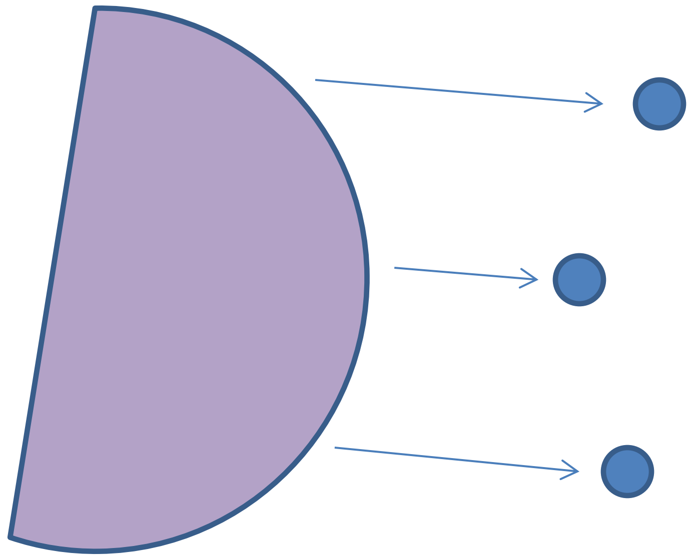
Extinction, not emigrations!

Patch colonization

- Island-Mainland model

- Colonization of patches (pi) does not depend upon immigration among patches, but occurs via a continuous source of migrants from a large source population (propagule rain)

- Subpopulations (islands, patches) are sourced by a large mainland population that is providing constant immigrants



Island-mainland patch colonization rate

- Probability of **local colonization** (p_i)
  - Chance that an unoccupied patch will be colonized over the next time step.
- Immigration rate (I)
  - dependent on probability of colonization (p_i) from the mainland, and availability of unoccupied sites (1-f).

$$I = p_i(1 - f)$$

Island-mainland extincitonrate

- **Probability of local extinction (*p_e*)**

- **Extinction rate (*E*) is the product of local extinction probability (*p_e*) and the fraction of sites occupied (*f*).**

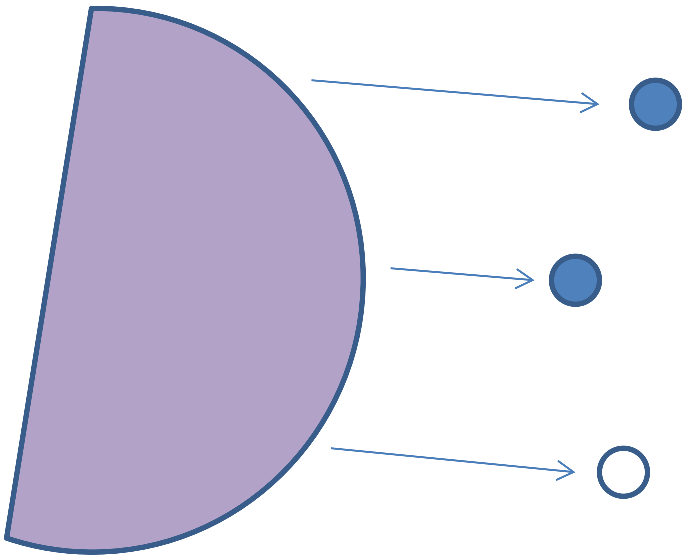
$$E = p_e f$$

Island-mainland metapopulation model

- **Change in the fraction of sites occupied over time (*df/dt***

$$\frac{df}{dt} = I - E = 0$$

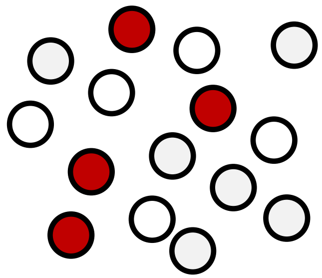
$$\frac{df}{dt} = p_i(1 - f) - p_e f$$



Island-Mainland Model

- Ecological questions:
  - What is the expected fraction of occupied sites over time?
  - What is the stable fraction of sites occupied over time?

$$\frac{df}{dt} = 0 = p_i(1-f) - p_e f$$



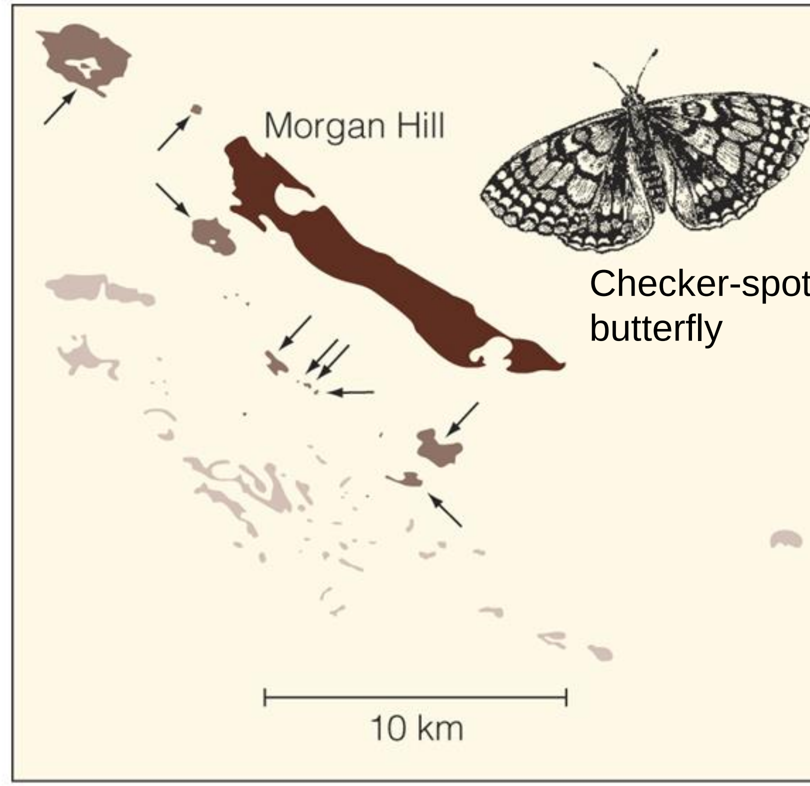
  - Estimated frequency of sites occupied
    - Fraction of sites occupied is balance between immigration (p_i) and extinction (p_e)

$$\hat{f} = \frac{p_i}{p_i + p_e}$$

  - Due to background immigration some satellite patches will always be occupied

Island-mainland model

- one large population (low extinction risk)
- provides colonists for many small populations (high risk)

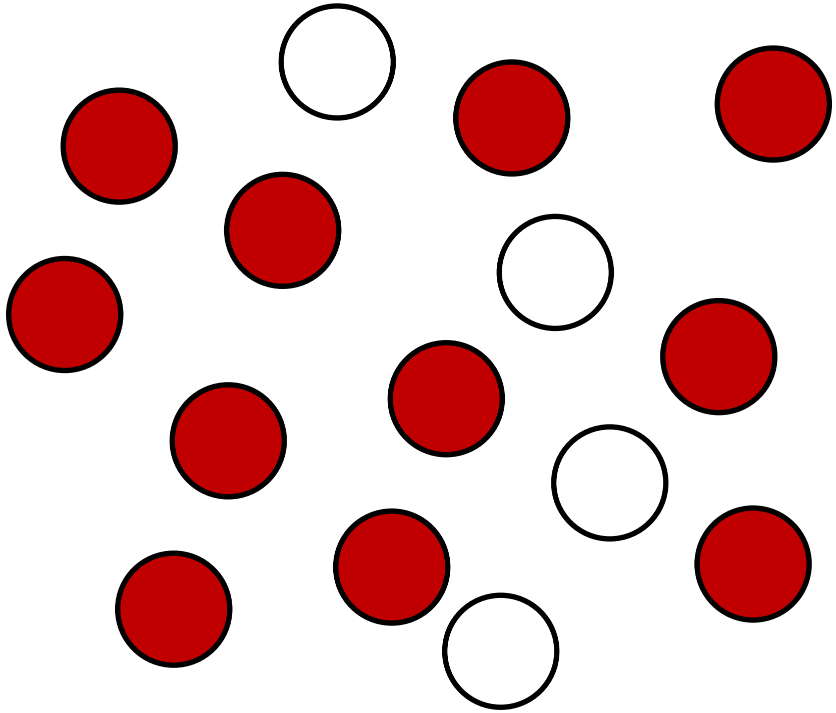


Rescue effect:

- Island recolonized from “mainland”
  - High quality / permanent population = **source** population
  - Temporary patches = **sink** populations

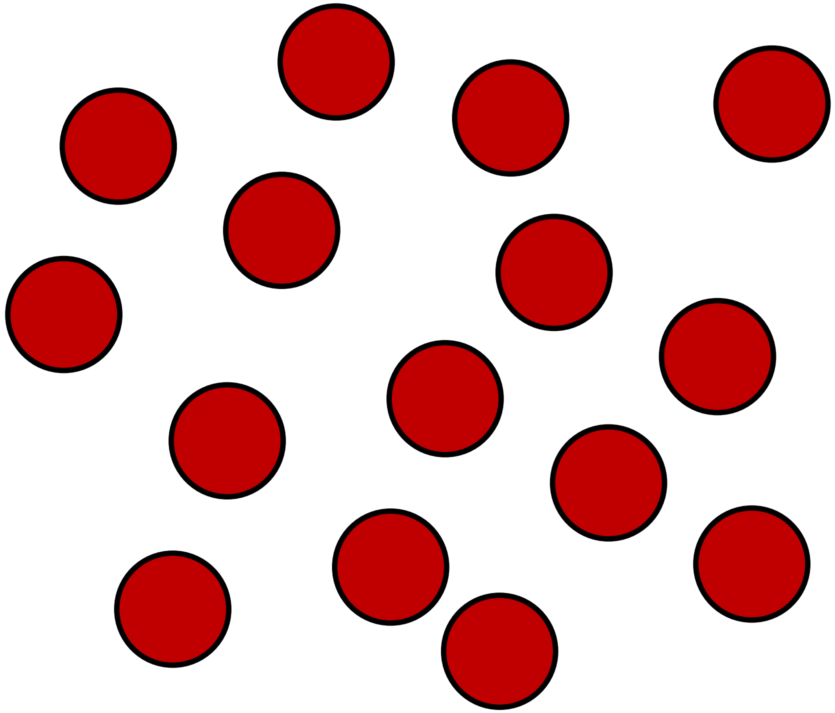
Patch Colonization

- What if there is no mainland to supply a steady steam of colonizing propagules?



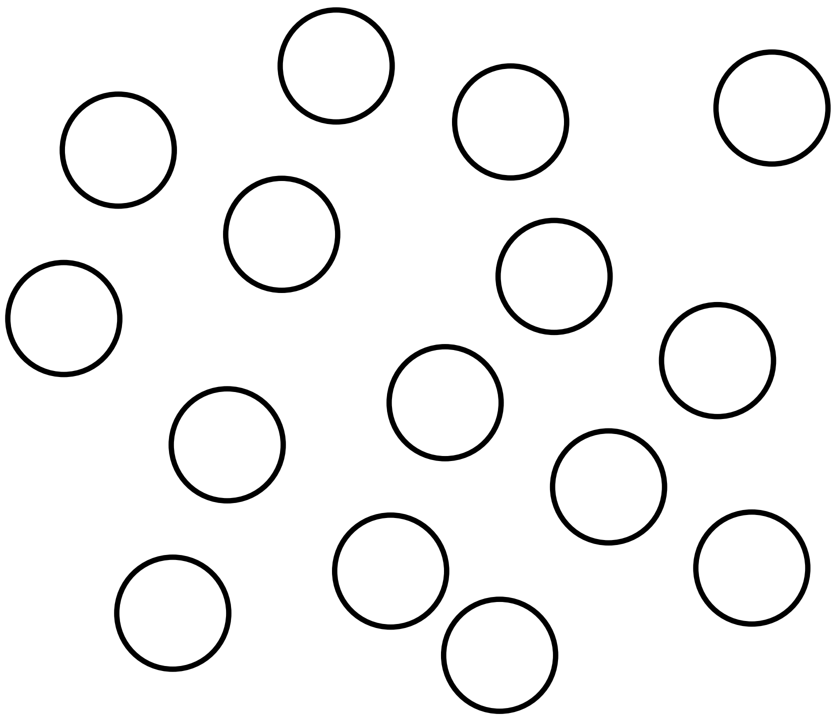
Patch colonization

- What is the probability that a colonization event will occur?



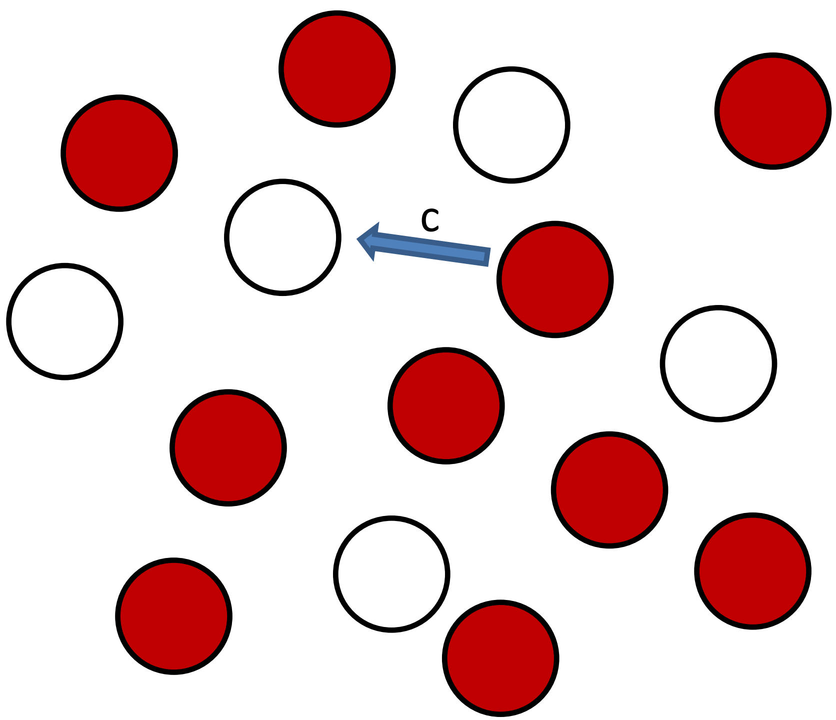
Patch colonization

- What is the probability that a colonization event will occur?



Patch colonization

- Colonization rate = m



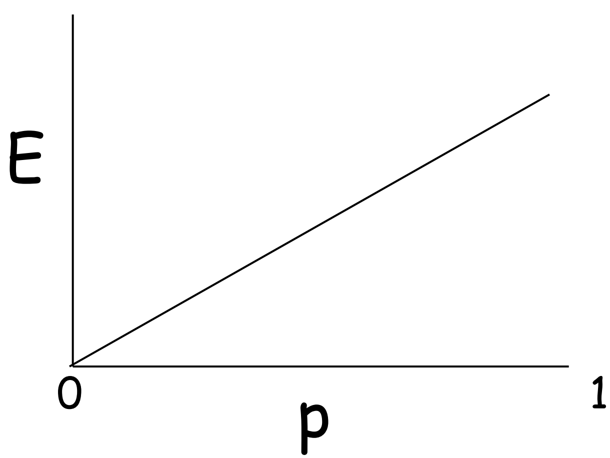
- Single colonization rate for system
  - What does this assume about system?

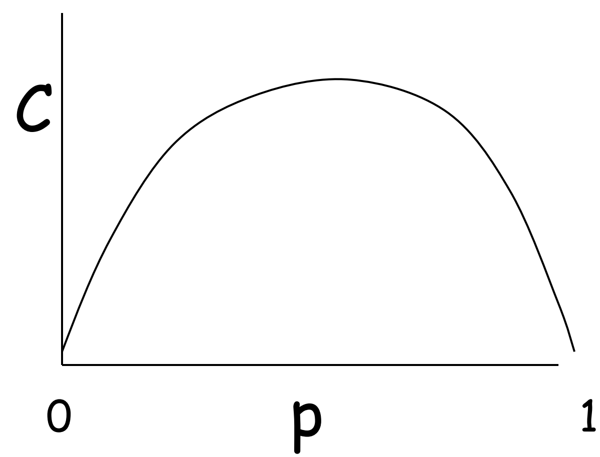
$$C = cp(1 - p)$$

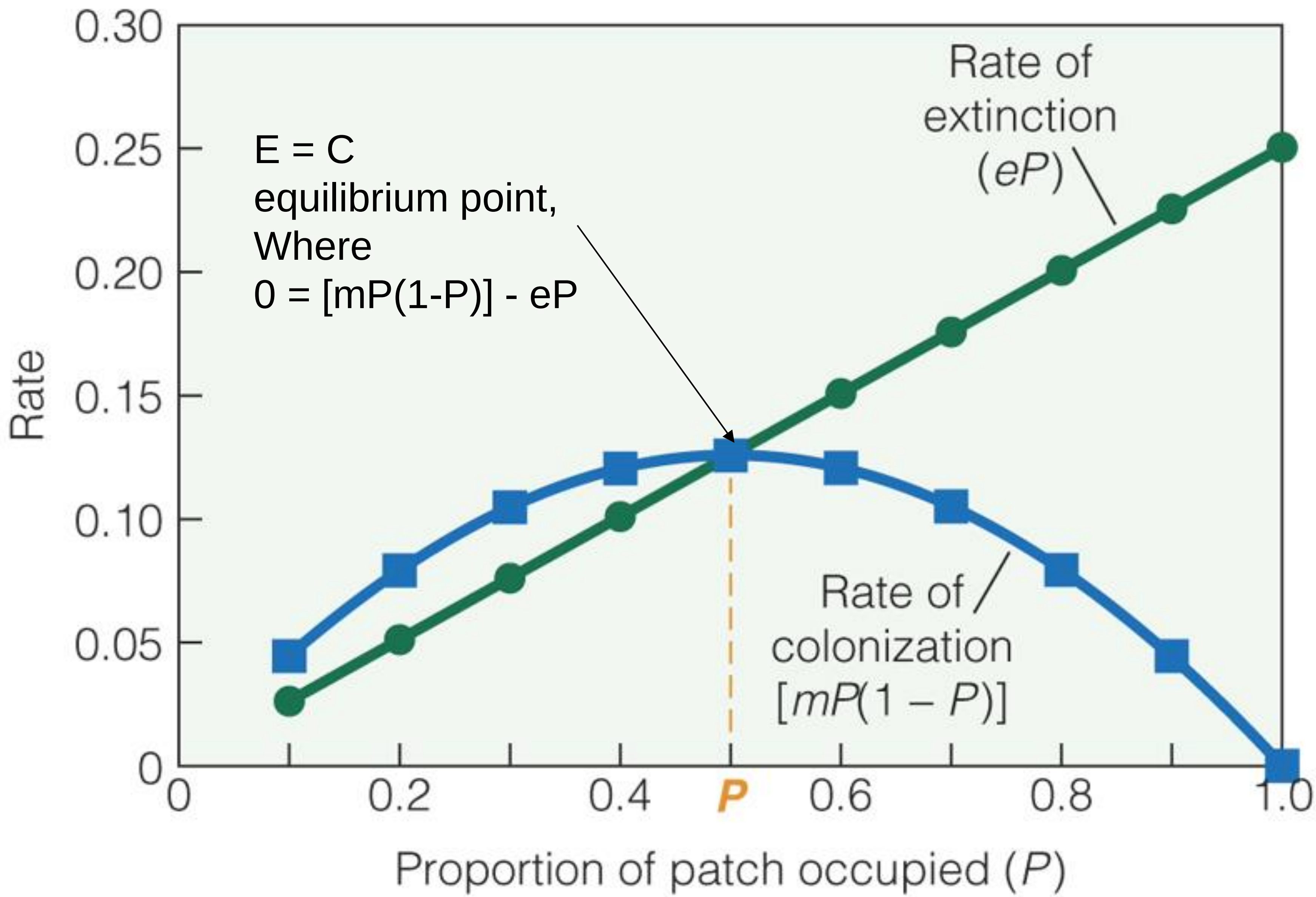
Classic metapopulation

Extinctions = extinction rate x prop'n patches occupied
= e·p

Colonization = colonization rate x prop'n unoccupied patches
= c·p· (1-p)

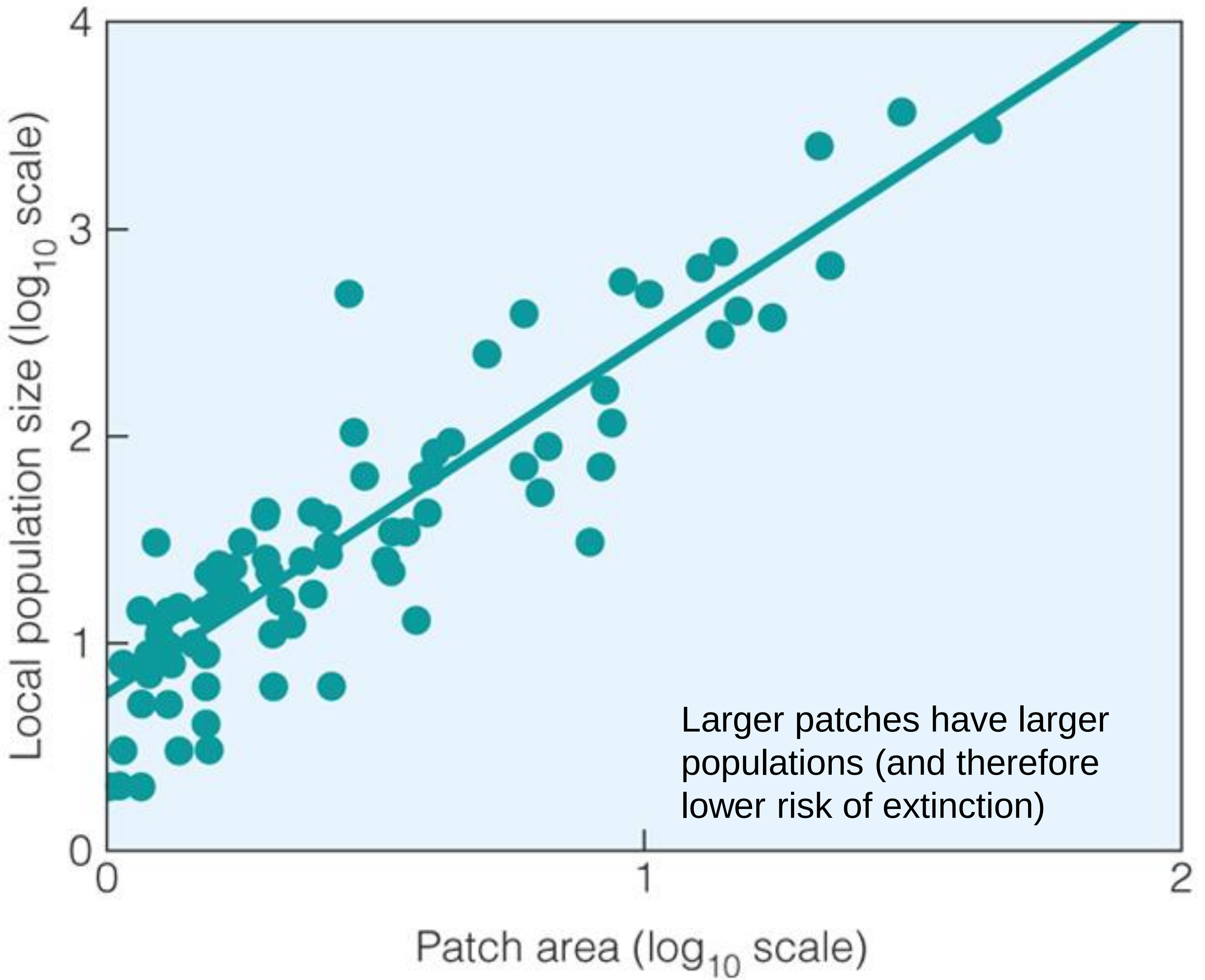






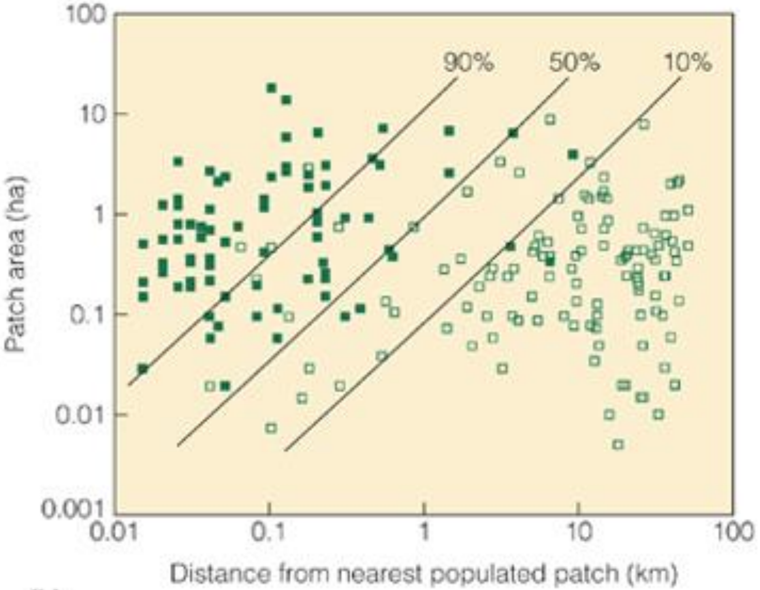
If C>E, P increases; If C<E, P decreases

$P_{equilibrium} = 1\text{-}e/m$



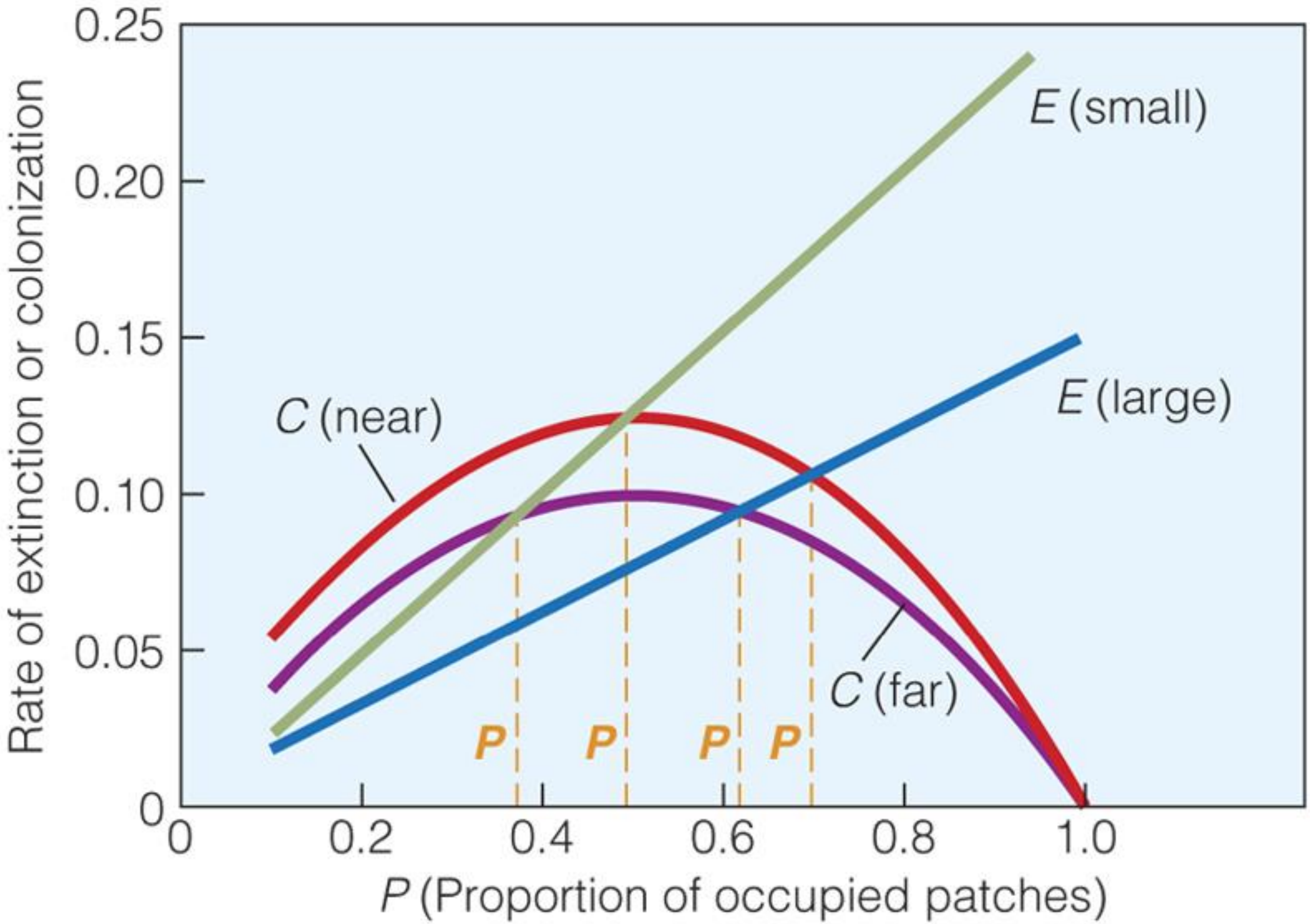
Local population size (log_{10} scale)
4
3
2
1
0
0
1
2
Patch area (log_{10} scale)
Larger patches have larger populations (and therefore lower risk of extinction)

(a)



(b)

Skipper butterfly



Rate of extinction or colonization
0.25
0.20
0.15
0.10
0.05
0
E (small)
E (large)
C (near)
C (far)
P
P
P
P
0
0.2
0.4
0.6
0.8
1.0
P (Proportion of occupied patches)

Metapopulations

- Occupancy models
  - Patch state: occupied, unoccupied
  - Patch processes: extinction, colonization

- Classic Levin's metapopulation model (1970)
  1. Habitat occurs in discrete patches
  2. Patches are not so isolated as to prevent dispersal
  3. Individual populations have a chance of going extinct
  4. The dynamics of populations in different patches are not synchronized
     - i.e., they do not fluctuate or cycle in synchrony

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

Levins, R. 1969. *Bull. Ent. Soc. Am.* 15:237-240.

Classic metapopulation model

- Determine fraction of sites occupied (p) where rate of site occupancy is stable (change is zero)

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

$$\hat{f} = 1 - \frac{e}{c}$$

Island-mainland

$$\hat{f} = \frac{p_i}{p_i + p_e}$$

- Population persists only if e < c

Metapopulation model

- If the fraction of occupied sites is assumed to decrease in proportion to the number of destroyed sites (*D*), we get

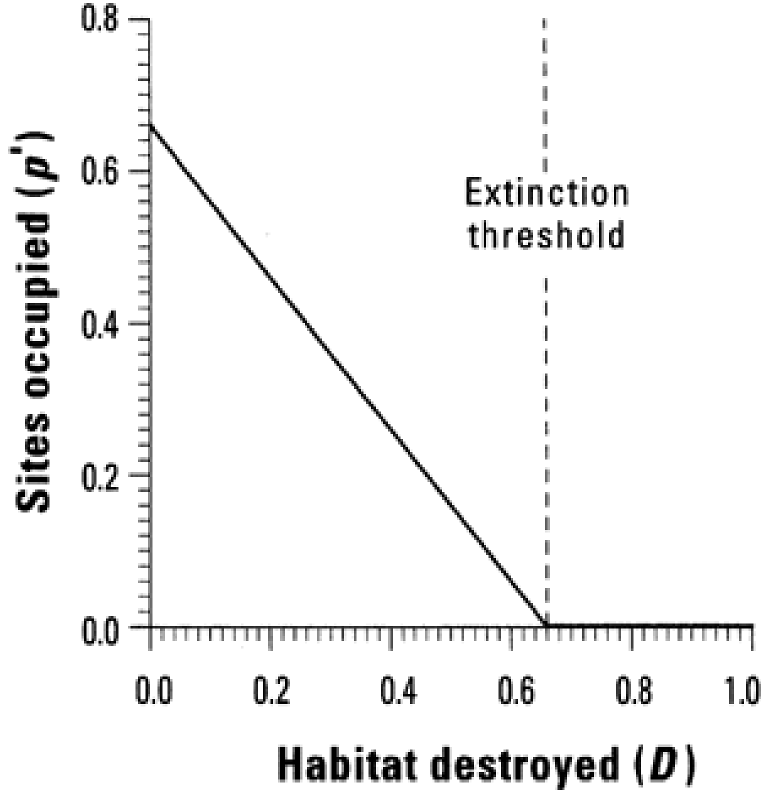
$$\frac{dp}{dt} = cp(1 - D - p) - mp$$

- Hence, the estimate of expected colonized sites (equilibrium solution)

$$p' = 1 - D - \frac{m}{c}$$

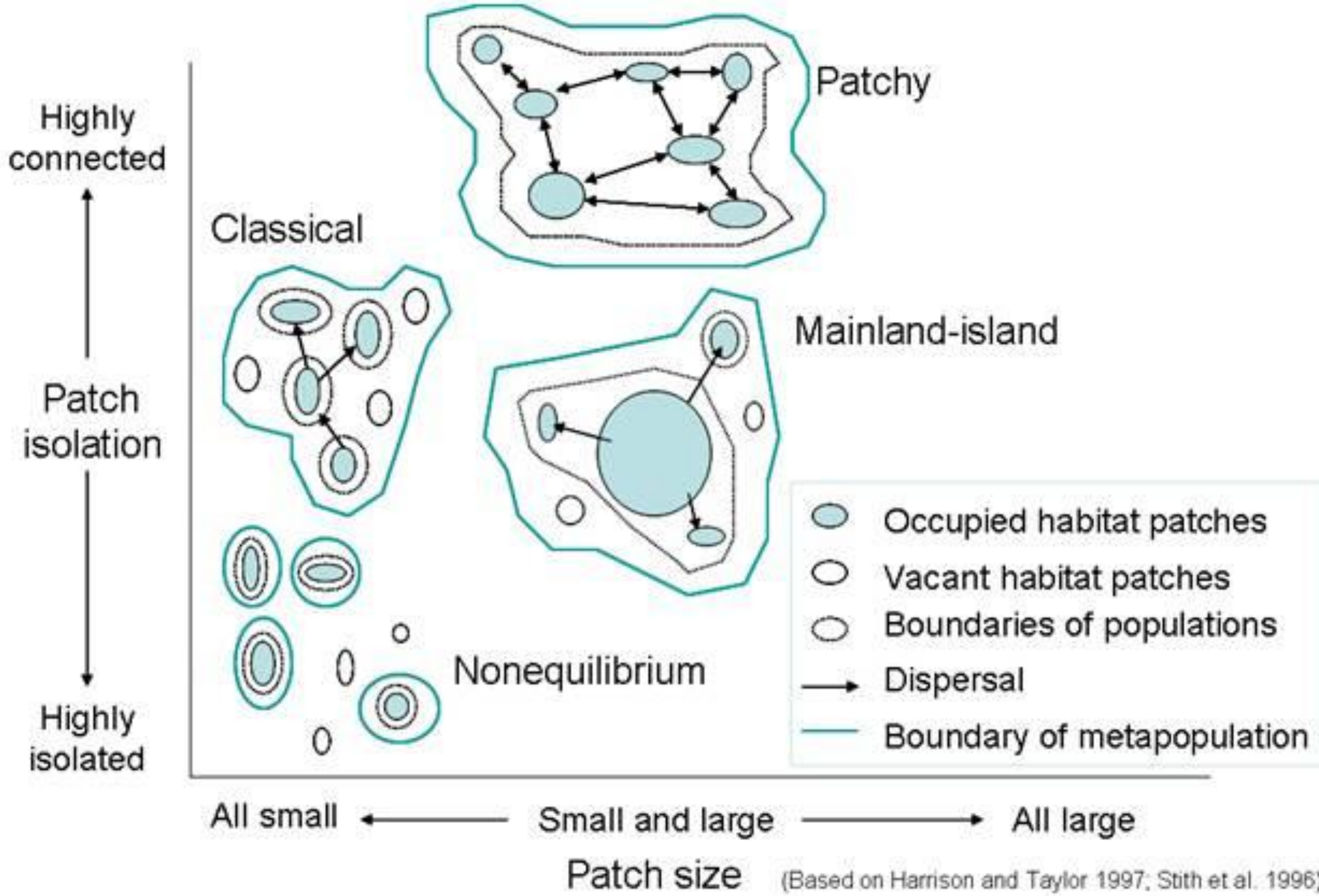
- The extinction threshold occurs when the fraction of available sites(1-D) <= *m/c*
- This means a population will disappear long before the final patches are removed

m = 0.2, c = 0.6;
1- m/c = 0.666



Turner *et al.*, 2001

Metapopulation structure



What processes are most important for each system?

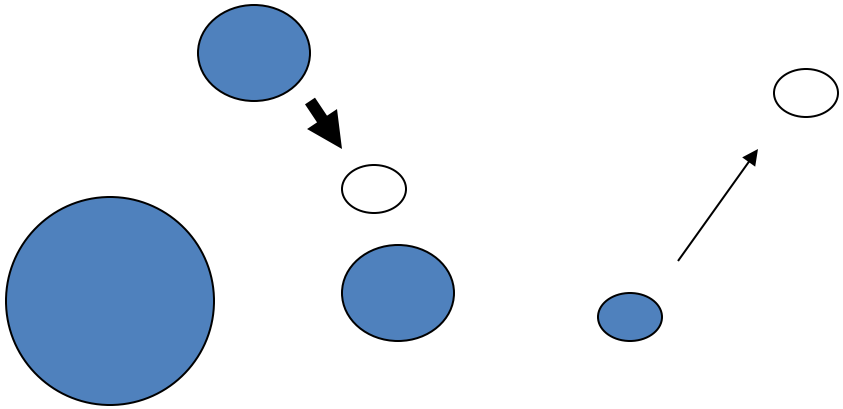
The classical metapopulation model is unrealistic

all patches are the same size

all patches are equally connected

BUT patches in nature vary in size and isolation

Spatially realistic metapopulation models

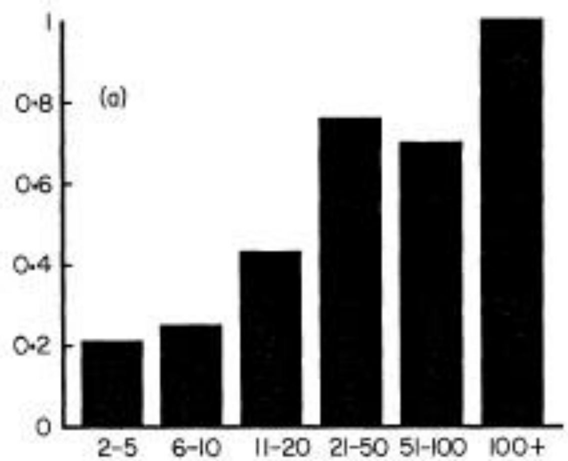


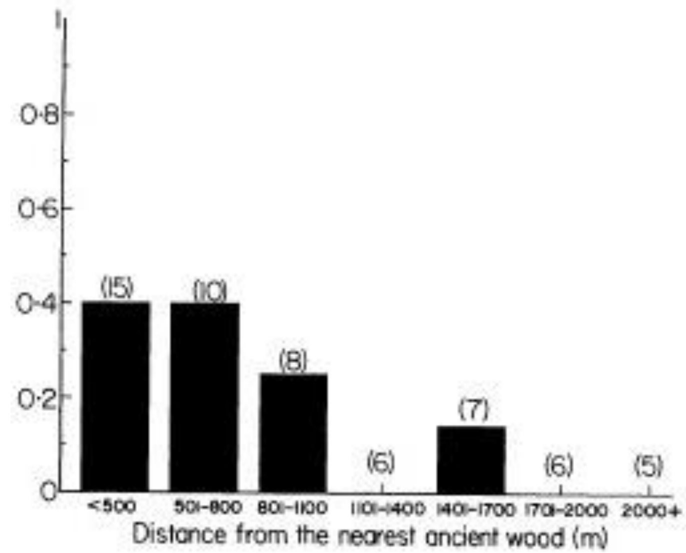
Which patches are most likely to go extinct or become colonized?

Effect of patch area and isolation on occupancy

Dormice - 238 woodlands in the UK

Occupancy





Area

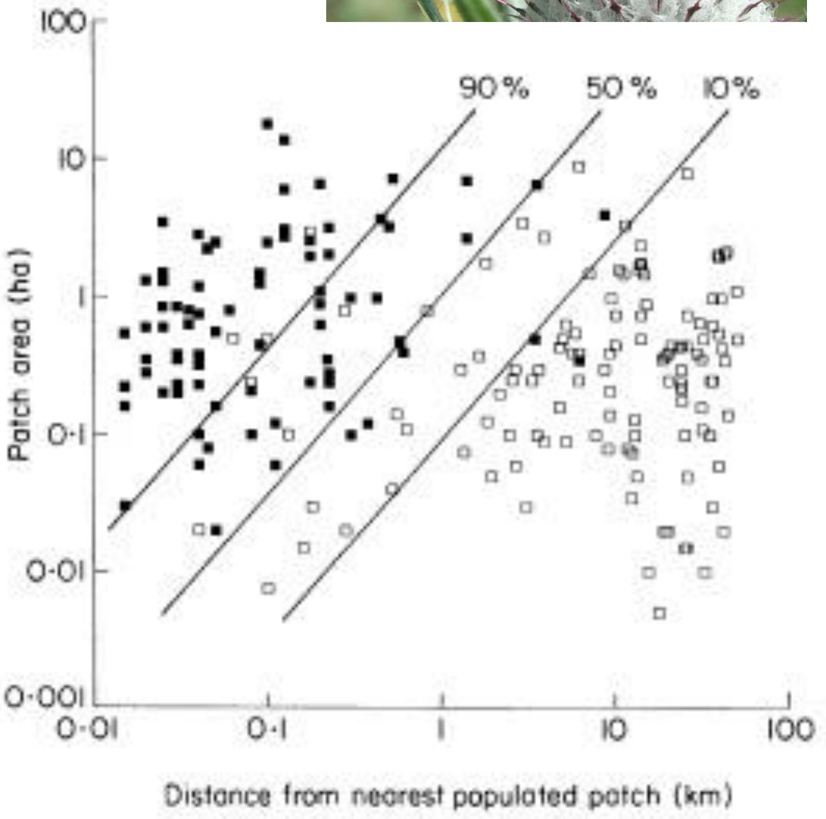
Isolation

Patch area and isolation effects on occupancy

Skipper - grass meadows in the UK

Closed = occupied

Area



Isolation

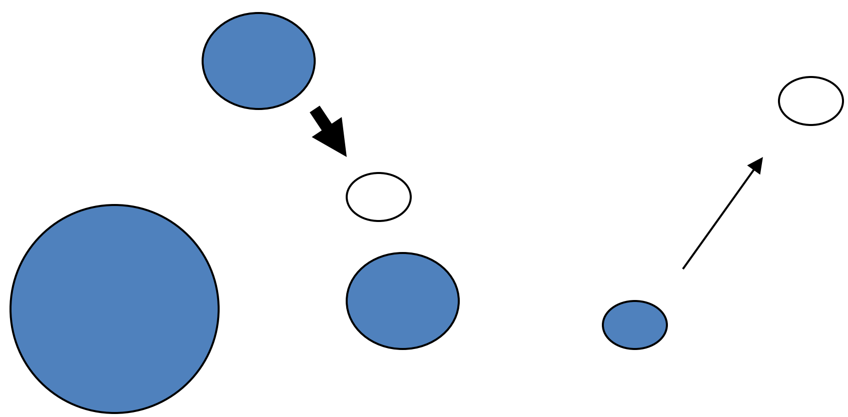
The classical metapopulation model is spatially implicit

all patches are the same size

all patches are equally connected

BUT patches in nature vary in size and isolation

Spatially realistic metapopulation models



Patch size influences extinction

Isolation and patch size influence colonisation

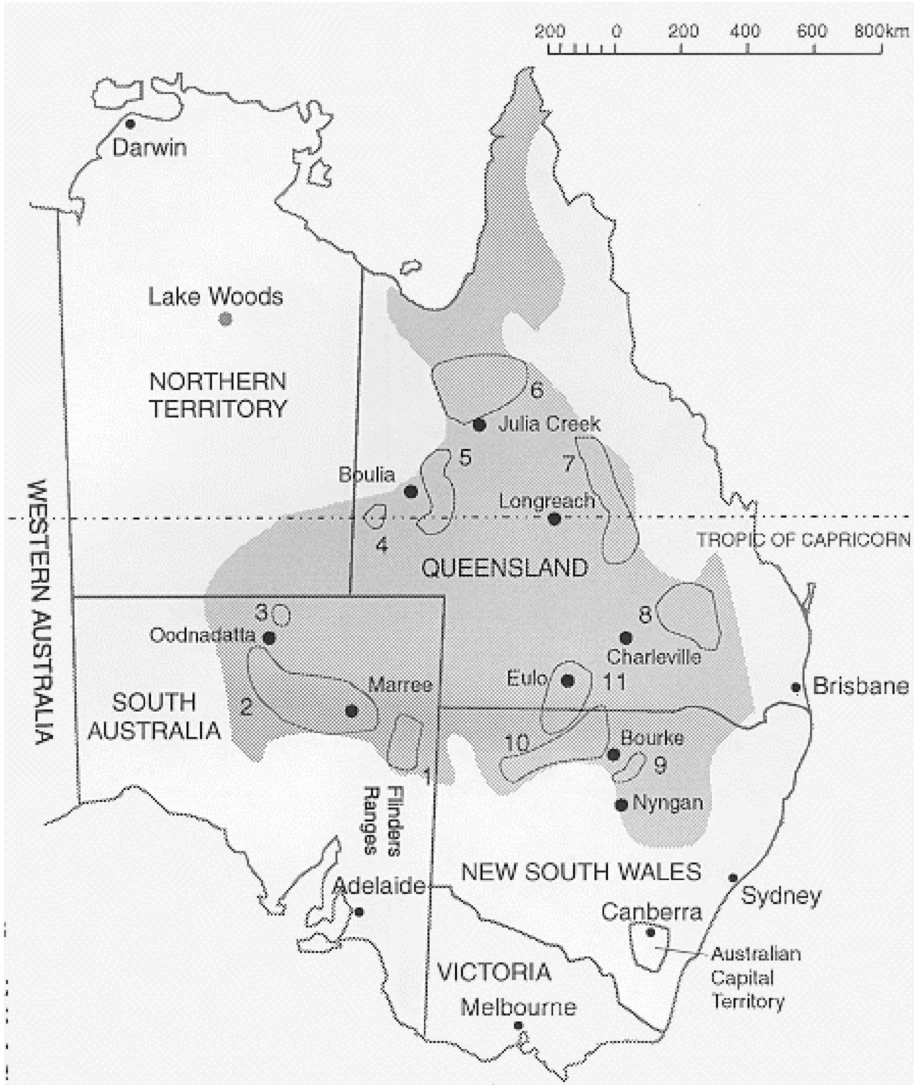
Stochastic patch occupancy models

- Incidence function model
  - Generated from snapshot data
    - i.e. presence/absence at one point in time
  - Metapopulation is at an equilibrium state

Probability a patch i is occupied

$J_i = C_i / C_i + E_i$

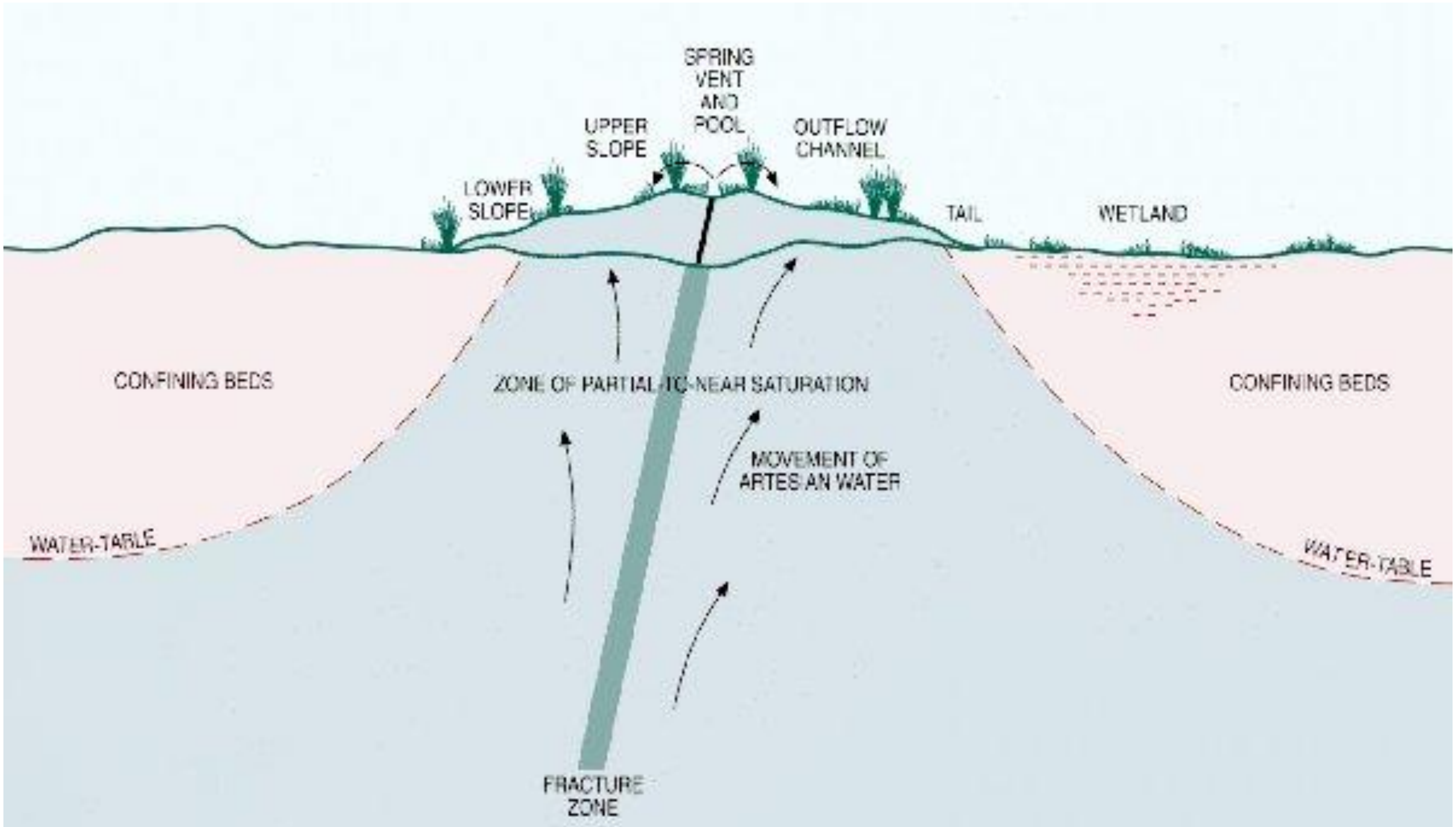
Mound springs in Arid Australia



Great Artesian Basin

- Covers ~ 22% Australia (1.76 million square km)
- Recharged from rainfall and stream flow
- Artesian springs on fringes of basin

Mound springs in Arid Australia



Mound springs in Arid Australia

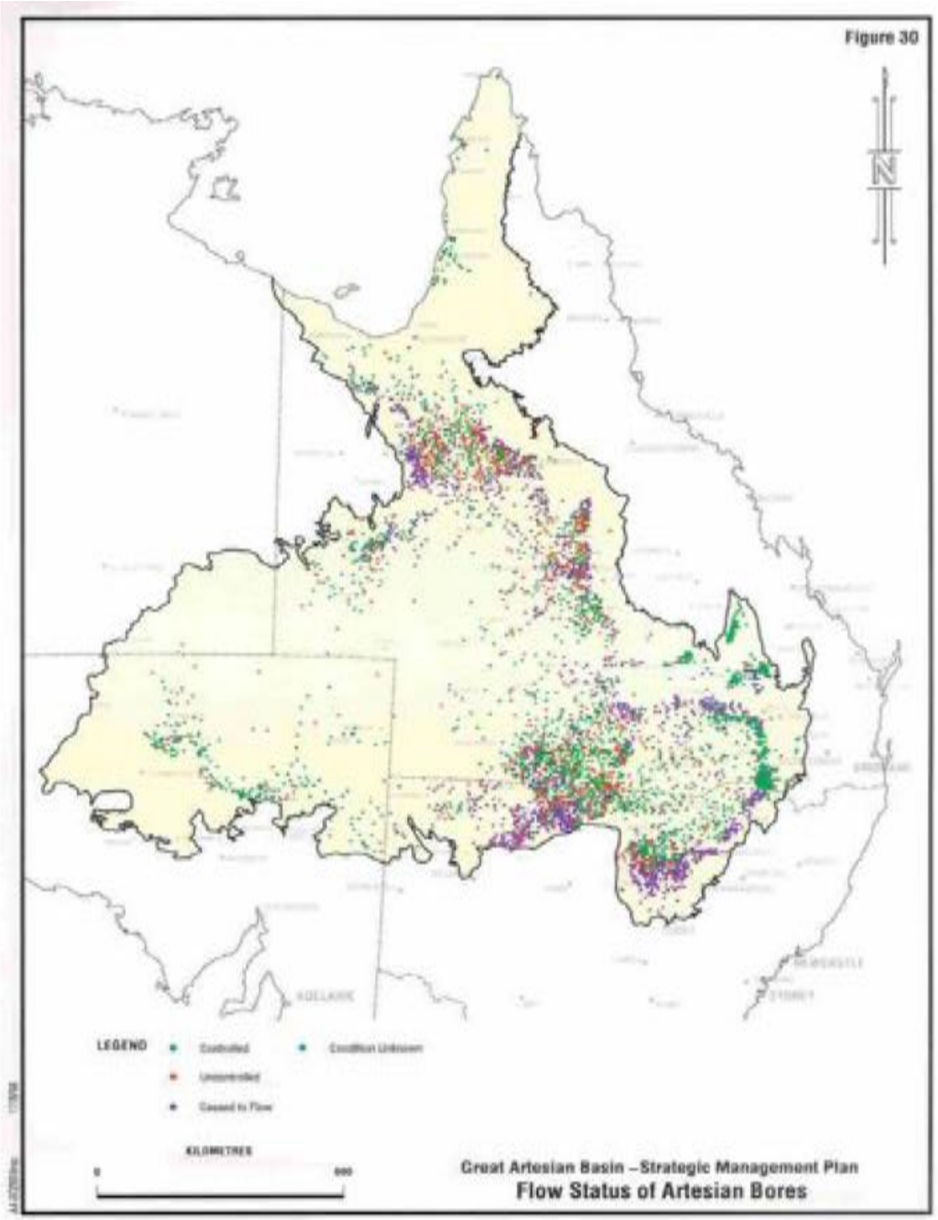


Figure 30
N
LEGEND
Controlled
Uncontrolled
Ceased to Flow
Condition Unknown
KILOMETRES
Great Artesian Basin – Strategic Management Plan
Flow Status of Artesian Bores


WELCOME TO
OLYMPIC DAM OPERATIONS
WMC
COPPER URANIUM DIVISION
BUILDING OUR FUTURE SAFELY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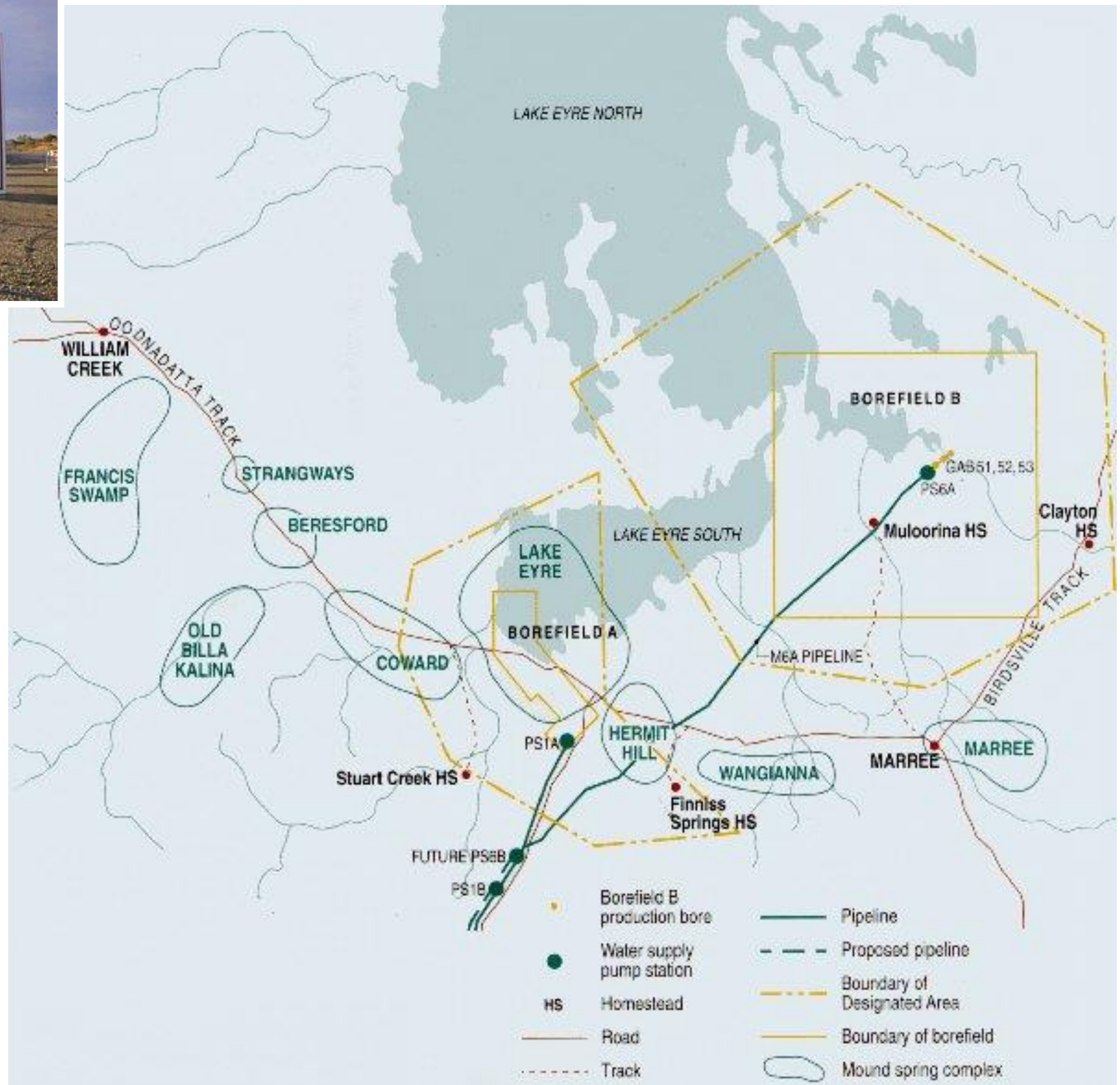
LAKE EYRE NORTH
LAKE EYRE SOUTH
BOREFIELD B
BOREFIELD A
GAB51, 52, 53
PS6A
Muloorina HS
Clayton HS
WILLIAM CREEK
OODNADATTA TRACK
FRANCIS SWAMP
STRANGWAYS
BERESFORD
OLD BILLA KALINA
COWARD
LAKE EYRE
M6A PIPELINE
BIRDSVILLE TRACK
PS1A
HERMIT HILL
Stuart Creek HS
WANGIANNA
MARREE
MARREE
Finniss Springs HS
FUTURE PS5B
PS1B
Borefield B production bore
Water supply pump station
HS Homestead
Road
Track
Pipeline
Proposed pipeline
Boundary of Designated Area
Boundary of borefield
Mound spring complex

Mound springs in Arid Australia

How will mound spring invertebrates respond to water reductions?

What is the most appropriate way to model this system?

What biological scale should we focus on in the PVA?

Relevant biological scale?

- Individuals
- Populations
- **Metapopulation**
- communities

Mound springs in Arid Australia

- Metapopulations
  - Patches of habitat embedded in a landscape that is unsuitable
- Defined by two processes
  - Patch colonization (λ)
  - Patch extinction (μ)