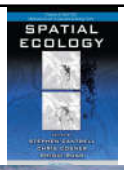
Spatial Ecology



- Landscapes are complex, yet most of our approach has been to treat it as a uniform entity (e.g. K in population models).
- We have used the term “patch” throughout the semester without any kind of formal definition.
- **Patch** – small unit of suitable habitat surrounded by less suitable habitat.

Habitat Patchiness

- Habitats are patchy, organism distributions are patchy, our previous model of population size is **not** patchy. $N_{t+1} = N_t + B + I - D - E$
- Solution: define patch size, model each patch independently, quantify movement and dispersal among patches
  - Incorporates patchiness, immigration and emmigration among patches.
- **Metapopulation** – subpopulations, patches where individuals are concentrated. Metapopulations have a reasonable probability of extinction and colonization on an ecological time scale.

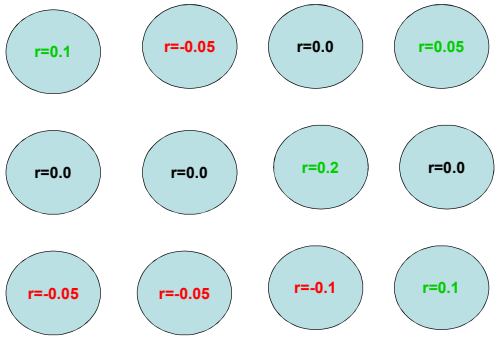
Patch dynamics and modeling movement

- **Non-spatially explicit** – movement among any two patches equally likely.
- **Simple diffusion model** – probability of movement to a patch decreases as the square of the distance.

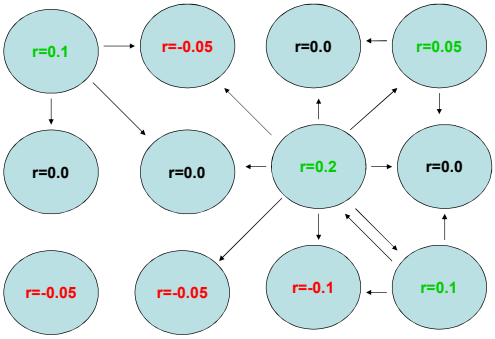
$$rate = D\frac{conc}{dist^2}$$

- **Spatially explicit** – greater distance among patches decreases movement. Patch size and geometry affect dispersal rates. Allows for stepping-stone type patterns.

Movement Models

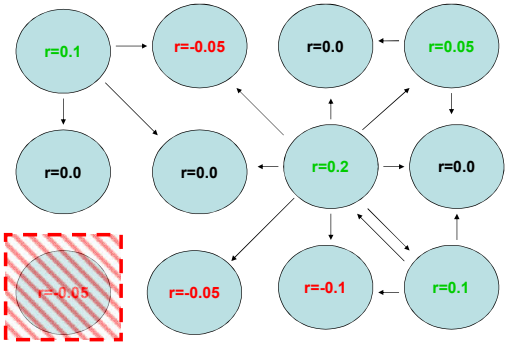


Source-Sink Dynamics



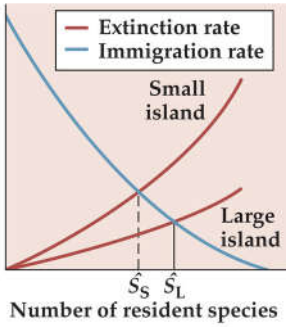
- **Sink** – patch with r<0 sustained by immigration from other patches
- **Sink** - patch with r=0 increase only possible due to immigration
- **Source** - patch with r>0 supply other patch
- Remember – r is not constant, expect it to be modified by local conditions and density (intraspecific comp.)

Source-Sink Dynamics



- **Rescue effect** – metapopulation not sustainable (sink), sustained by immigration from source.

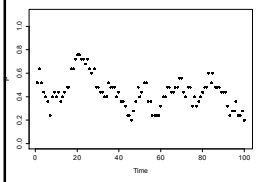
- Island Biogeography based on similar concept, **equilibrium** between **colonization** and **extinction**



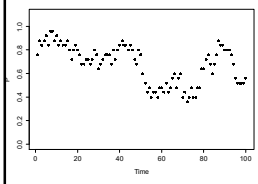
Levins Metapopulation Model

- Rate of population growth:
- $\frac{dP}{dT} = cP(1-P) - mP$
  - P – proportion of patches occupied
  - c – colonization rate (rate of occupied cells)
  - m – extinction rate
- Proportion of occupied patches at equilibrium ($\hat{P}$)
- $\hat{P} = 1 - \frac{m}{c}$

Levins Metapopulation Model, 100 year simulations

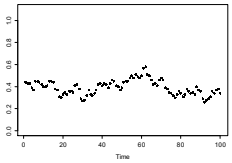


C-0.25
M-0.15
25 patches:
45% persistence mean T of 55.4
mean P 0.32

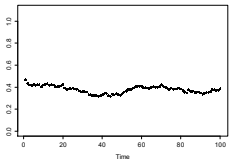


C-0.3
M-0.1
25 patches:
99% persistence mean T of 99.9
mean P 0.66

Levins Metapopulation Model, 100 year simulations



C-0.25
M-0.15
100 patches:
99% persistence mean T of 99.3
mean P 0.34



C-0.25
M-0.15
900 patches:
100% persistence mean T of 100
mean P 0.35

100 patches maximum **T=1000**:
83% persistence mean T of 921.3
mean P 0.31

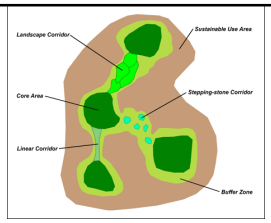
900 patches maximum **T=1000**:
100% persistence mean T of 1000
mean P 0.34

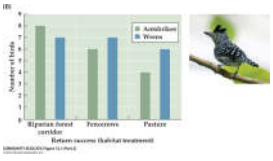
Metapopulation implications

- Direct link between habitat loss and species persistence over time.
  - Persistence for 1000 years (c=0.25 m=0.15)
    - 25 patches: 0%
    - 100 patches: 83%
    - 900 patches 100%
- Proportion of patches remain unoccupied. Loss of these currently empty habitats will slow future growth and increase risk of extirpation.
- Species decrease from patch loss may be slow. **Extinction debt** – slow decline of a species with insufficient patches.
- Conservation implication – conserving the habitat where a species currently occurs may be inadequate.

Corridors

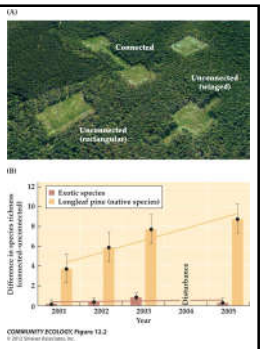
- Corridors: connections between patches to facilitate dispersal.
- Fundamental to modern conservation biology, attempt to increase **c**
  - $\frac{dP}{dT} = cP(1-P) - mP$
- Experimental evidence shows corridors facilitate movement most of the time.
- **Edge effects**
- Criticism – few studies address whether corridors facilitate movement **and** reproduction.





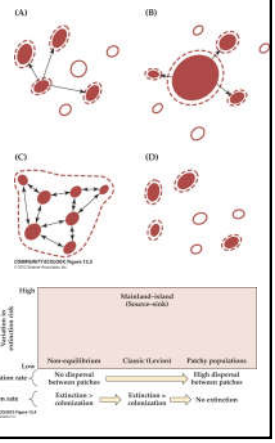
Corridors

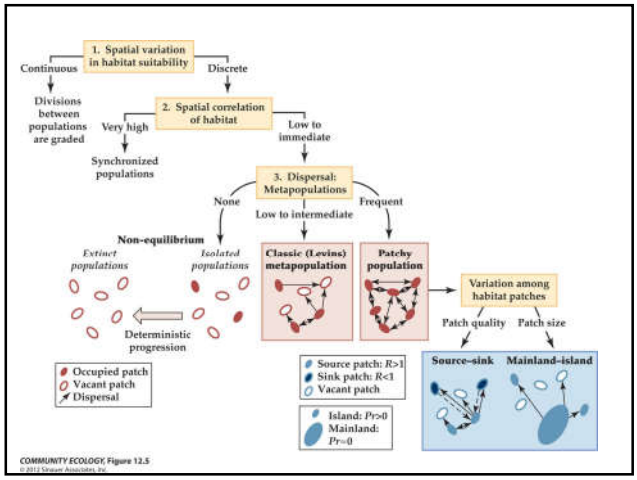
- Also increase species diversity overall (connected patches support more diversity than unconnected).
- Controversy – instead of having corridors, why not simply move individuals (**assisted dispersal**).



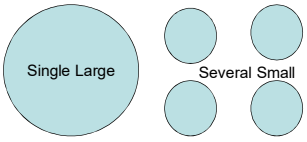
Empirical Examples of Metapopulations

- Do real populations fit predicted patterns?
- Might expect populations to fit into one of four categories:
  - **Levins model** – classic metapopulation (A)
  - **Mainland-island**: one large patch with smaller "islands" (B)
  - **Patchy population** – patches not well isolated (C)
  - **Non-equilibrium** – isolated patches where extinction exceeds colonization and extinction is imminent (D)





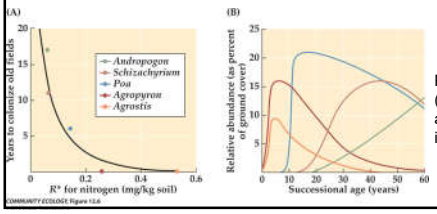
Metapopulation application to conservation biology



- Single Large
  - Less edge (+)
  - More core (+)
  - Only one population, single disturbance dangerous (-)
  - Fewer habitat types possible (-)
  - Large population (+)
  - No rescue effect (-)
- Several Small
  - More edge (-)
  - Less core (-)
  - Multiple populations, single disturbance less dangerous (+)
  - Multiple habitat types possible (+)
  - Small populations (-)
  - Rescue effect (+)

Metapopulation Implications: Competition and coexistence

- Even at equilibrium, some patches unoccupied (1-P).
- May represent an opportunity for "**fugitive species**" to specialize in colonization ability.
- Recall paradox of plankton
- Competition-colonization tradeoff



Plant competitive ability (A) quantified as R* for N, and order of colonization in succession (B)

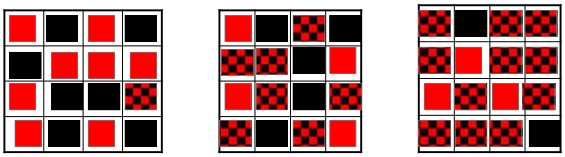
Competition and Metapopulations

- Checkerboard distributions
  - Viewing species distribution (presence/absence) among patches.

Species A alone

Species B alone

Species A and B together



Classic work by Stuart Pimm – worked on patterns in island bird species.

Metapopulation and Habitat Heterogeneity

- Patchy environments are going to be more heterogeneous, something we expect to increase diversity.
- Disturbances create patches of habitat of different quality for different resident species. Recall intermediate disturbance hypothesis (**IDH**)
- **Patch dynamics** - Disturbances on various scales facilitate coexistence and increase diversity though metapopulation processes.