Cons. Sci. Week 5: Population Ecology and Island Biogeography

Isla Myers-Smith
School of GeoSciences

Schedule for Today

9:30 - 10:00 - Lecture Population Ecology

10:00 - 10:30 Activity 1 - Island biogeography colonisation

10:30 - 10:45 Break

10:45 - 11:15 - Lecture Island Biogeography

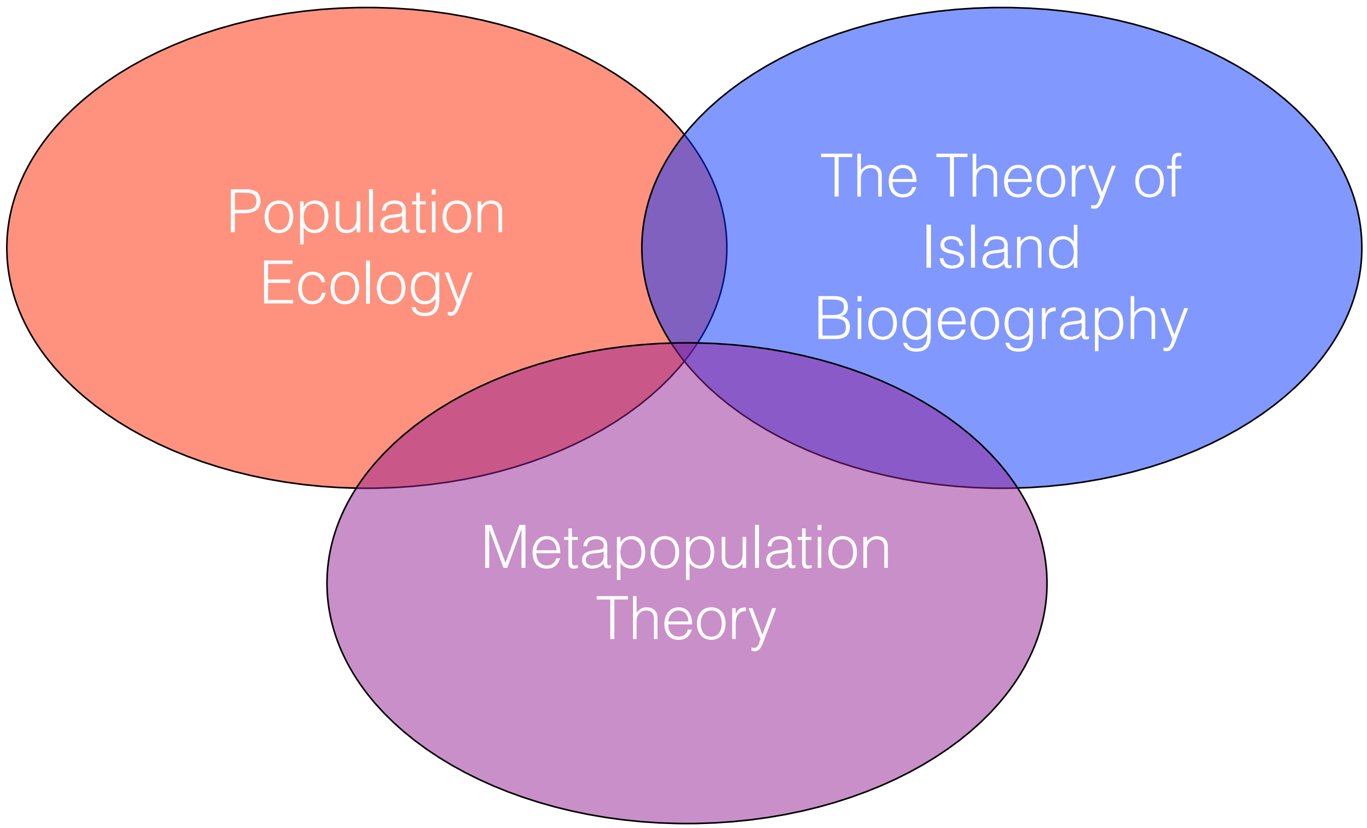
11:15 – 11:40 Discussion of Island Biogeography as applied to conservation

11:40 - 12:15 Activity in groups - mark recapture population estimates

12:00 - 12:30 Debrief of discussions and activities
- Report back from each group on the mark recapture estimates

Discussion of homework, fieldtrip, blog, opinion pieces, course conference, etc.

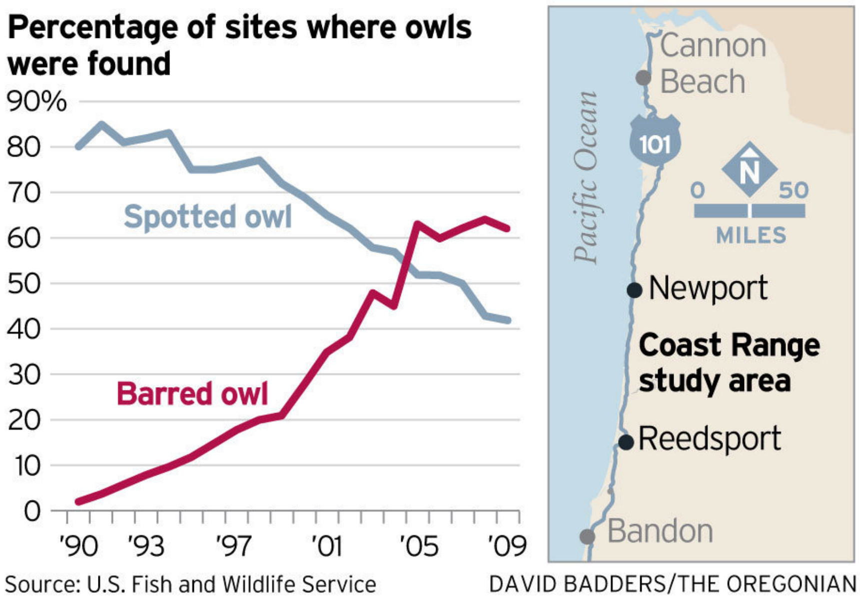
Today's Lecture



Population Ecology

- Learning Objectives:
- Population viability analysis
- Exponential population growth
- Demographic stochasticity
- Population matrices
- The extinction vortex
- Genetics in conservation

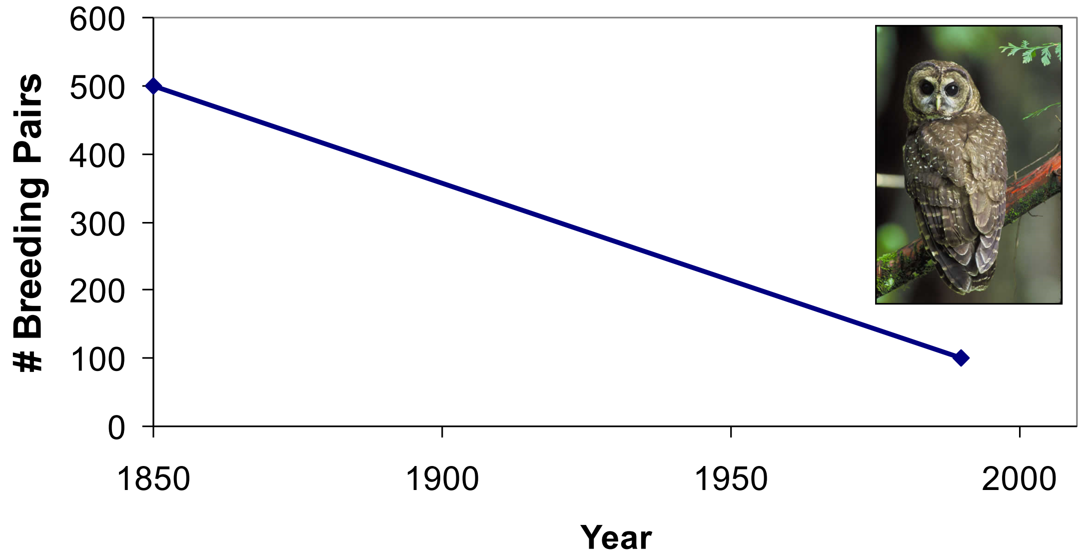
Population Viability analysis



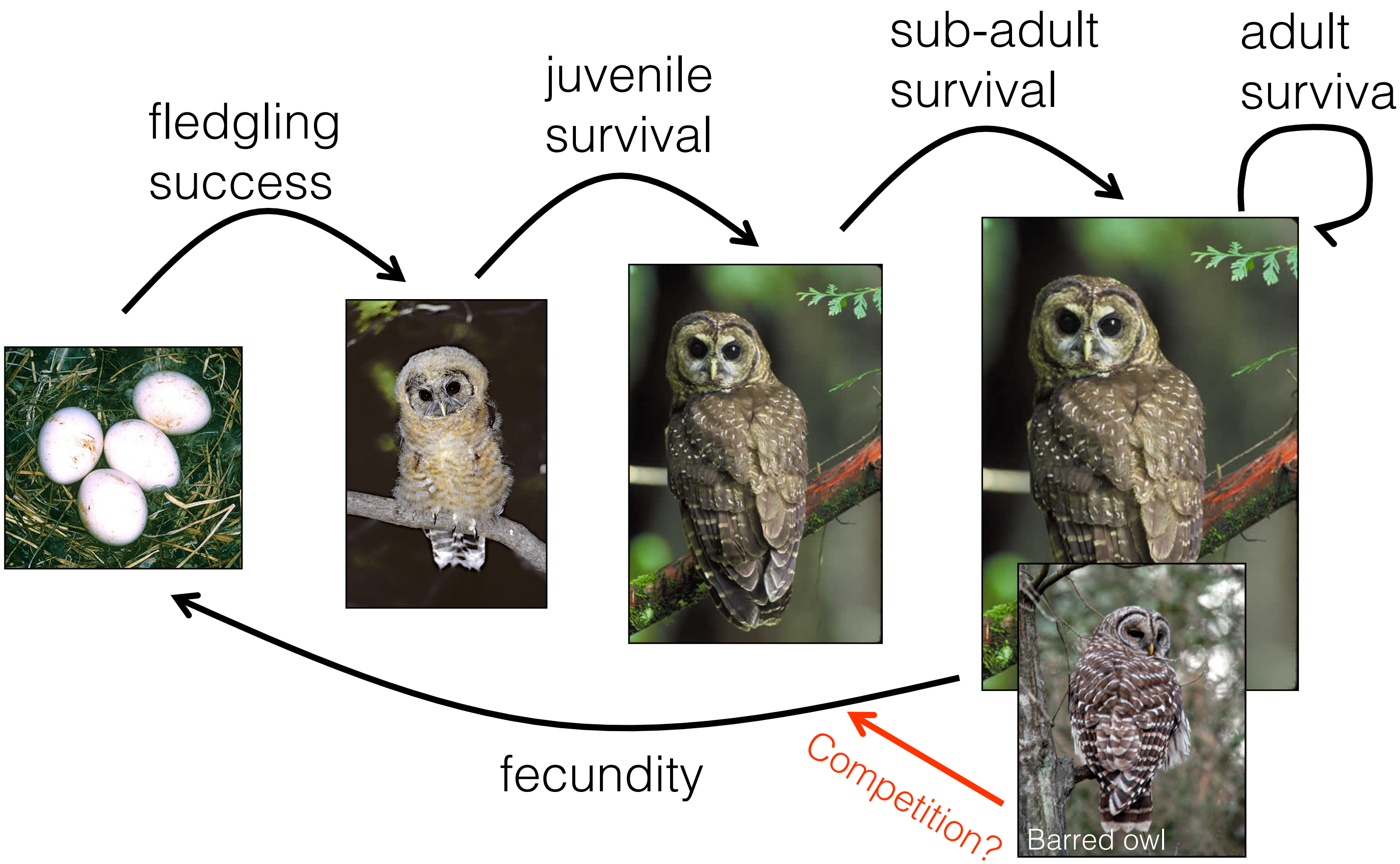
Morris & Doak (2002) Quantitative Conservation Biology

Simple Model:

- Count individuals over time
- Estimate trend
- Project forward



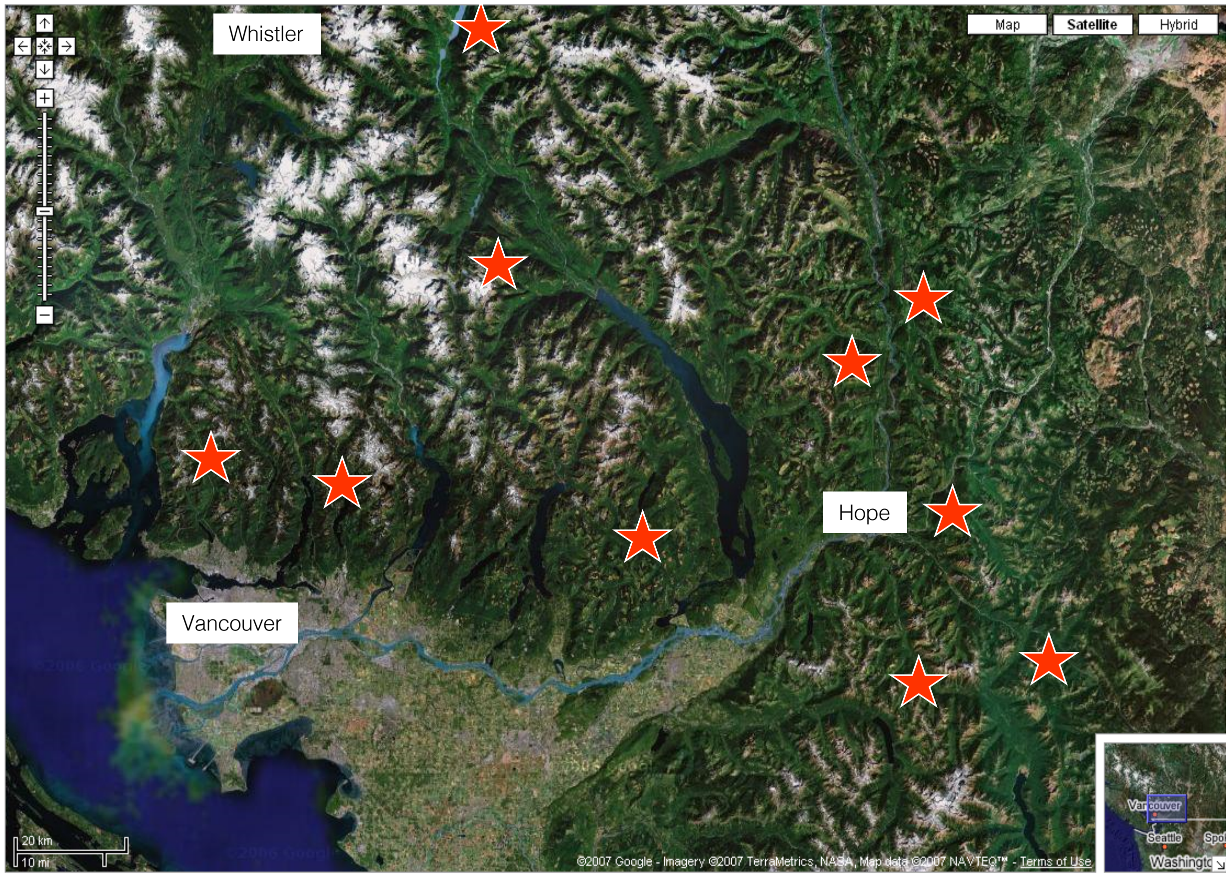
Adding realism: Demographic structure



Adding realism: Spatial structure

★

Potentially suitable owl habitat



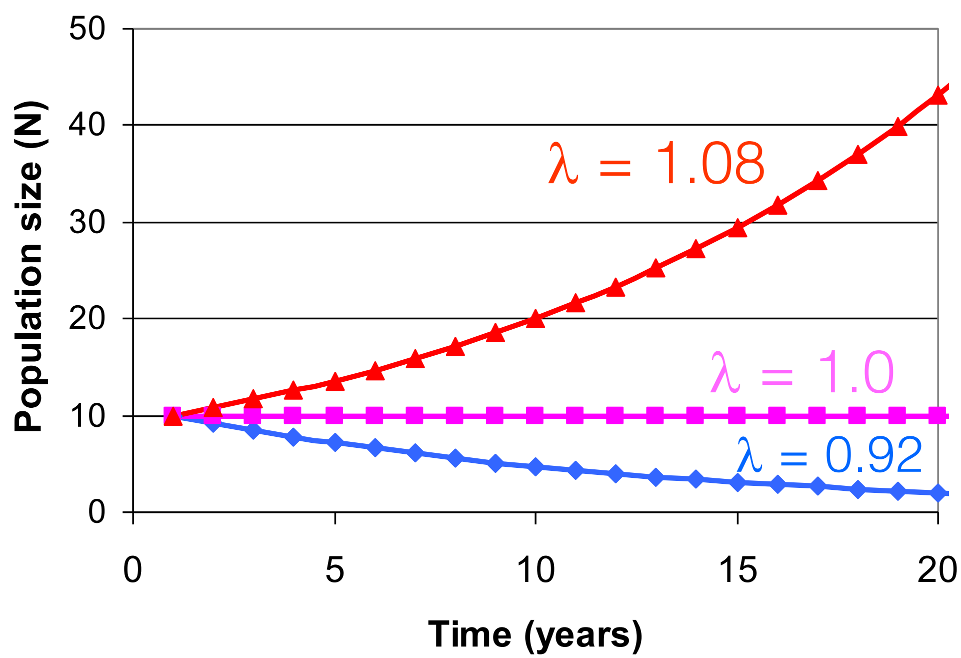
A SIMPLE MODEL:
Exponential Population Growth

$$N_{t+1} = N_t \times \underbrace{(1 + \text{birth} - \text{death} + \text{immigration} - \text{emigration})}_{\lambda}$$

$$N_{t+1} = N_t \times \lambda \leftarrow$$ Annual population growth rate

If λ is constant in time, we have only three possibilities

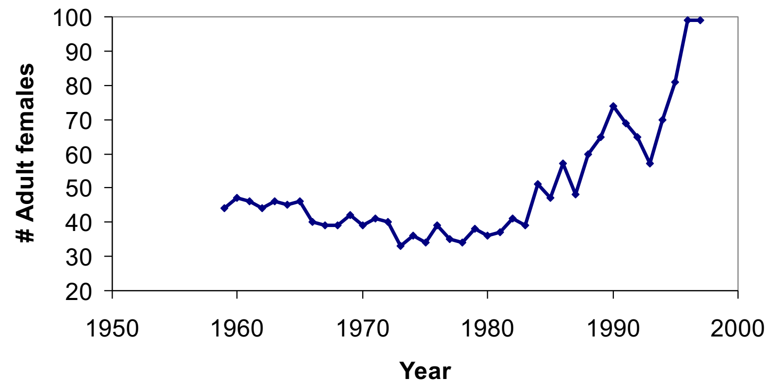
$$N_{t+1} = N_t \times \lambda$$



The outcome is deterministic

But life is not entirely deterministic…

Grizzly bears in Yellowstone



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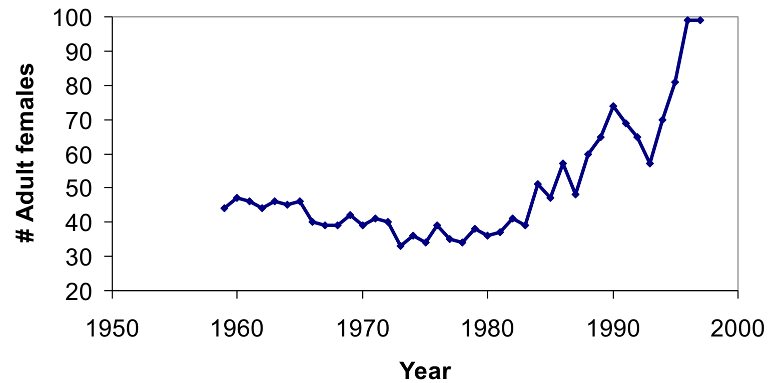


Sources of stochasticity:

- Demographic
- Environmental
- Genetic

Demographic Stochasticity

What does a per capita birth rate of 0.2 mean?

Does every adult have 0.2 offspring?

Demographic Stochasticity

What does a per capita birth rate of 0.2 mean?

Does every adult have 0.2 offspring?

No, for every z individuals now, we expect $0.2 \times z$ new offspring next year

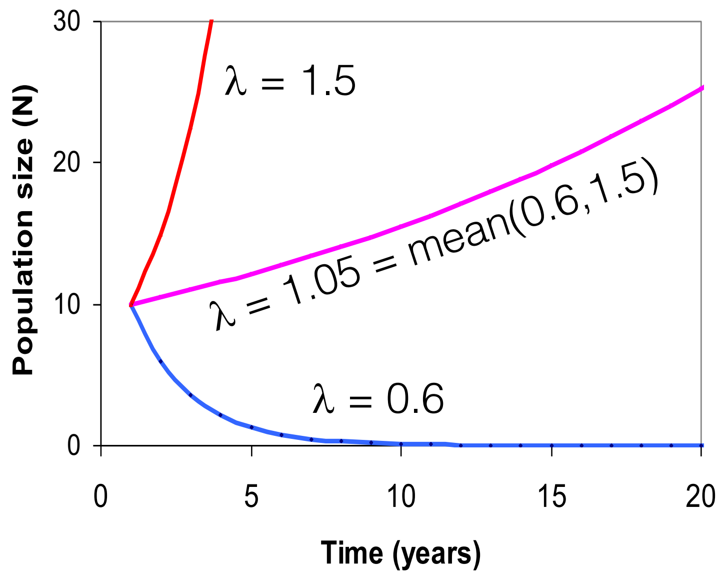
e.g., in a population of 100, we expect 20 new offspring next year

Each adult produces 0, 1, 2… etc. offspring,
and the average is 0.2

With 10 individuals, we expect 2 offspring in an average year,
but we could get 0, 1, 2, 3, etc.
because of demographic stochasticity

Environmental variability

Deterministic population growth



$$N_{t+1} = N_t \times \lambda$$

What happens if we alternate
λ = 0.6 and λ = 1.5?

(A) Population increase

(B) Population decrease

(C) Population steady

(D) Unpredictable

$$N_{t+1} = \underbrace{N_t \times \lambda_1}$$

$$N_{t+2} = N_{t+1} \times \lambda_2$$

$$N_{t+2} = N_t \times \lambda_2 \times \lambda_1$$

and so on…

- If this is > 1, the pop. will grow over the 2 yrs
- If < 1 it will shrink

If we pick randomly from n possible values of λ in each year, the long-term expected population growth rate is given by the geometric mean of the λ's

$$\lambda_1 = 0.6$$

$$\lambda_2 = 1.5$$

Geometric mean:

$$\left(\prod_{i=1}^{n} \lambda_i\right)^{1/n}$$

In this case (n = 2):

$$N_{t+1} = \underbrace{N_t \times \lambda_1}$$

$$N_{t+2} = N_{t+1} \times \lambda_2$$

$$N_{t+2} = N_t \times \lambda_2 \times \lambda_1$$

and so on…

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If we pick randomly from n possible values of λ in each year, the long-term expected population growth rate is given by the geometric mean of the λ's

$\lambda_1 = 0.6$

$\lambda_2 = 1.5$

Geometric mean:

$$\left(\prod_{i=1}^{n} \lambda_i\right)^{1/n}$$

In this case (n = 2):

$$(0.6 \times 1.5)^{1/2} = 0.949$$

(arithmetic mean = 1.05)

Why?

Population growth is a multiplicative process

λ = 1.5 means we multiply the population size by 1.5

λ = 0.6 means we divide the population size by 1/0.6 = 1.67

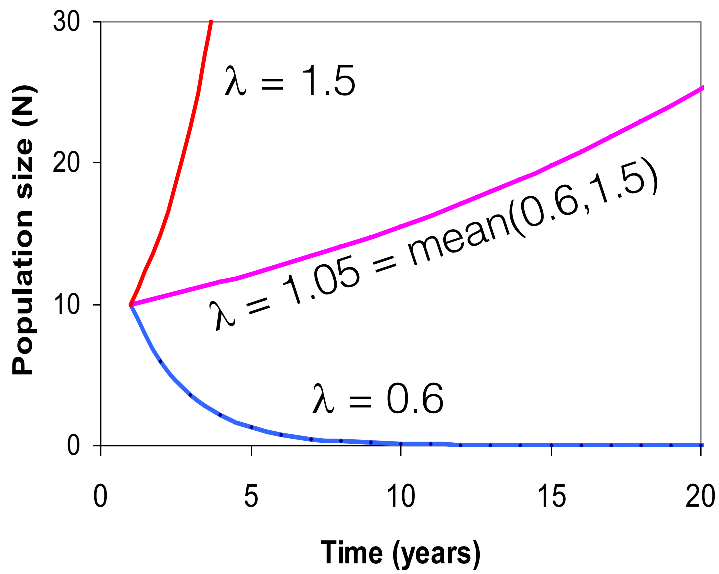
If we randomly chose λ_1 and λ_2 at each time step, the expected average population growth is the geometric mean, not the arithmetic mean

Arithmetic mean	Geometric mean
$(0.6 + 1.5)/2 = 1.05$	$(0.6 \times 1.5)^{1/2} = 0.949$
Population grows (wrong)	Population shrinks (right)

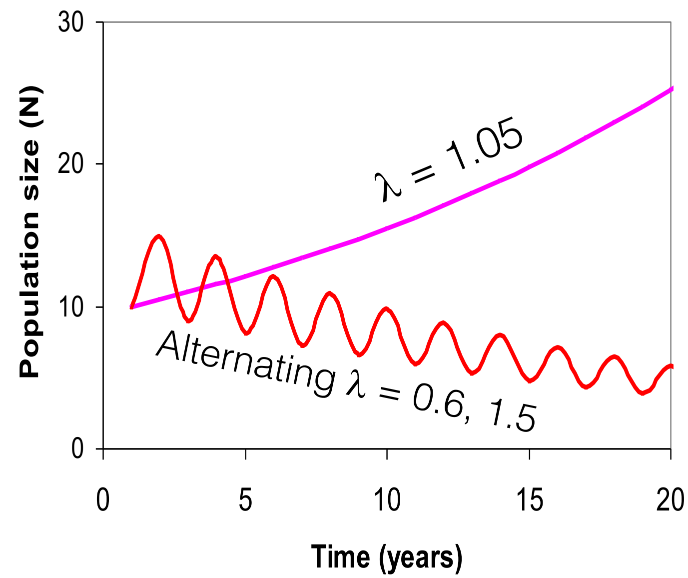
Environmental variability

$$N_{t+1} = N_t \times \lambda$$

Deterministic population growth



What happens if we alternate
λ = 0.6 and λ = 1.5?



Simple Population Viability Analysis

- Start with 41 bears, pick one of six λ's at random in subsequent years, project forward
- Decide on extinction/viability threshold, N = 10
- Calculate proportion of simulations that dip below threshold during 100 years

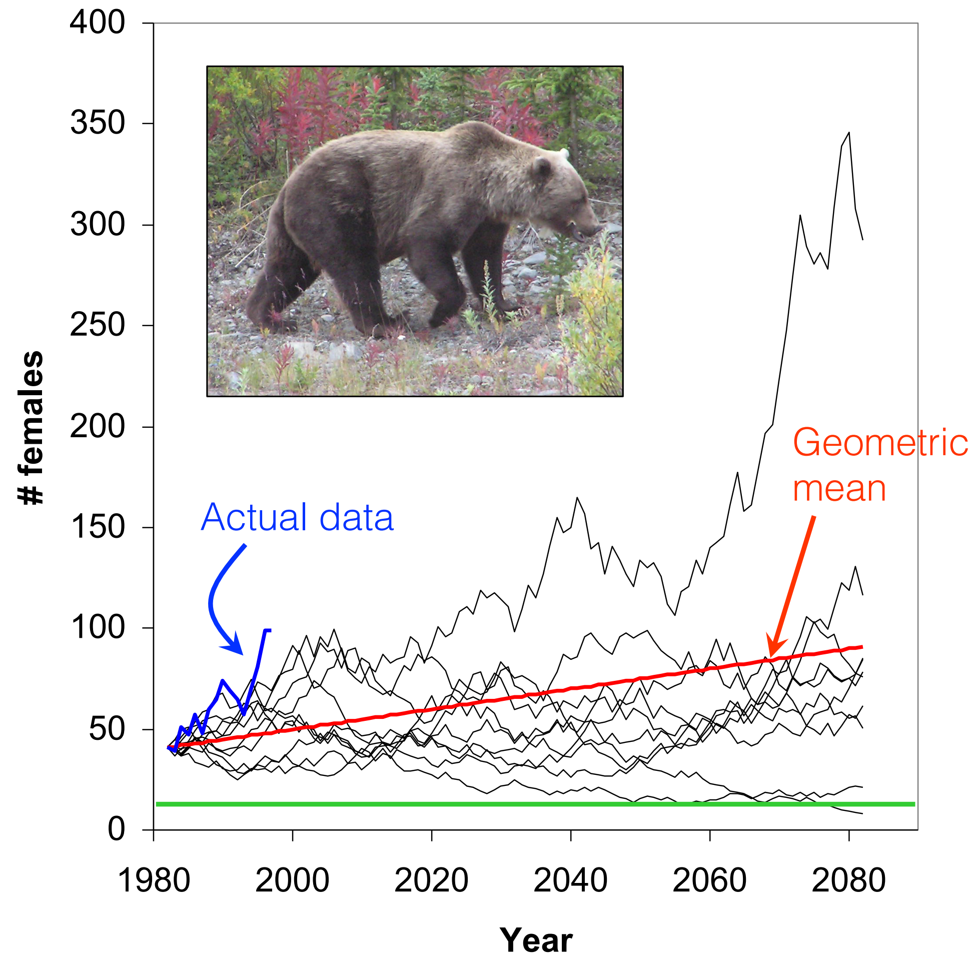
Simple Population Viability Analysis: Grizzly Bears in Yellowstone

- Extinction threshold: 10

- Ten simulations

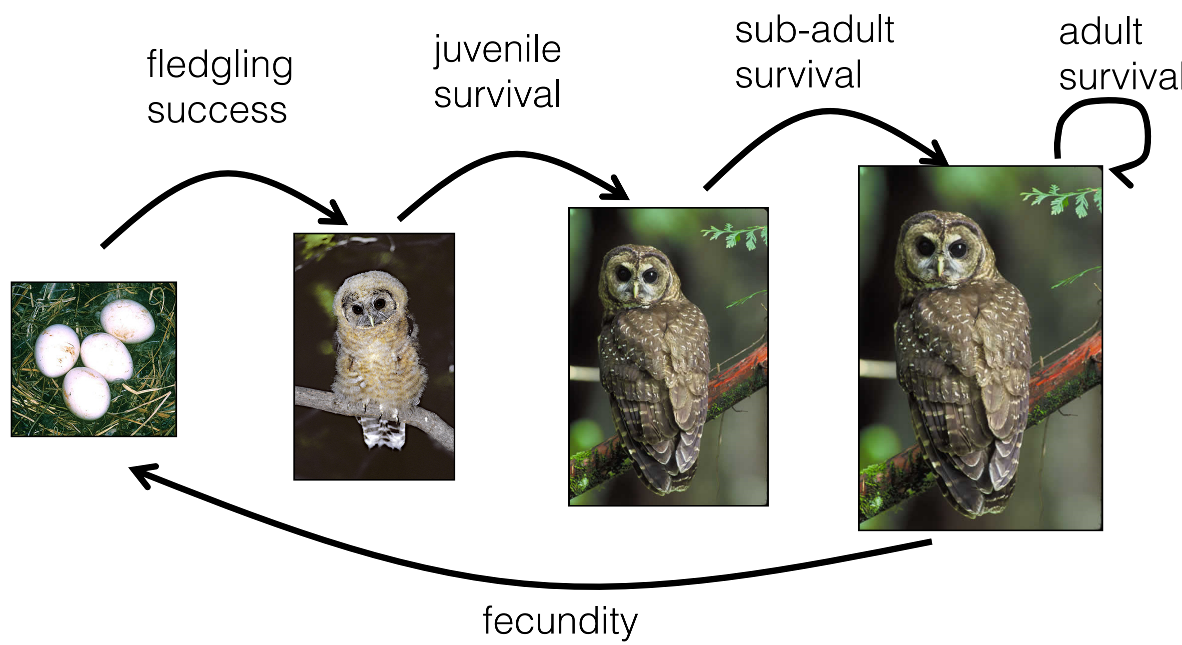
- Positive expected pop. growth

- Actual pop. growth better than expected



Structured population models:
The population projection matrix

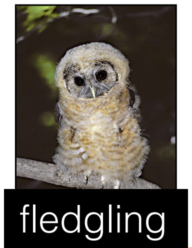
If we can collect the data, a more realistic (complex) model can be more useful



The population projection matrix

Stage at time: → t

t + 1



0	0	2
0.8	0.35	0
0	0.4	0.8

only adults produce eggs

(# surviving fledglings/adult)

prob. of juv. staying juv.

fledgling survival

adult survival

prob. of juv. becoming adult

Projecting population growth: Matrix algebra

Projection matrix

individuals in each stage at time t

individuals in each stage at time t+1

$$\begin{bmatrix} 0 & 0 & 2 \\ 0.8 & 0.35 & 0 \\ 0 & 0.4 & 0.8 \end{bmatrix} \times \begin{bmatrix} 10 \\ 8 \\ 7 \end{bmatrix} = \begin{bmatrix} \underset{0\times 10 + 0\times 8 + 2\times 7}{14} \\ \underset{0.8\times 10 + 0.35\times 8 + 0\times 7}{10.8} \\ \underset{0\times 10 + 0.4\times 8 + 0.8\times 7}{8.8} \end{bmatrix}$$

$$A \times n(t) = n(t+1)$$

Using matrix algebra and some other mathematical tools, we can calculate:

1) The population growth rate, λ

2) The stable stage distribution (proportions of individuals in each stage at equilibrium)

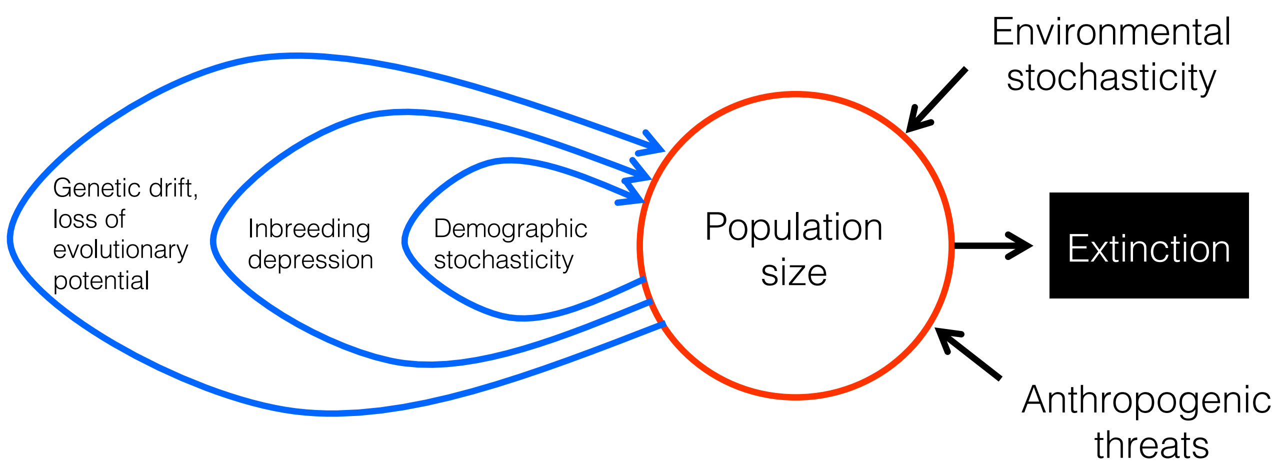
3) The sensitivity of λ to small changes in each matrix element

What would be the consequences of management interventions that affected different life stages?

The Problem with Being Small

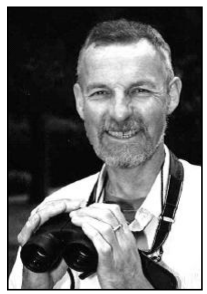
- Sensitivity to environmental variation (one bad year could wipe you out)
- Inbreeding and loss of genetic variation
- Amplified effect of demographic stochasticity

THE EXTINCTION VORTEX

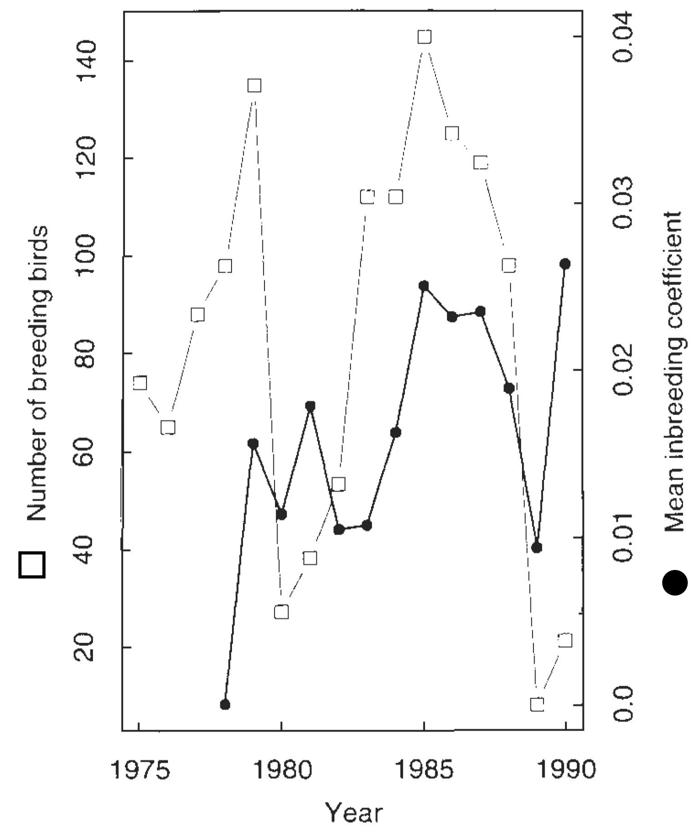


Song sparrows on Mandarte Island, B.C.

Inbred birds selected against during severe population crash, 1989

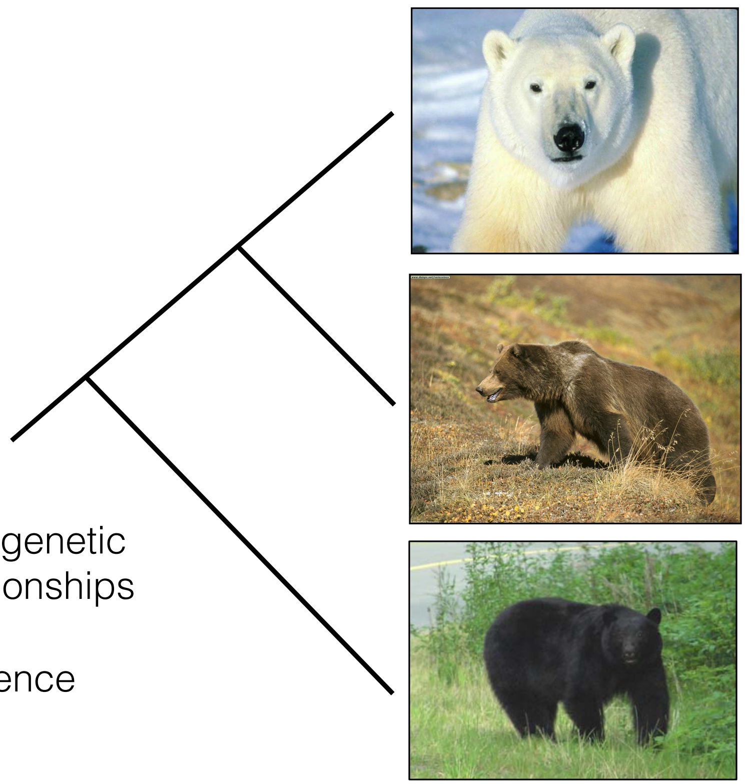
Jamie Smith



Keller et al. (1994) Nature

Other applications of genetics in conservation
Resolving taxonomic uncertainty

Some distinctions are clear ……. others are not so clear

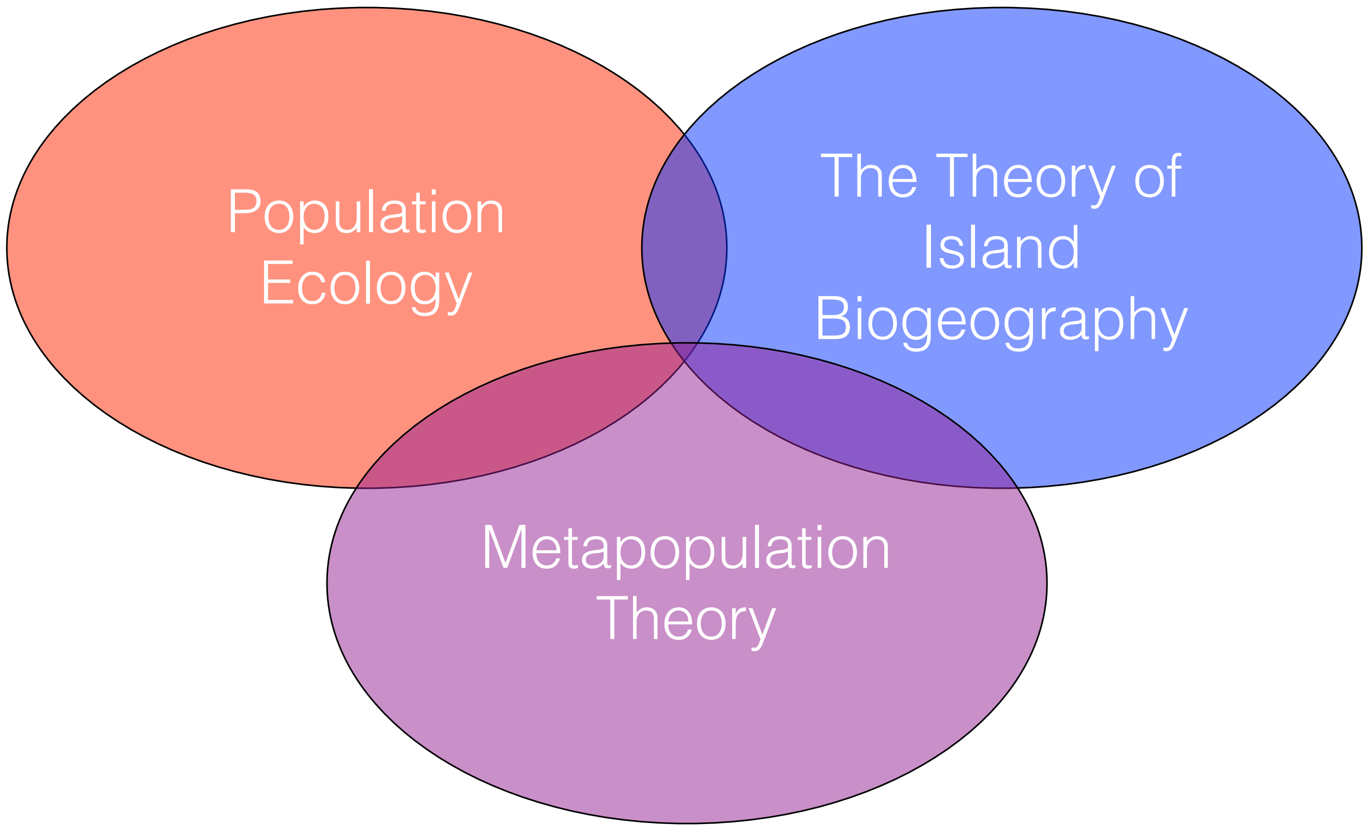


Phylogenetic Relationships (DNA sequence data)

hybridization

April 2006, NWT

Today’s Lecture



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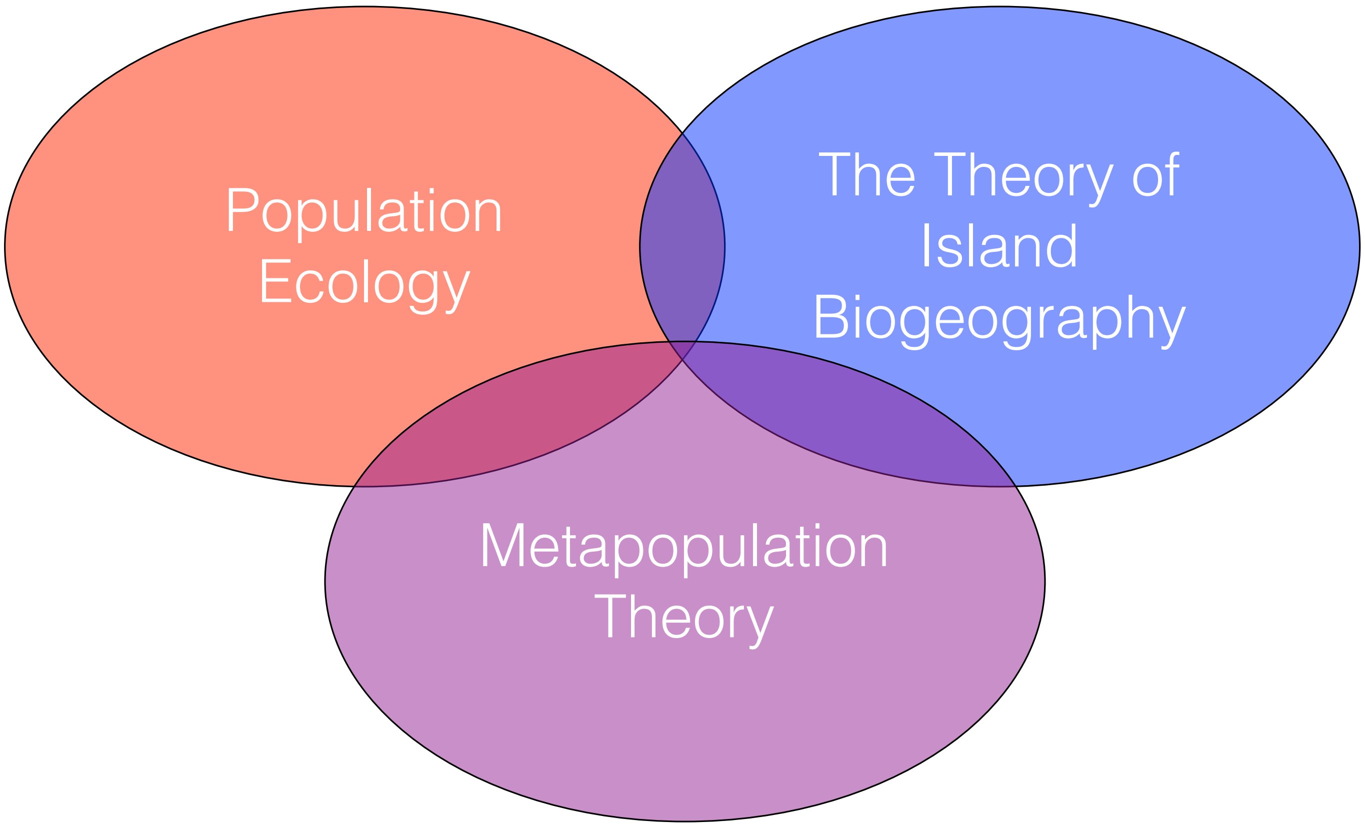


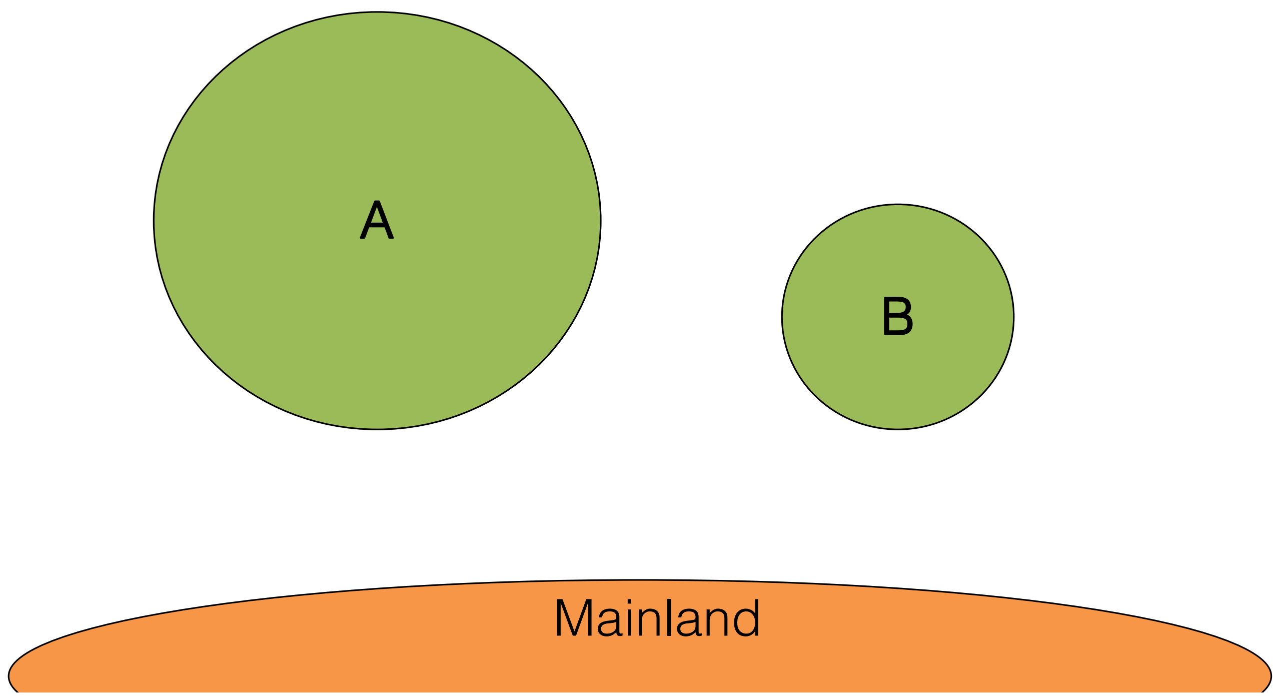
Island Biogeography

Learning Objectives:

- Species-Area and Species-Isolation relationships
- Equilibrium Theory of Island Biogeography
- Metapopulation dynamics
- Habitat fragmentation and edge effects
- Extinction debt and colonisation credit

Island Area and Species Richness

Which island has more species?



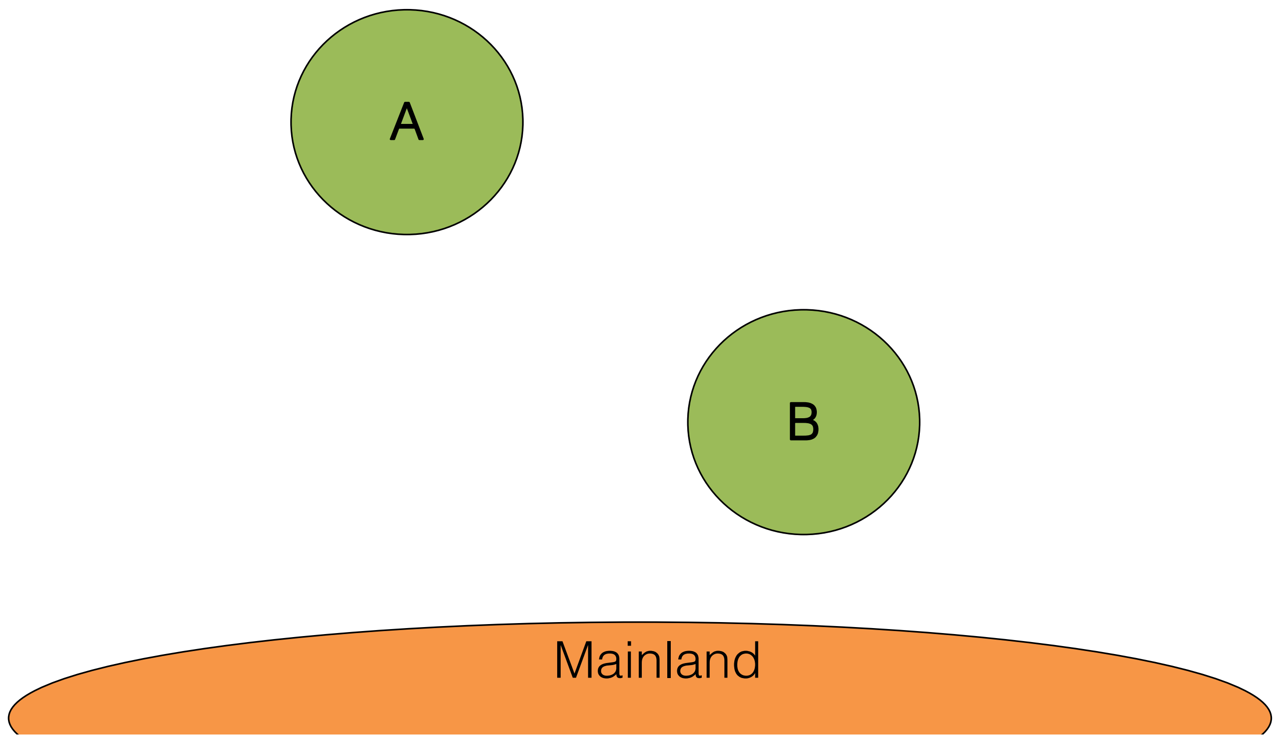
Island Area and Species Richness

Larger islands tend to have more species

- More area → more habitat heterogeneity → more niches → more species
- Larger population sizes → lower extinction rates
  - Less chance of a stochastic event wiping out species
  - Less chance of inbreeding
- Larger islands can support species with large ranges

Island Isolation and Species Richness

Which island has more species?



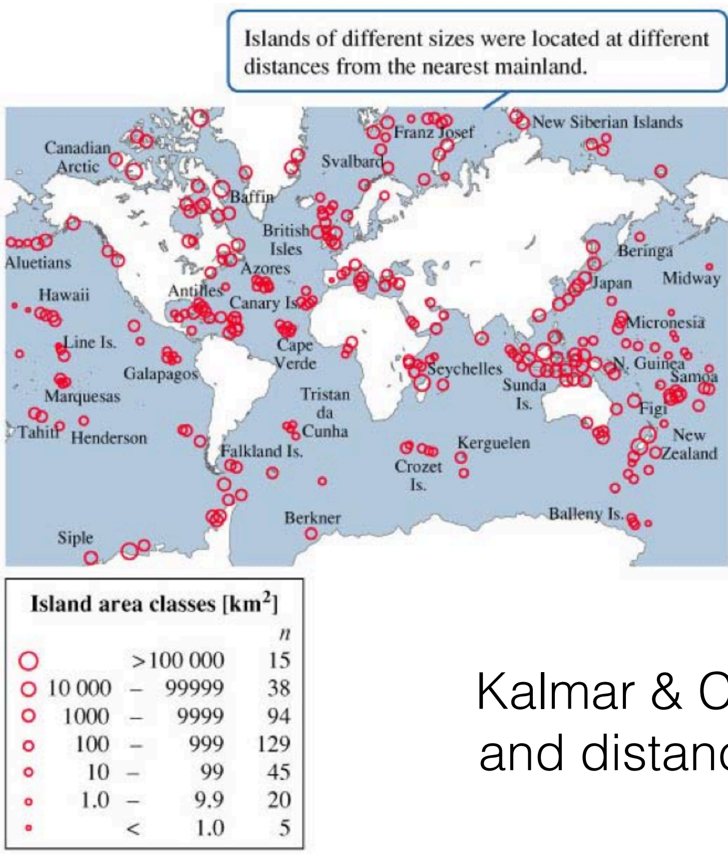
Island Isolation
and Species Richness

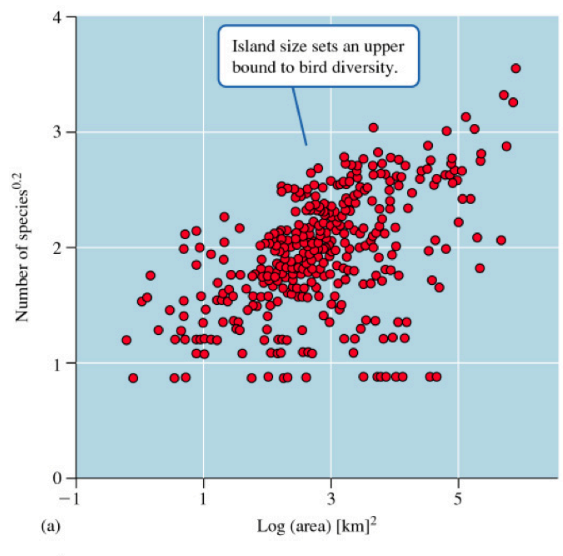
Islands closer to the mainland tend to have more species

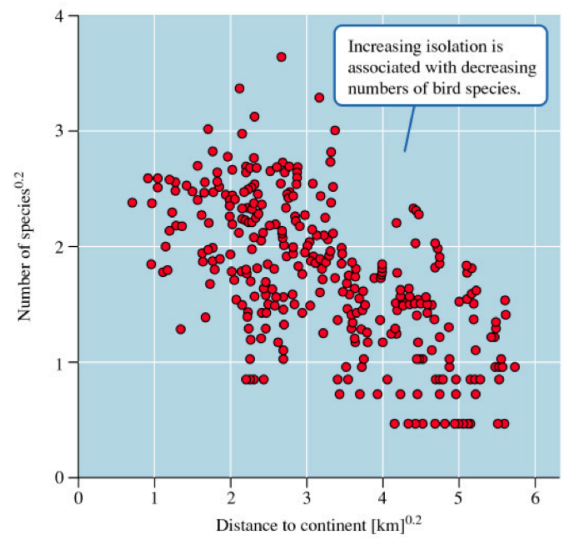
- Higher colonization rates on close islands
  - New species can more easily disperse there

- Varies hugely for different groups of organisms based on dispersal ability

Island Bird Diversity





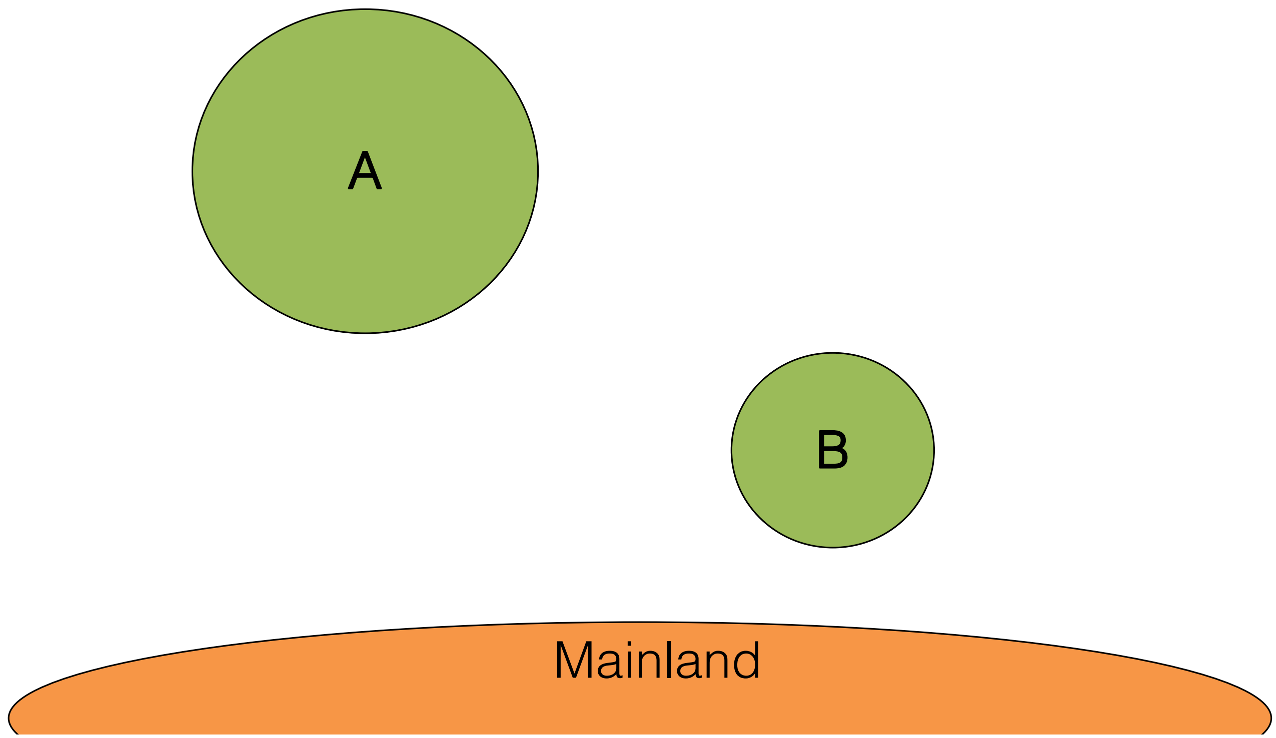


Kalmar & Curry (2006) concluded that both island size and distance from the mainland affected bird diversity

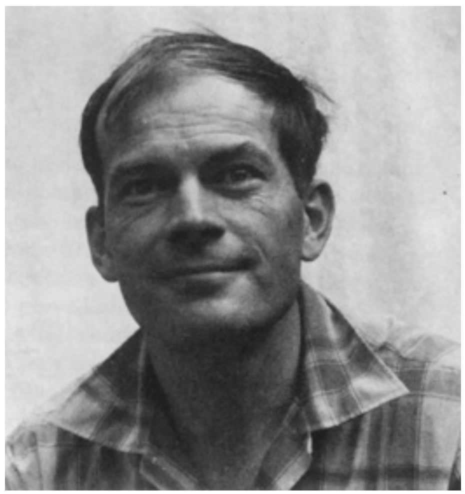
Kalmar & Curry Global Ecology and Biogeography, 2006

Isolation and Area

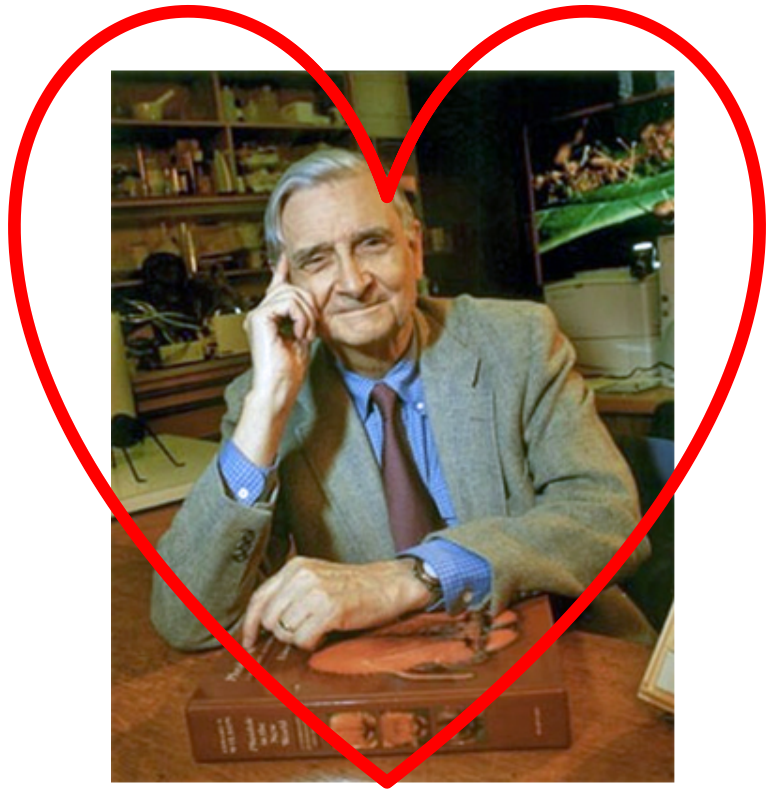
Which island has more species?



Theory of Island Biogeography
(1963, 1967)



Robert MacArthur



E.O. Wilson

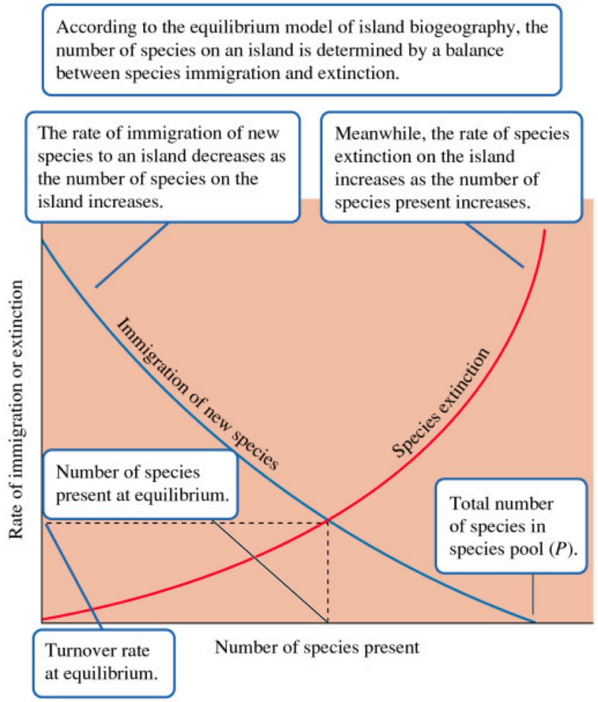
Theory of Island Biogeography

- Patterns of species diversity on islands are the result of a balance between rates of immigration and extinction.
- The causal mechanisms are all those that contribution to immigration or extinction (e.g., ease of dispersal, larger population size, etc.).
- Mac & Wil used this model to predict how island size and isolation affect rates of immigration and extinction.

Theory of Island Biogeography

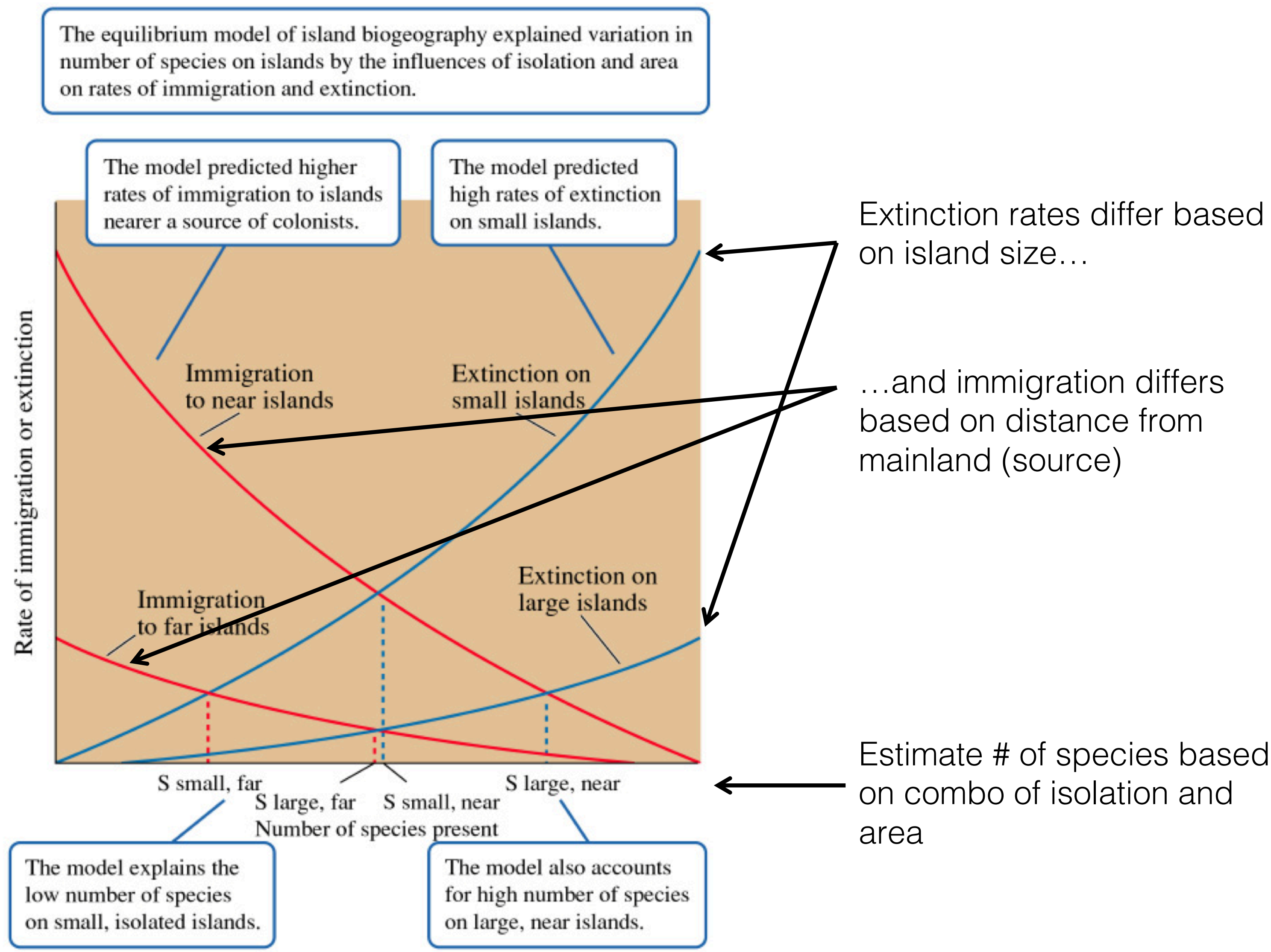
Rate of immigration slows as number of species present increases:

The chance that a new arrival is a new species becomes less as the number of species present approaches the size of the entire species pool.



Rate of extinction speeds up as number of species present increases:

1) Larger pool of possible extinctions
2) As total number of species increases, population size of each species must decrease
3) As number of species increases, potential for competitive interactions between species increases


The equilibrium model of island biogeography explained variation in number of species on islands by the influences of isolation and area on rates of immigration and extinction.
The model predicted higher rates of immigration to islands nearer a source of colonists.
The model predicted high rates of extinction on small islands.
Immigration to near islands
Extinction on small islands
Extinction on large islands
Immigration to far islands
Rate of immigration or extinction
S small, far
S large, far
S small, near
S large, near
Number of species present
The model explains the low number of species on small, isolated islands.
The model also accounts for high number of species on large, near islands.
Extinction rates differ based on island size…
…and immigration differs based on distance from mainland (source)
Estimate # of species based on combo of isolation and area

Criticisms of the Theory

- Interspecific differences and interactions among species
  - Assumption that identities and characteristics of particular species aren't important
- Isolation from mainland may not be most meaningful measure of isolation
  - Species can disperse from other islands in an archipelago ("stepping stone" colonization)
- Importance of speciation
  - Speciation not included in model; generally considered a much slower process than colonization

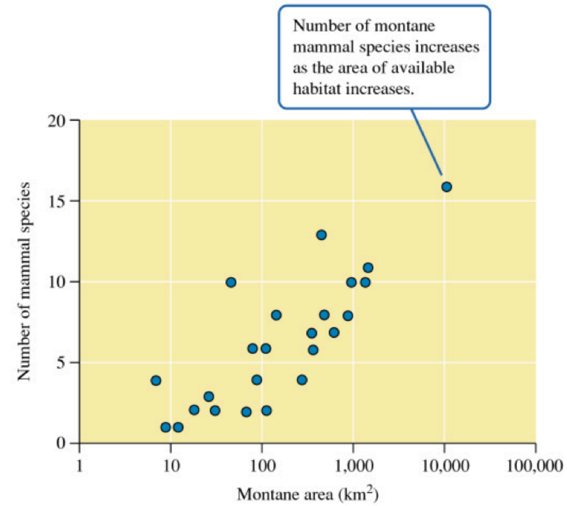
Island Biogeography – Just for Islands?

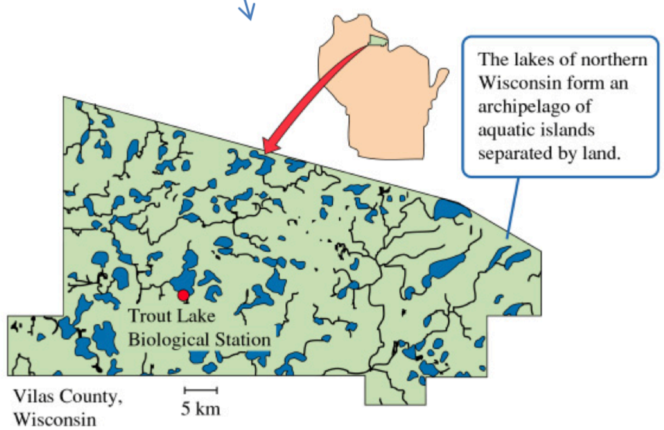
Species-area curves

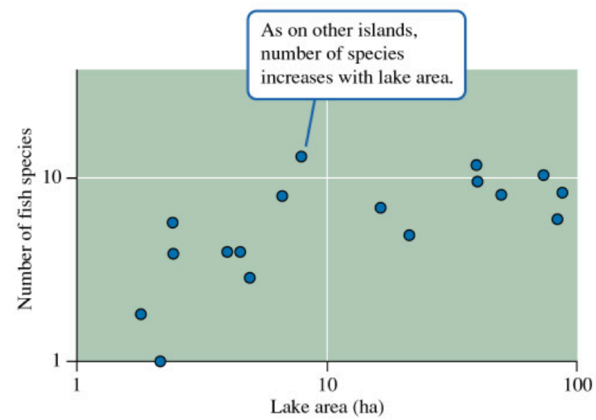
"Islands" can include any habitat "patch" –

e.g. mountain habitat

or lakes







Island Biogeography for populations?

- The same principles (species-area relationships and species-isolation relationships) apply to colonization and extinction rates of habitat patches in **meta-populations.**

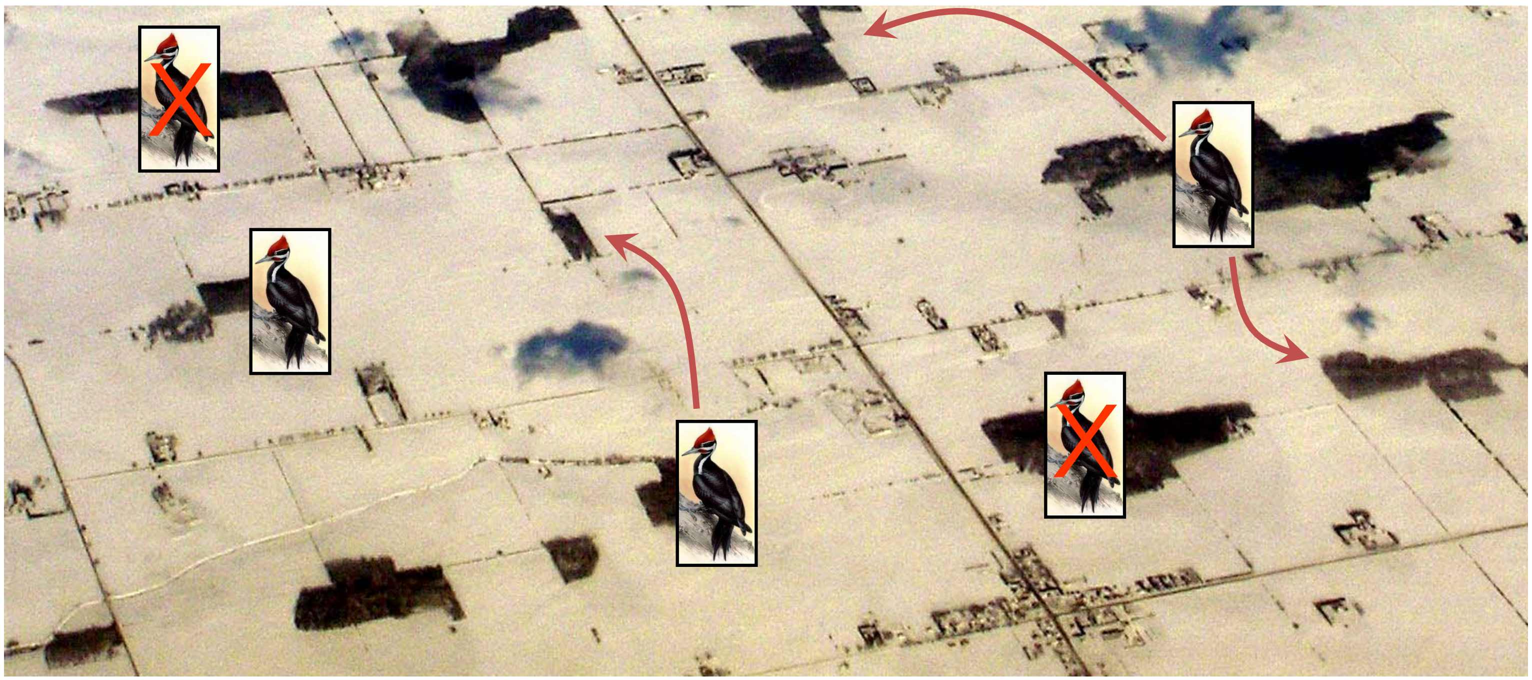
- Instead of focusing on species richness (# of species) we now focus on the maintenance of a single species in a region.

Metapopulations

Metapopulations

- Small populations within fragments – prone to extinction
- Recolonization of empty patches from occupied patches
- Persistence at regional scale: extinction-colonization balance

Extinction and Colonisation



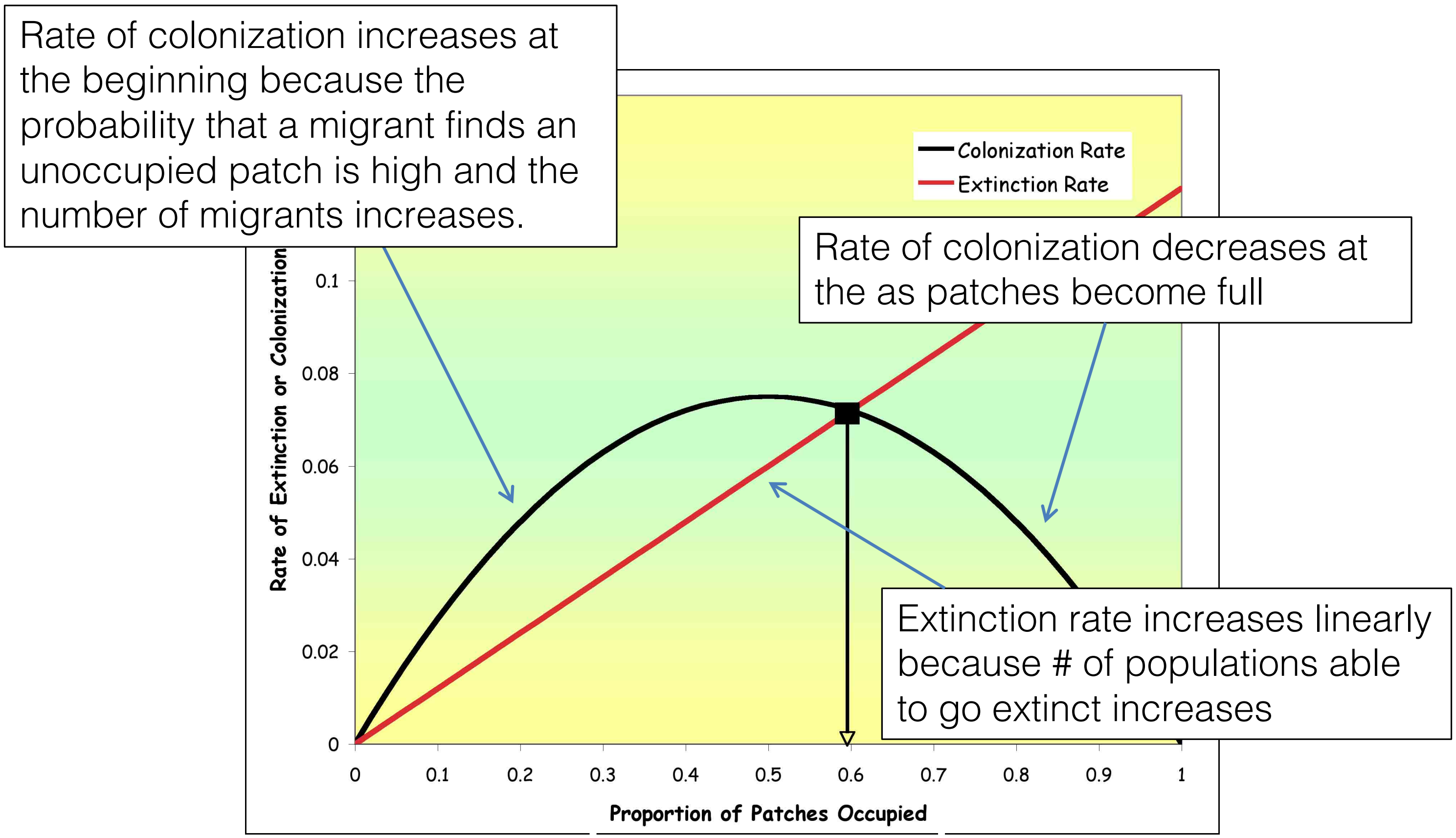
12 habitat patches, 5 are occupied

2 local extinctions, 3 patches colonised – now 6 are occupied

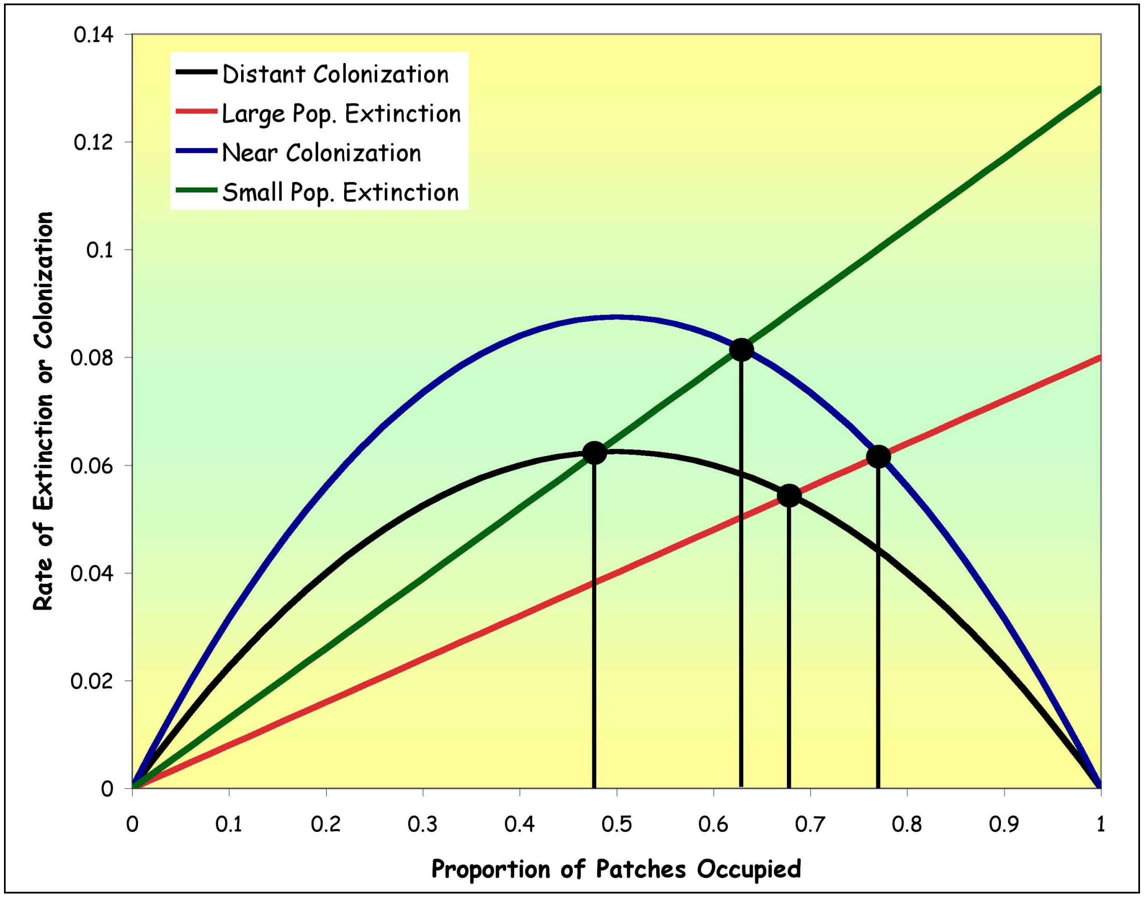
Extinction and Colonisation

12 habitat patches, 6 are occupied

Extinction and Colonisation



Metapopulation dynamics also depend on size and isolation



Extinction and Colonisation

Would destruction of this habitat affect our metapopulation?

A simple (but important) lesson from metapopulation models – sources and sinks

Criterion for metapopulation persistence:

Extinction must be less than or equal to colonization.

What if we destroy some habitat?

- Fewer sources of colonization
- Same local extinction probability
- Push <u>meta</u>population closer to extinction threshold

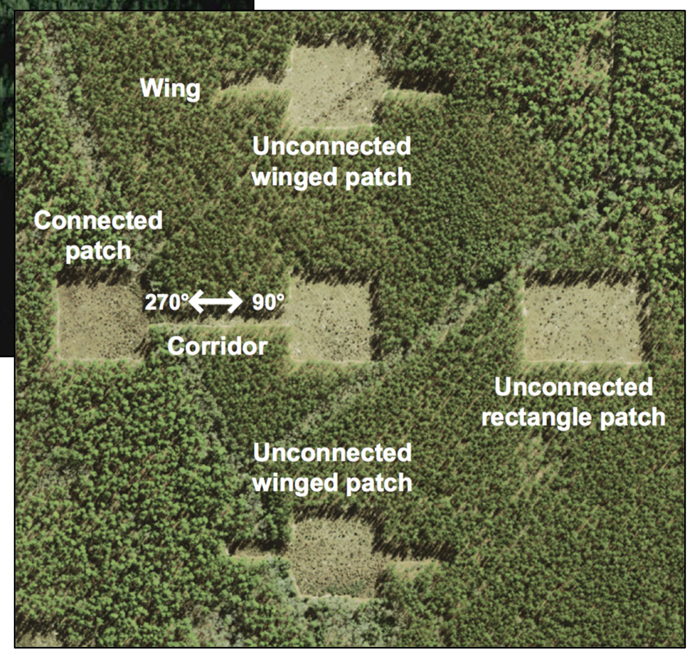
This is true even if we destroy unoccupied habitat!

Key conservation messages from metapopulation theory

- Habitat patch size and connectivity/isolation are important
- Unoccupied but suitable habitat can be very important
- Occupied habitat may not be suitable
- What happens locally depends on regional context (destruction/creation of habitat)
- Lags such as extinction debts and colinisation credits in local extinctions/invasions can occur

What are extinction debts and colinisation credits?

Corridors

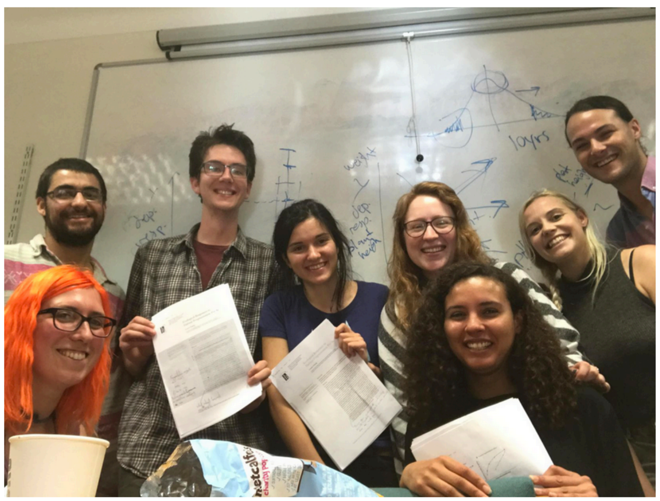

Wing
Unconnected
winged patch
Connected
patch
270° ⟷ 90°
Corridor
Unconnected
rectangle patch
Unconnected
winged patch

Edge Effects

Habitat Fragmentation

EdGE meeting – positive vs. negative effects of habitat fragmentation

Are the negative effects of habitat fragmentation a zombie idea? Do we see positive or negative effects of habitat fragmentation more often? And even before we do that, can we make broad generalisations about the effects of habitat fragmentations; if we can, should we be? What would be the potential effects on conservation policy and actions?



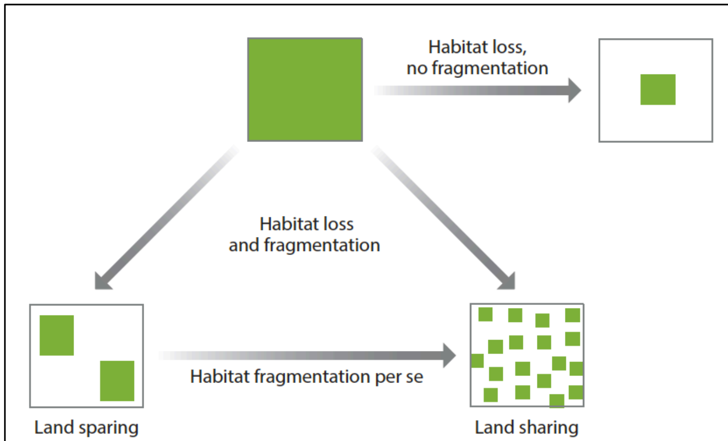
Review in Advance first posted online on May 31, 2017. (Changes may still occur before final publication online and in print.)

Ecological Responses to Habitat Fragmentation Per Se

Lenore Fahrig

Geomatics and Landscape Ecology Research Laboratory, Department of Biology, Carleton University, Ottawa, Ontario, Canada K1S 5B6; email: lenore.fahrig@carleton.ca

http://www.annualreviews.org/doi/abs/10.1146/annurev-ecolsys-110316-022612



https://edineconet.wordpress.com/blog/

How can Island Biogeography and Metapopulation Theory inform conservation?

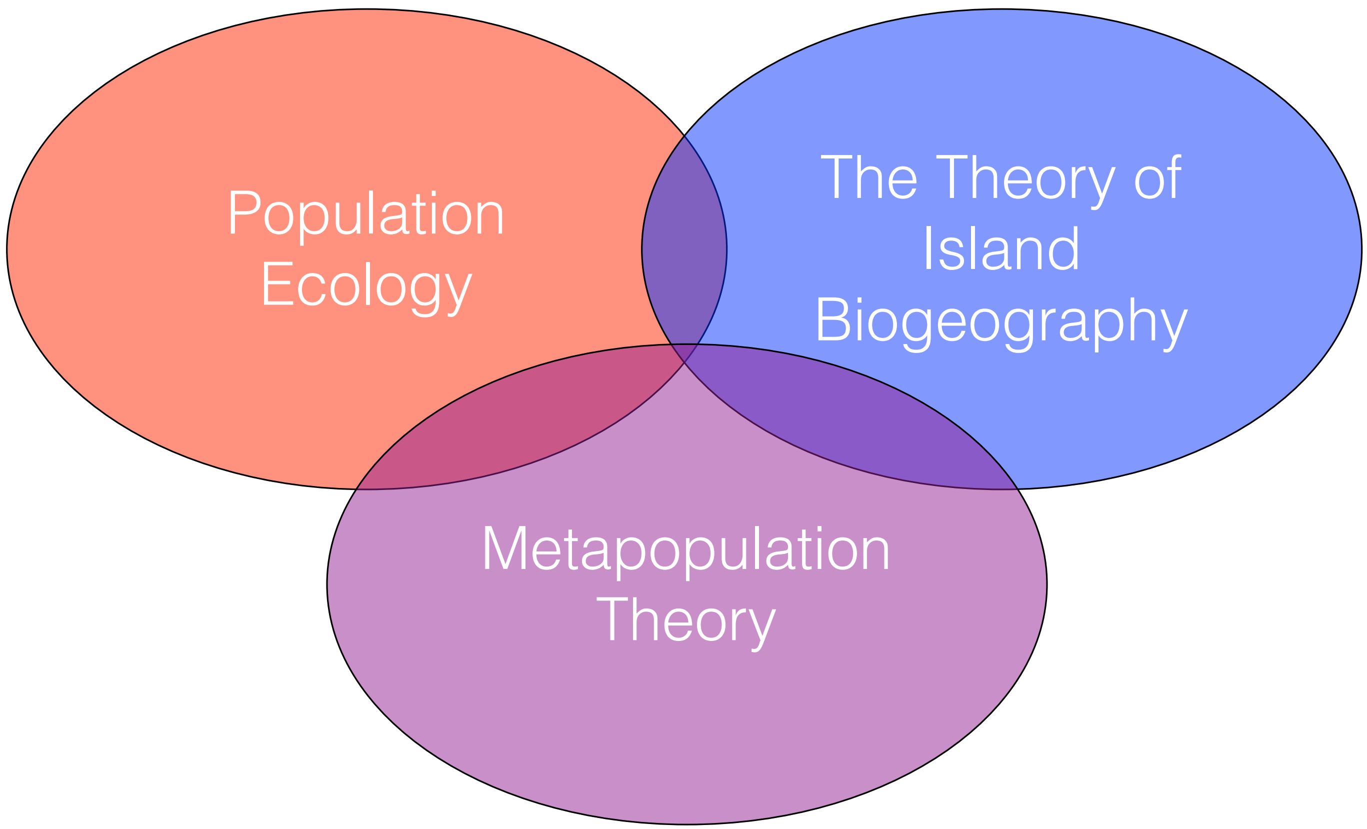
How can Island Biogeography and Metapopulation Theory inform conservation?

- Large reserves are better than small ones
  - IB: larger reserves contain more species
  - MT: larger reserves reduce extinction rates for existing species

- Connected patches are better than isolated ones
  - IB: connected patches contain more species
  - MT: connected patches allow better recolonization, rescue effect for existing species

- But, fragmentation can create greater habitat heterogeneity potentially enhancing biodiversity

Today's Lecture



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