## BIOL 410 Population and Community Ecology

Island biogeography

## **Ecological communities**

- Competition, Predation, Mutualism
- Niche (n-dimensional hypervolume)
  - Potential
  - Fundamental
  - Realized
  - Niche partitioning
- Ecological guild
  - Group of species that exploit the same class of environmental resources in a similar way
    - Groups together species without regard to taxonomic position.

## Ecological guild

- Foliage-gleaning bird guild in oak woodlands
  - Major portion of a bird species' diet must consist of arthropods obtained from the foliage zone of oaks
  - Birds that only occasionally use the foliage zone are excluded



## Species richness

• Species-area relationship

Larger "habitat" areas contain more species

Small # species



Large # species

#### Species-area relationship

Large islands support more species than small Islands



http://www.doe.ky/terrestrial/animals/lizards/



http://www87.homepage.villanova.edu/todd.jackman/anolis/todd.html

 Species Richness – the number of species within a community

## Darlington's Rule

"A tenfold increase in island area results in a doubling of species number"

 $S = cA^z$ 



Island Area (A) in km<sup>2</sup>

#### Darlington's Rule

 $\log S = \log c + z \log A$ 



## Distance of Island from Mainland

 Species richness decreases with increasing isolation of the island from the source population





**Distance from Source (km)** 

## Habitat Diversity Hypothesis

- Large Islands contain more habitat types than small islands
- Habitat specialists restricted to large islands where rarer and more diverse habitat types are found
- However, even in homogenous habitat of the same types, larger islands hold more species that small





MacArthur and Wilson's Equilibrium Model of Island Biogeography

 Number of Species on an Island is a balance between Immigration of new species and Extinction of resident species



 Equilibrium occurs when immigration and extinction rates are equal – no change in number of species (S) over time (<sup>ds</sup>/<sub>dt</sub> = 0)

- Assumes permanent mainland source pool (P) of species
- Immigration rate  $(\lambda_s)$  number of new species colonizing the island per unit time
- Extinction rate  $(\mu_s)$  number of resident species on island that go extinct per unit time
- Focus on # of species (not population # or occupancy)



• Immigration Rate ( $\lambda_s$ )



Maximum Immigration Rate (I) – occurs when the island is empty

Immigration rate is zero when the number of species on the island (S) is equal to the total pool of species from the mainland source (P)

• Extinction Rate  $(\mu_s)$ 



Maximum Extinction Rate (E) – occurs when the number of species on the Island equals the number from the source population (S=P)

If there are no species, extinction rate is zero

 Substitute in the values for Immigration and Extinction rates into the main equilibrium model

$$\frac{dS}{dt} = \lambda_s - \mu_s$$
$$\frac{dS}{dt} = \left(I - \frac{I}{P}S\right) - \left(\frac{E}{P}S\right)$$

 What number of species are present on the Island when the rate of species richness change over time is 0 (immigration rate balances emigration rate)?

$$\frac{dS}{dt} = \mathbf{0} = \left(I - \frac{I}{P}S\right) - \left(\frac{E}{P}S\right)$$

$$0 = I - \frac{IS}{P} - \frac{ES}{P}$$

- Not maintenance of the same species
- Zero change is species richness

$$\frac{IS}{P} + \frac{ES}{P} = I$$

$$S\left(\frac{I+E}{P}\right) = I$$

solve for S:

$$\hat{S} = \frac{IP}{I+E}$$

 Species richness is increased by large source pools and higher immigration rates, and decreased by higher extinction rates.



#### **Turnover Rate**

 ratio of turnover rate to number of species on the island is the same as the extinction rate relative to the pool of species on the mainland source

$$\frac{\widehat{T}}{\widehat{S}} = \frac{E}{P}$$

• Solve for T:

$$\widehat{T} = \frac{E\widehat{S}}{P} = \frac{E\left(\frac{IP}{I+E}\right)}{P} = \frac{IE}{I+E}$$

 turnover rate at equilibrium depends only on the maximum immigration and extinction rates, not on the size of the source pool (P)

#### **Turnover Rate**

At equilibrium – species richness doesn't change

 $\frac{dS}{dt} = 0$ 

, but species composition might.



## Assumptions of colonizing species

To understand how this relates to the Species-Area relationship, we make two assumptions about colonizing species

- 1. The total population size for each species is proportional to island area.
- 2. The probability of population extinction decreases with increasing population size.

$$P_{extinction} = \left(\frac{d}{b}\right)^{N_0}$$

Small islands have smaller populations of individual species, suffer more demographic stochasticity and, thus, have higher extinction rates

#### Species Area effect – MacArthur-Wilson Model Extinction



#### Distance effect – MacArthur-Wilson Model Immigration



## Model Assumptions

- An island potentially can be colonized by a set of P source pool species that have similar colonization and extinction rates
- 2. The probability of colonization is inversely proportional to isolation or distance from source pool
- 3. The population size of given species is proportional to the area of the island
- 4. The probability of the population becoming extinct is inversely proportional to its size
- 5. Colonization and extinction of local populations is independent of species composition on the island.

### **Nonlinear Rates**



Number of species on Island (S)

## Area and distance Effects

- MacArthur-Wilson Equilibrium Model of Island Biogeography:
  - Island Area affects Extinction Rates
  - Island's proximity to mainland affects Immigration Rates
- Can Island *Location* affect Extinction?
- Can Island Area affect Immigration?



# Rescue Effect – Island location and extinction

- Islands near other islands or source pool may receive immigrants from both mainland and other islands
  - These individuals can supplement resident populations that would otherwise go extinct
  - Isolated islands ("far") would be predicted to have more local extinctions than less isolated ("near") islands – they have fewer immigrants to "rescue" local populations



#### Rescue Effect – location and extinction



Relative species richness between near (S<sub>n</sub>) and far (S<sub>f</sub>) islands at equilibria doesn't change, but the relative size of the expected turnover rates (T<sub>n</sub> vs T<sub>f</sub>) reverses with the addition of a rescue effect

#### Target Effect –immigration and area

- Island Area and Immigration (Target Effect)
- Large Islands, regardless of their location provide larger "targets" for colonizers





#### Target Effect –immigration and area



Relative species richness between large  $(S_l)$  and small  $(S_s)$  islands at equilibria doesn't change, but the relative size of the expected turnover rates  $(T_s vs T_l)$  reverses with addition of a target effect

- Islands as passive accumulators of species
- Set of k islands (k<sub>i</sub>)
- Area of each island (a<sub>i</sub>)
- Set number of potentially colonizing species (s).
- Number of individuals in each species (n<sub>j</sub>) colonizing islands



• Islands as passive accumulators of species

Total Area of all islands for colonizing

$$A = \sum_{i=1}^{\kappa} a_i$$

Relative area of each island in archipeligo

$$x_i = \frac{a_1}{A}$$



- Probability single colonizing individual will NOT land on a specific island
- $P(1 miss) = 1 x_i$
- Probability that ALL individuals of a particular species (j) colonizing the archipeligo will miss the focal island
- $P(n_j misses) = (1 x_i)^{n_j}$



Therefore, probability that at least ONE individual from species j will colonize island I

 $P(species \ j \ occurs \ on \ island \ i) = 1 - [(1 - x_i)^{n_j}]$ 

Summing across all species gives predicted species richness of island i.

$$E(S_i) = \sum_{j=1}^{s} [1 - (1 - x_i)^{n_j}]$$

- Comparison with MacArthur Wilson model
  - Both predict big islands sustain more species than small islands
  - M-W predicts recurrent extinction and turnover of species.
  - Passive Sampling Model does not invoke turnover. Rather it predicts relatively abundant species (large nj) will have a greater likelihood of occurring on an island than less abundant species (small nj)
  - Passive sampling doesn't directly address distance effect

#### Example

EXPERIMENTAL ZOOGEOGRAPHY OF ISLANDS: THE COLONIZATION OF EMPTY ISLANDS

DANIEL S. SIMBERLOFF<sup>1</sup> AND EDWARD O. WILSON The Biological Laboratories, Harvard University, Cambridge, Massachusetts 02138



- Examined colonization of six small mangrove islands in Florida bay
- Focused on terrestrial arthropods (monitored yearly)
- Island extinction (methyl bromide fumigation)

### Simberloff & Wilson 1969



## Rescue effect example

Ecology (1977) 58: pp. 445-449

#### TURNOVER RATES IN INSULAR BIOGEOGRAPHY: EFFECT OF IMMIGRATION ON EXTINCTION<sup>1</sup>

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- Recolonization of thistle by insects and spiders following experimental defaunation
- Predictions followed MacArthur-Wilson, except that turnover rates were higher at isolated distant "islands" rather than near islands (as M-W model predicts)
- Explained by repeated colonization of same species to the nearer plants, rescuing the resident populations from extinction.