

An introduction to ecological modelling

2. Simple Theoretical Ecological Models

Lecture Outline

Simple models of the species richness of ecological communities

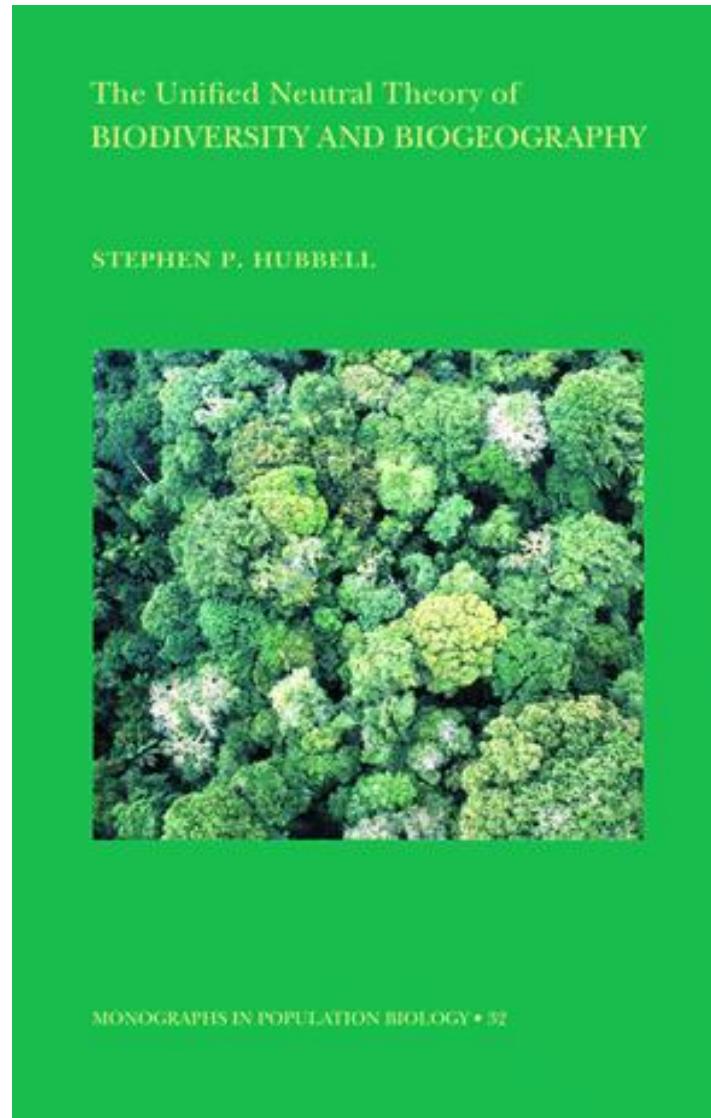
Simple models of individual-level processes

- Competition
- Predation
- Metabolism

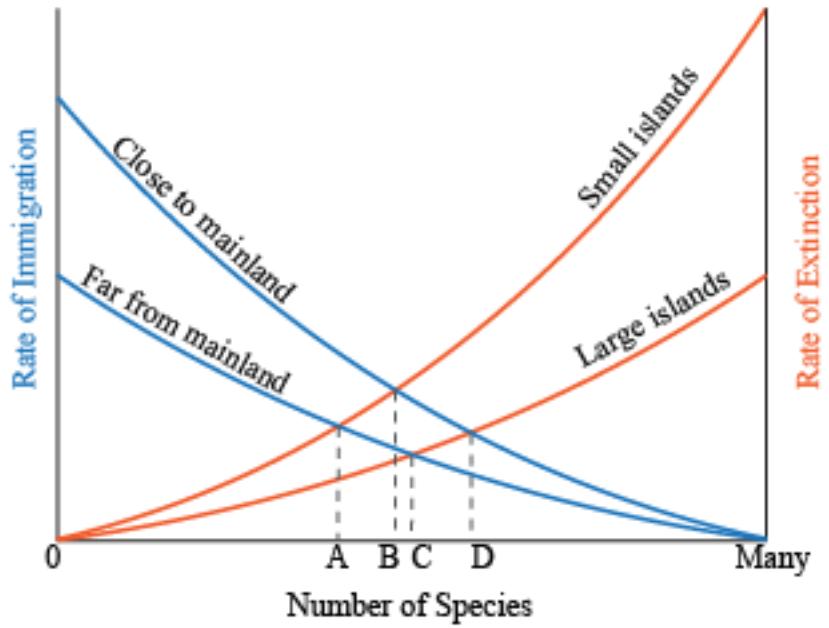
Understanding the diversity of ecological communities, and how they respond to human threats



A model I don't have time to talk about



The Equilibrium Theory of Island Biogeography



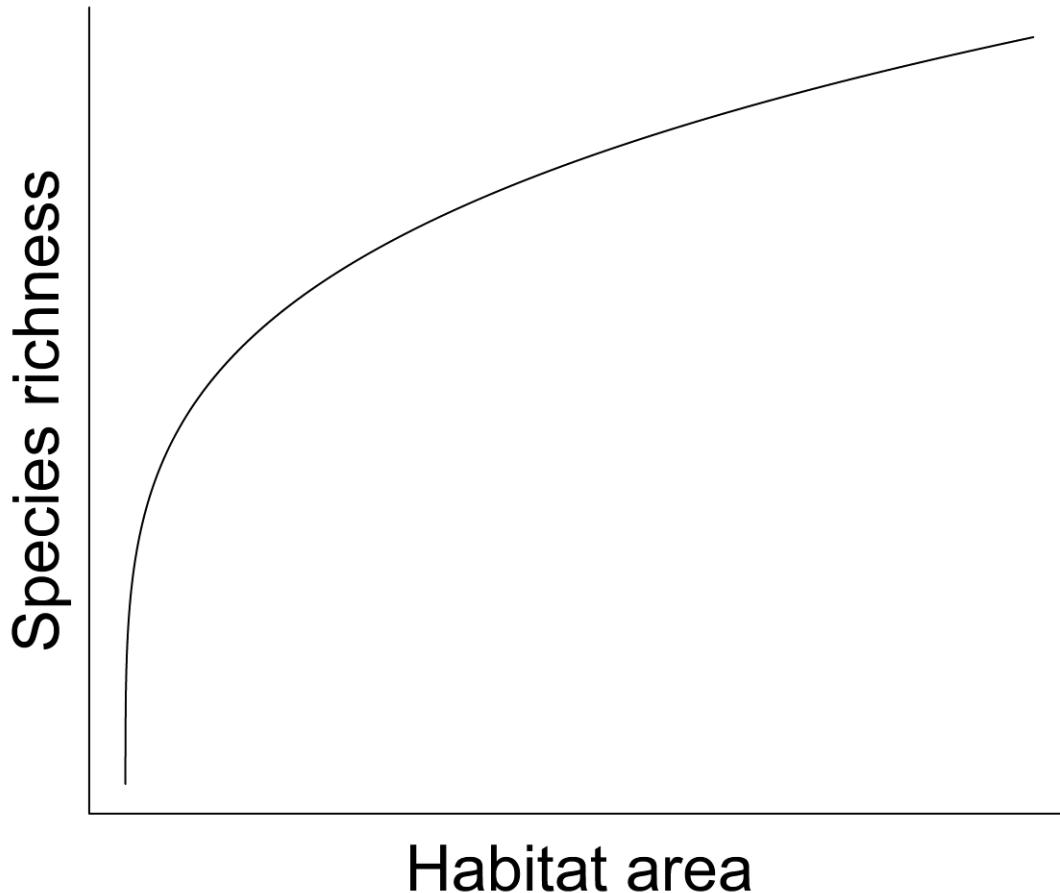
MacArthur & Wilson (1967). *The Theory of Island Biogeography*. Princeton University Press

Species number depends on the balance between immigration and extinction rates

Extinction rates are lower on larger islands; immigration rates are higher on islands nearer the mainland

The species-area relationship

First described by Arrhenius (1921). *J Ecology* **9**: 95-99.



$$S = cA^z$$

Preston (1962). *Ecology* **43**: 185-215

- Individuals log-normally distributed among species
- Total number of species I related to total number of species N :
$$\log I = 3.821m \log N - 1.21m$$

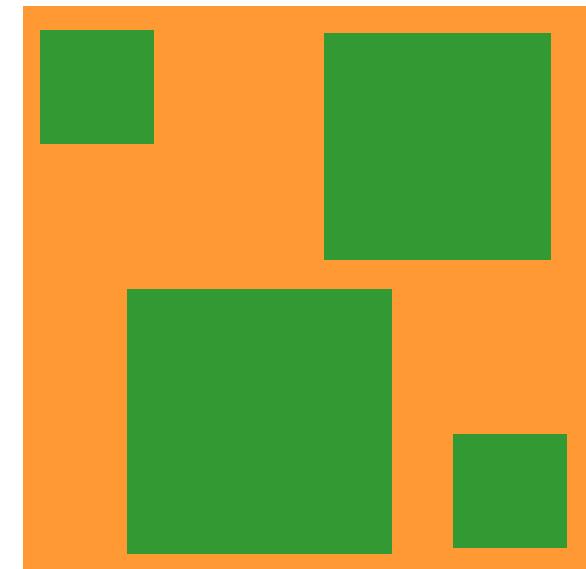
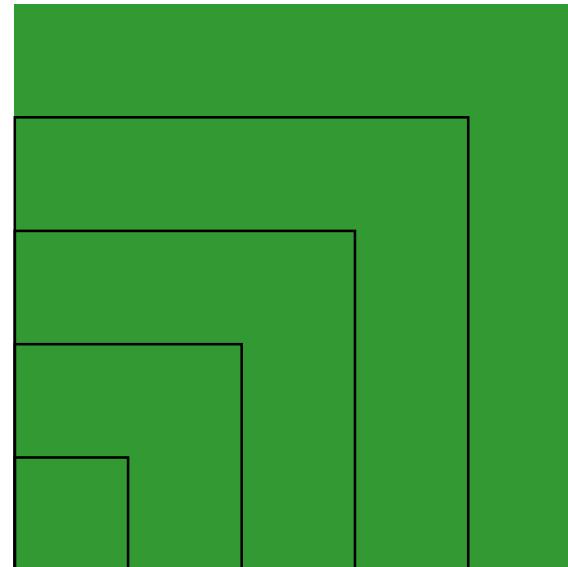
(m is no. of individuals in rarest species)
- $I = \rho A$, where A is area and ρ is density
- $N = 2.07(\rho/m)^{0.262} A^{0.262}$
- Data for islands support this theoretical relationship

Species-area relationships: theoretical considerations

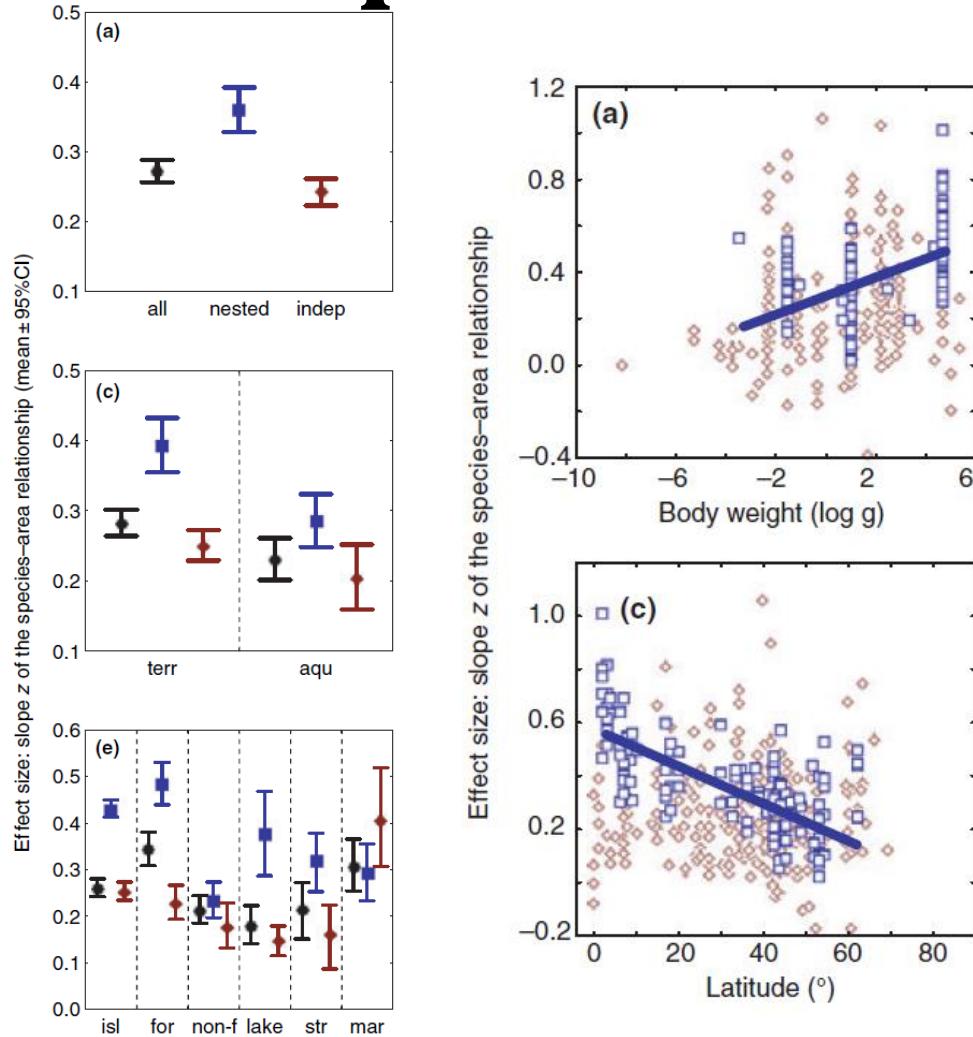
True islands vs. habitat islands



Nested samples vs. isolated samples



Species-area relationship: variation in shape



Average exponent (z) of species-area relationship = 0.27, but ranging from 0 to 1

Higher with nested compared with independent sampling

Higher for terrestrial compared with aquatic systems

Higher in forests and oceans than non-forests and lakes/streams

Increases with body mass and at lower latitudes (increased turnover of community composition)

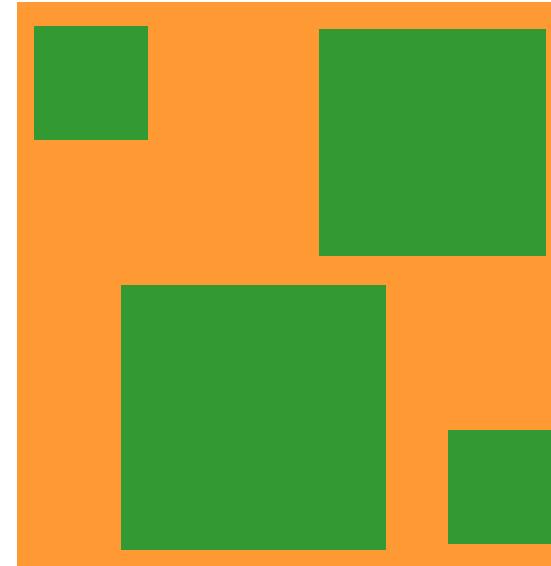
Applications of species-area relationships

Predicting the consequences of habitat loss and fragmentation

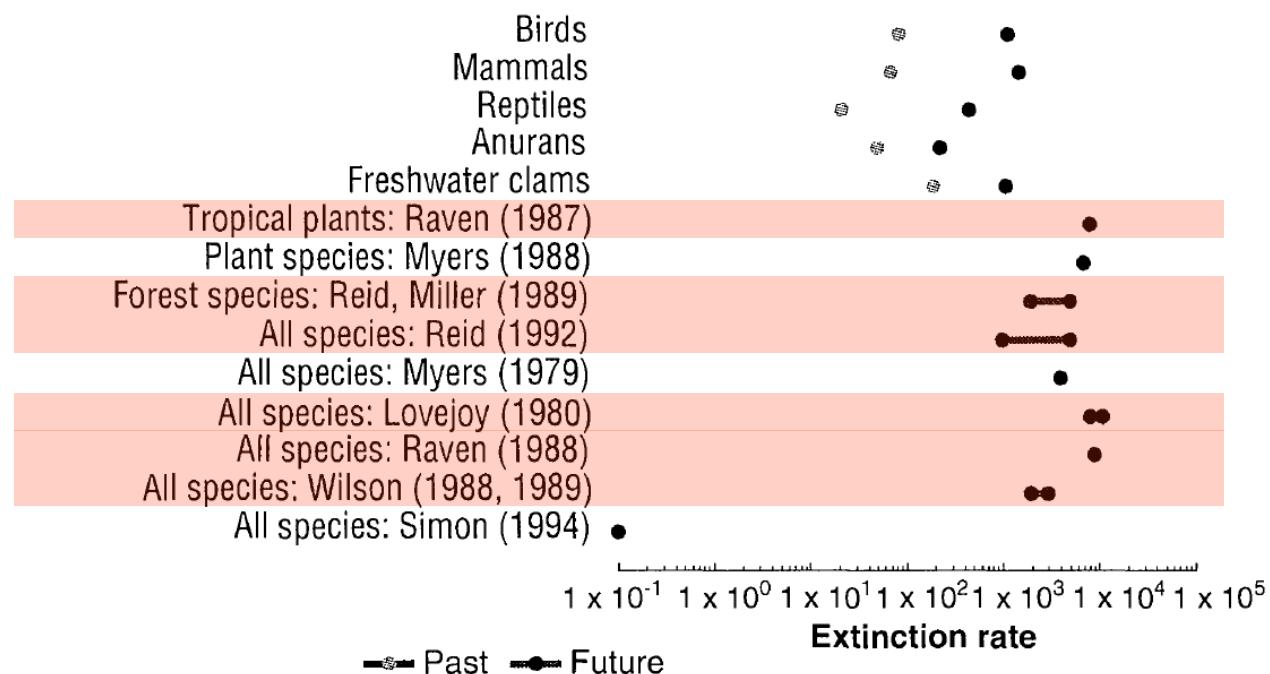
Easily applied to maps of habitat

Makes simple predictions of species loss

$$\frac{S_{new}}{S_{original}} = \left(\frac{A_{new}}{A_{original}} \right)^z$$



Applications of species-area relationships



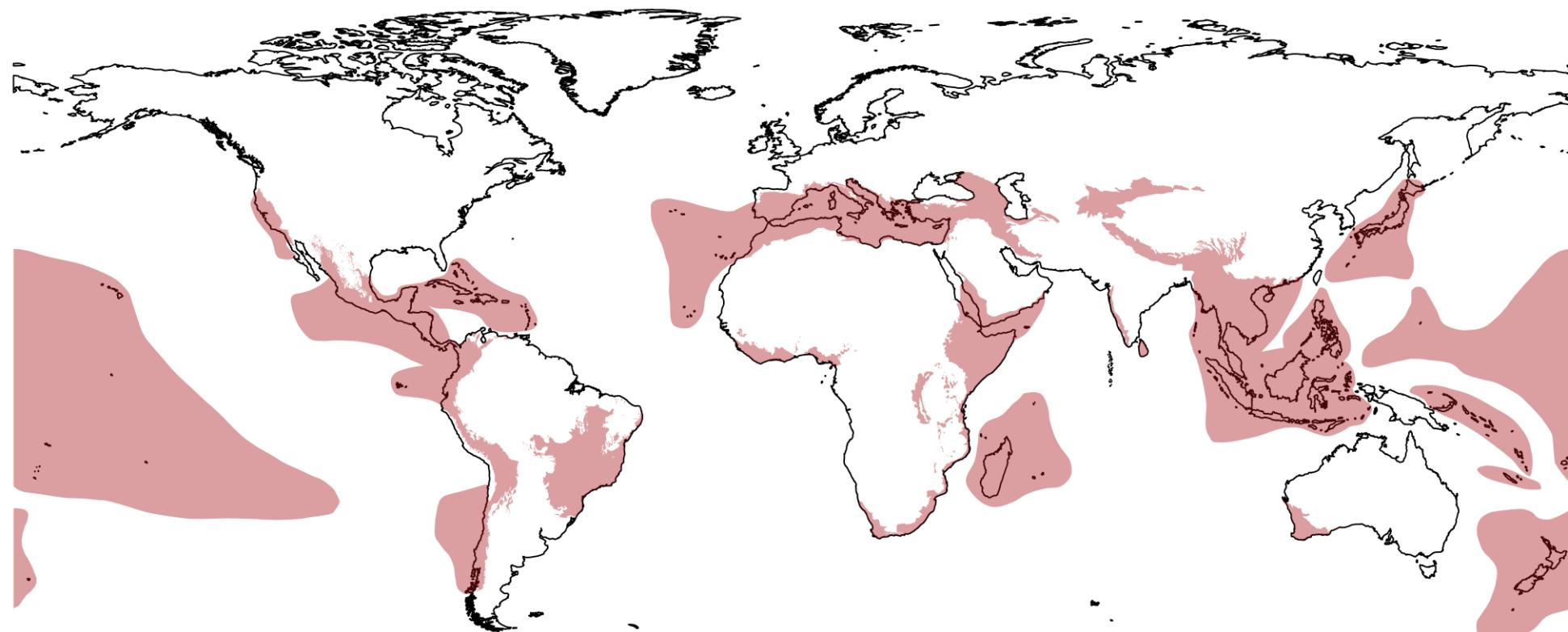
Naturally: 0.1–1 Extinctions per Million Species-Years (E/MSY)

With habitat loss: 1,000–10,000 E/MSY

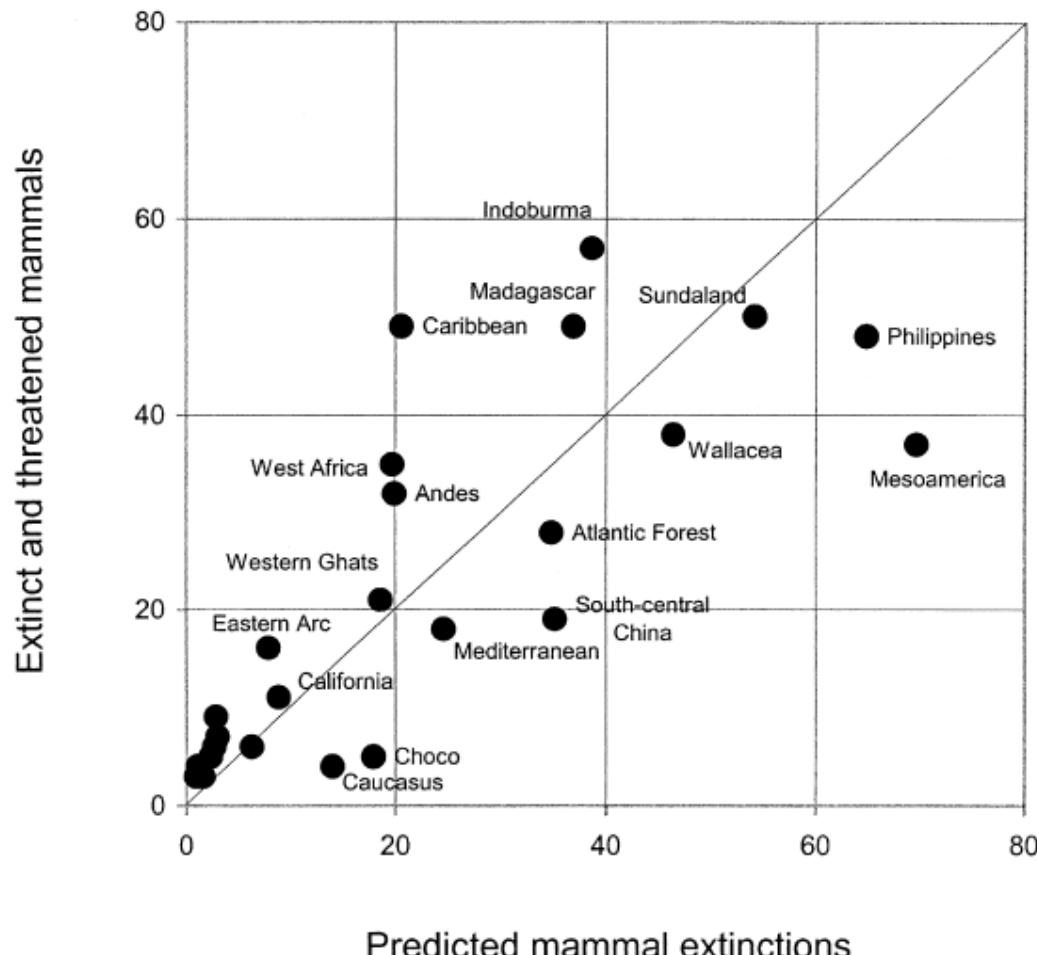
Only appropriate to apply species-area relationships to species endemic to an area

Applications of species-area relationships

The biodiversity hotspots: concentrations of endemic species in areas that have suffered a high degree of habitat loss



Applications of species-area relationships



Application of species-area relationships for vertebrates and plants in the biodiversity hotspots

Predictions based on past habitat loss matched known numbers of known extinctions and threatened species well for mammals and birds

Less good for amphibians, reptiles and plants (probably because of poor data on threatened species)

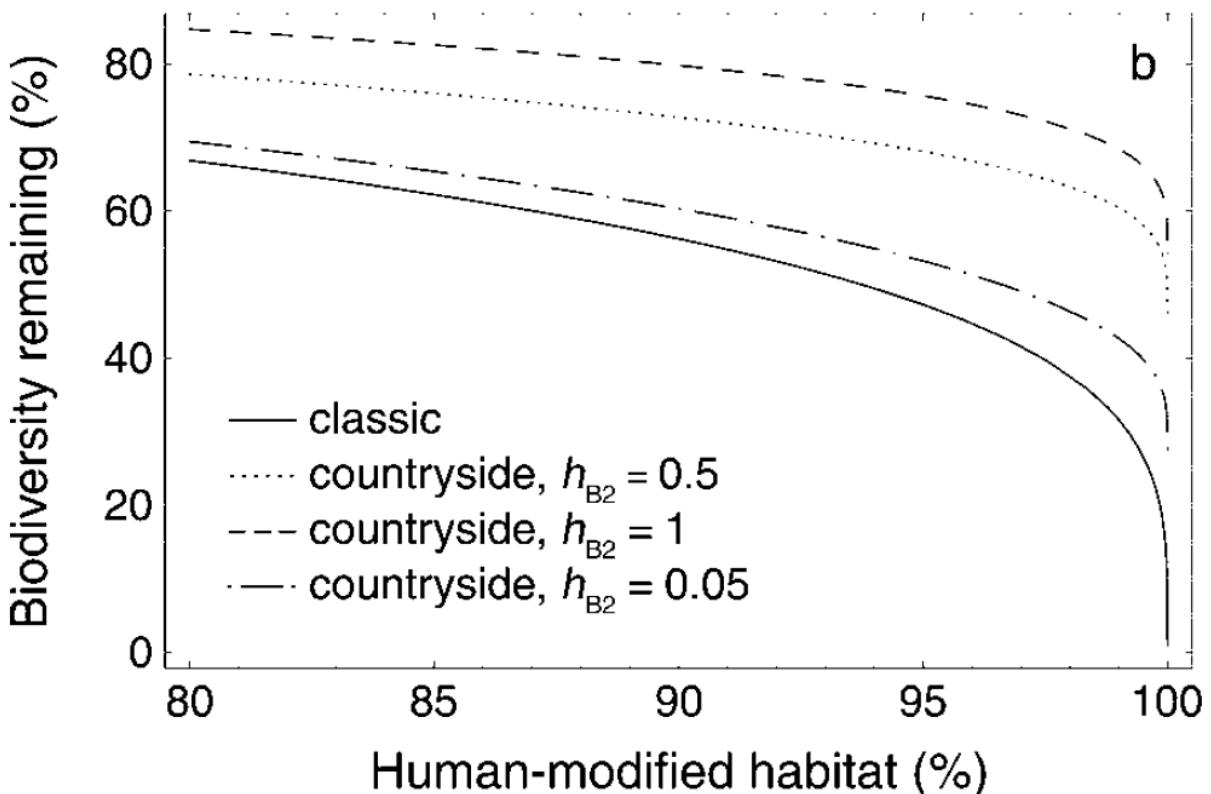
Applications of species-area relationships

| Hotspot | Additional Extinctions | |
|---|------------------------|-------------|
| | Plants | Vertebrates |
| Eastern Arc and Coastal Forests of Tanzania-Kenya | 121.4 | 9.8 |
| New Caledonia | 96.5 | 3.2 |
| Philippines | 70.2 | 6.2 |
| Polynesia-Micronesia | 59.1 | 4 |
| Cape Floristic Province | 56.6 | 0.5 |
| Caribbean | 34.4 | 3.8 |
| Western Ghats-Sri Lanka | 23.1 | 3.8 |
| Madagascar | 23.2 | 1.8 |
| Southwest Australia | 18.8 | 0.4 |
| Sundaland | 15.9 | 0.7 |
| Mediterranean Basin | 13.8 | 0.2 |
| Tropical Andes | 11.3 | 0.9 |
| Brazil's Atlantic Forest | 11.4 | 0.8 |
| Succulent Karoo | 11.8 | 0.3 |
| Indo-Burma | 8.3 | 0.6 |
| Southcentral China | 7.3 | 0.4 |
| Choco-Darien-Western Ecuador | 6.3 | 1.2 |
| Wallacea | 4.5 | 1.6 |
| New Zealand | 5.4 | 0.4 |
| California Floristic Province | 4.7 | 0.2 |
| Caucasus | 4.5 | 0.2 |
| Mesoamerica | 3.6 | 0.8 |
| Central Chile | 3.3 | 0.1 |
| West African Forests | 2.5 | 0.3 |
| Brazil's Cerrado | 2.1 | 0.1 |

Predictions of species loss with a fixed amount (1,000 km²) of additional habitat loss reveals differing sensitivity

Brooks et al. (2002). *Conservation Biology* 16: 909-923

Species-area relationships: accounting for species in the matrix



The traditional species-area relationship assumes that species are confined to natural habitat

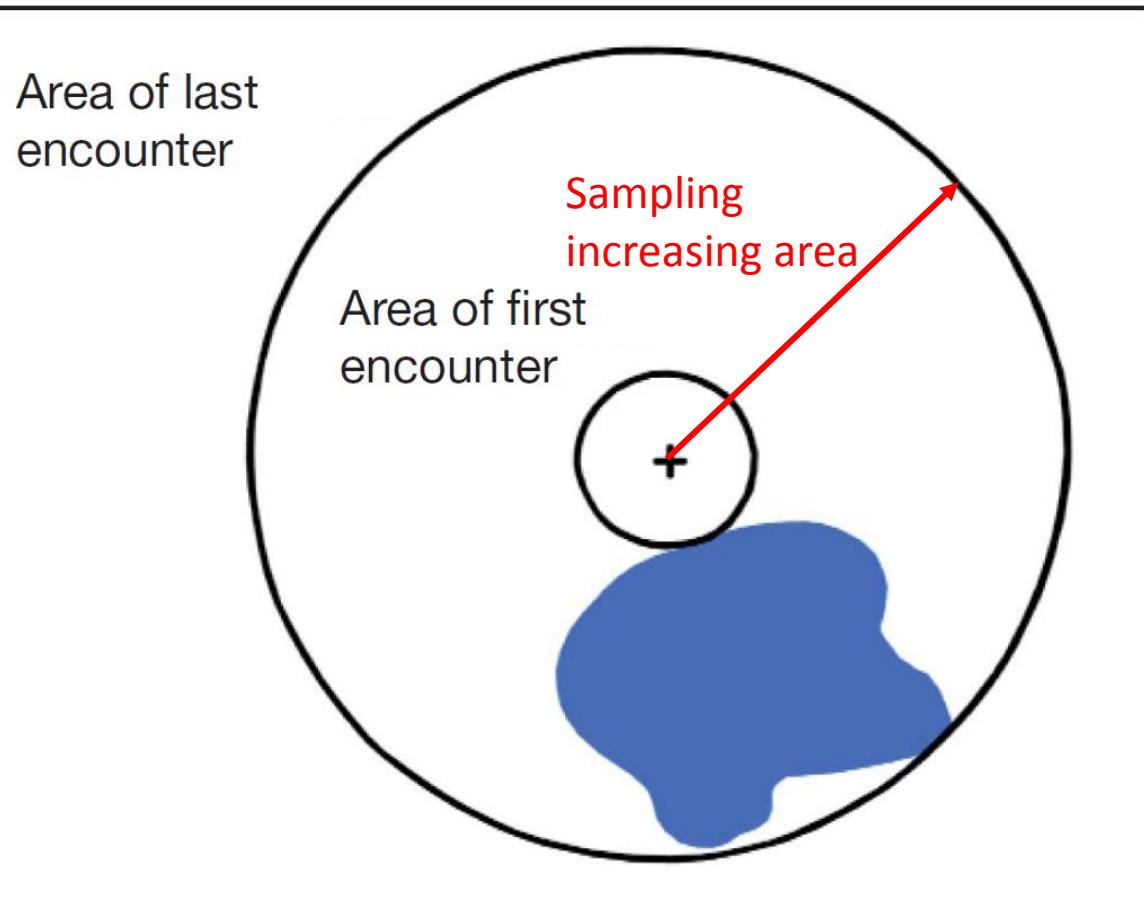
However, other habitats are not completely barren of species

Countryside species-area relationship:

$$S = c \left(\sum_j h_j A_j \right)^z$$

where h_j is the affinity of species for habitat j

Species-area relationships: sampling issues

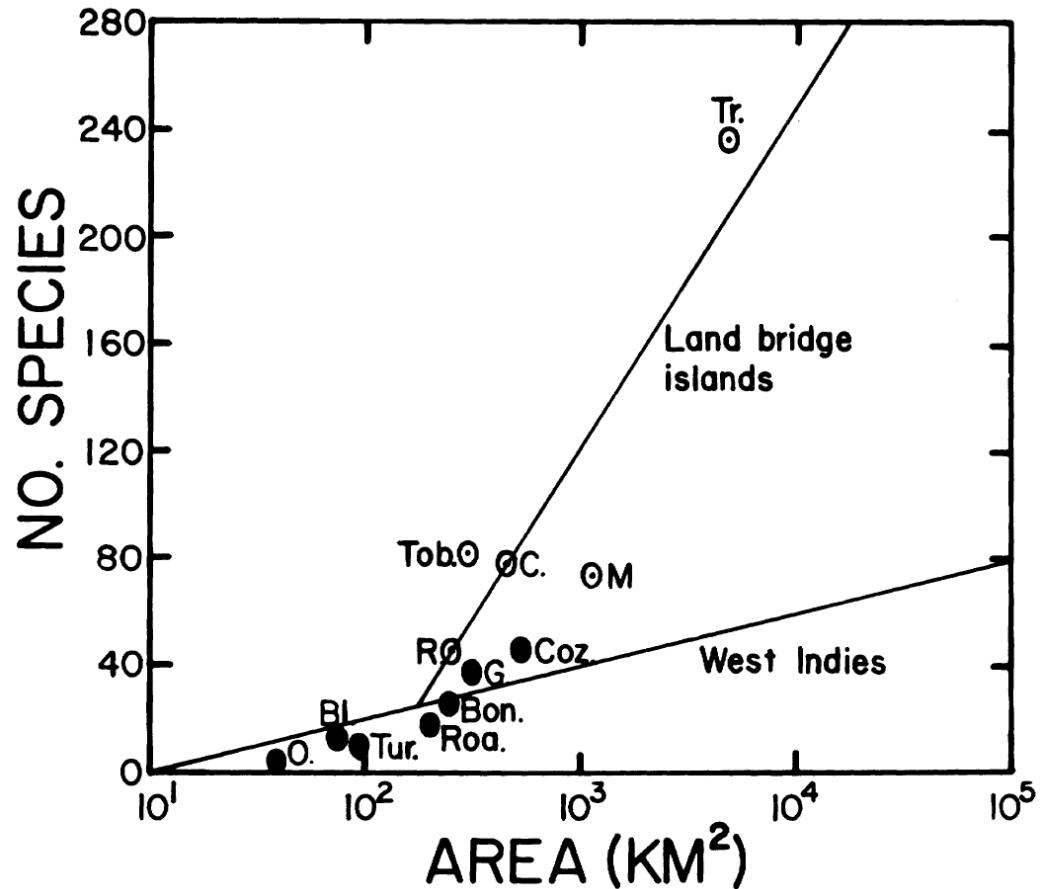


Application of species-area relationships to habitat loss is based on the reverse of the accumulation of species sampled with increasing area

But more area has to be lost for the entire range of a species to be lost, than for first detection

Classic species-area relationships are only useful if species are randomly distributed – in reality distributions are often clumped

Extinction debt

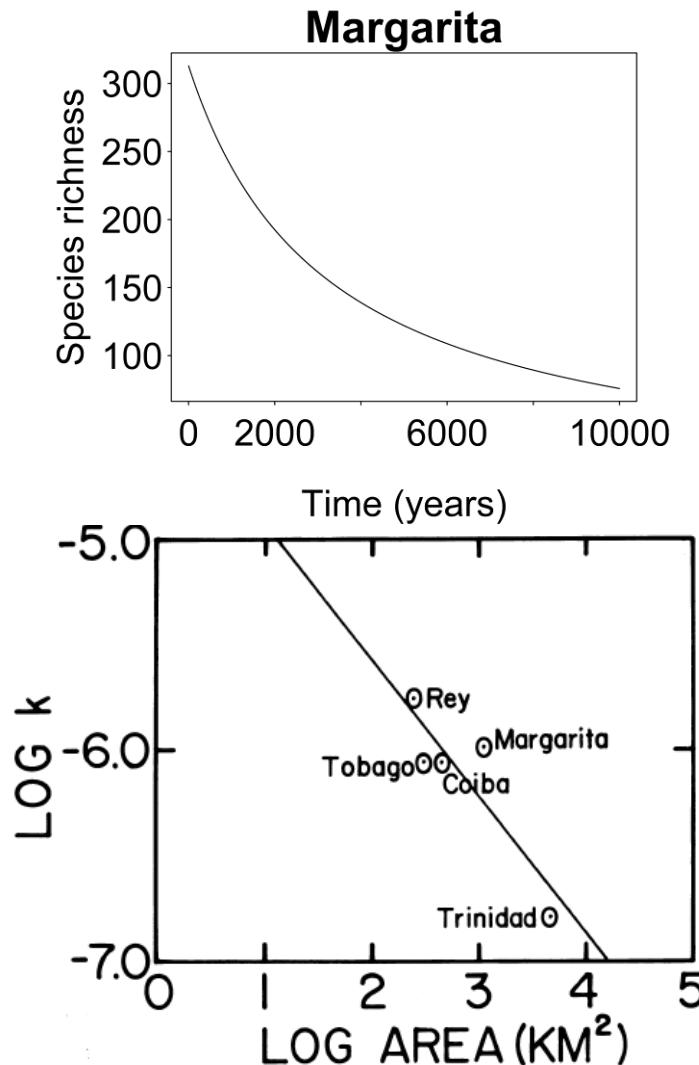


Land-bridge islands (formed relatively recently by sea-level rise) have more species than expected based on their area

May still be undergoing 'relaxation'

In other words, they have an 'extinction debt'

Extinction debt



$$\frac{dS}{dt} = -kS^2$$

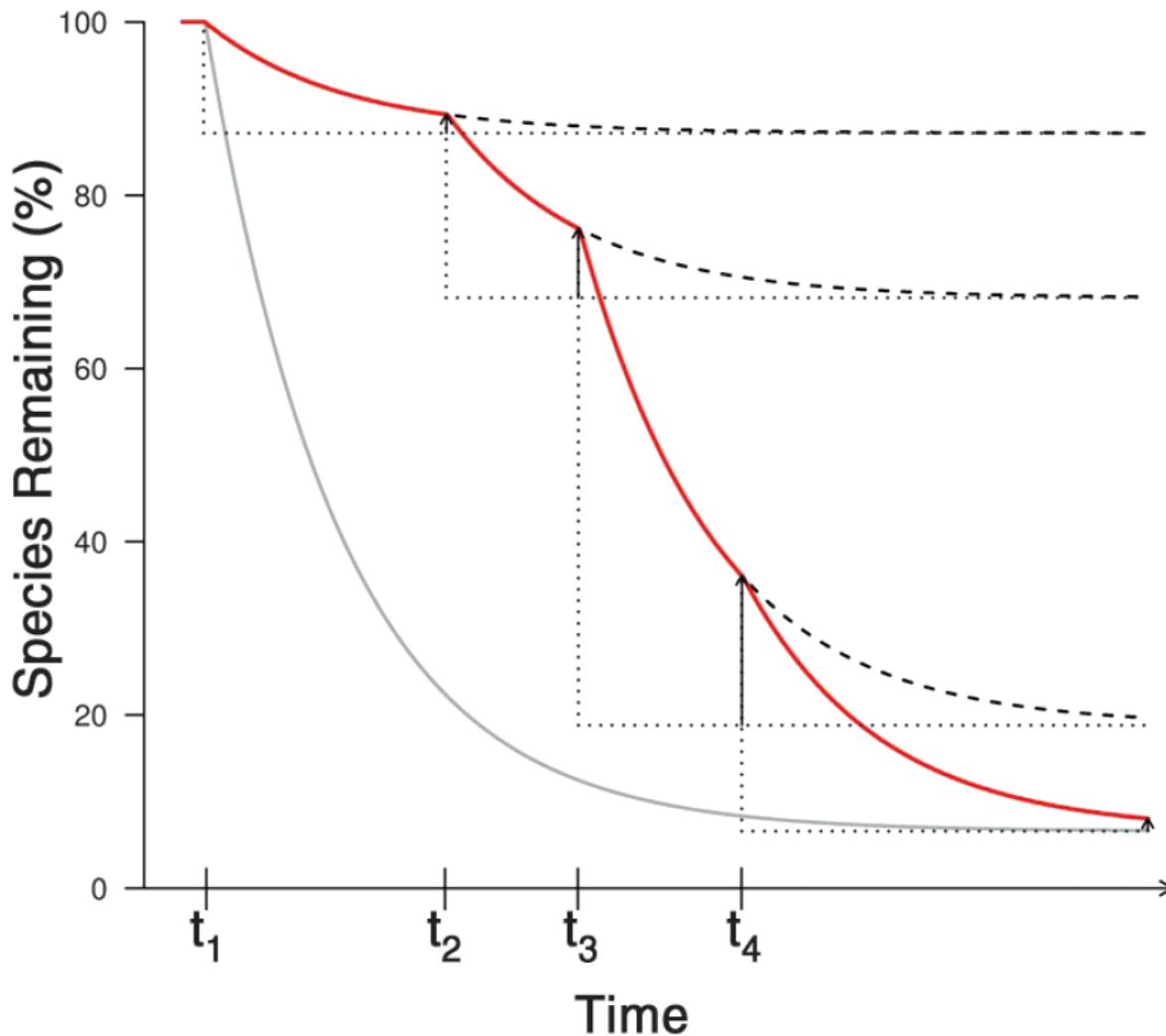
$$k = \frac{\frac{1}{S_p} - \frac{1}{S_o}}{t}$$

S = species richness, k = extinction rate, S_o = original species richness, S_p = present species richness

Fitting to data shows negative relationship between island size and extinction rate

Predicted 17 extinctions on Barro Colorado Island (observed = 13 to 18)

Applications of extinction-debt models



$$\begin{aligned}\frac{dS}{dt} &= -k(S - S_{eq}) \\ &= -k(S - cA^z)\end{aligned}$$

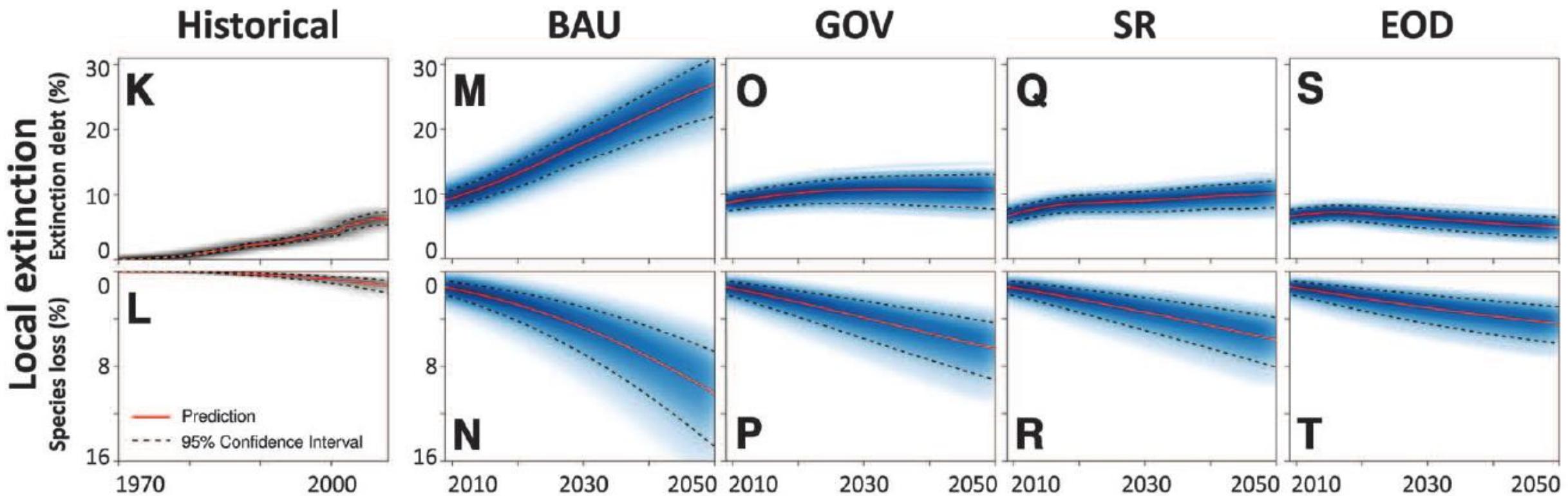
Species-area relationships for forest-dependent amphibians, mammals and birds

Maps of forest cover through time

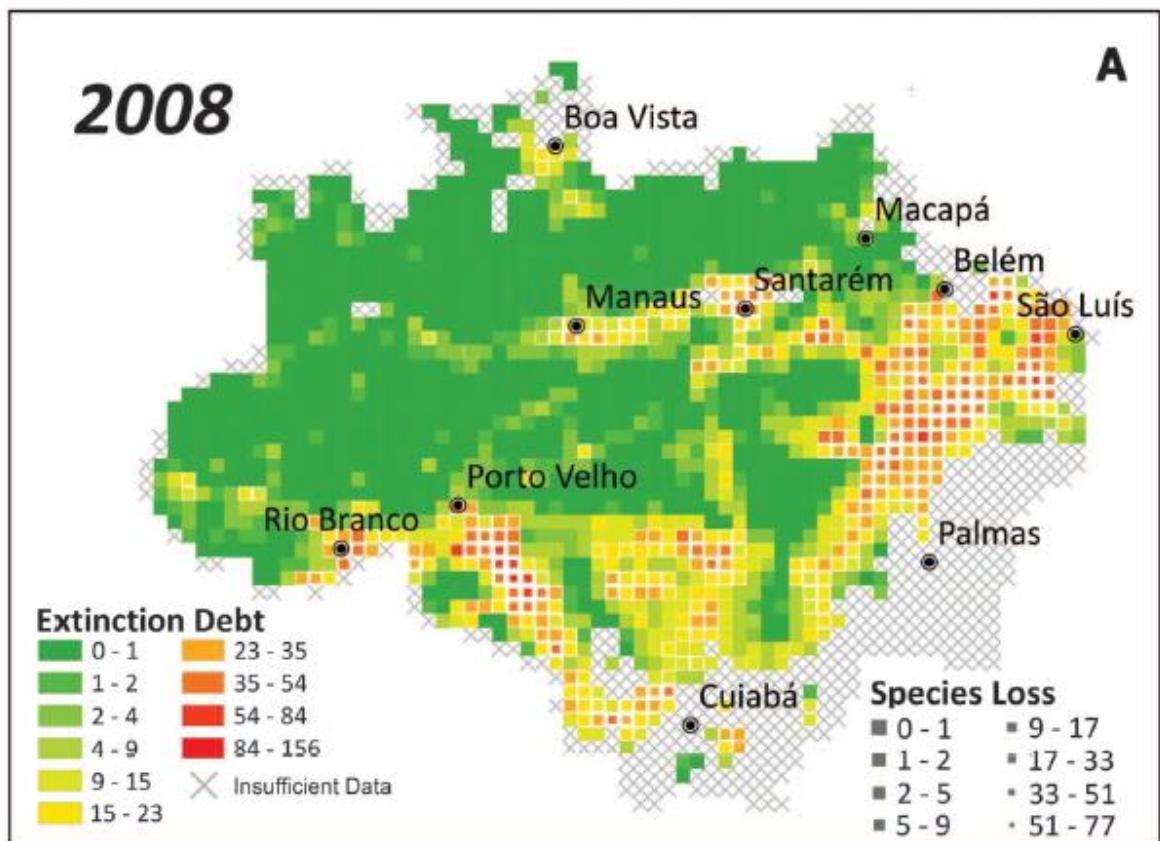
Applications of extinction-debt models

Most extinctions from past habitat loss yet to occur

Predictions of extinction debt correspond well with known threatened species



Applications of extinction-debt models



Spatial patterns of actual species loss and extinction debt

Applications of extinction-debt models

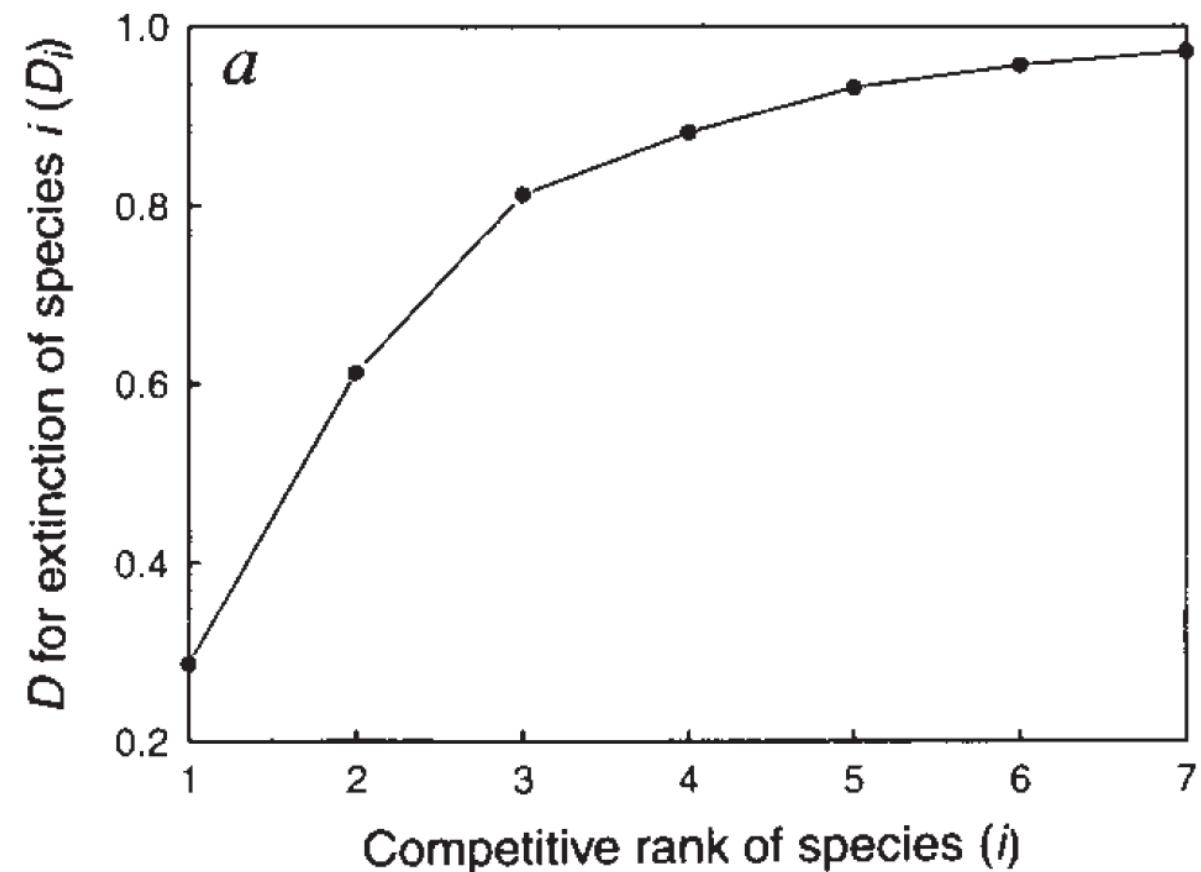
Proportion of patches occupied by species i (p_i):

$$\frac{dp_i}{dt} = c_i p_i \left(1 - D - \sum_{j=1}^i p_j\right) - m_i p_i - \sum_{j=1}^{i-1} c_j p_i p_j$$

c_i = colonization rate, m_i = mortality rate, D = proportion of habitat patches destroyed

Better competitors assumed to be poorer colonizers

Better competitors predicted to be committed to extinction soonest



Basic population biology

$$N_{t+1} = N_t + B - D + I - E$$

B = births, D = deaths, I = immigrations, E = emigrations

Basic population biology: life tables

| Age (days) | Number surviving (a_x) | Proportion surviving (I_x) | Fecundity (F_x) | Proportional fecundity (m_x) | $I_x m_x$ |
|------------|-------------------------------|-----------------------------------|---------------------|-------------------------------------|--------------------------------|
| 0-63 | 996 | 1.000 | 0 | 0.00 | 0.00 |
| 63-124 | 668 | 0.671 | 0 | 0.00 | 0.00 |
| 124-184 | 295 | 0.296 | 0 | 0.00 | 0.00 |
| 184-215 | 190 | 0.191 | 0 | 0.00 | 0.00 |
| 215-264 | 176 | 0.177 | 0 | 0.00 | 0.00 |
| 264-278 | 172 | 0.173 | 0 | 0.00 | 0.00 |
| 278-292 | 167 | 0.168 | 0 | 0.00 | 0.00 |
| 292-306 | 159 | 0.160 | 53.0 | 0.33 | 0.05 |
| 306-320 | 154 | 0.155 | 485.0 | 3.13 | 0.49 |
| 320-334 | 147 | 0.148 | 802.7 | 5.42 | 0.80 |
| 334-348 | 105 | 0.105 | 972.7 | 9.26 | 0.97 |
| 348-362 | 22 | 0.022 | 94.8 | 4.31 | 0.10 |
| 362- | 0 | 0.000 | 0 | 0.00 | 0.00 |
| | | | | TOTAL: | $R_0 = 2.41$ |



Begon et al. (2006). *Ecology: From Individuals to Ecosystems*. Blackwell Publishing. Data from Leverich & Levin (1979). *The American Naturalist* **113**: 881-903.

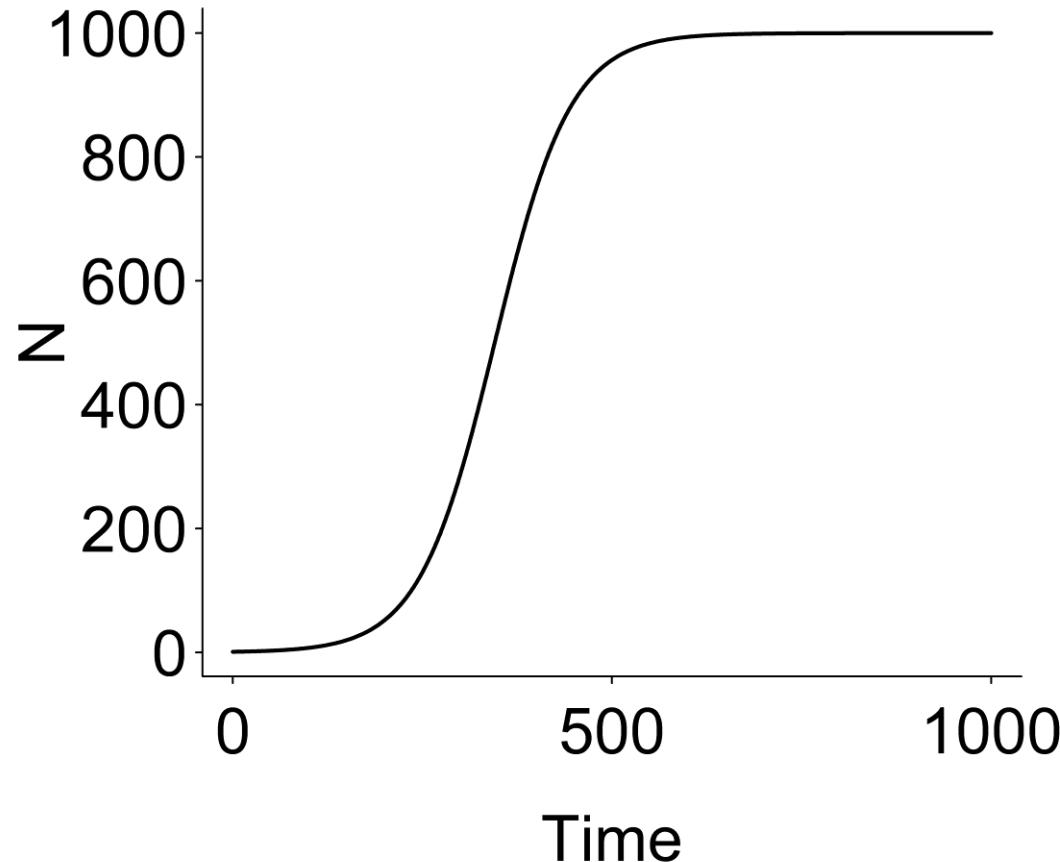
Basic population biology: life tables

| Age (years) | Number surviving (a_x) | Proportion surviving (l_x) | Proportional fecundity (m_x) | $l_x m_x$ | $x l_x m_x$ |
|-------------|-------------------------------|-----------------------------------|-------------------------------------|---------------------------------|--------------|
| 0 | 1,000,000 | 1.000 | 0 | 0 | 0 |
| 1 | 62 | 0.0000620 | 4600 | 0.285 | 0.285 |
| 2 | 34 | 0.0000340 | 8700 | 0.296 | 0.592 |
| 3 | 20 | 0.0000200 | 11600 | 0.232 | 0.696 |
| 4 | 15.5 | 0.0000155 | 12700 | 0.197 | 0.788 |
| 5 | 11 | 0.0000110 | 12700 | 0.140 | 0.700 |
| 6 | 6.5 | 0.0000065 | 12700 | 0.082 | 0.492 |
| 7 | 2 | 0.0000020 | 12700 | 0.025 | 0.175 |
| 8 | 2 | 0.0000020 | 12700 | 0.025 | 0.200 |
| | | | TOTAL: | $R_0 = 1.282$ | 3.928 |

$$r = \frac{\ln R_0}{T_c}; T_c = \frac{\sum x l_x m_x}{R_0} = \frac{3.928}{1.282} = 3.1; r = \frac{\ln 1.282}{3.1} = 0.08014$$



Competition: Lotka-Volterra Model



Based on logistic population growth
(i.e. with density-dependence, e.g.
via intraspecific competition):

$$\frac{dN}{dt} = rN \frac{K - N}{K}$$

r = intrinsic population growth, K =
carrying capacity

Competition: Lotka-Volterra Model

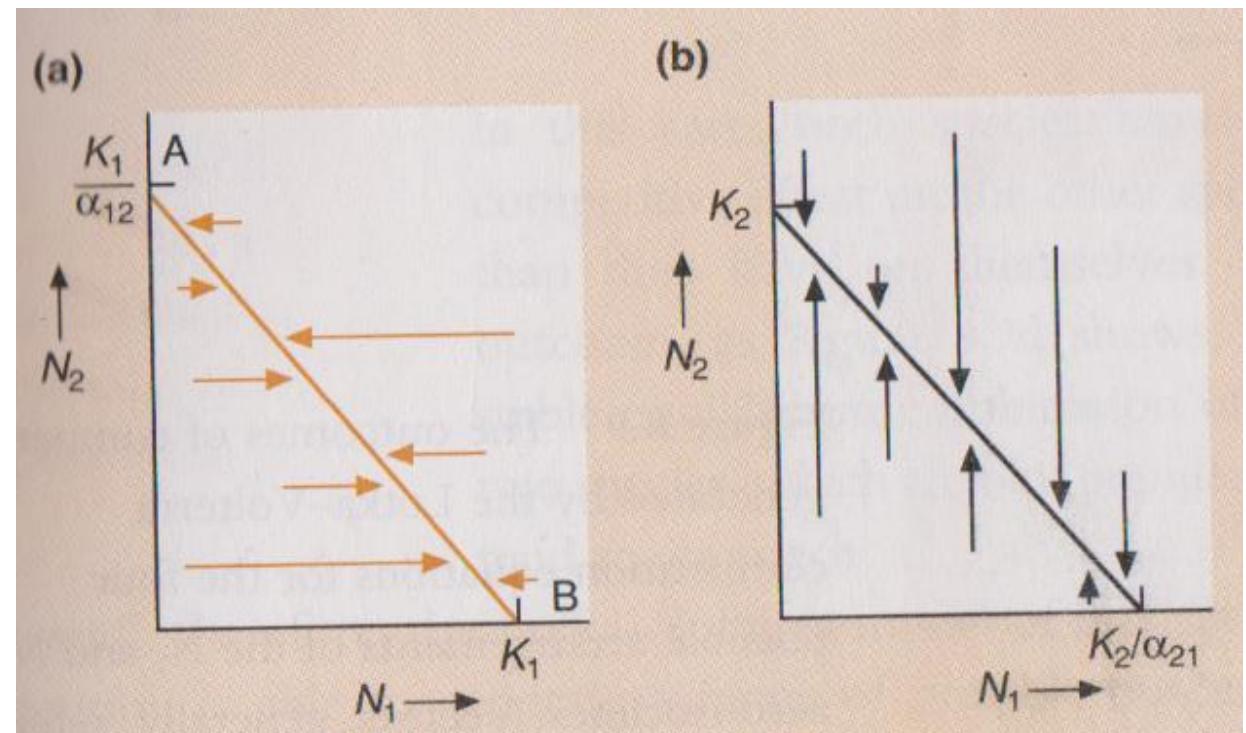
Logistic growth for two species modified to account for effect of interspecific competition:

$$\frac{dN_1}{dt} = r_1 N_1 \frac{K_1 - N_1 - \alpha_{12} N_2}{K_1}$$

$$\frac{dN_2}{dt} = r_2 N_2 \frac{K_2 - N_2 - \alpha_{21} N_1}{K_2}$$

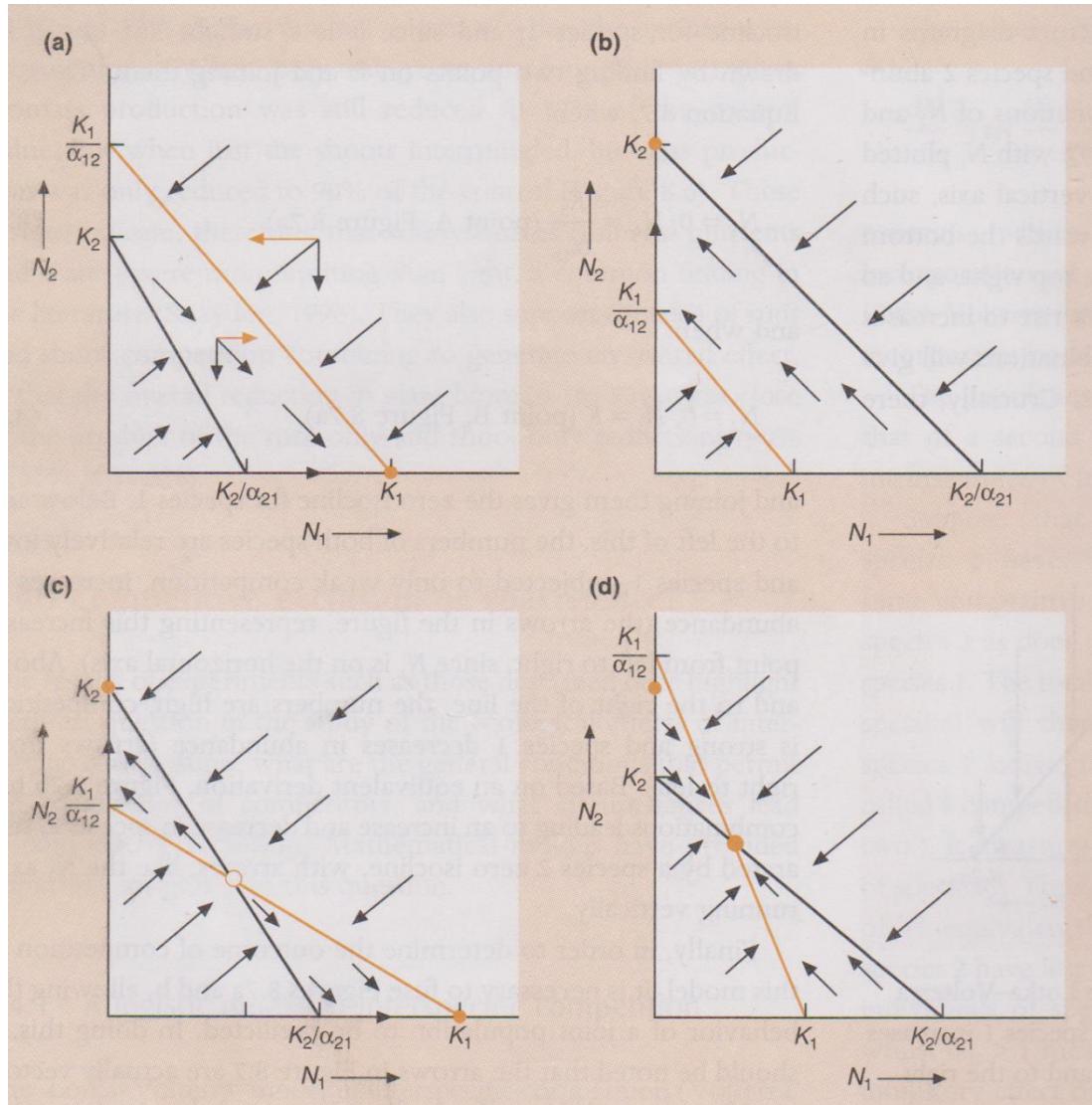
α_{12} = competitive effect of species 2 on species 1

Zero-growth isoclines:



From Begon et al. (2006). *Ecology: From Individuals to Ecosystems*. Blackwell Publishing.

Competition: Lotka-Volterra Model



When $\frac{K_1}{\alpha_{12}} > K_2$ and $K_1 > \frac{K_2}{\alpha_{21}}$, or $K_1 > K_2\alpha_{12}$ and $K_1\alpha_{21} > K_2$, species 1 self-regulates more strongly than species 2 regulates it, and species 1 regulates species 2 more strongly than species 2 regulates itself. Therefore, species 1 outcompetes species 2

When $\frac{K_1}{\alpha_{12}} > K_2$ and $\frac{K_2}{\alpha_{21}} > K_1$, or $K_1 > K_2\alpha_{12}$ and $K_2 > K_1\alpha_{21}$, both species self-regulate more strongly than they affect each other, so co-exist stably

From Begon et al. (2006). *Ecology: From Individuals to Ecosystems*. Blackwell Publishing.

The importance of stochastic effects for ecological dynamics



Simulating stochastic effects in ecological models: stochastic Markov models

Individual-based model with probability of transitioning between states

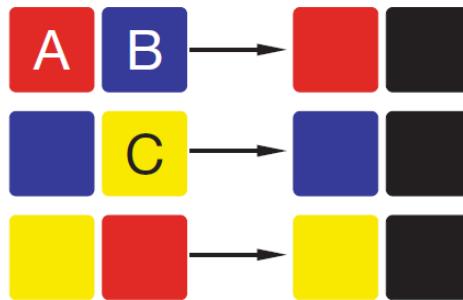
A simple example with only birth and death:



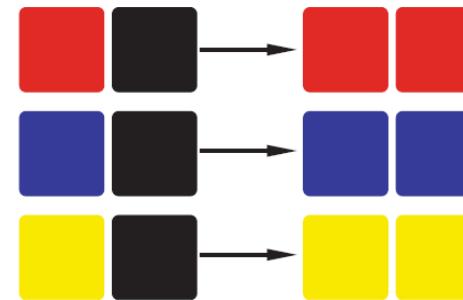
E = empty patch, d = death rate, b = birth rate

Competition: Lotka-Volterra Model – space, dispersal and stochasticity

a Selection (rate σ)

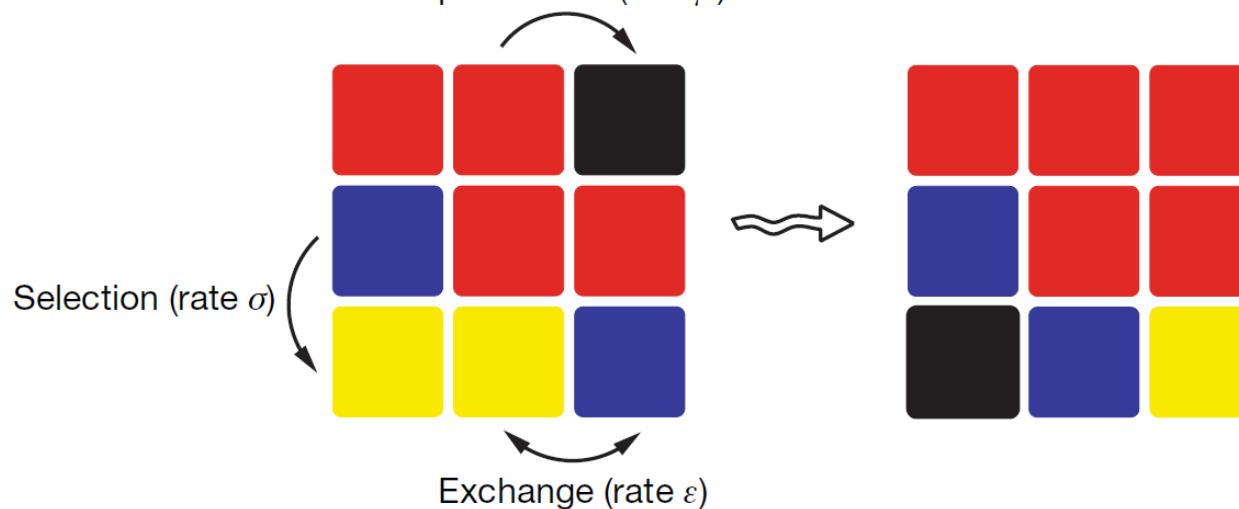


Reproduction (rate μ)

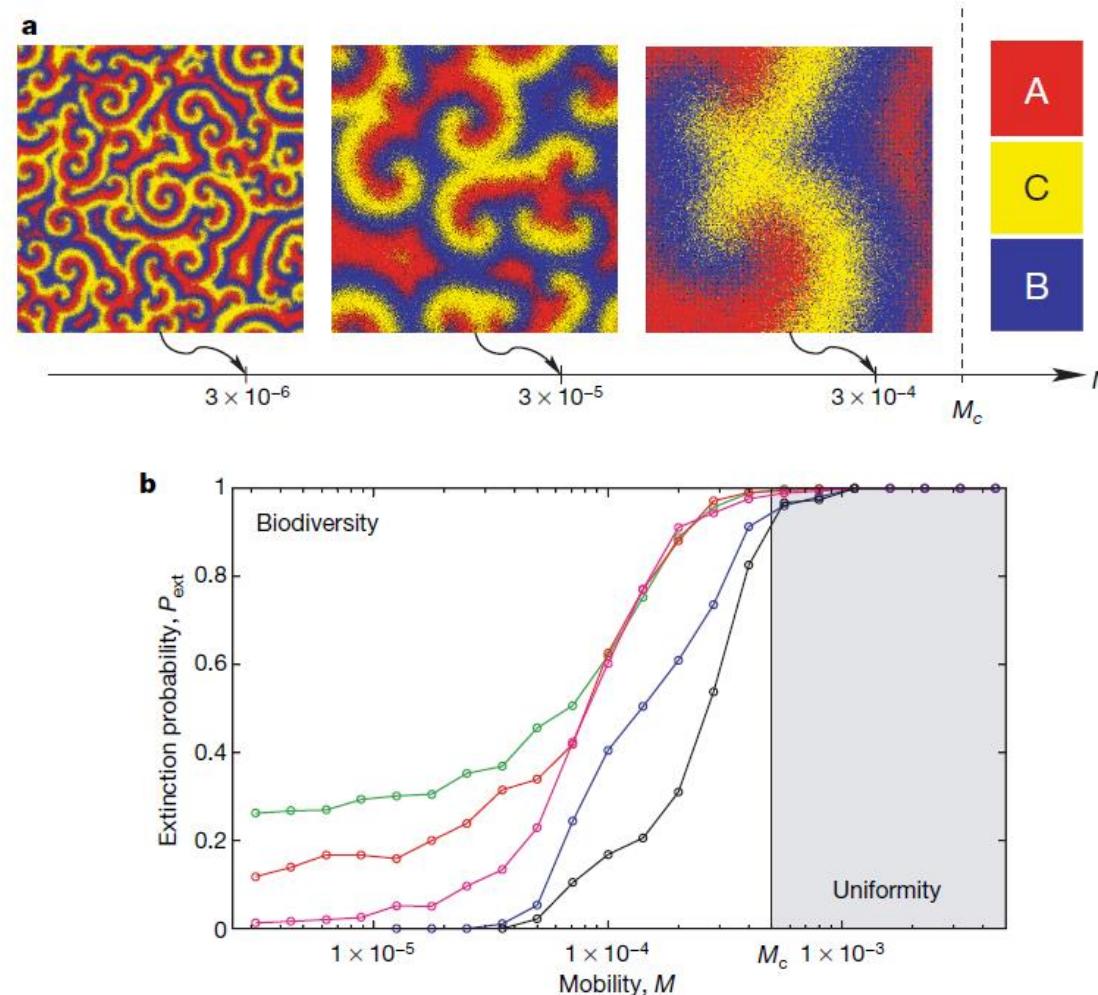


b

Reproduction (rate μ)



Competition: Lotka-Volterra Model – space, dispersal and stochasticity



Competition: Lotka-Volterra Model – space, dispersal and stochasticity

Wang & Loreau (2016):

$$\frac{dN_{il}(t)}{dt} = r_{il}N_{il}(t) \cdot \left(1 - \frac{N_{il}(t) + \alpha_{ijl} \cdot \sum_{j \neq k} N_{jl}(t)}{K_{il}} \right) +$$

Exponential growth

$$\left(-d_i \cdot N_{il}(t) + \sum_{p \neq l} N_{ip}(t) \cdot \frac{d_i}{m-1} \right) +$$

Lotka-Volterra competition

$$N_{il}(t) \cdot E_{il}(t)$$

Emigration and immigration

$$E_{il}(t) = \eta_l(t) + \varepsilon_i(t) + \kappa \cdot \eta_l(t) \cdot \varepsilon_i(t)$$

Environmental stochasticity

Patch-specific environment effect

Species-specific environment effect

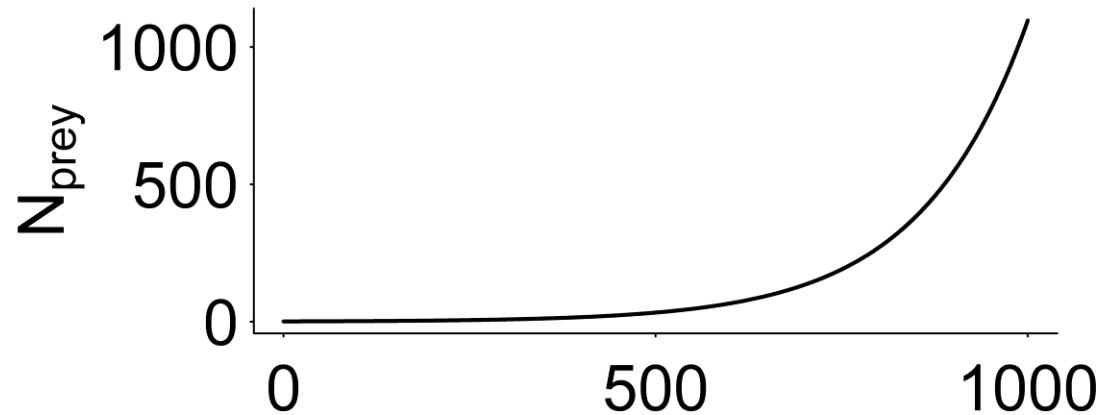
Interaction between patch and species effects

For species i and patches l

Wang & Loreau (2016).

Ecology Letters 19: 510-518

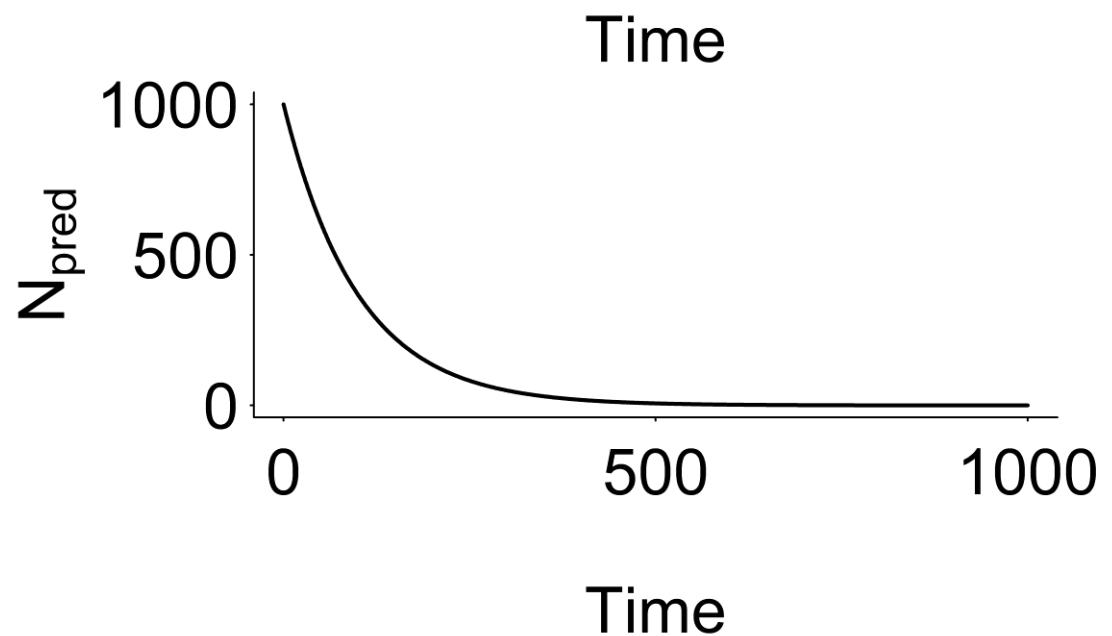
Predation: Lotka-Volterra Model



In the absence of interactions:

Exponential growth of prey:

$$\frac{dR}{dt} = rR$$



Constant per capita loss of predators through mortality:

$$\frac{dC}{dt} = -mC$$

R = Prey abundance, C = predator abundance, m = predator mortality rate

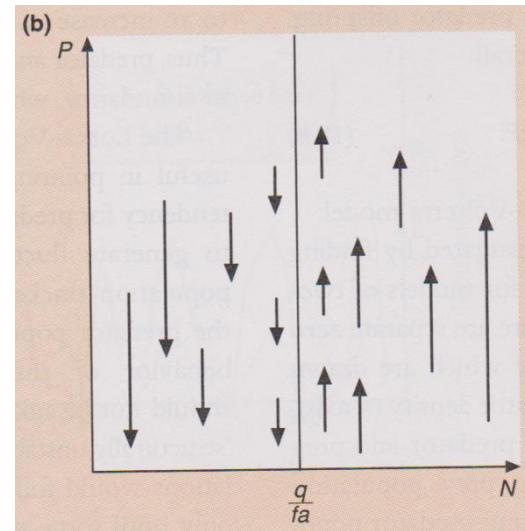
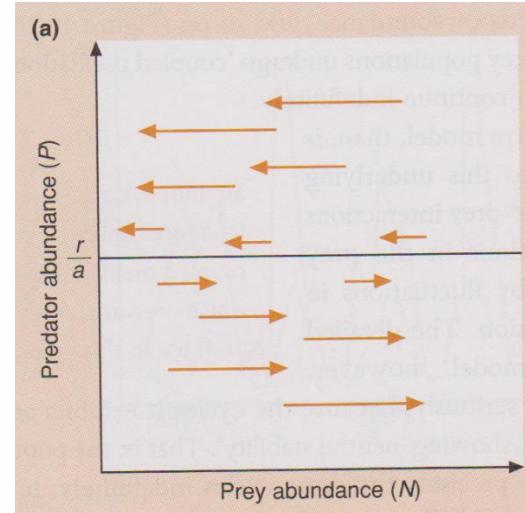
Predation: Lotka-Volterra Model

With interactions between predators and prey:

$$\frac{dR}{dt} = rR - \alpha_{rp}CR$$

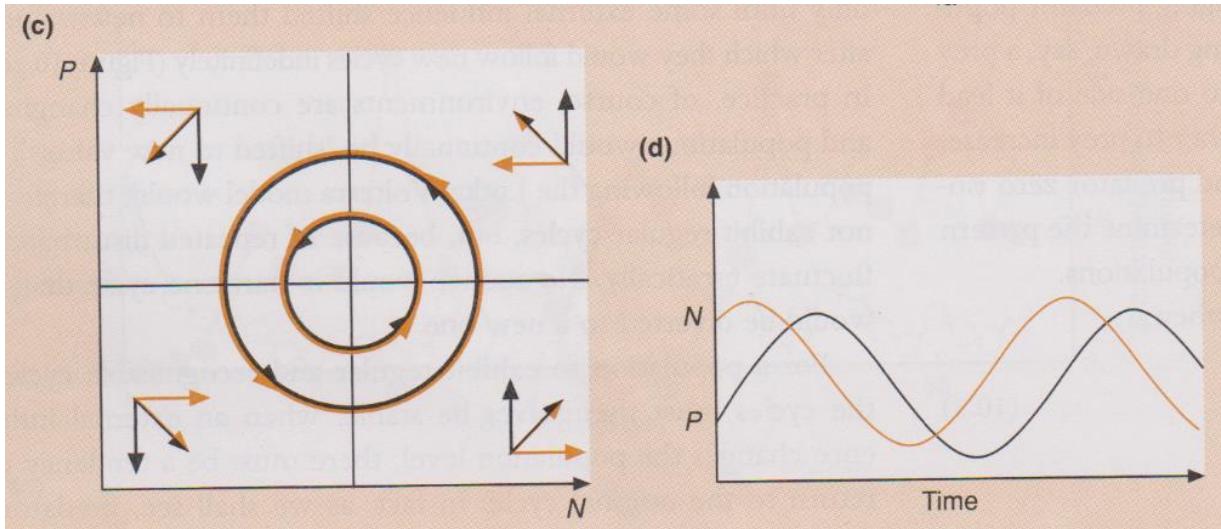
$$\frac{dC}{dt} = e\alpha_{rp}CR - mC$$

e = predation conversion efficiency



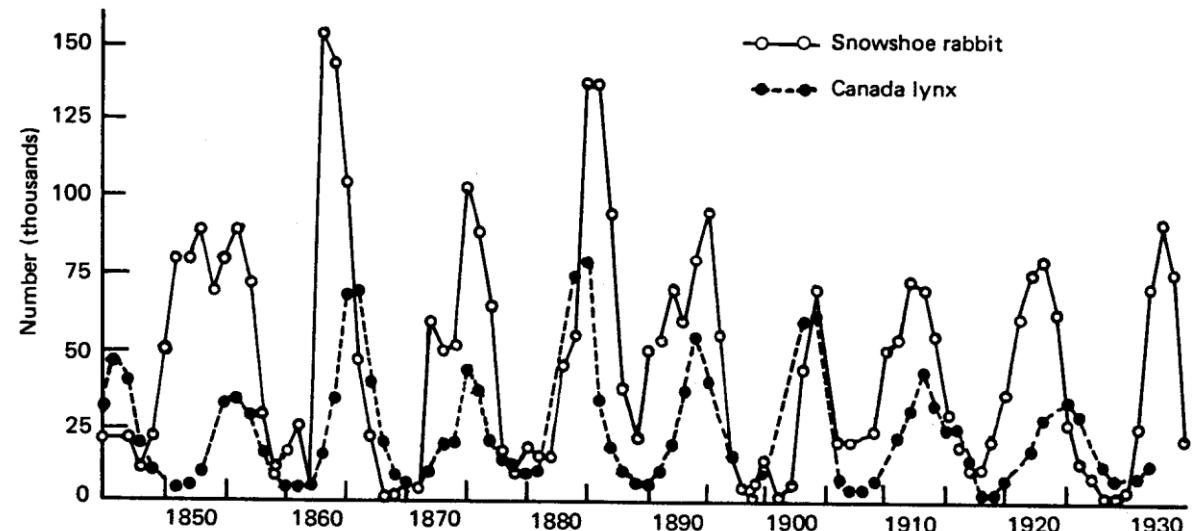
From Begon et al. (2006). *Ecology: From Individuals to Ecosystems*. Blackwell Publishing.

Predation: Lotka-Volterra Model



Lynx and snowshoe hare, from
MacLulick (1937)

From Begon et al. (2006). *Ecology: From Individuals to Ecosystems*. Blackwell Publishing.



How fast can species eat?

When prey are scarce, predation rate might increase linearly with prey density

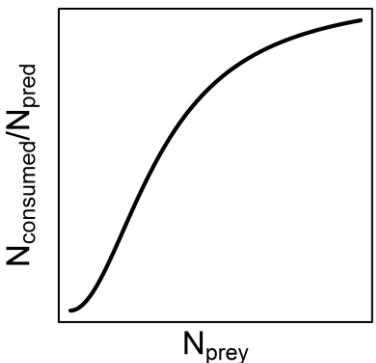
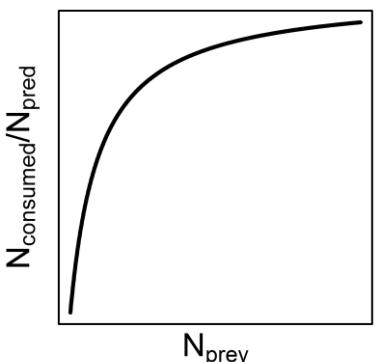
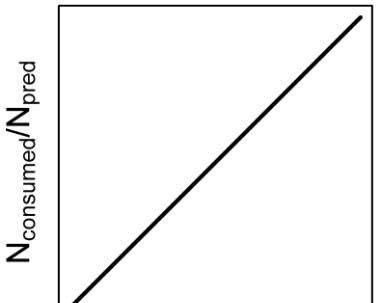


When prey are abundant, predators might be limited by handling time



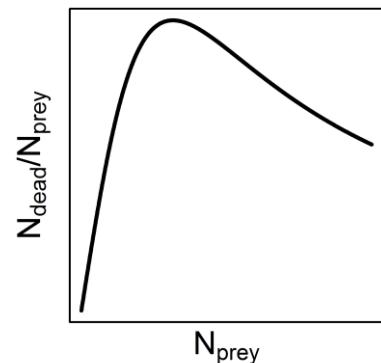
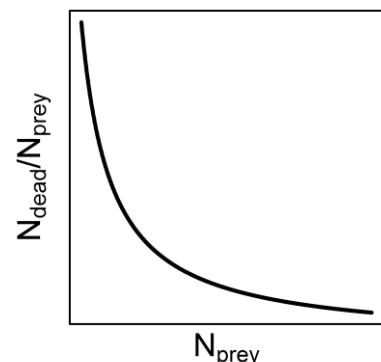
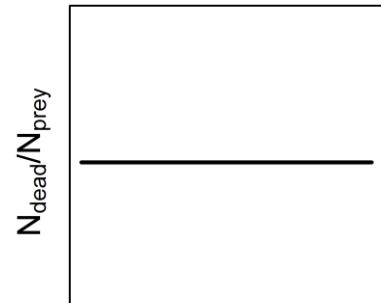
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Functional Responses



| Type | Predator per capita prey consumption rate | Prey per capita predation mortality |
|------|---|---|
| I | aR | Ca |
| II | $\frac{aR}{1 + ahR}$ | $C \frac{a}{1 + ahR}$ |
| III | $\frac{aR^q}{1 + ahR^q}, 1 < q < 2$ | $C \frac{aR^{q-1}}{1 + ahR^q}, 1 < q < 2$ |

a = predator attack rate, R = prey abundance, C = predator abundance, h = handling time, q = prey-abundance exponent



Functional Responses – multiple prey

| Type | Predator per capita prey consumption rate | Prey per capita predation mortality |
|------|---|---|
| I | aR | Ca |
| II | $\frac{aR}{1 + \sum_{r \in S_r} a_r h_r R_r}$ | $C \frac{a}{1 + \sum_{r \in S_r} a_r h_r R_r}$ |
| III | $\frac{aR^q}{1 + \sum_{r \in S_r} a_r h_r R_r^q},$ $1 < q < 2$ | $C \frac{aR^{q-1}}{1 + \sum_{r \in S_r} a_r h_r R_r^q},$ $1 < q < 2$ |

S_r is the set of species that the predator can consume

Functional Responses – generalized form

$$\text{Consumption rate} = \frac{aR^q}{1 + \sum_{r \in S_r} a_r h_r R_r^q}$$

$$\text{Mortality rate} = C \frac{aR^{q-1}}{1 + \sum_{r \in S_r} a_r h_r R_r^q}$$

Type I: $h = 0, q = 1$

Type II: $h > 0, q = 1$

Type III: $h > 0, 1 < q < 2$

Predation and competition: Generalized Rosenzweig-MacArthur Model

$$\frac{dN_i}{dt} = N_i \left(r_i(t) + \sum_{j=1}^s \tilde{\alpha}_{ij} N_j \right)$$

Exponential growth

$$\frac{dN_i}{dt} = N_i r_i(t) - N_i \sum_{j \in L(i)} \alpha_{ij} N_j$$

Competition (including intraspecific, when $i=j$)

$$-N_i \sum_{j \in C(i)} \left(N_j \frac{h_{ij} \alpha_{ij} N_i^{q_{ij}-1}}{1 + \sum_{n \in R(j)} T_{nj} h_{nj} \alpha_{nj} N_n^{q_{nj}}} \right)$$

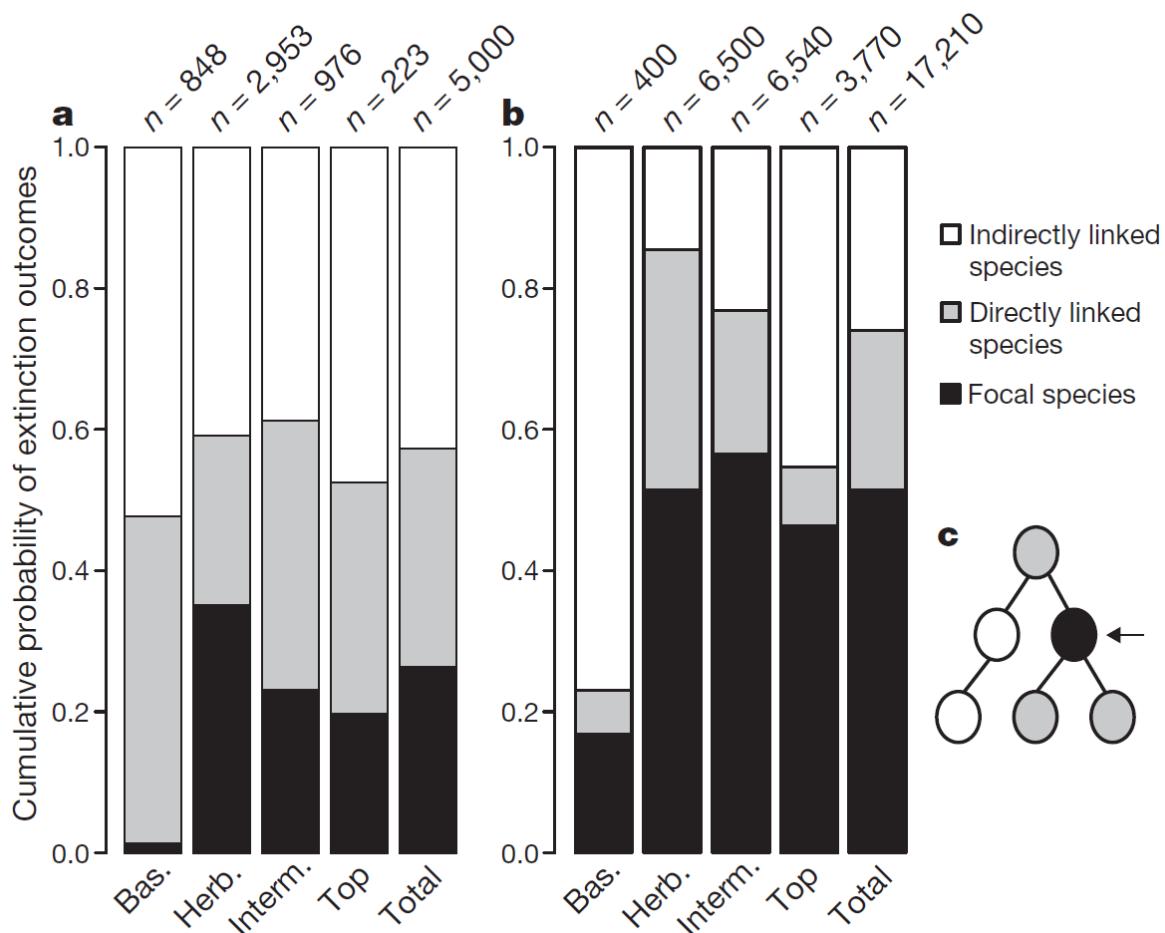
Being predated upon

$$+N_i \sum_{j \in R(i)} \left(e_{ji} \frac{h_{ji} \alpha_{ji} N_j^{q_{ji}}}{1 + \sum_{n \in R(i)} T_{ni} h_{ni} \alpha_{ni} N_n^{q_{ni}}} \right)$$

Predating

$L(i)$ is the set of species competing with i , $C(i)$ is the set of species consuming i , and $R(i)$ is the set of species eaten by i .

Applications of simple community models: extinction risk in ecological networks

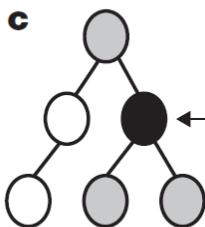


Generalized Rosenzweig-MacArthur model

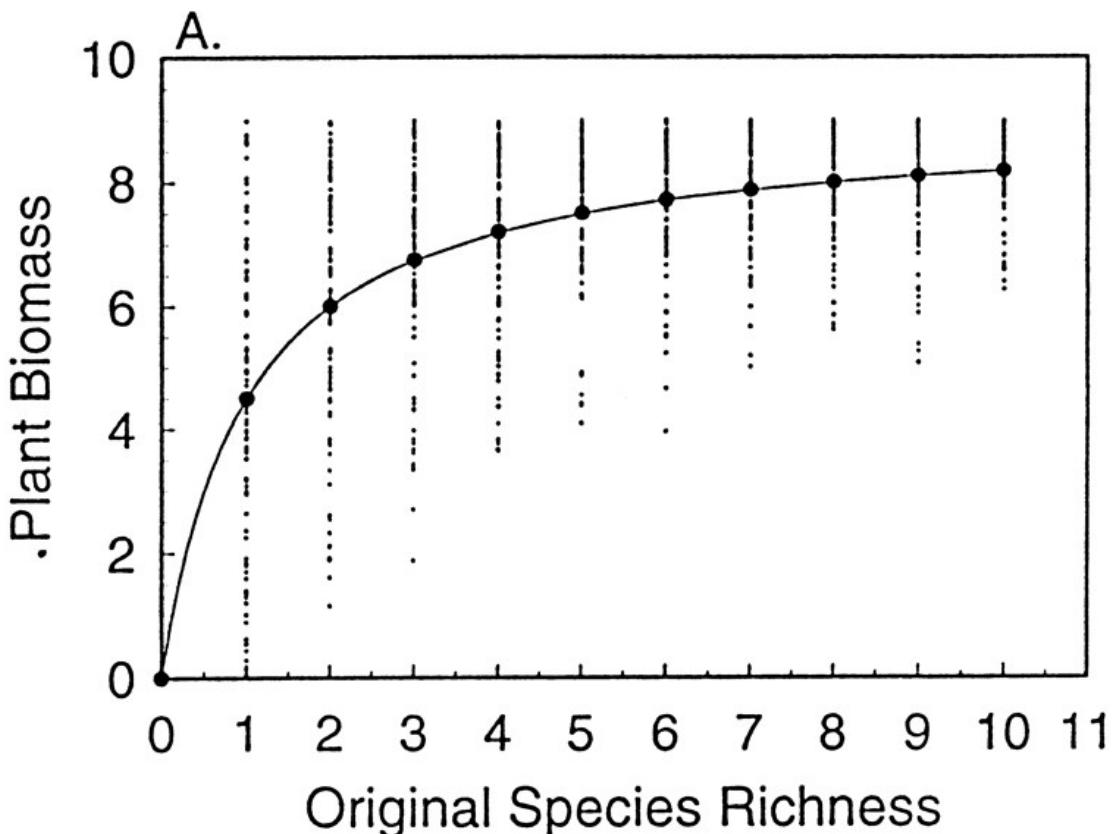
Mortality rate of one species is increased until any species goes extinct

First species to go extinct is often not the species with the increased mortality rate

‘Functional extinction’ before actual extinction



Biodiversity and ecosystem functioning

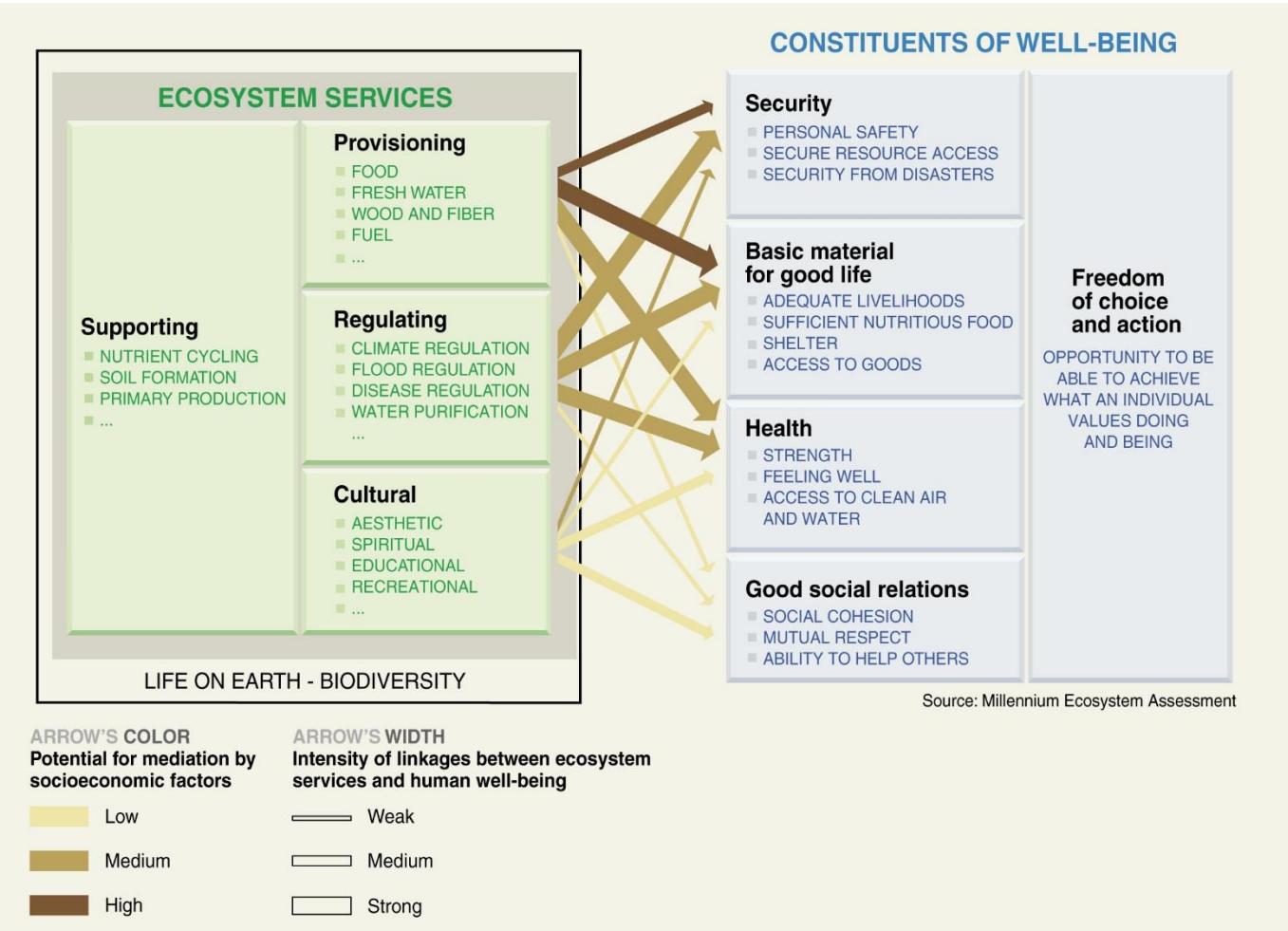


A big question in ecology is whether increased biodiversity supports increased ecosystem function

Empirical tests have tended to focus on grasslands in temperate environments

Simple community models can help to address this question

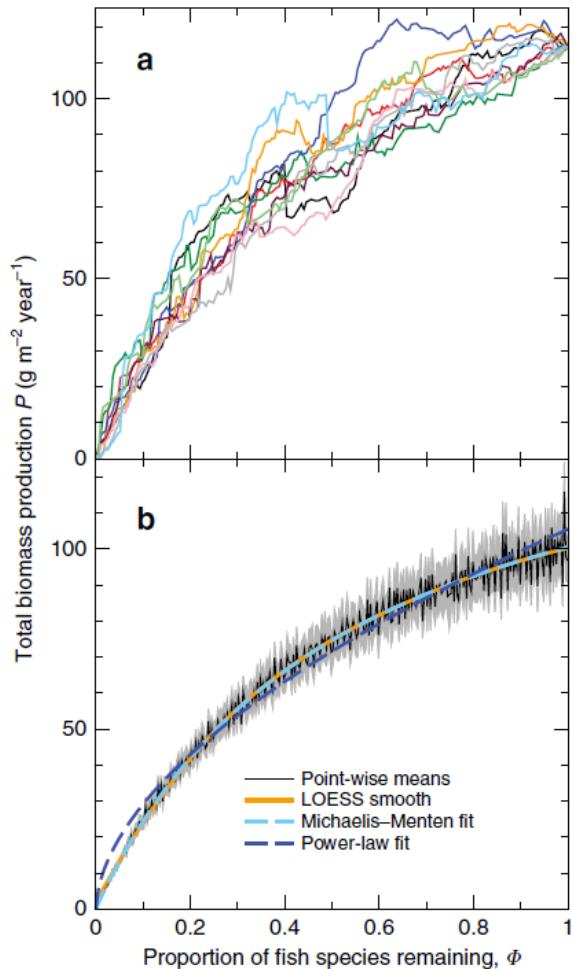
Ecosystem function and ecosystem services



“The benefits people obtain from ecosystems”

Underpinned by key ecosystem functions

Applications of simple community models: biodiversity and ecosystem functioning



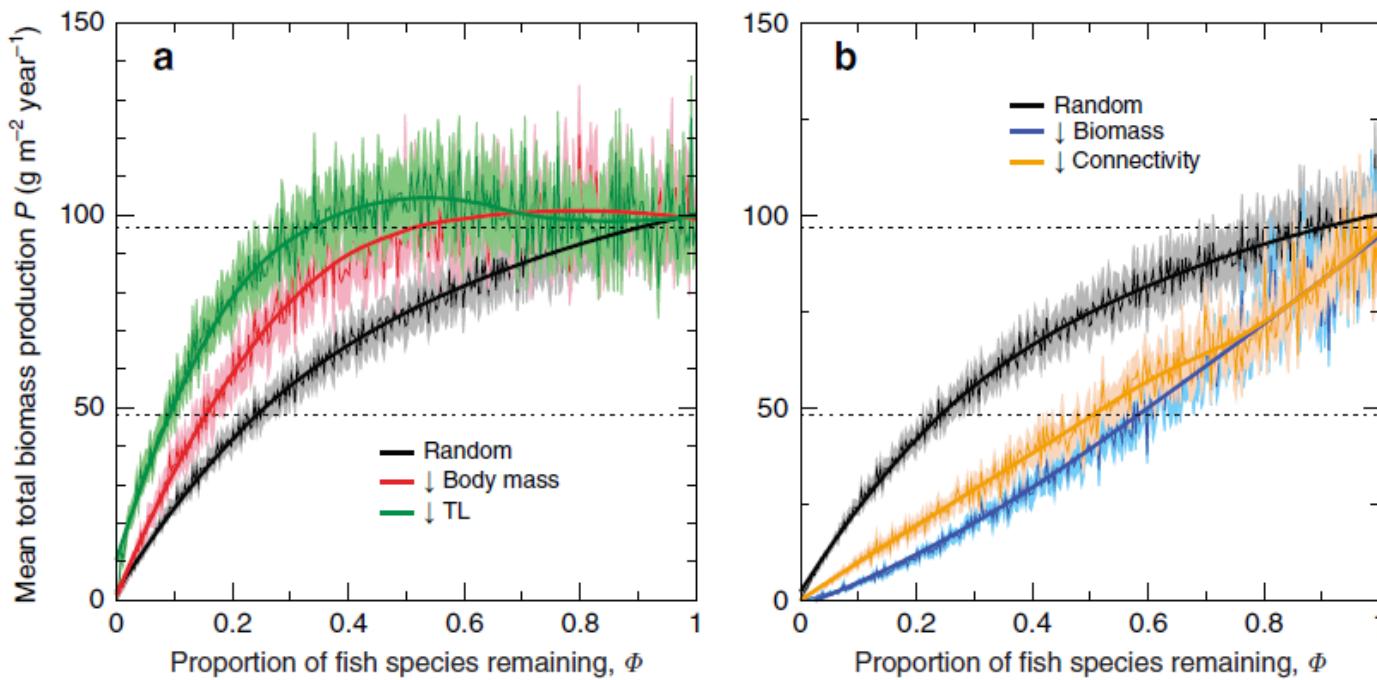
Marine food-web model with thousands of species

Competition: Lotka-Volterra

Predator-prey relationships:
Holling Type II functional response

Loss of species led to loss of fish production

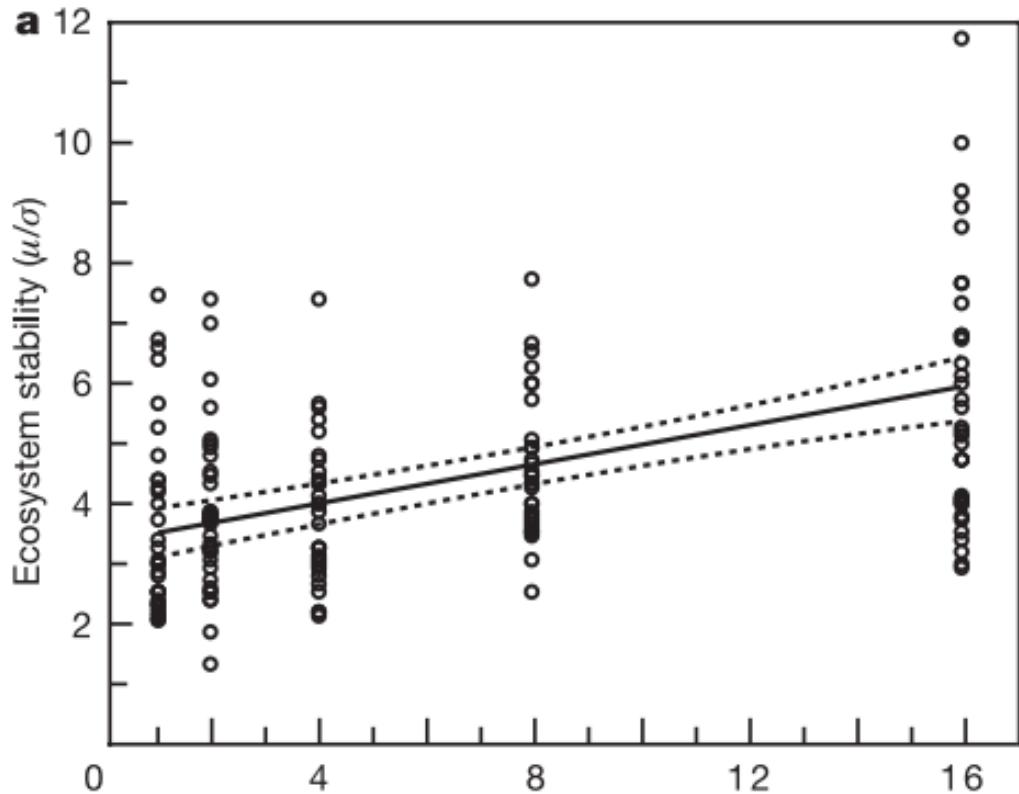
Applications of simple community models: biodiversity and ecosystem functioning



If large or high-trophic-level species were removed first, small species losses had little effect on production

If the species of highest biomass or highest connectivity were removed first, species losses had steep effect on production

Does biodiversity stabilize total community properties?



If species respond differently to environmental changes, higher biodiversity might stabilize properties of the total community

‘Insurance’ effect

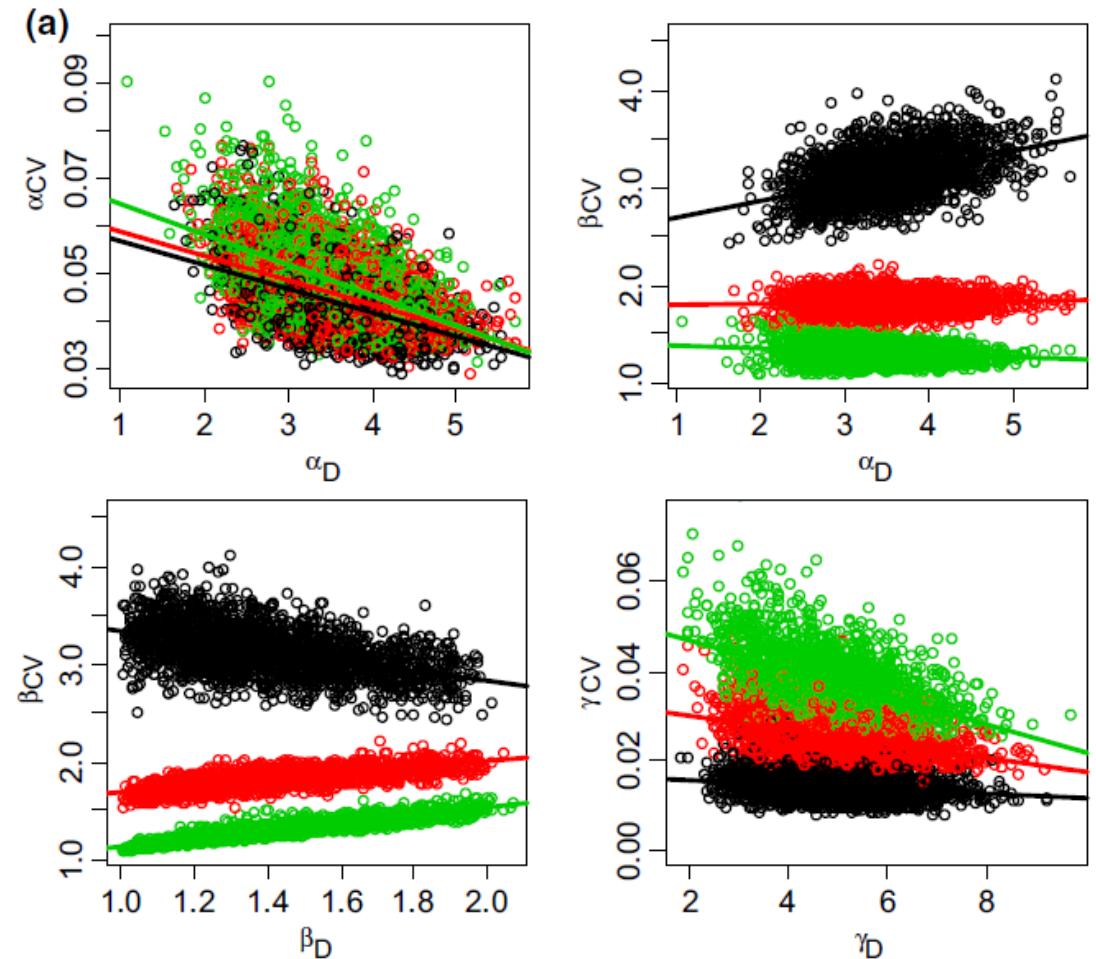
Applications of simple community models: biodiversity and community stability

Stochastic, spatial Lotka-Volterra competition model

Varied intrinsic growth rates, carrying capacities, interaction coefficients, and dispersal rates

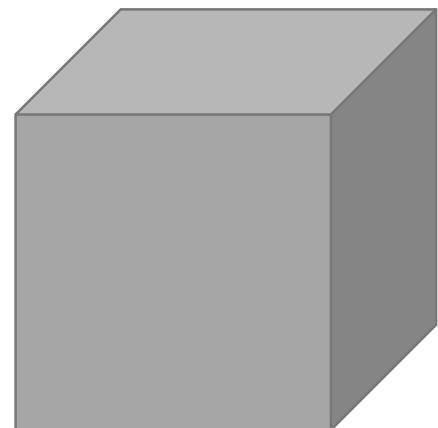
Analysed effects of diversity (alpha, beta and gamma) on stability of total population size (alpha, beta and gamma)

Local (alpha) diversity stabilized local population size, and regional diversity stabilized regional population size



Negatively correlated environmental responses
No correlation in environmental responses
Positively correlated environmental responses

Metabolic theory



$$\text{Surface area} \propto \text{Length}^2$$

$$\text{Volume} \propto \text{Mass} \propto \text{Length}^3$$

$$\text{Surface area} \propto \text{Mass}^{2/3}$$

Rubner (1883):

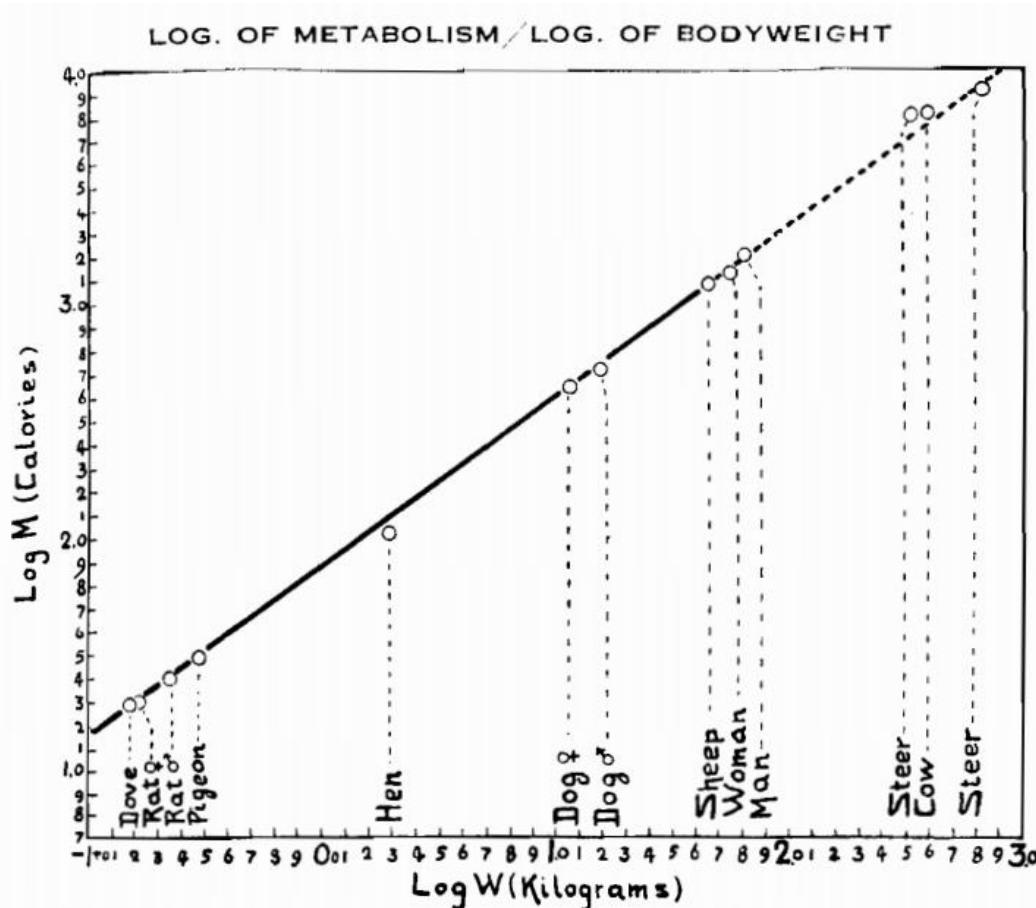
Metabolic rate of dogs divided by surface area independent of mass

Therefore:

$$B \propto M^{2/3}$$

Rubner (1883). *Zeitschrift für Biologie* 19: 536-562

Metabolic theory

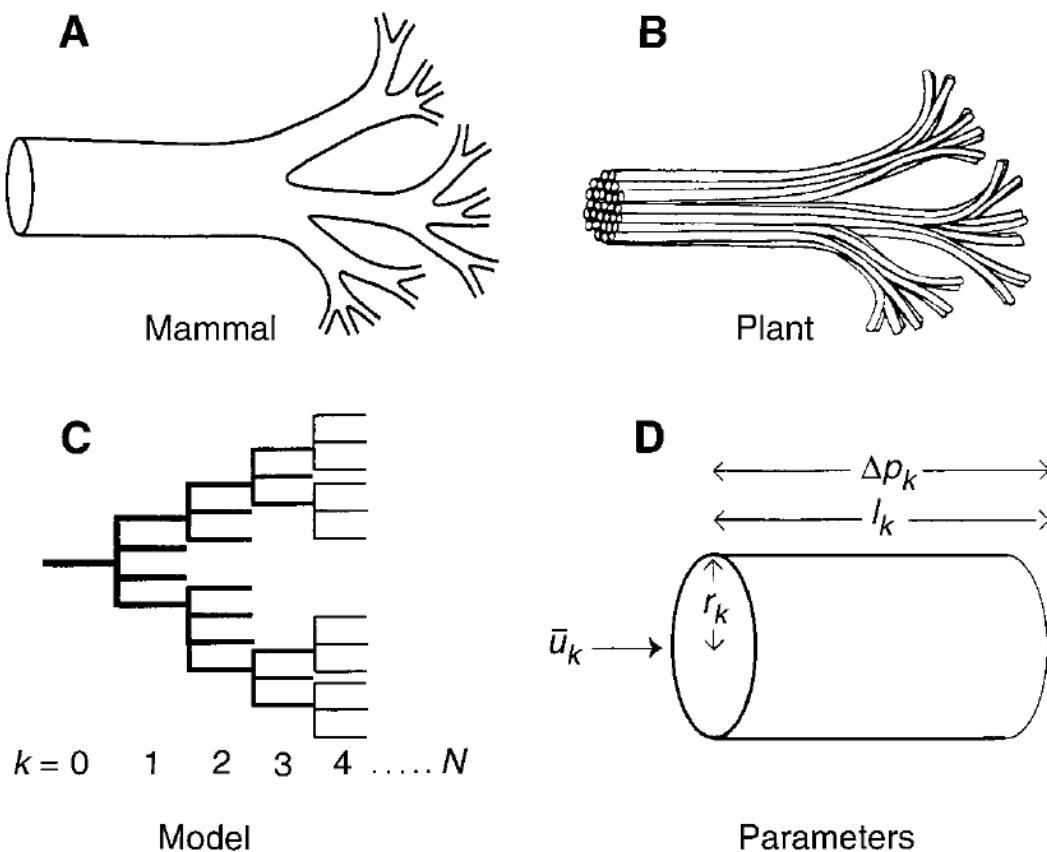


Kleiber (1932):

$$B \propto M^{3/4}$$

Assuming that metabolism scales with body surface area is overly simplistic

Metabolic theory

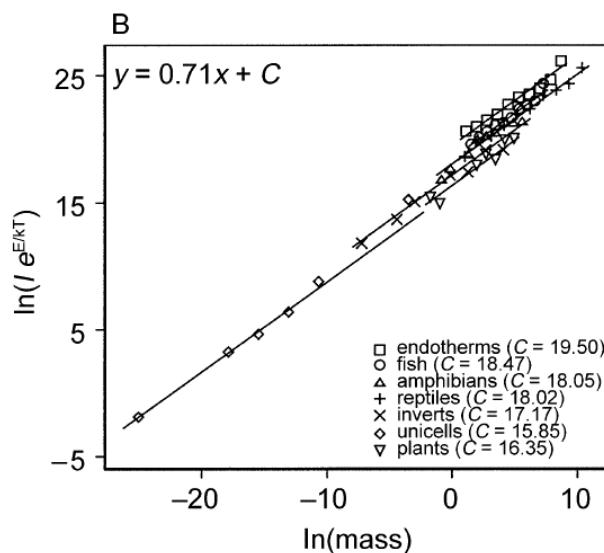
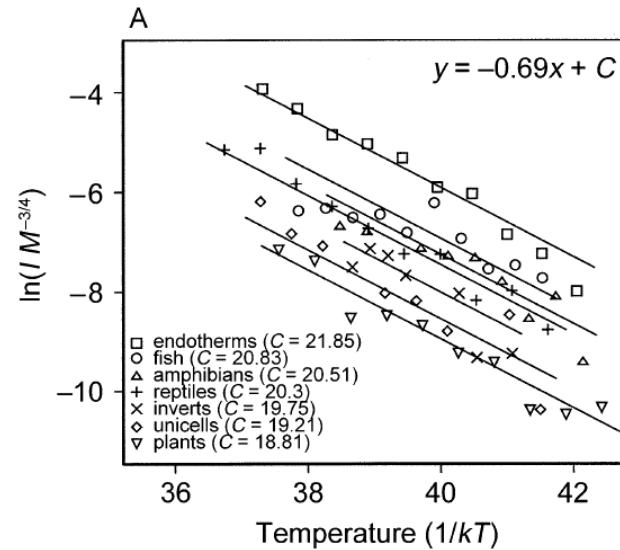


Transport through networks, e.g. capillaries, of resources required for metabolism scales with $M^{3/4}$

Makes some relatively straightforward assumptions

Predicts accurately the mass-scaling of properties of mammalian circulatory systems

Metabolic theory



Combined effects of mass and temperature:

$$B = b_0 M^{3/4} e^{-E/kT}$$

E = activation energy; T = temperature; k = Boltzmann constant; b_0 = constant

Critiques of metabolic theory

AN ILLUSION OF MECHANISTIC UNDERSTANDING

HÉLÈNE CYR¹ and STEVE C. WALKER

THE VALUE OF NULL THEORIES IN ECOLOGY

JOHN HARTE¹

METABOLIC ECOLOGY: LINKING INDIVIDUALS TO ECOSYSTEMS

PABLO A. MARQUET,^{1,3} FABIO A. LABRA,¹ and BRIAN A. MAURER²

DOES METABOLIC THEORY APPLY TO COMMUNITY ECOLOGY?
IT'S A MATTER OF SCALE

DAVID TILMAN,¹ JANNEKE HILLERISLAMBERS, STAN HARPOLE, RAY DYBZINSKI, JOE FARGIONE,
CHRIS CLARK, AND CLARENCE LEHMAN

CAN FUNCTION AT THE ORGANISMAL LEVEL EXPLAIN
ECOLOGICAL PATTERNS?

M. A. R. KOEHL¹ AND BRYCE D. WOLCOTT

A ONE-RESOURCE “STOICHIOMETRY”?

ROBERT W. STERNER¹

Ecology, Evolution and Behavior, University of Minnesota, St. Paul, Minnesota 55108 USA

The approach of Brown et al. (2004) might succeed or fail on two levels. On one level, it can be used as a purely statistical, predictive tool. Examples given by Brown and colleagues leave no doubt that temperature and body size “explain” (in the statistical sense) a great deal. We do need good predictive models for many reasons, one of them for incorporating more ecology

course, is less certain than is the existence of good statistical correlations.

Brown et al. view the “big three” variables to be temperature, body size, and stoichiometry. Temperature turns out to be approachable using decades-old formulations of Arrhenius, Boltzmann, and others. It

Main criticisms:

- Assumptions justified?
- Extent of applicability
- Many other important ecological processes
- Contingency
- Explanation of mechanisms, or just good fit to patterns?
- Usefulness to community dynamics
- Organisms face multiple limiting factors
- Is metabolic rate really $\propto M^{0.75}$?

Metabolic theory

Table 2. Ordinary least-squares (OLS) and reduced major axis (RMA) allometric regression parameters for the scaling of mammalian metabolic rate

| | OLS | | RMA | | |
|-------------------|----------|----------|----------|----------|--------|
| | <i>a</i> | <i>b</i> | <i>a</i> | <i>b</i> | 95% CI |
| SMR | 4.17 | 0.675 | 3.85 | 0.689 | 0.013 |
| BMR | 3.98 | 0.686 | 3.61 | 0.706 | 0.014 |
| RMR _t | 3.66 | 0.712 | 3.33 | 0.729 | 0.013 |
| FMR | 9.99 | 0.73 | 4.53 | 0.75 | 0.04 |
| RMR _{pp} | 7.91 | 0.75 | 7.70 | 0.76 | 0.03 |
| MMR _c | 31.56 | 0.65 | 28.3 | 0.68 | 0.05 |
| MMR _e | 16.71 | 0.87 | 0.4 | 0.88 | 0.05 |

Mammalian metabolic rate (MR)= aM_b^b . All regressions are presented in standardised units (BMR in ml O₂ h⁻¹; M_b in g). SMR, standard metabolic rate; BMR, basal metabolic rate; RMR_t, thermoneutral resting metabolic rate; FMR, field metabolic rate; RMR_{pp}, peak postprandial resting metabolic rate; MMR_c, cold-induced maximum metabolic rate; MMR_e, exercise-induced maximum metabolic rate; see text for details.

But perhaps metabolic rates are not really $\propto M^{3/4}$

White & Seymour (2005): slopes vary depending on measures, methods, and exclusion of problematic large herbivores

Evidence to reject a slope of 2/3 not always strong

Metabolic theory

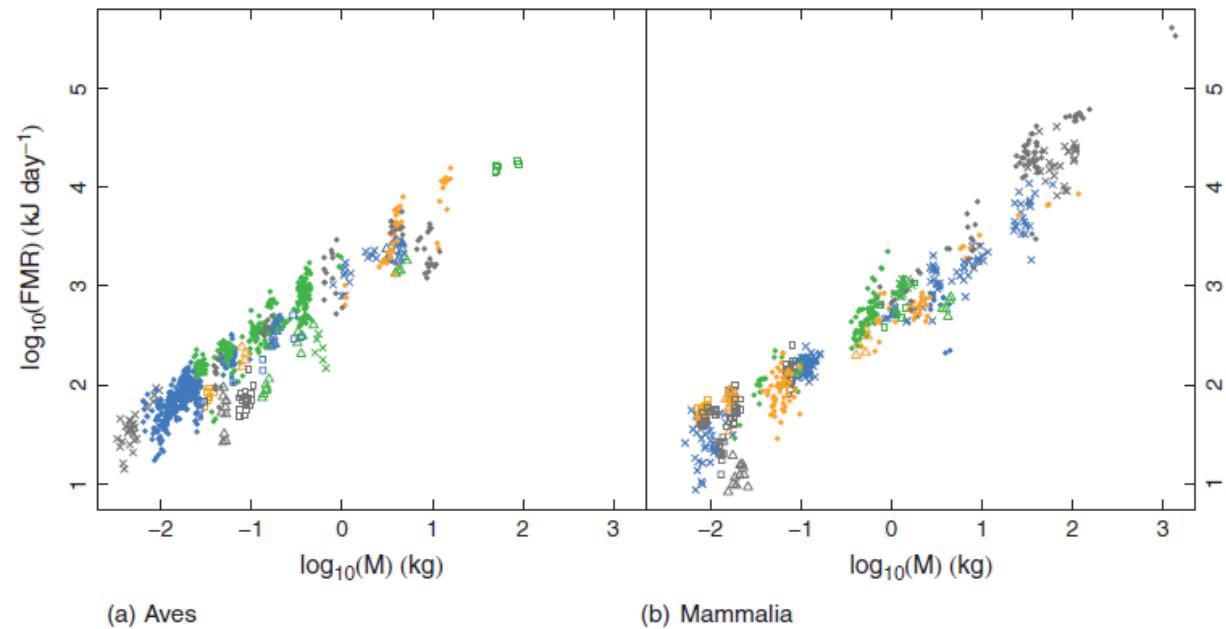
Hudson et al. (2013):

Wide taxonomic variation in slopes

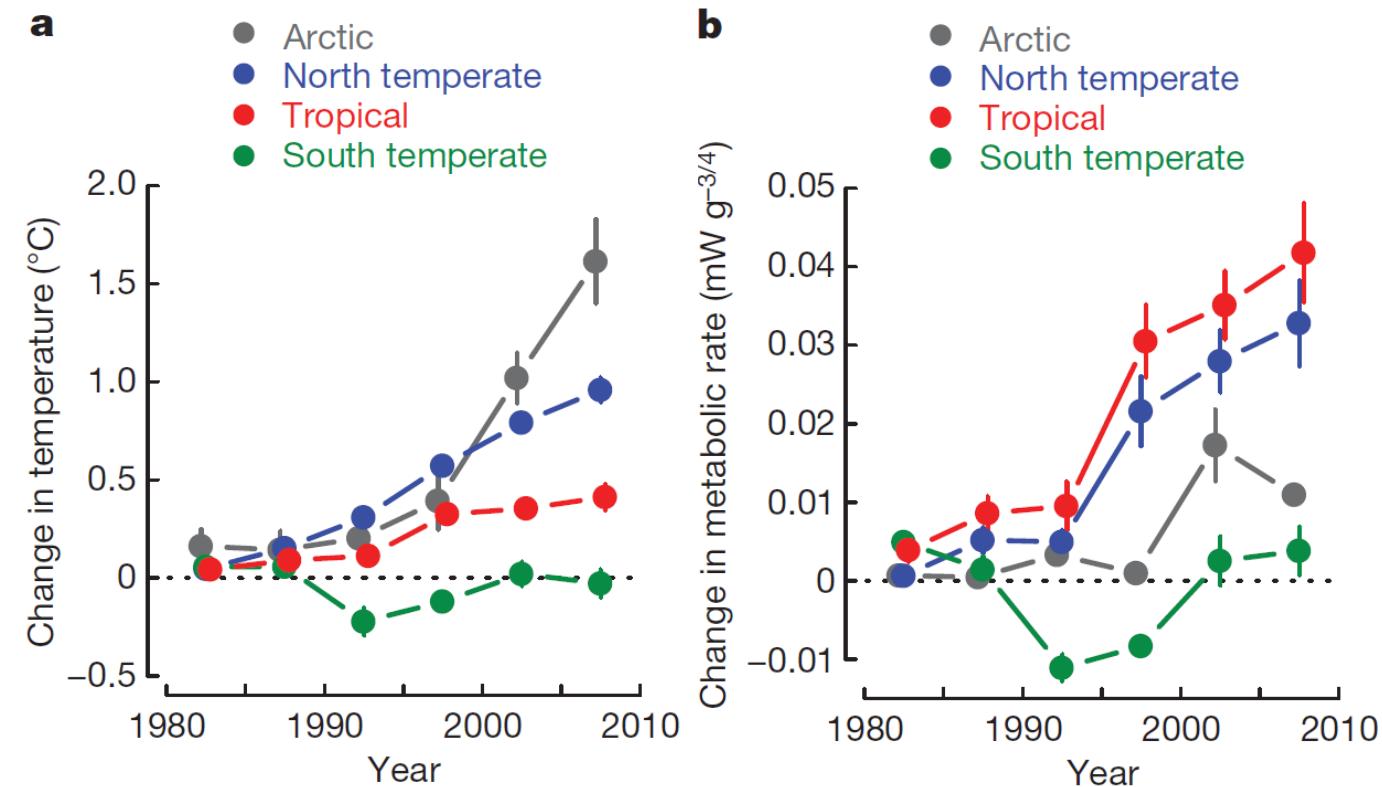
No evidence to reject slope of 2/3,
Sometimes can reject slope of 3/4

Legend of bird and mammal orders:

| | | | | | |
|------------------|----------------|-------------------|----------------|-----------------|--------------|
| Apodiformes | Falconiformes | Procellariiformes | Afrosoricida | Diprotodontia | Primates |
| Caprimulgiformes | Galliformes | Psittaciformes | Artiodactyla | Lagomorpha | Rodentia |
| Charadriiformes | Passeriformes | Sphenisciformes | Carnivora | Monotremata | Soricomorpha |
| Columbiformes | Pelecaniformes | Strigiformes | Chiroptera | Peramelemorphia | |
| Coraciiformes | Piciformes | Struthioniformes | Dasyuromorphia | Pilosa | |



Applications of metabolic theory: effects of climate change

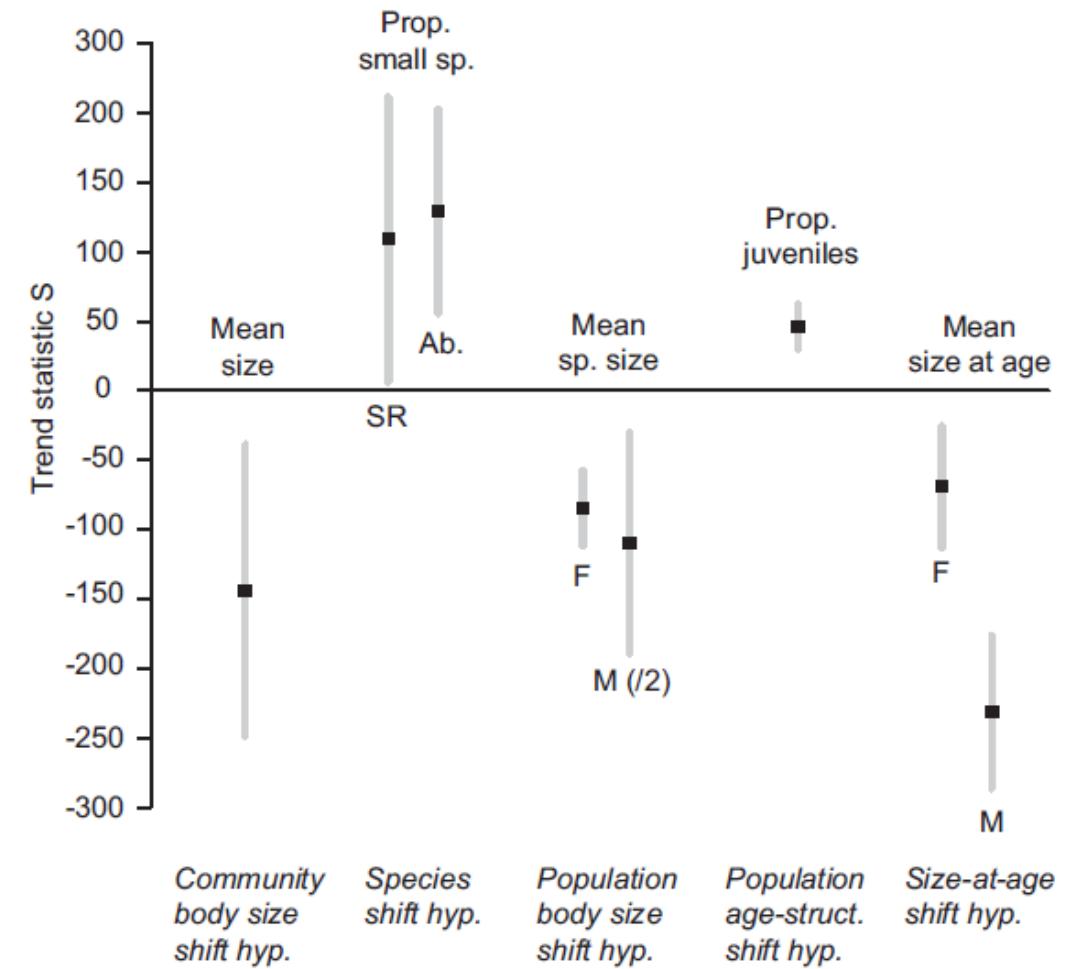
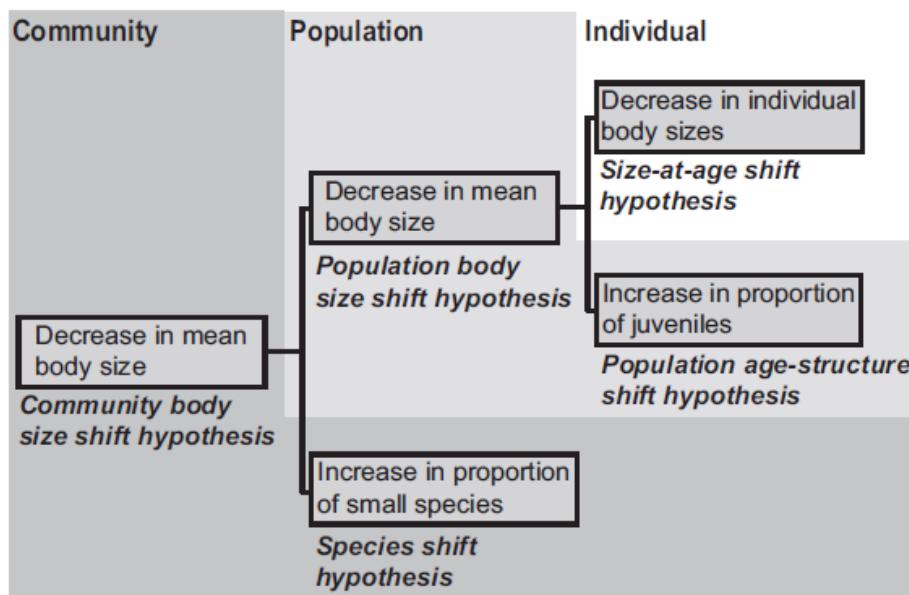


Mass-normalized metabolic rate based on weather-station temperature estimates

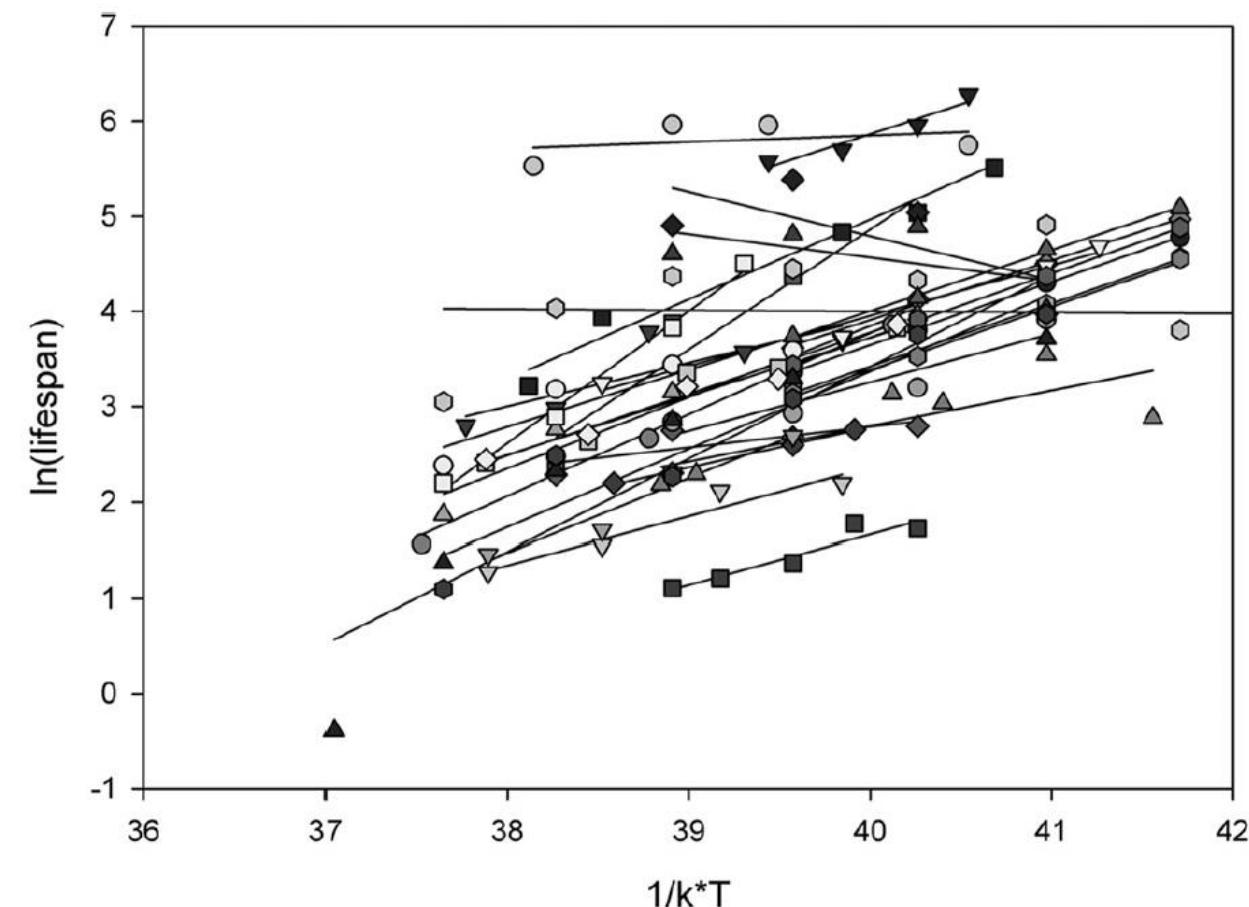
Arctic warmed fastest, but metabolic rates increased most in tropics

Applications of metabolic theory : effects of climate change

Relationship between temperature and metabolic rates predicts effects of climate change on body size



Applications of metabolic theory : effects of climate change



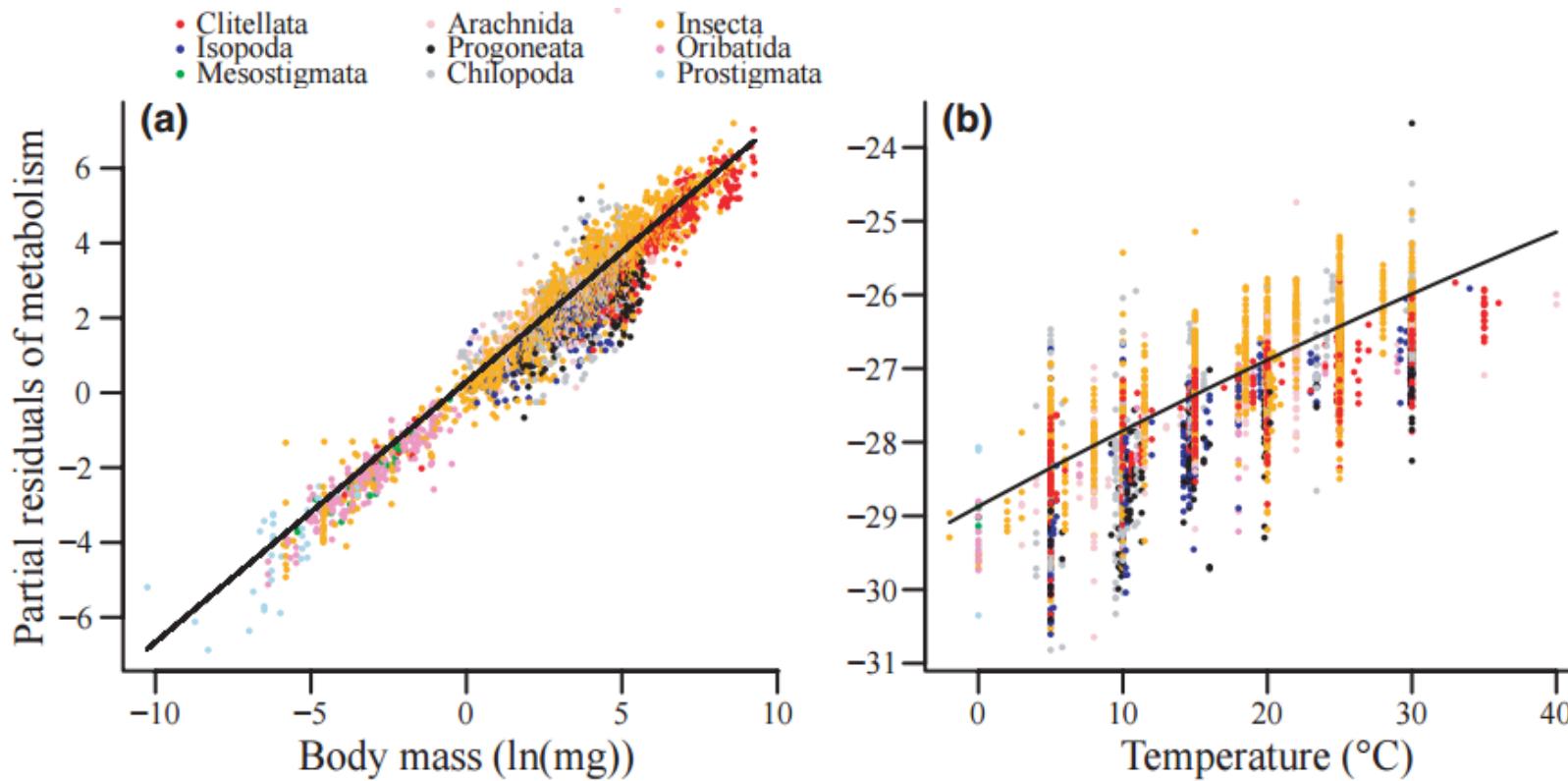
Intraspecific relationships between temperature and lifespan

Slopes between 0.2 and 1.2 (proposed activation energies) considered conforming to metabolic theory

Slopes within predicted range for $\sim 80\%$ of species

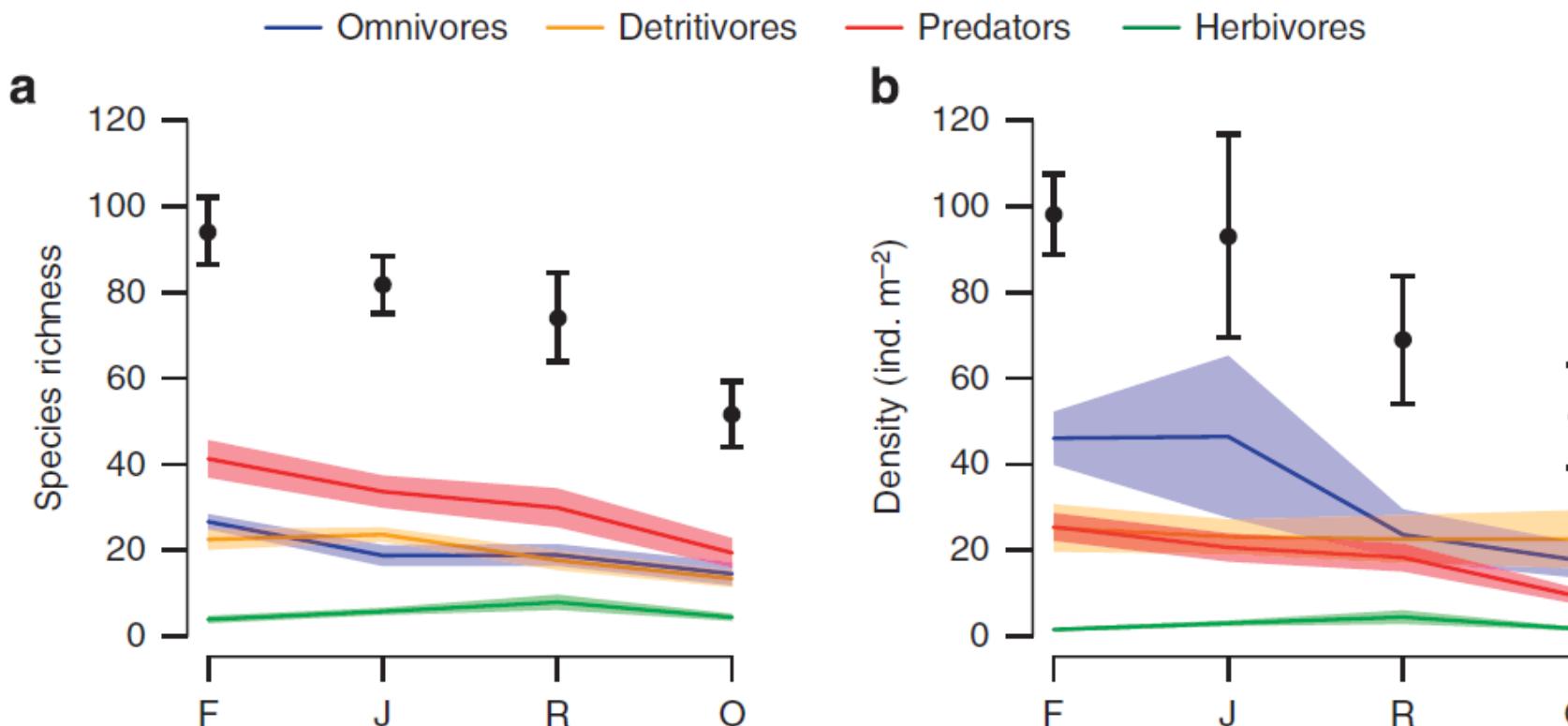
Likely effects of climate change on lifespan

Applications of metabolic theory: biodiversity and ecosystem functioning again



Metabolic rates of
invertebrate groups
as a function of
mass and
temperature

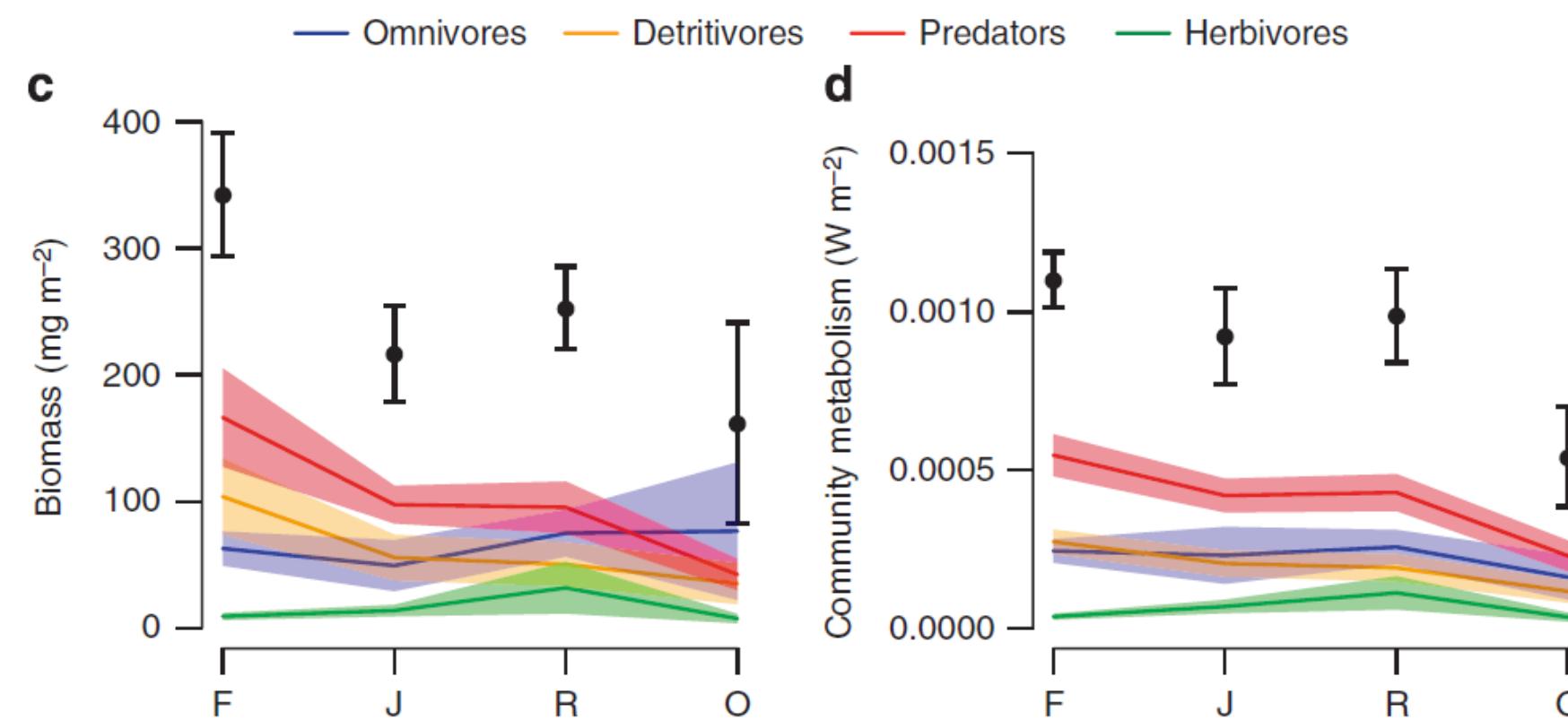
Applications of metabolic theory: biodiversity and ecosystem functioning again



F = Forest; J = Jungle rubber; R = Rubber plantation; O = Oil palm

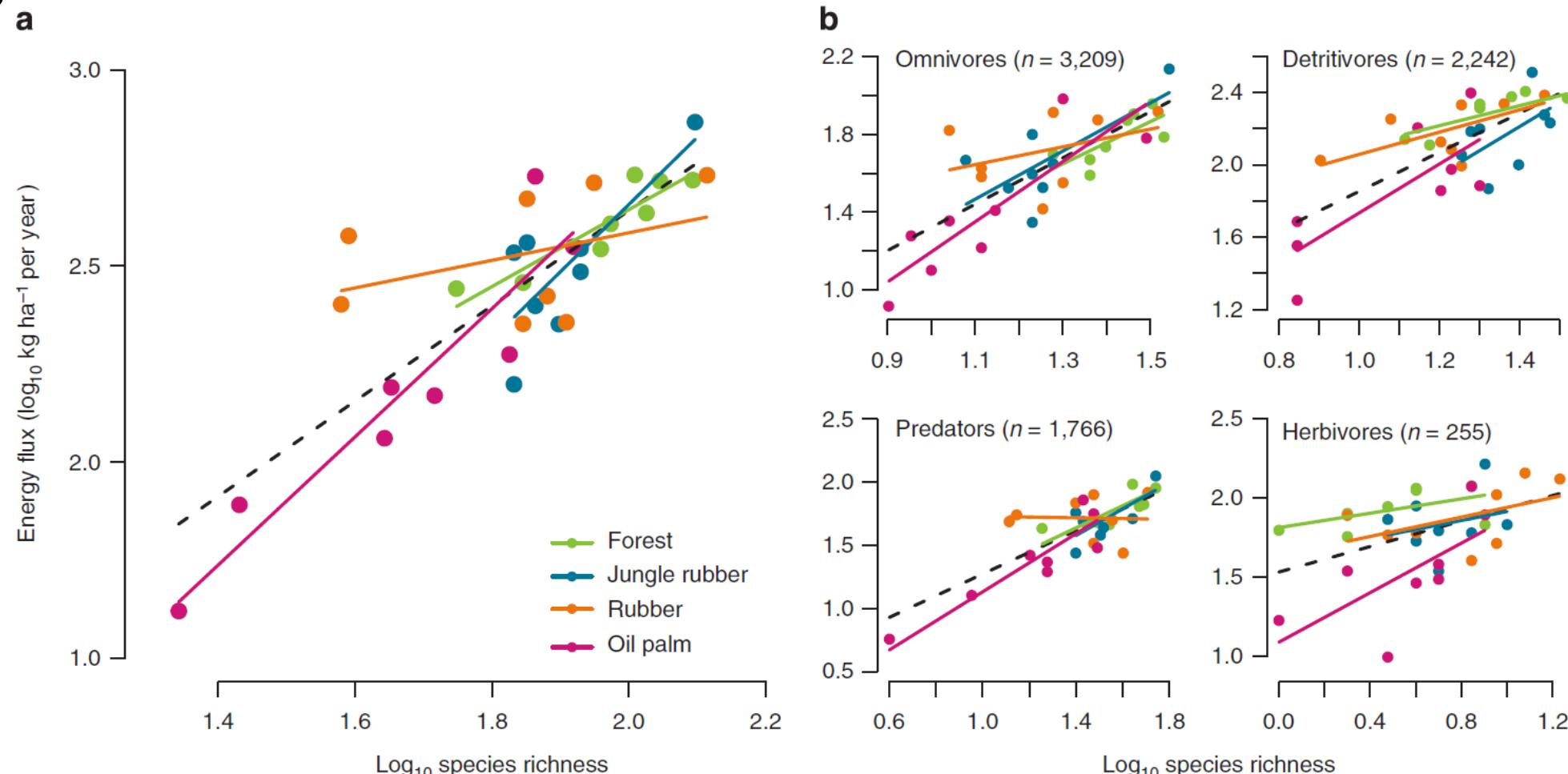
Remember from
last lecture,
study showing
impacts of land
use on
biodiversity at
different trophic
levels

Applications of metabolic theory: biodiversity and ecosystem functioning again

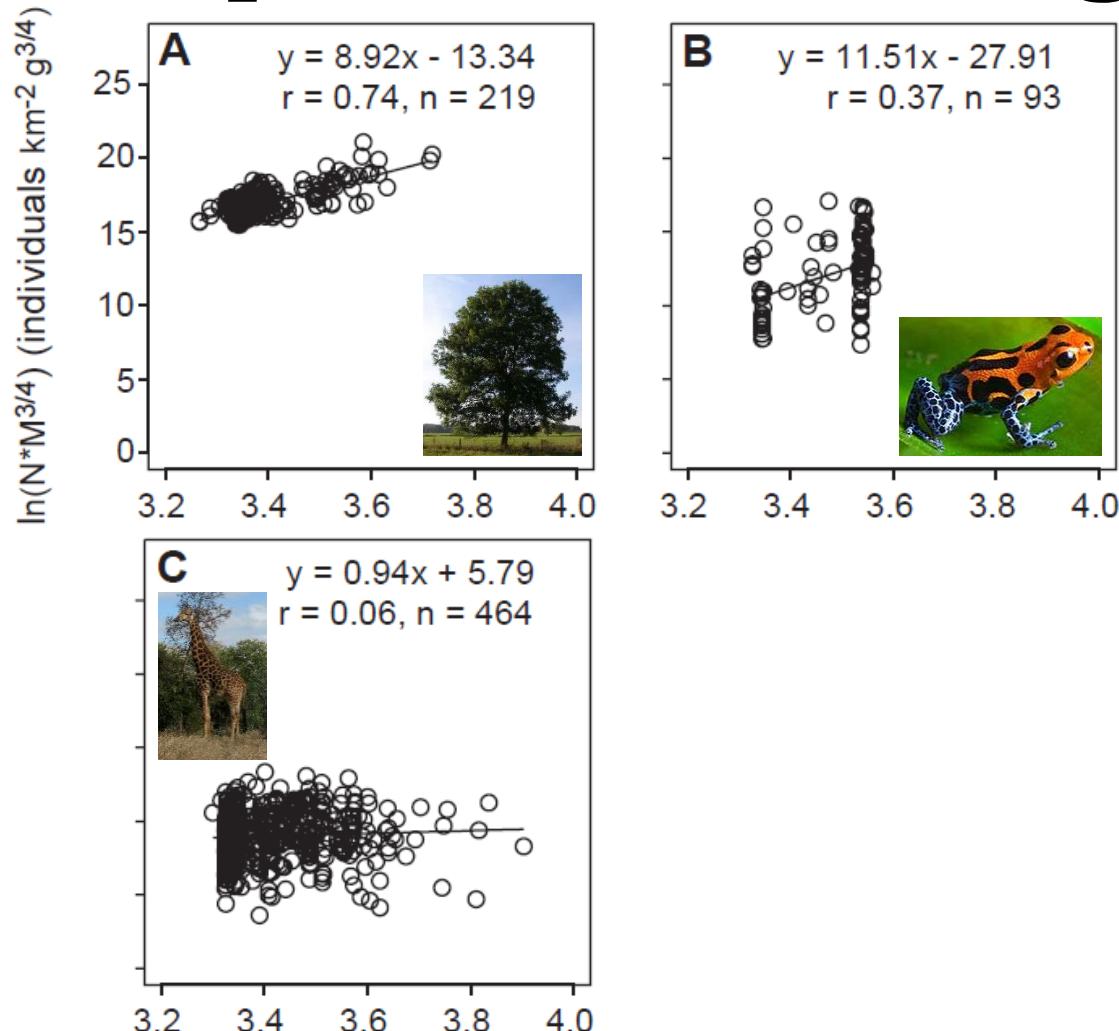


They also calculated impacts on biomass and metabolic rates

Applications of metabolic theory: biodiversity and ecosystem functioning again



Applications of metabolic theory: species richness gradients



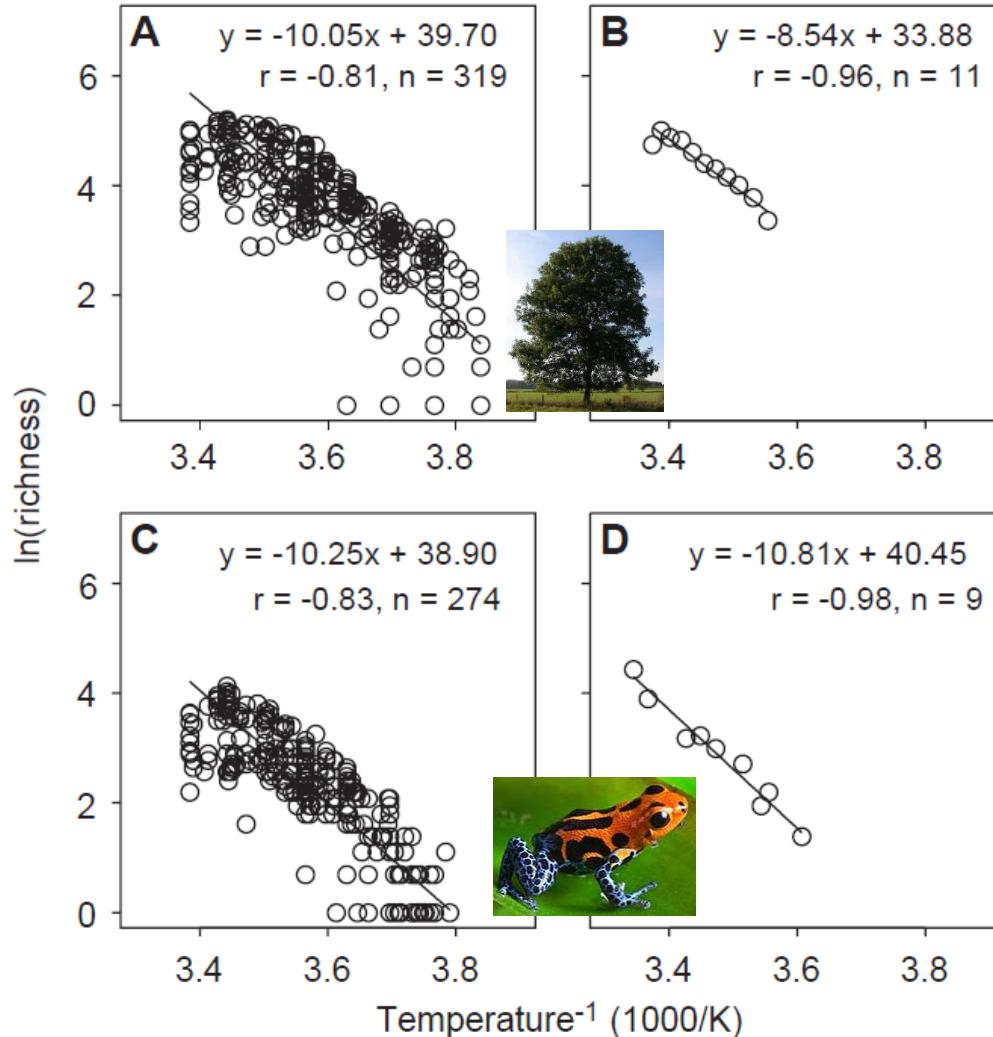
Energetic equivalence rule ('Damuth's rule') – total energy flux in a population (B_T) independent of body size:

$$\begin{aligned} B_T &= B_i N_i \propto M^0 : \\ B_i &\propto M^{3/4} \text{ and } N_i \propto M^{-3/4} \\ B_i &= b_0 M^{3/4} e^{-E/kT} \end{aligned}$$

$$\begin{aligned} \therefore \ln(N_i M^{3/4}) &= \frac{E}{1000k} \times \frac{1000}{T} + \ln \frac{B_T}{b_0} \\ &= 9.05 \times \frac{1000}{T} + \ln \frac{B_T}{b_0} \end{aligned}$$

B_i = individual metabolic rate, N_i = population density

Applications of metabolic theory: species richness gradients



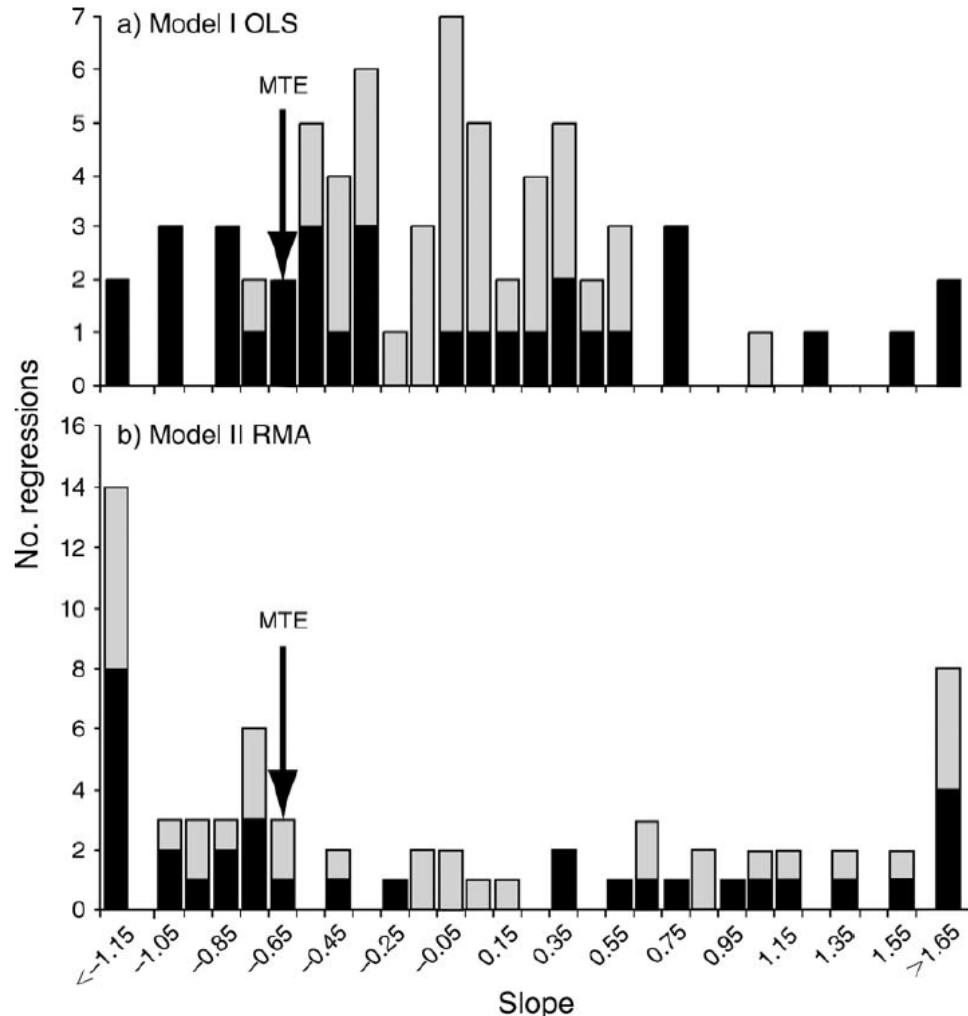
$$\bar{N} = \frac{N_T}{S}$$
$$\bar{B} = \bar{B}_0 e^{-E/kT}, \bar{B}_0 = b_0 \bar{M}^{3/4}$$

$$\bar{B}_T = \bar{N} \bar{B} = \frac{N_T}{S} \bar{B}_0 e^{-E/kT}$$

$$\therefore \ln(S) = \left(-\frac{E}{1000k} \times \frac{1000}{T} \right) +$$

$$\ln \left(\frac{\bar{B}_0}{\bar{B}_T} \times N_T \right)$$

Applications of metabolic theory: species richness gradients



46 datasets on broad-scale species richness

Very few conformed with predictions of metabolic theory

Summary: Simple theoretical models

Useful for revealing general principles underlying ecological processes

Can make predictions about general patterns expected under environmental change

Often simple, deterministic and rely on sometimes unsupported assumptions

Don't account for complex interacting effects of environment, other organisms in community etc.

Therefore, predictions might be inaccurate in specific contexts

Reading list (I am not expecting you to read all of these!)

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- Barnes et al. (2014). Consequences of tropical land use for multitrophic biodiversity and ecosystem functioning. *Nature Communications* **5**: 5351.
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Reading list (I am not expecting you to read all of these!)

- Fung et al. (2015). Impact of biodiversity loss on production in complex marine food webs mitigated by prey-release. *Nature Communications* **6**: 6657.
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- He & Hubbell (2011). Species-area relationships always overestimate extinction rates from habitat loss. *Nature* **473**: 368-371.
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Reading list (I am not expecting you to read all of these!)

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Reichenbach et al. (2007). Mobility promotes and jeopardizes biodiversity in rock-paper-scissors game. *Nature* **448**: 1046-1049.

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Tilman et al. (1994). Habitat destruction and the extinction debt. *Nature* **371**: 65-66.

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Wearn et al. (2012). Extinction debt and windows of conservation opportunity in the Brazilian Amazon. *Science* **337**: 228-232.

West et al. (1997). A general model for the origin of allometric scaling laws in biology. *Science* **276**: 122-126.

White & Seymour (2005). Allometric scaling of mammalian metabolism. *Journal of Experimental Biology* **208**: 1611-1619.