Introduction to Theoretical Ecology

What is theoretical ecology

Week 1 (Sept. 28, 2021)

Outline

1. What is an ecological model?

2. How are ecological models created?

3. How to use ecological models in your study?

4. What will we cover in this course?

5. Quick review on relevant math techniques

1. What is an ecological model?

- **What is an ecological theory?**

  An explanation of a phenomenon in the form of narratives that explain how a process works or why a pattern is observed, and have become scientifically useful when expressed in a logical structure

- **What are mathematical models?**

  Transforming the idea in narrative form into logical testable theory often involves the use of mathematics

  Equations that describe how different aspects of a system relate to one another; they are idealized and simplified versions of reality

1. What is an ecological model?

Math provides a clearer and more objective expression of relationships, it brings to light assumptions and logical errors that may be obscured in verbal hypotheses, and it places ideas and hypotheses concise form

Intermediate disturbance hypothesis: fluctuations prevent competitive exclusion

slow fluctuations

uneven favorable time

fast fluctuations

even favorable time
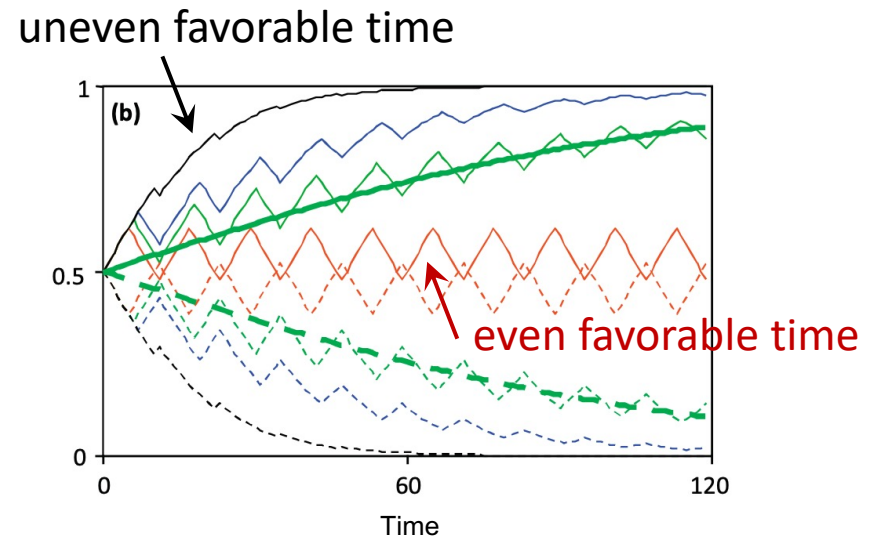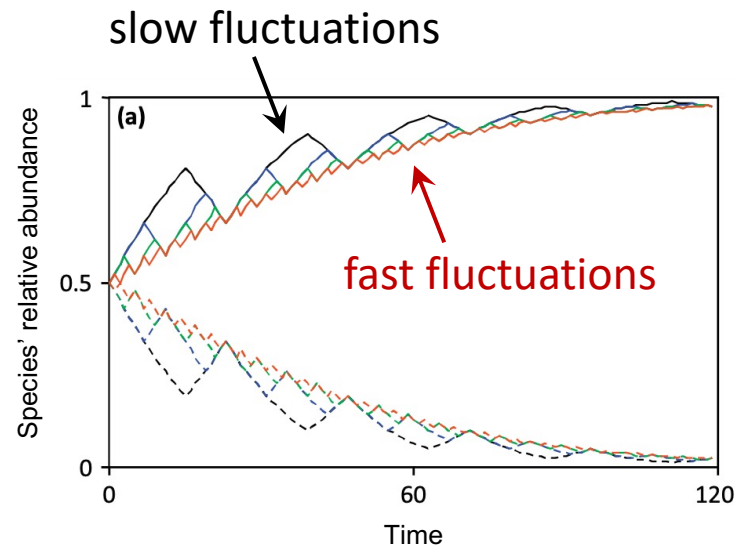
1. What is an ecological model?

- **Continuous feedback between empirical work and model**
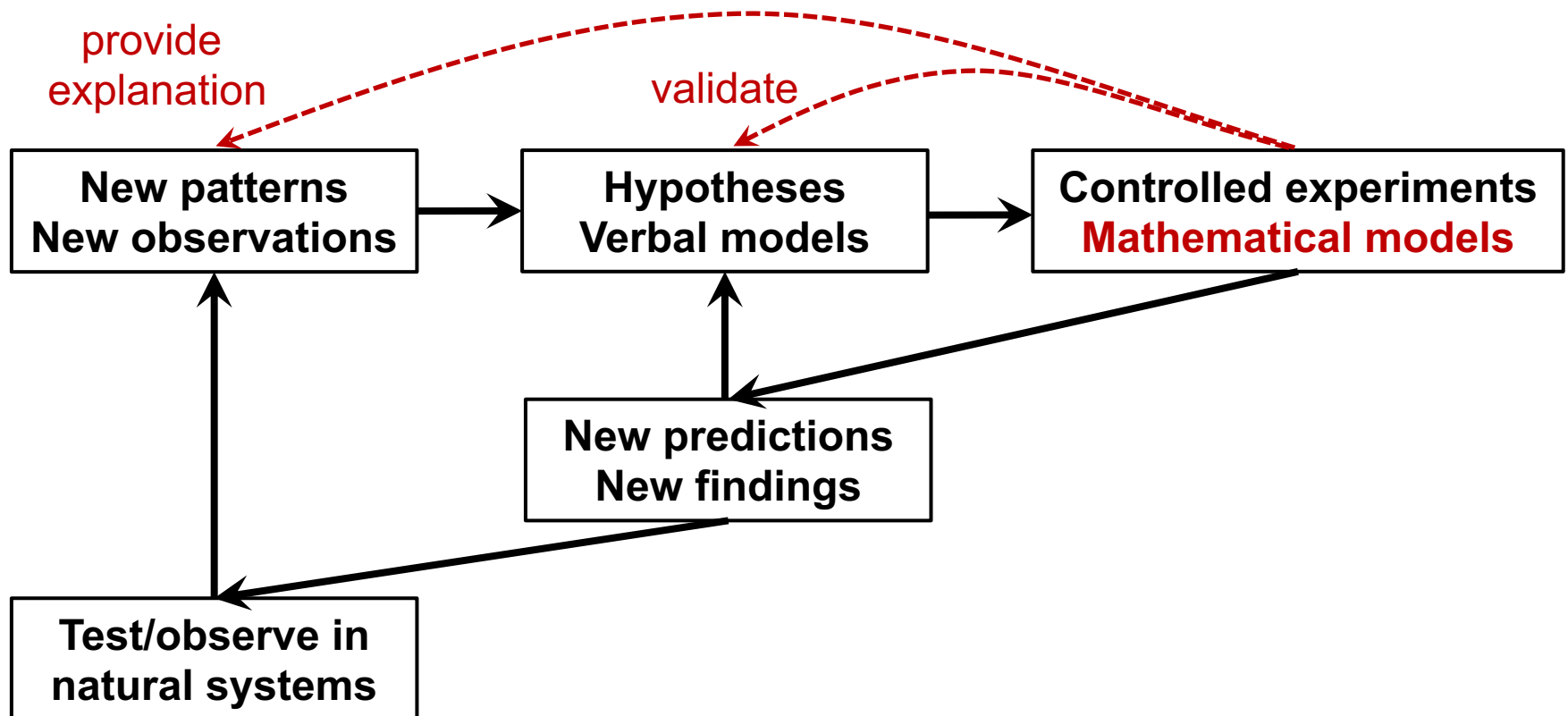
2. How are ecological models created?

- **Step 1: formulate the motivating question**

  Theoreticians think of a biological question that they are interested in or a process that they wish to understand. Similar to empirical research, it can be motivated by unsolved problem or new observations

  Example: How does the number of branches of a tree change over time?

2. How are ecological models created?

- **Step 2: Determine the basic ingredients**

  Think about what entities change over time (variables), what are the biological constraints of the variable, how to deal with the passage of time, what parameters are needed?

  Example: How does the number of branches of a tree change over time?
  Variable: number of branches, n(t), must be a positive number

Discrete time model
(recursion equations)

$$n(t+1) = \text{some function of } n(t)$$

Continuous time model
(differential equations)

$$\frac{dn(t)}{dt} = \text{some function of } n(t)$$
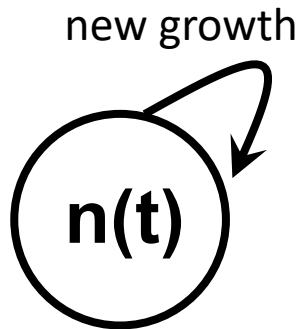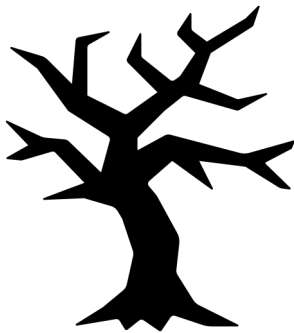
2. How are ecological models created?

- **Step 3: Qualitatively describe the biological system**

  Organize the model conceptually using diagrams or tables. This makes it easier to see whether the necessary variables/parameters are included

  Example: How does the number of branches of a tree change over time?
  Variable: number of branches, n(t), must be a positive number

new growth

n(t)

$n(t+1) = $ some function of $n(t)$
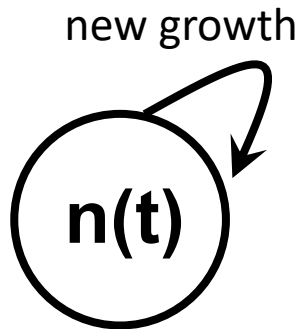
$$\frac{dn(t)}{dt} = \text{some function of } n(t)$$

2. How are ecological models created?

- **Step 4: Quantitatively describe the biological system**

  Derive the mathematical equations by tracking all of the factors that cause the variable to increase or decrease

  Example: How does the number of branches of a tree change over time?
  Variable: number of branches, n(t), must be a positive number

  B: proportion of branches that
  produced new branches (unitless)

  new growth

  n(t)

  $$n(t+1) = n(t) + Bn(t)$$

  $$\frac{dn(t)}{dt} = bn(t)$$

  b: per capita production rate
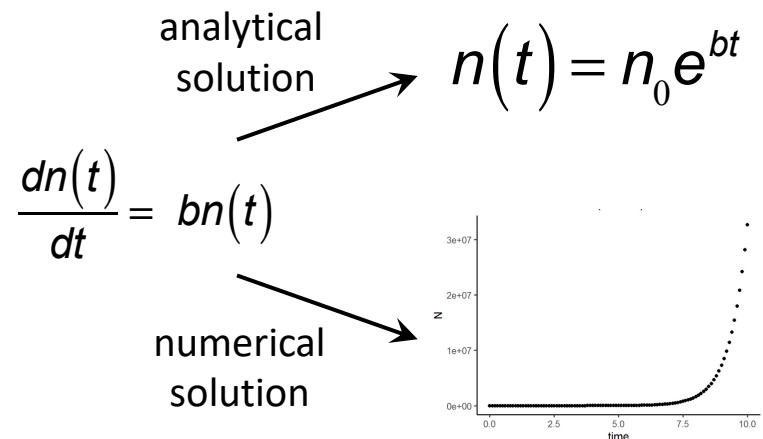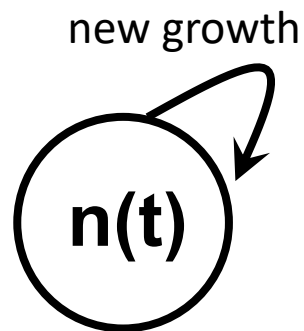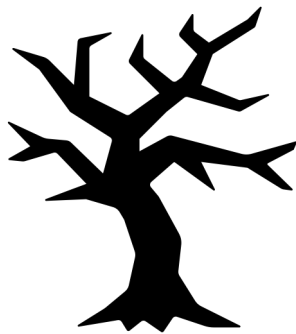 of new branches (1/time)

- **Step 5: Analyze the model**

  Analytically: graphical analysis, stability analysis, deriving general solutions

  Numerically: simulations

 **Example:** How does the number of branches of a tree change over time?
  Variable: number of branches, n(t), must be a positive number

new growth

n(t)

$$\frac{dn(t)}{dt} = bn(t)$$

analytical
solution

$$n(t) = n_0 e^{bt}$$

numerical
solution

3. How to use ecological models in your study?

- **Approach 1: adopt the framework**

  Some theory offer a new way of thinking about a problem or a unification of related ideas. They reorient how we study a biological process and can help focus empirical research on a specific process or relationship
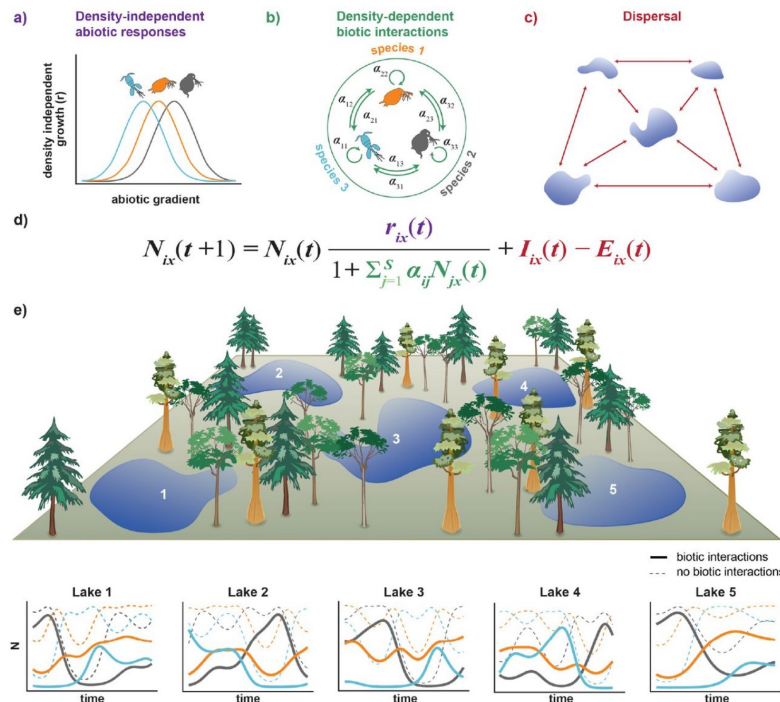
Metacommunity theory
The combined role of local and regional process

Thompson et al. (2020) Ecol. Lett.

3. How to use ecological models in your study?

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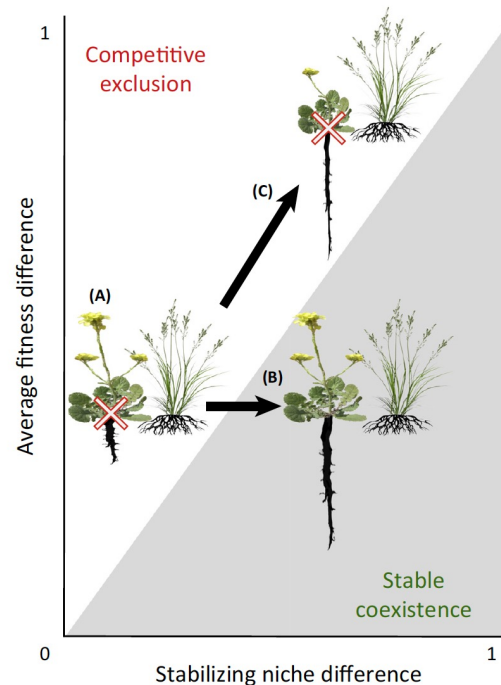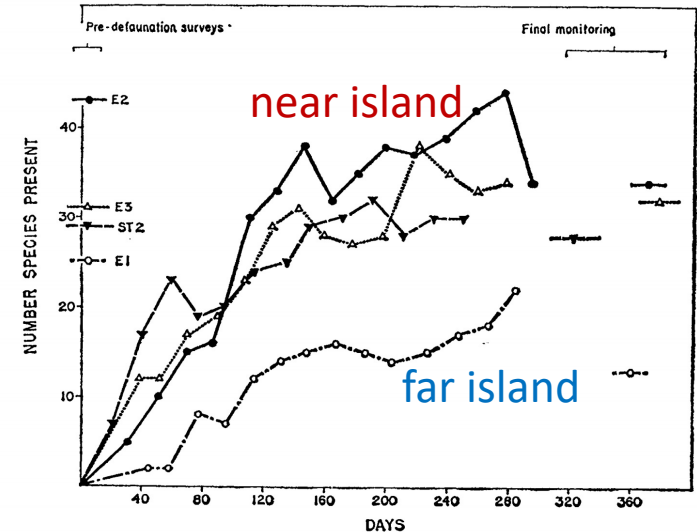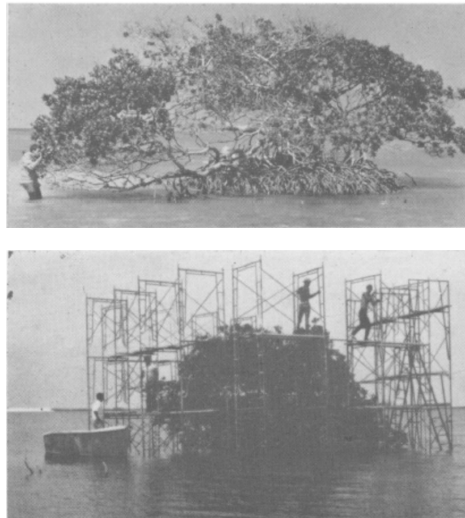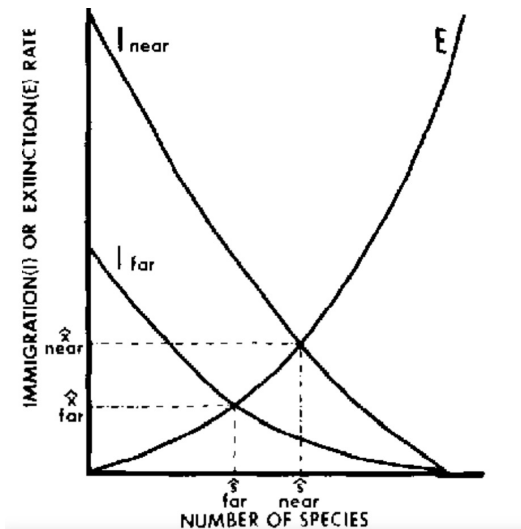

Modern coexistence theory
Species differences can both help and hinder coexistence

3. How to use ecological models in your study?

- **Approach 2: test the predictions**

  Theoretical work often generates specific predictions, and one way to use theory is to test whether a theoretically-predicted pattern matches a pattern that manifests in a natural or experimental system

  The theory of island biogeography: far islands equilibrate with lower species

MacArthur & Wilson (1967); Wilson & Simberloff (1969) Ecology

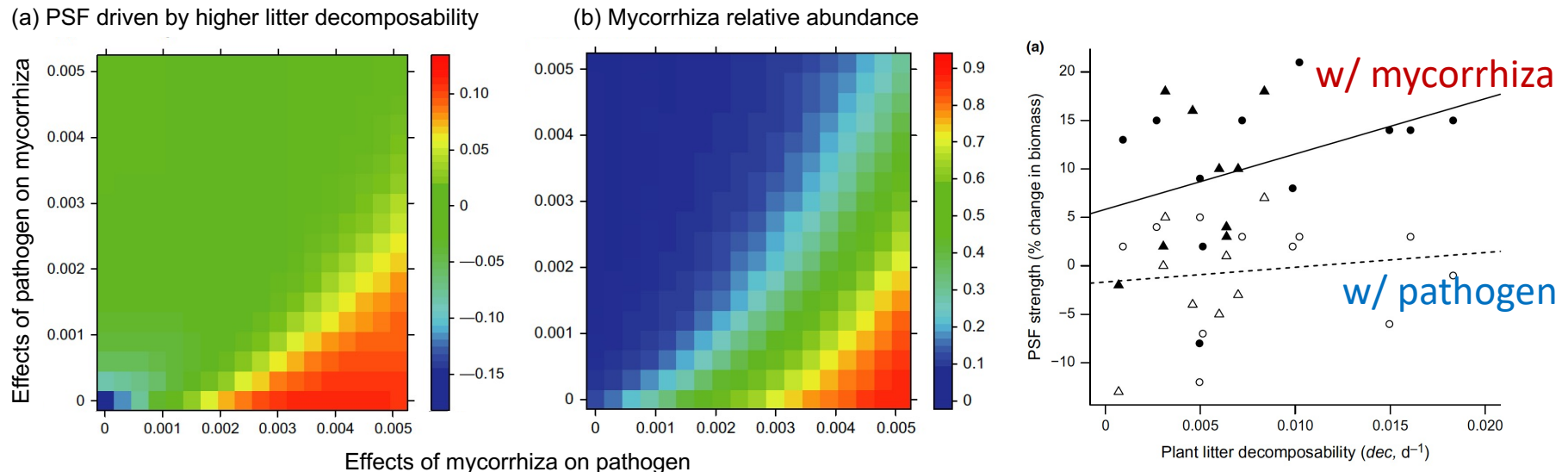# 3. How to use ecological models in your study?

- **Approach 2: test the predictions**

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  Trait-based plant-soil feedback model: litter is important in mycorrhiza-dominant soil

Ke et al. (2015) New Phyt

- **Approach 3: use the equations (for model fitting)**

  Some theory provide empiricist a specific equation that can be used to obtain a quantitative estimate of a biological process that is difficult or impossible to measure directly

  Holling's disc equation: type II functional response for feeding rate

attack rate

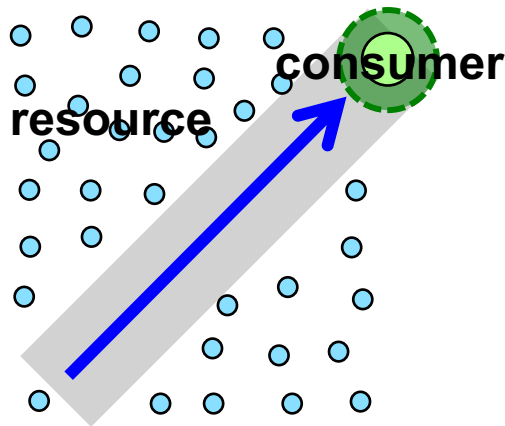$$y = \frac{aR}{1+ahR}$$

handling time

3. How to use ecological models in your study?

- **Approach 3: use the equations (for proxy calculation)**

  Some theory provide empiricist a specific equation that can be used to obtain a quantitative estimate of a biological process that is difficult or impossible to measure directly
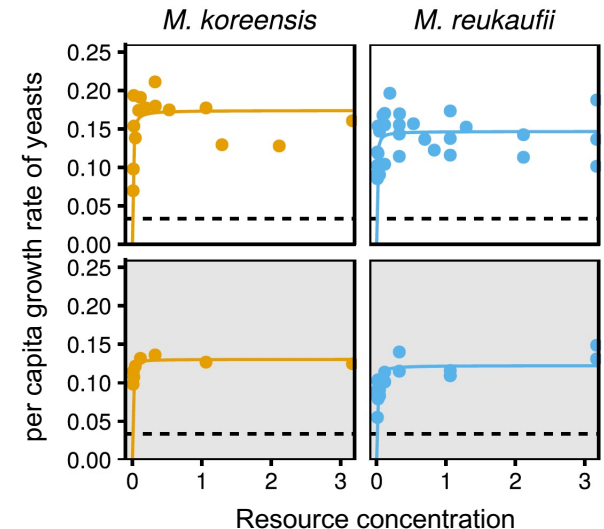
  SIR models for epidemiology: R_0 for disease spread

$$\frac{dS}{dt} = -\beta SI$$

$$\frac{dI}{dt} = \beta SI - \gamma I$$

$$\frac{dR}{dt} = \gamma I$$

$$R_0 = \frac{\beta}{\gamma}$$

Luz et al. (2010) PLOS Neglect Trop D
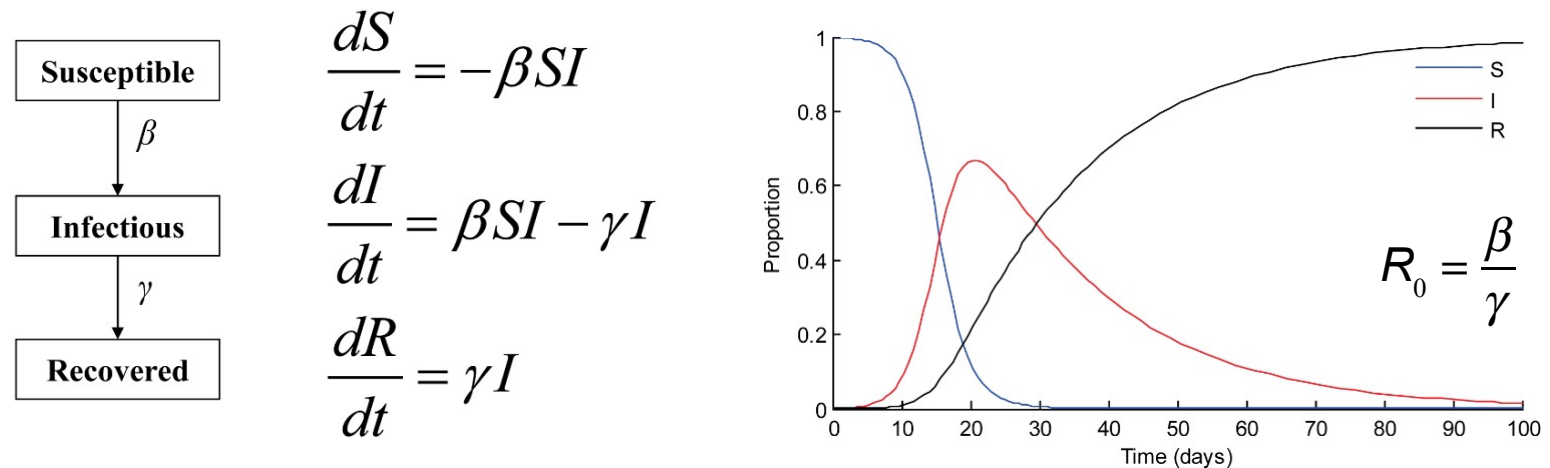
3. How to use ecological models in your study?

- **Approach 4: test model assumptions**

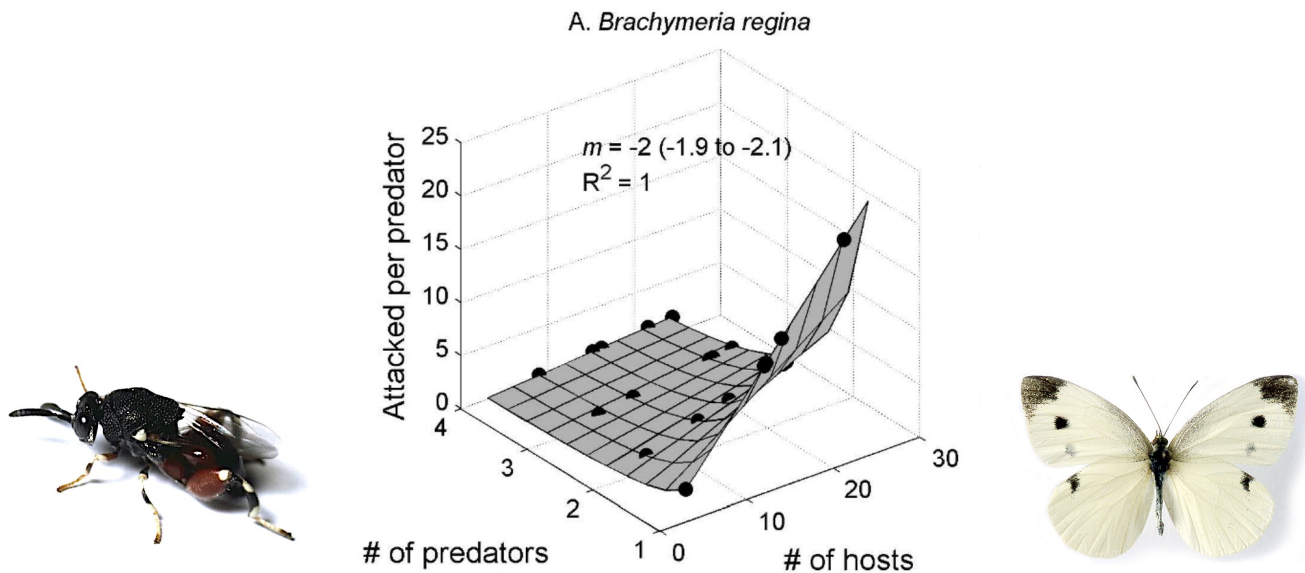 Some assumptions that theoretical studies are based on may not yet be well-supported by empirical work. Empirical studies that test model assumptions can feed back to inform subsequent theoretical work

  Predator-dependency in funcitonal responses

A. *Brachymeria regina*

$m = -2$ (-1.9 to -2.1)
$R^2 = 1$

3. How to use ecological models in your study?

- **A study can apply all at the same time, each at different stages**

Grainger et al (2021) Am Nat; Narwani et al (2013) Ecol Lett
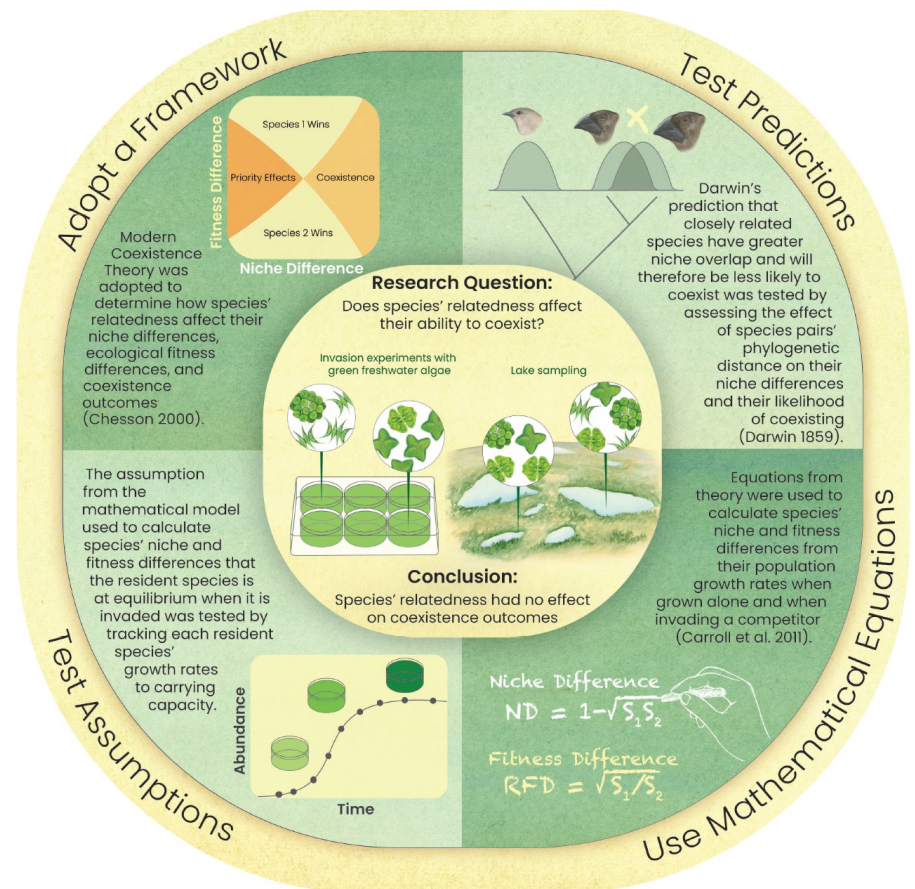
4. What will we cover in this course?

- **Course will focus on:**

  Classic models in population and community ecology

  Analytical (pen-and-paper) and numerical (R) analyses of models

Date	Lecture topic
Week 1 (28-Sept-2021)	Introduction: what is theoretical ecology?
Week 2 (05-Oct-2021)	Exponential and geometric population growth
Week 3 (12-Oct-2021)	Age-structured population models
Week 4 (19-Oct-2021)	Density-dependence and logistic population growth
Week 5 (26-Oct-2021)	Stability analysis of single population dynamics
Week 6 (02-Nov-2021)	Metapopulations and patch occupancy models
Week 7 (09-Nov-2021)	Lotka-Volterra model of competition: graphical analysis
Week 8 (16-Nov-2021)	Lotka-Volterra model of competition: linear stability analysis
Week 9 (23-Nov-2021)	Midterm exam
Week 10 (30-Nov-2021)	Predator-prey interactions
Week 11 (07-Dec-2021)	Mutualisms
Week 12 (14-Dec-2021)	Multispecies models of competition
Week 13 (21-Dec-2021)	Multispecies models of predation
Week 14 (28-Dec-2021)	Disease dynamics and SIR models
Week 15 (04-Jan-2022)	Ecosystem models and feedbacks
Week 16 (11-Jan-2022)	Final exam

single-species population-level (Weeks 2–6)

multi-species community-level (Weeks 7–15)

4. What will we cover in this course?

- **Logistics:**

    Tuesday 1:20pm – 4:20pm @ Life science 3C

    Two hour lecture (blackboard) + one hour practice (laptop)

    Website
    https://genchanghsu.github.io/2021_Fall_Introduction_to_Theoretical_Ecology/

    Assignment submission via NTU Cool https://cool.ntu.edu.tw/courses/9312

    Contact us to schedule office hour

    Po-Ju Ke (pojuke@ntu.edu.tw); Gen-Chang Hsu (b04b01065@ntu.edu.tw)

    First three weeks will be online (lecture: Google meet; lab: Gather town)

    Google meet https://meet.google.com/nzd-cdjp-kbt

    Gather town https://gather.town/app/osrqFSf0a7q0I6uo/TheoreticalEcology

4. What will we cover in this course?

- **Grading:**

  Assignments (60%), midterm (15%), final (15%), participation (10%)

- **Textbooks:**

  1. Case (2000) *An illustrated guide to theoretical ecology*

  2. Gotelli (2008) *A primer of ecology 4th edition*

  3. Pastor (2011) *Mathematical ecology of populations and ecosystems*

  4. Otto & Day (2011) *A biologist's guide to mathematical modeling in ecology and evolution*

- **By the end of this course I hope you will:**

  Be familiar with the basic building blocks of ecological models

  Have the ability to analyze and formulate simple models

5. Quick review on relevant math techniques