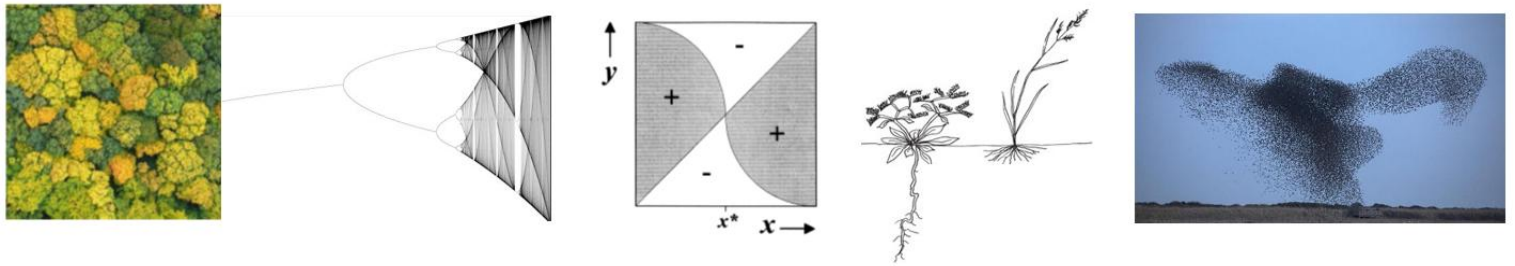
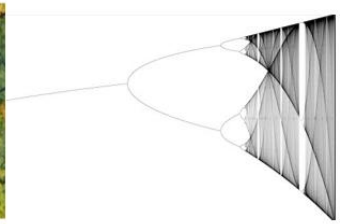
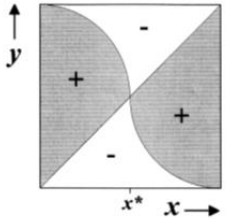
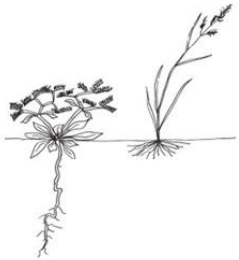



# Ecological Theory for Everyone! A practical introduction to engaging with theory in your own research for those with little or no theoretical experience

Caroline Farrior[1], Robin Decker[2], Sun Yi Soh[1], Ravi Ranjan[1*], and Xinyi Yan[1*]
[1]University of Texas at Austin
[2]University of California, Davis
[*]Not here in person




# Ecological Theory for Everyone!
# A practical introduction to engaging with theory in your own research for those with little or no theoretical experience

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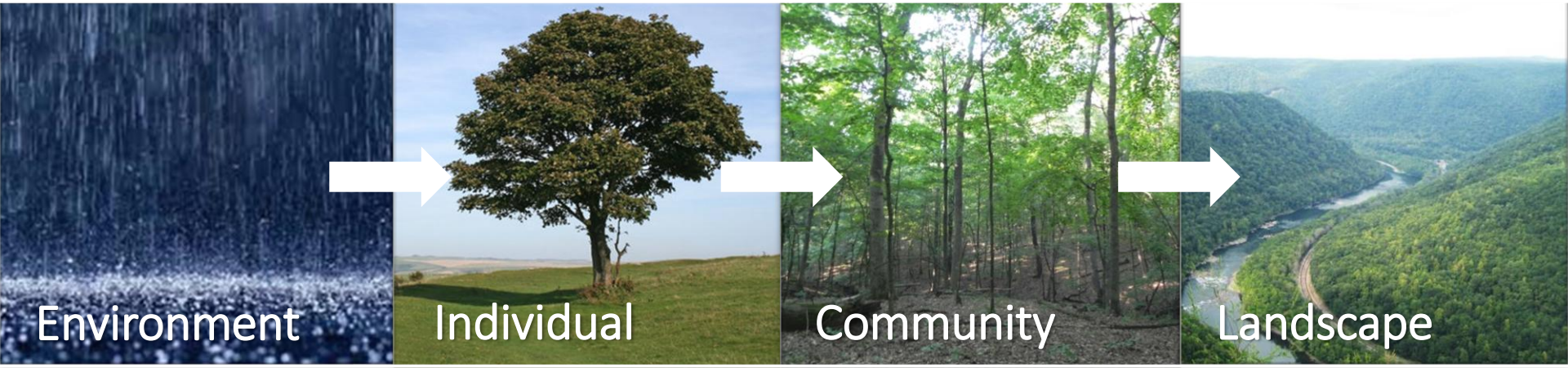
Welcome In!

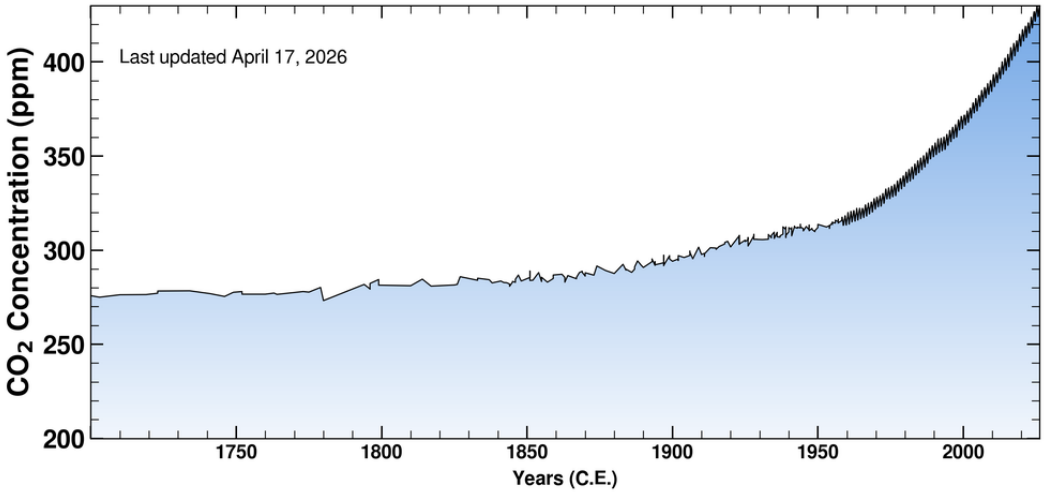
Please introduce yourself to others at your table.

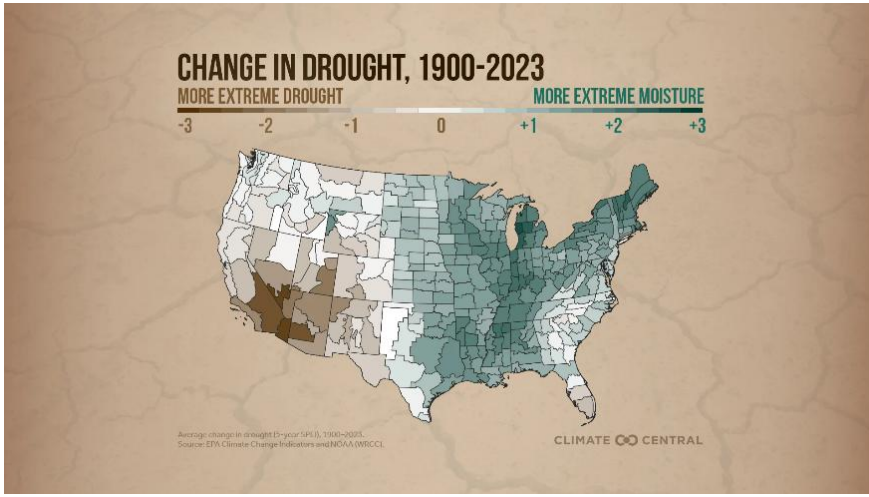
Describe your interest in or experience with theory.

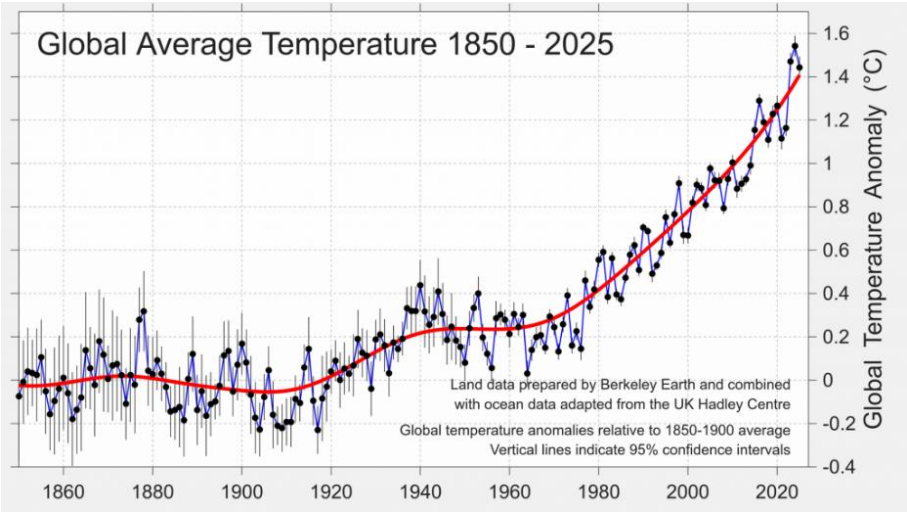

Environment
Individual
Community
Landscape


What is an ecosystem, anyway? North Carolina Wildlife Federation. https://ncwf.org/blog/ecosystem/

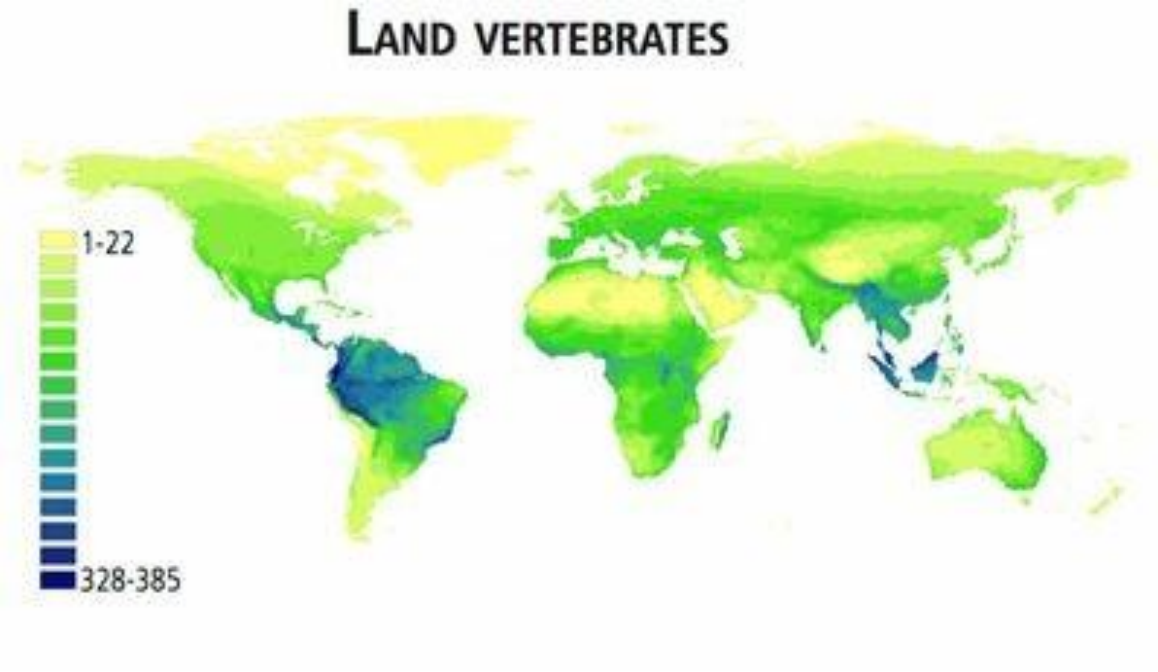
# On top of all of ecology's natural complexity, The environment is changing



# And the *species* are changing



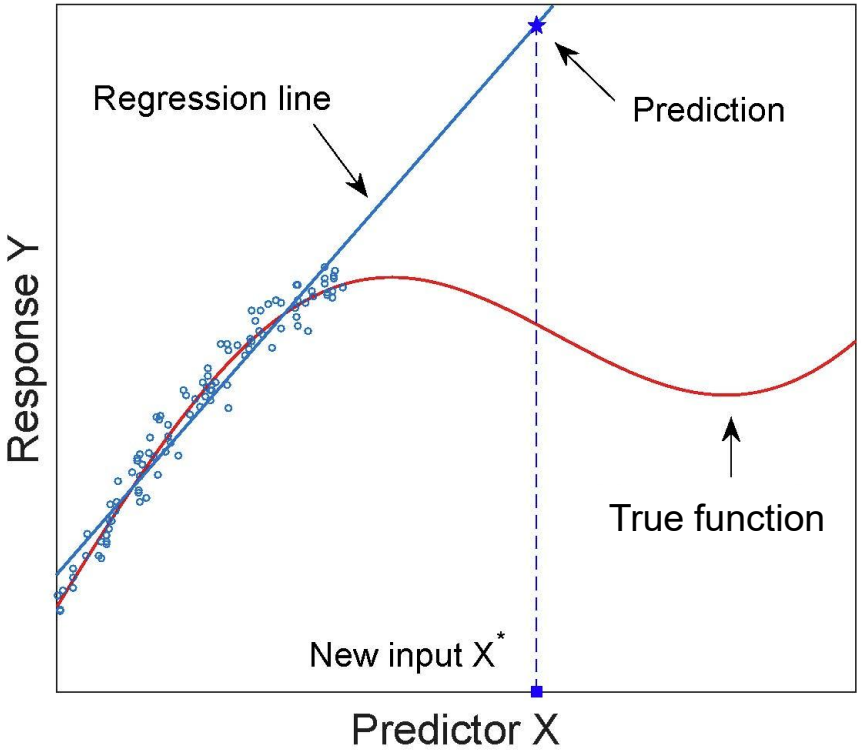

Decreases in species richness of 10,000km$^2$ quadrats

Ceballos, G., Ehrlich, P.R. and Dirzo, R., 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *Proceedings of the national academy of sciences*, *114*(30), pp.E6089-E6096.

We are pushing ecosystems outside of the realm of our observations.

Because these are complex systems, to predict and/or manage ecosystems, we likely cannot merely extrapolate our current ecology.

*We must build understanding of the mechanisms that govern ecosystems.*



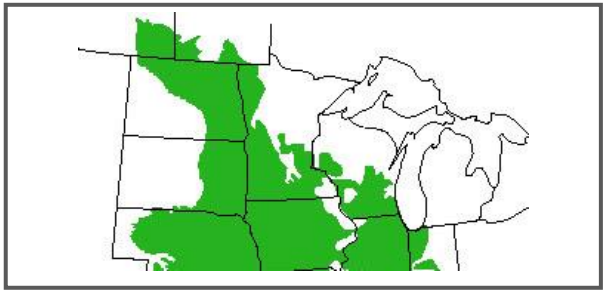
# How do we build mechanistic understanding?

Experiments

- Allow you to prove the effect of a treatment
- Downsides:
  - Not valid in other contexts
  - Often not feasible

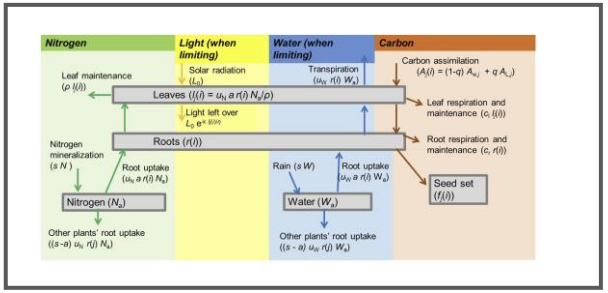
Observations

- Real patterns
- Downsides:
  - Multiple mechanisms interacting, hard to build understanding
  - May not be relevant in novel future circumstances



Theory

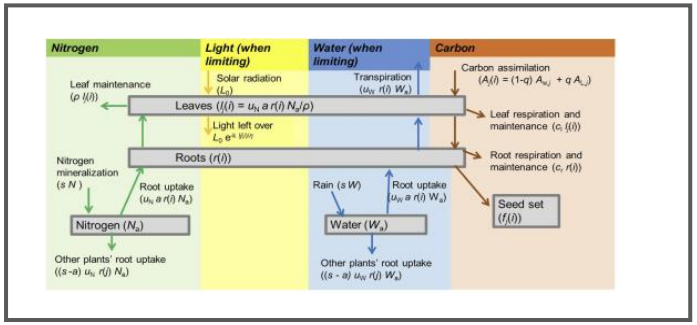
- Allows you to explore implications of particular mechanisms, hypotheses
- Downsides:
  - If assumptions are wrong, may not be relevant at all
  - Alone, does cannot prove anything

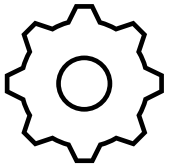


# The best path to predictive understanding may be to integrate these methods

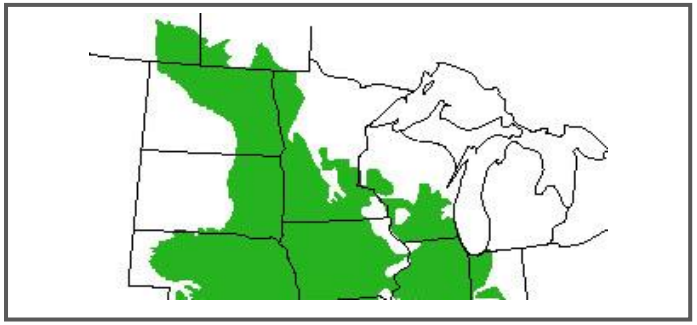
Experiments


Theory



Observations



# But we can’t all do everything at once!

We must work together to make progress along these different fronts.

As theoreticians, we want to better communicate our findings.

And as educators, we want to give empiricists the tools to engage with theory efficiently and effectively.

# Outline
# Ecological theory for everyone

- What is theory?

  and What is theory good (and not good) for?

- How to read theory effectively and efficiently.
  - Exercises
  - Time to address specific experiences, frustrations

- Brainstorming some theoretical questions related to your own research

- Other tips and tricks for going deeper into understanding specific theories, developing your own

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# Let’s take a step back.

- We all do theory before doing any “real” science!
  - We have detailed hypotheses for our experiments or observations.
  - We think about how our findings will inform us about the way the system works.
  - We find questions that have useful and interesting alternate hypotheses.

- What makes something “Theory”?
  - Sometimes ecology is complex enough that a bit of math or simulations can help us to refine hypotheses.
  - And that work can be substantial enough to be shared formally.

Photo from: https://columns.wlu.edu/a-model-of-possibility/. Students work on an ecological model.

# Why theory?

- We use theory (math and/or simulations to work through the effects of mechanisms) when a hypothesis is too complex to think or to communicate with words alone.

- We use theory when:
  - we want to know the larger scale outcome of smaller scale processes.
  - we want to figure out which mechanism is likely to produce a pattern

# What is theory?
## Take-home points

- Theory is hypothesis-forwarding.
- Theory alone cannot prove anything about the natural world.
- We all do some theory when we plan a project and think about hypotheses or interpret our results.
- People do “Theory” for research when there are ideas that are too complex to think through in your head alone.
  - Mathematical formulations, analysis, and computer simulations are used to work out the ideas.

# Breakout exercise 1, Theoretical questions

- We have given you about 30 questions.
- Work with your group to make your best guess to sort the questions into:

**Empirical:** Best answered with experiments or observations

or

**Theoretical**: Best answered with theory (math or simulations)

# Theoretical questions exercise, debrief

- Which questions were most difficult to sort?

- Did you notice any patterns while sorting questions? What patterns occur in theory versus empirical questions?

**Empirical:** Best answered with experiments or observations

or

**Theoretical**: Best answered with theory (math or simulations)

# What about these questions?

- What determines the number of species that can coexist?
- How vulnerable are ecosystems to species loss?
- What limits species ranges?

These big, general, ecological questions can only be answered empirically because they ask about what is (not what *could be* or what *is likely*).

These thought-provoking, big questions are more tools than real research questions. They are not likely to have a single answer.

These questions motivate theory and often help us to make real progress through theory/data integrations.

> … but as theoreticians, we should be clear that we cannot answer these questions with theory alone.

# What is theory good (and not good) for
## Take-home messages

- True theoretical questions:
  - Have words like: could, can, may, might
  - Address the underlying mechanisms

- Empirical questions:
  - Demand definitive answers about real species and environments (not just about theoretical concepts)

- For the biggest questions, an integration of theory and empirical research is often necessary to attempt any answer.

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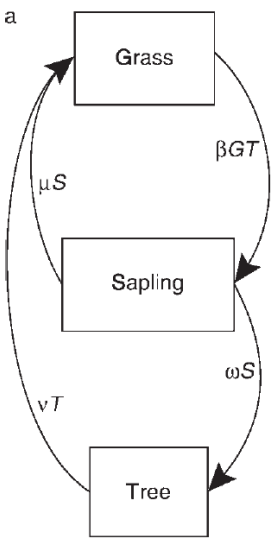
# How do we answer theoretical questions?

By building and analyzing a model.




A model: (methods)

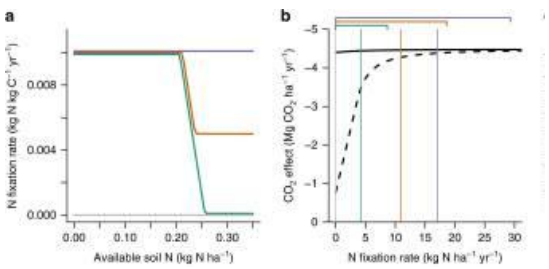
Is a set of assumptions

Simplifications of the real world

- simple enough for the model to work and generate insights
- complex enough to have the mechanisms you care about

Analysis: (results)

- Logical result of those assumptions (as arrived at through math or simulations)




Examples from: Staver et al. 2011 and Kou-Giesbrecht and Menge 2019

# To read theory efficiently, Get to the Insights!

- Insight is the goal of theory.

- But, when taking insights from theory, it's important not to go overboard.
  - There is no *magic* in theory.

- Any result of a model is, must be, and can only be due to the model assumptions.
- To get to the insights, connect the model's results with the model's key assumptions.

- A common insight:

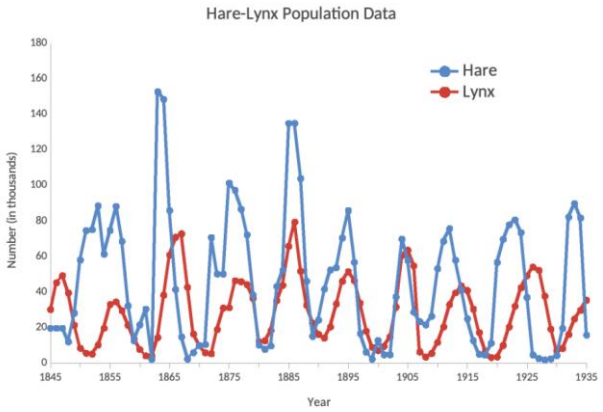
  This result can come from this mechanism (that is in the model) and not necessarily from this other mechanism (that is not in the model).

# Reading theory efficiently

Get to the insights!
How do the assumptions generate the results?

Example: Lotka-Volterra Predator Prey

# Example of theory
# *Lotka-Volterra Predator-Prey Model*




Question: What is a likely cause of cycling in predator/prey population dynamics?

Model: One species eats another (contributing to births in one species and deaths in the other whenever the species interact) and otherwise grow/decline exponentially.

Result: For certain parameter values, the predators and prey experience sustained cycles (not getting bigger or smaller)

<u>Why do predator and prey populations cycle in this model?</u>

Because predators chase prey hard when they are abundant, leading to their decrease.

Prey have limited hiding places and can grow more easily when there are few individuals.

Insight: Predator and prey populations cycle in this model because predators rely on prey for their growth and prey are limited by predators.

# How to efficiently engage with theoretical work?

1. Identify the overarching research questions.
2. Try to identify the specific theoretical question addressed by this paper.
3. Identify key assumptions (simplifications) and key mechanisms included in the model.
4. Find the major insights that the authors draw.
5. Identify the points of connection to the real world.

   From abstract motivation all the way to quantitative comparisons.

6. Do you buy it?

   Are there simplifications that get in the way of the relevance for you.

# Breakout exercise 2 – Reading theory

# Breakout exercise 2 – Reading theory

We have translated a few theoretical studies into digestible summaries. In groups, pick one of the studies to read together.

- While reading, identify:
  1. The research question
  2. General approach
  3. Assumptions and analysis approach
  4. Main results
  5. Do you buy it? How would you make it more applicable to your study system?
- Discuss the guiding questions to check if you are thinking critically.

If time permits, do a second one!

# Breakout exercise 2 – Reading theory

Topics of studies chosen:

1. Mutualism, population cycles, cross-feeding microbes
2. Coexistence, resource competition, predation
3. Intraguild predation, productivity
4. Group movement behavior, decision making

While reading, identify:

1. The research question
2. General approach
3. Assumptions and analysis approach
4. Main results
5. Do you buy it? How would you make it more applicable to your study system?

Discuss the guiding questions to check if you are thinking critically.

# Breakout exercise 2 – Reading theory
**Debrief**

- What was easy?
- What was challenging?
- How was reading these similar or different from reading real theory?
  - Additional challenges with real theory?

## Note!

Some of these challenges are, of course, due to theoreticians having trouble writing clear theory.

We are trying to be better! (Shoemaker et al. 2021, Ou Germain et al. 2022)

# What about the math in middle?

- Words are imperfect. Getting into the math can lead to a deeper understanding.

- The math in the middle is the proof that the insight comes from those assumptions.
- …It can take a lot of time to get from the assumptions to the results.

- Depending on your level of interest, you can:
  1. Trust the authors and the reviews that the math is correct
  2. Ask a theoretician friend if they have problems with the paper
  3. Watch for critical papers or discussions
  4. Dive in yourself! See some tips and tricks at the end.

# Reading theory efficiently and critically
# Take-home message

When reading real theory papers,
stay on track to get to the insights

1. Identify the overarching research questions.
2. Try to identify the theoretical question addressed by this paper.
3. Identify key assumptions (simplifications) and key mechanisms included in the model.
4. Find the major insights that the authors draw.
5. Identify the points of connection to the real world.
   From abstract motivation all the way to quantitative comparisons.
6. Do you buy it?
   Identify insights that are important to you.
   Do the simplifications get in the way of this relevance?

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# Exercise 3 – Theory in your own research

Starting with some solo work

Take a piece of paper and use it to help you think through any theoretical research questions in your own research.

- Write down your big research question of interest.
- Try to find a component of this that is good for theoretical research.
  - Think about the situations you have been in where you talk yourself (or a colleague) in circles with predictions.

Next: share in small groups and give one another feedback

# Exercise 3 – Theory in your own research
# Debrief

We hope you came up with something interesting that has helped you to think about your research in a new way.

Ideas might occur to you in the next few days.

You will have another chance to share and get feedback on your ideas in a follow-up survey.

But, please feel free to reach out to us at other times as well.

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- **Other tips and tricks for going deeper into understanding specific theories or developing your own**

# A few handy bits about approaching the math in a theory paper

- Look for the state variables!
  - Focal quantities that the model is tracking.
  - Things that are influenced by the interactions with one another and the environment. These are the things that are the key interacting pieces and likely key to the core research question of the theory.

- The **math** of ecological theory is usually not that hard.

  dx/dt = ….  - these equations do not *really* mean we need calculus.

  They are just describing how state variables change depending on one another. Usually, we are just interested in the inevitable endpoint of a set of processes (dx/dt = 0), and then we do some **algebra**.

- A lot of the most relevant theory for empiricists today is in simulations.

  There may be some initial math, but usually, to get to the more realistic pieces, people have to do simulations.
  And these simulations can be understood easily by seeing step by step how things interact. *These might be written out clearly in an appendix.*

# Little simulations can be easy and help

To understand a concept or process in a model, you can often write yourself a little **for loop** in R to demonstrate it.

With some knowledge of a few other basic functions (saving data, plotting), you can get pretty far.

Turning a differential equation into a simulation:

```
x = 1
for(t in seq(1,100,by=deltaT)){
        dx.dt = something  #whatever process you want. Constant reproduction
                (dx.dt = r*x); Logistic growth (dx.dt = r*x(1-x/K))
        x = x + dx.dt * deltaT  #This line is carrying out the meaning of dx.dt.
                Don't change this part
}
```

Trying this once can give you a lot of intuition for how things work. And the ability to quickly check understanding.

Tutorials to come on our workshop website

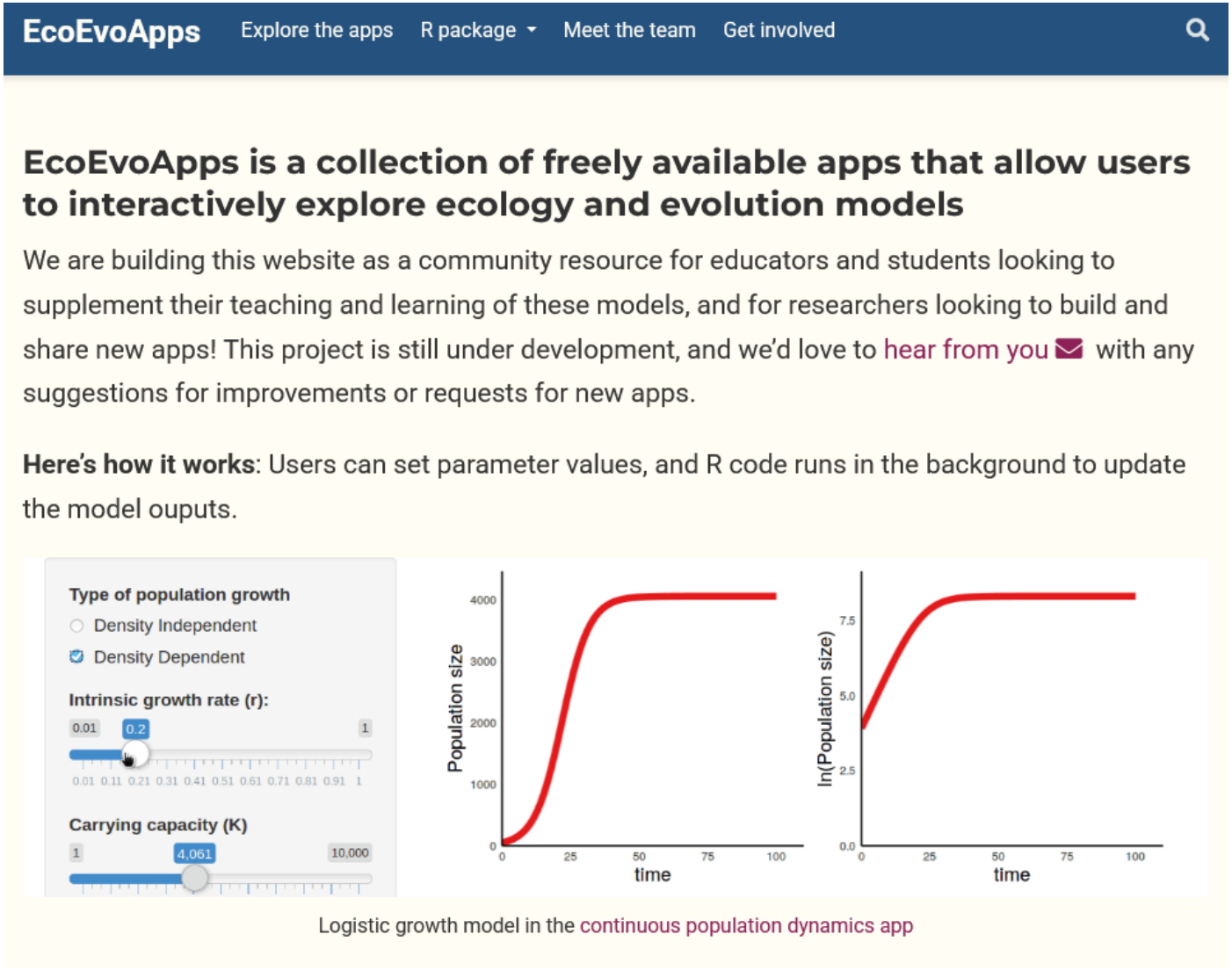
# Internalize the definitions of a few key terms

- State variables versus Parameters
- Discrete versus continuous
- Stochastic versus deterministic
- Demographic versus environmental stochasticity
- Equilibrium
- Stable versus unstable

- Analytical, mathematical model
- Numerical analysis of a mathematical model
- Differential equation
- Simulation
- Individual-based simulation

Watch our workshop website for a cheat sheet with these definitions.

# https://ecoevoapps.gitlab.io/



# In summary

- Theory is hypothesis-forwarding.
  - Theory alone cannot prove anything about the natural world.
- Integrating theory with empirical work can be incredibly powerful for studying the complex and changing systems we are tasked with studying as ecologists.
- To engage with theory:
  - Get to the insights!
    - The results of any theory are the result of model assumptions and mechanisms (only!).
  - Get into the math for a more precise understanding.
- In your own research, whenever hypotheses lead you in circles, it might be a good time for some theory!

# Thank you!

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Asst. Prof of Instruction
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PhD Student
UT Austin

Ravi Ranjan
Postdoc
UT Austin

Xinyi Yan
PhD Student
UT Austin

Look out for a survey in your inbox *after ESA*.

## Workshop website

farriorlab.github.io/theory-workshop

We will update this space as we do other workshops in the future.
Contact: **cfarrior@utexas.edu**


## Funding: NSF CAREER