Modeling in ecological research

EEB C119B / EEB C219B

Lecture, 2.5 hours; discussion, 1 hours. 4 units
Requisites: EEB C119A/C219A or permission of instructor

Advanced techniques in mathematical and computational modeling of ecological dynamics and other population dynamic problems. Students carry out independent research projects aiming for publication quality work. Topics include model formulation, stochastic models, fitting models to data, sensitivity analysis, presentation of model results, and other topics from the current literature.

Who are we? (and how did we get here?)

Jamie Lloyd-Smith

Professor, EEB and Biomath

Research in infectious disease dynamics

(ecology, evolution and epidemiology, including modeling and empirical research)

Background: Physics → Biophysics → Population dynamics → Disease dynamics

Ana Gomez

Doctoral student, EEB

Research in infectious disease dynamics

Background: Broad biology → Quantitative biology → Disease dynamics

And we'll ask about your backgrounds and interests later in the class.

Inclusive classroom

This is an inclusive classroom environment, and it is my intent that students from all diverse backgrounds and perspectives be well served by this course, that students' learning needs be addressed both in and out of class, and that the diversity that students bring to this class be viewed as a resource, strength and benefit. All students can succeed in and benefit from this course.

I aim to foster a supportive and creative environment in the class, where all students feel comfortable sharing their ideas and asking questions. Feedback and interactions among students are essential to the course, but must always be conveyed respectfully.

Please let me know ways to improve the effectiveness of the course for you personally or for other students or student groups. Your suggestions are encouraged and appreciated.

If any of our class meetings conflict with your religious events, please let me know so that we can make arrangements for you.

Some logistics

Shift location to Terasaki 4000?

current enrollment: 119B – 4 students

219B – 8 students

Course websites being linked

Discussion sections…

- location? 1A (Kaplan A30, Th 2-3 PM)
- timing? 1B (Kaplan A48, Th 3-4 PM)

current enrollment: 1A 8 students (3 + 5)

1B 4 students (1 + 3)

Office hours… TBD depending on above.

This week: Jamie’s OH at Thurs 12:15-1:15

What is this course?

- NOT a lecture-based “knowledge transfer” course
- NOT a standard seminar where we read papers and discuss

- More like a workshop or working group, where we learn together by pursuing modeling projects.

→ Will raise topics that we will cover in lecture or seminar style, but the emphasis of the course is on learning by doing, and on learning by helping others.

→ This will allow all students to get a breadth of exposure to different modeling methods, and (crucially) to the stages of model design, trouble-shooting, analysis, and presenting results.

→ Experiment in ‘parallelized teaching’

Modeling project

- Working individually or in teams (C119B only), students will work to advance modeling project on a problem that involves ecological dynamics (interpreted broadly).
- Model must be mechanistic and analyzed using mathematical or computational methods – or ideally both.
- Undergraduate students can take the opportunity to conduct a research project from start to finish, and answer an interesting question.
- Graduate students are strongly encouraged to pursue a project related to (or part of) their dissertation research. The aim for graduate students is to develop this project into a published paper.
- Projects may be at any stage from an idea to a half-completed study. This will allow the class to experience all phases of the modeling process, from conception to formulation to analysis to presentation. (Grading will be based on progress from where you start.)

Disciplinary scope

- ‘Ecological’ is interpreted broadly.
- Includes almost any problem that involves populations… at many scales, and across many taxonomic and organizational levels
- Can be basic or applied science.
- Some examples of acceptable topics:

predator-prey dynamics	conservation of endangered species
seed dispersal and plant spatial distributions	
viral dynamics in a human	immune cell dynamics
coral reef communities	nutrient cycling in the ocean
human migratory behavior	Ebola epidemics
etc etc…	

Learning objectives

By the end of the course students will:

- Gain exposure to a broad array of modeling approaches used to study ecological dynamics.
- Become educated and critical consumers of the ecological modeling literature.
- Develop technical skills that enable them to pursue their own modeling research.
- Gain facility in translating from ideas to model formulation and from model results to intuition.
- Improve communication skills (writing, and oral and visual presentation).
- ***Make progress on moving a modeling project toward publication.***

My goals in teaching this course

- Go beyond introductory material to content that is relevant to current research practice.
- Avoid busy-work and orient all course requirements to work that helps learn core concepts and skills (and apply them), and to build experience 'thinking like a modeler' and working through challenges.
- Build the community of people using these approaches → continue to support each other, and maybe collaborate, after the course.
- Support development of career skills: problem-solving, writing, presenting, discussing.

My expectations…

- I will not know the answers to all questions… this is research.
- I hope to learn new things during the course, about methods and systems.
- I hope to be surprised and challenged by your ideas.

Expected background

The following knowledge will be assumed as a baseline in the class.
Students who lack elements of this background can fill it in readily with some additional effort, but we won't spend class time on these topics.

Population modeling

- Models of population growth in continuous and discrete time
  - Qualitative analysis of these models (equilibria and stability)
- Matrix models for structured populations (age, space, etc)
  - Eigenvalue analysis of these models
- Basics of stochastic modeling (concepts and simple implementation)
  - Demographic and environmental stochasticity

Programming

- How to write simple simulation models in R (or a similar language)
  - Discrete time models using a for loop
    - Including matrix models, stochastic models
  - Continuous time models using an ODE solver

Course format

First four weeks: focused on developing and refining project proposal

Learning weeks: generally focused on learning new methods*

- Lecture or discussion of reading on method
- Student-led discussion of a research paper that uses that method.

Sharing weeks: generally focused on projects

- Presentations of progress, challenges, etc. (lab meeting style)
- Discussion and feedback from group
- Each student/team will do 2 presentations, in weeks 5-8, plus a final presentation in week 10.

Discussion sections: discussing class content, developing project ideas, reviewing/developing programming skills

* Choice of methods will arise from student requests and project needs, mixed with what I think is important for you to know.

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Course schedule

	Tuesday	Thursday
Week 1	Introduction and course aims	Projects – examples and decisions
Week 2	Model formulation exercise	Model formulation exercise
Week 3	Presentations (project proposals)	Presentations (project proposals) **(Written proposals due Friday)**
Week 4	Project consultations	Project consultations **(Revised proposals due Friday)**
Week 5	Topic: new methods and alternative formulations*	Topic: dealing with data I. Estimating parameter values*
Week 6	Presentations Discussion	Presentations Discussion
Week 7	Topic: new methods and alternative formulations*	Topic: dealing with data II. Fitting models to data **(Progress reports due Friday)**
Week 8	Presentations Discussion	Presentations Discussion
Week 9	Topic: representing and interpreting model results*	Topic: representing and interpreting model results*
Week 10	Final presentations	Final presentations

* All topics are actually TBD.

Project proposals due on Friday Jan 24; revised proposals on Jan 31

Progress reports due on Friday Feb 21

Final project reports due on Monday March 23

Course schedule (v1a)

<table>
<tr><th></th><th>Tuesday</th><th>Thursday</th></tr>
<tr><td>Week 1</td><td colspan="2" rowspan="4">Intro and project formulation</td></tr>
<tr><td>Week 2</td></tr>
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Final project reports due on Monday March 23

Course schedule (v1b)

	Tuesday	Thursday
Week 1	Intro and project formulation	Intro and project formulation
Week 2	Intro and project formulation	Intro and project formulation
Week 3	Intro and project formulation	Intro and project formulation
Week 4	Intro and project formulation	Intro and project formulation
Week 5	Learning new tricks	Learning new tricks
Week 6	Project presentations	Project presentations
Week 7	Learning new tricks	Learning new tricks
Week 8	Project presentations	Project presentations
Week 9	Final tips, consult and trouble-shoot	Final tips, consult and trouble-shoot
Week 10	Final presentations	Final presentations

Final project reports due on Monday March 23

Course schedule (v2a)

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discussion,
trouble-shooting
and feedback</td><td rowspan="4">Learning new tricks:
new methods, best practice in modeling, discussing literature</td></tr>
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Final project reports due on Monday March 23

Course schedule (v2b)

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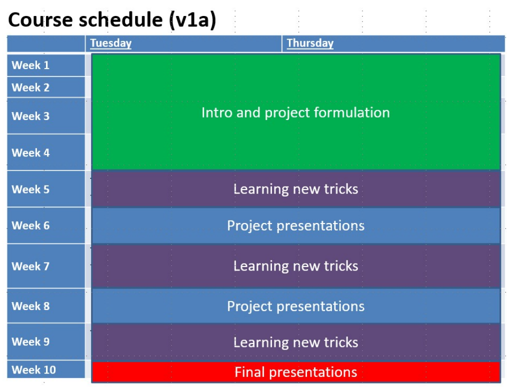
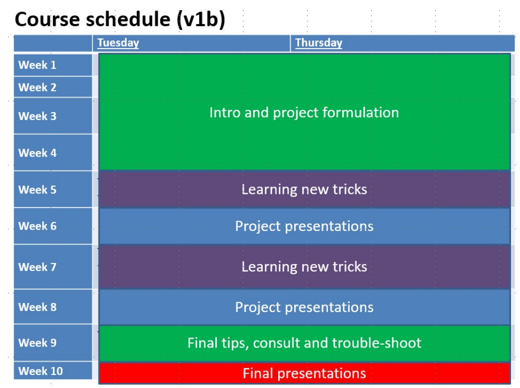
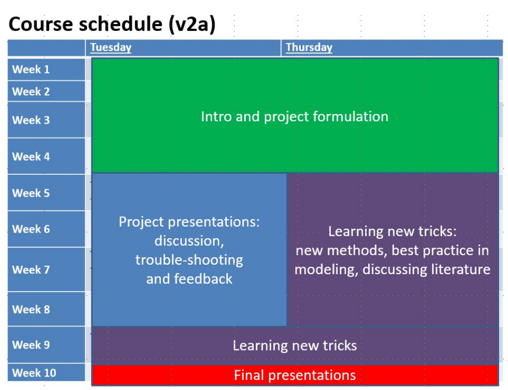
Final project reports due on Monday March 23

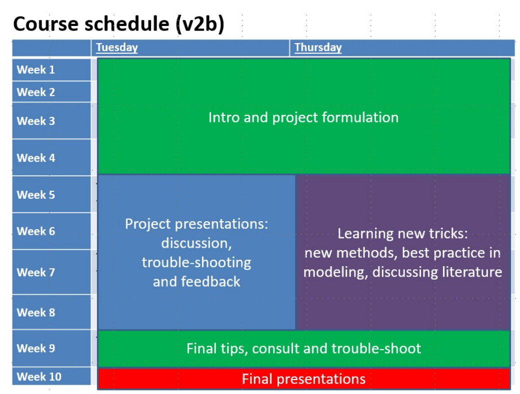
Course schedule – direct democracy

Think about it. We will vote on Thursday (enrolled students only).









Either way, you will present your project work twice in weeks 5-8, and briefly present a paper once in weeks 5-9.

Evaluation

20%	Presentations
20%	Participation
10%	Written feedback to peers
50%	Project

I recognize that people are coming to the class with different backgrounds, and have different degrees of focus on modeling in their work.

Grades will reflect each individual's level of effort, engagement, participation, thoughtfulness, and *progress* over the course of the term. Interim and final reports on the project should reflect these virtues.

Undergraduate vs graduate sections: major difference is level of effort and sophistication expected in project; also some minor variations in other work (see syllabus).

Useful references

Modeling in general

Otto & Day, A Biologist's Guide to Mathematical Modeling

Ellner & Guckenheimer, Dynamic Models in Biology

Stevens, A Primer of Ecology in R

Modeling and data

Bolker, Ecological Models and Data in R

Hilborn & Mangel, The Ecological Detective

Bjornstad, Epidemics: Models and Data Using R

Clark, Models for Ecological Data

Selected special topics

Caswell, Matrix Population Models

Karlin & Taylor, Introduction to Stochastic Processes

Strogatz, Nonlinear Dynamics and Chaos

The students speak…

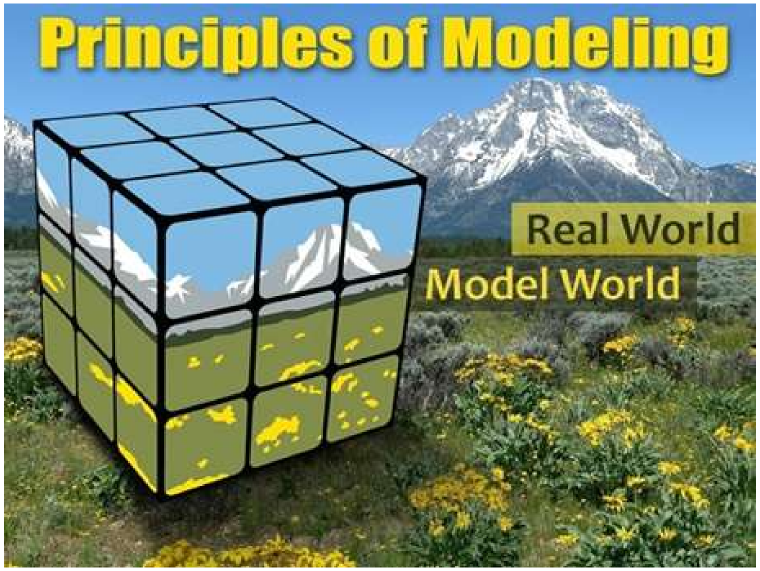
Introduce yourself

- Name, degree, year…
- Why are you interested in this class?
- Background in modeling or ecological theory?
- Background in programming?
- Ideas about a modeling project?
    - No pressure… could be as simple as a class of problem you're interested in studying

Dynamic models

A dynamic model is a simplified representation of a real system, where we pare the system down to its essential components and the essential processes that link them.

- models can begin as verbal, but then tools of mathematics and/or computation are used to formalize and explore them.



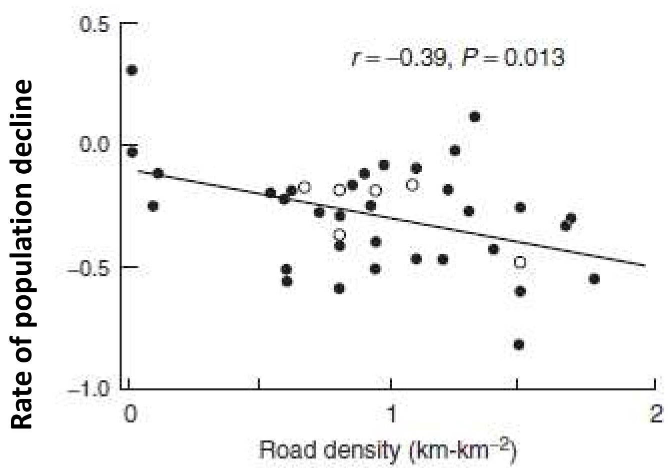
Principle of parsimony: a simple explanation is better than a complex one if they match the observed data equally well.

http://www.uvm.edu/rsenr/vtcfwru/spreadsheets/?Page=pom/pom.htm

Mechanistic vs descriptive models

Dynamic models are *mechanistic*: they explicitly represent the mechanisms that underlie observed patterns. Relationships between model variables emerge as a result of these mechanisms.

Different from *descriptive* models: like a linear regression or many *statistical* models, descriptive models represent the pattern in data without explicitly representing the mechanisms.



From Ellner & Guckenheimer, 2006

- descriptive models are very useful for detecting and summarizing relationships, but don't tell us why the relationship exists.
- also don't tell us anything beyond the particular data we're looking at.

Statistical Models

- Account for bias and random error to find correlations that may imply causality.
- Often the first step to assessing relationships.
- Assume independence of individuals (at some scale).

Dynamical Models

- Systems Approach: Explicitly model multiple mechanisms to understand their interactions.
- Links observed relationships at different scales.
- Explicitly focuses on dependence of individuals

Credit: Steve Bellan, UT Austin

Ingredients of a dynamic model

State variables: quantities that describe the entities of interest for your model.

e.g. population size, disease prevalence

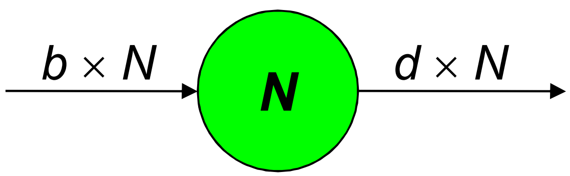
Parameters: quantities that govern the dynamics, but don't describe the state of the system and (typically) don't change over time.

e.g. per capita birth rate, carrying capacity, transmission rate

Dynamic equations: a set of equations or rules specifying how state variables change over time, as a function of current and past values of the state variables.

The simplest model in ecology

Example: population growth



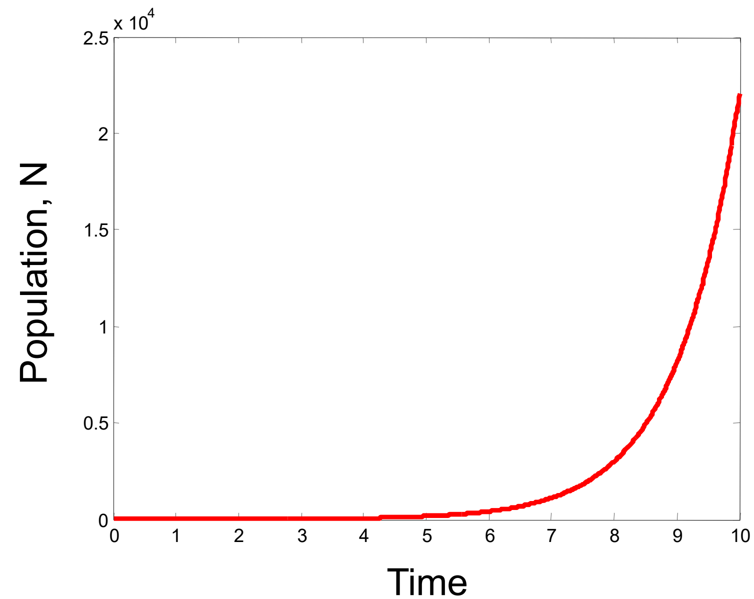
$$\frac{dN}{dt} = bN - dN$$

N state variable for population size

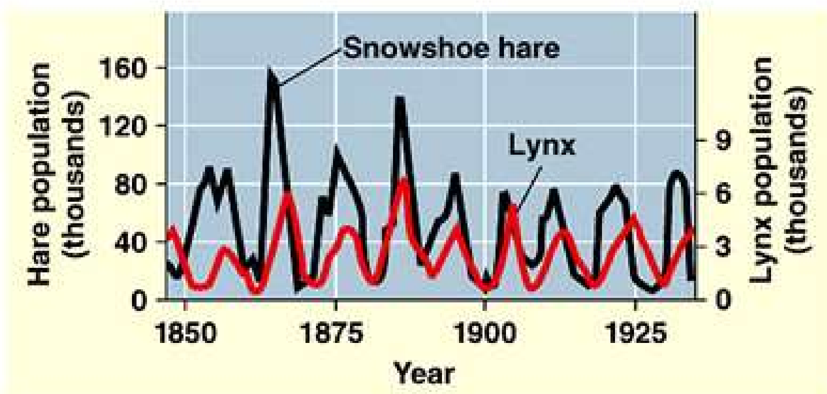
b per capita birth rate

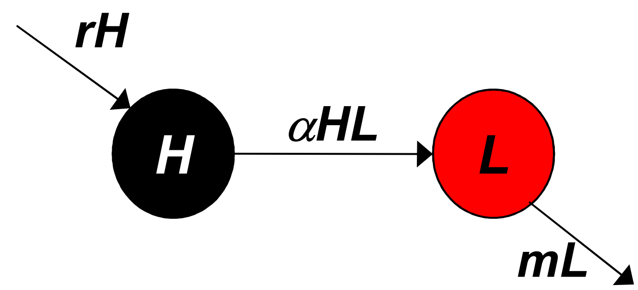
d per capita death rate

* per capita means ‘per head’, and means that the rate is calculated as the average # of events per individual per unit time.

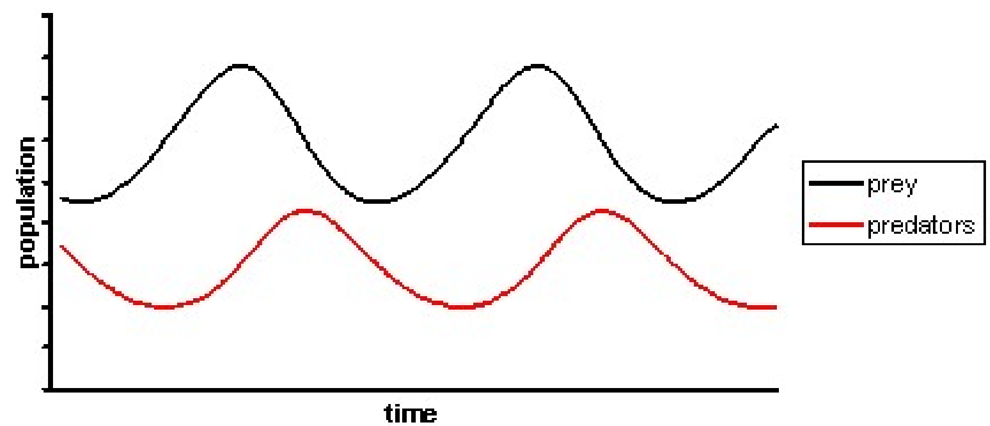


Another classic, simple ecological model

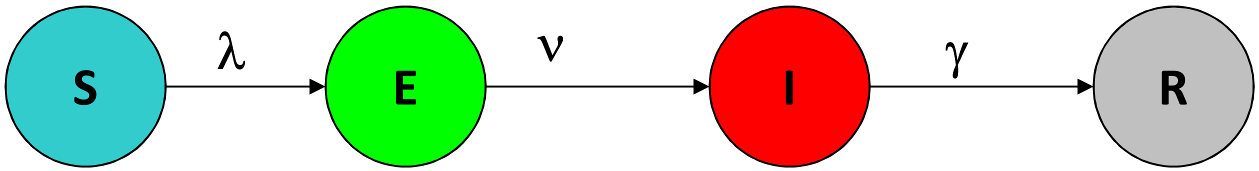




H	number of hares
L	number of lynxes
r	intrinsic growth rate of hare population
α	rate at which lynxes eat hares
m	per capita death rate of lynxes



The SEIR framework for infectious disease dynamics



Susceptible: naïve individuals, susceptible to disease

Exposed: infected by parasite but not yet infectious

Infectious: able to transmit parasite to others

Removed: immune (or dead) individuals that don’t contribute to further transmission