50% Lectures, 50% Projects/Discussion

Organization of Lectures:
- Introductory lecture on empirical dynamics to set the stage
- Section I: Foundations of Population Dynamics
- Section II: Empirical Dynamics (aka Nonlinear State Space Reconstruction)

Class Plan:
- Introduce Empirical Dynamics (EDM) as a new paradigm with minimal assumptions.
- Introduce foundations of classical population dynamics models
  - Acquire literacy in rEDM tools (required for student projects)
  - rEDM package on CRAN: [https://cran.r-project.org/web/packages/rEDM/index.html](https://cran.r-project.org/web/packages/rEDM/index.html)
  - Student project presentations

Proposed Outline for Section I: Foundations of Population Dynamics:
1) Objectives:
   - Provide an understanding of the foundations and origins of population models
   - Survey of population dynamical behaviors in nature and the lab.
   - Survey of population dynamical behaviors in simple models and field examples.
   - Insights into nature gained from simple models.
   - Multiple time scales as a source of richness in dynamical behavior.
   - Critical review of assumptions underlying classical models.
   - Real time/out-of-sample prediction as a rigorous measure of scientific merit of models.
   - Evidence for the classical assumption of a stable balance of nature.
   - The conflict between classical stable dynamics and the actual empirical evidence.
   - The implications of constant-linear versus unstable nonlinear systems for understanding nature and doing experiments.

   (i) Empirical Examples From Nature and the Lab
      - variety of different kinds of population dynamics in nature and the lab.

   (ii) Foundations and Origins of Population Models
      - historical reasons for interest in population regulation (pestilence).
      - intellectual roots

   (iii) Quantitative Population Biology and Dynamical Systems Theory
      - fundamental problem: finding a sufficient dynamical description
      - model complexity: measurement error vs detail (systematic) error

   (iv) State Space and the Niche
      - full knowledge state space
      - fundamental nice, n-dimensional hyper-volume (an intellectual cornerstone).
      - How to reduce complexity?

   (v) Understanding Assumptions Used to Reduce a Full Knowledge State Space to The Single Species Case
      - Taylor’s formula
      - Ockum’s Razor
      - simplifying assumptions

   (vi) Unrestricted Growth: Geometric versus Exponential Growth
      - discrete time vs. continuous time

   (vii) Introduction to Second Order Growth
2) Properties and Behaviors of Higher Order Systems: Part I

(i) Reducing Dimensionality: Review

(ii) Expanding r in the Laboratory: Algal Growth in a Chemostat

(iii) Population Regulation Debate: Biotic versus Climate School
    - Historical Roots: a central debate with many names.
      - biotic / climatic
      - density dependent / density dependent
      - equilibrium / non-equilibrium
      - stability / instability
      - biological / physical
      - chaos / noise

(iv) Testing for Density Dependence
    - field examples (Tanner 1966)
    - lab examples (Gause 1934)

(v) Property I: Equilibrium N*

(vi) Property II: Attractor
    - phase portraits
    - omega limit set

(vii) Property III: Stability
    - local stability defined
    - local linear stability analysis (theory and practice)
    - Taylor approximation in the nbhd of an equilibrium point
    - Lambda (slope of F(N) with respect to N, at N*).
    - characteristic return time

(viii) Property IV: Thresholds (Allee Effect)
    - 3rd order
    - separatrix
    - phase portrait
    - domains of attraction
    - calculation of stability

3) Properties and Behaviours of Higher Order Systems: Part II

(i) Review of Local Linear Stability Analysis

(ii) Property V: Multiple Stable States
    - allee and model examples

(iii) Property VI: Fold Catastrophe
    - fishing example

(iv) Tychenoff Theorem and Center Manifold Theory for Analysing Systems Having Different Time Scales
    - the importance of characteristic return time

(v) Fold Catastrophe: Models Meet Data
    - spruce budworm example
    - resource control vs. predator control
    - review of examples from nature (fisheries, corals, lakes, etc)
    - what constitutes sufficient evidence?
4) Properties and Behaviors of Higher Order Systems: Part III

(i) Property VII: Smoothing and Tracking Environmental Variation
- field examples (daphnia and algae etc)

(ii) r and K Selection
- Size and cycle: time scales and body size

(iii) Property VIII: Intrinsic Oscillations with Time Lags in Regulatory Mechanisms (Continuous Time)
- the relationship between characteristic return time and time delay in feedback
- stable points and stable limit cycles

(iv) Evidence and Insights:
- Nicholson’s sheep blowfly study
- nature’s 4-year cycle
- storage product beetles
- etc.

(v) Property IX: Intrinsic Oscillations with Discrete-Time Models
- derivation of discrete time logistic

(vi) Analysis of The Discrete-Time Logistic
- return map
- equilibria
- stability analysis (discrete time analogue to local linear nbhd method)

5) Properties and Behaviours of Higher Order Systems: Part IV

(i) Analysis of The Discrete-Time Logistic
- return map
- equilibria
- stability analysis (discrete time analogue to local linear nbhd method)

(ii) Review of Destabilizing Factors
- paradox of enrichment

(iii) Property X: Chaos
- implications
- applications

(iv) Property XI: Stability and Complexity from Models

Proposed Outline for Section II - Empirical Dynamics (aka. Nonlinear state space reconstruction)

1) Deducing Dynamics with Empirical Dynamics
- Taken’s Theorem
- Lagged coordinate embeddings
- Nonlinear Forecasting
- Simplex Projection
- S-maps
- Measuring and understanding nonlinear state dependence
- Distinguishing regime shifts from noise
- larval reef fish example

2) Deducing Structure and Understanding Causality
- distinguishing mirage correlation from causation
- convergent cross mapping
- identifying key drivers
- identifying functionally coupled species groups.
- ecosystem based management
- understanding variable interactions