SIO 276 Sugihara Fall 2020

Proposed course time allocation: 50% Lectures/Readings, 50% Projects/Discussion

Class Plan: Organization of Lectures:

1) Section I: Empirical Dynamics (aka Nonlinear State Space Reconstruction)
   -Introductory lecture on empirical dynamics to set the stage:
   Empirical Dynamics (EDM) A Minimalist Inductive Approach to Scientific Inquiry.
   - Using Data to Inform Theory (Induction)
   - Static versus Dynamic?
   - Finding Determinism in Data
   - Out of Sample Prediction
   - Identifying Causal Mechanisms
   - Measuring and Understanding Nonlinear Associations

   -Identify Research Project/Problem related to thesis interests – find time series data.
   -Lab Practicum on rEDM: Acquire literacy in rEDM tools (required for student projects)
   - 3 class periods to acquire familiarity with computational tools needed for projects)
   - rEDM package on CRAN: https://cran.r-project.org/web/packages/rEDM/index.html

   -Make certain data are available to answer Research Problem – find time series data asap!!!

2) Section II: Foundations of Population Dynamics
   - Overview of Classical Theory
   - Technical Background for EDM

3) Section III: Student Presentations

<u>Outline for Section I -Empirical Dynamics (aka. Nonlinear state space reconstruction)</u>

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
     - Time varying episodic interactions
   - 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

<u>Proposed Outline for Section II: Foundations of Population Dynamics:</u>

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

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

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

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

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

- (vi) 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) Reveiw 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 beatles
        - 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