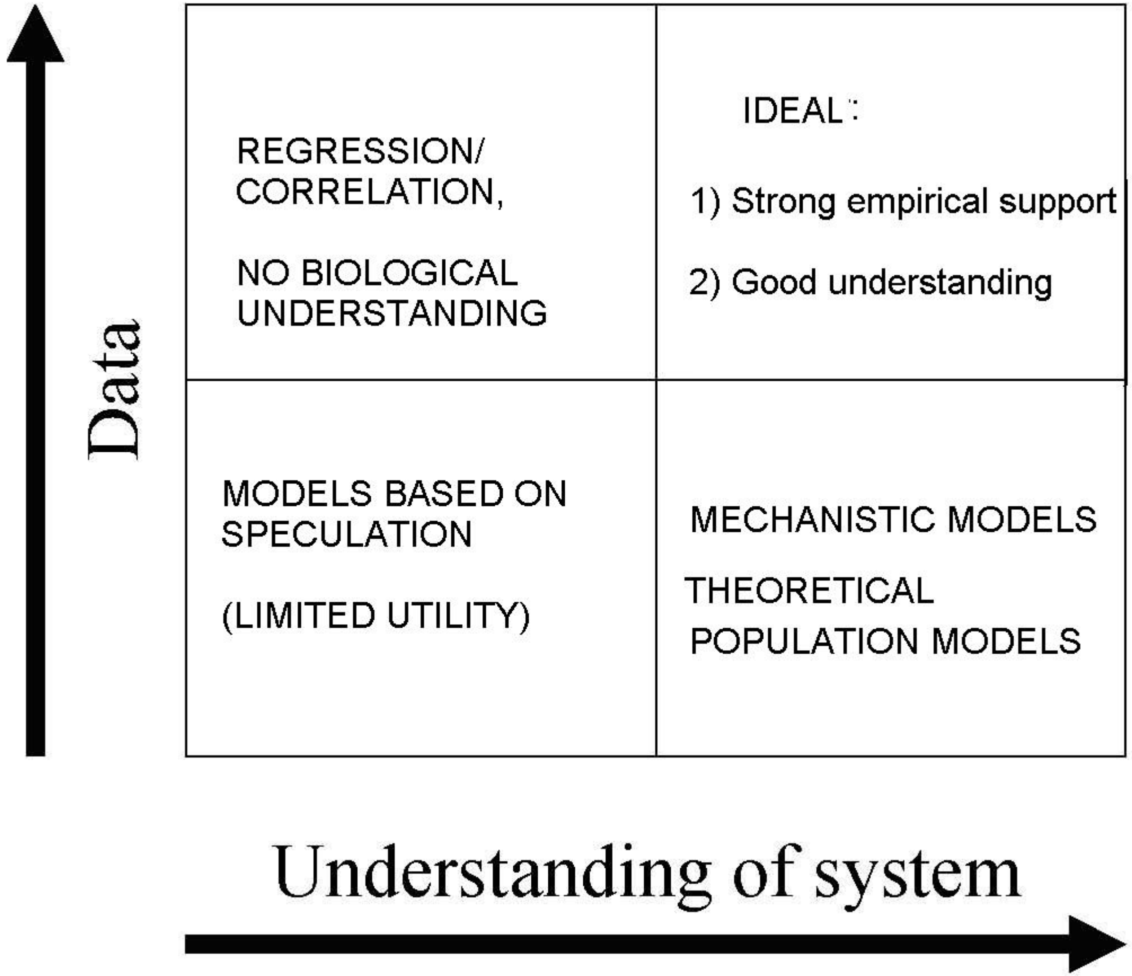
Principles of model development and assessment

Common model features

- Abstraction /parsimony
  - Highlight the system features important to the model application
    - E.g., population model: emphasize birth, death, age structure, possibly ignore genetic composition
  - Parsimony
    - Prefer models with less complexity
- Symbolic reference
  - Symbols
  - Graphical objects
  - Equations
  - Statistical distributions


REGRESSION/
CORRELATION,
NO BIOLOGICAL
UNDERSTANDING
IDEAL:
1) Strong empirical support
2) Good understanding
MODELS BASED ON
SPECULATION
(LIMITED UTILITY)
MECHANISTIC MODELS
THEORETICAL
POPULATION MODELS
Data
Understanding of system

Conflicting modeling goals

- Generality
  - General models are simple, lack detail, have low precision
  - Many theoretical population models
- Realism
  - Detailed
  - Limited generality
  - Low precision (predictive power)
- Accuracy
  - Good precision (predictive power)
  - Limited range of operation (lower realism, generality)
  - Many statistical models

Example goals

- Identify broad information needs
  - Broad conceptual (e.g, ecosystem models)
  - Useful for identifying what is *not* known

- Management
  - Forecast biological impacts of management decisions
  - Need both predictive capacity *and* realism

Types of models

- Graphical/ analog models
- Analytic – math equations
- Computer simulation-computer code
- Statistical – prob. distributions, parameter estimation
- Dynamic optimization-
  - Dynamic decisions
  - Seek to reach an objective over time

Model forms

- Discrete vs. continuous
  - Discrete- often more appropriate for certain processes (e.g., birth), is typically how we measure populations
  - Continuous- limiting form of discrete
- Deterministic vs. stochastic
  - Deterministic- no random variables
    - Output is always same given parameter values, inputs
    - More analytically solvable
  - Stochastic- random variables
    - Output is a random outcome
    - More realistic

Example: Deterministic vs. stochastic

Model: $N(t+1)=N(t)+rN(t)$

Deterministic:

$N(0)=100$, $r=0.04$ → $N(4)$ always is 117

Stochastic:

$N(0)=100$, $r=0.04$ or 0.1 (equal prob.)

$N(4) = 117$ or 146 (equal prob.)

Describing population models

- Initial time t_0

- Time frame
  - Discrete- equally spaces points between t_0 and t_f
  - Continuous– all points between t_0 and t_f
- Population states
  - $N(t)$ – population size at time t
  - $N_i(t)$- size of component (e.g., age class) i at time t

Describing population models (cont'd)

- *Z(t)* – exogenous (outside) driving factors that influence the population (often random, e.g., weather)
- *a(t)* – Management controls that influence the population (e.g., harvest)

Generic transition equation

Discrete time:

$$N(t+1) = N(t) + f(N,Z,a,t)$$

$$N(t+1) - N(t) = f(N,Z,a,t)$$

Continuous:

$$dN/dt = f(N,Z,a,t)$$

f is described by parameters (survival, recruitment, density dependence, etc)

Model components

- Accumulators
  - State variables, e.g., population size
- Flows
  - E.g., birth, death, movement
- Sources
  - From outside system boundaries (e.g., immigration)
- Sinks
  - Movement to accumulators outside system (death, emigration)
- Flow regulators
  - Regulate movement between states (e.g.,birth and death rates

Model components (cont'd)

- Exogenous factors
  - Influence, but are not influenced by, system dynamics
- Endogenous factors (see 'connectors')
  - Influence, and are influence by, system dynamics (e.g., density feedback)
- Controls
  - Means by which system dynamics can be manipulated
- Connectors
  - Indicate that the value of 1 component influences the value of another

Steps in constructing a population model

- Identify system of interest
  - Top down
  - Bottom up
- Identify system states (accumulators) and flows between them
- Model flow rates
- Incorporate initial and terminal conditions and other constraints
  - E.g., N(0) =1000, T=20 year time span

Model assessment

- Verification- verify that mathematical structure is correct (does what was intended) and output reflects data and assumptions used
  - E.g., N(t) must not be <0, ever!

- Validation- comparison of model output to independent data
  - Single comparison
  - Multiple alternative models (better)

Model assessment (cont'd)

- Sensitivity (elasticity) analysis
  - Sensitivity to changes in system initial conditions, parameter values, and structural features

Continuous $$e(N_t \mid \theta) = \frac{\partial N_t / N_t}{\partial \theta / \theta}$$

$$e(N_t \mid \theta) = \frac{\Delta N_t / N_t}{\Delta \theta / \theta}$$ Discrete

- Identify model equilibria
  - Discrete N(t+1)= N(t) ⇔ N(t+1) - N(t) = 0
  - Continuous dN/dt =0

Model assessment (cont'd)

- Stability
  - Model tends to return to equilibrium (or not) after perturbations
- Ergodicity
  - Asymptotic behavior of N(t) not influenced by N(0)

Process for model building

1. Establish model goals and objectives
2. Identify system features and boundaries
3. Develop mathematical/ simulation model
4. Verification
5. Validation
6. Sensitivity analysis
7. Stability analysis

Application to management

1. Verify, validate, and analyze based on available data
2. Use model to assess consequences of alternative management actions
3. Management actions influence population, provide update information through monitoring
4. Updated information used to refine model
5. Revised model informs decision making
6. Return to step 2