Role of Theory in Ecology

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Alternative approaches to ecological investigation

Natural history - descriptive biology

Experimental manipulation - field or lab - isolate effects of some factors on some aspect of organism/population/community behavior - observe response to interactions of several factors

Theory development - abstract general properties of system by ignoring certain components and emphasizing others (selective ignorance). Can do this (i) ad hoc - don't think it's important so will ignore it, (ii) data suggests a factor or set of factors can be ignored, (iii) based upon scale so processes on a fast or slow time scale (or equivalently spatial) are ignored dependent upon scale you are interested in

Expressing theory

- Verbally
- Graphically
- Mathematically
- Through Simulation

Science is thought to be a process of pure reductionism, taking the meaning out of mystery, explaining everything away, concentrating all our attention on measuring things and counting them up. It is not like this at all. The scientific method is guesswork, the making up of stories. The difference between this and other imaginative works of the human mind is that science is then obliged to find out whether the guesses are correct, the stories true. Curious-ity drives the enterprise, and the open acknowledgement of ignorance.

Lewis Thomas - Sierra Club Bulletin, March/April 1982, P. 52

What can theory do?

1. Suggest observations and experiments
2. Provide a framework to assemble bodies of facts - provide a means to standardize data collection
3. "Allows us to imagine and explore a wider range of worlds than ours, giving new perceptions and questions about how our world came to be as it is" F. Jacob - The Possible and the Actual, 1982
4. Clarifies hypotheses and chains of argument
5. Identifies key components in systems
6. Allows simultaneous consideration of spatial and temporal change
7. Extrapolate to broad spatial or long temporal scales for which data can not easily be obtained
8. Prompts tentative and testable hypotheses
9. Serves as a crude guide to decision making in circumstances where action cannot wait for detailed studies
10. Provides an antidote to the helpless feeling that the world is too complex to understand in any generality - provides a means to get at general patterns and trends

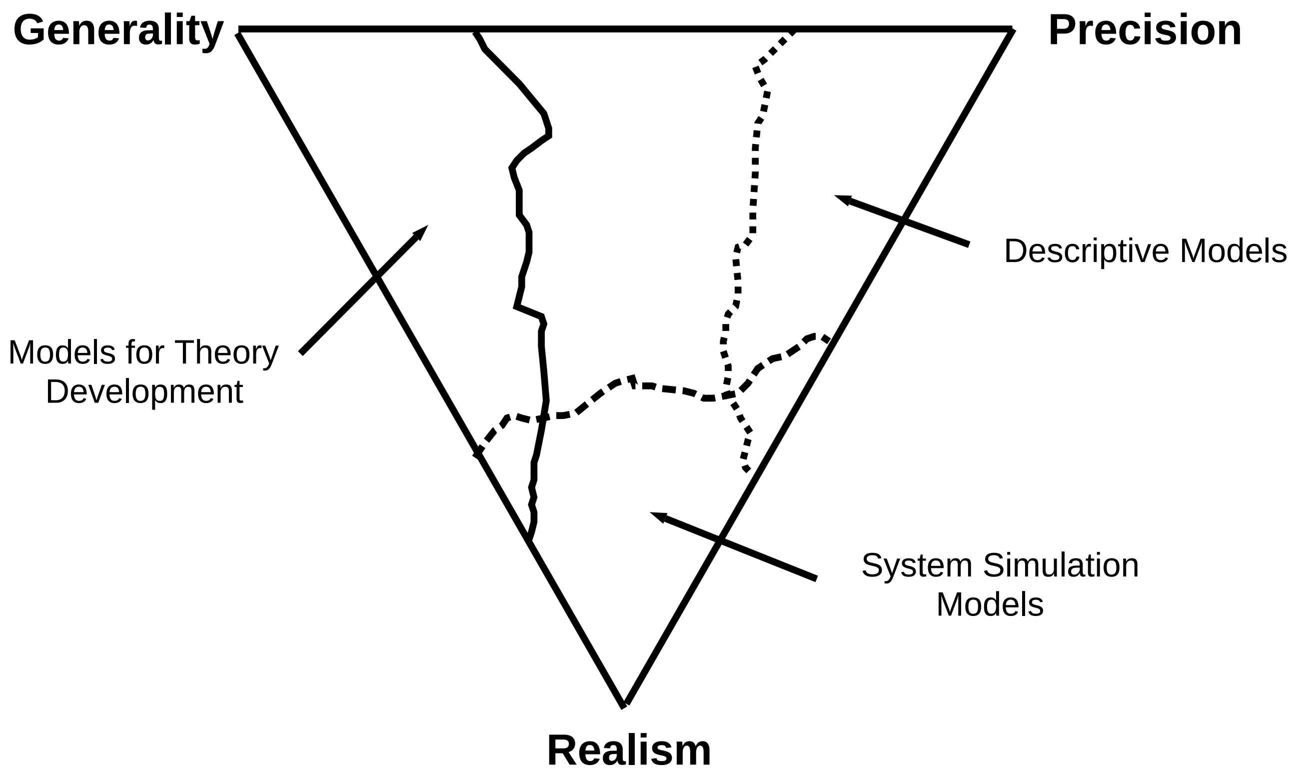
Purposes for Model Construction:

1. Descriptive - use as a summary for data sets
2. Analysis - wish to determine effects of varying inputs
3. Simulation - guide for experiments, as a teaching aid
4. Prediction/forecasting - contrast alternative management options

Objectives define the appropriate scale (spatial, temporal), level of resolution (including the hierarchical levels within biology to utilize), and sometimes the type of modeling approach.

Models cannot be proven, only falsified or rejected at the level of interest.

Approaches - numerous possible taxonomies are possible. One is:
1. Descriptive (a) Empirical or statistical
   (b) Comparative
2. Mechanistic (a) Compartmental
   (b) Optimization - adaptationist
3. Systems - hierarchy theory
4. Individual-based
5. Expert systems


Generality
Precision
Realism
Descriptive Models
Models for Theory Development
System Simulation Models

It is a common fallacy to confuse scientists' models of reality with reality itself. A model is a map. A map is not the territory it describes.

Richard Casement

Constraints on Realism in Modeling:

Data constraints:
Available data may not be sufficient to specify appropriate functional forms, interrelationships, or parameters. May force aggregation of components. May not be sufficient to elaborate criteria for evaluation of model performance.

Effort contraints:
Resource constraints may limit the amount of detail it is feasible to include. Limits time modelers and collaborators may invest as well as pressure to produce results.

Computational constraints:
Technology to produce spatially-explicit dynamic models is lacking, as are easily accessible parallelization algorithms.

Given the above, the entire modeling process involves evaluation of alternative approaches to assess the most appropriate procedures for the questions of concern. This is part of the process of selective ignorance involved in constructing models.

Just as public policy decisions involve a balancing act between various alternatives which satisfy to varying degrees the desires of different stakeholders, realism in modeling involves balancing different approaches to meet a goal.

Realistic modeling is the science of the actual rather than the science of the ideal.

This is the starting point for *multimodeling* - a hierarchy of models at varying levels of detail may be necessary with the above constraints limiting the spatial, temporal and organismal extent and resolution possible to include within these.

Model Evaluation - Some terminology:

Verification - model behaves as intended, i.e. equations correctly represent assumptions; equations are self-consistent and dimensionally correct. Analysis is correct. Coding is correct - there are no bugs. Some call this **Testing**

Calibration - use of data to determine parameters so the model "agrees" with data. This is specific to a given criteria for accuracy. Some call this **Tuning or Curve-fitting.**

Corroboration - model is in agreement with a set of data independent from that used to construct and calibrate it.

Validation - model is in agreement with real system it represents with respect to the specific purposes for which it was constructed. Thus there is an implied notion of accuracy and domain opf applicability here.

Evaluation - Validation plus: appropriateness to objectives; utility; plausibility; elegance; simplicity; flexibility.

Evaluating different types of models:

Models for theory development -

General, some realism, little precision

Make qualitative comparisons to nature, not quantitative ones, over some parameter space. No calibration or corroboration performed, except theoretical corroboration (meaning that model agrees with the general body of theory in the field).

Note: these models are often elaborated to produce models for specfific systems.

Descriptive models-

Precise, little realism, not general

Statistical hypothesis testing; time series analysis methods applied.

Models for specific systems -

Realism, some precision, not general

Quantitative comparisons, constrained by available data. Compare component-by-component if data are available.

Why is there so little emphasis on model testing?

1. It’s modelers who do models and they have a vested interest in the models.

2. Sociology of science - what’s "accepted" depends to some extent on non-scientific factors, including the personality and aggressiveness of the proponent.

Set some criteria *before* expending alot of effort on any one model

Reviewing criteria for modeling papers:

1. Are the models appropriate to the biological questions being addressed?

2. Are the underlying biological questions of potential interest to a significant fraction of the journal's audience?

3. Does the mathematics teach us anything new that is biologically significant?

4. Is the mathematics correct?

5. If the paper is strictly theoretical, does it point out broadly useful new insights?

6. Are the model parameters and variables estimable from observations?

Key quantitative concepts for undergraduate life science students:

1. Rate of change - population growth
    - Discrete
    - Continuous
2. Scale - different questions arise on different scales
    - What is important to include is different on different scales
    - Modeling is a process of "selective ignorance"
    - Trade-offs in modeling - generality. precision, realism
3. Equilibria - rate of change = 0
    - There can be more than one
    - These can be dynamic
    - Can arise in an average sense in periodic systems
4. Stability - notion of a perturbation
    - Alternative definitions - return to equilibrium is just one
5. Structure - effect of grouping components of a system
6. Interactions - a few key types with some general properties for each. Though ultimately everything is hitched to everything else (as Muir says), effects are not automatically transfered to everything. Thus we can correctly ignore much of what occurs within natural systems when we focus on a particular issue.
7. Stochasticity - what counts as unpredictable
    - When does stochasticity matter

What math is needed to get the above across? Linear algebra, discrete models, some calculus, exposure to modeling process, basic probability.

Another Taxomony of Modeling Approaches:

	Continuous	Discrete
Deterministic	ODE/PDE Integral equations	Difference Equations Integro-differenec equations Matrix models Cellular automata
Stochastic	Birth and death processes Stochastic DE Continuous-time Markov	Branching processes Markov chains Random walk models on lattices Stochastic cellular automata