Ecological Dynamics

Philosophy of modeling

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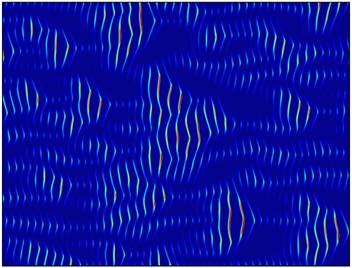
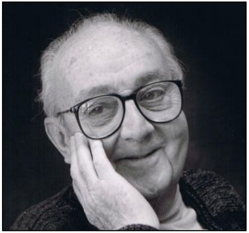


Models in science

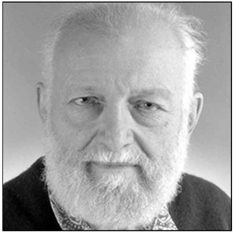
What are models?

Models are abstract representations of nature; their purpose is to help explain some aspect of the real world (Giere, 2004)



George Box

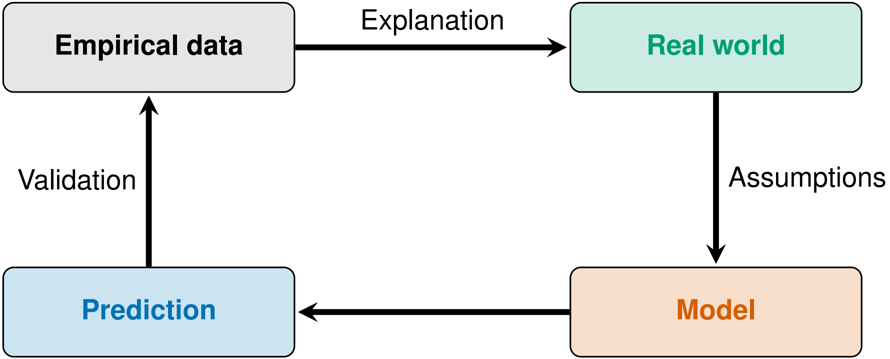
"Essentially, all models are wrong, but some are useful." – Box (1987)



Richard Levins

"Truth is the intersection of two lies." – Levins (1966)

The place of models in science



Prediction can refer to **forecasting** (e.g., quantitative predictions) or **understanding** (e.g., qualitative relationship between variables)

May’s perspective on models and physics-envy in ecology

May (2004) described the evolution of science as follows:

Observations

Tycho Brahe

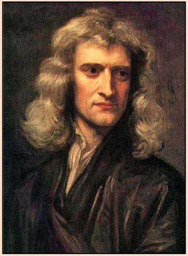
→

Patterns

Johannes Kepler

→

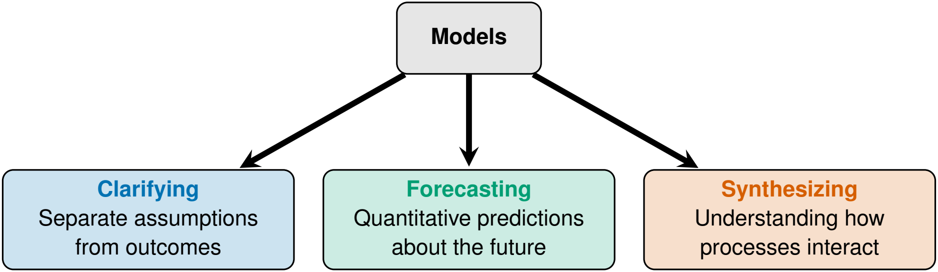
Models



Isaac Newton

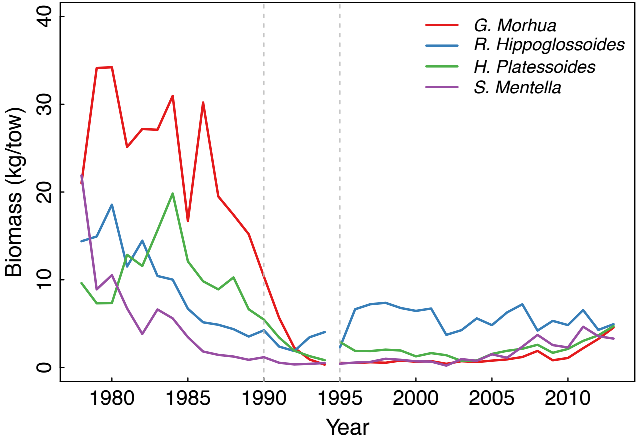
- **Observations**: careful observations about the natural world
- **Patterns**: identify relationships based on observations
- **Models**: develop models to explain patterns

The many roles of models



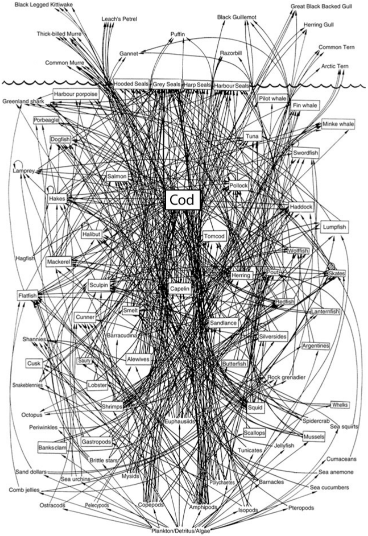
Models are valuable tools even when their predictions are not validated (i.e., can still be used to clarify and synthesize)

Example: The collapse of Cod in the Atlantic Northwest



- The abundance of Cod and other important commercial species collapsed in the 1990s prompting a moratorium on fishing
- **Implicit model**: Cod will recover due to reduced fishing

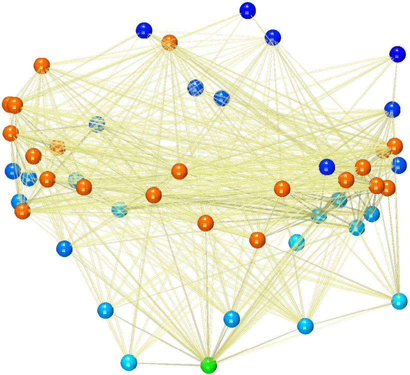
Example: The collapse of Cod in the Atlantic Northwest



A simplified food web for the Northwest Atlantic. © IMMA

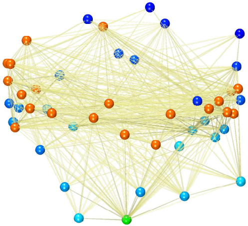
- Clarifying: modeling the dynamics of Cod as a function of harvesting
- Forecasting: predict the dynamics of Cod with moratorium
- Synthesizing: explain lack of recovery in Cod despite moratorium

Example: Ecological complexity and stability



- Elton (1958) suggested that complex ecosystems are more stable
- This verbal hypothesis is still being investigated today; why?

Example: Ecological complexity and stability



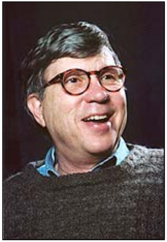
- Hypothesis is fuzzy: many ways of defining "complexity" and "stability"
- Mathematical formalism made this fuzziness obvious and clarified the original hypothesis
- Theory showed that there was no *a priori* reason for complexity to promote stability in ecological systems (May, 1972)
- Suggests that factors other than complexity promote stability in nature
- Spurred a 30+ year hunt for "stabilizing processes" in nature

Theory vs. models

Theory and (mathematical) modeling are not equivalent:

Hal Caswell

"Models are to theoretical problems as experiments are to empirical problems." – Caswell (1988)



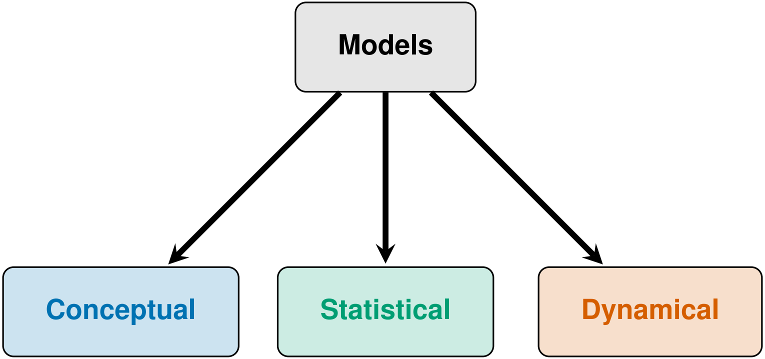
Richard Lewontin

"Theory is the science of the possible; only observation can yield knowledge of the actual." – Lewontin (1968)

- Theory is about understanding; can be done without models
- Modeling can be used to address practical problems

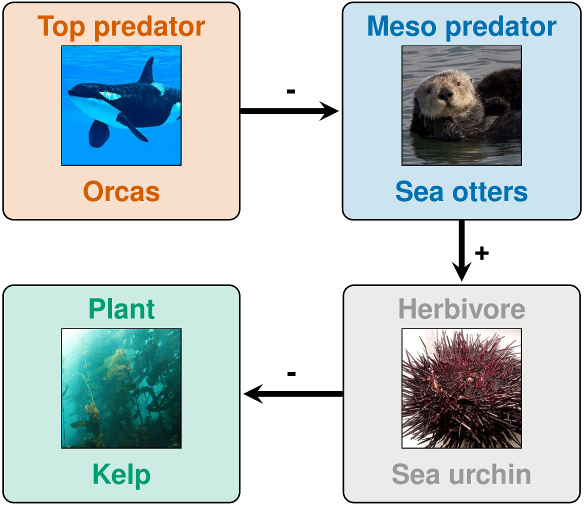
Types of models

Models represent the relationships between variables (natural patterns) and parameters (processes or mechanisms) via the following approaches:



- **Conceptual**: verbal or diagrammatic representation
- **Statistical**: phenomenological representation
- **Dynamical**: mechanistic representation

Example: Trophic cascades in Western Alaskan waters



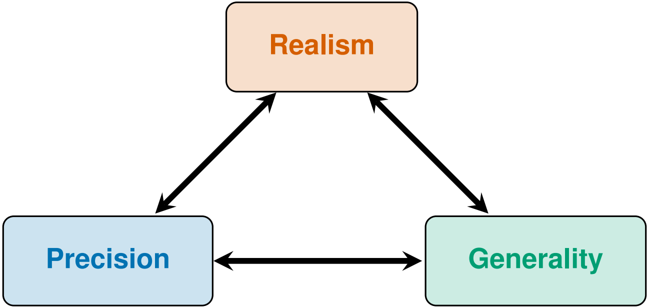
Estes et al. (1998) showed that the consumption of sea otters by orcas led to lower kelp abundance

Pros and cons of different model types

Conceptual	Statistical	Dynamical
Pros: 1. Easy to produce and describe 2. Qualitative hypotheses	**Pros**: 1. Easy to test with empirical data 2. Quantitative predictions	**Pros**: 1. Mechanistic so easier to extrapolate 2. Quantitative predictions 3. Assumptions explicit
Cons: 1. Fuzzy description 2. Assumptions implicit 3. No quantitative predictions	**Cons**: 1. Cause and effect 2. Phenomenological interpretation 3. Hard to extrapolate	**Cons**: 1. Harder to develop 2. Hard to test empirically 3. Interpretation can be tricky

Levins' triangle

Levins (1966) developed the following classification for models:



A model can fulfill two of these three criteria:

- **Realism** & **Precision**: short term testable quantitative predictions
- **Realism** & **Generality**: generate broad qualitative predictions
- **Generality** & **Precision**: model the basic features of the system

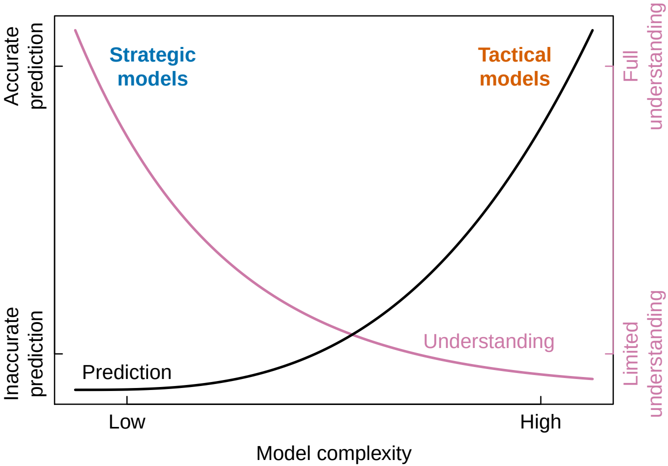
Holling's continuum

Holling (1966) developed the following continuum for classifying models:

Strategic models: simple caricatures for understanding basic principles

Tactical models: complex and system-specific for making predictions

Model complexity and accuracy vs. understanding



- Simpler models tend to be easier to analyze and understand
- Complex models tend to generate more accurate quantitative predictions but are harder to understand

Example of strategic models: Lotka-Volterra model

The Lotka-Volterra model can be used to determine the effects of trophic interactions on the dynamics of predators and their prey:

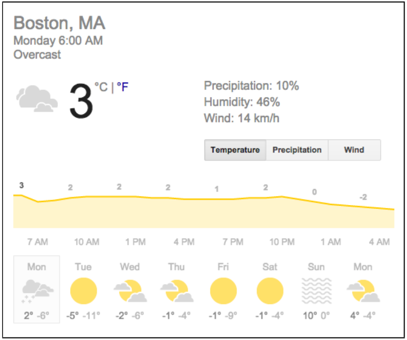
$$\frac{\mathrm{d}N}{\mathrm{d}t} = \alpha N - \beta NP$$
$$\frac{\mathrm{d}P}{\mathrm{d}t} = \delta NP - \gamma P$$

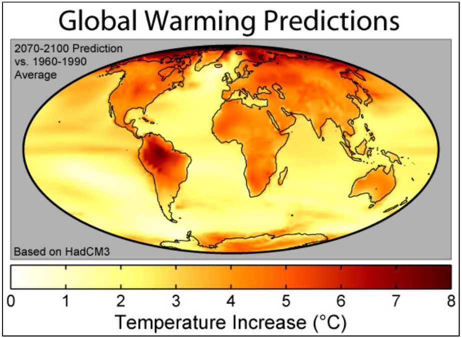
This **toy model** assumes a simple linear functional relationship between the predator P and the prey N (i.e., insatiable predator) and exponential prey growth in the absence of the predator.

The goal of this model is to **understand** but not necessarily **predict** predator-prey dynamics.

In Levins' classification, this model sacrifices **realism** in favor of **generality** and **precision**.

Example of tactical models: Weather and climate models

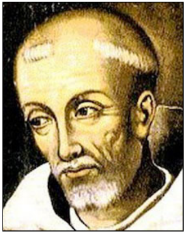




Weather and climate are classic examples where predictive/forecasting ability is critical and achieved via tactical models

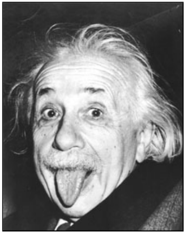
In Levins' classification, these models sacrifice **generality** in favor of **realism** and **precision**.

The parsimony principle in model building



William of Ockham

Ockham's razor: "Shave away all that is unnecessary."

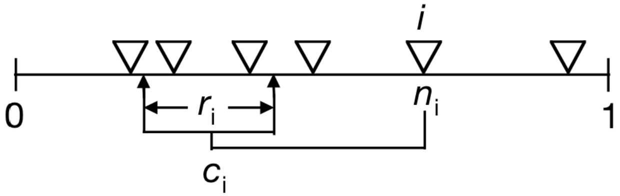


Albert Einstein

"Scientific theory should be as simple as possible, but no simpler."

- One of the goals of modeling is to extract and understand the **essence** of natural systems
- To do so, models **deconstruct** the natural world and attempt to rebuild it with as few parts as possible in order to understand the key components and relationships

Example: The structure of ecological food webs



- Williams and Martinez (2000) developed a simple model that allowed them to build realistic food webs based on only two parameters: number of species S and connectance C
- Each species i is given a random position n_i along a single niche axis using a uniform distribution between 0 and 1
- Species i consumes all species falling in a range r_i that is placed by drawing the center of the range c_i randomly in the interval $[r_i/2, n_i]$
- This shows the minimal rules needed to produce observed patterns
- Suggests new types of data to collect and allows us to better understand more complex models via comparisons to this baseline

Conclusions

- Models are tools that scientists use to make sense of the real world
- Mathematical models can help clarify assumptions, synthesize conflicting hypotheses and generate quantitative forecasts about the natural world
- Models can be used to address theoretical and applied problems; their value is not necessarily tied to empirical validation
- There are inherent trade-offs when building models: the “right” model depends on the goal at hand

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