Pattern-Oriented Modeling

EES 4760/5760

Agent-Based and Individual-Based Computational Modeling

Jonathan Gilligan

Class #20: Wednesday, October 30 2024

Pattern-Oriented Modeling

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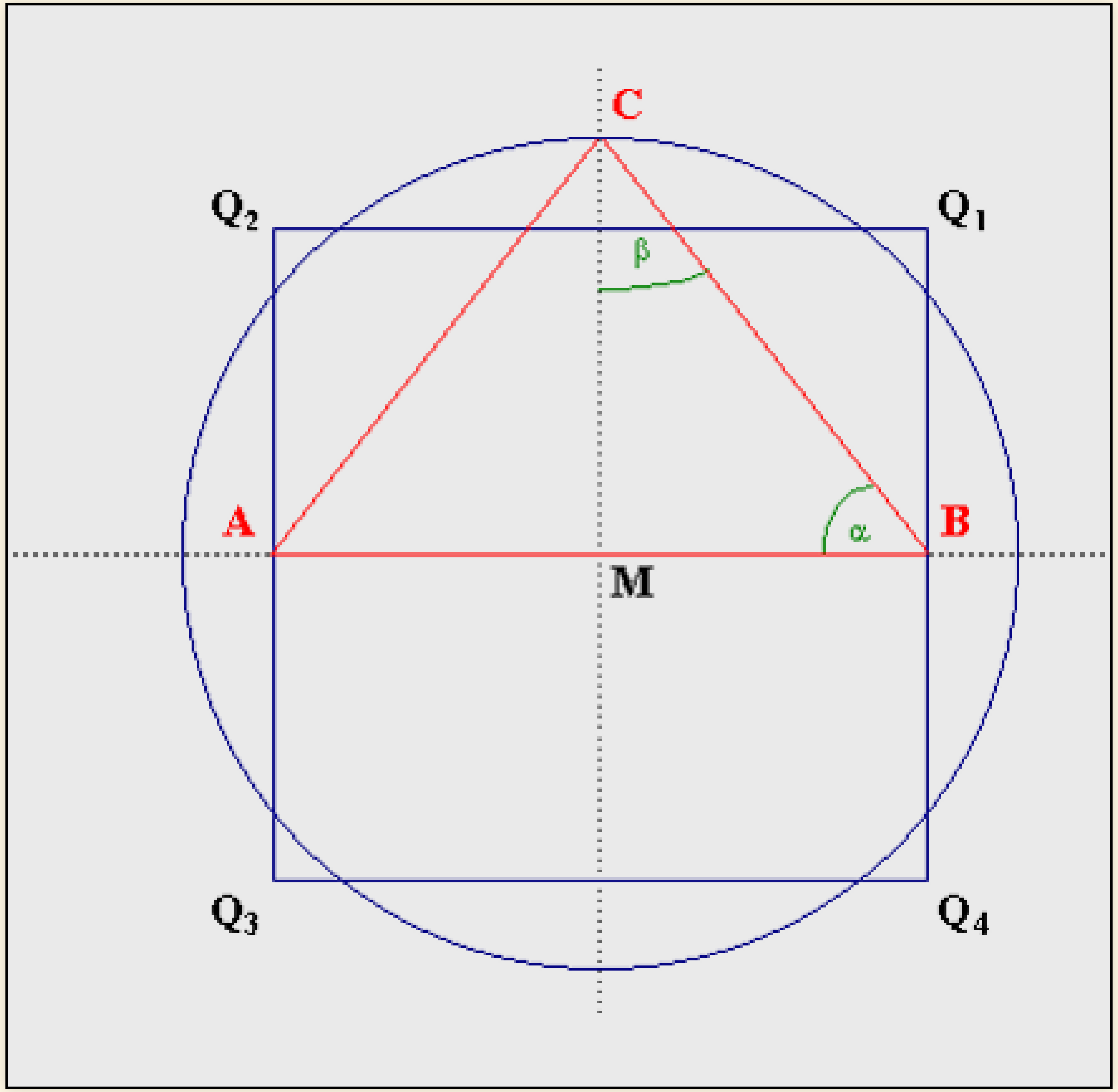
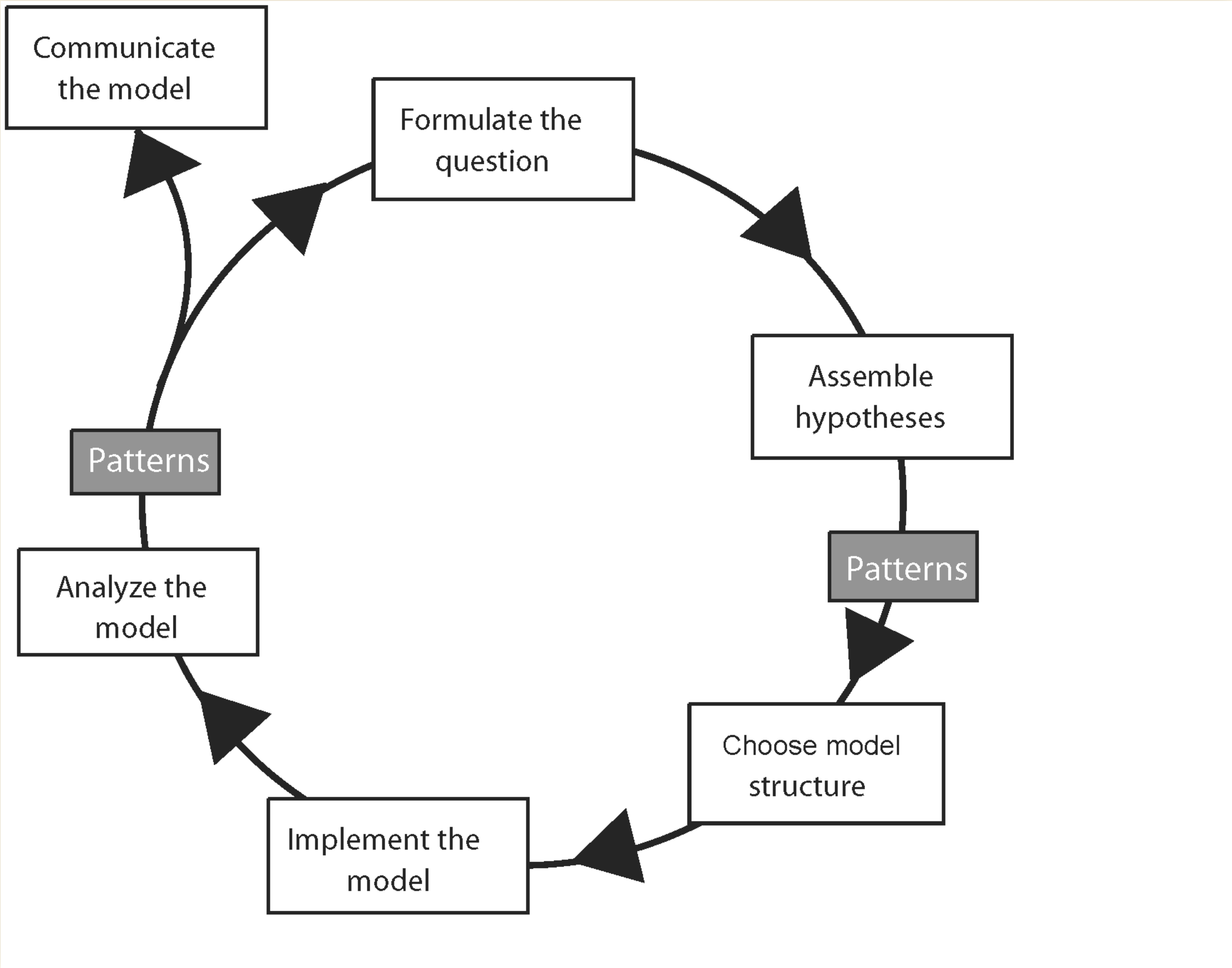
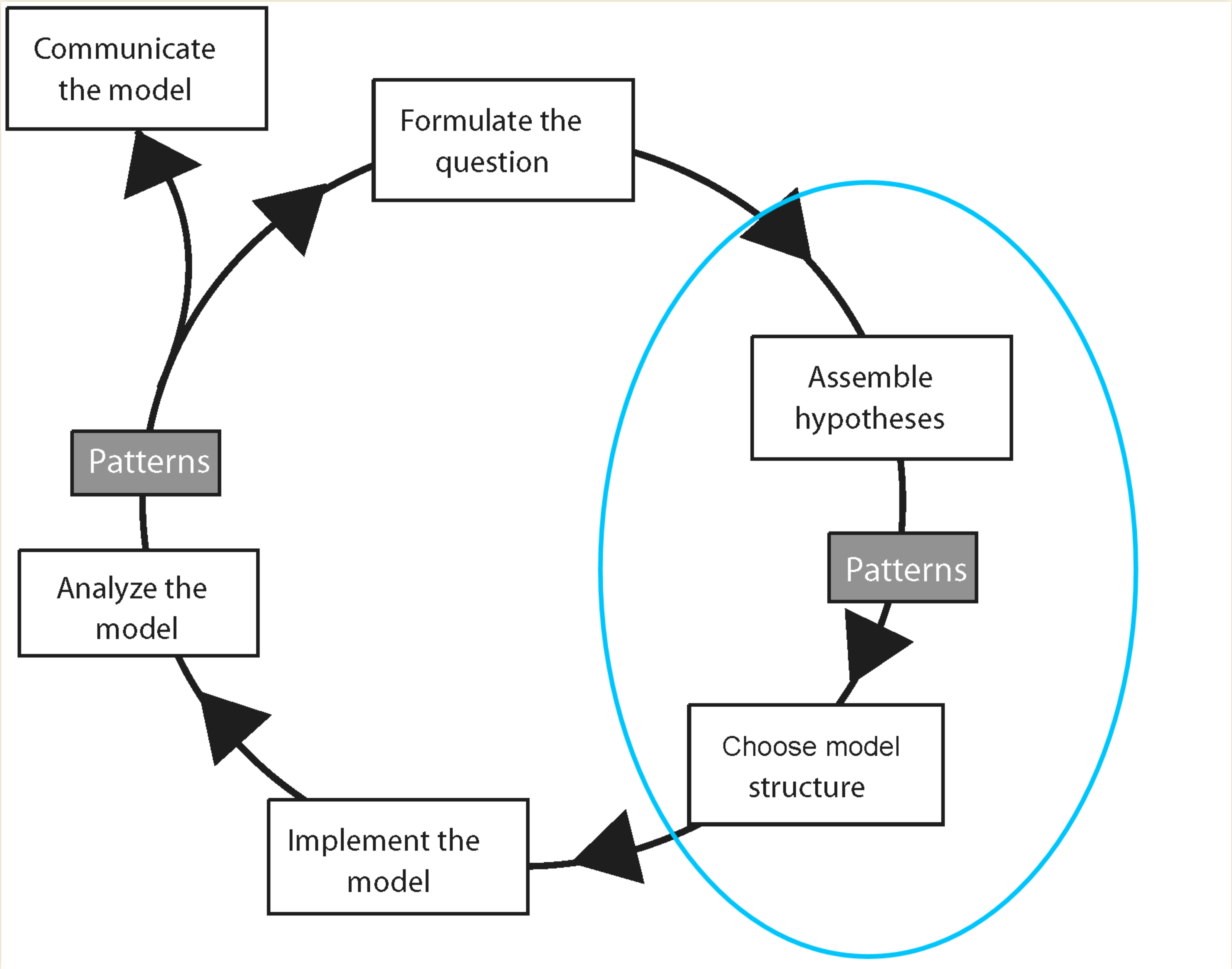


The Modeling Cycle



The Modeling Cycle



Validatioon and Verification

Goals of Modeling

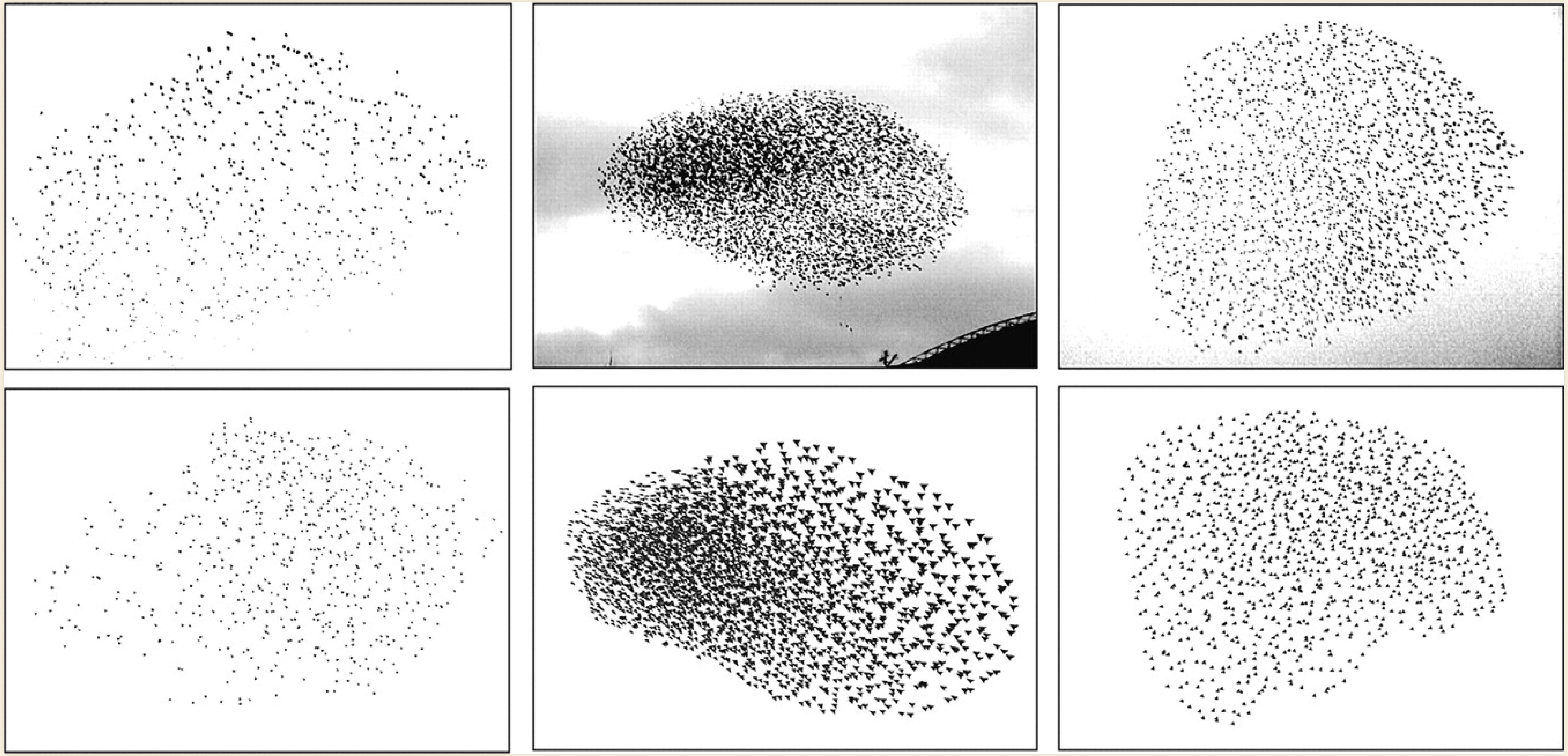
- Goals:
  - Models are “sufficiently good” representations of real counterparts
  - Learn about real world:
    - Capture essential elements of real system’s *internal organization*
    - Capture *generative mechanisms* that produce structure and behavior of real systems

Problem: Validation and Verification

- **Version 1:**
  - The model *mimics the real world well enough for its stated purpose*
- **Version 2**
  - We can place confidence in *inferences about real system based on model results*

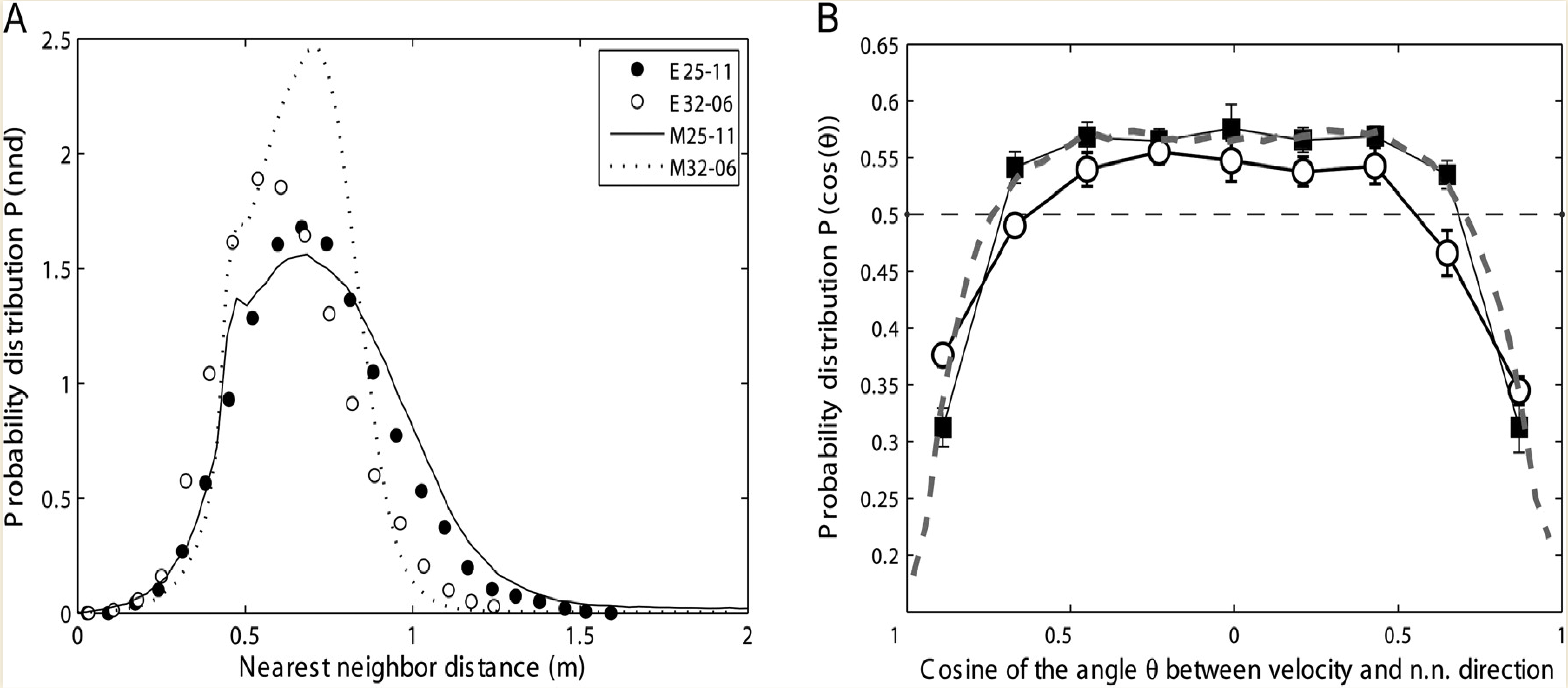
E.J. Rykiel "Testing ecological models: The meaning of validation" Ecological Modeling **90**, 229 (1996)

Starling Flocks



H. Hildenbrandt *et al.*, "Self-organized aerial displays of thousands of starlings: a model," Behav. Ecol. **21**, 1349–1359 (2010).

Validation of Starling Model



H. Hildenbrandt *et al.*, "Self-organized aerial displays of thousands of starlings: a model," Behav. Ecol. **21**, 1349–1359 (2010).

Fundamental Problem

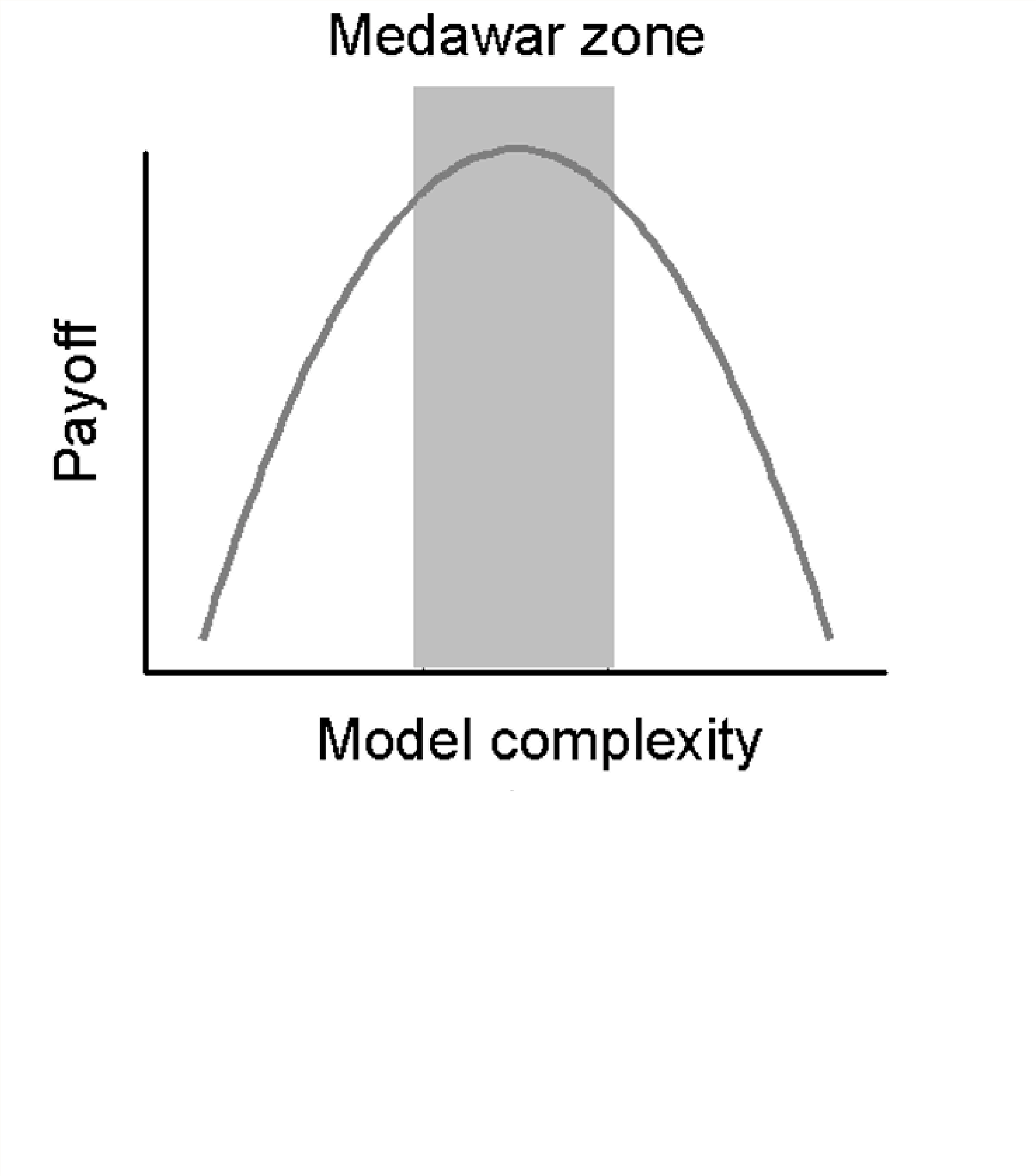
- Our model might reproduce the *right pattern* for the *wrong reasons*
- How can we be sure to capture the *real generative mechanisms*?
- How can we design models so that we can *optimize* model complexity?

The Medawar Zone

P. Medawar (1967):

Optimal level of difficulty for a good research problem:

- Not difficult enough:
  - Result is trivial, uninteresting.
- Too difficult:
  - Unlikely to solve it



P. Medawar, *The Art of the Soluble* (Oxford, 1967)

Mechanistically Rich Models

- If model structure is too simple it will not capture essential mechanisms
  - There will be too few ways to test the model
- Complexity of model is not bad *per se* and can increase the payoff

D.L. De Angelis and W.M. Mooij, "In Praise of Mechanistically Rich Models," in C.D. Canham, J.J. Cole, and W.K. Lauenroth (eds.), *Models in Ecosystem Science* (Princeton, 2003)

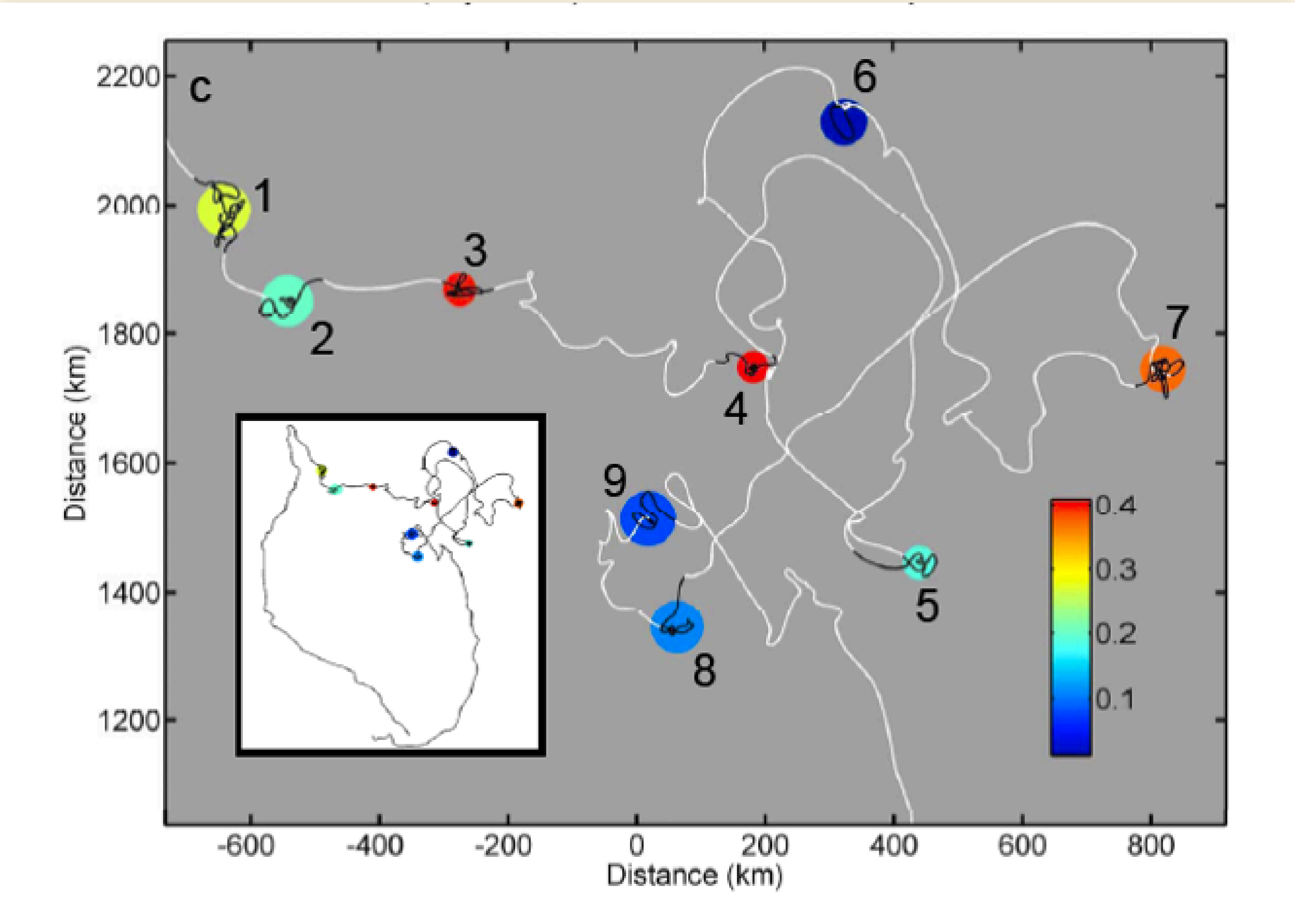
Spatial Patterns in Ecology

Spatial Patterns in Ecology

Wave forest of *Empetrum nigrum* (Crowberry), Mistaken Point Ecological Reserve, Newfoundland. Photo: John Maunder.

http://www.digitalnaturalhistory.com/images/empetrumnigrumlivedeadwaveforestmistakenpoint.jpg

Spatial Patterns in Ecology



M. Antolos, S.A. Shaffer, H. Weimerskirch, Y. Tremblay, and D.P. Costa, "Foraging Behavior and Energetics of Albatrosses in Contrasting Breeding Environments," Front. Mar. Sci. **4**, 414 (2017). doi: 10.3389/fmars.2017.00414

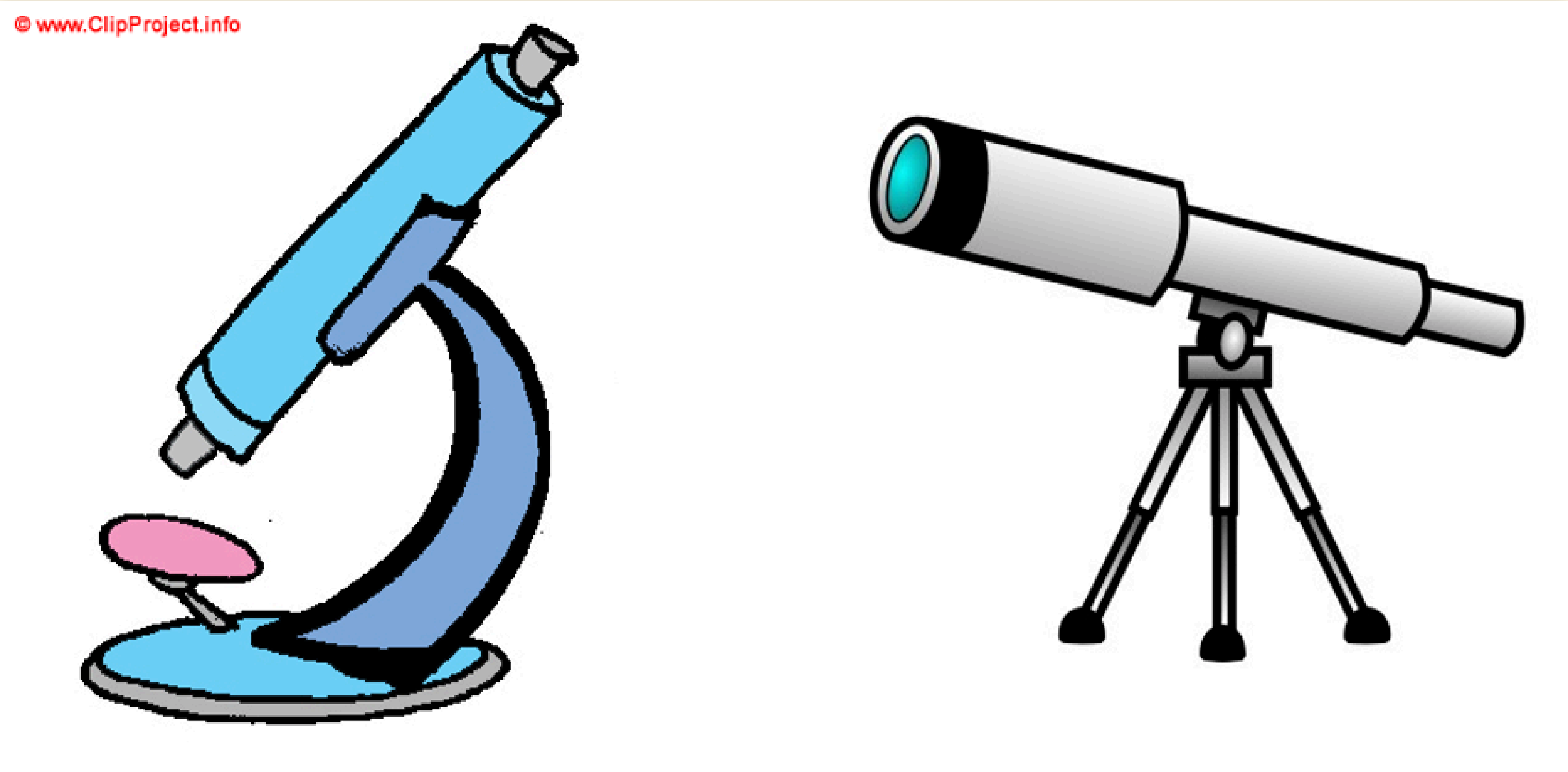
What Scientists do with Patterns

- **Pattern:** Something beyond random variation
- Pattern contains information about internal organization
- Develop models that reproduce observed pattern
- Inference: Real system's internal mechanisms are like model's
- ***Squeeze*** the pattern!

Complex Systems

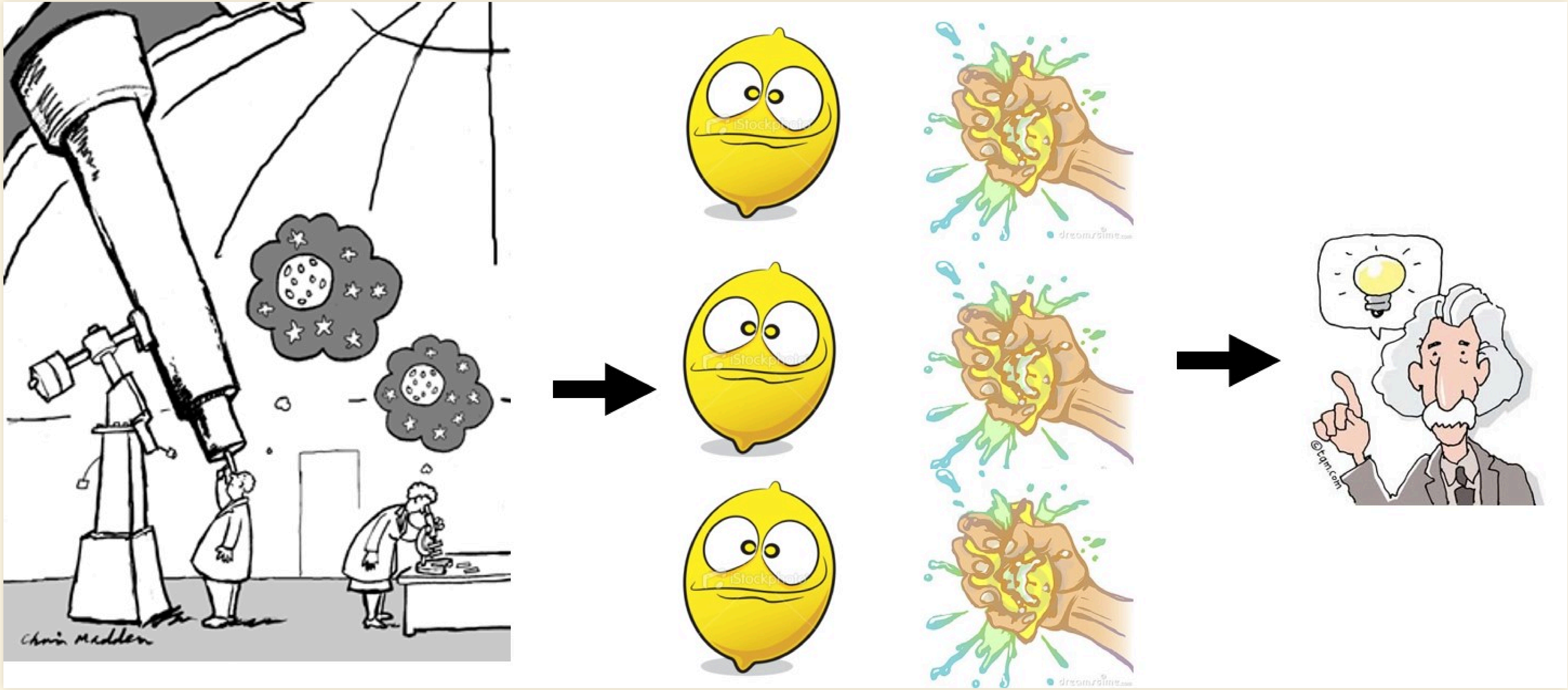
- A single pattern may not contain enough information
- Tendency to focus on *single* patterns observed at *one level* of observation:
  - Individual Behaviors
  - Population dynamics
  - Community composition

Monoscopic View



Most approaches (and modelers) are not making the best use of available information (lemons)

We Need a Multiscope



Multiscope View

- Consider multiple patterns
  - Observed at different scales, levels of organization
- Get model to reproduce multiple patterns simultaneously
- Use each pattern as a *filter* to reject faulty submodels or parameterizations
- Multiple (3 or more) *weak* patterns may constrain model better than single *strong* pattern
- ***Pattern-Oriented Modeling***

Pattern-Oriented Modeling

REVIEW

Pattern-Oriented Modeling of Agent-Based Complex Systems: Lessons from Ecology

Volker Grimm,[1*] Eloy Revilla,[2] Uta Berger,[3] Florian Jeltsch,[4] Wolf M. Mooij,[5] Steven F. Railsback,[6] Hans-Hermann Thulke,[1] Jacob Weiner,[7] Thorsten Wiegand,[1] Donald L. DeAngelis[8]

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2012) **367**, 298–310
doi:10.1098/rstb.2011.0180

Research

Pattern-oriented modelling: a 'multi-scope' for predictive systems ecology

Volker Grimm[1,*] and Steven F. Railsback[2]

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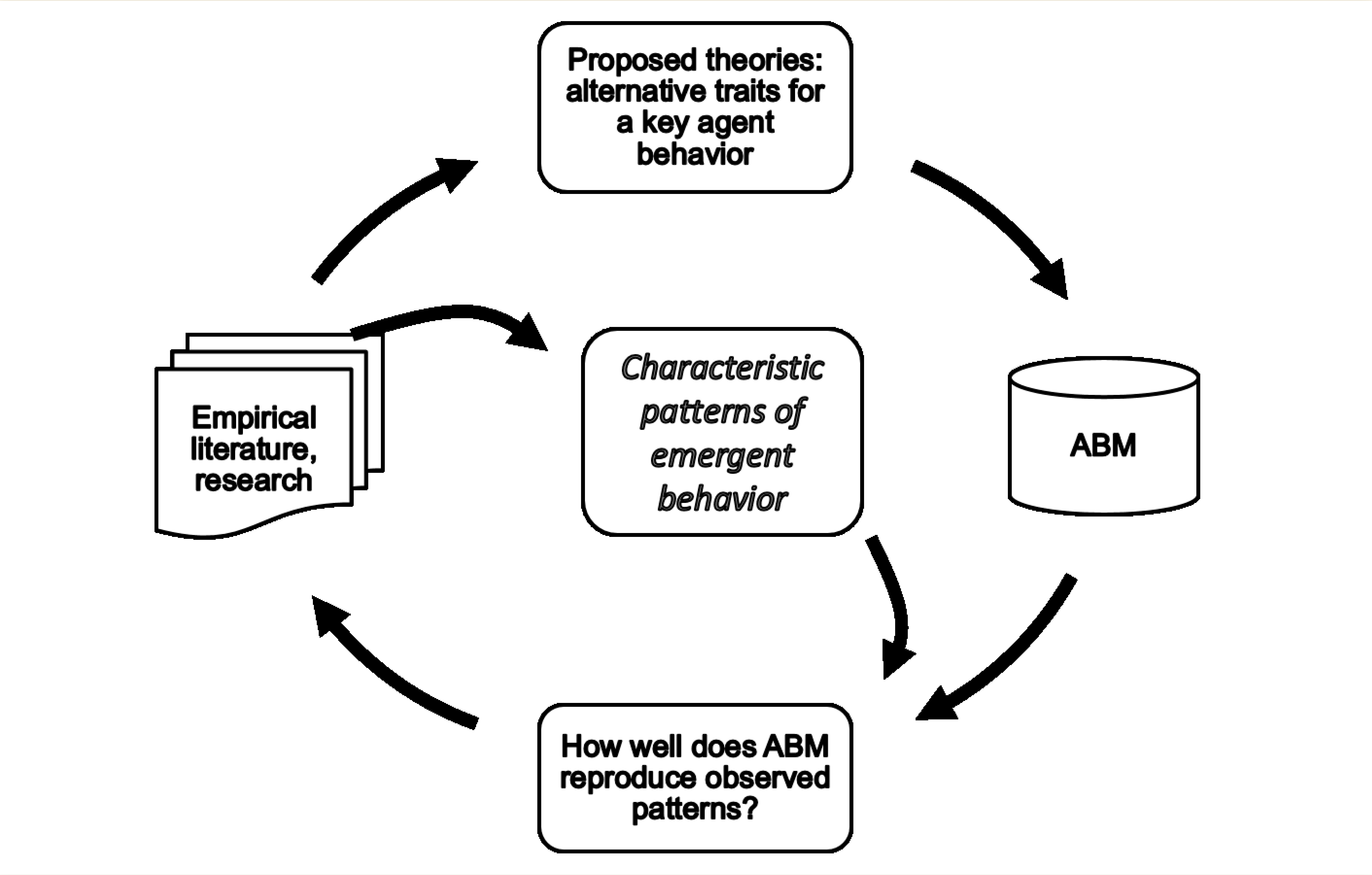
[2]*Department of Mathematics, Humboldt State University and Lang, Railsback and Associates, 250 California Avenue, Arcata CA 95521, USA*

Modern ecology recognizes that modelling systems across scales and at multiple levels—especially to link population and ecosystem dynamics to individual adaptive behaviour—is essential for making the science predictive. 'Pattern-oriented modelling' (POM) is a strategy for doing just this. POM is the multi-criteria design, selection and calibration of models of complex systems. POM starts with identifying a set of patterns observed at multiple scales and levels that characterize a system with respect to the particular problem being modelled; a model from which the patterns emerge should contain the right mechanisms to address the problem. These patterns are then used to (i) determine what scales, entities, variables and processes the model needs, (ii) test and select submodels to represent key low-level processes such as adaptive behaviour, and (iii) find useful parameter values during calibration. Patterns are already often used in these ways, but a mini-review of applications of POM confirms that making the selection and use of patterns more explicit and rigorous can facilitate the development of models with the right level of complexity to understand ecological systems and predict their response to novel conditions.

Three Elements of Pattern-Oriented Modeling

1. **Design:** Choose state variables that allow real-world patterns to emerge in models.
2. **Selection:** Use multiple patterns to compare & reject submodels
3. **Parameterization:** Use multiple patterns to constrain entire sets of unknown parameters (*inverse modeling*)

From Theories to Models and Back Again



Example: Vultures and Carcasses

Vultures Feeding at a Carcass

Modeling Vulture Feeding: Roles

Role	Description
Searcher	A vulture without personal or social information about carcass location
Finder	A vulture that has seen either the carcass, feeders on a carcass, or finders sinking in vertical flight to a carcass
Follower	A vulture that is following other vultures (either finders or other followers)
Feeder	A finder that has already arrived at a carcass

Modeling Vulture Feeding Behavior: Variables

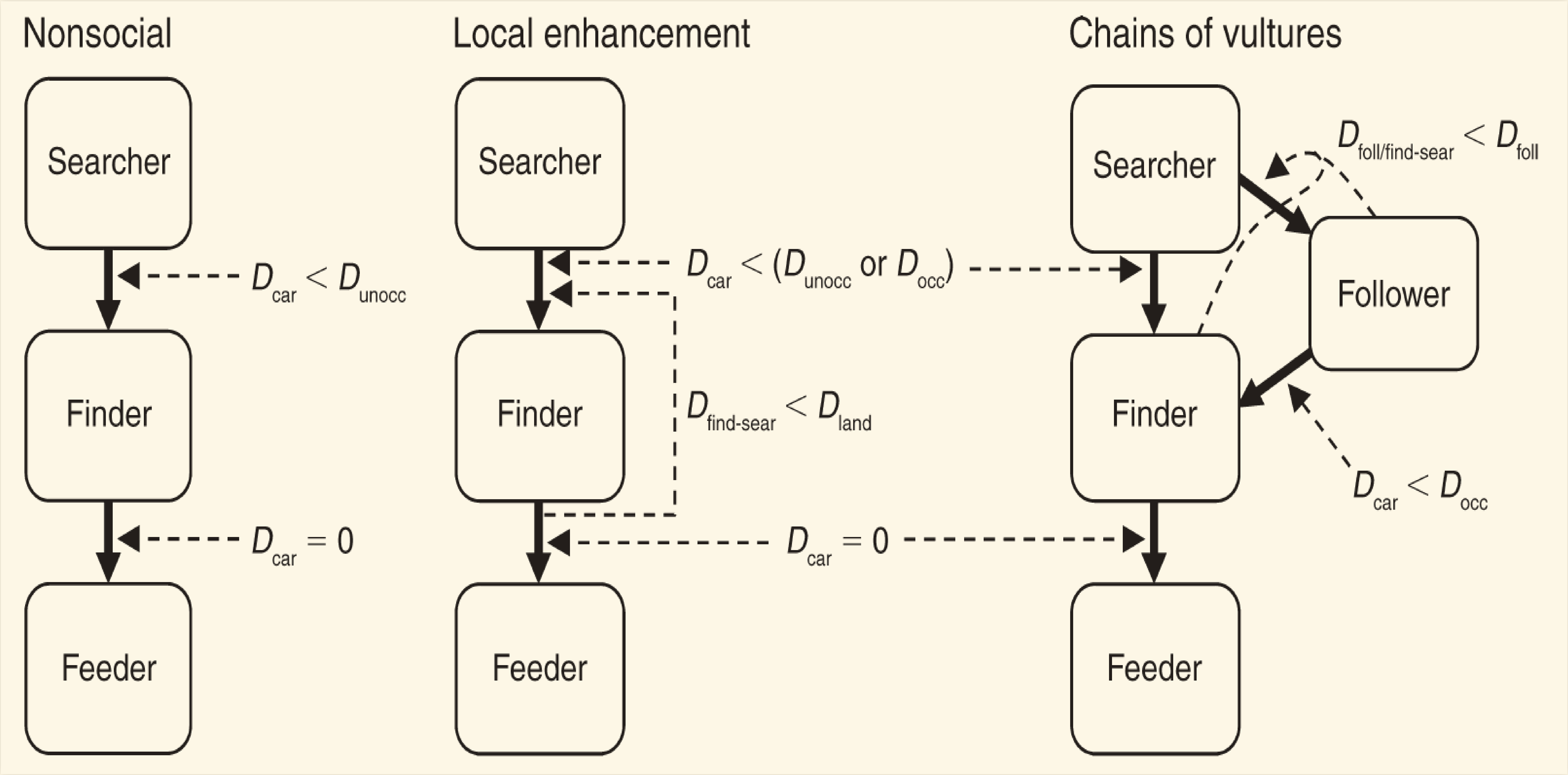
Variables

Variable	Meaning
D_{car}	Distance to nearest carcass
$D_{find\text{-}sear}$	Distance to a finder that's landing to feed
$D_{foll/find\text{-}sear}$	Distance to the nearest follower or finder

Fixed Parameters

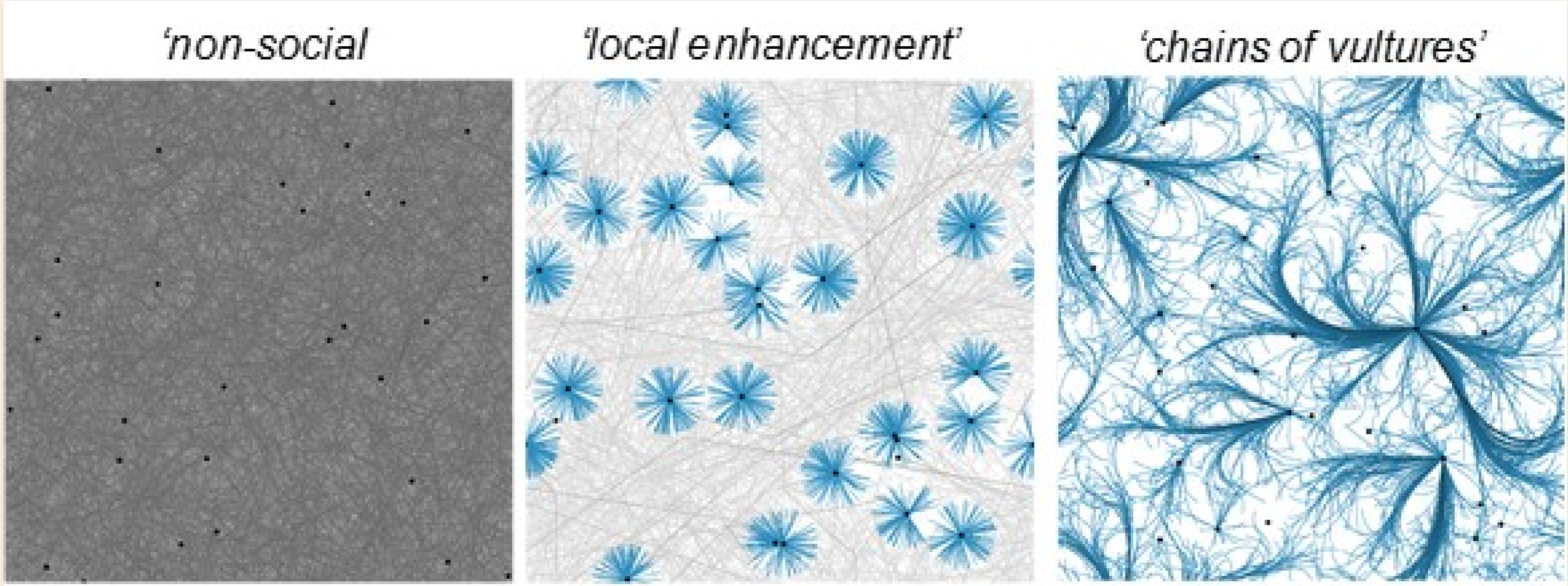
Parameter	Meaning
D_{unocc}	Farthest distance for vulture to see an unoccupied carcass
D_{occ}	Farthest distance for vulture to see an occupied carcass, $D_{occ} > D_{unocc}$
D_{foll}	Farthest distance for vulture to see a finder or follower flying toward a carcass, $D_{foll} > D_{occ}$
D_{land}	Farthest distance for vulture to see a finder/follower landing on a carcass, $D_{land} = D_{foll}$

Modeling Vulture Feeding Behavior: Submodels

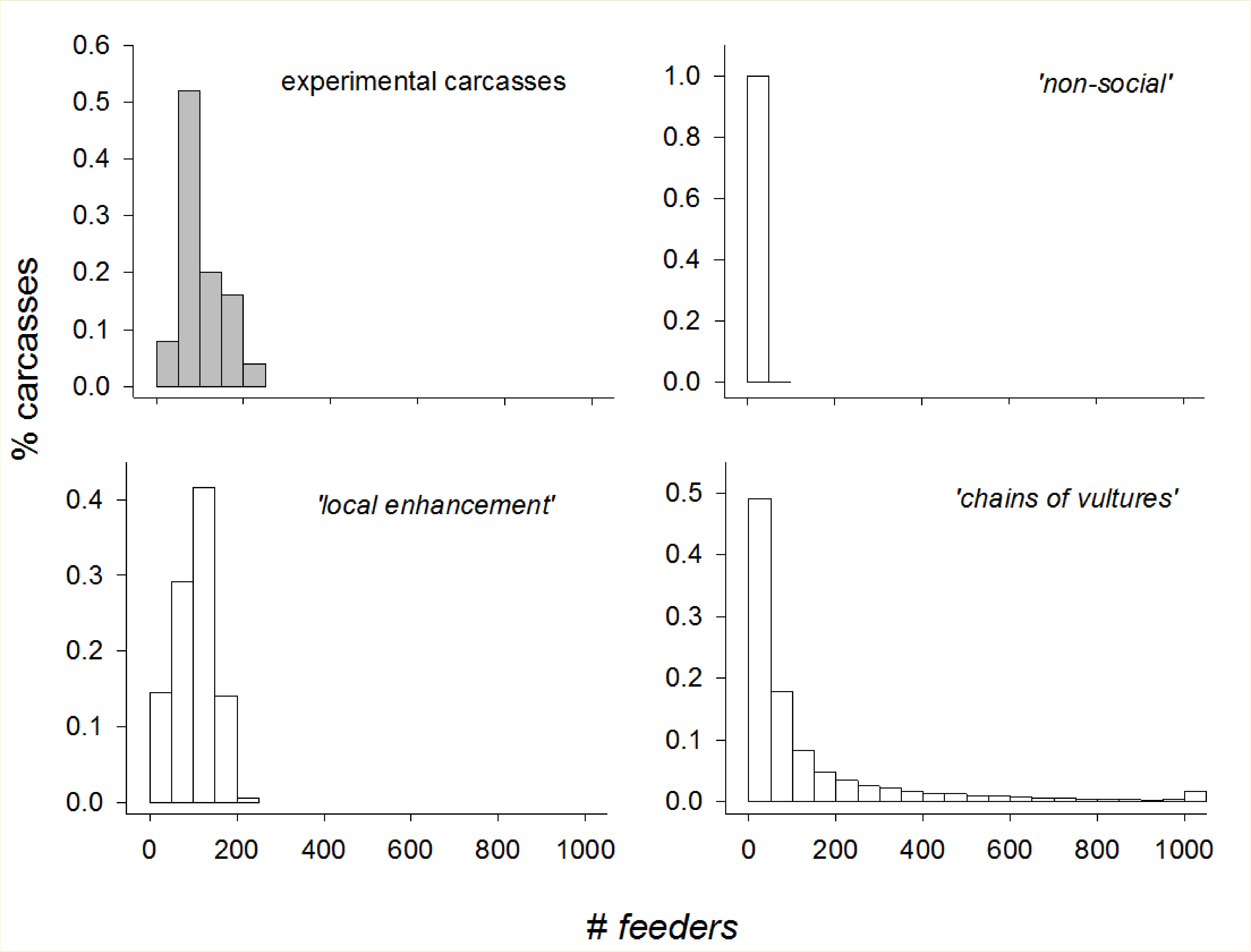


A. Cortes-Avizanda *et al.*, “Bird sky networks: How do avian scavengers use social information to find carrion?” Ecology **95**, 1799–1808 (2014)

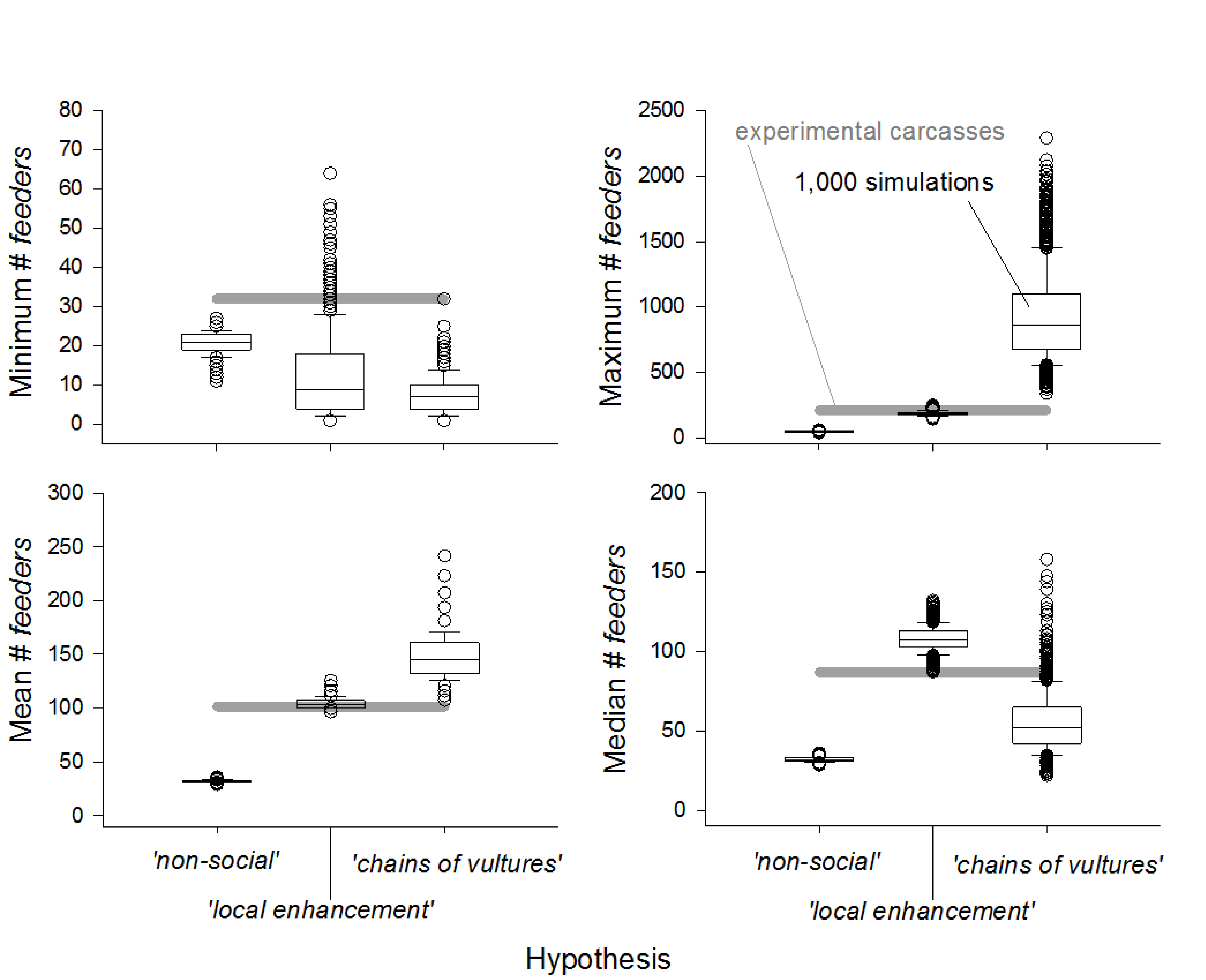
Interactions among Vultures



Patterns of Feeding



Model Comparisons

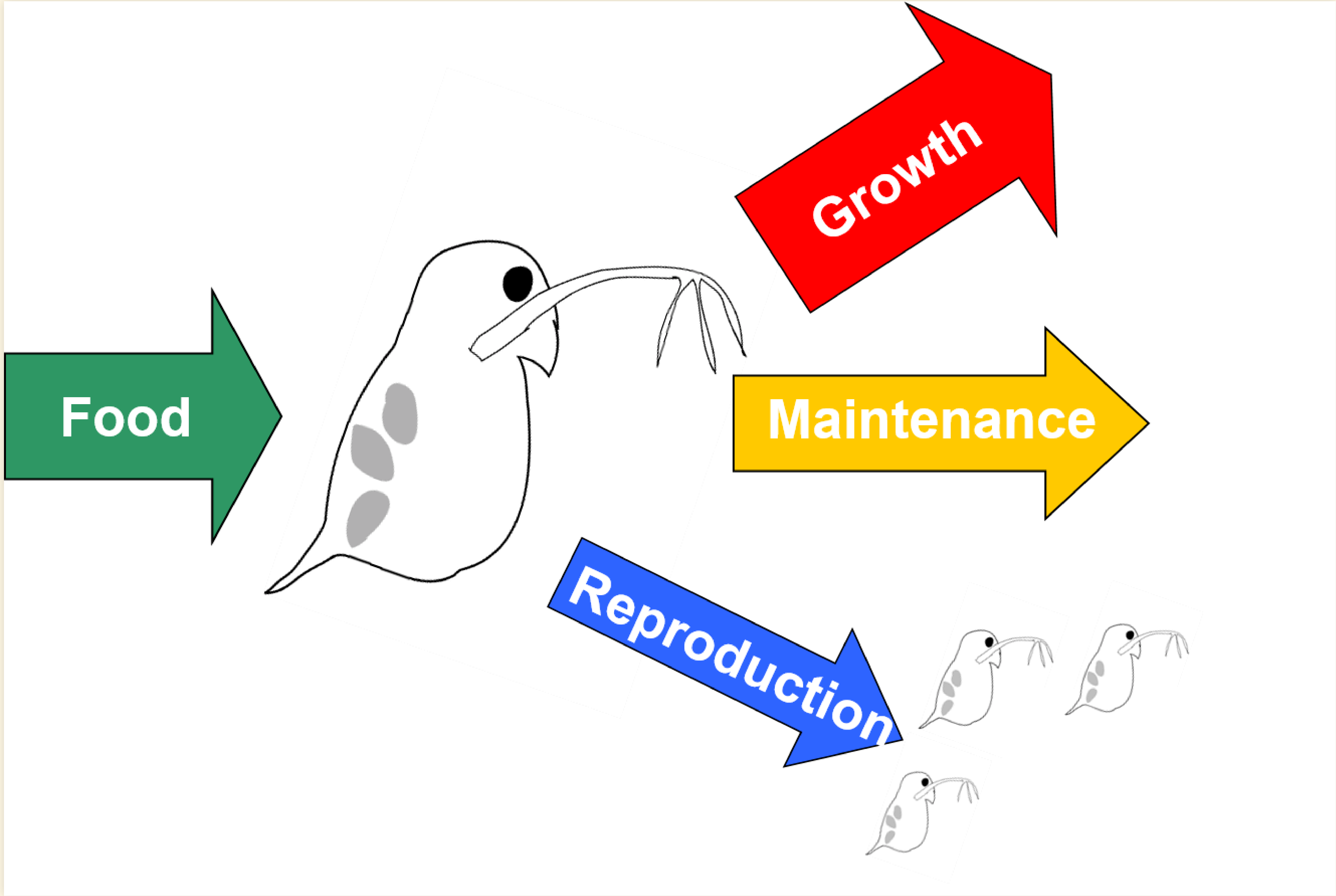


Impacts of Pesticides on Aquatic Ecosystems

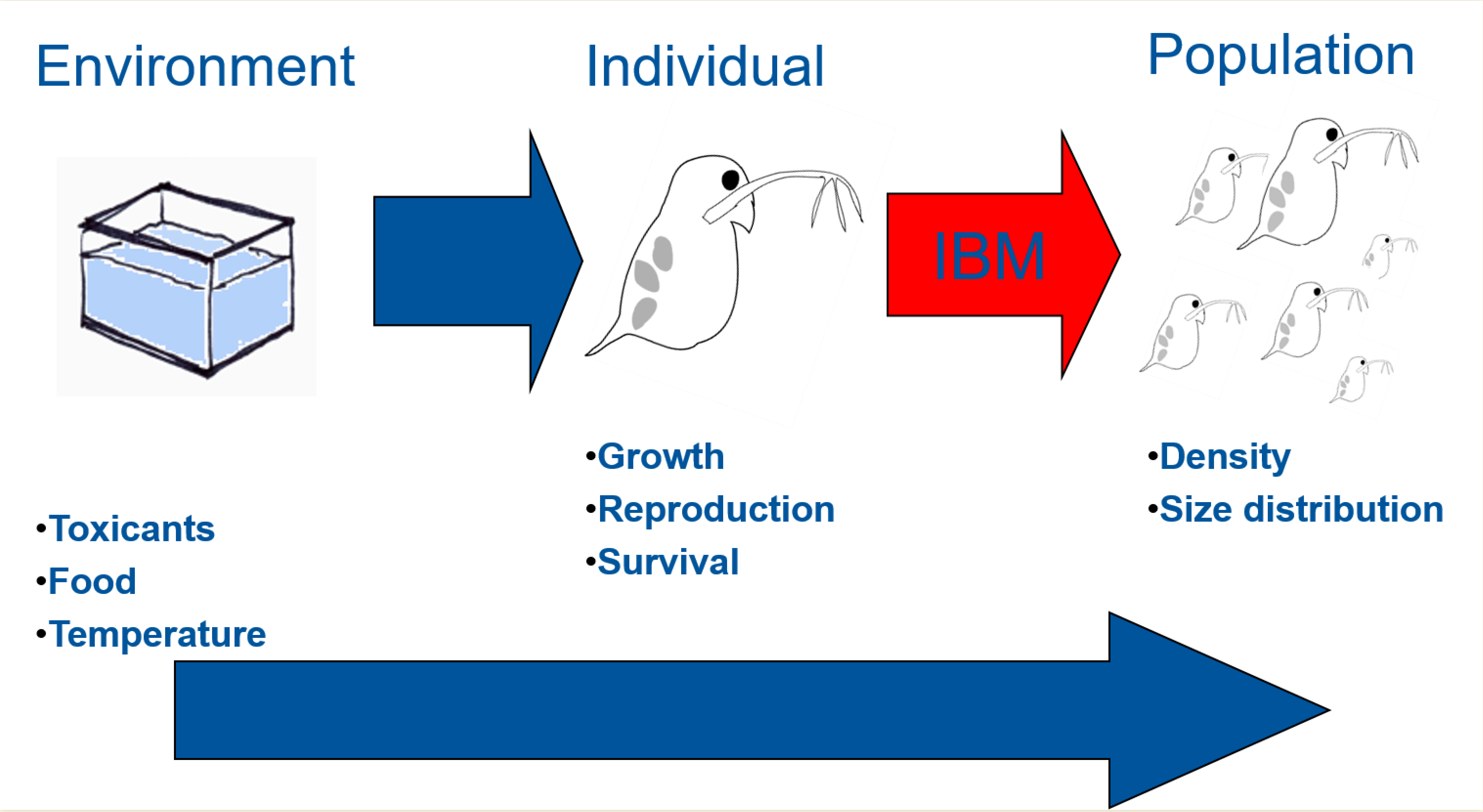
Dynamic Energy Budget Model

- *Daphnia* (water flea) population dynamics observed in laboratory
- Previous models focused on details of each species
- Dynamic Energy Budget is generic:
  - Calibrate with known species, apply to new (unknown) species

Individual Metabolic Energy Balance

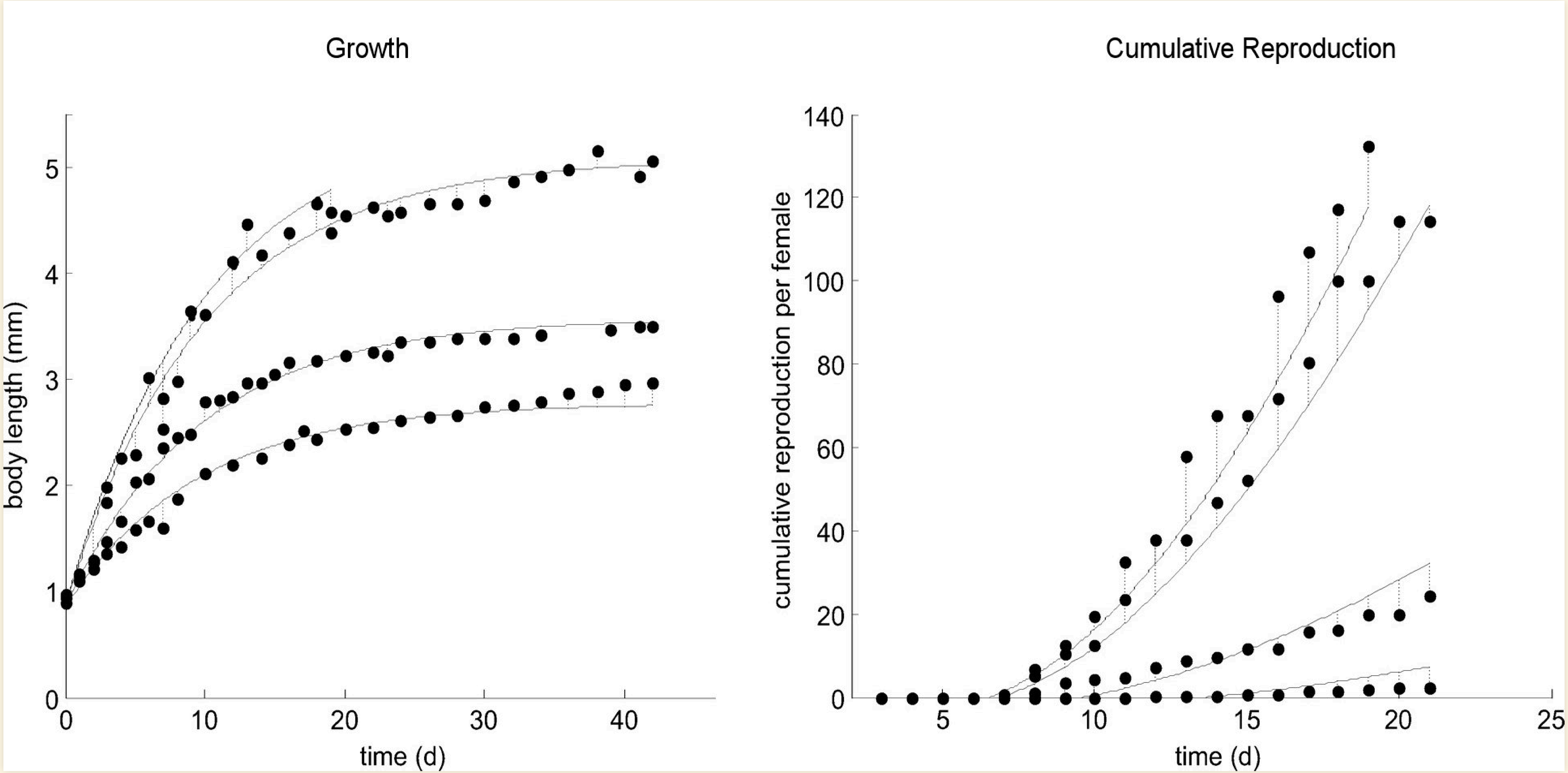


Dynamic Energy Balance Model in NetLogo



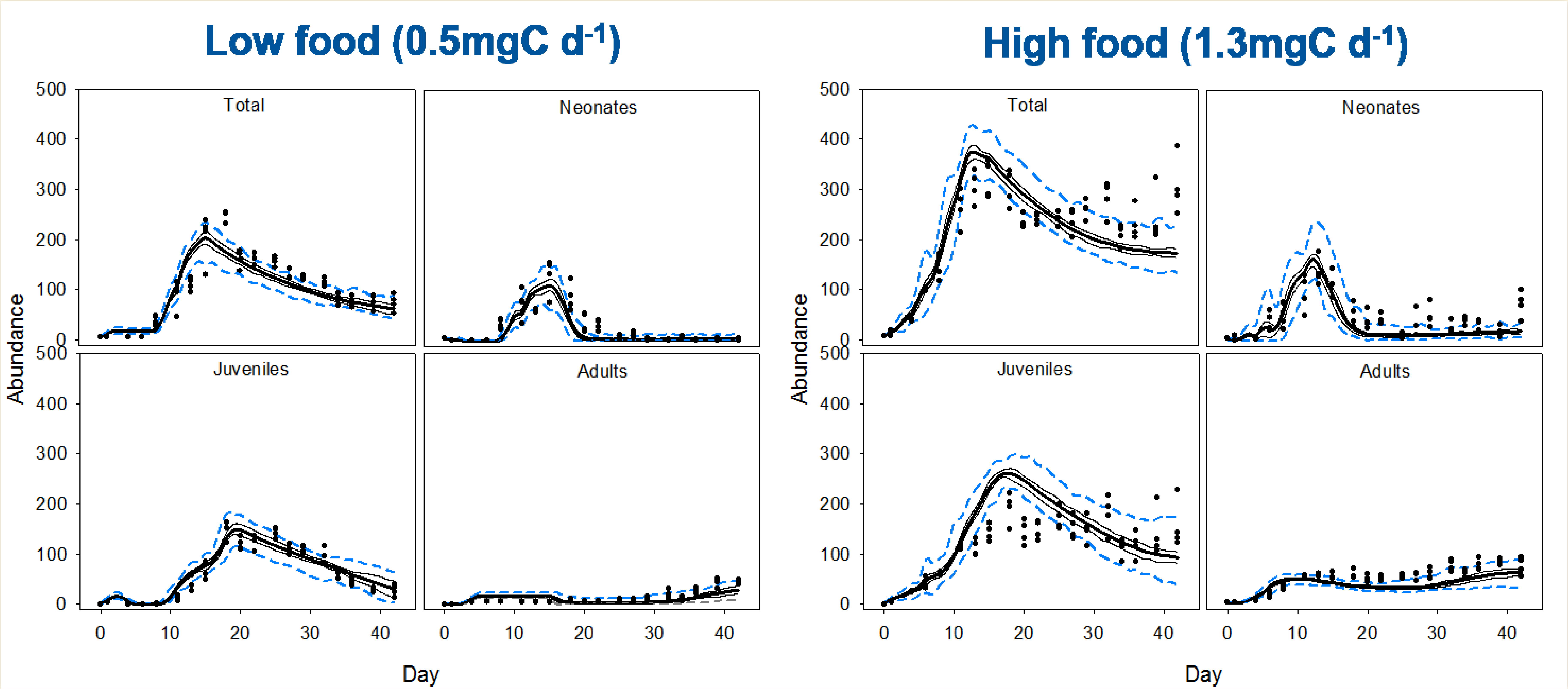
B.T. Martin *et al.*, "Predicting Population Dynamics from the Properties of Individuals: A Cross-Level Test of Dynamic Energy Budget Theory", Am. Naturalist **181**, 506–519 (2013)

Testing the Model



Different Environmental Conditions

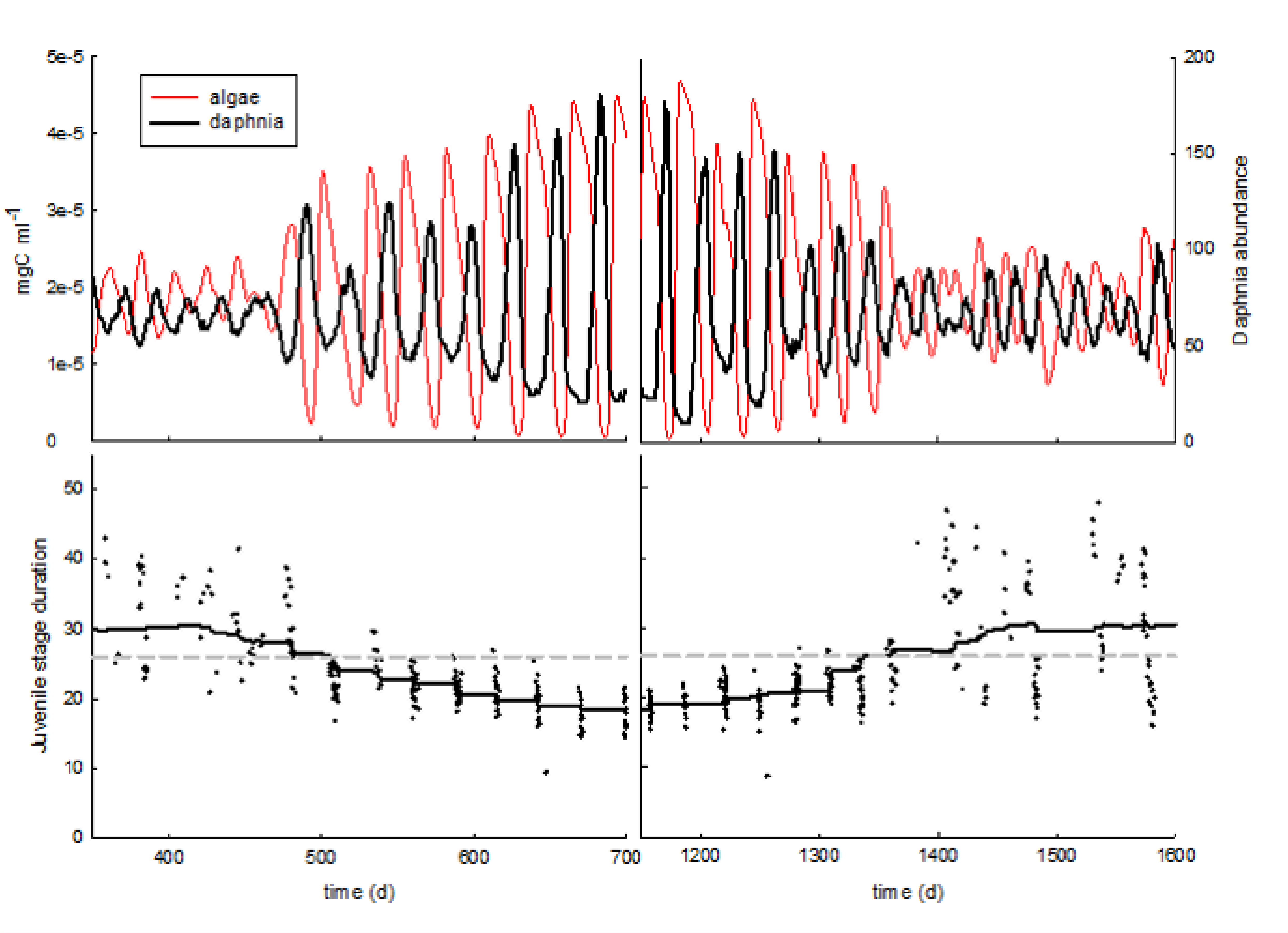
Model reproduces population density and body size distribution at multiple levels of food supply and toxicant exposure



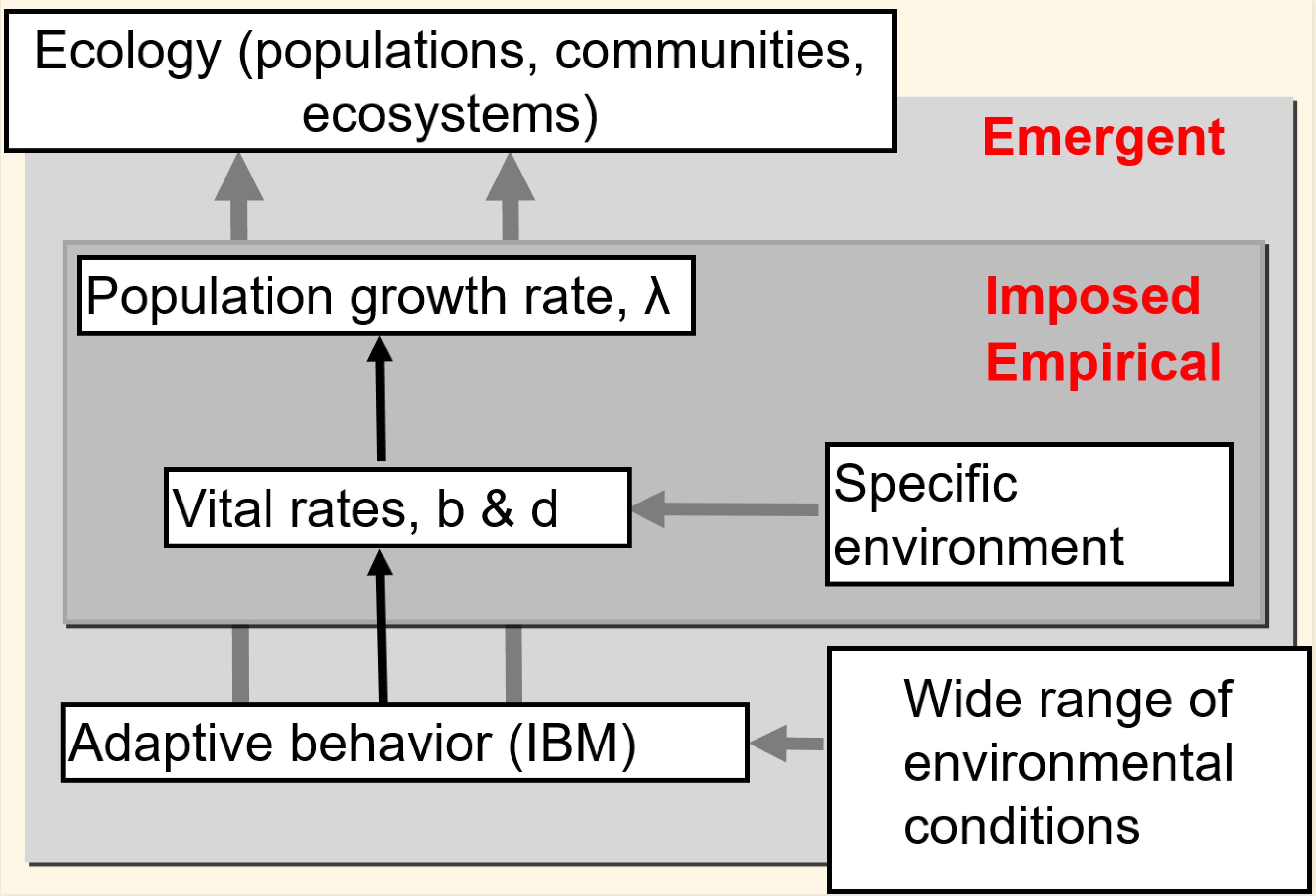
Dynamical Patterns: Population Cycles

- Experiments find that predator-prey population cycles can occur between *Daphnia* (predator) and algae (prey).
- These can have small amplitude (SA) or large amplitude (LA)
- A pattern is that when the population is the relation of amplitude to the duration of the juvenile stage of *Daphnia* development
  - In SA oscillations, juvenile stage lasts longer than average.
  - In LA oscillations, the juvenile stage is shorter than average.

Simulations of Population Cycles



How Model Fits into Research



Pattern-Oriented Process

Individual-Based Ecology

Overview Articles

2015. BioScience 65: 140-150

Making Predictions in a Changing World: The Benefits of Individual-Based Ecology

RICHARD A. STILLMAN, STEVEN F. RAILSBACK, JARL GISKE, UTA BERGER, AND VOLKER GRIMM




Phase-1: Conceptualization

- Define research question(s)
  - Determine whether agent-based/individual-based modeling is the right conceptual framework
- Identify link between research question and behavioral mechanisms
- Identify key parameters and processes to represent environment and behavior of the agents (biological species, human actors, etc.)

Phase-2: Implementation

- Start with proof-of-concept:
- Program initial model
  - Ideally, starting model should contain little or no code or submodels specific to a single situation
- Test whether model can produce predictions that are *accurate enough* to answer research question
- Run sensitivity analysis of model to determine *key parameters and processes* and relationship between model complexity and predictive power

Phase-3: Diversification

- Simplify model as much as possible by removing unnecessary parameters and processes
- Minimize number of parameters (e.g., global variables) that need to be measured in each new system
  - Derive as many of these as you can from research literature or general relationships
- Parameterize and test simplified model for a wide range of systems to determine limits of approach
- Perform *meta-analysis* of model runs specific to different sites, or situations
- Use model to test more general theories: gain broadly applicable insights.