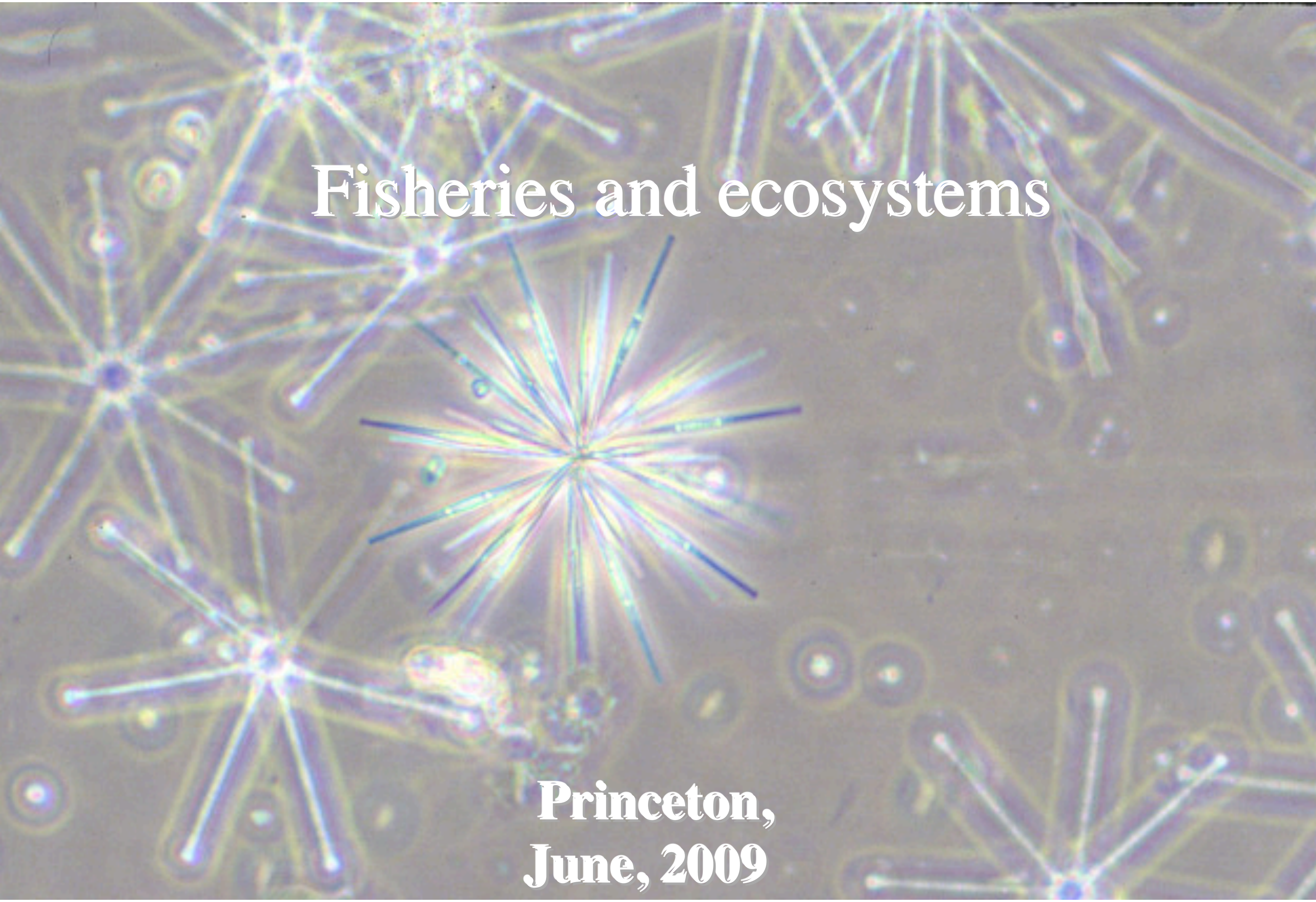

Fisheries and ecosystems
Princeton,
June, 2009

The Roots of Mathematical Ecology were in Marine Ecosystems

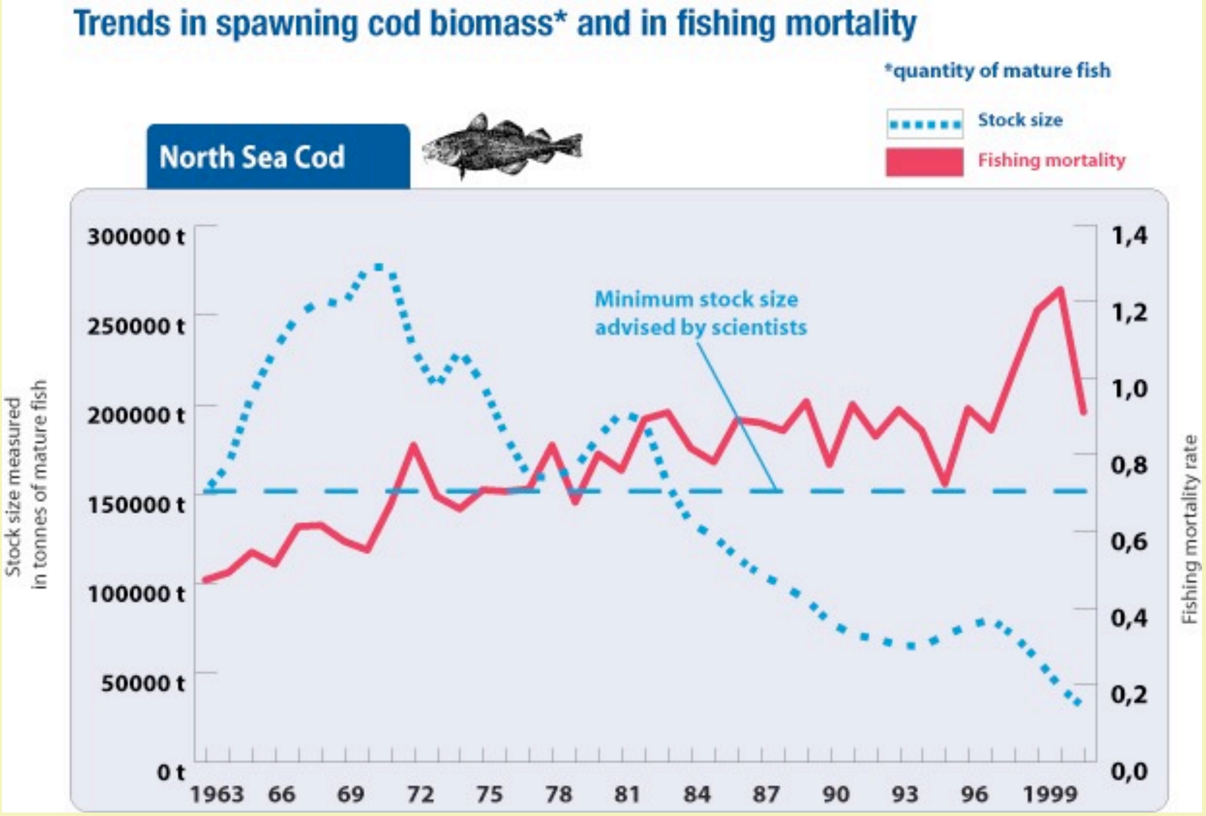
Vito Volterra

(1860-1940)

Volterra was enticed by his son-in-law, Umberto D'Ancona, to explain the fluctuations in the Adriatic Fisheries

Despite this elegant theory, marine management has been a disaster

Vito Volterra



http://europa.eu.int/comm

Vito Volterra

Despite elegant theory, we have not sustained these resources

- Marine ecosystems are complex systems, characterized by nonlinearities and sudden flips

http://www.iee.uu.se/zooekoll

Despite elegant theory, we have not sustained these resources

- They are complex adaptive systems, integrating phenomena at multiple scales

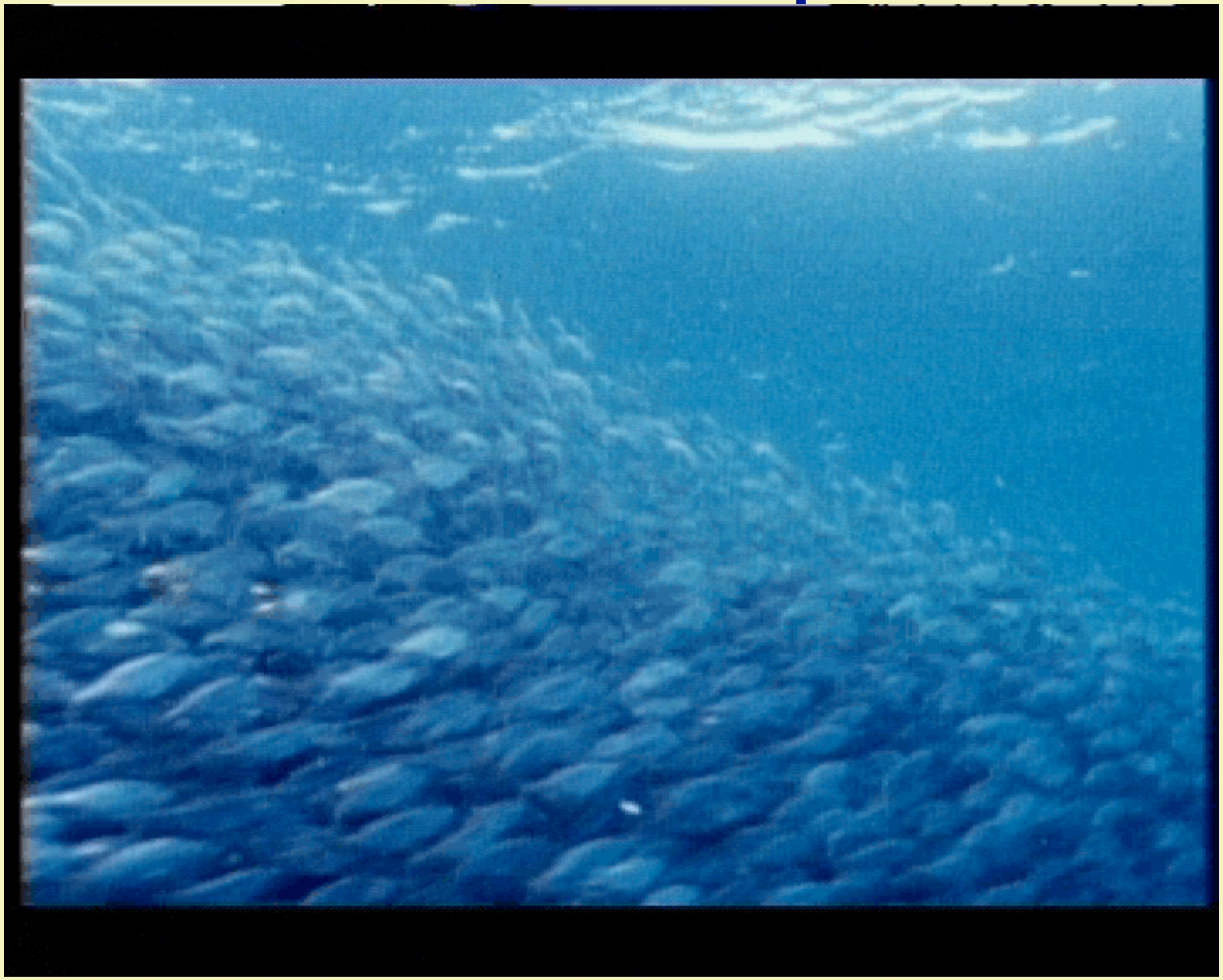
This implies a need to relate phenomena across scales, from

- Cells and nutrients to organisms to collectives to ecosystems, N-P-Z-F

and to ask

- How robust are the properties of ecosystems?
- How does the answer to this vary as a function of scale -- spatial, temporal, and organizational?
- How does robustness of macroscopic properties relate to ecological and evolutionary dynamics on finer scales?

Scaling from microscopic to macroscopic



Iain Couzin, BBC

Lagrangian-Eulerian connections

- Begin from microscopic (Lagrangian) rules

$$m\ddot{x} = \underbrace{F_1}_{\text{Random}} + \underbrace{F_2}_{\text{Directed}} + \underbrace{F_3}_{\text{Grouping}} + \underbrace{F_4}_{\text{Arrayal}}$$

Flierl et al.: Boltzmann equation

$$\frac{\partial}{\partial t} n(\mathrm{x},\mathrm{v},t) = -\frac{\partial}{\partial x_i}[v_i n(\mathrm{x},\mathrm{v},t)$$

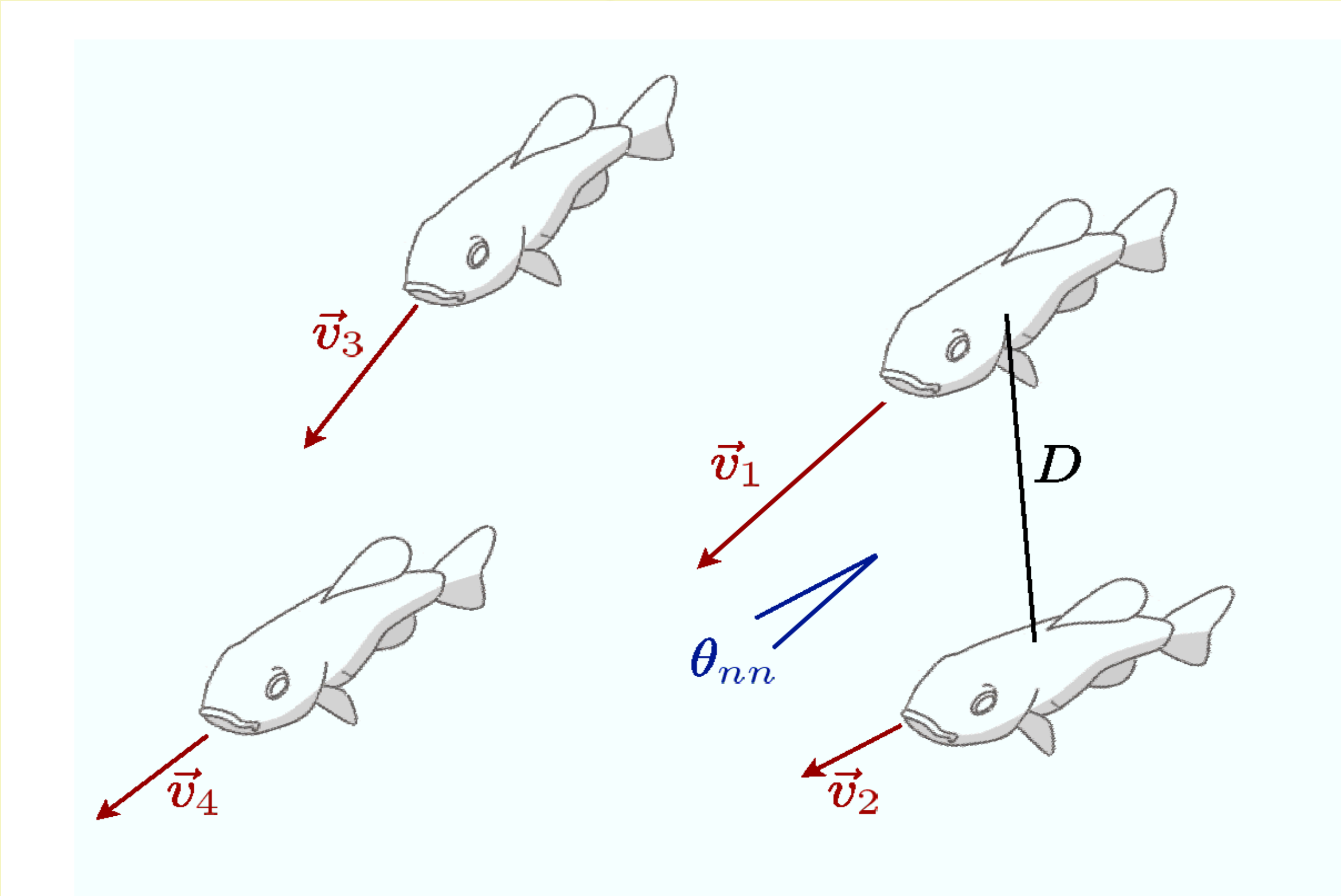
$$-\frac{\partial}{\partial v_i}[a_i n(\mathrm{x},\mathrm{v},t)]$$

$$+\frac{1}{2}\frac{\partial^2}{\partial v_i \partial v_j}[\gamma_{ij} n(\mathrm{x},\mathrm{v},t)]$$

Couzin, Krause, Franks, Levin

- Utilize simulations to explore these issues

Velocity vectors

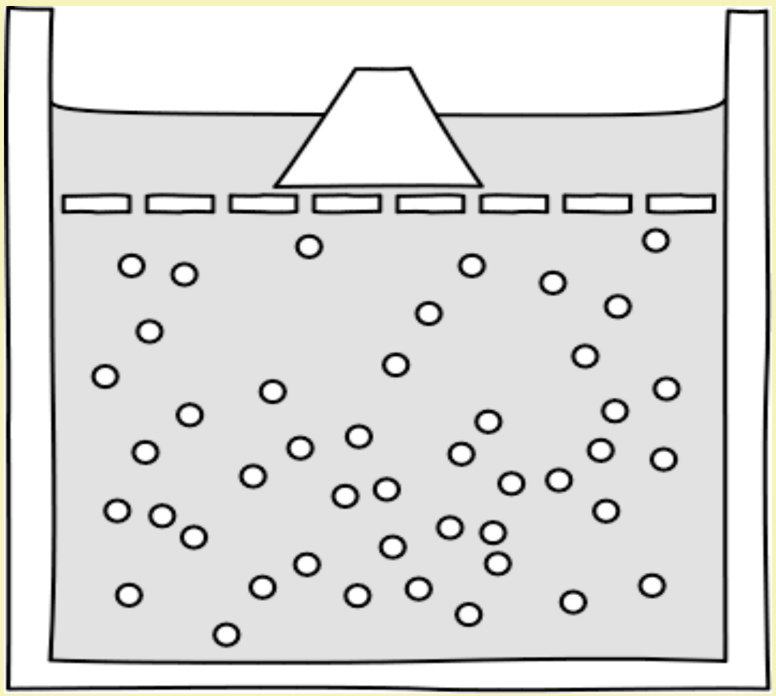


QuickTime™ and a
decompressor
are needed to see this picture.

There are striking regularities in macroscopic patterns, which support fisheries and other ecosystem services

- Element ratios
- Patterns of productivity
- Size-structure distributions

Sustainability of fisheries and other ecosystem services must focus on macroscopic features, while recognizing that control of those rests at lower levels of organization



Models too large, too complicated, too detailed should raise eyebrows

Research challenges

- Werner: Too much detail not necessarily a good thing
- Need to identify how to cluster
- Are there relevant functional groups, etc.?
- Can an evolutionary perspective guide aggregation?

Research challenges

- Identification of invariants and scaling laws, like the Redfield ratios
- Establishment of patterns of variation: Are they invariants?
- Development of theory to explain patterns, and that have predictive value

Redfield ratios

(in marine organic matter)

$P : N : C : -O_2$

(oxygen required to respire marine organic matter)

1 : 16 : 106 : 138

(subject to some debate)

SINGLE-SPECIES/RESOURCE DYNAMICS

Klausmeier et al.

Ambient

$$\frac{dP}{dt} = a\left(P_{in} - P\right) - f_P(P)B$$

$$\frac{dN}{dt} = a\left(N_{in} - N\right) - f_N(N)B$$

Storage

$$\frac{dP_S}{dt} = Bf_P(P) - A\alpha B - mP_S$$

$$\frac{dN_S}{dt} = Bf_N(N) - A\beta B - mN_S$$

Biomass

$$\frac{dB}{dt} = AB - mB$$

where

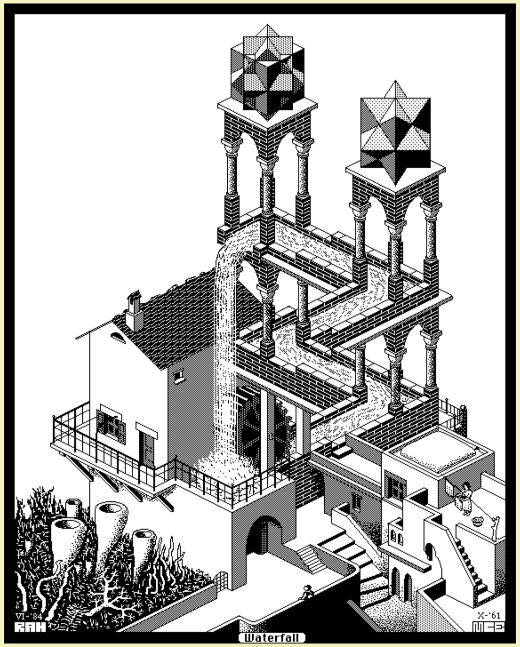
$$A = \mu \min\left(P_S/(P_S + \alpha B),\ N_S/(N_S + \beta B)\right)$$

Klausmeier et al.: The evolutionary ecology of nutrient utilization

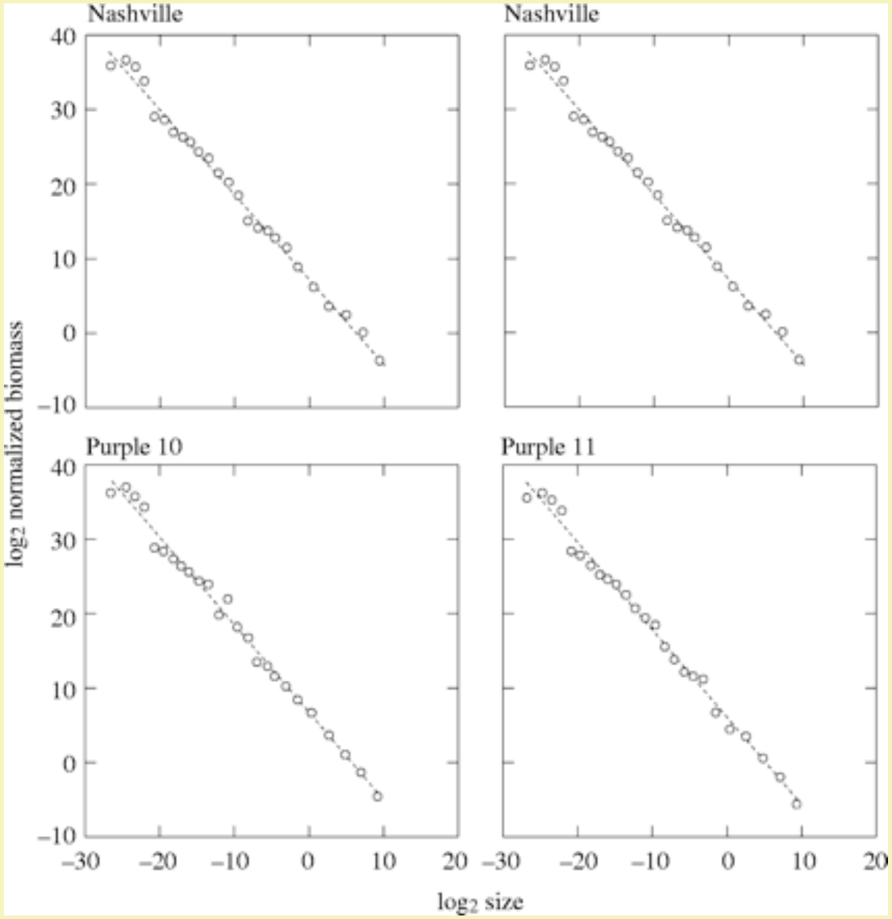
- Trait-dependent dynamics on ecological time scales
- Competition dynamics on evolutionary time scales

In a game-theoretic sense, what strategies are most successful at resource acquisition?

Stoichiometry provides just one set of robust patterns



Particle Size Spectrum (Sheldon)



Normalized biomass size-spectra in carbon units from several stations in the New England Seamounts Area (Northwest Atlantic). (Marquet et al, after Quiñones et al., 2003.)

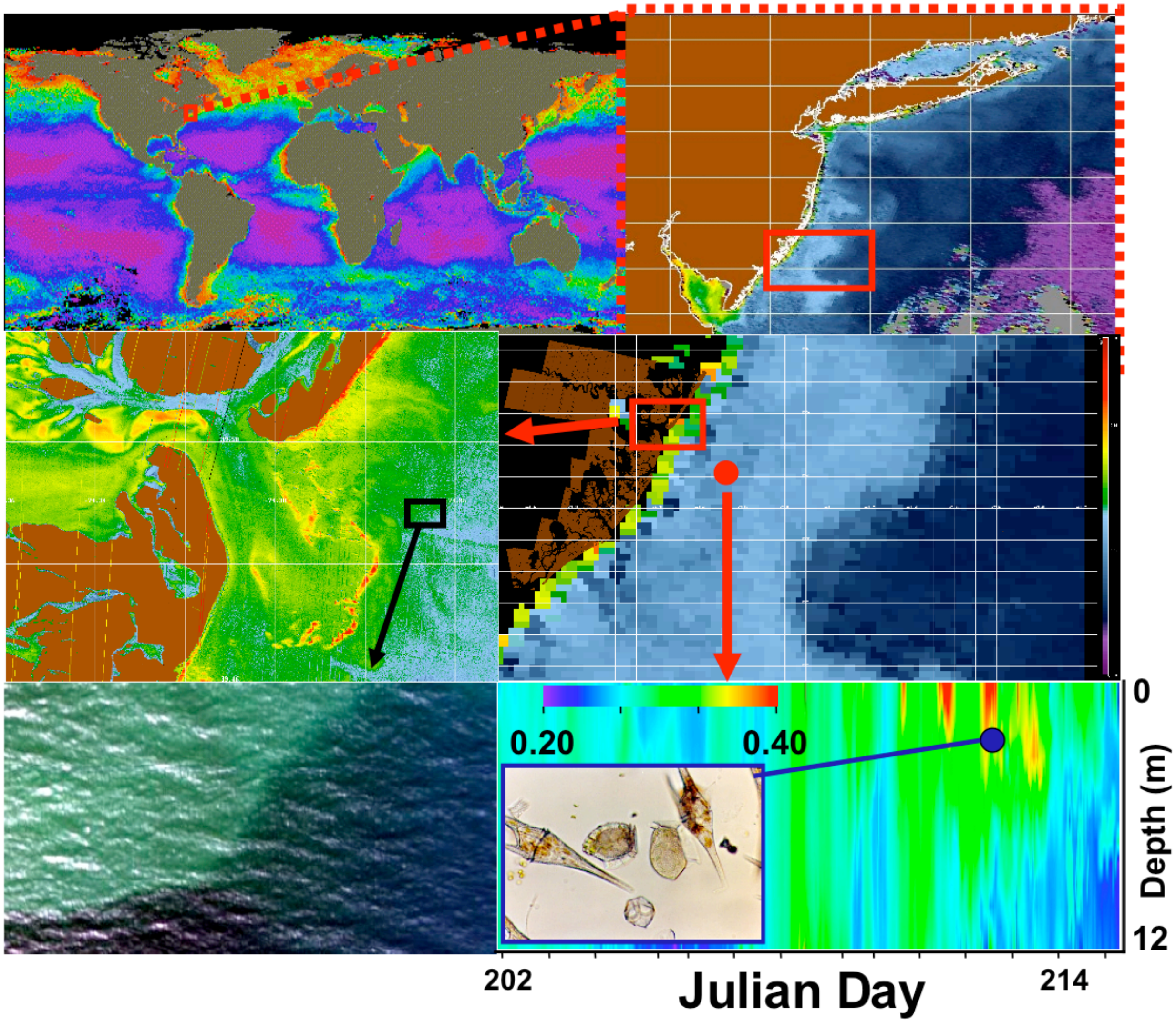


Figure 1: Variability in chlorophyll a over a range of scales.

Goal of our work

- Characterize macroscopic patterns that maintain ecosystem properties, and support fisheries
- Develop models that explain those patterns
- Develop evolutionary models that allow prediction of what should be where, in relation to environmental conditions