Modelling phytoplankton distributions in the ocean: a novel multi-species approach

Anna Hickman

Massachusetts Institute of Technology
Gordon and Betty Moore Foundation
Atlantic Meridional Transect
University of Liverpool
Outline

Motivation:
• Why are multi-species models important for export?
• What’s new with the stochastic approach?

Illustrating the model:
• Hypothesis
• Model framework and outcomes
• How do the phytoplankton interact?

Global Application

Summary
Motivation

- Diatoms
- Coccolithophores
- Biogeochemical cycles

from Karl et al., 2001
Motivation

**Stochastic approach**

- Avoid preconceived combinations of parameter values
- Initialise many potentially viable ecotypes
- Let the ecosystem do the work

**Emergent Biogeography of Microbial Communities in a Model Ocean**

Michael J. Follows, Stephanie Dutkiewicz, Scott Grant, Sallie W. Chisholm

A marine ecosystem model seeded with many phytoplankton types, whose physiological traits were randomly assigned from ranges defined by field and laboratory data, generated an emergent community structure and biogeography consistent with observed global phytoplankton distributions. The modeled organisms included types analogous to the marine cyanobacterium Prochlorococcus. Their emergent global distributions and physiological properties simultaneously correspond to observations. This flexible representation of community structure can be used to explore relations between ecosystems, biogeochemical cycles, and climate change.

*(Follows et al. 2007, Science)*
Darwin Ecosystem Model

10’s phytoplankton
Variety of physiologies

Interaction
Competition
Selection

Physical, chemical
environment

Ecosystem
structure
and function

(Follows et al. 2007, Science)
Hypothesis

Are pigments important for phytoplankton distributions?

- 1-D profile
- Data AMT-15
Phytoplankton distributions

(Data courtesy: M. Zubkov, J. Heywood)
Phytoplankton pigments

(Data courtesy: D. Suggett, L. Moore)
Phytoplankton pigments

(Data courtesy: L. Moore)
Model Framework

- 1000 phytoplankton ‘phenotypes’
- Temperature
- Nutrients
- Light

\[
\begin{align*}
\mu & \quad P_j \\
& \quad g \\
& \quad K_r \\
N & \quad Z_i
\end{align*}
\]

- MITgcm (1-D)
- 13 wavebands 400–700 nm

Riley (1946)

Coin Flips
Random selection

Variable Chl-a:C
(Geider et al. 1997)
Model Framework

Model Phytoplankton

NH4, NO2, NO3

NH4, NO2

NH4

Eukaryote analogue
Syn. analogue

HL Pro analogues
LL Pro analogues

Photoinhibition
Model Framework

Model Phytoplankton

- NH4, NO2, NO3
- NH4, NO2
- NH4

Temperature Optima
Nutrient Half Saturation

random from ranges

+ Photoinhibition
Model vs. Data

(DATA courtesy: J. Heywood, M. Zubkov)
Model vs. Data

(Data courtesy: J. Heywood, M. Zubkov)
Ecotype Selection

MODEL

Pro and non-Pro coexist
Vertical gradient Syn vs. Euk
Vertical gradient HL vs. LL Pro
Ecotype Selection

Thought experiment:

Pro and non-Pro coexist
Vertical gradient Syn vs. Euk
Vertical gradient HL vs. LL Pro
Thought experiment:

Pro and non-Pro coexist
Vertical gradient Syn vs. Euk
Vertical gradient HL vs. LL Pro
Thought experiment:

Pro and non-Pro coexist
Vertical gradient Syn vs. Euk
Vertical gradient HL vs. LL Pro

Nutrients
Spectral Light Absorption
Thought experiment:

Pro and non-Pro coexist
Vertical gradient Syn vs. Euk
Vertical gradient HL vs. LL Pro

Nutrients
Spectral Light Absorption
Photoinhibition
Ecotype Selection

Selection for lowest $K_{sat}$
Competition on Temp gradient
Hypothesis Summary

Are pigments important for phytoplankton distributions?

• Pigments are important for
  Syn  vs.  Euk

• Photoinhibition important for
  LLPro  vs.  HLPro  (Six et al. 2007)

• Combination of traits is important
  nutrients, temperature, light  “optimised”
Global Application

What about global distributions?

3-D application (MITgcm)  8 phytoplankton types:
   Includes Large (size trade-offs)
   Includes Large Si -using

Primary production
0-55m

(gC m^{-2} y^{-1})
Global Model

MODEL:

Biomass (µM P) Diatoms

Large Euk

Small Euk

Syn

HLPro

LLPro

DATA:

Fuc:Chla (g:g)

Fraction Chla > 2µm

Pico Euk (µM P)

Syn (µM P)

Total Pro (µM P)

Latitude

(Data courtesy: AMT community)
Global Model

Large Phyto : Total Phyto Biomass

0-55m

0-175m
Export:

POC flux through 0.1% light level

POC flux through 0.1% light level: Primary Production

("ez-ratio" of Buesseler & Boyd, 2009)
Overall Summary

The stochastic approach:

• is flexible new tool
• brings to the fore the fundamentals of physiology and ecosystem processes

Open Questions: physiological principles, trade-offs.
Potential for modelling export:

- resolving size structure
- explicit carbon
- resolving optics (radiative transfer)
  - Coccolithophore scattering
- trophic interactions
Acknowledgements:

Mick Follows, Stephanie Dutkiewicz, Ric Williams, Oliver Jahn, Dave Suggett, Lisa Moore, Jane Heywood, Mike Zubkov, Gerrald Moore, AMT community.