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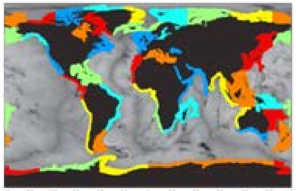
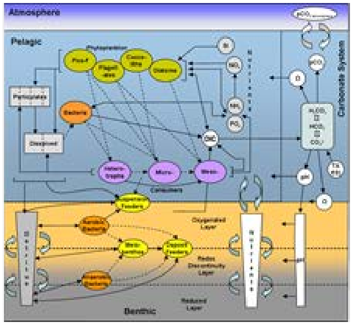
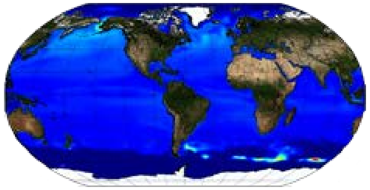
Marine Matters

Towards next generation of Marine ecosystem models

Icarus Allen,

Y Artioli, J Blackford, J Bruggeman, M Butenschon, J Clark, L de Mora, L Polimene, S Sailley.

Why Model Marine Ecosystems

- **Improve understanding of the regulation of key ecosystem services**
- **Integrate improved knowledge in models**
- **Apply models to potential management solutions**

1. Described by ecosystem model

Marine Ecosystem

Components
Habitats
Functional diversity

Processes
Production
Decomposition
Foodwebs
Ecological interactions

2. Emergent properties of ecosystem model

Intermediate Services

Supporting
Primary production
Nutrient cycling
Oxygen

Regulating
Biological control
Carbon sequestration

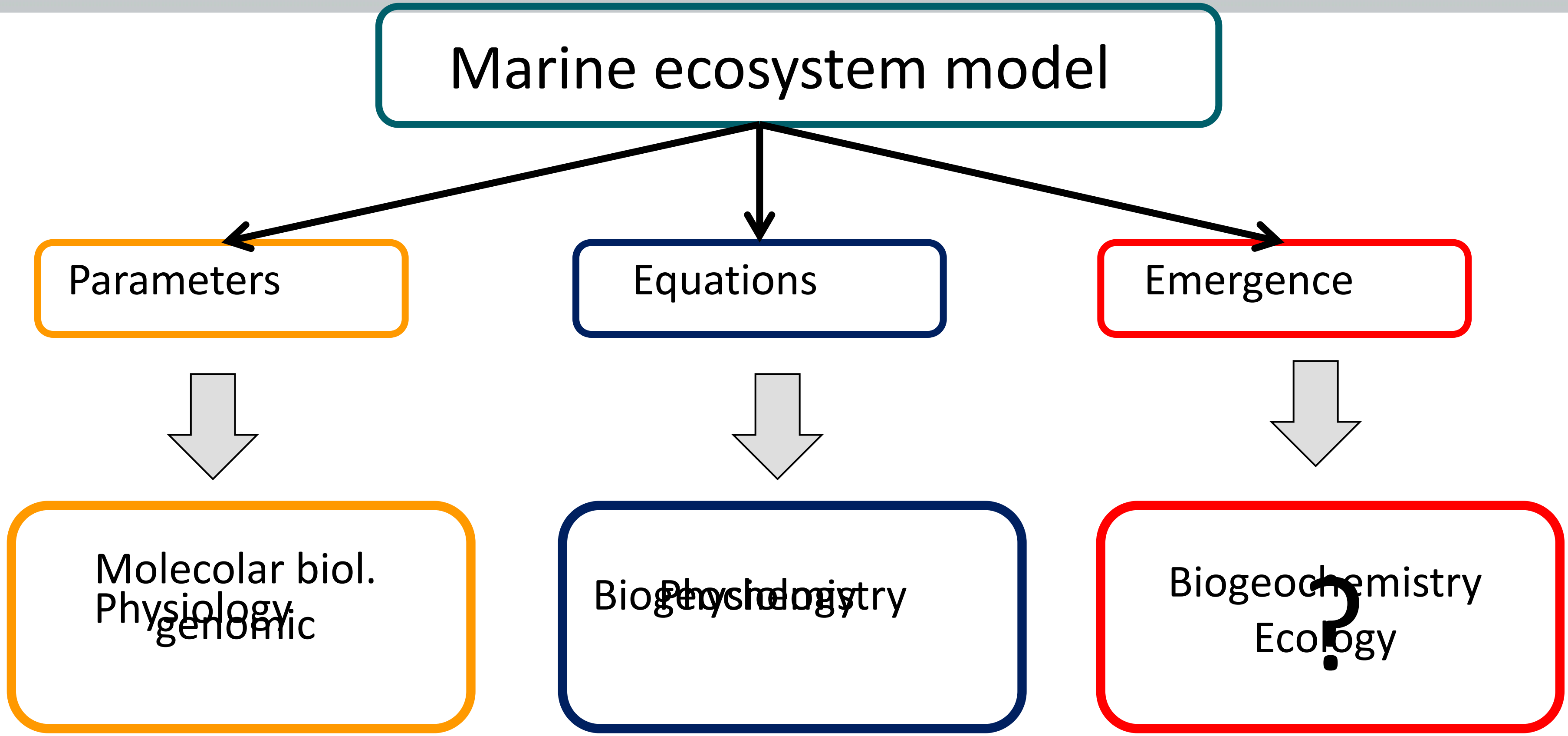
3. Informed by ecosystem model

Final Services

Provisioning
Fish & Shellfish
Seaweed

Regulating
Climate regulation

Cultural
Healthy environment



Marine ecosystem model

Parameters

Equations

Emergence

Molecolar biol.

Physiology

genomic

Biogeochemistry

Physiology

Biogeochemistry

Ecology

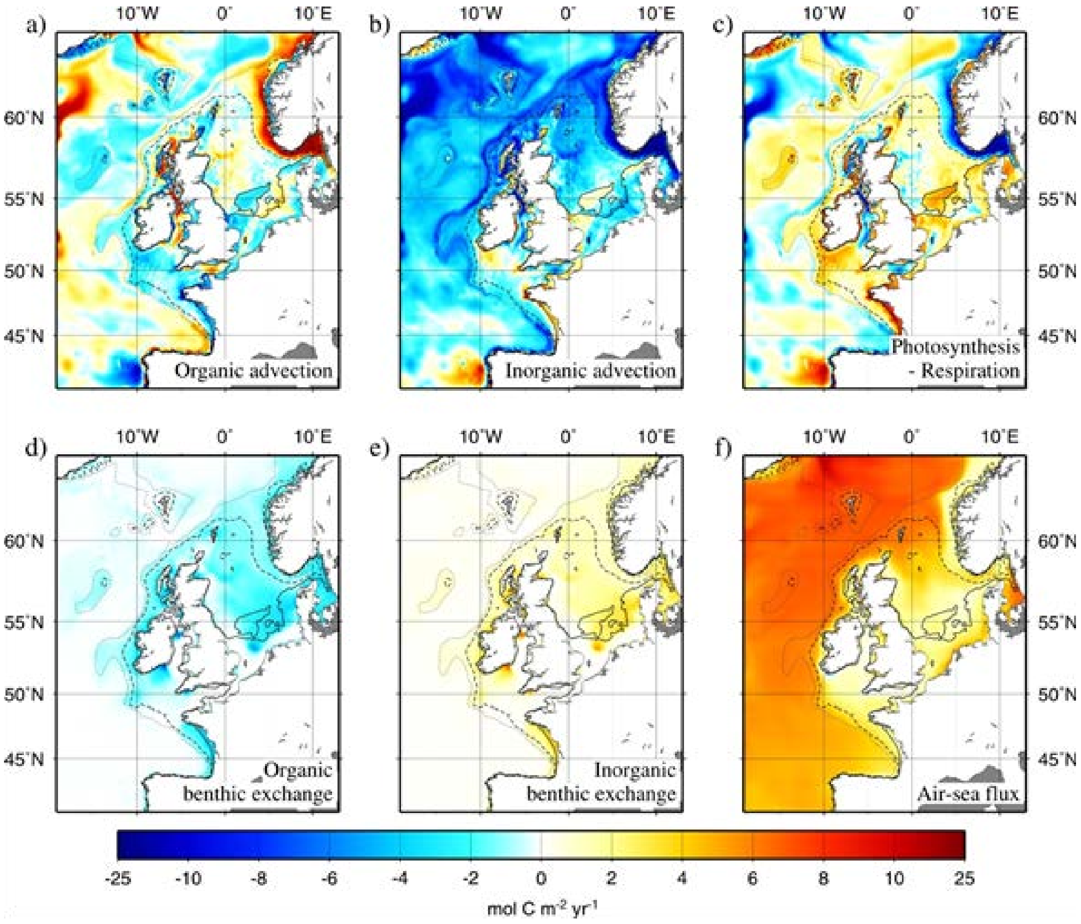
?

“traditional models are static structures which are not able to evolve under changing environmental conditions”
(Hood et al., *Oceanography*, 2007)

Capacity to evolve emergent properties

Biogeochemical Modelling

.



Shelf Carbon Budget
Wakelin et al 2012

The overarching scientific goal is to enhance our capacity to assess the controls on biogeochemical cycling and hence to quantify with uncertainties the budgets of carbon, nitrogen, phosphorous and silicon including their response to climate, natural variability and anthropogenic stress.

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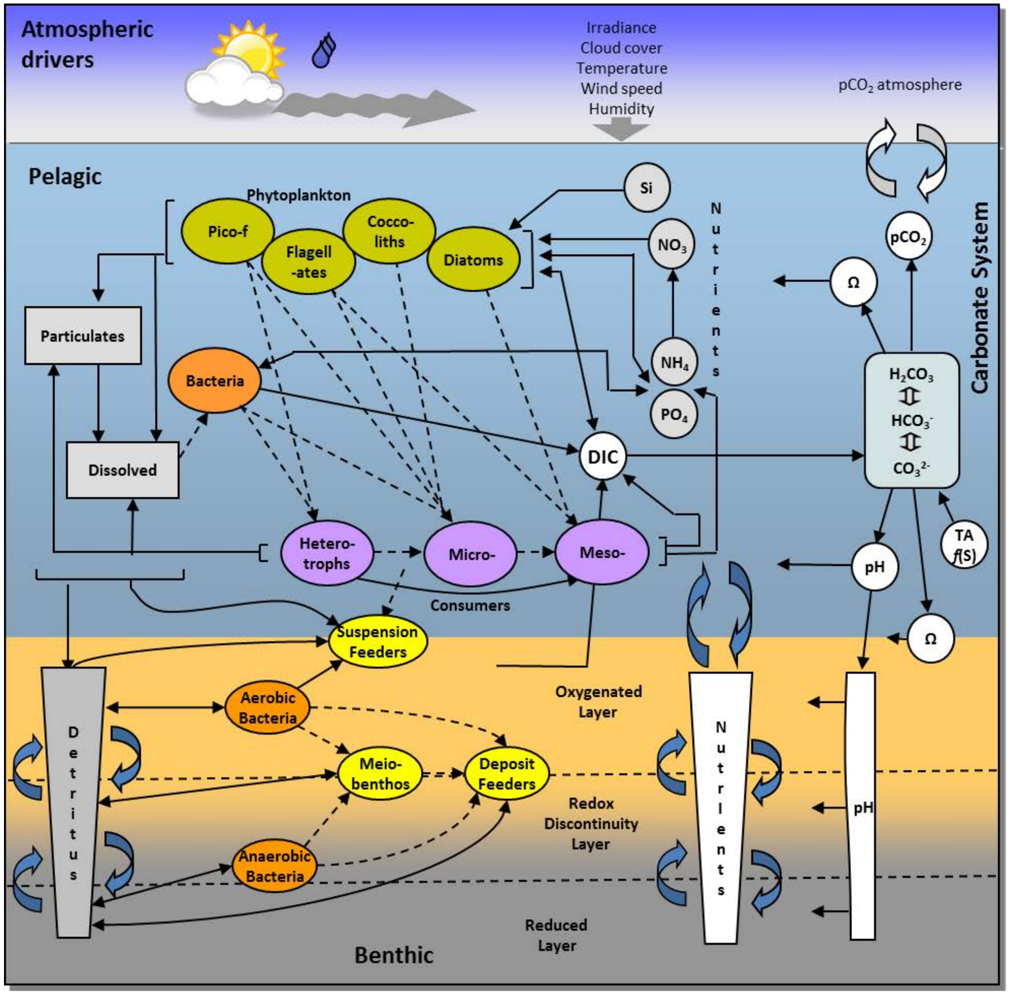
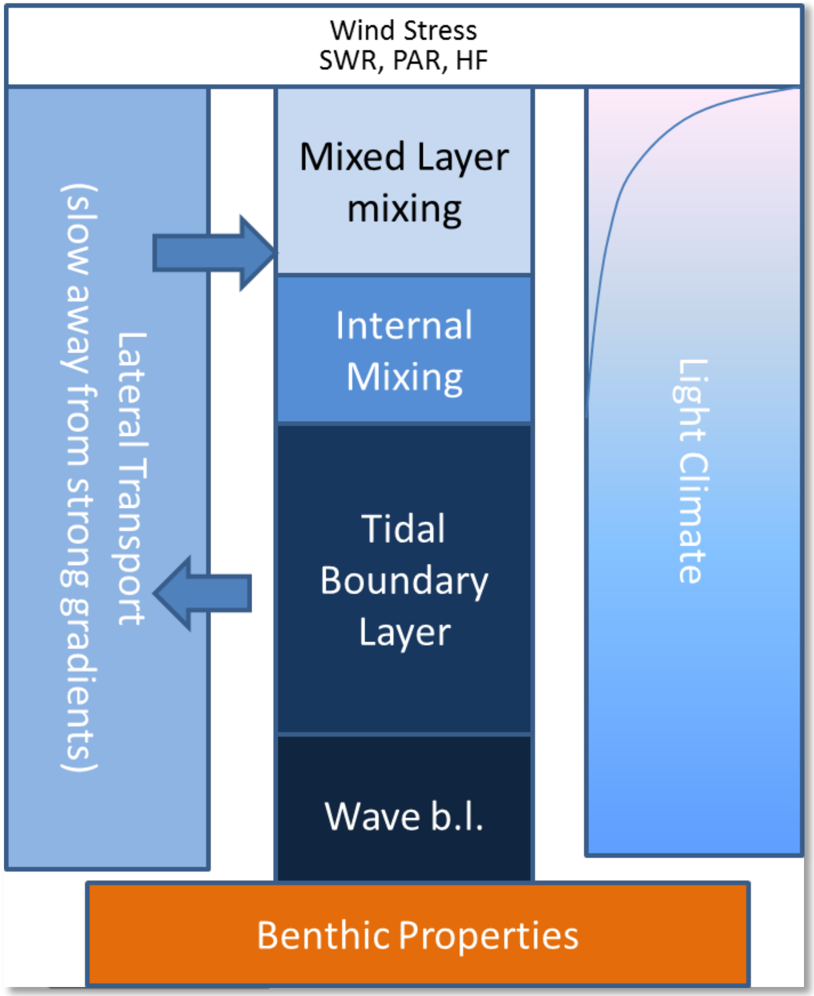
UK Shelf Modelling System

Biogeochemical Processes



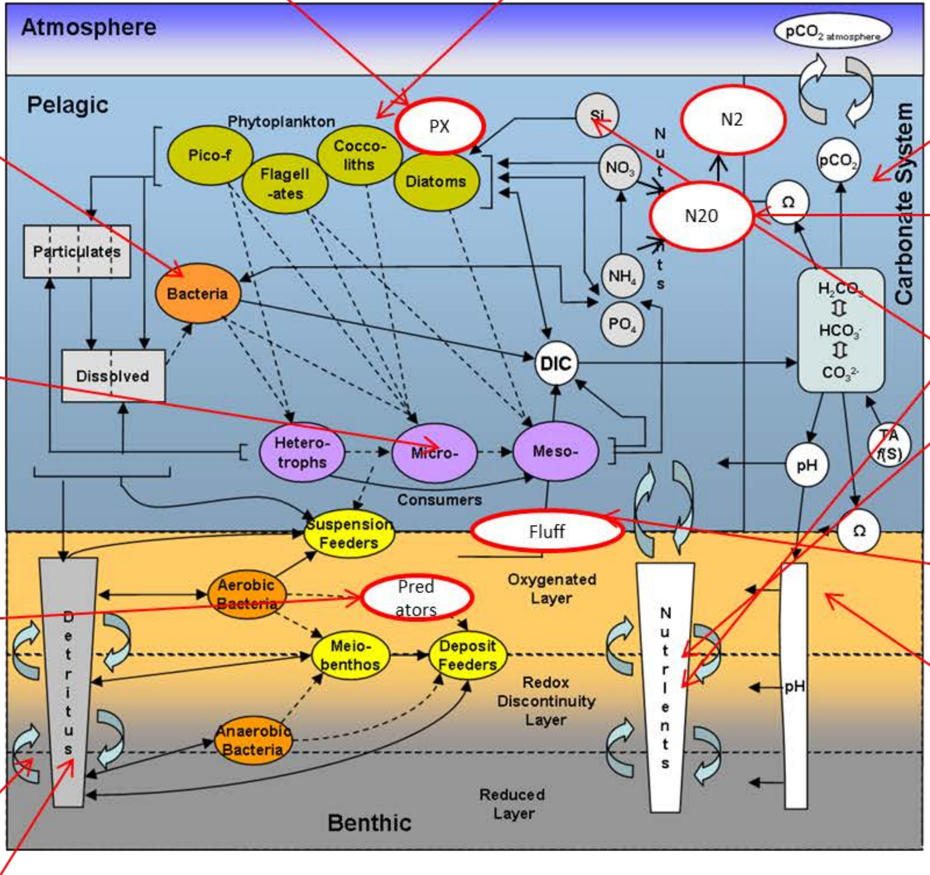
European Regional Seas Ecosystem Model
ERSEM

Physical Processes



3D: NEMO- Shelf
1D: GOTM

Summary of SSB Model Developments



2. Plankton community structure

3. Plankton physiology and stress
Composition of released DOC and POC

1. Vertical Mixing processes

4. Bacteria Growth Efficiency

6. N cycle
N20, nitrification/ de-nitrification/ N2 fixers?

5. Grazing Plasticity
Food quality vs behaviour. modification of C:N C:P in waste products

7. Silica dissolution

11. Re-suspendable fluff layer

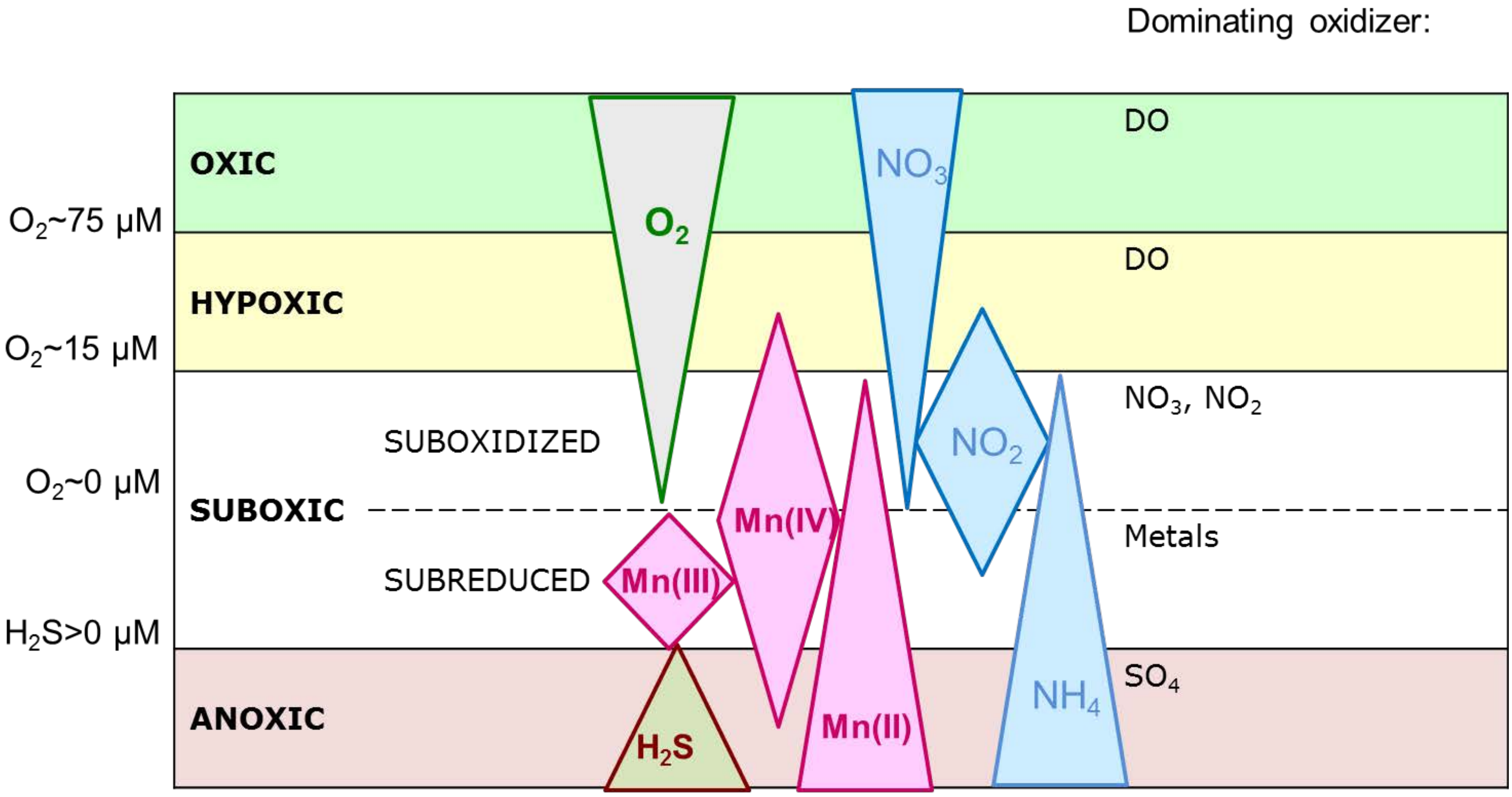
10. Benthic foodweb
Bioturbation/ irrigation

12. Advective fluxes through sediments

9. Vertical structure

8. Cohesive Sediment ----- Non Cohesive sediment

Redox conditions



Dominating oxidizer:

O_2~75 µM

O_2~15 µM

O_2~0 µM

H_2S>0 µM

OXIC — DO

HYPOXIC — DO

SUBOXIC

SUBOXIDIZED — NO_3, NO_2

SUBREDUCED — Metals

ANOXIC — SO_4

(Yakushev, Newton, 2012)

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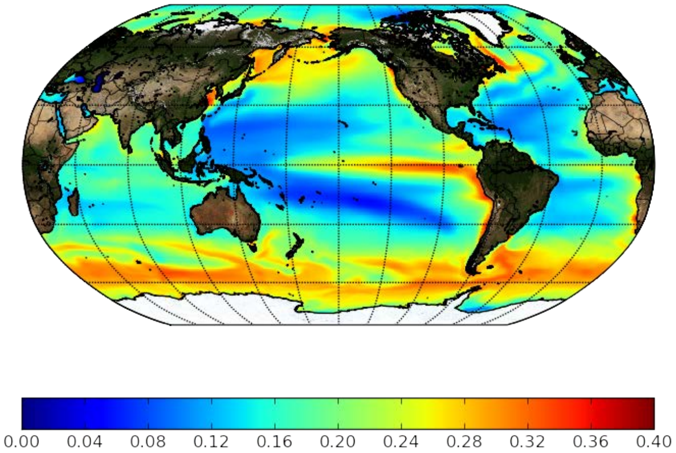
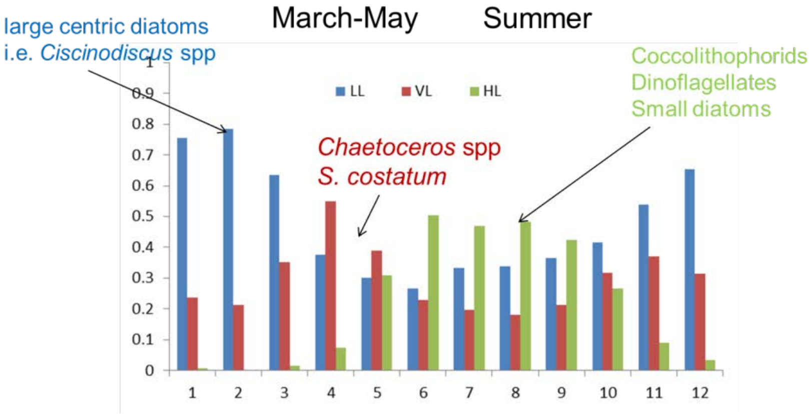
Pelagic Process Developments

Bacterial Growth Efficiency



Phytoplankton Succession


large centric diatoms
i.e. *Ciscinodiscus* spp

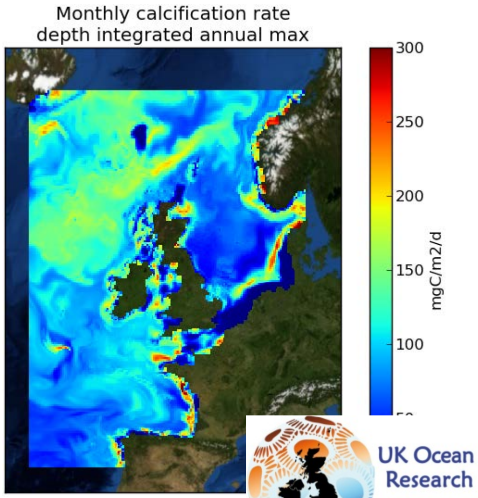
March-May

Summer

Coccolithophorids
Dinoflagellates
Small diatoms

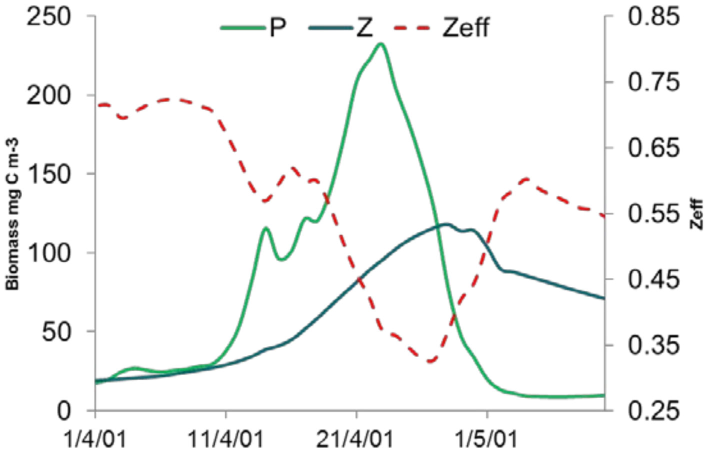
Chaetoceros spp
S. costatum

Calcification


Monthly calcification rate
depth integrated annual max

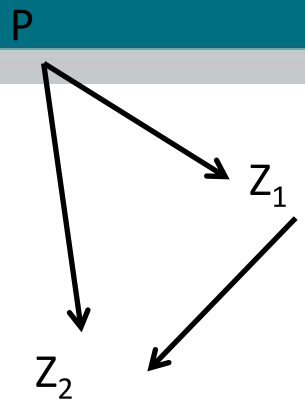
UK Ocean Acidification
Research Programme

Stoichiometry **M**odulation of **P**redation

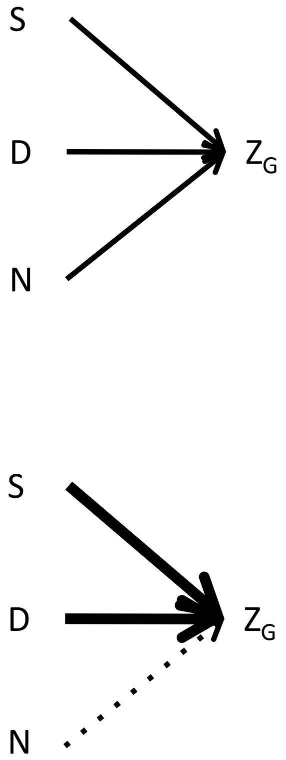


Analysis of Grazing interactions

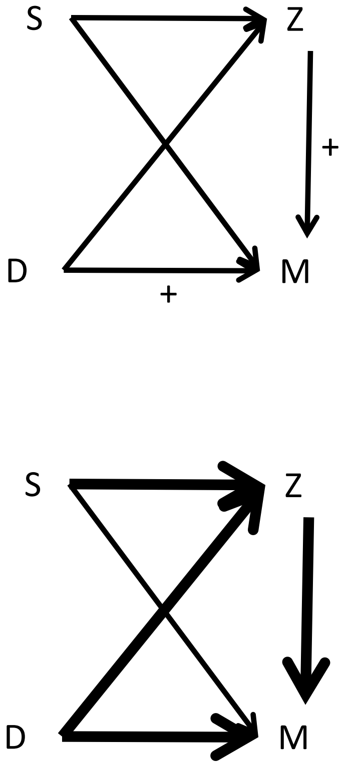
Sailley et al 2013



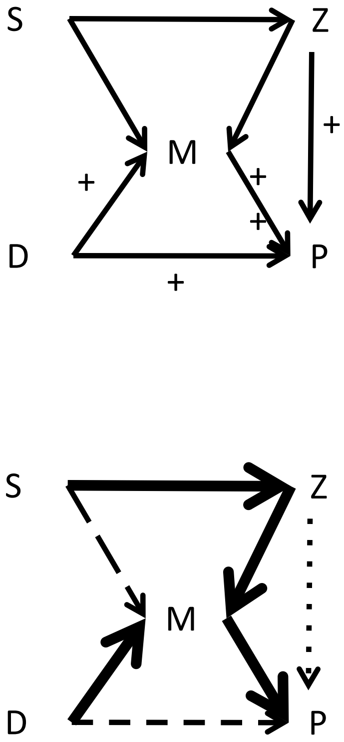
CCSM-BEC



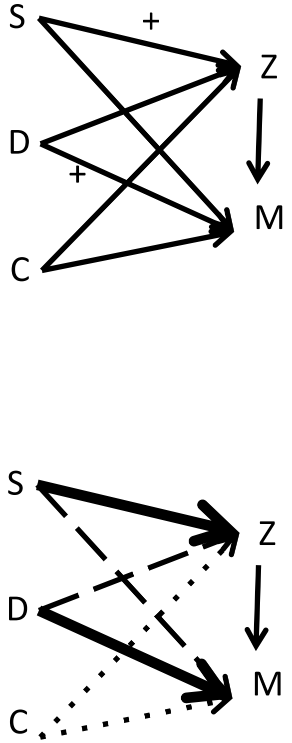
PISCES



NEMURO

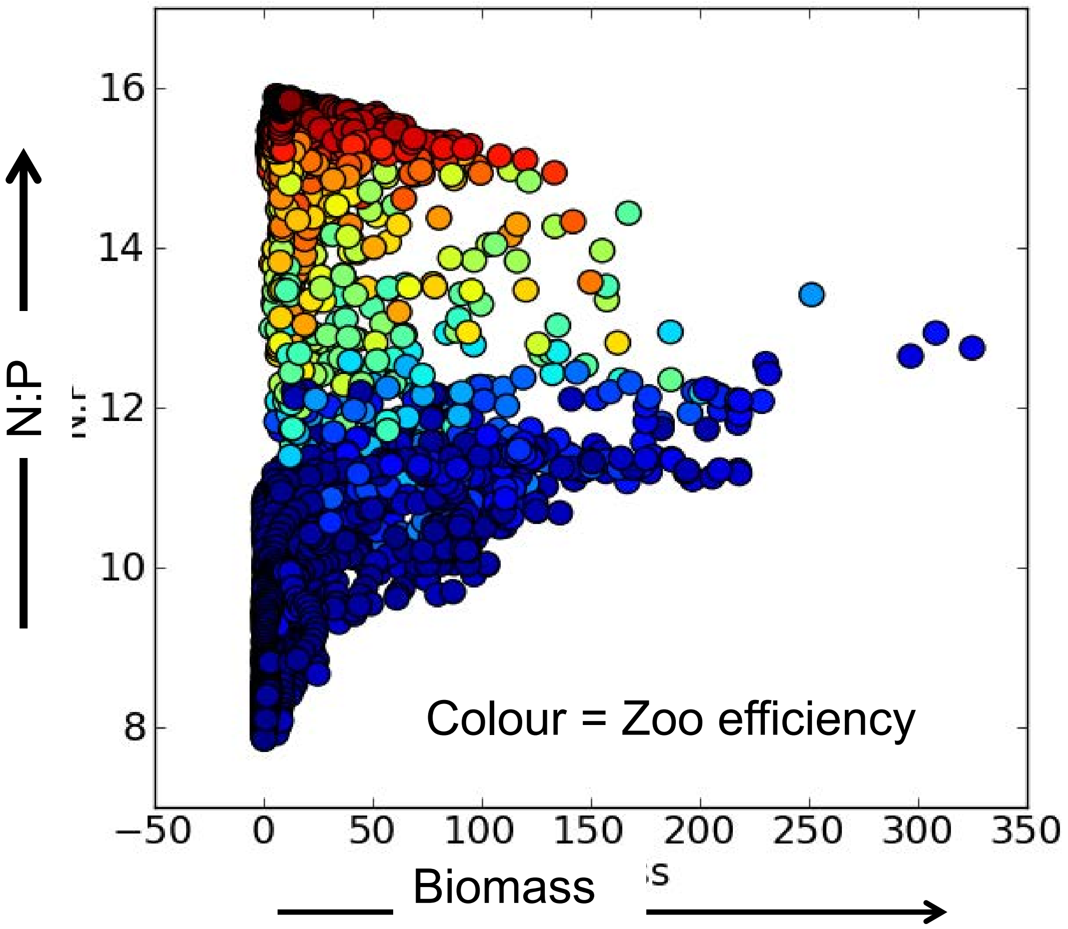


PlankTOM5



Modelling Stoichiometric Modulation of Predation

Zooplankton efficiency is dependent on the nutritional quality (nutrient content) of the prey



Preliminary results
(GOTM-ERSEM at L4)

(Mitra et al, 2008;
Polimene et al., in prep)

Modelling: Challenges and possible solutions….

Benthic

Benthic model component is the biggest challenge

- Historically a poor relation to pelagic / ocean modelling in terms of effort
- Current ERSEM benthic models – enabled ~200 pubs
- Computationally efficient at expense of accessibility – black box
- Need to open (Pandora's?) box, no longer fit for purpose
- Important?: e.g. 90% shelf calcification on sea floor

Opportunity to restructure, re-conceptualise

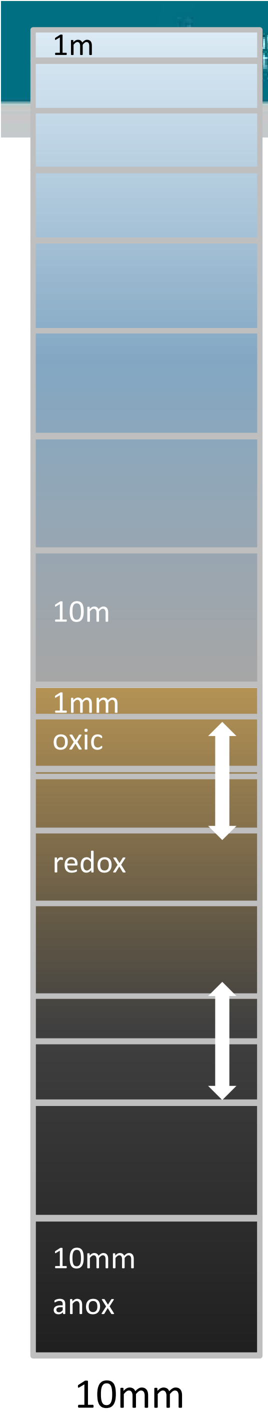
Flexible basic structure that enables SSB, OA, CCS and Ecosystems work
Break down conceptual barriers between pelagic and benthic

Include multiple sediment types
Sands: Advective physics
Physical burial
Detritus resuspusension

Revise functional groups
Biogeochemical functionalit
Improve bioturbation
Trophic transfer

Improve redox chemistry
Improve inorganic carbon / carbonate system, inc alkalinity

Potential Physical Structure

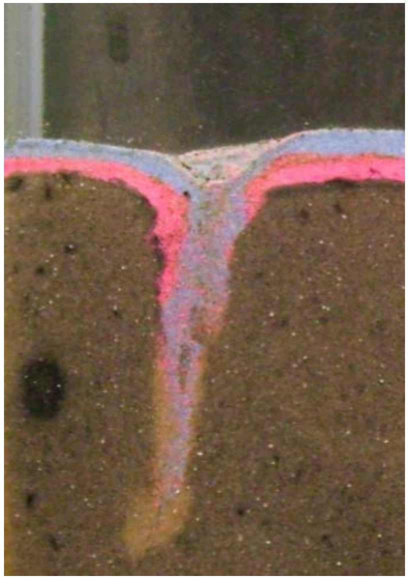


Currently have a three layer implicit model: Standard chemical profiles are fitted to the model chemical concentrations (O_2, NO_3, NH_4), from which the depths of 3 layers oxic – redox – anoxic are derived.

Proposal: convert to Z level configuration.

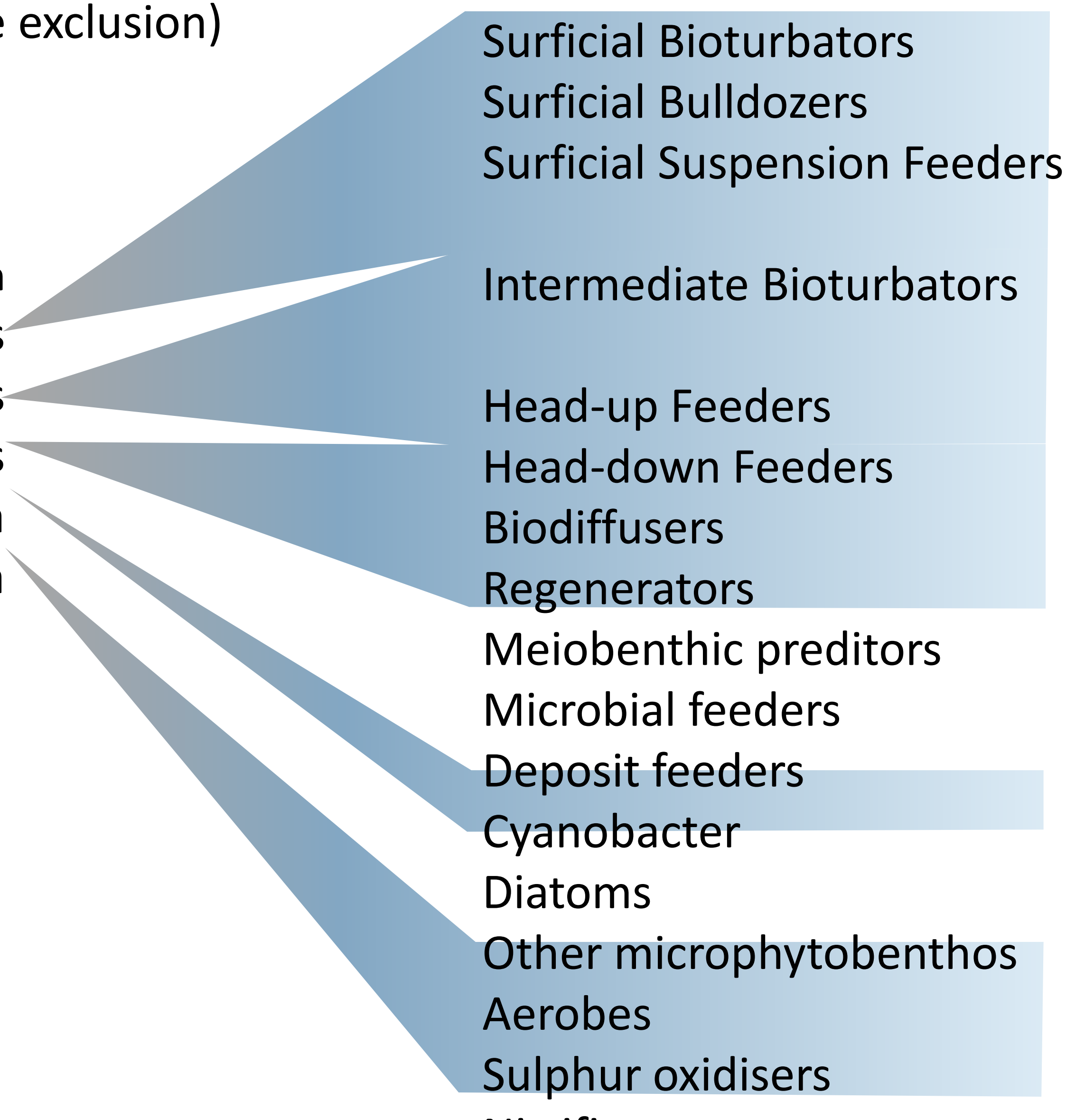
- Perfect for physical advection
- Good for characterisation of sediments (variable porosity)
- Similar conceptually to pelagic
- Need care in choosing z coordinate (mm scale structures at surface)
- Problematic in dealing with biota that live across several layers or create intrusions of surface chemical environment into deeper layers

- Sub grid scale spatial variability?



Which Functional types?

- Need to be right for chemistry / bioturbation / trophic transfer
- Limited in numbers (competitive exclusion)



Current minimum implementation
Suspension feeders
Deposit feeders
Meiobenthos
Aerobic bacteria
Anaerobic bacteria

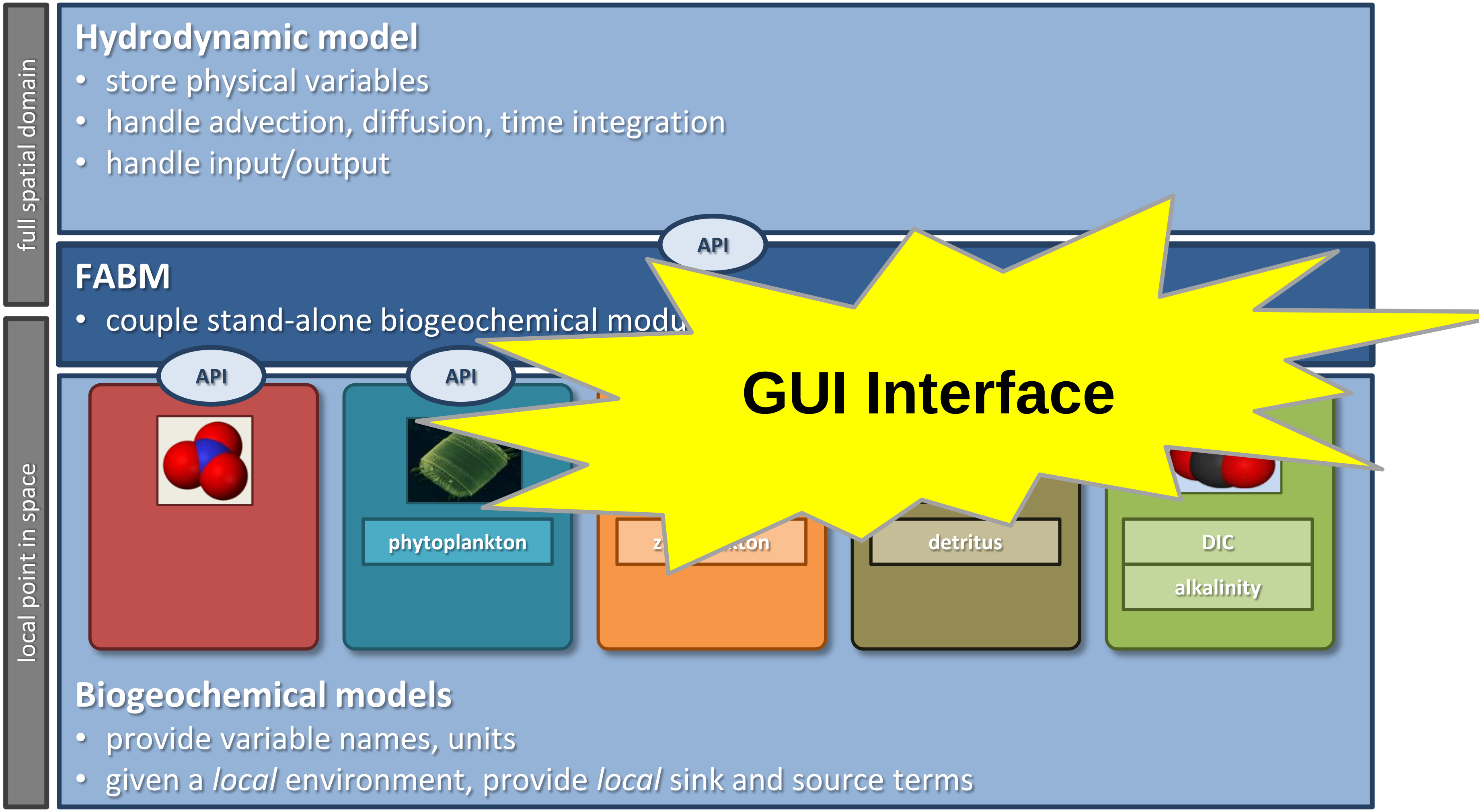
Surficial Bioturbators
Surficial Bulldozers
Surficial Suspension Feeders

Intermediate Bioturbators

Head-up Feeders
Head-down Feeders
Biodiffusers
Regenerators
Meiobenthic preditors
Microbial feeders
Deposit feeders
Cyanobacter
Diatoms
Other microphytobenthos
Aerobes
Sulphur oxidisers

SSB-ERSEM v1 - Coupled to FABM

SHELF SEA BIOGEOCHEMISTRY
www.uk-ssb.org



Hydrodynamic model

- store physical variables
- handle advection, diffusion, time integration
- handle input/output

FABM

- couple stand-alone biogeochemical modu

Biogeochemical models

- provide variable names, units
- given a *local* environment, provide *local* sink and source terms

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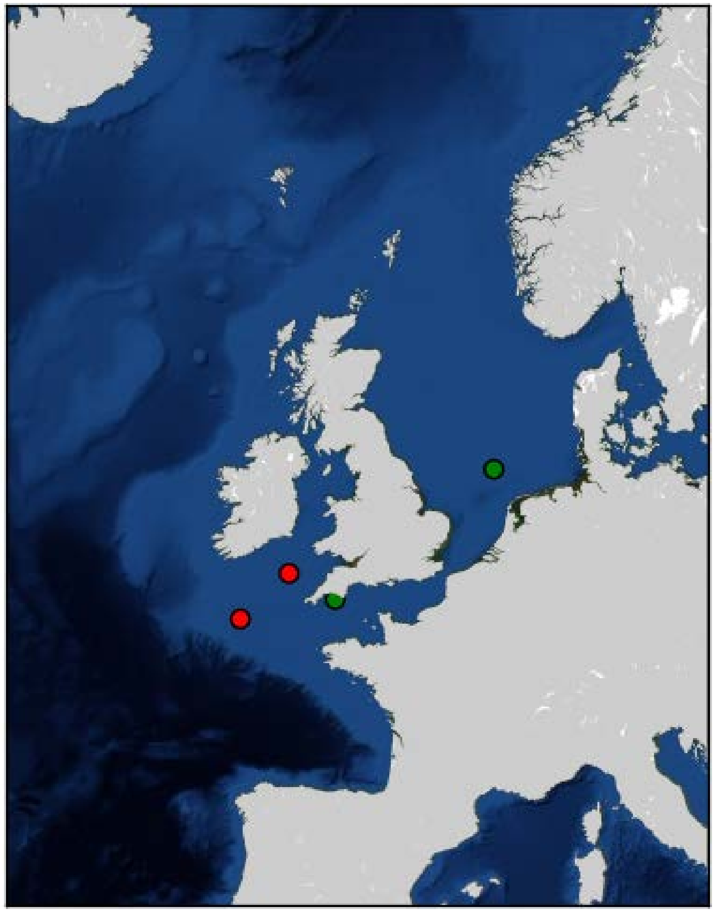
SSB-ERSEM v0

http://www.shelfseasmodelling.org/

- **Currently configured**:
  - Station L4 (4°13 W, 50°15 N)
  - Oyster Grounds (4°02 E, 54°25 N)
- **Future configurations:**
  - Celtic Deep (4°80 W, 51°14 N)
  - Celtic Sea - new (9°00 W, 49°50 N)
- **Model evaluation:**
  - OPEC benchmarking tool
    - Basic univariate statistics for assessing model skill.
    - Taylor & Target diagrams.
    - Uses current and new data to be collected during the course of the SSB project.



Challenges for Ecosystem Modelling

- What are the relative roles of **top down and bottom up control** processes and to what extent do impacts of environmental changes cascade through marine food webs and affect ecosystem services?

- As many processes are inherently scale-dependent, and **scale-dependence** is poorly understood, what are the most appropriate approaches to quantify the large-scale impacts on ecosystem services of changes at small spatial scales (e.g. marine conservation zones); and *vice versa*?

- How does **functional diversity affect the way marine food webs regulate ecosystem services**? This is potentially important because there is growing evidence that the loss of biodiversity from marine ecosystems can adversely impact ecosystem function.

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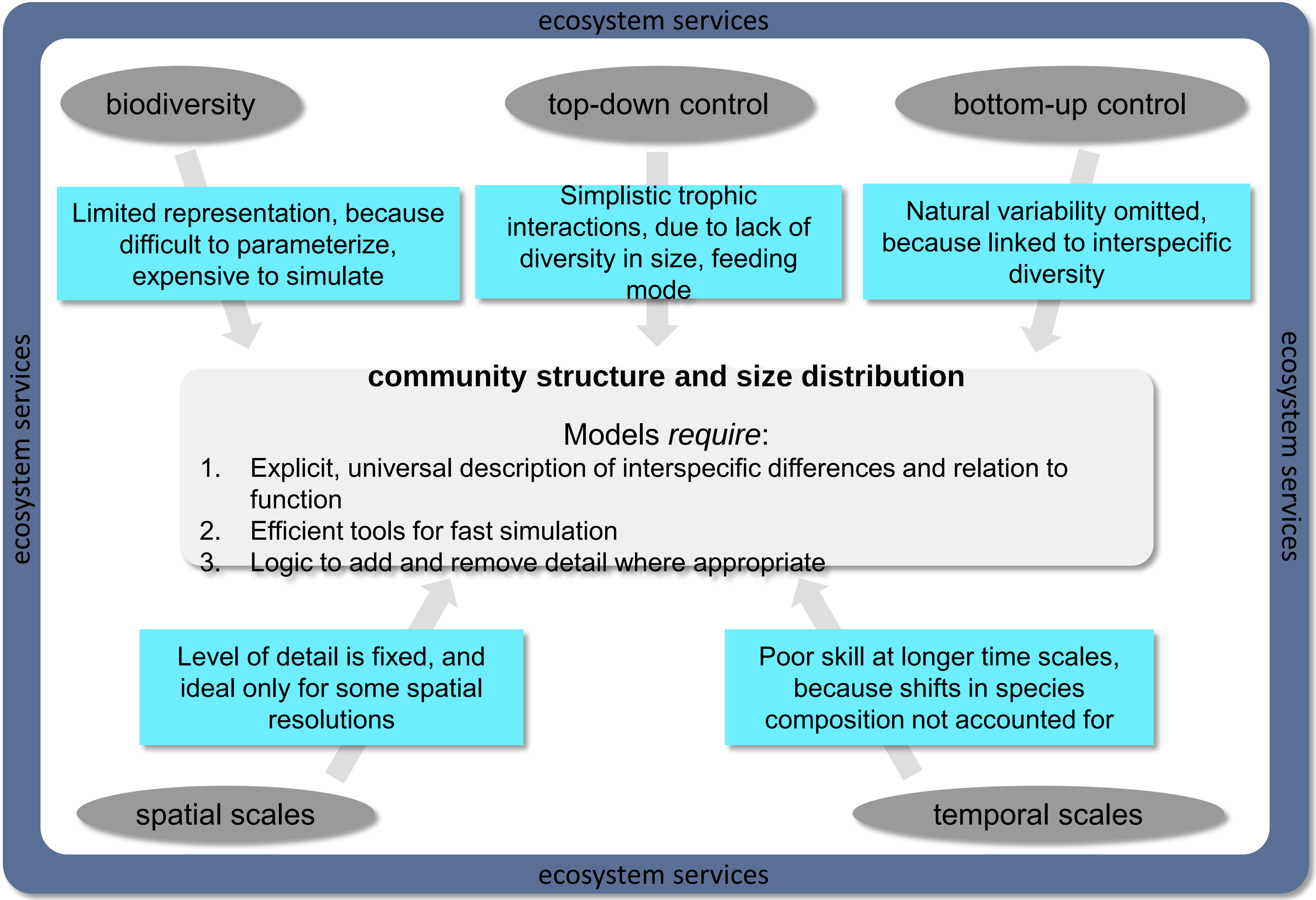
Challenges for Ecosystem Modelling



ecosystem services

biodiversity

top-down control

bottom-up control

Limited representation, because difficult to parameterize, expensive to simulate

Simplistic trophic interactions, due to lack of diversity in size, feeding mode

Natural variability omitted, because linked to interspecific diversity

community structure and size distribution

Models *require*:

1. Explicit, universal description of interspecific differences and relation to function
2. Efficient tools for fast simulation
3. Logic to add and remove detail where appropriate

Level of detail is fixed, and ideal only for some spatial resolutions

Poor skill at longer time scales, because shifts in species composition not accounted for

spatial scales

temporal scales

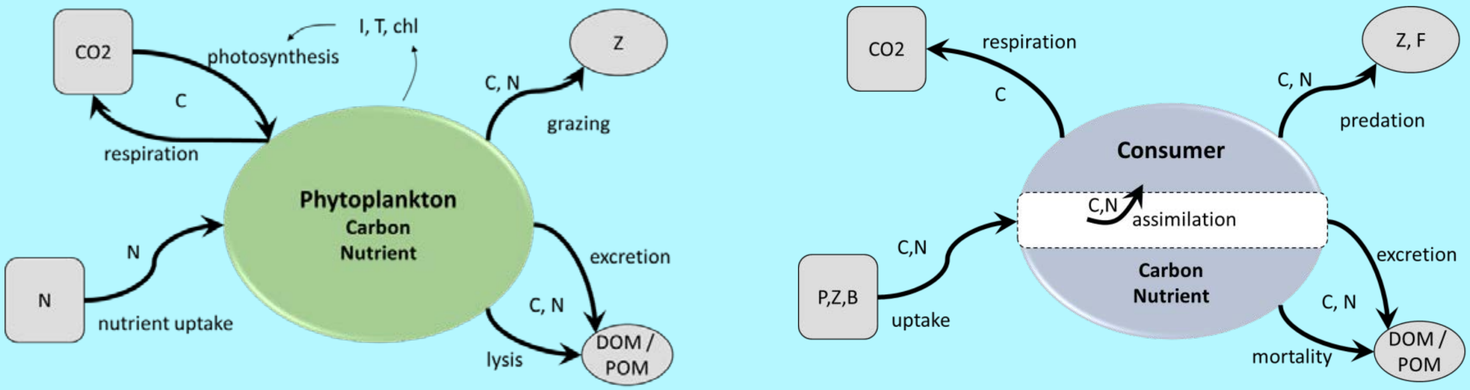
ecosystem services

ecosystem services

ecosystem services

Conceptual Approach

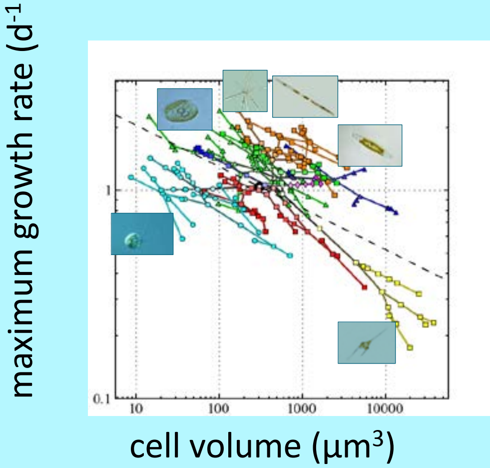
1. Define *standard organism*



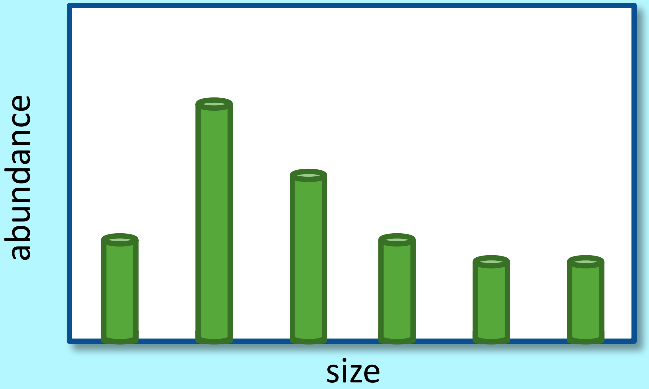
CO2
photosynthesis
I, T, chl
C
respiration
Z
C, N
grazing
Phytoplankton
Carbon
Nutrient
N
N
nutrient uptake
excretion
C, N
lysis
DOM / POM

CO2
respiration
C
Z, F
C, N
predation
Consumer
C,N
assimilation
Carbon
Nutrient
P,Z,B
C,N
uptake
excretion
C, N
mortality
DOM / POM

2. Select *traits*, link to function via *trade-offs*

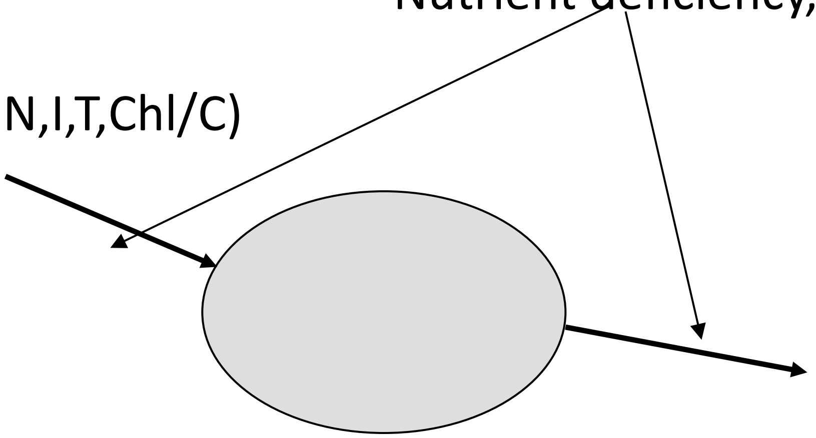


3. Community *emerges* from random initial assemblages



Challenges: Beyond the Cell as a Black Box

In “traditional” phytoplankton models, the cell is a sort of “black box” with an income and outcome of carbon.



Environment Stress (excess of light, UV,
Nutrient deficiency, viruses, pollutants)

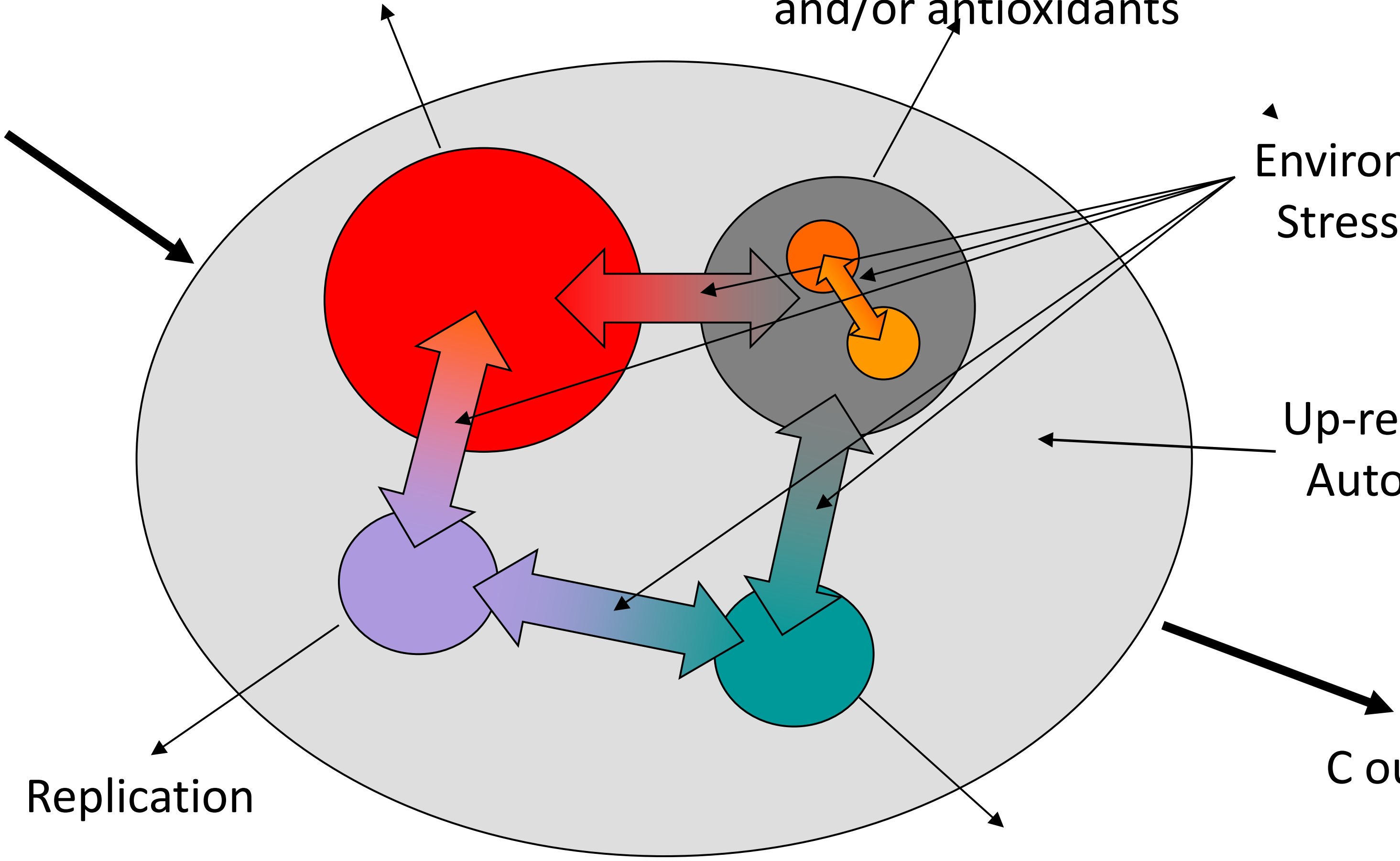
Photosynthesis (N,I,T,Chl/C)

Respiration (T)
Lysis
exudation

No mechanistic description of what happens inside the cell when exposed to stress
In other words, there is **no link** between physiology, biogeochemistry and ecology

Physiology ↔ **Biogeochemistry** ↔ **Ecology**

The Physiological Functions (PF) approach



Photochemistry
Synthesis of photosynthetic pigments

Photo-protection
Synthesis of photo-protective compound
and/or antioxidants

C in

Environmental
Stress

Up-regulated
Autophagy

C out

Replication

Virus metabolism

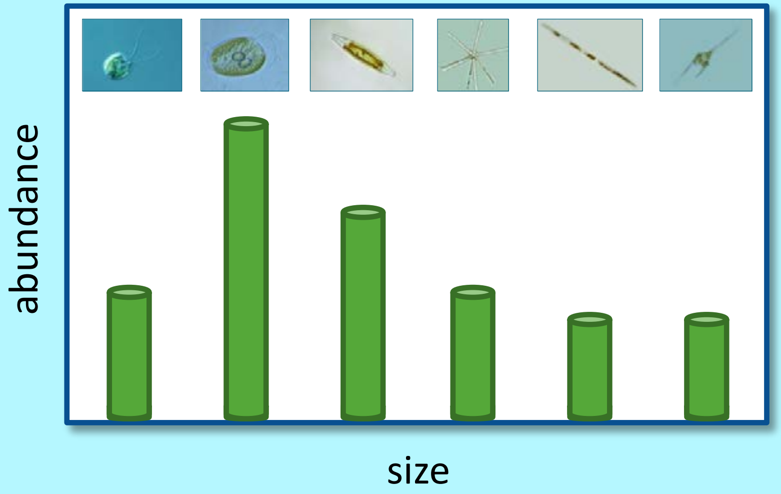
Efficient Simulation

Development of new methods enabling

- Calibration and sensitivity studies
- Investigation of optimal level of detail
- High-resolution 3D simulation

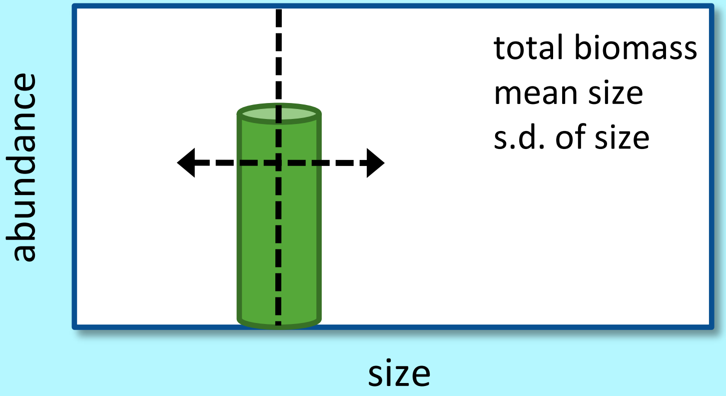
Full model – *N* species

DivERSEM



Adaptive dynamics

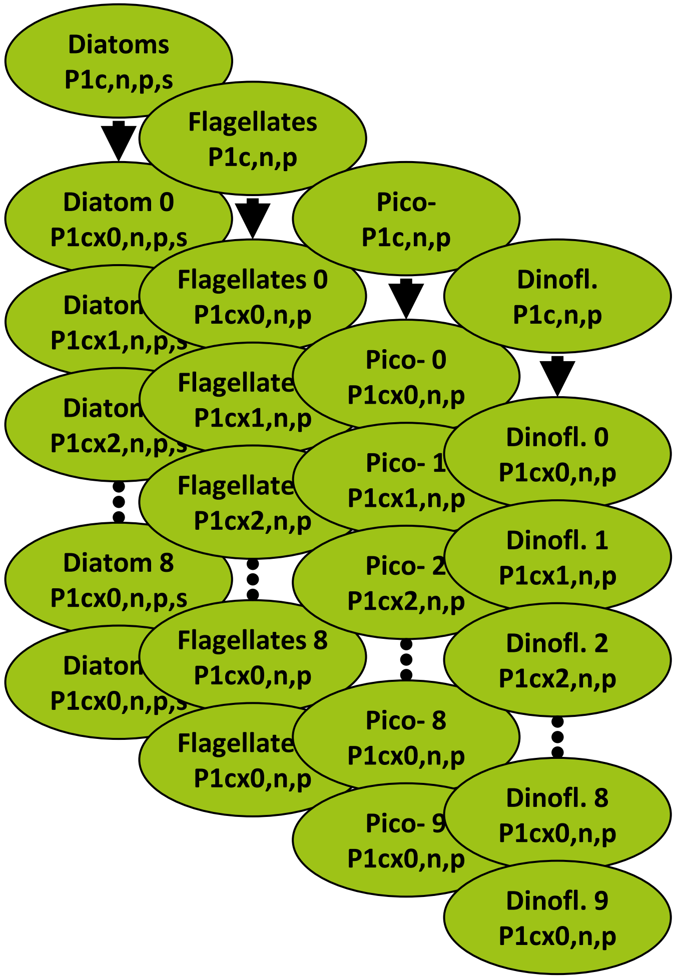
Summarize in terms of aggregate statistics



Optimized advection

- Mixing schema (1 master variable, *N*-1 subservient variables)
- Schema that scale better with increasing variable number

Darwinian ERSEM



Diatoms
P1c,n,p,s

Diatom 0
P1cx0,n,p,s

Diaton
P1cx1,n,p,s

Diaton
P1cx2,n,p,s

Diatom 8
P1cx0,n,p,s

Diaton
P1cx0,n,p,s

Flagellates
P1c,n,p

Flagellates 0
P1cx0,n,p

Flagellate
P1cx1,n,p

Flagellate
P1cx2,n,p

Flagellates 8
P1cx0,n,p

Flagellate
P1cx0,n,p

Pico-
P1c,n,p

Pico- 0
P1cx0,n,p

Pico- 1
P1cx1,n,p

Pico- 2
P1cx2,n,p

Pico- 8
P1cx0,n,p

Pico- 9
P1cx0,n,p

Dinofl.
P1c,n,p

Dinofl. 0
P1cx0,n,p

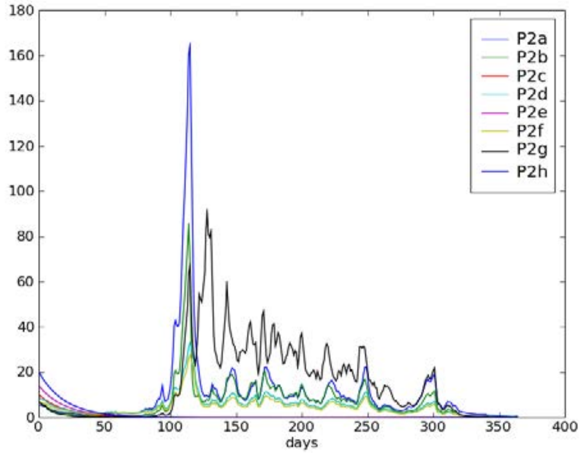
Dinofl. 1
P1cx1,n,p

Dinofl. 2
P1cx2,n,p

Dinofl. 8
P1cx0,n,p

Dinofl. 9
P1cx0,n,p

P2a
P2b
~~P2c~~
P2d
~~P2e~~
P2f
P2g
~~P2h~~

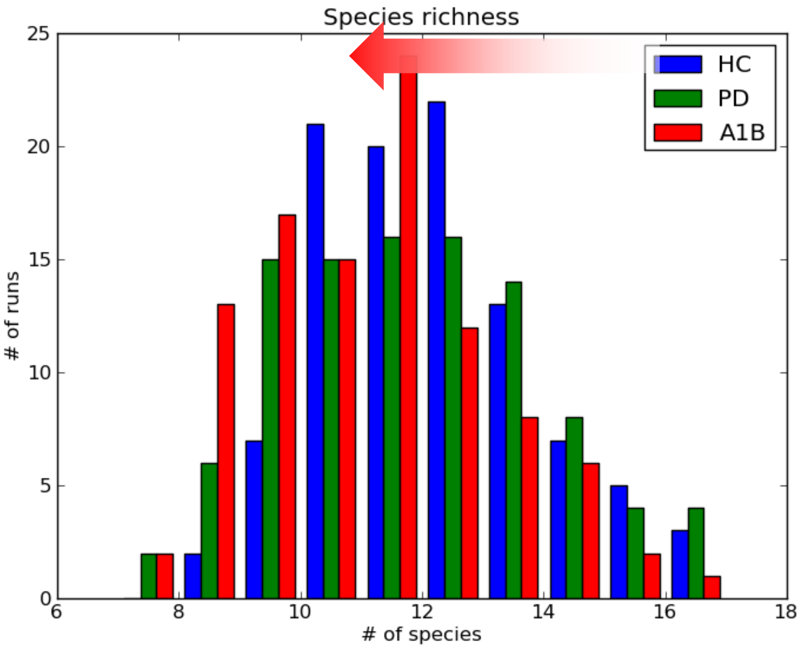


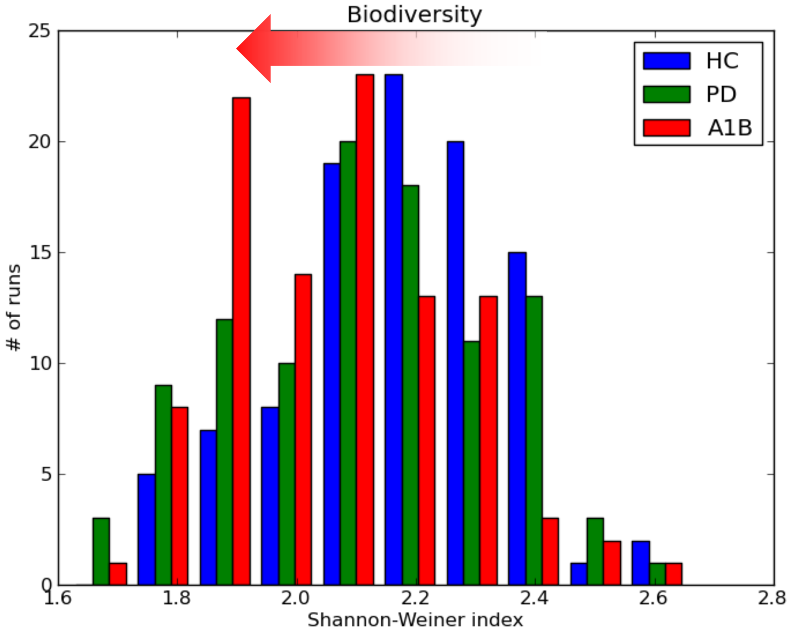
X 5 years

P2a
P2b
P2d
P2f
P2g

P2h

Biodiversity





Shannon index calculated using biomass

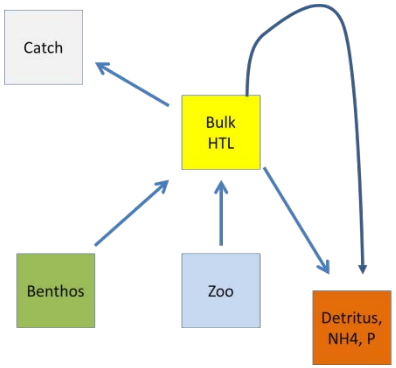
Trophic Control and links to HTL's

1. Top closure ERSEM

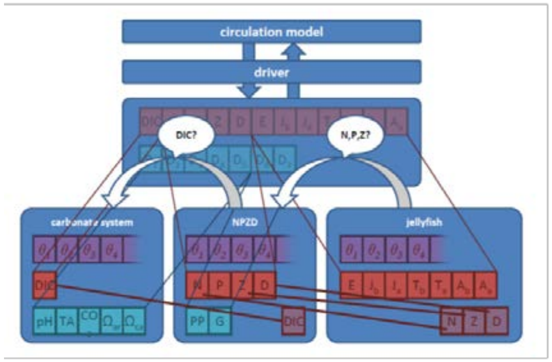
- Density dependent mortality
- Bulk HTL model (see right)
- Two way coupled dynamic size spectra (Phase II)

2. Coupling to HTL models

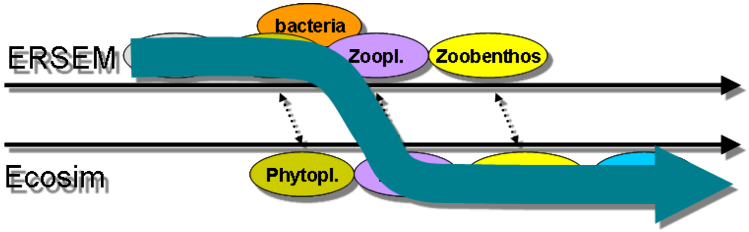
- Predation fields from offline model /data
- 2 way coupling to HTL model



Generic Coupler



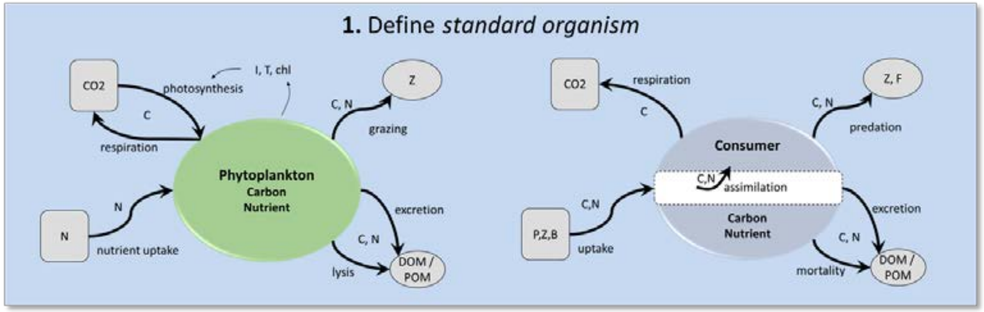
"a thin layer of code for communication and data exchange, enveloped by explicit programming interfaces through which a physical host and any number biogeochemical models can pass information"



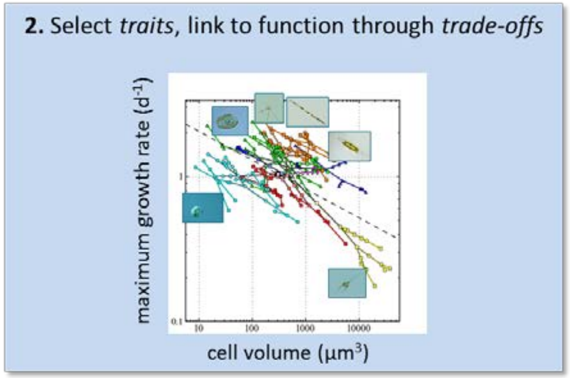
Data Needs: Processes and Parameters

1. Standard Organisms:

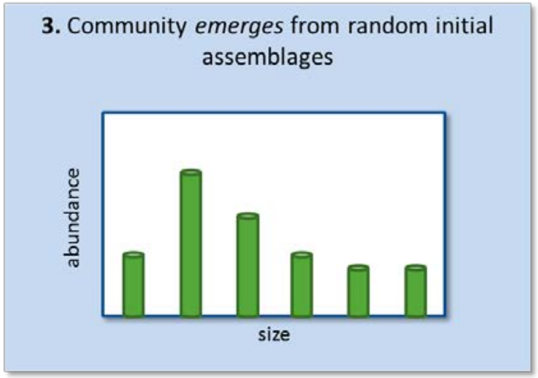
- Conceptual frameworks,
- Allometric and metabolic scaling rules to simplify the parameterisations.
- Trophic interactions.



1. Define *standard organism*



2. Select *traits*, link to function through *trade-offs*



3. Community *emerges* from random initial assemblages

2. Traits:

- trait definition e.g. diatoms, macroalgae, zooplankton and macrobenthos,
- feeding strategies,
- trade offs,
- trophic interactions,
- mortality.

3. Diversity:

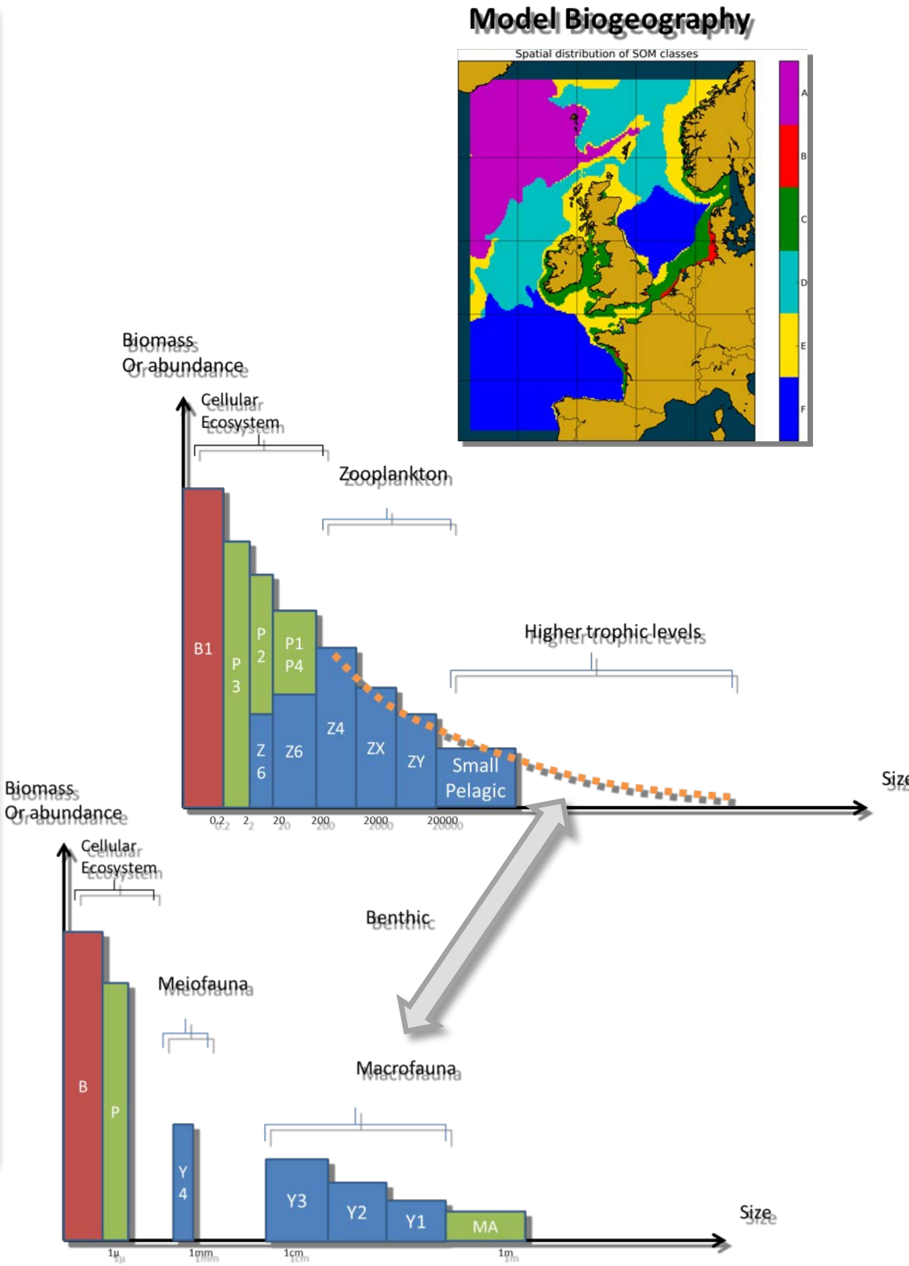
- Parameter ranges

Data Needs: Skill Assessment

1. **Bulk Properties**
   - Habitats (T, S, O_2, pH)
   - Biogeochemistry (N, P, Si)
   - Chlorophyll, PP, SP
   - Zooplankton and benthos
   - Trait based biomass

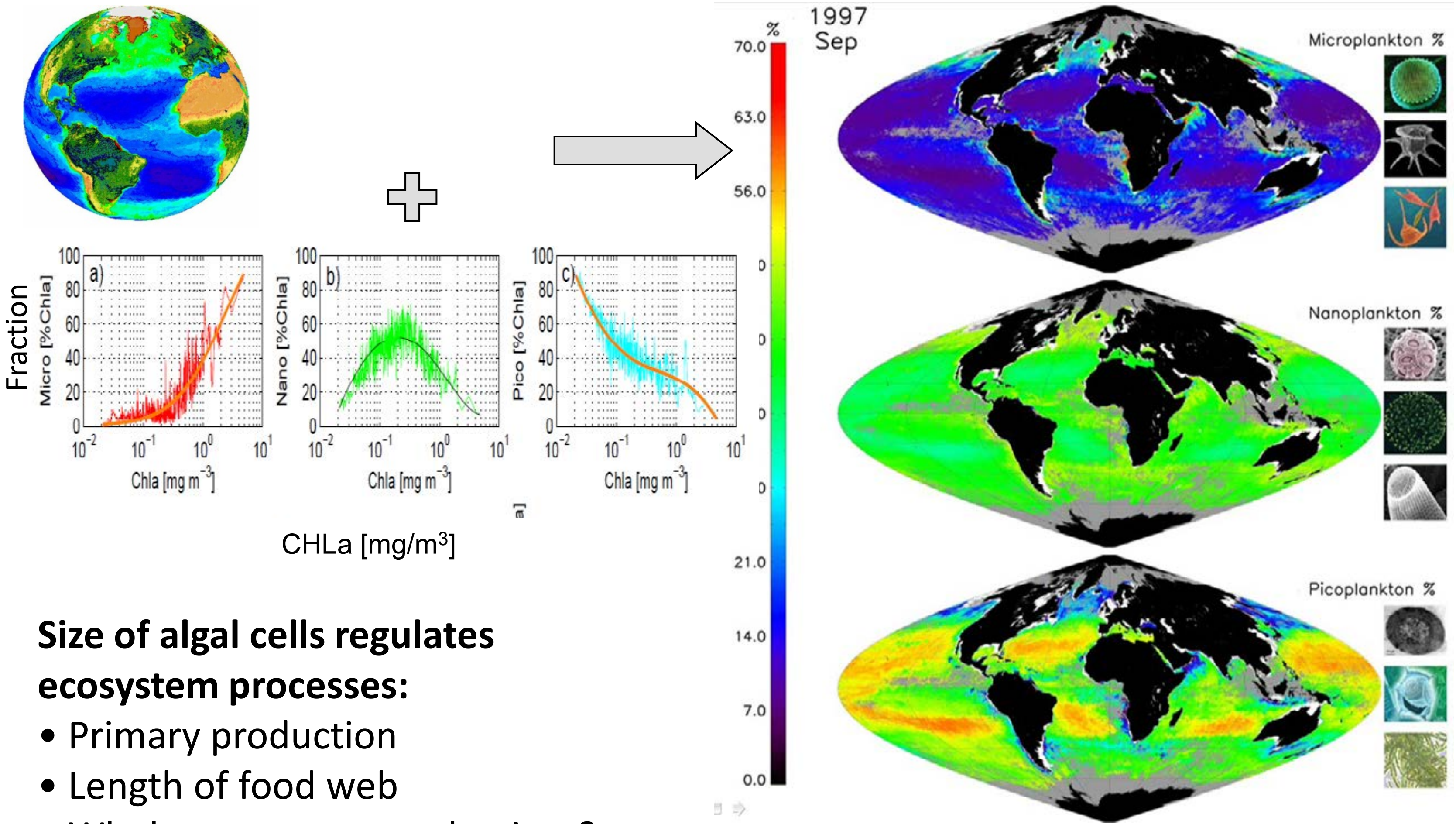
2. **Scaling relationships**
   - Size spectra
   - Biogeographic
   - Trophic level relationships
   - Trophic transfer
   - Connectivity
   - Diversity

3. **Expert knowledge**
   - Is the model behaviour plausible?



Validation: How do we tell if the biology works?

Phytoplankton Community Structure



Bigger cells (>20µm)

Medium cells (2-20 µm)

Smaller cells (<2 µm)

Size of algal cells regulates ecosystem processes:

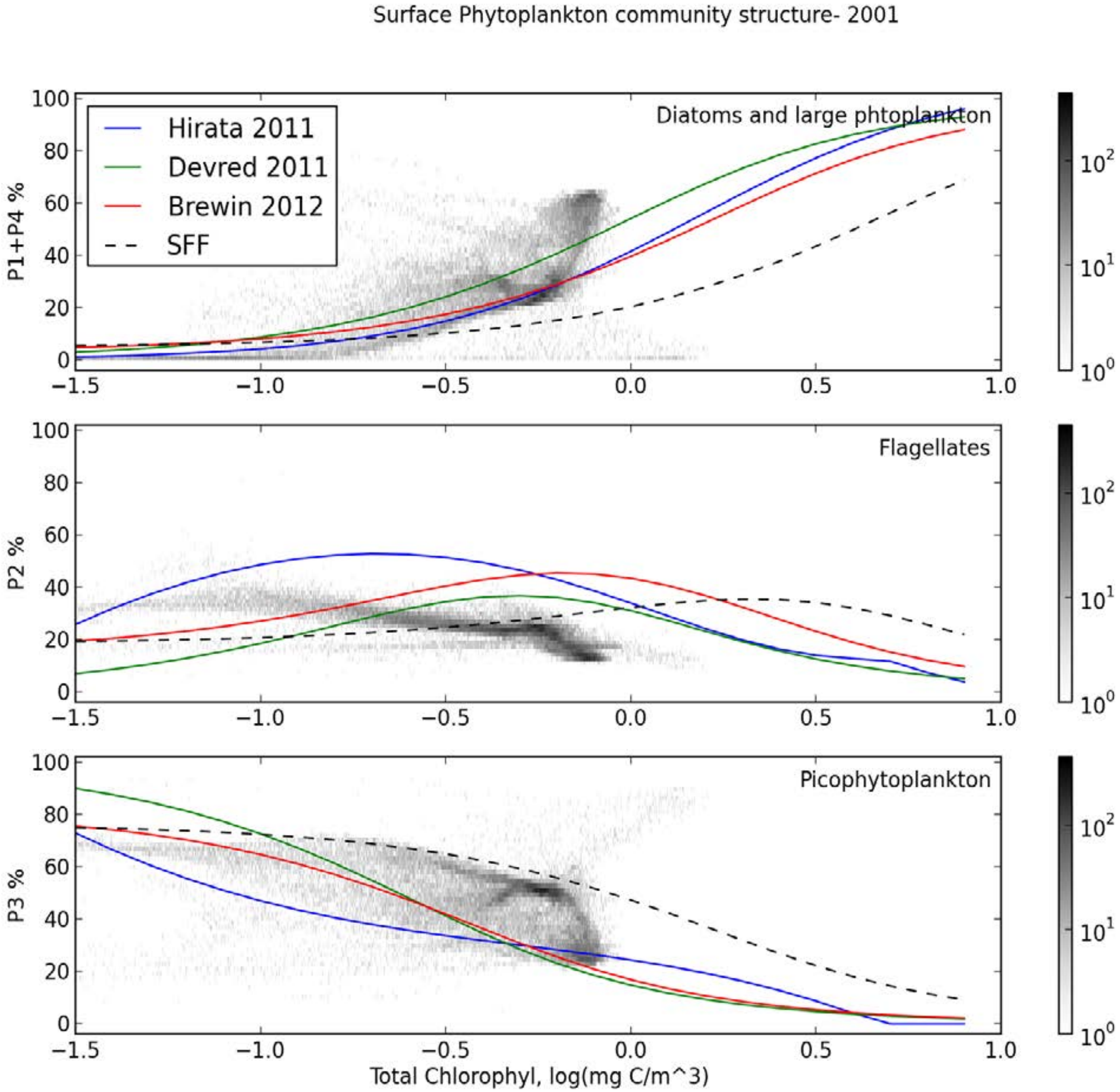
- Primary production
- Length of food web
- Whole ecosystem production & respiration
- Carbon dioxide drawdown

Hirata et al., 2008, 2011

Brewin et al., 2010 a,b,c, 2011

Validation: How do we tell if the biology works?

- **Pigment models**: Hirata 2001, Brewin 2012, Devred 2011
- **Size based models**: Size fractionated filtration.



Towards a traceable model hierarchy

1. Trophic structure in terms of organism size and function (here we refer to high level ecosystem function, i.e. autotrophy, heterotrophy, decomposition).

2. Within size / functional class diversity, by subdividing by biological traits (e.g. feeding strategy, motility, physiology).

3. Within trait diversity whereby intra- and inter-specific competition is described by defining a set of species within each trait type, stochastically drawing parameters from a rule based parameter space.