Observing Ocean Ecosystems: Needs, Capabilities, and Gaps

Ken Denman

Fisheries & Oceans Canada

EC Canadian Centre for Climate Modelling & Analysis c/o University of Victoria

&

Institute of Ocean Sciences, Sidney, BC

Email: *ken.denman@ec.gc.ca*

CCCma

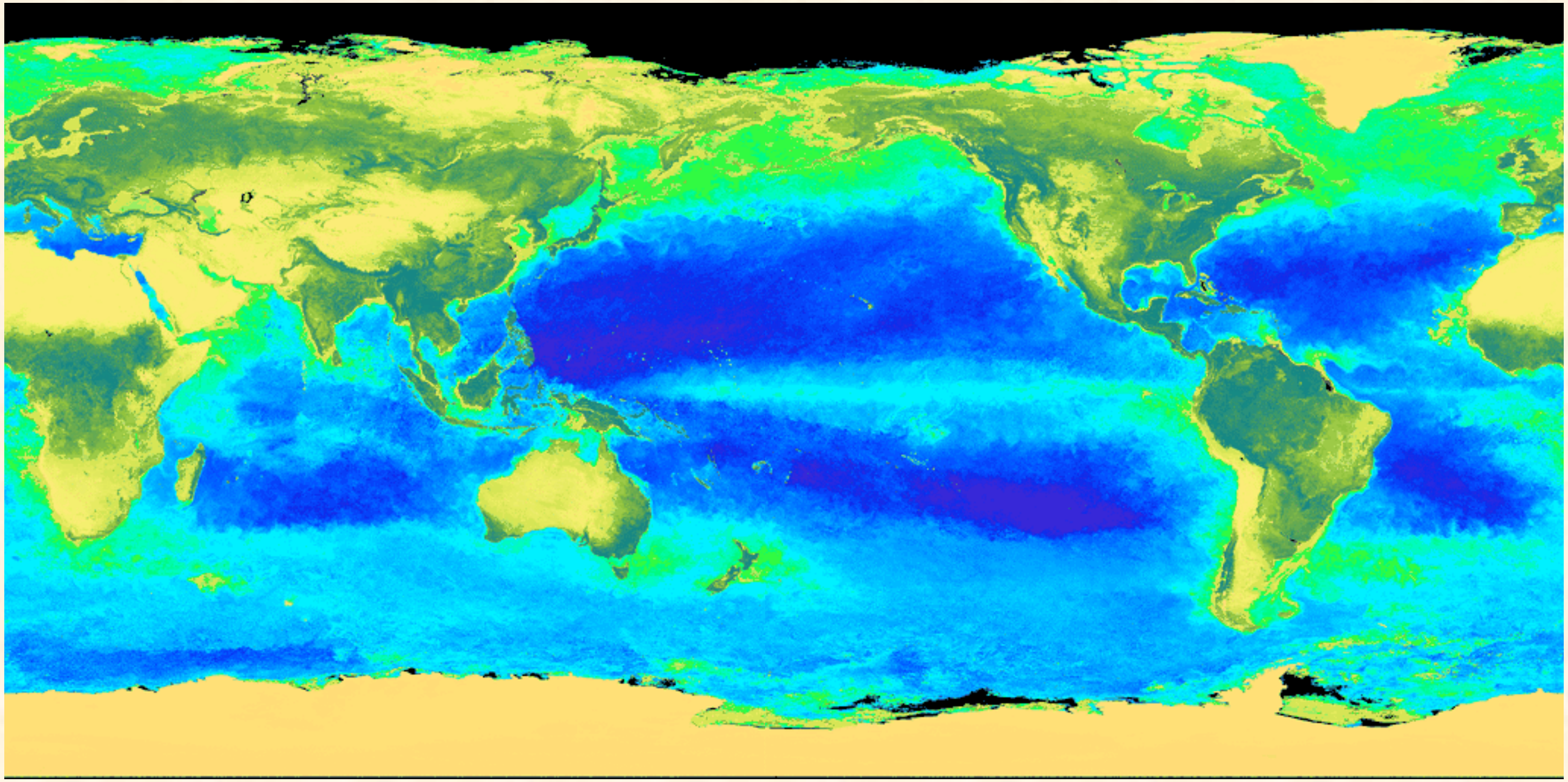
U. Victoria

IOS

Key Questions for Understanding Marine Ecosystems and their Dynamics

1. **What species are present at any location & at what abundances?**
   – ***i.e. what is the 'texture' of life in the sea?***
2. **Who eats who, how fast, when, and why?**
   – ***what rates are amenable to observation / inference?***
3. **What are the scales of variability of marine life, how fast do things change, and what environmental factors regulate this change?**
4. **What observational techniques and systems are available to inform us about questions 1 – 3?**
5. **What are key gaps in our observing abilities?**

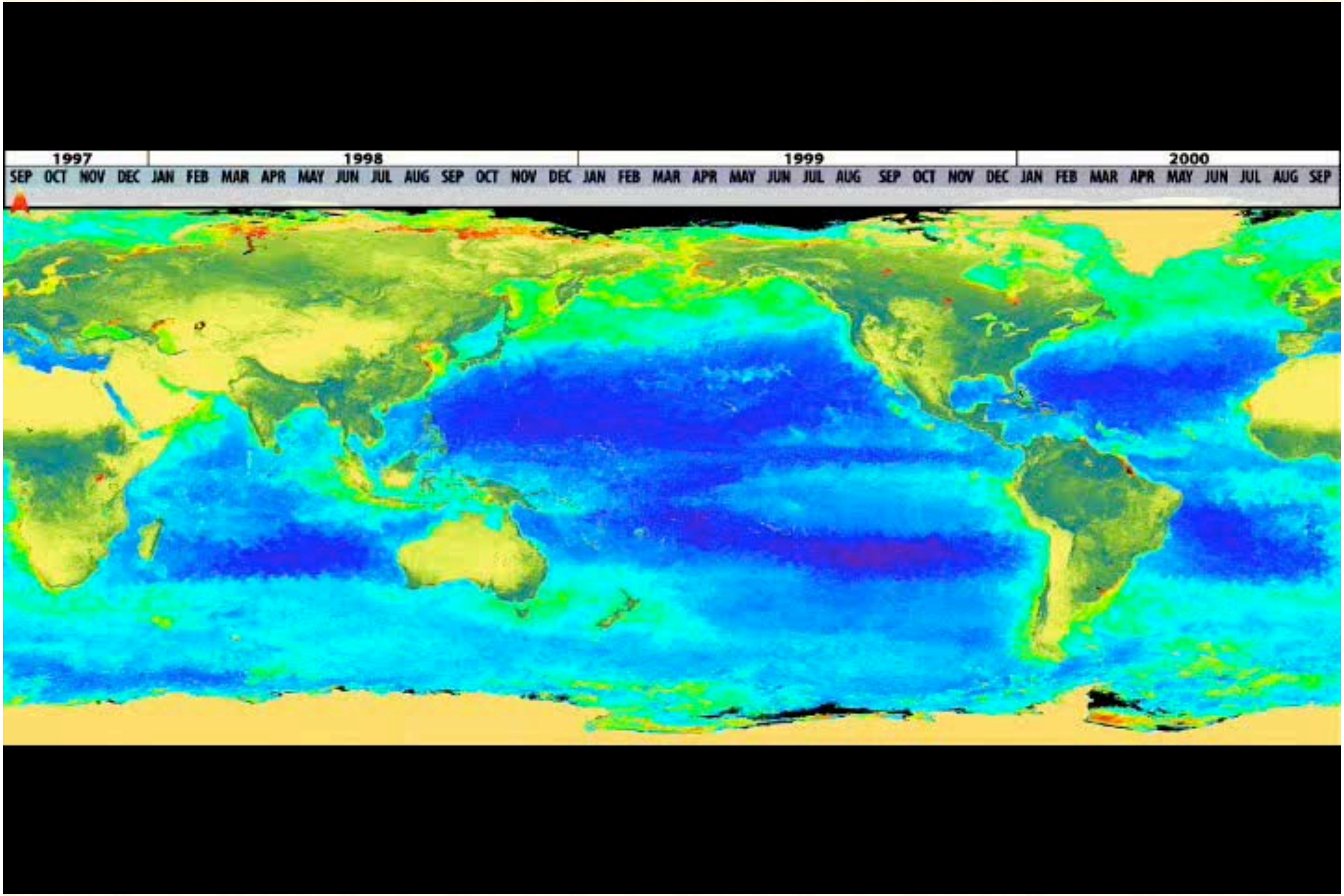
Marine Ecosystems Are Complex & Dynamic



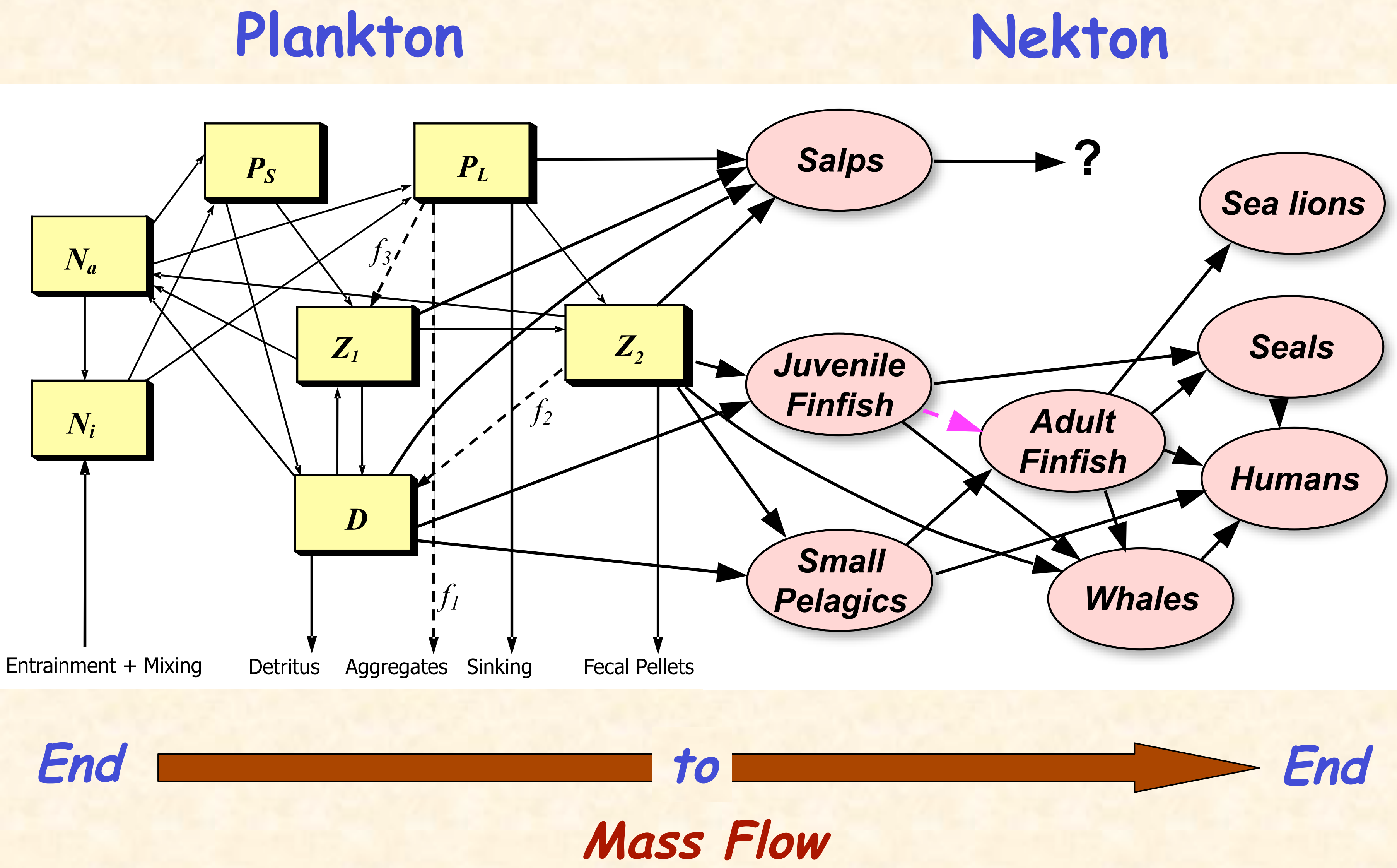
Each SeaWiFS image is an 18-day composite (to account for clouds), with a time separation of 8 days – allowing a smooth movie.

Movie prepared by K. Zahariev, L. Waters & K. Denman (CCCma) from 141 SeaWiFS images downloaded from NASA

Marine Ecosystems Are Complex & Dynamic

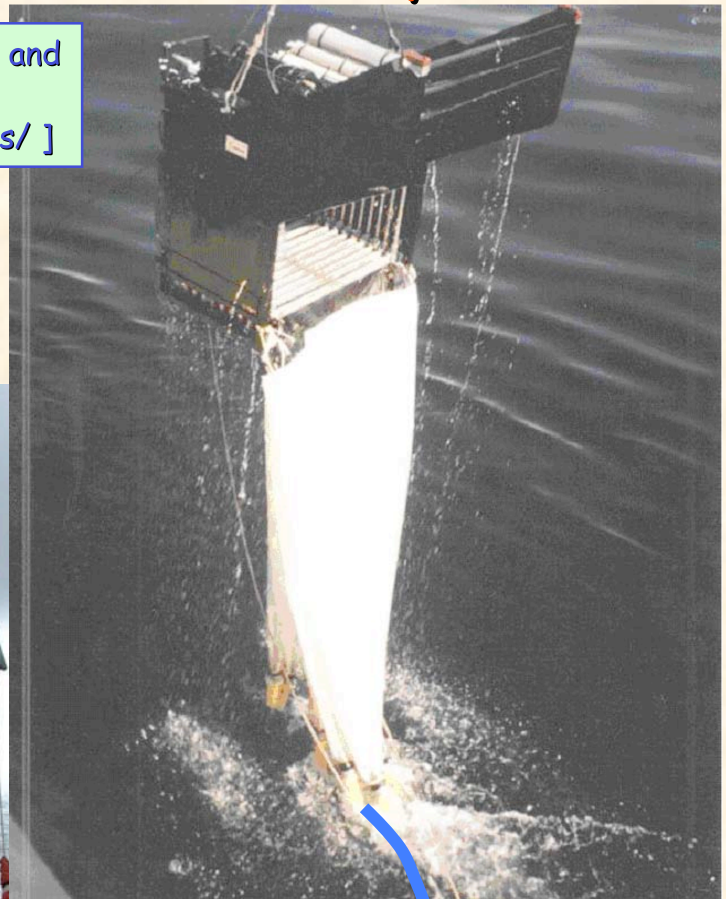


Marine Ecosystems: 'Physics to Fish to Us'



Shipborne Studies of Planktonic Ecosystems

BIONESS – multiple opening and closing net sampling system [www.mar.dfo-mpo.gc.ca/sabs/]



Rosette Sampler
Global Change NewsLetter
No. 73 April 2009

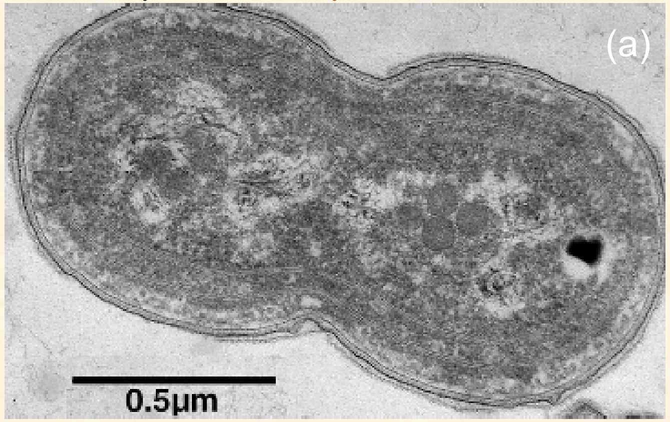
http://pal.lternet.edu/sci-research/zooplankton/

Phytoplankton Under Microscope

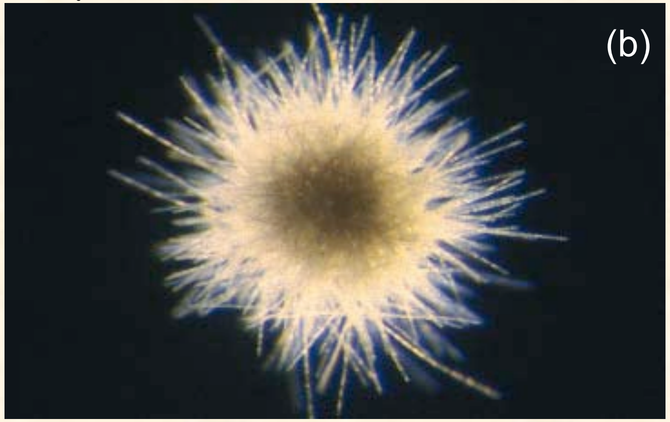
Take up CO_2 during photosynthesis

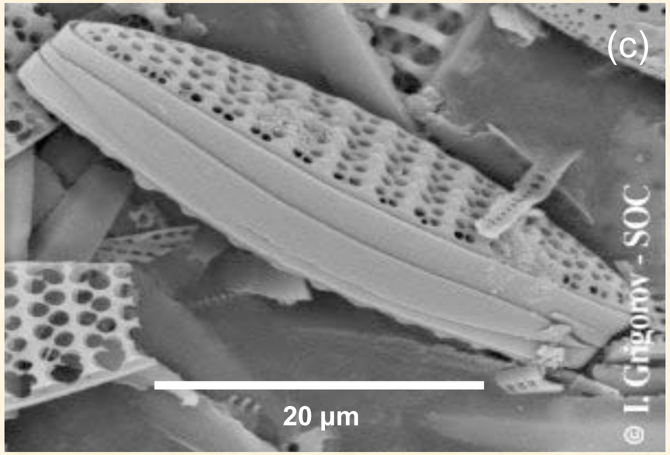
Modelling Has Led to the Concept of *'Plankton Functional Types* (PFTs)'

Picoplankton *Synechococcus*

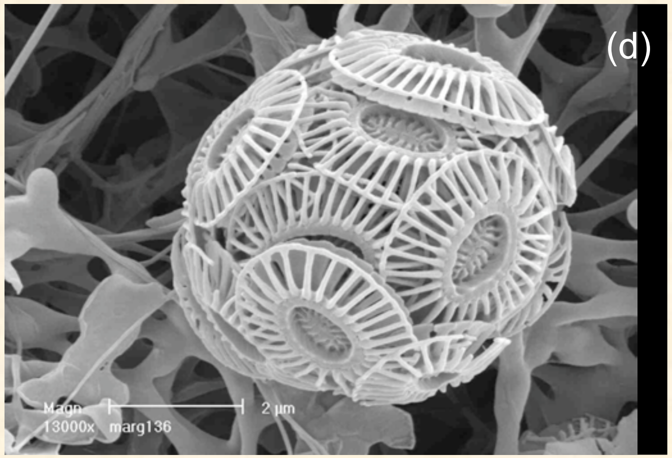


Cyanobacterium *Trichodesmium*





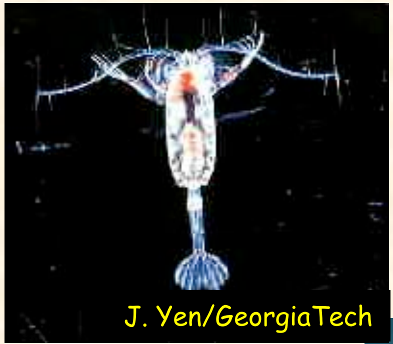
Diatom *Fragilariopsis kerguelensis*



Coccolithophorid *Emiliania huxleyi*

The PARADIGM Group, Oceanography 19(1), March 2006
& Le Quéré et al., CWP

Zooplankton Are Also Diverse



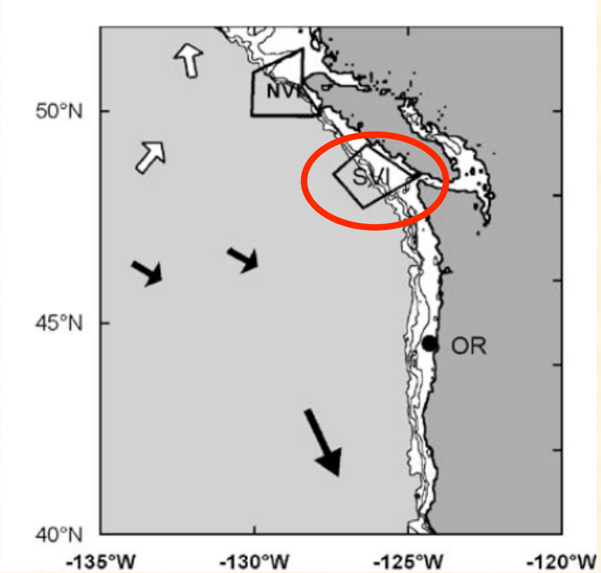
J. Yen/GeorgiaTech

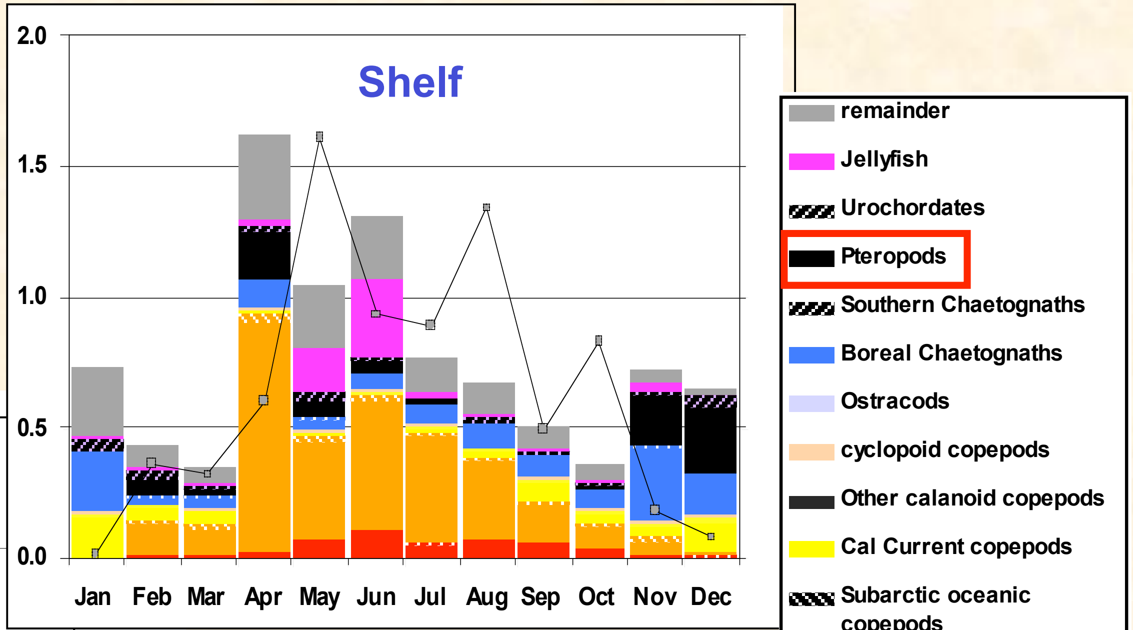
R. Hopcroft/UAF/COML

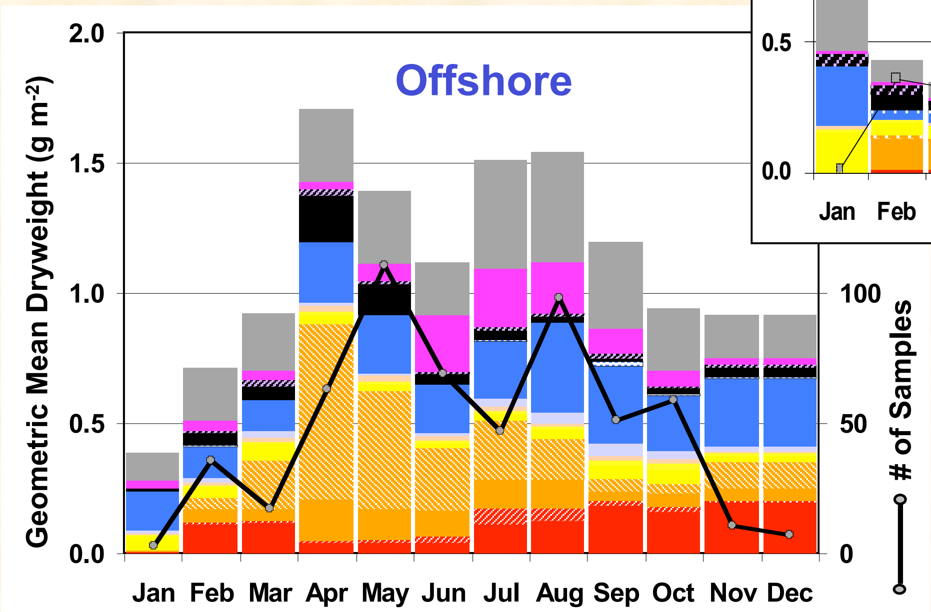
www.MAR-ECO.no/
Øystein Paulsen

Other credits: www.pac.dfo-mpo.gc.ca/sci/osap/projects/plankton/

The Zooplankton Community off Southern Vancouver Island







Updated from:

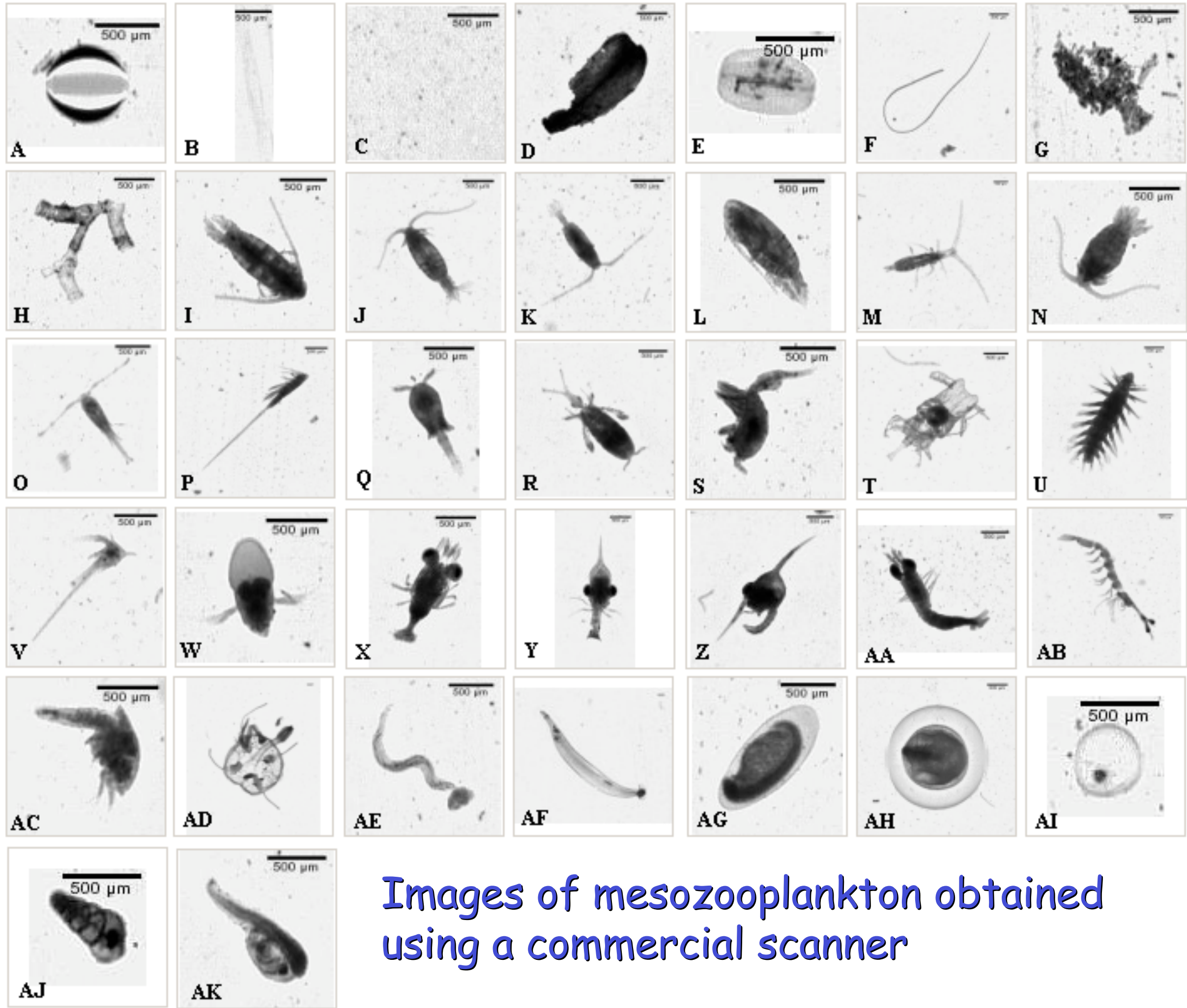
Mackas, Peterson & Zamon, 2004. Deep-Sea Res. II, 51, 875-896.

Automated Plankton Identification

Sieracki et al. CWP;   www.scor-wg130.net/

Lab & Shipboard Systems

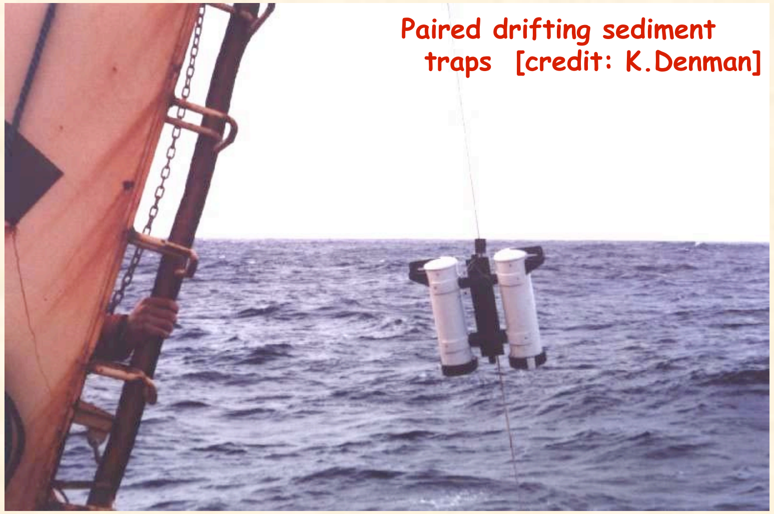
- Technology ahead of recognition imaging software
- Organisms <20 μm too similar
- Discriminating between 10 to 30 classes 70–80% accurate, which approaches agreement between human experts



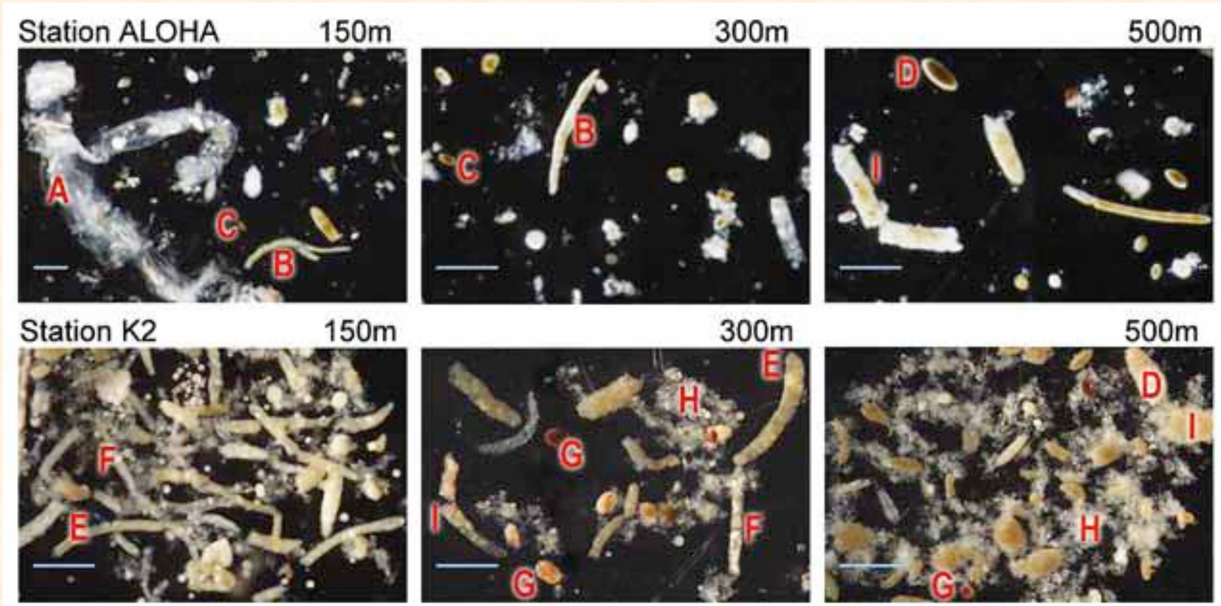
Images of mesozooplankton obtained using a commercial scanner

Detritus 'D' - Sinking Particles

Moored sequential sediment traps [credit: K.Denman]



Paired drifting sediment traps [credit: K.Denman]



Global Change NewsLetter No. 73 April 2009

Ecosystem Observation Systems

(modified from *Le Quéré et al., CWP*)

- Remote sensing – space, acoustics, video ($\sim 10^6$ m)
- Video plankton recorders, shape recognition ($\sim 10^{-6}$ m)
- Time series data – images, long term stations (HOT, BATS, OSP)
- Drifting buoys and gliders - *Claustre et al. CWP; Freeland et al., CWP*
- Repeat sections –CLIVAR, CPR/SAHFOS, AMT
- Census of Marine Life (CoML) / OBIS
- Data management & sharing/co-referencing e.g CoML / OBIS *Vanden Berghe et al CWP*

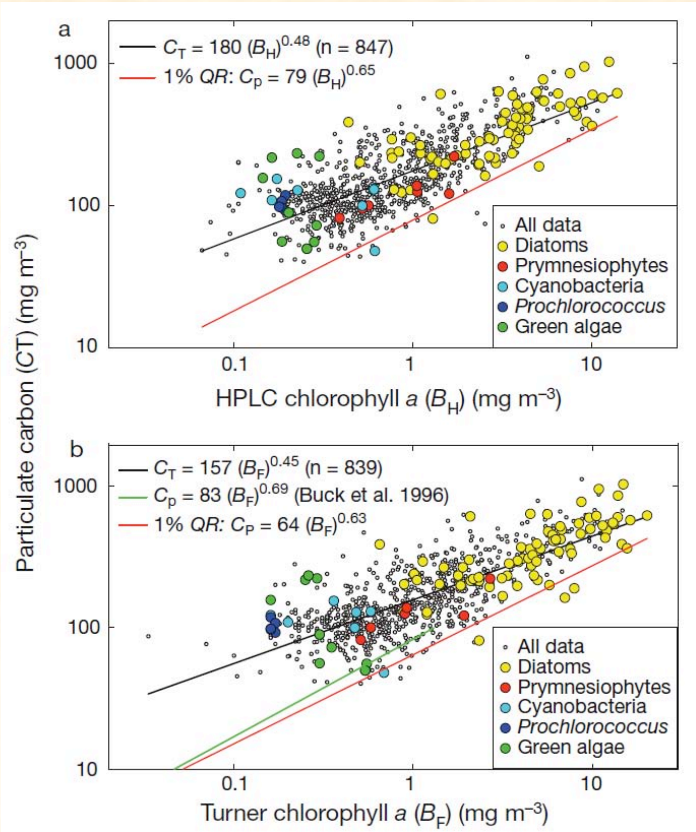
Remote Sensing from Satellites

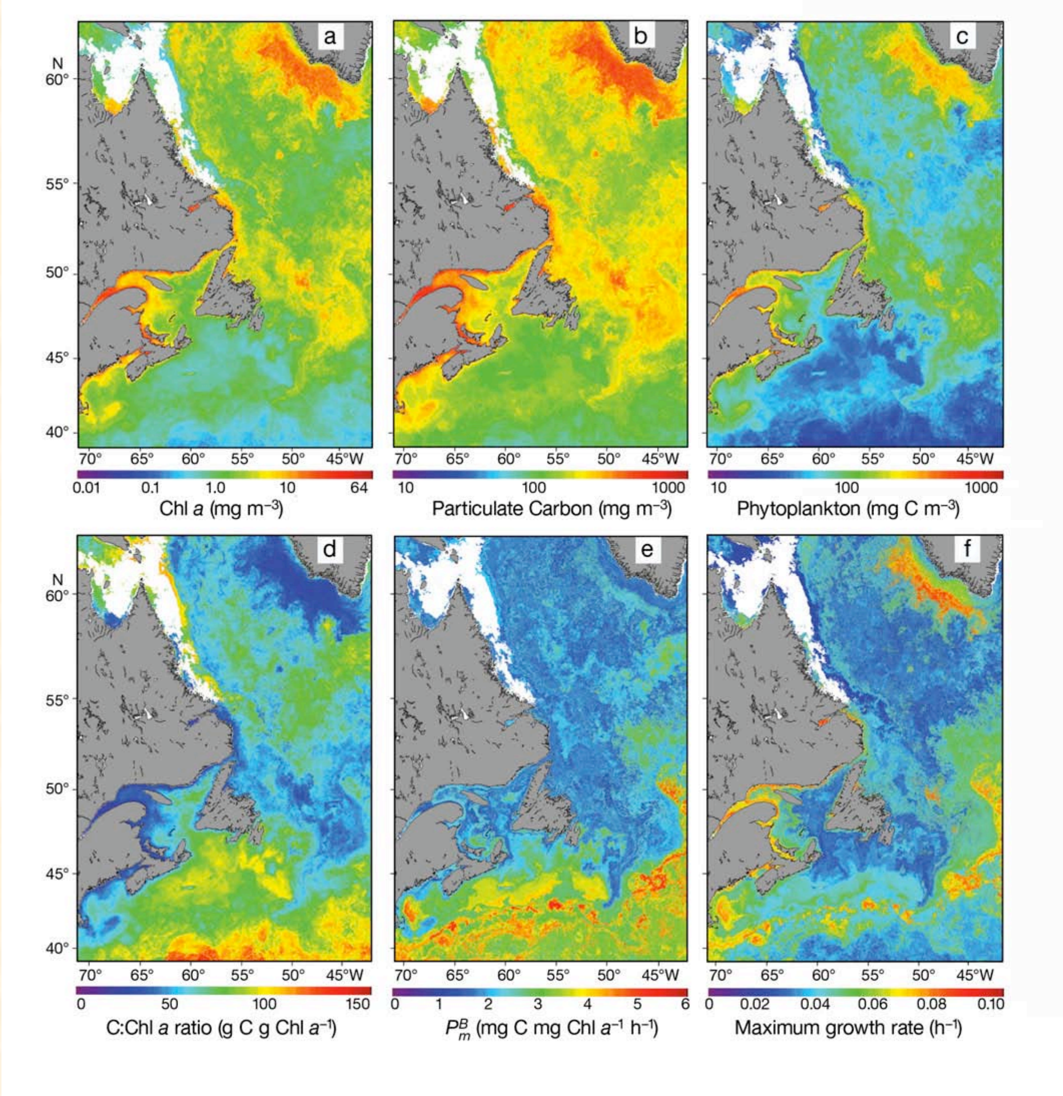
CWPs: Sathyendranath et al., Yoder et al.

- Phytoplankton Chlorophyll pigment
- Primary Productivity: need Chlorophyll, SST, Subsurface Light & Carbon from C:Chl ratio
- Plankton Functional Types (PFTs): e.g. Coccolithophorids from visible bands
- Organism Size
- Need to extend Satellite Ocean Color Radiometry to long times (multi-decadal) using mission / sensor overlap and models to bridge gaps between missions

Regional Lab & Field Data + Satellite Imagery ⇒

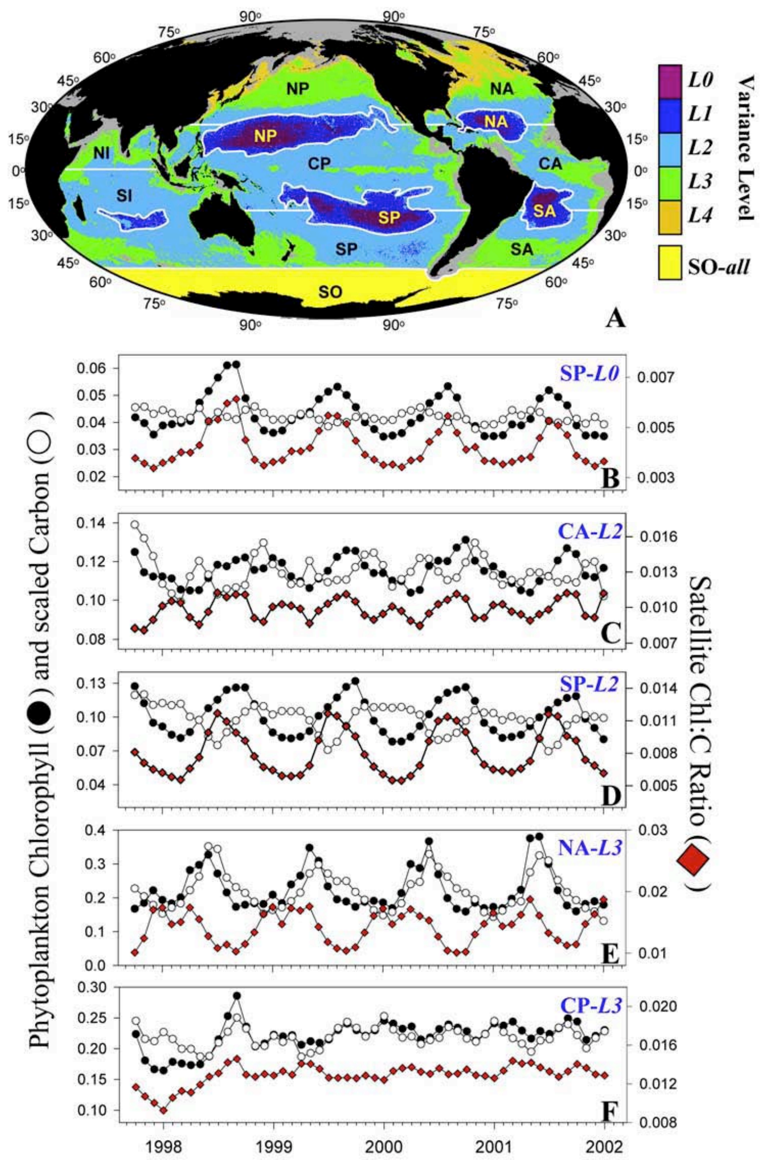
- *Carbon:Chl ratio*
- *PP in C units*
- *Prob. of diatoms*





Sathyendranath et al 2009. Mar Ecol Prog Ser, 383, 73-84
Platt et al 2009. Remote Sens Environ, 112, 3427-3448

Regional to Global Derived Time Series



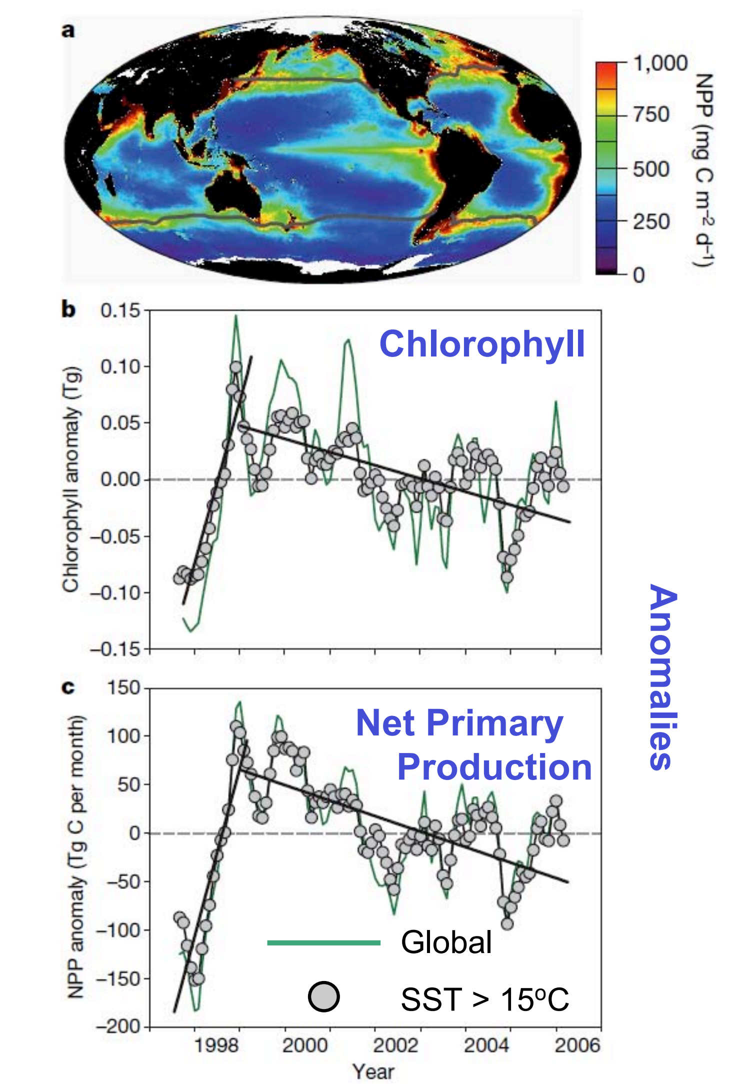


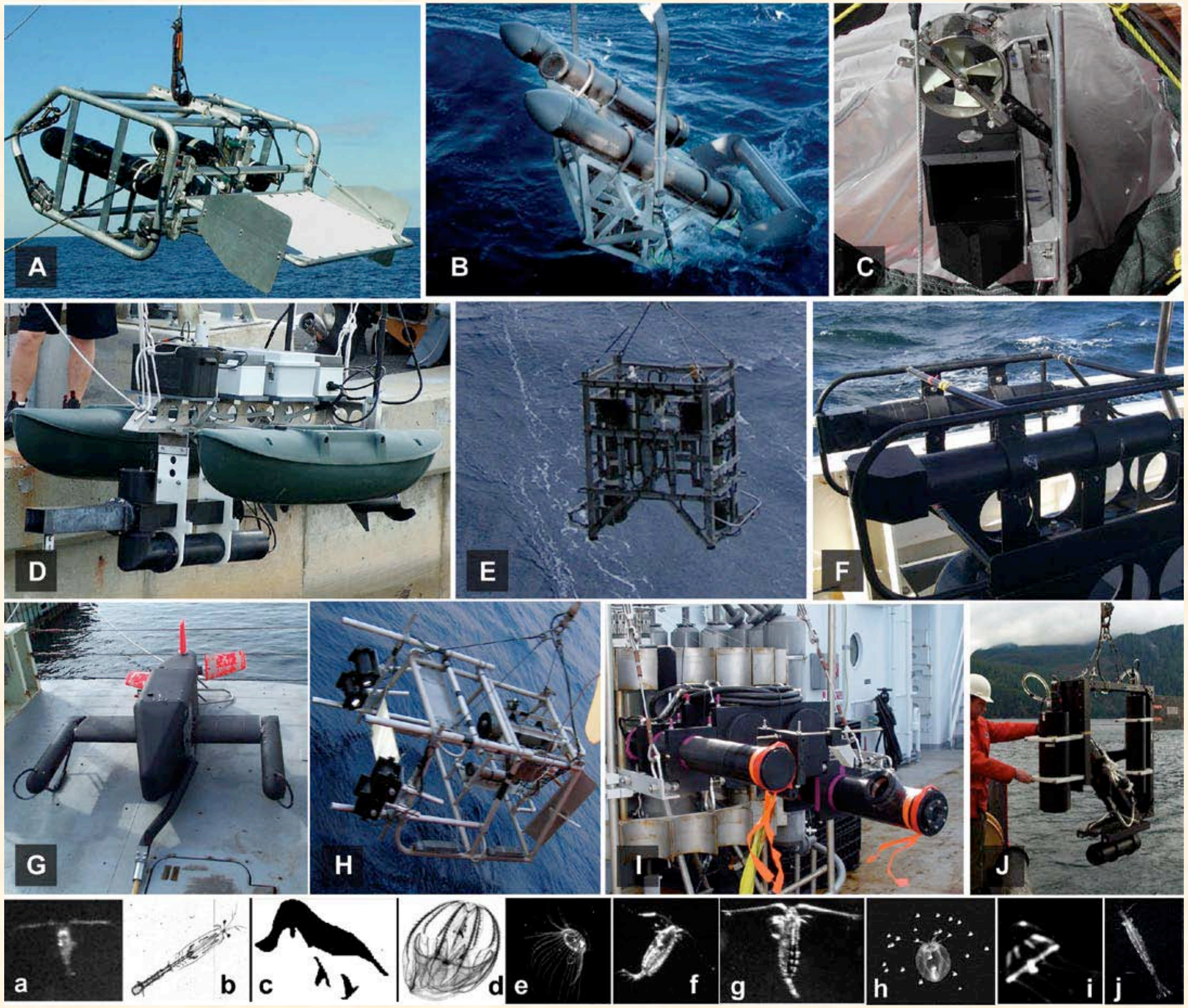
Figure 1 | Distribution and trends in global ocean phytoplankton productivity (NPP) and chlorophyll standing stocks.

Behrenfeld et al: 2005 GBC 19, GB1006, doi:10.1029/2004GB002299; 2006 Nature 444, doi:10.1038

Need to Integrate Video Plankton Techniques into Observing Systems

Many developmental systems

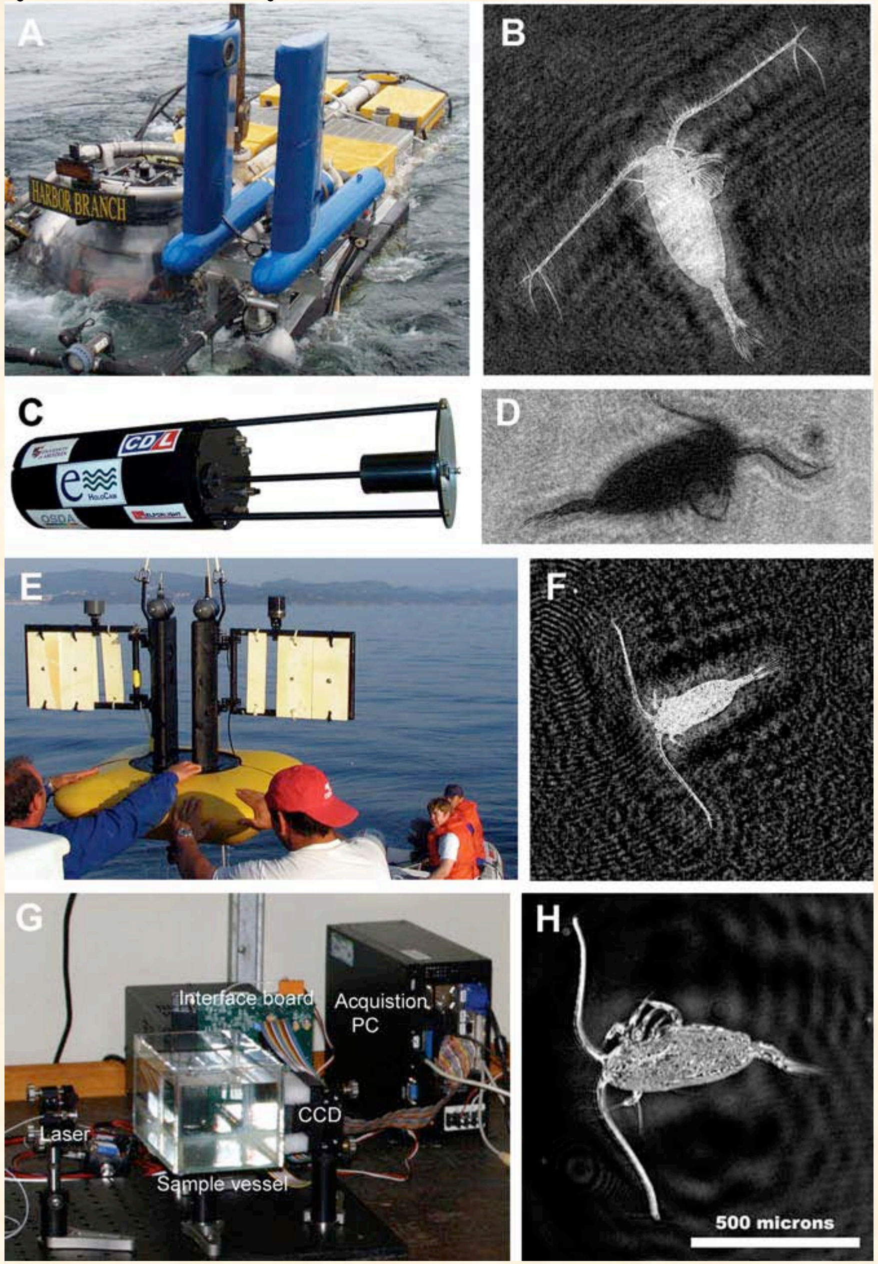
Benfield et al 2007 Oceanography 20 (2), 172-187



Digital Holographic Systems

- Low power requirements
- Broad range of sizes

Benfield et al 2007 Oceanography 20 (2), 172-187



Issues with Optical Systems for Long Term Deployment

- most require lots of power
- biofouling can be a problem

Drifting Buoys and Gliders

Claustre et al. CWP

'Carbon Explorer float' in Southern Ocean

- *In situ* POC:
  colour contours
- Sinking particles at depth:
  red vertical bars
- Depth of mixed layer:
  white line ———

Bishop & Wood 2009 GBC, in press

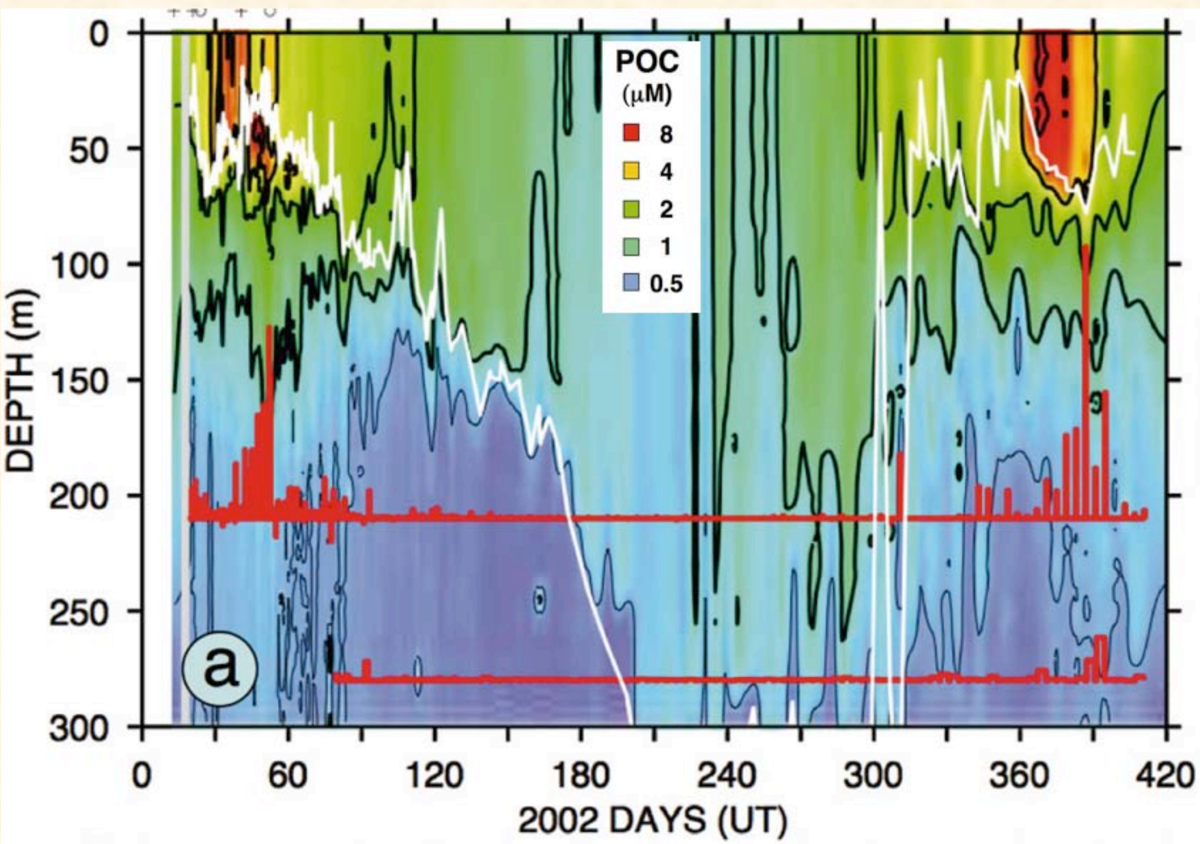
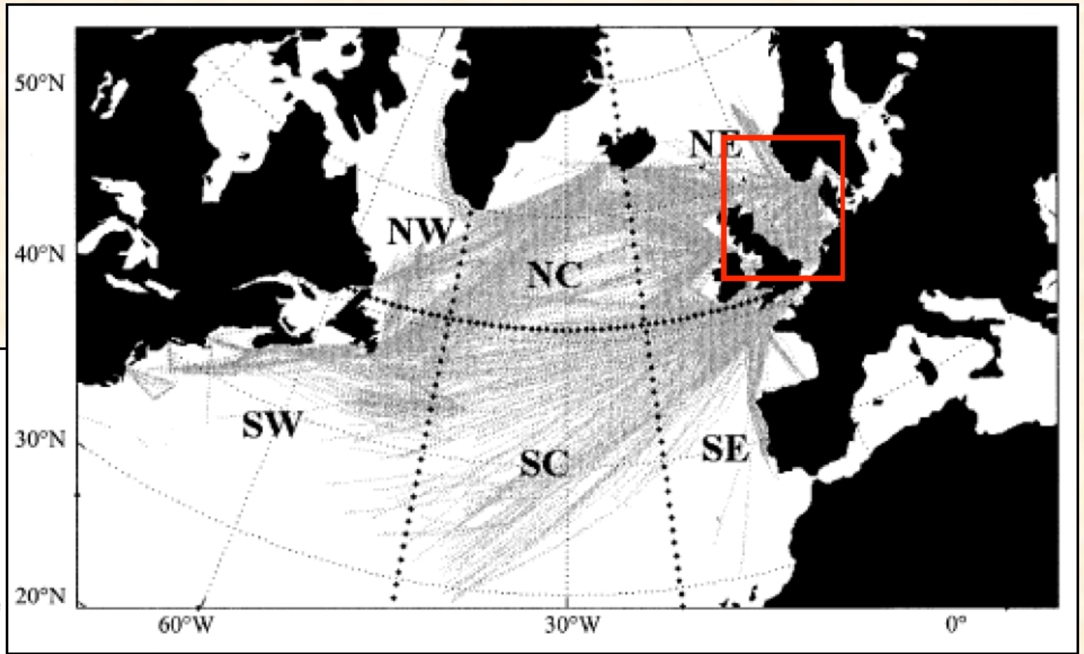


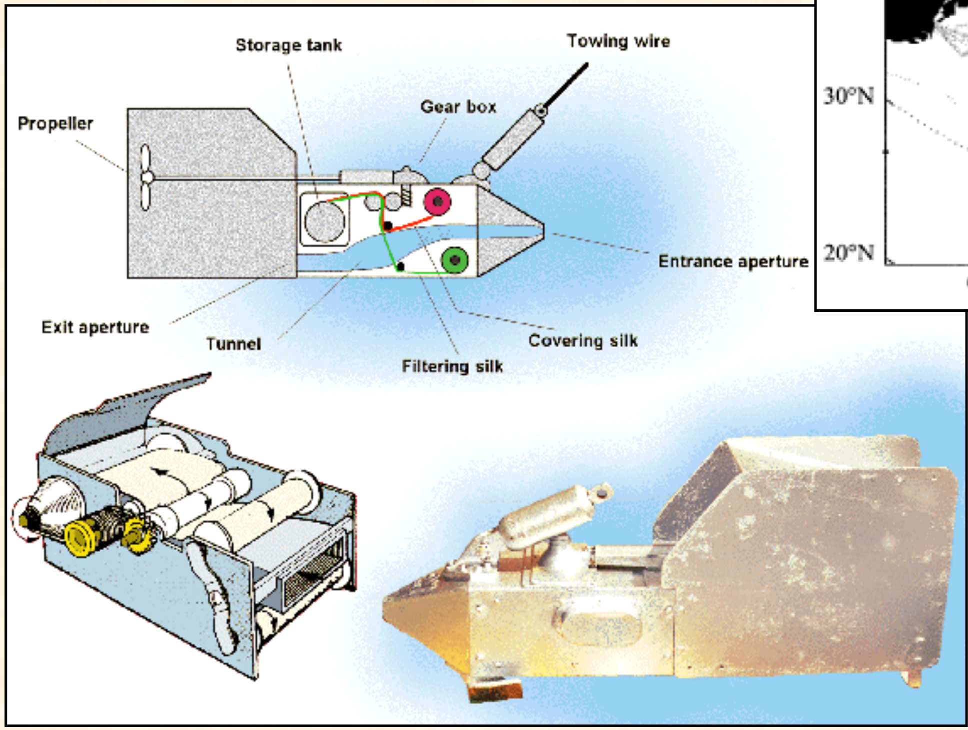
Figure 3. Time series of particulate organic concentration (color plot) and particle flux (red bars, in relative units) in the Southern ocean (around 55°S, 170°W). The data were acquired by the Carbon Explorer float which associates a Solo float to a suite of optical sensors. The reduction of the mixed layer (white line) in spring allows the increase in POC resulting from the development of the phytoplankton bloom, and the subsequent increase of particulate material export of at depth. From Bishop and Wood (2009)

Continuous Plankton Recorder (CPR) Survey:

Value of Long Term, Broadscale, Repeated Sampling with Stable Technology

Thanks: to Peter Burkill and Chris Reid, SAHFOS

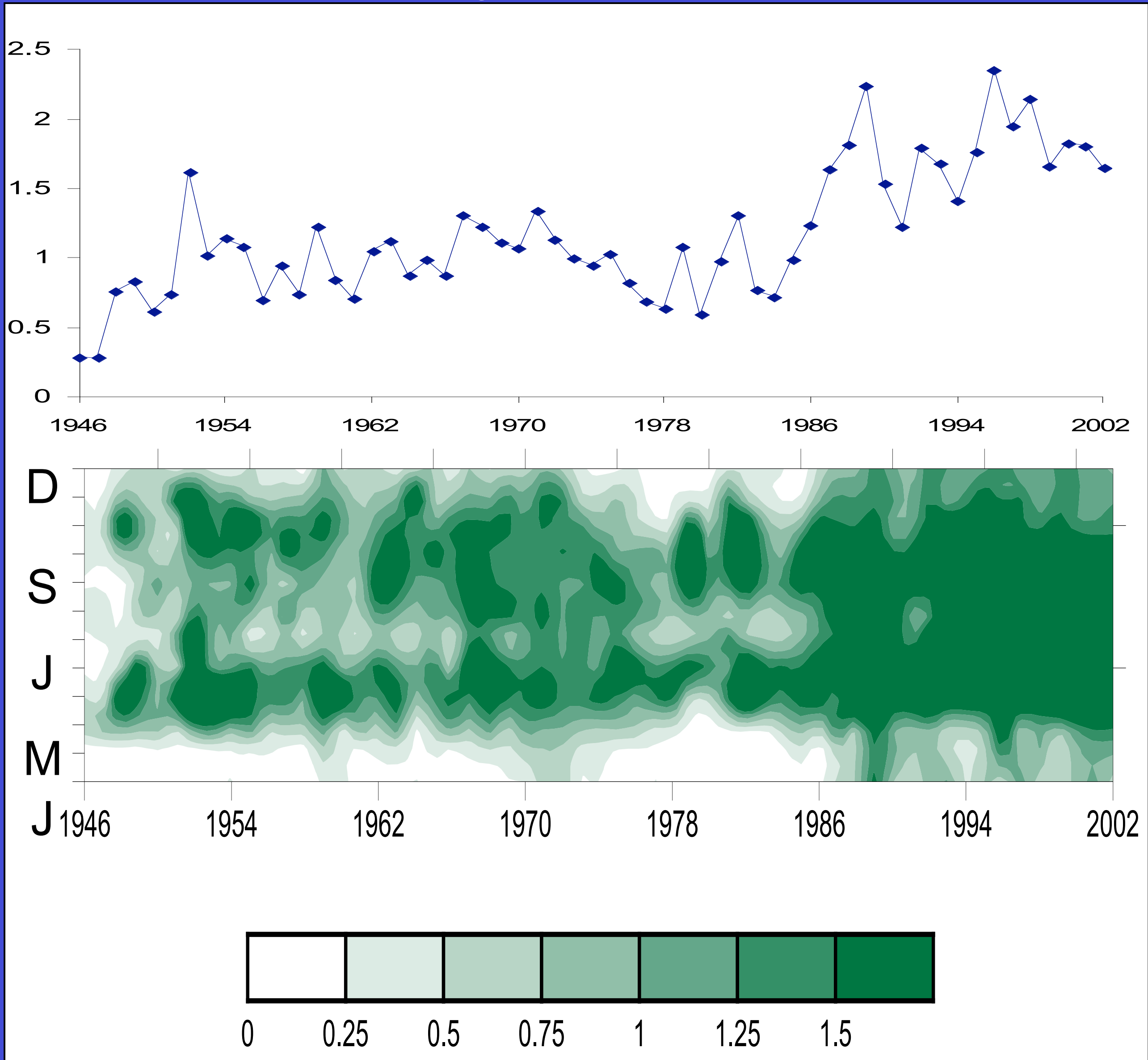




- uses ships of opportunity
- samples caught between 2 rolls of continuously moving silk netting onto roller
- CTDs etc can be added

North Sea Phytoplankton Colour

1946



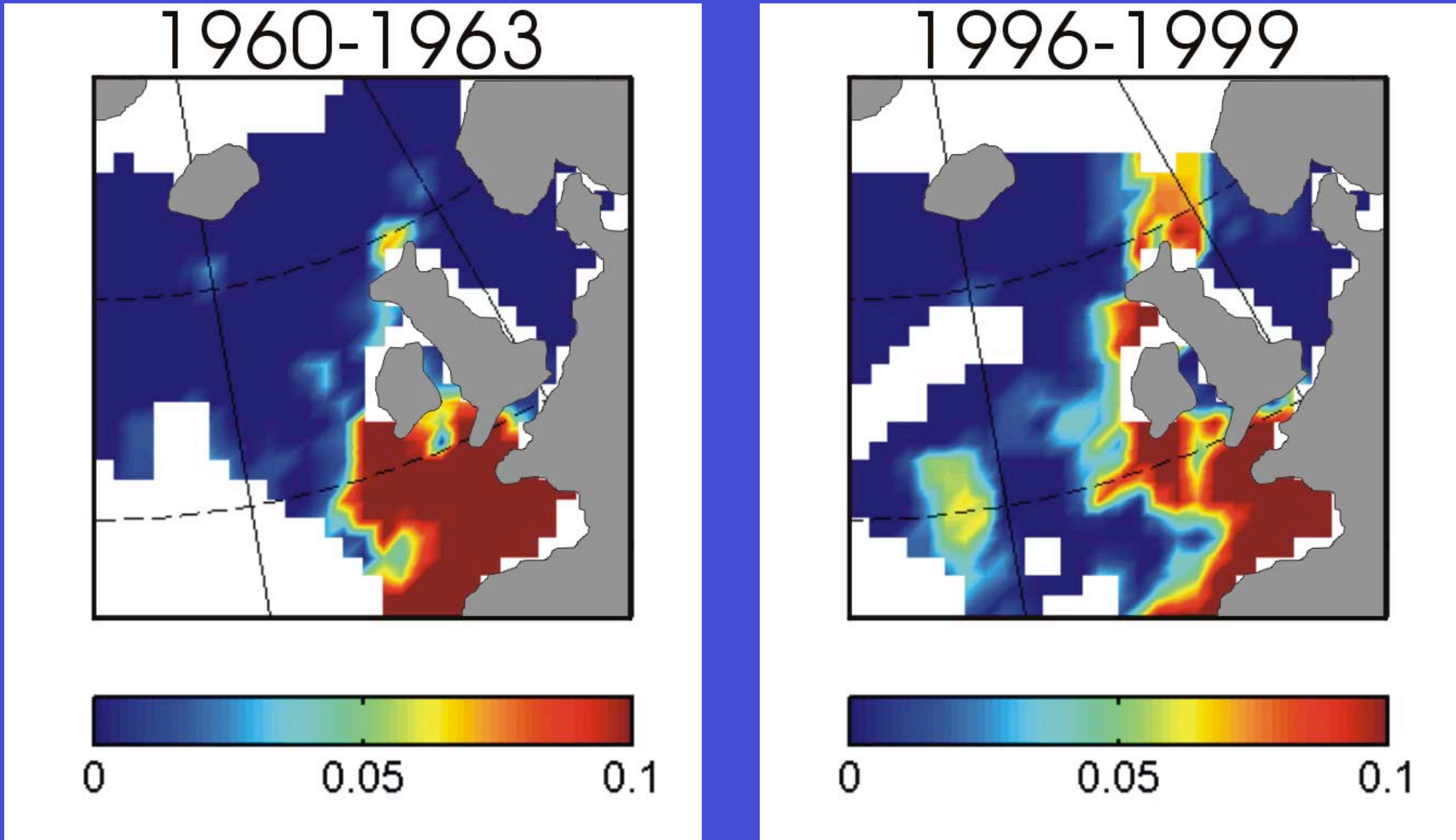
2002

Reid *et al*. 1998, Nature 391, 546 (updated)

SAHFOS

Step changes in regional sea systems: Regime shift

Northerly movement of plankton and fish

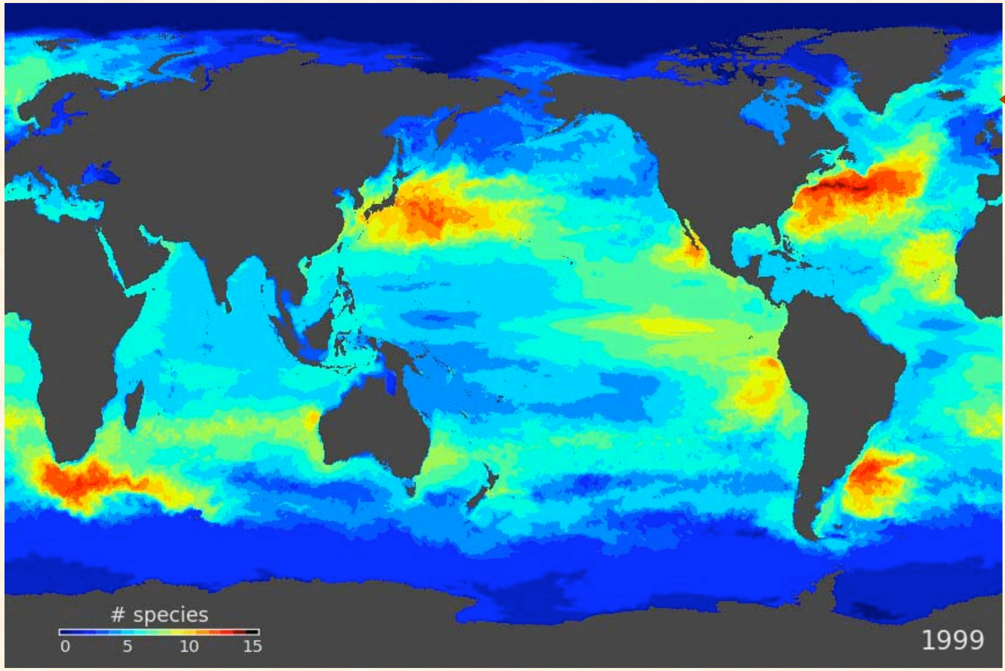


Warm temperate slope species

2005 *Euchaeta hebes, Clausocalanus, Ceratium hexacanthum*

Beaugrand *et al*. 2003. Science **296**, 1692-1694

Census of Marine Life, Biodiversity and Ocean Physics



Number of Species

Mick Follows et al., MIT:

- ECCO2 ocean circulation,
- 18km horizontal resolution
- 78 'synthetic' phytoplankton species

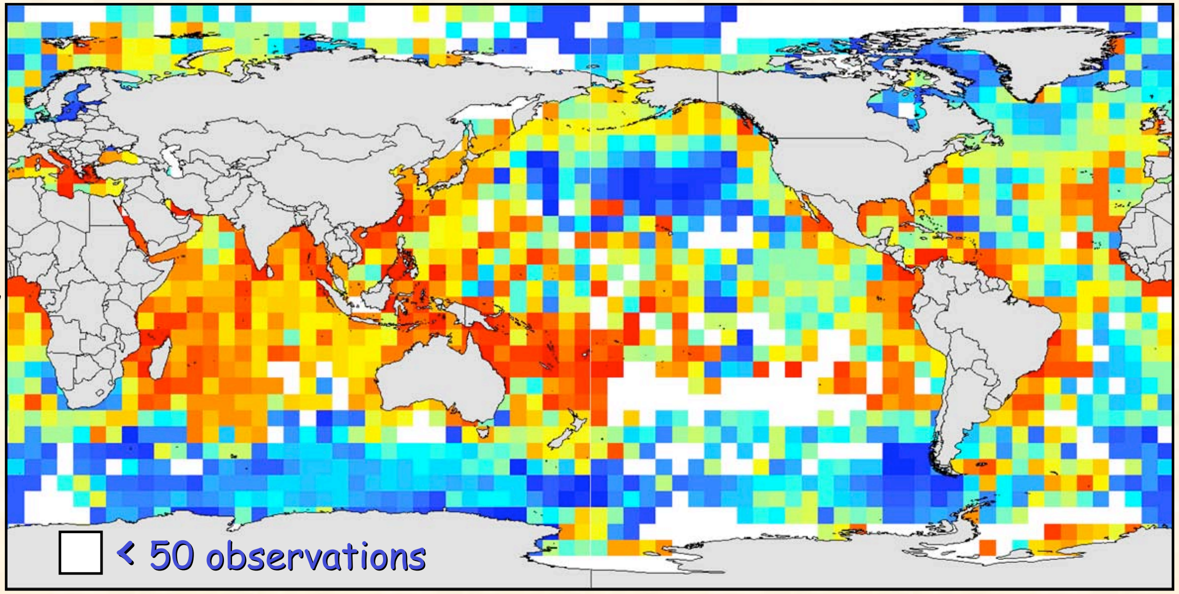
  Chris Hill and John Marshall (MIT), Dimitris Menemenlis (JPL), ...

Presented at the GLOBEC Open Science Meeting, Victoria, Canada, June 2009 Available at [http://web.pml.ac.uk/globec/products/OSM3/wa.htm]

Ref. *Follows, et al. 2007. Science, 315*

Vanden Berghe et al. CWP:

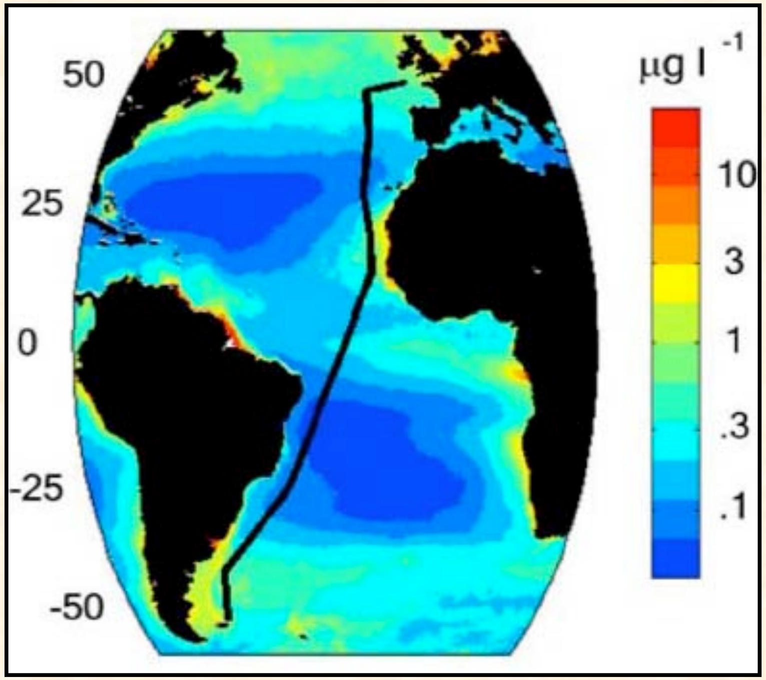
Hurlbert's index of diversity, ES(50): the expected number of distinct species in a random sample of 50 observations of "microbes to whales" calculated on a grid of 5x5 degrees.



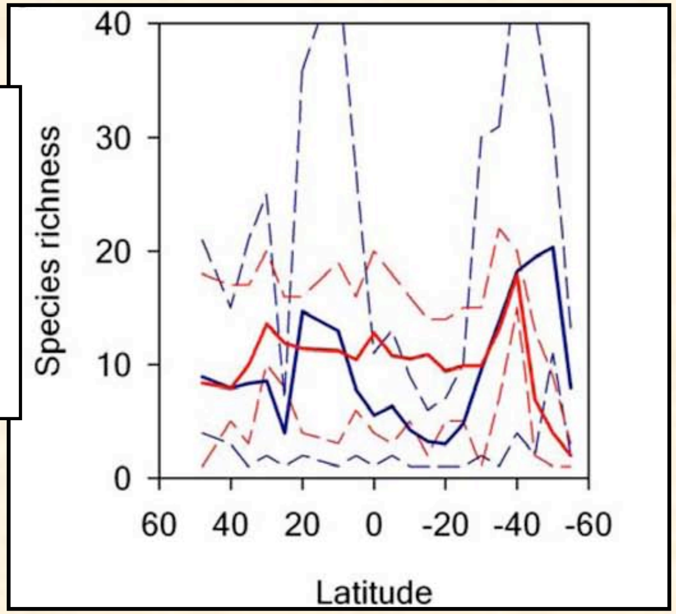
Four Repeat Sections Along Atlantic Meridonal Transect AMT project

Show high variability (in space & time) in the number of species, i.e. "Species richness".

Cermeño et al., 2008. PNAS, 105, 20344-20349.



Diatoms
Coccolithophorids
Mean
Range of data



Gaps

Ocean Physics & Engineering

- **Observations of vertical transport processes and rates**
- **Instrumentation: low power, low maintenance, robust & reliable**

Ocean Ecology

- **Microzooplankton – tightly coupled to phytoplankton through grazing**
- **Most rates need to be continuous and/or automatic, especially 'secondary production' by zooplankton**
- **Observations of fish abundances and change mostly obtained from fishing industry catch statistics:**
  - are usually normalized to *"catch per unit effort"*

Connecting observations by different groups

- **Need 'Database of Databases' linking NODCs, CLIVAR, Argo, SAHFOS, Satellite imagery (e.g.Ocean colour group IOCCG & ChloroGIN), FAO, CDIAC, OBIS/CoML programmes + …**

The End

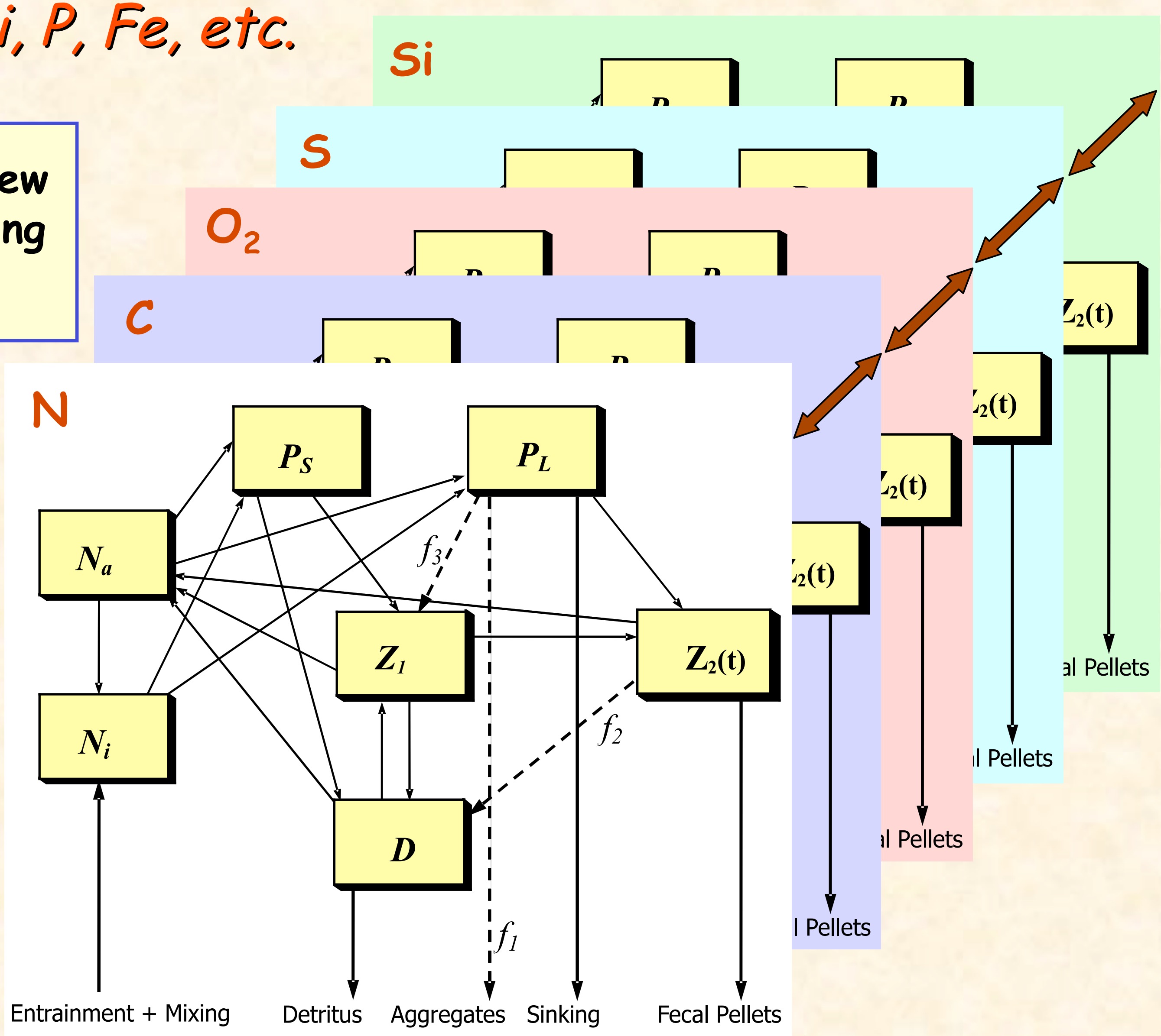
Thanks

ken.denman@ec.gc.ca

Ocean Ecosystems & Connected Elemental Cycles:

N, C, O_2, S, Si, P, Fe, etc.

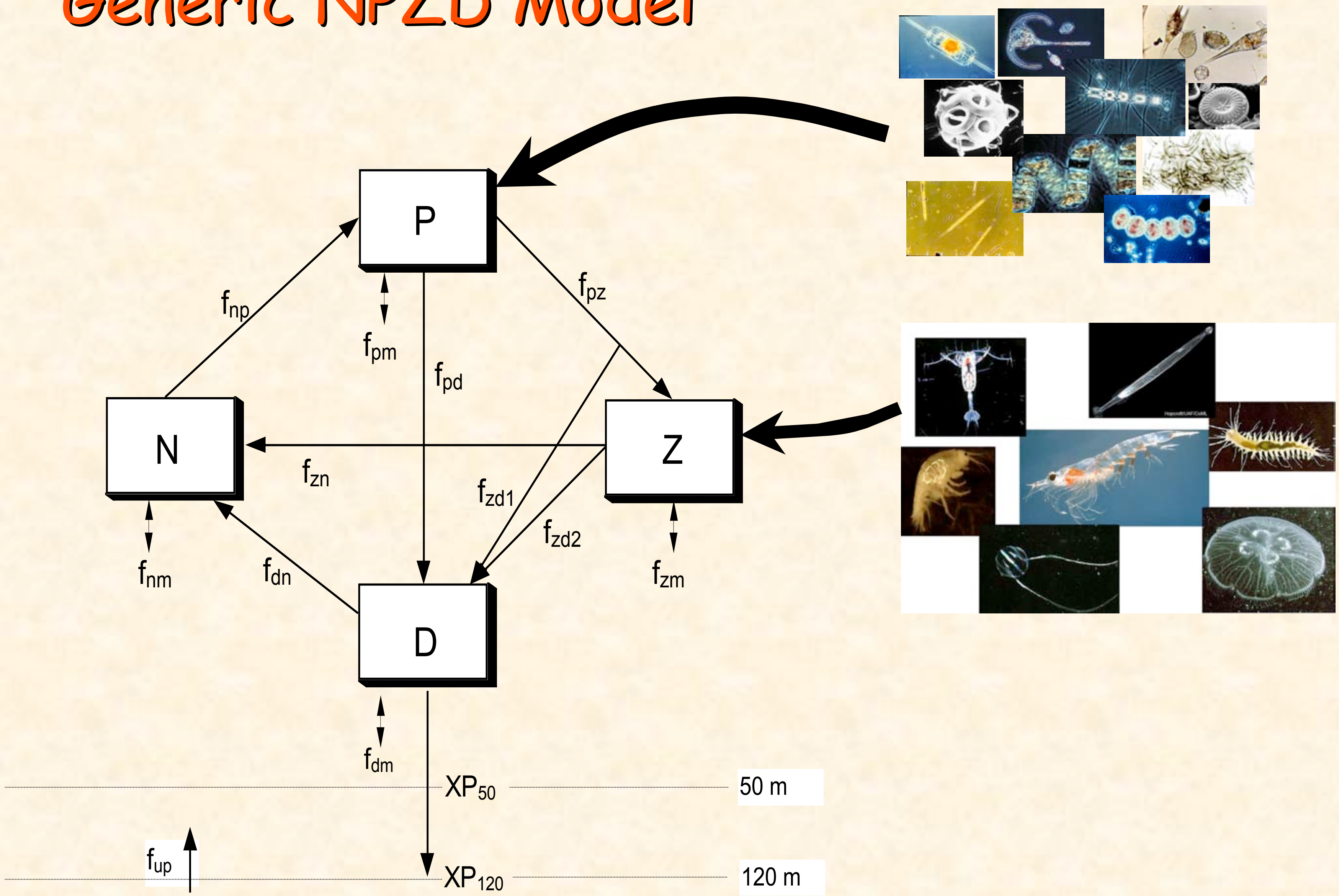
A *Front to Back'* view evolved from focusing on Carbon flows



- P_S small phytoplankton
- P_L large phytoplankton ie diatoms
- N_i nitrate
- N_a ammonium
- D detritus
- Z_1 microzooplankton
- $Z_2(t)$ specified mesozooplankton

Peña, Prog. Ocgy. 2003; Monahan and Denman, GBC, 2004; Denman, Voelker, Peña and Rivkin, DSR II, 2006; Steiner & Denman, DSR I,55, 2008.

Generic NPZD Model

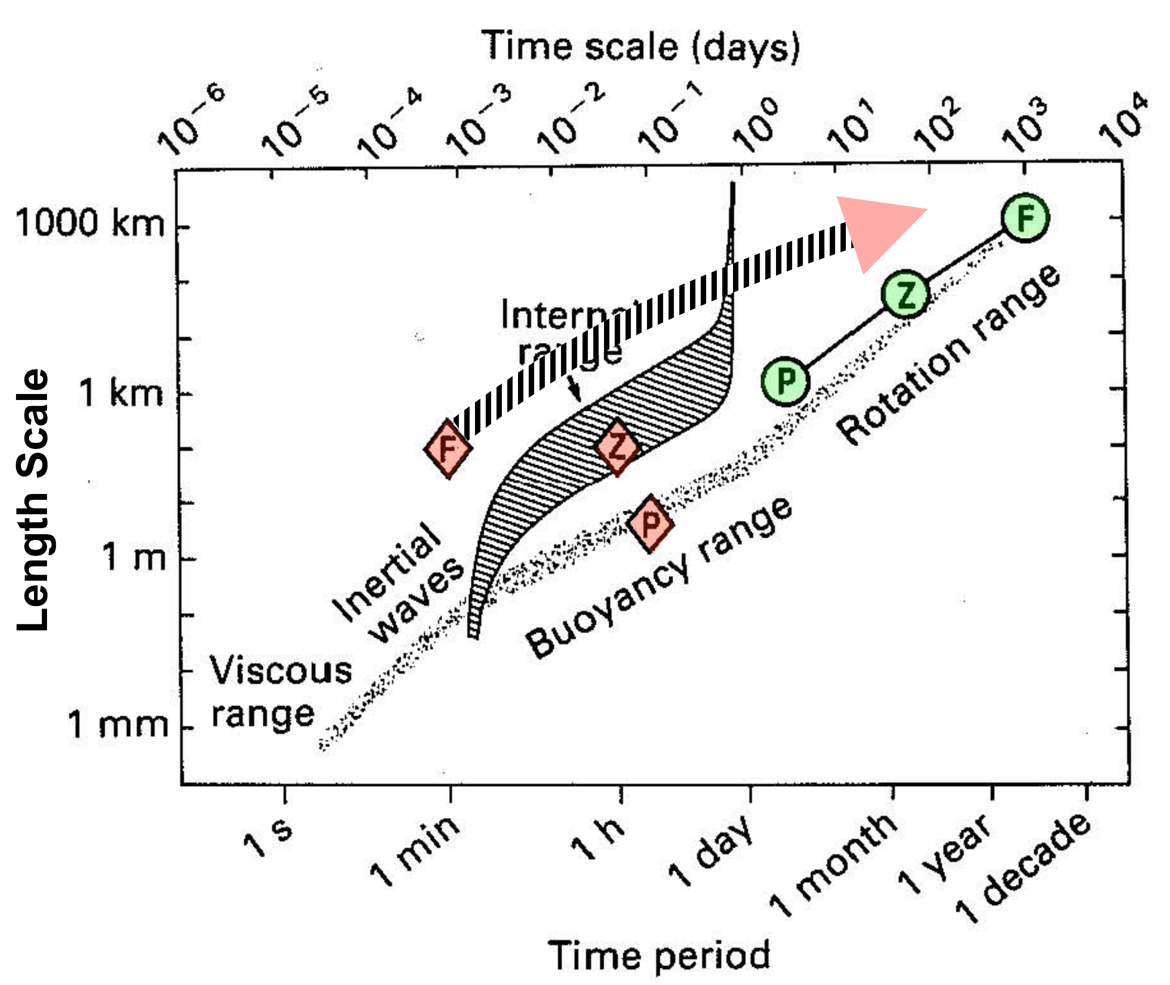


Scales of Variability

'Ecological' scales for
- phytoplankton P
- zooplankton Z
- fish F

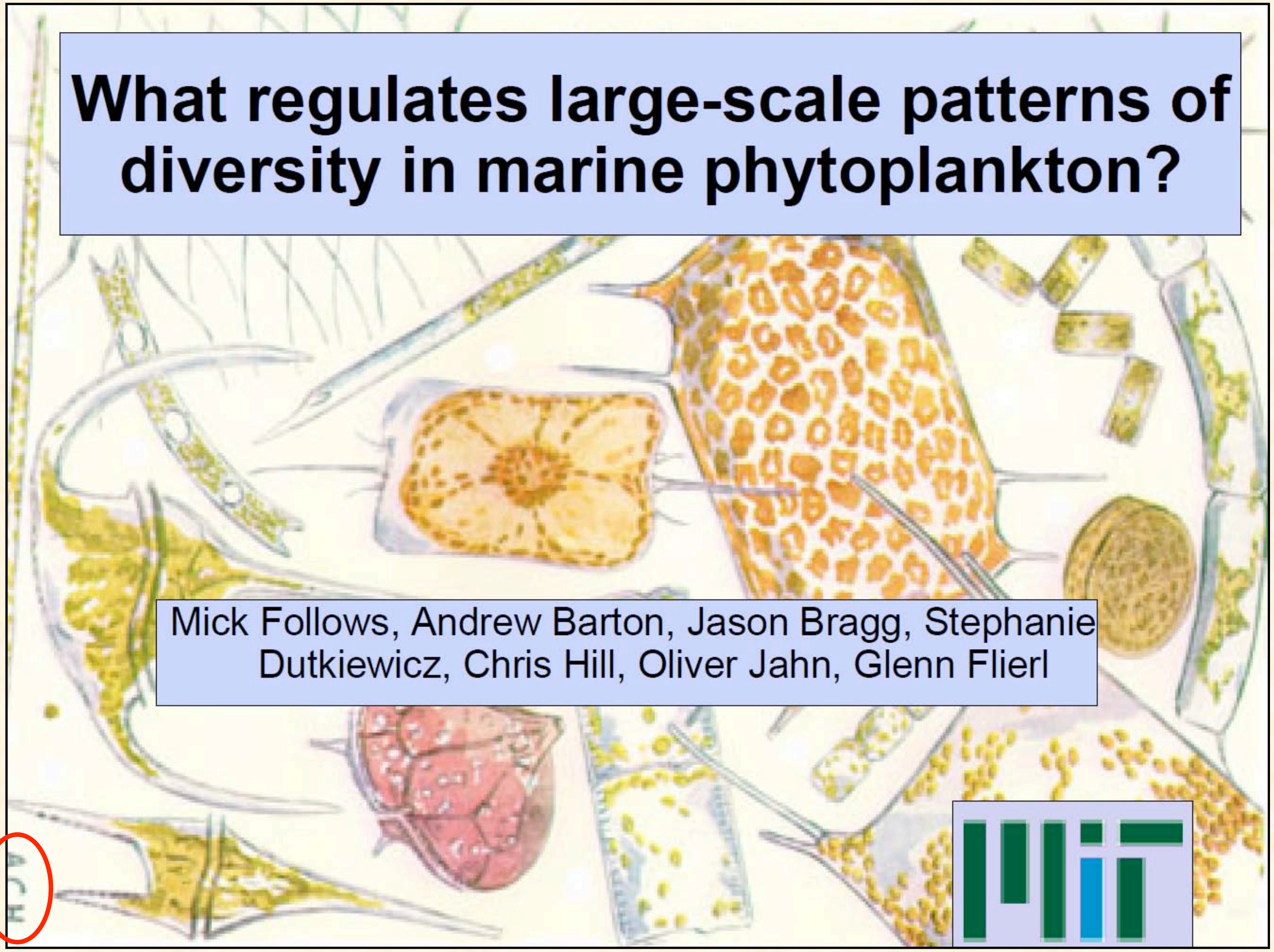
'Directed motility' scales

Modified from Woods (1977) & Steele (1978)



Denman, K., 1994. 379-402, In: P. Giller, A. Hildrew, and D. Raffaelli (eds.), *Aquatic Ecology: Scale, Pattern and Process*, Blackwell, 649 pp.

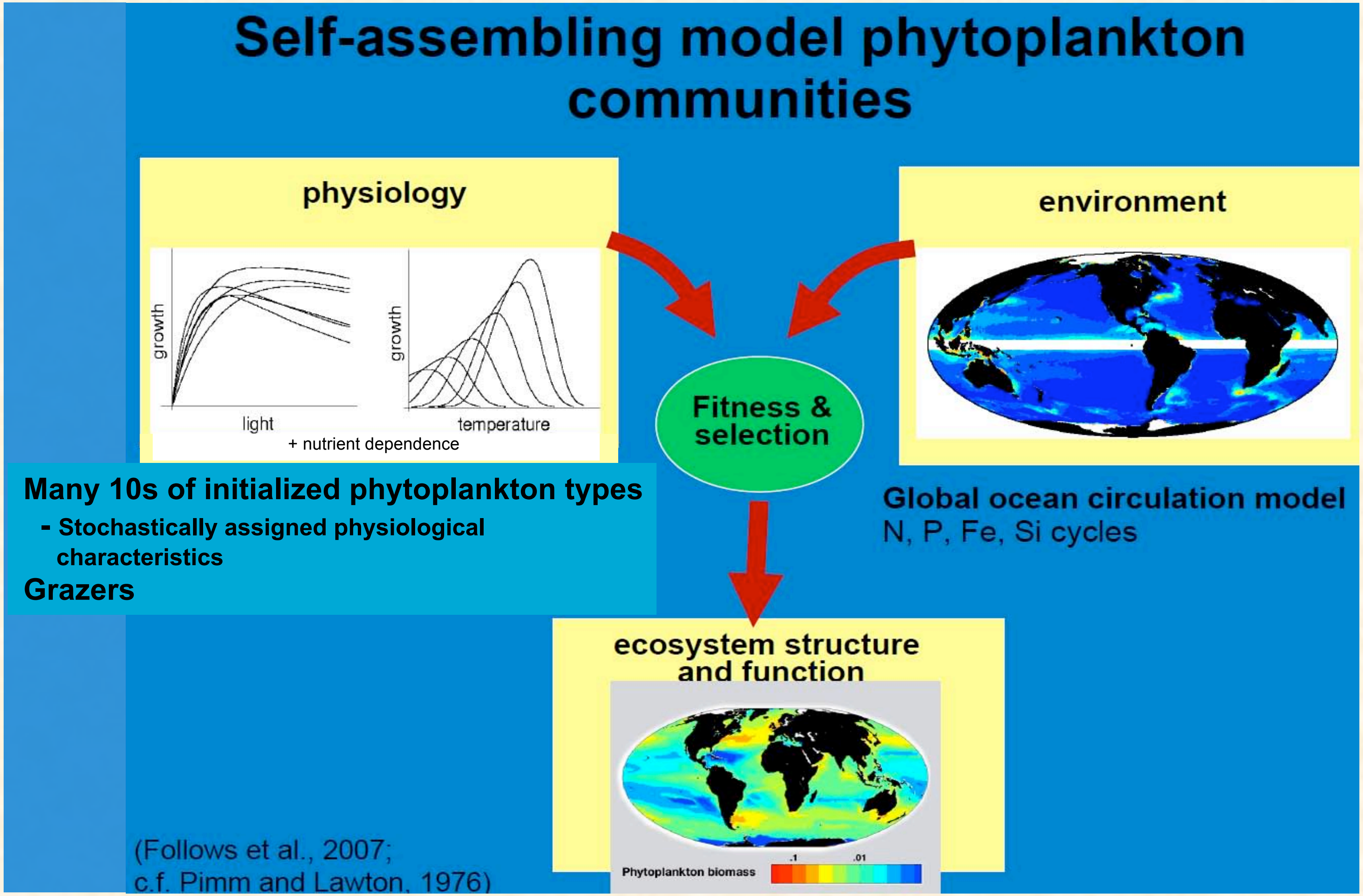
Marine Biodiversity and Ocean Physics (1)



Sir Alister Hardy

Presented at the GLOBEC Open Science Meeting, Victoria, Canada, June 2009, Available at [http://web.pml.ac.uk/globec/products/OSM3/wa.htm]
Ref. *Follows, M, et al., 2007. Science, 315, 1843-1846.*

Marine Biodiversity and Ocean Physics (2)



Many 10s of initialized phytoplankton types

- **Stochastically assigned physiological characteristics**

Grazers

Mick Follows, MIT, presented at the GLOBEC Open Science Meeting, Victoria, Canada, June 2009