Observing Ocean Ecosystems: Needs, Capabilities, and the Future

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CCCma

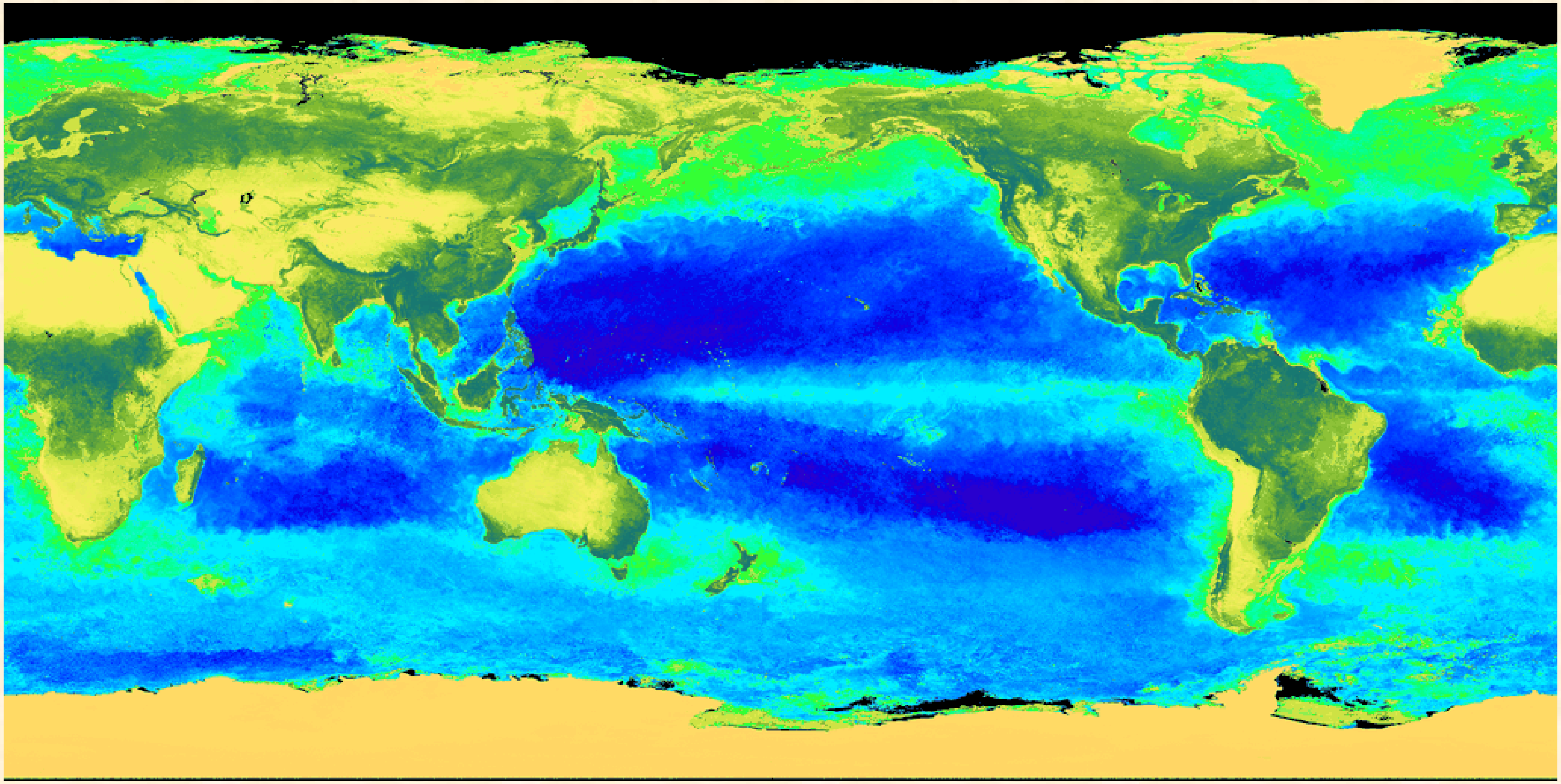
U. Victoria

IOS

Key Questions for Understanding Ocean 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?**

Ocean 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.

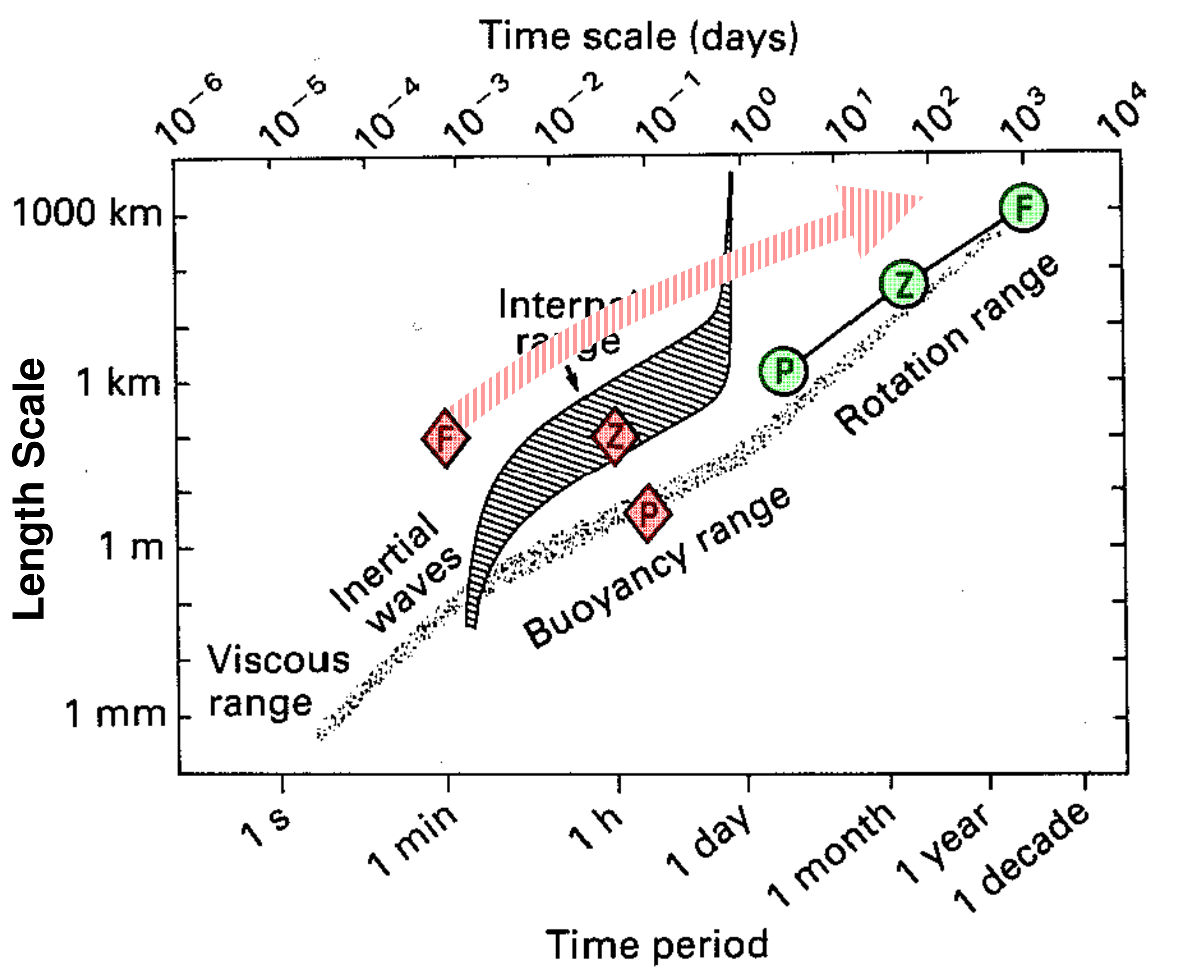
Movie prepared by K. Zahariev, L. Waters & K. Denman (CCCma) from 141 SeaWiFS images downloaded from NASA

Scales of Variability

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

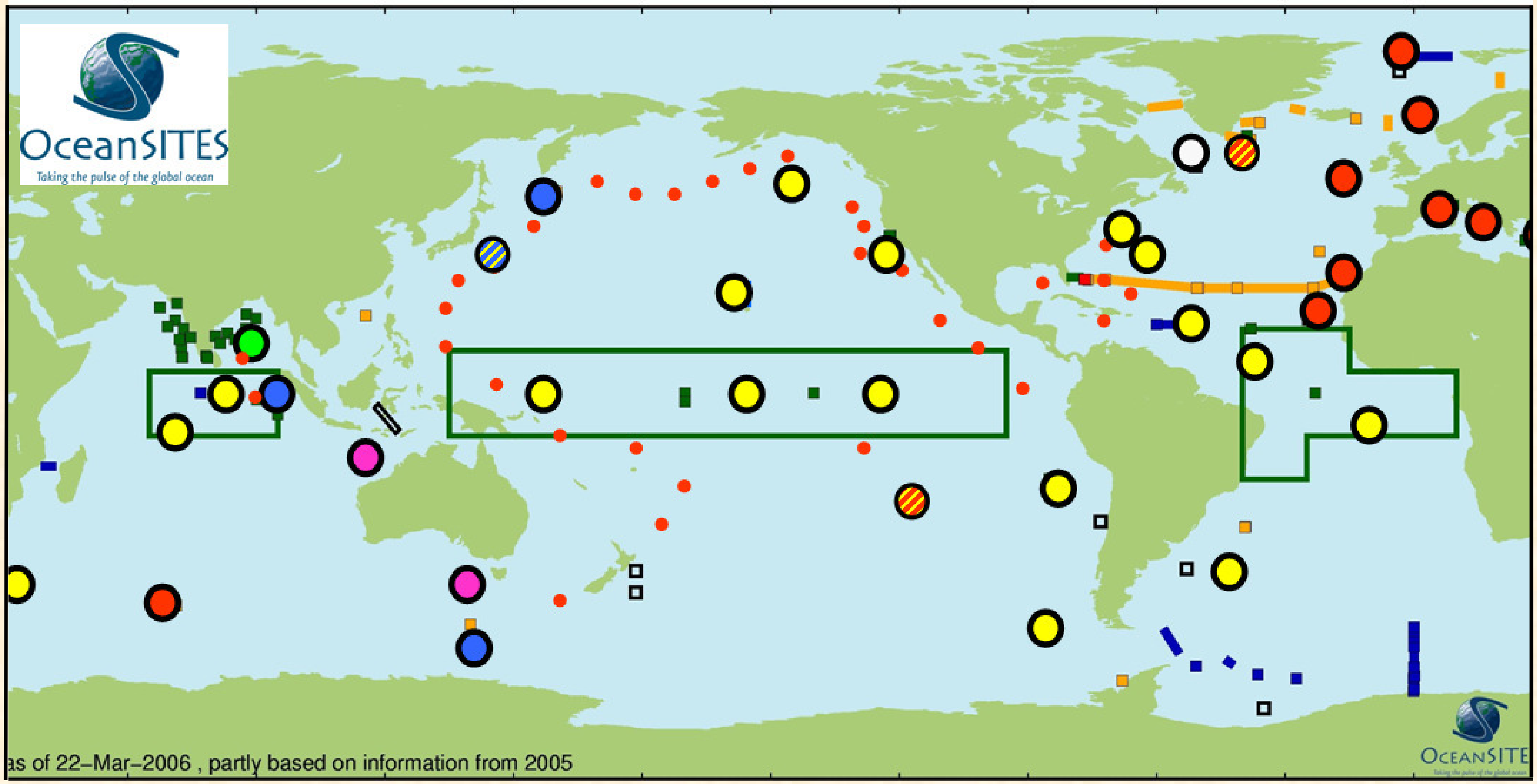
'Directed motility' scales

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.

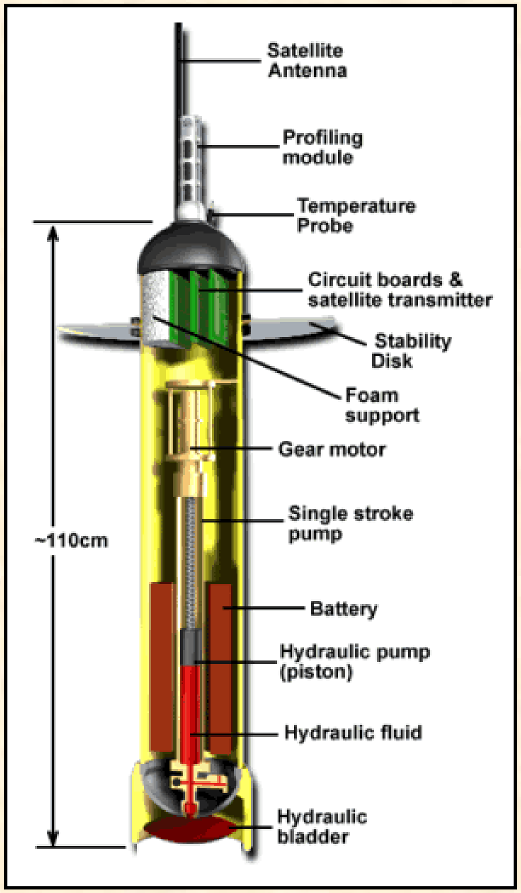
Strawman Backbone of OceanSITES Locations with Identical Multi-community Measurements.

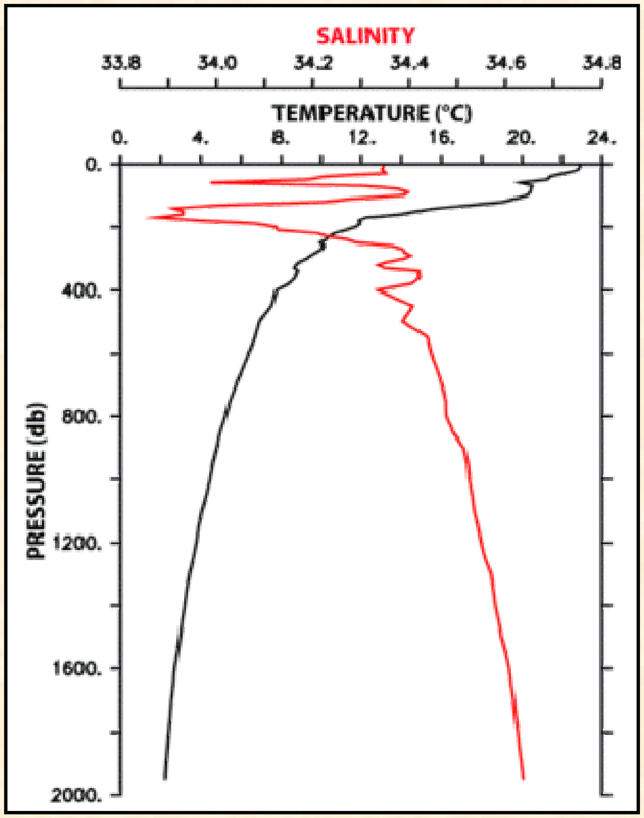


U. Send et al. 2010, PP OceanObs09

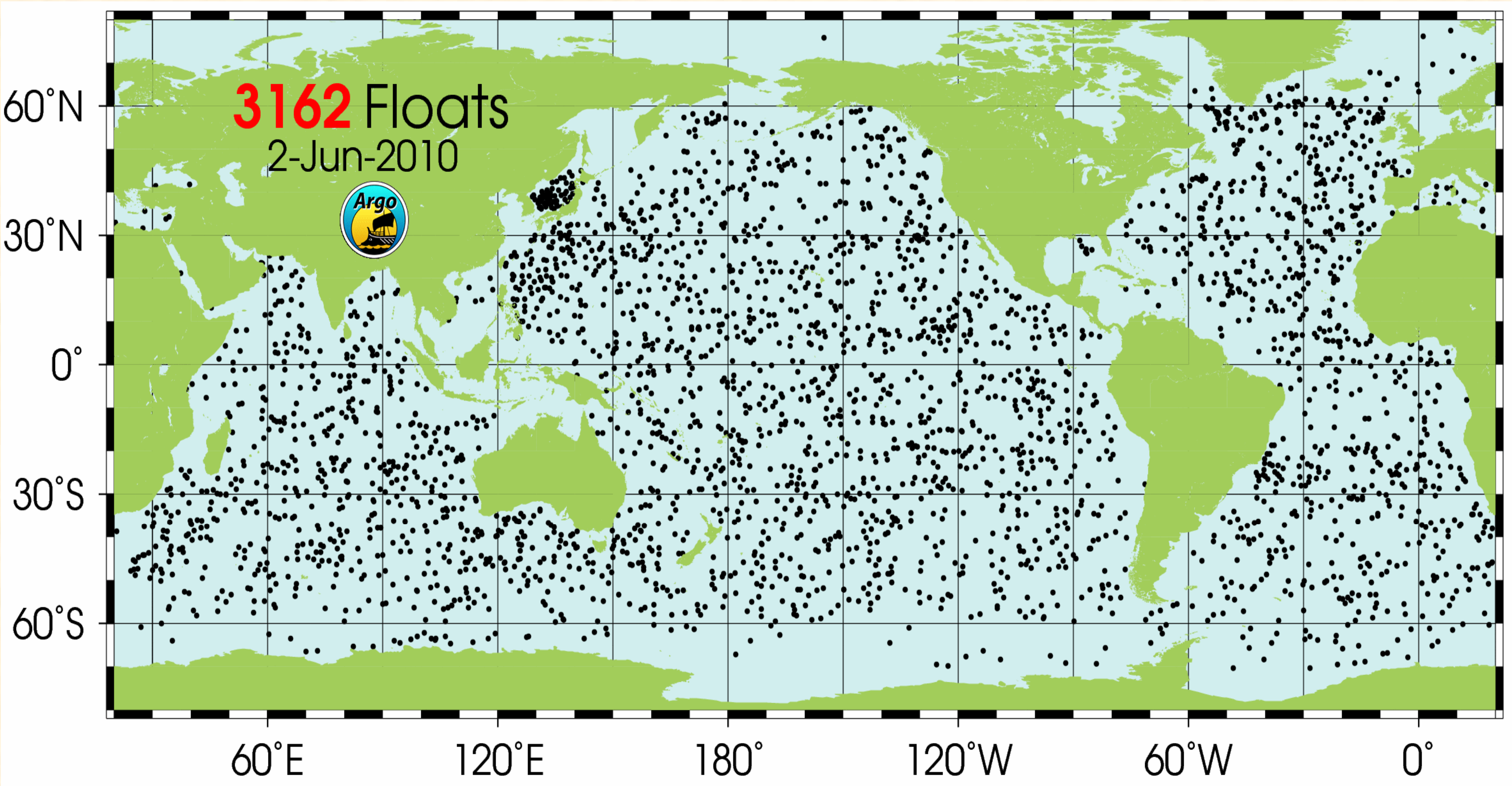
Argo System of Drifting Profiling Instrumented Buoys

http://www.argo.ucsd.edu/

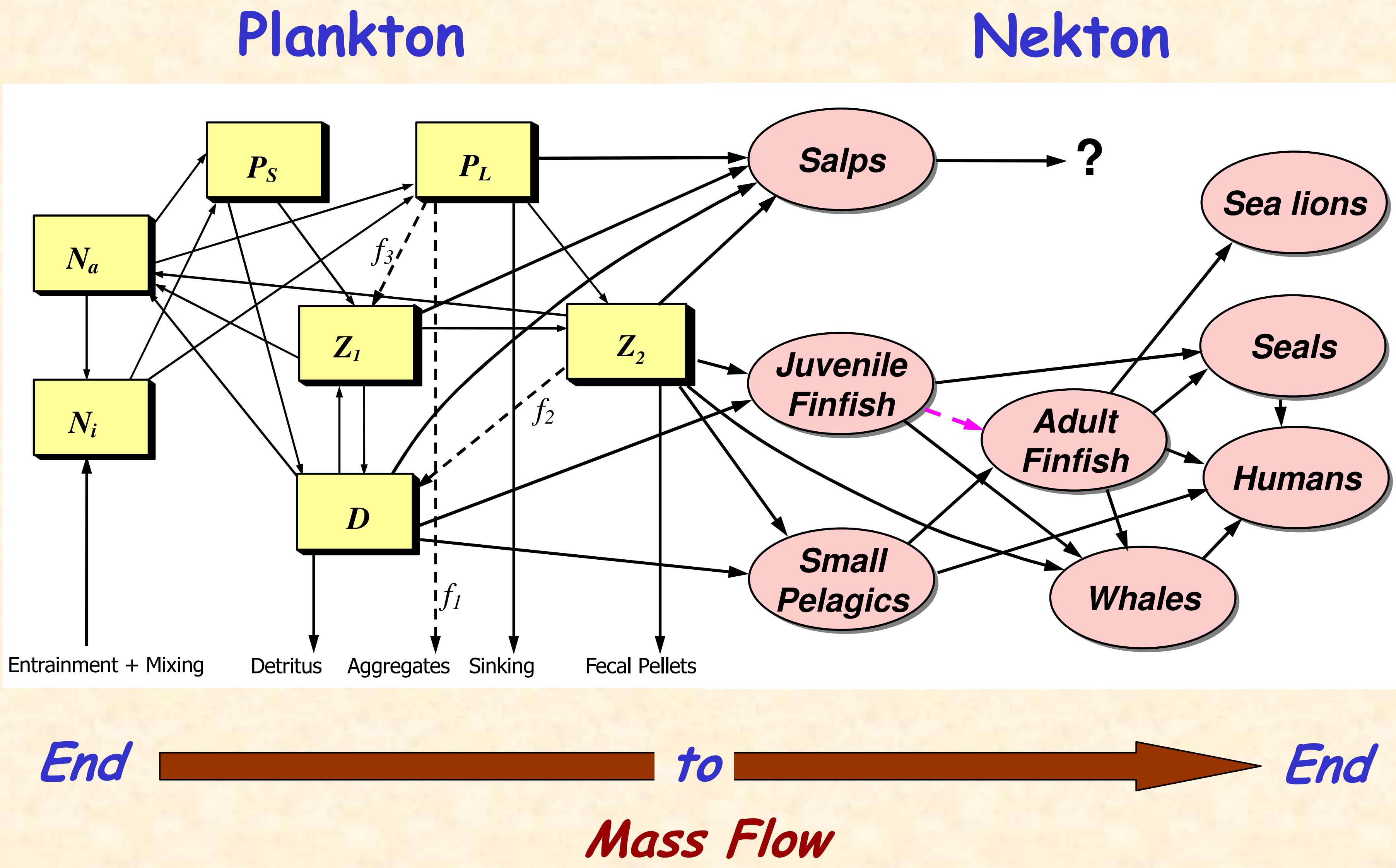




Argo Drifters on 2 June 2010



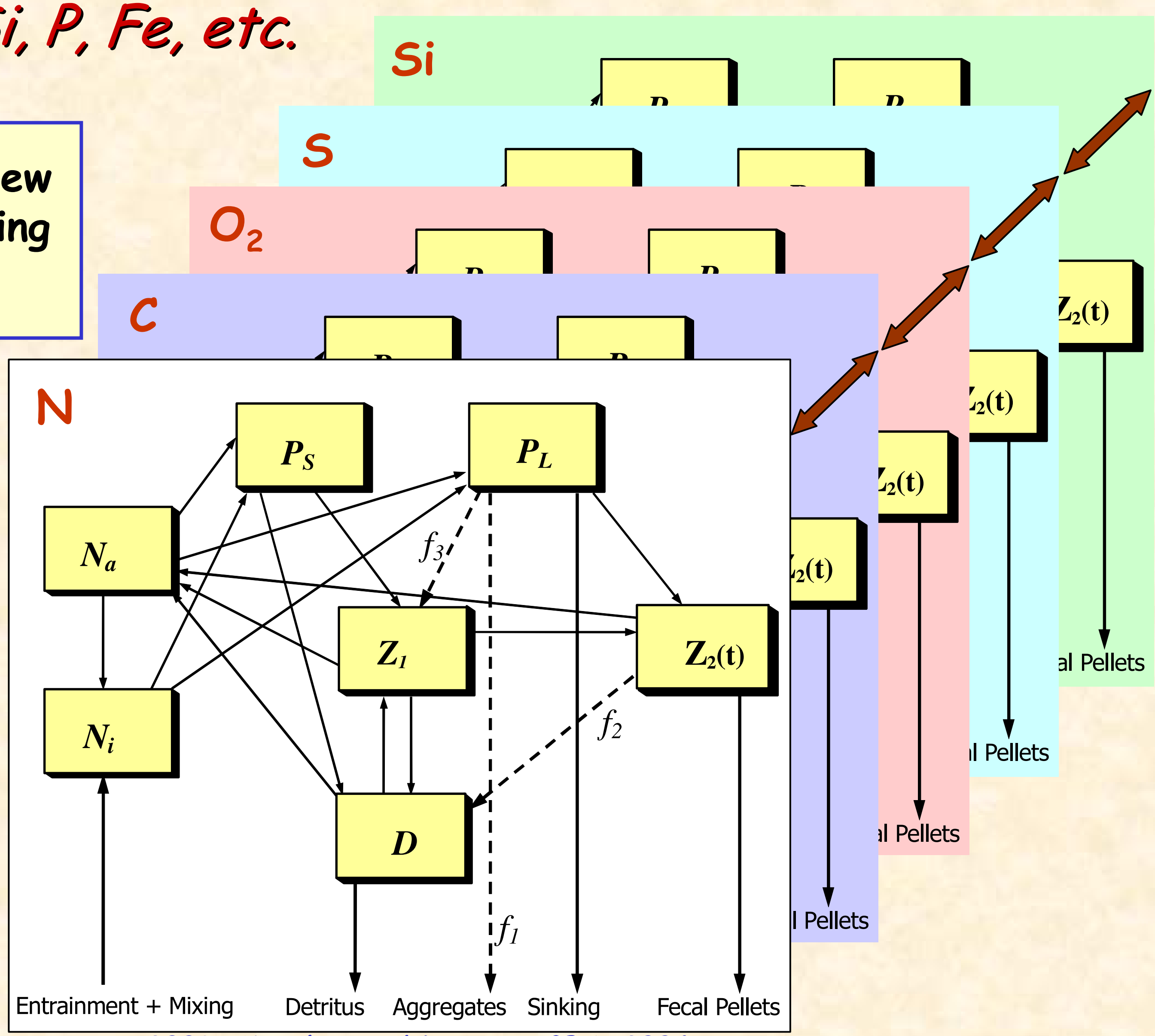
Ocean Ecosystems: *'Physics to Fish to Us'*



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

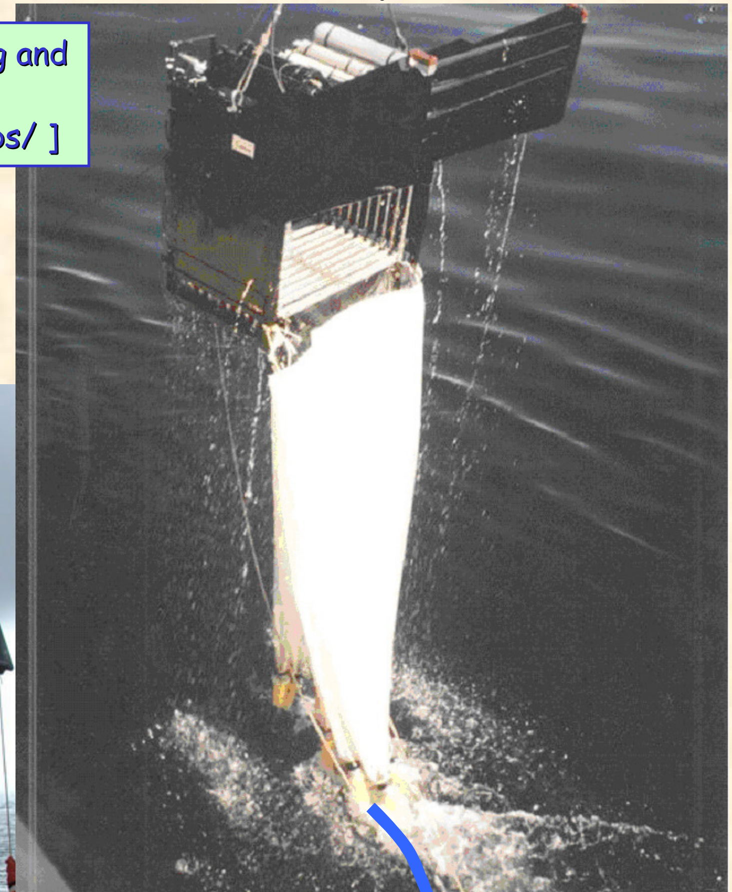
Peña, Prog. Ocgy. 2003; Monahan and Denman, GBC, 2004; Denman, Voelker, Peña and Rivkin, DSR II, 2006; Steiner & Denman, DSR I, 55, 2008.

Requirements for an Observing System for Ocean Ecosystems

- Must be able to observe the temporal and spatial 'texture' of ocean ecosystems over long times and large scales
  - powerful enough to extract the climate change signal from natural variability and observing noise
- Must be:
  - extensive
  - sustained
  - systematic
  - cross calibrated

Shipborne Studies of Planktonic Ecosystems

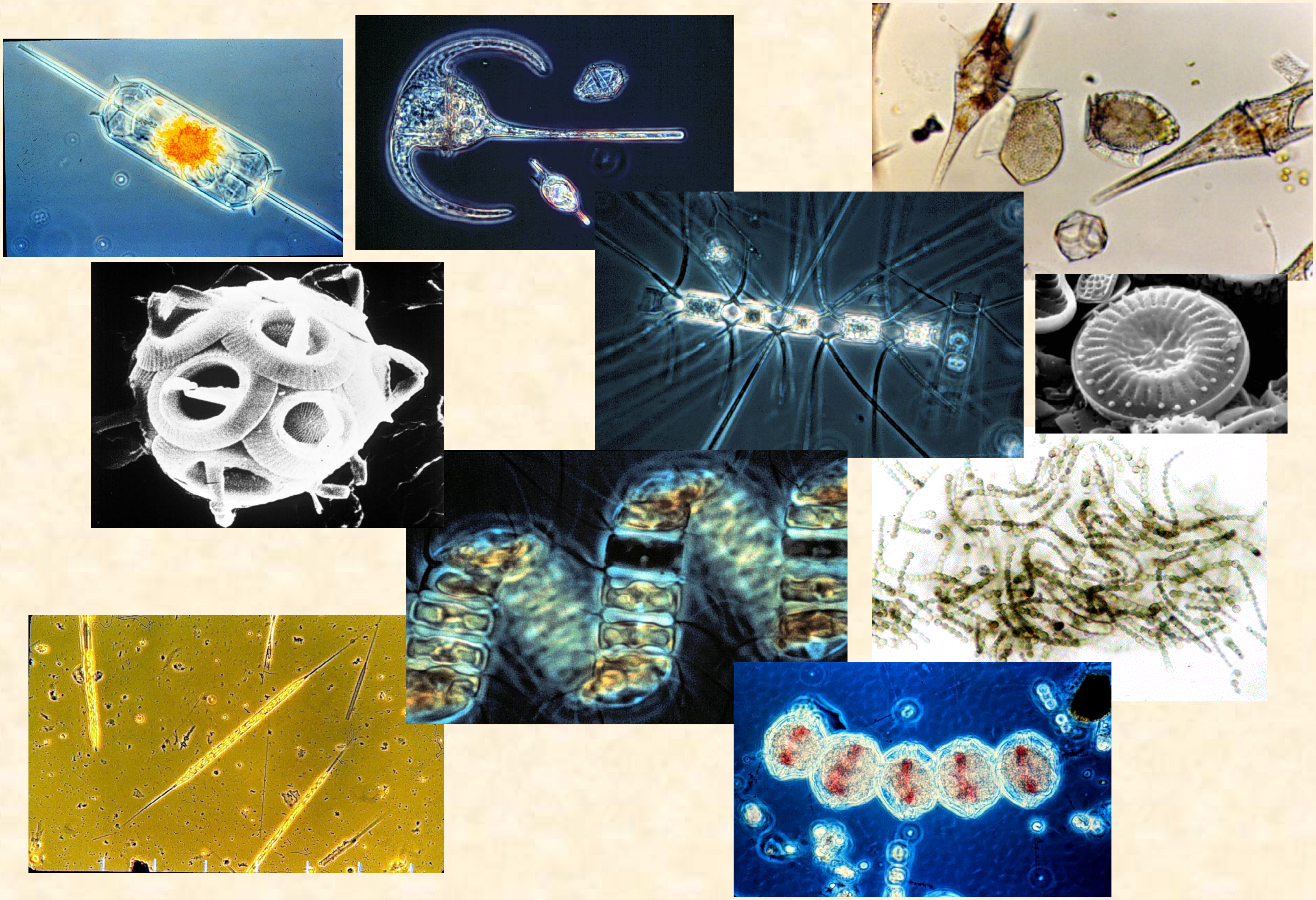
Rosette Sampler
Global Change NewsLetter
No. 73 April 2009



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

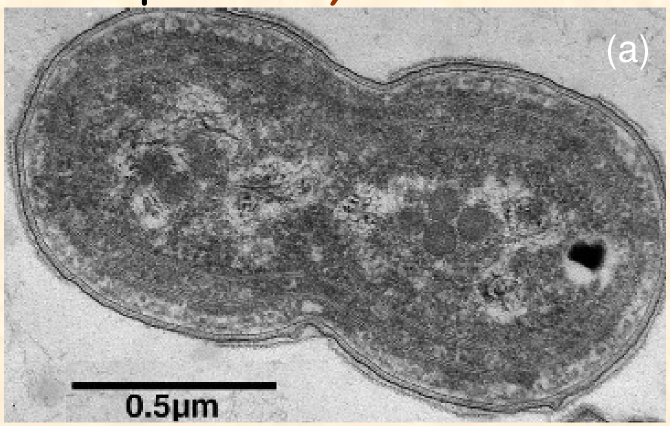
Phytoplankton Under Microscope

Take up CO_2 during photosynthesis

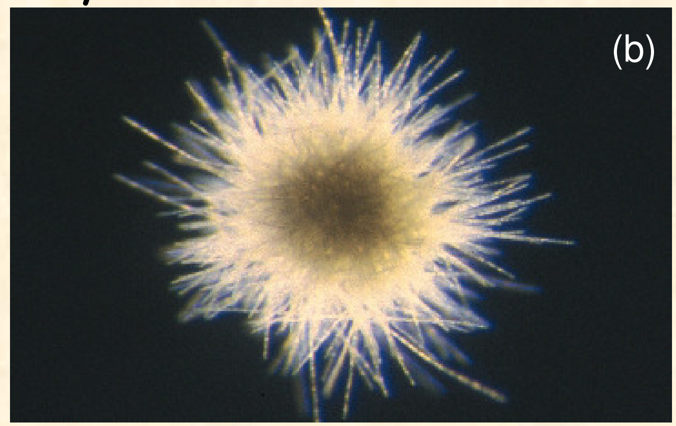


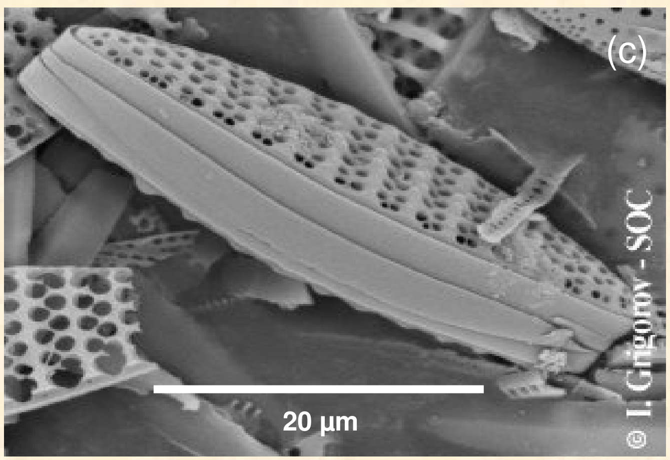
Modelling Has Led to the Concept of *'Plankton Functional Types* (PFTs)'

Picoplankton *Synechococcus*

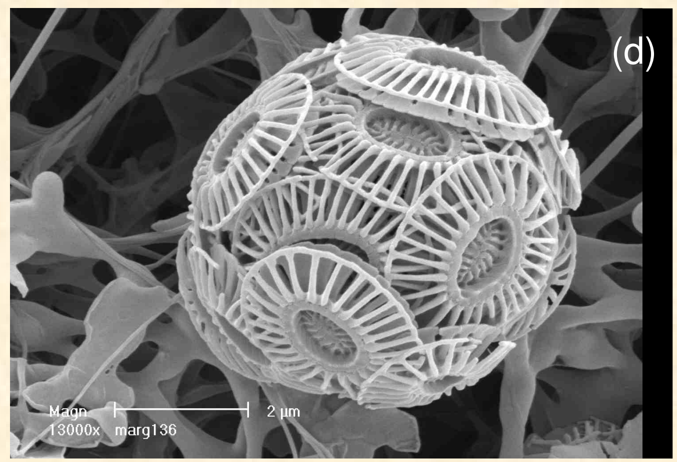


Cyanobacterium *Trichodesmium*





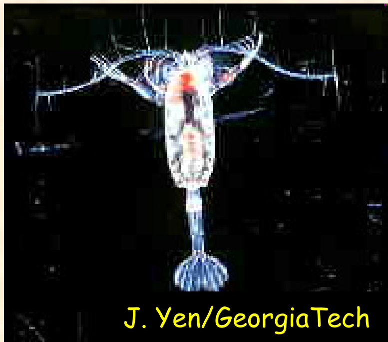
Diatom *Fragilariopsis kerguelensis*

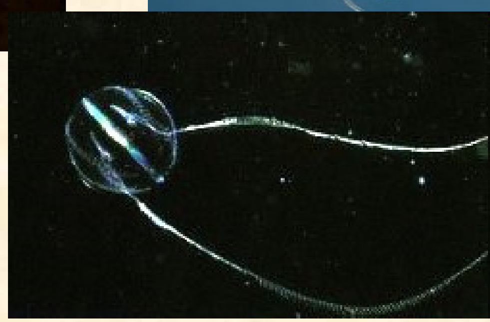


Coccolithophorid *Emiliania huxleyi*

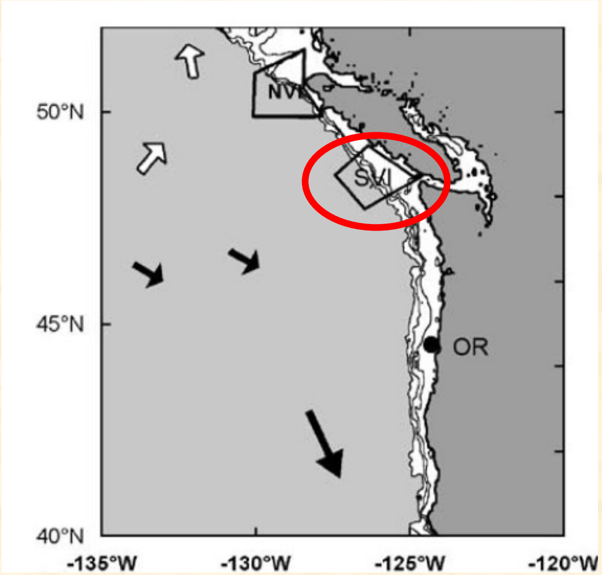
The PARADIGM Group, Oceanography 19(1), March 2006
& Le Quéré et al., CWP

Zooplankton Are Also Diverse

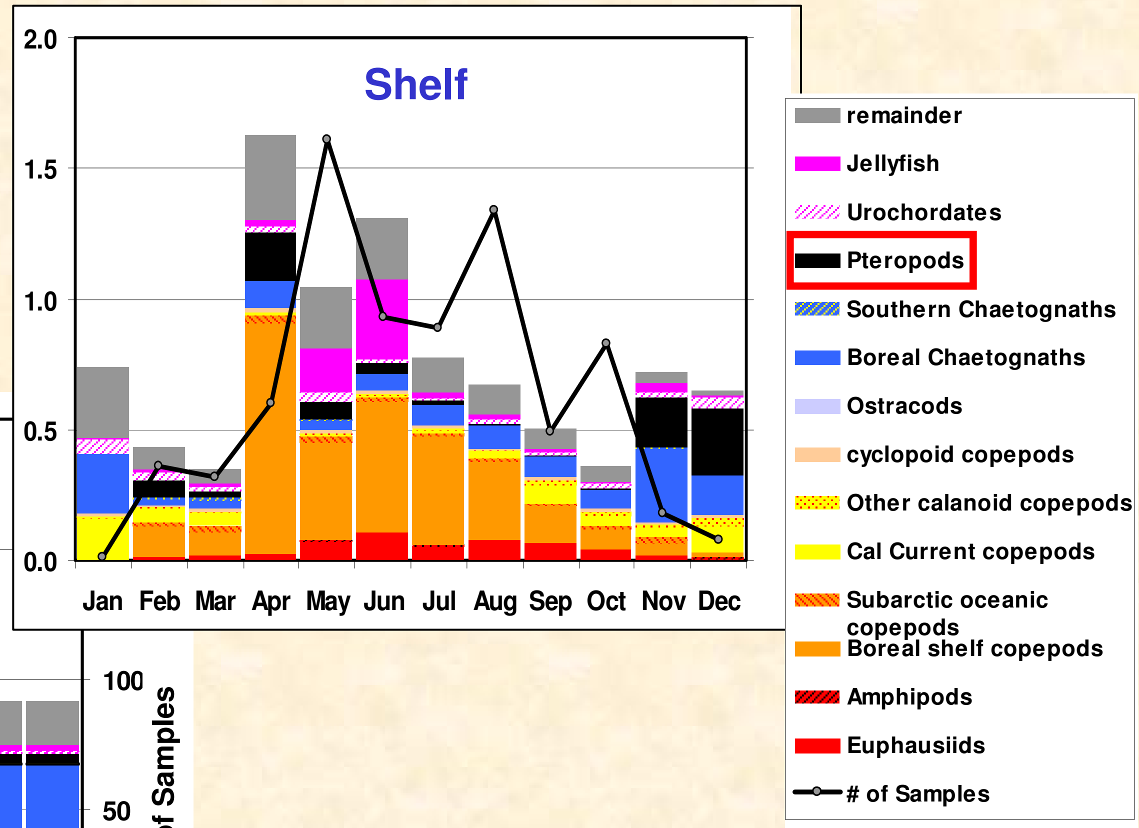


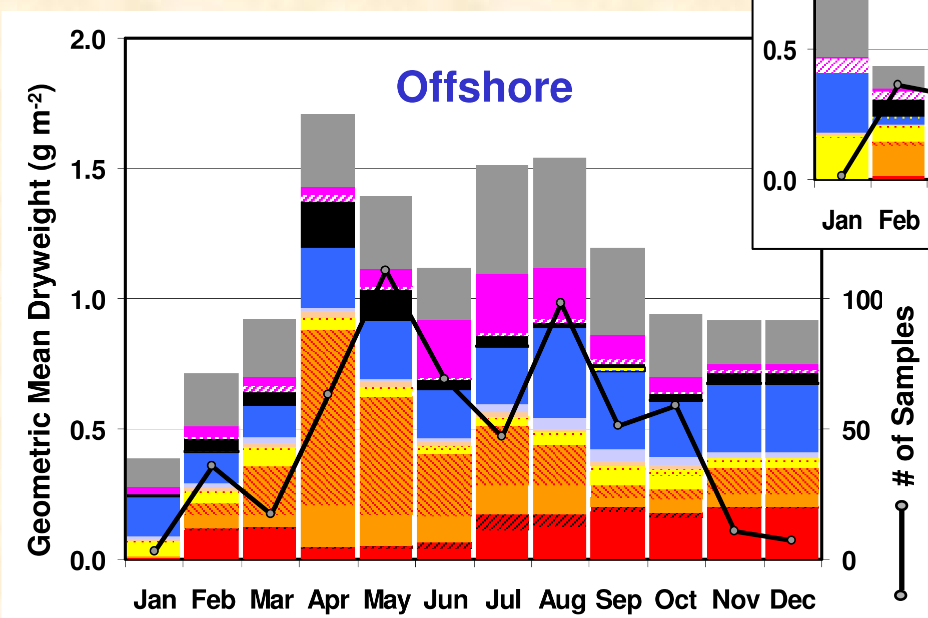


Other credits: www.pac.dfo-mpo.gc.ca/sci/osap/projects/plankton/



The Zooplankton Community off Southern Vancouver Island





Updated from:

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

Pteropods are made up of aragonite $CaCO_3$

Limacina helicina

are a food source for juvenile North Pacific salmon and also for mackerel, herring and cod.

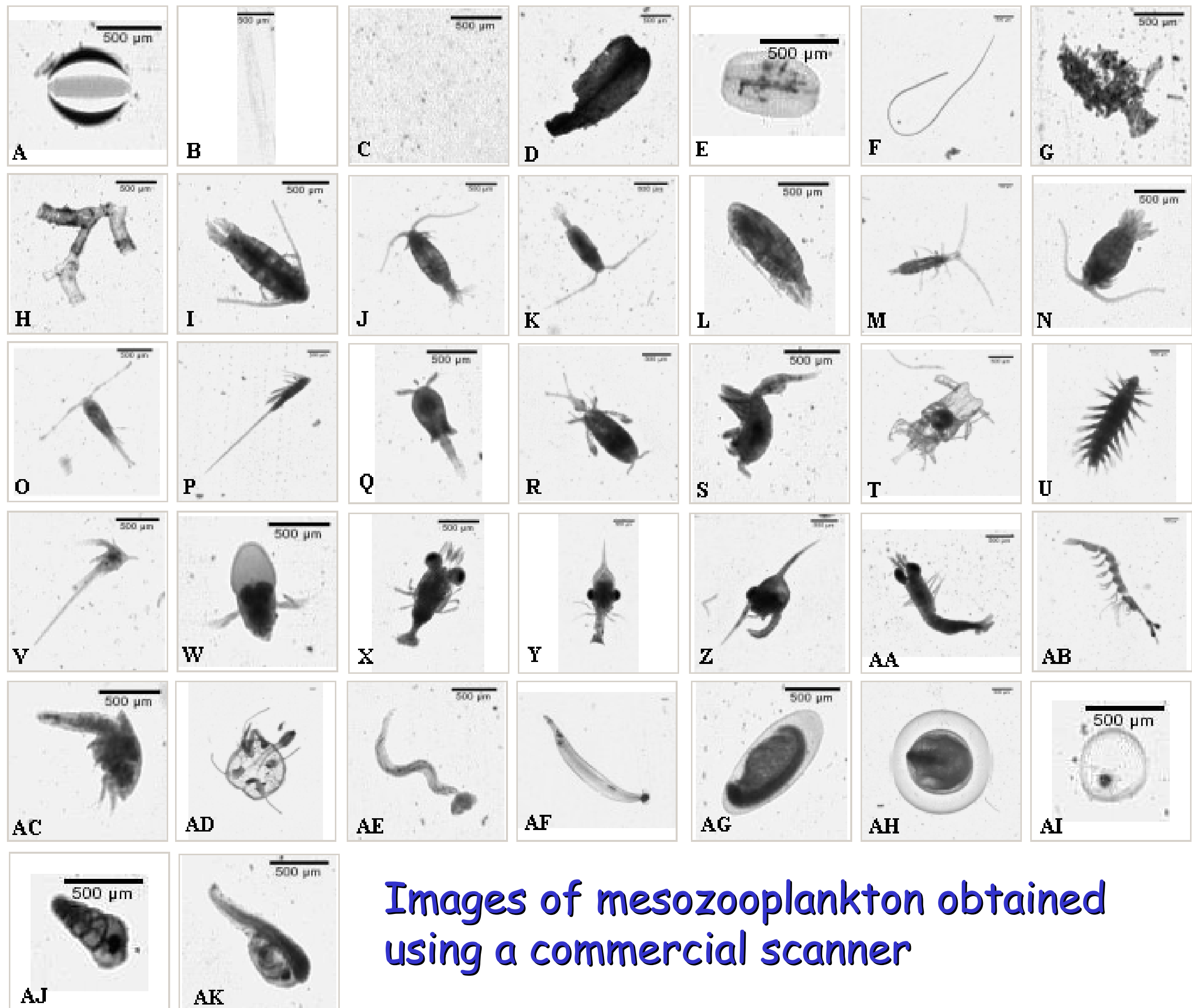
Limacina helicina [R. Hopcroft, UAlaska]

Automated Plankton Identification

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

Lab & Shipboard Systems

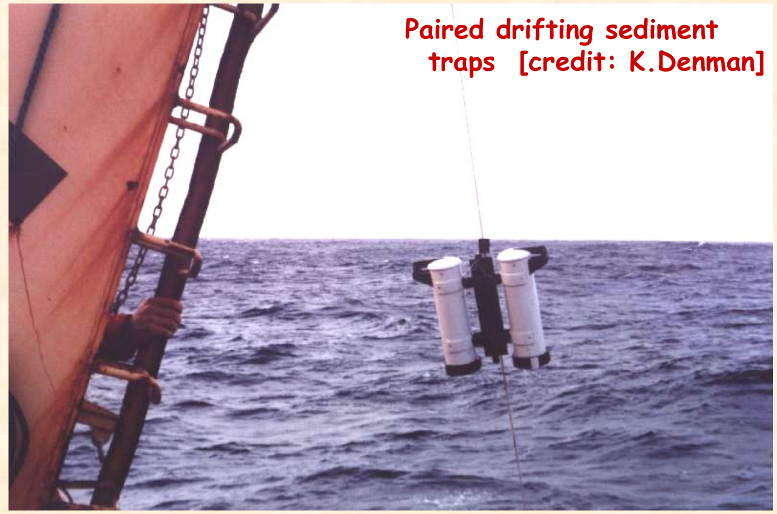
- Technology ahead of recognition imaging software
- Organisms <20 µm too similar
- Discriminating between 10 to 30 classes 70–80% accurate,which approaches agreement between human experts



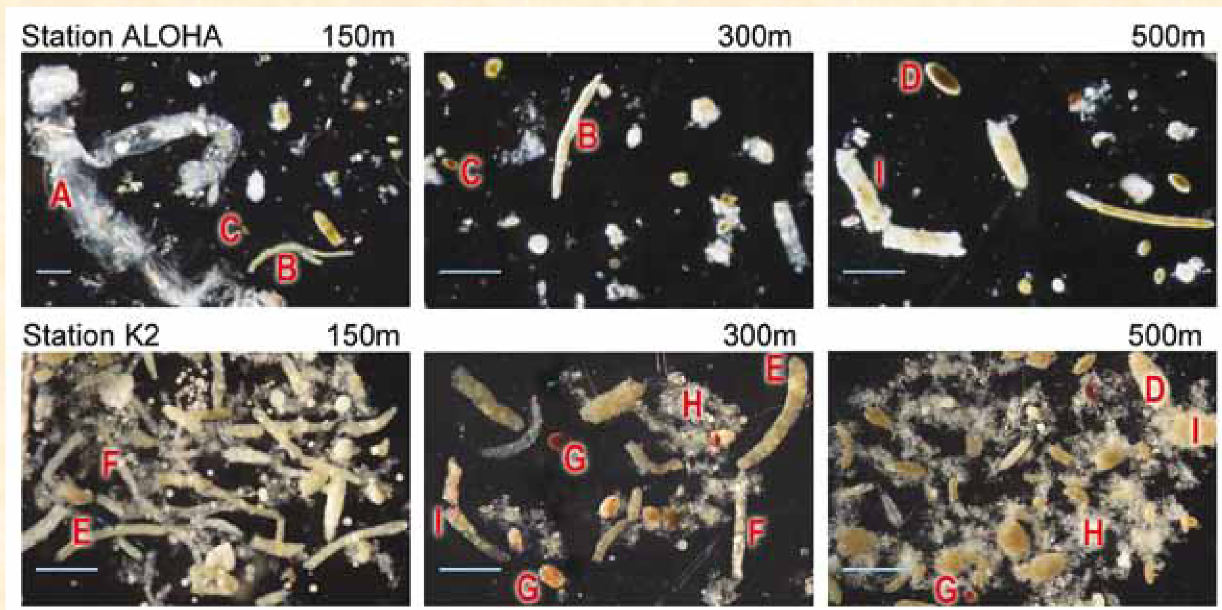
Images of mesozooplankton obtained using a commercial scanner

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 , OceanObs09*)

- Remote sensing – space, acoustics, video (~10^6 m)
- Video plankton recorders, shape recognition (~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*

All PPs & CWPs available at *http://www.oceanobs09.net/*

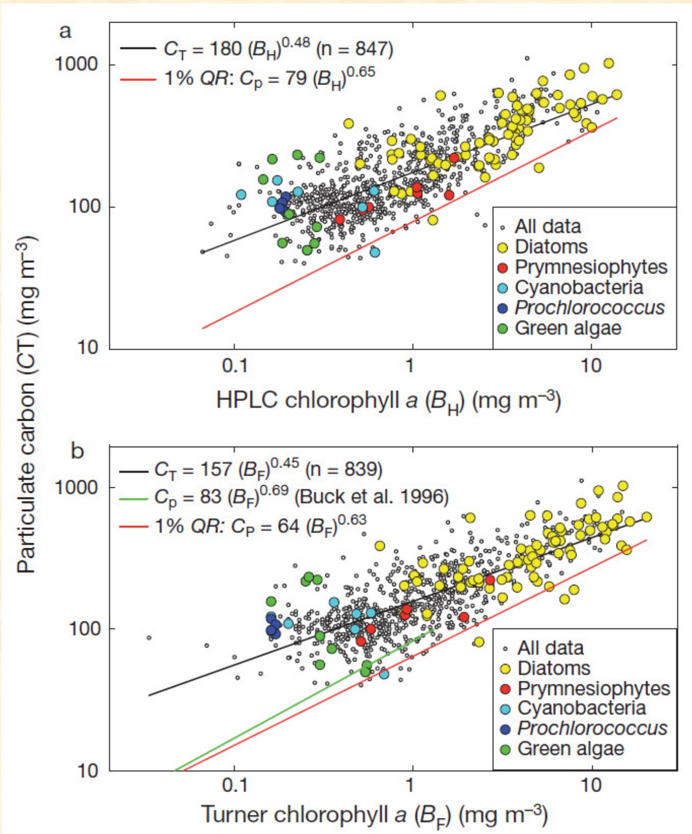
Remote Sensing from Satellites

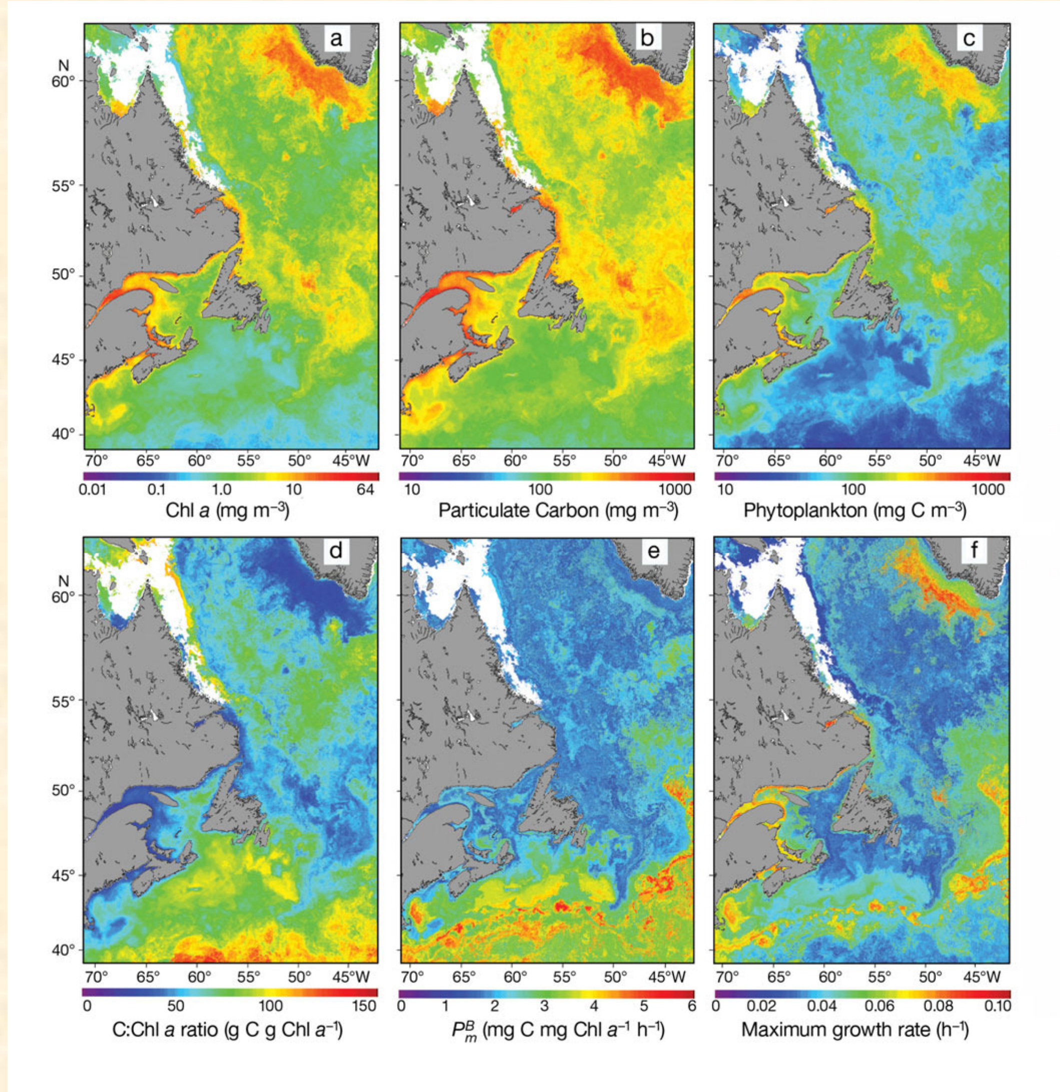
CWPs: Sathyendranath et al., Yoder et al.

- **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 satellite missions

Regional Lab & Field Data + Satellite Imagery ⇒

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





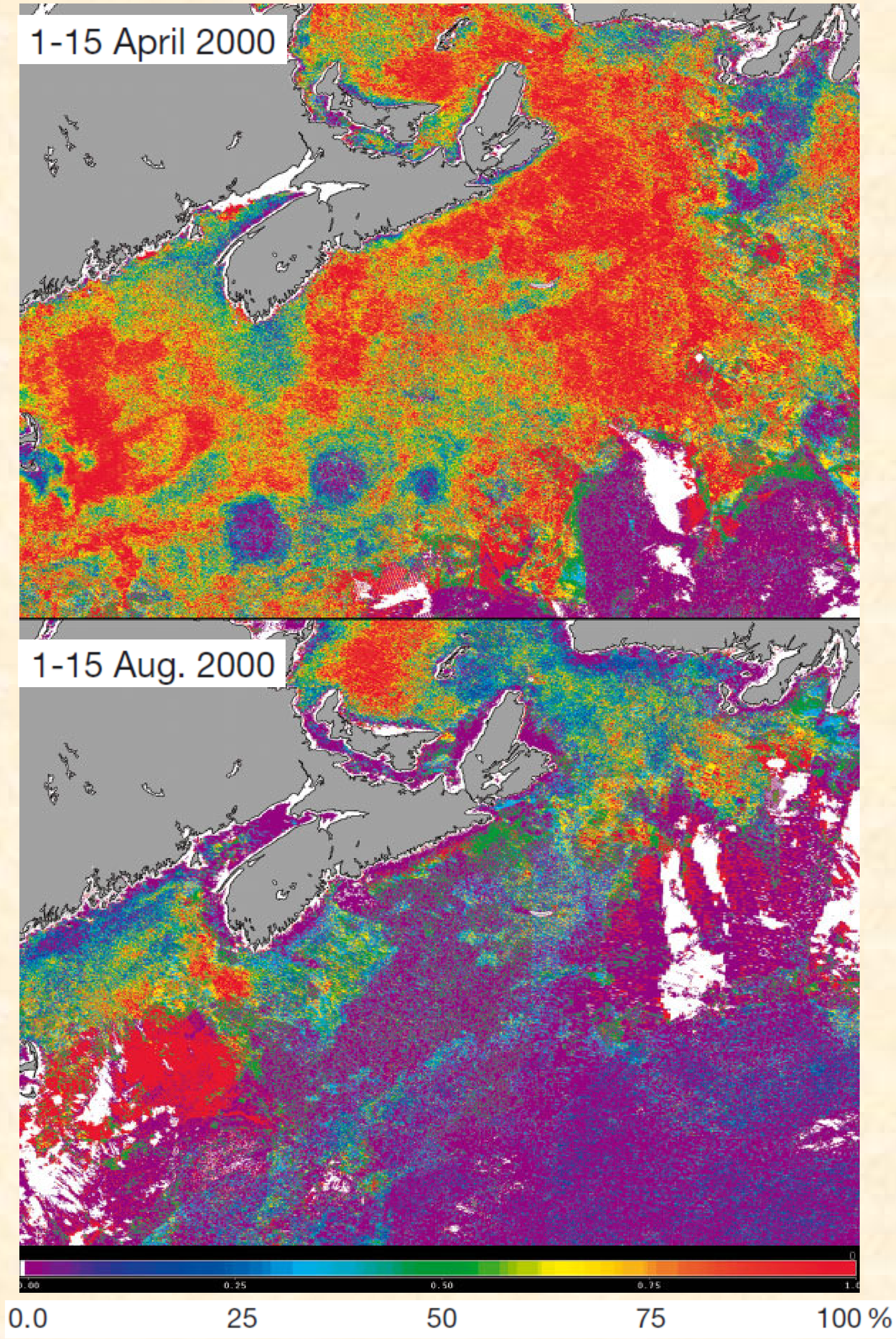
Sathyendranath et al 2009. Mar Ecol Prog Ser, 383, 73-84

Platt et al 2008. Remote Sens Environ, 112, 3427-3448

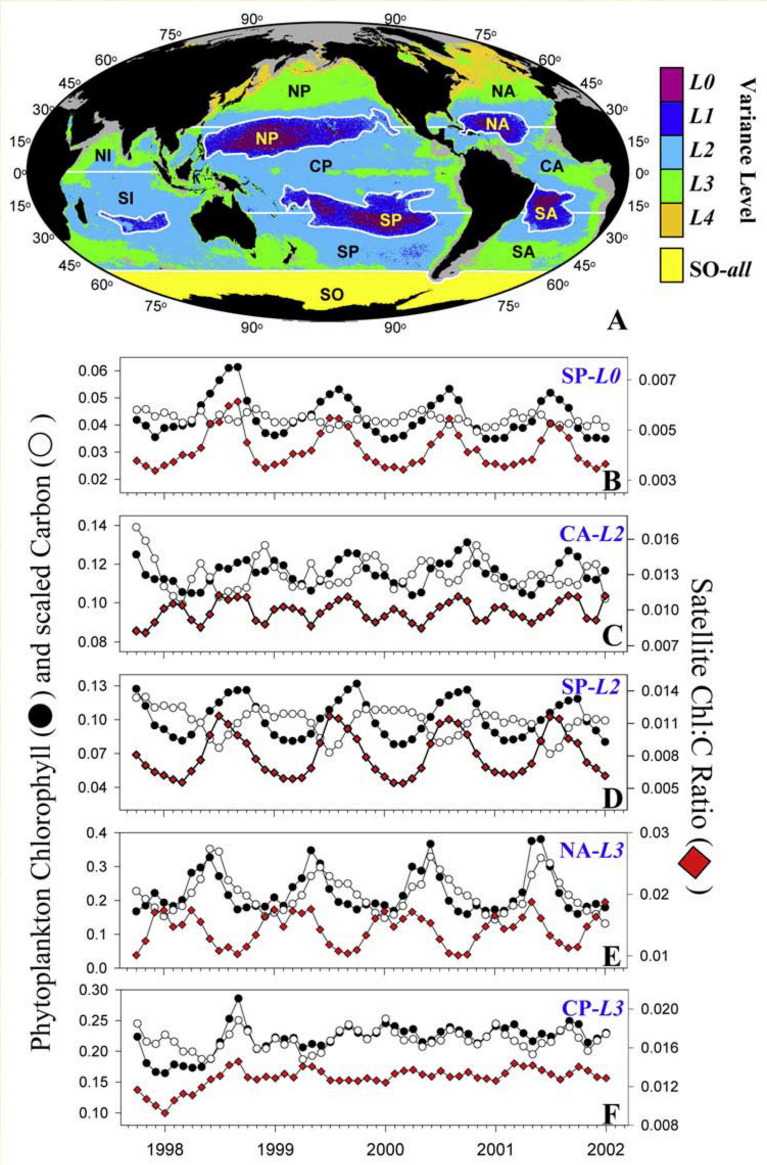
Estimated Probability of Phytoplankton Community Dominated by Diatoms from Satellite

- **Based on differences in light absorption spectrum for different PFTs**

Sathyendranath et al. 2004, Marine Ecology-Progress Series, 272, 59-68.



Regional to Global Derived Time Series



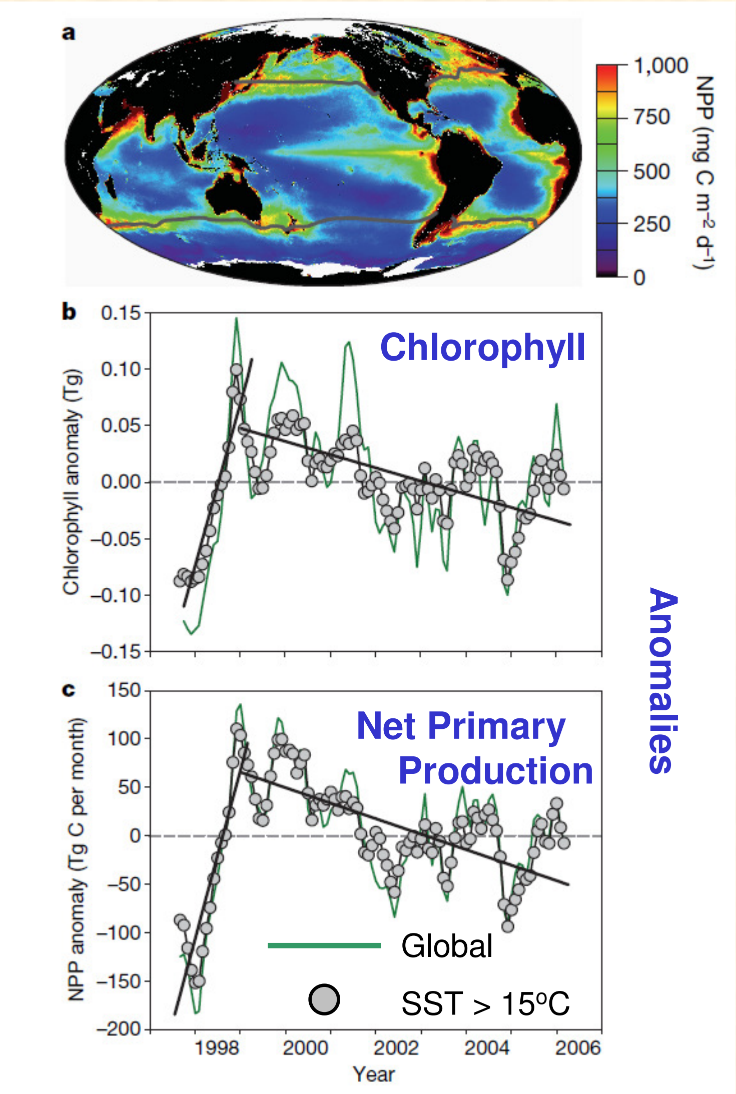
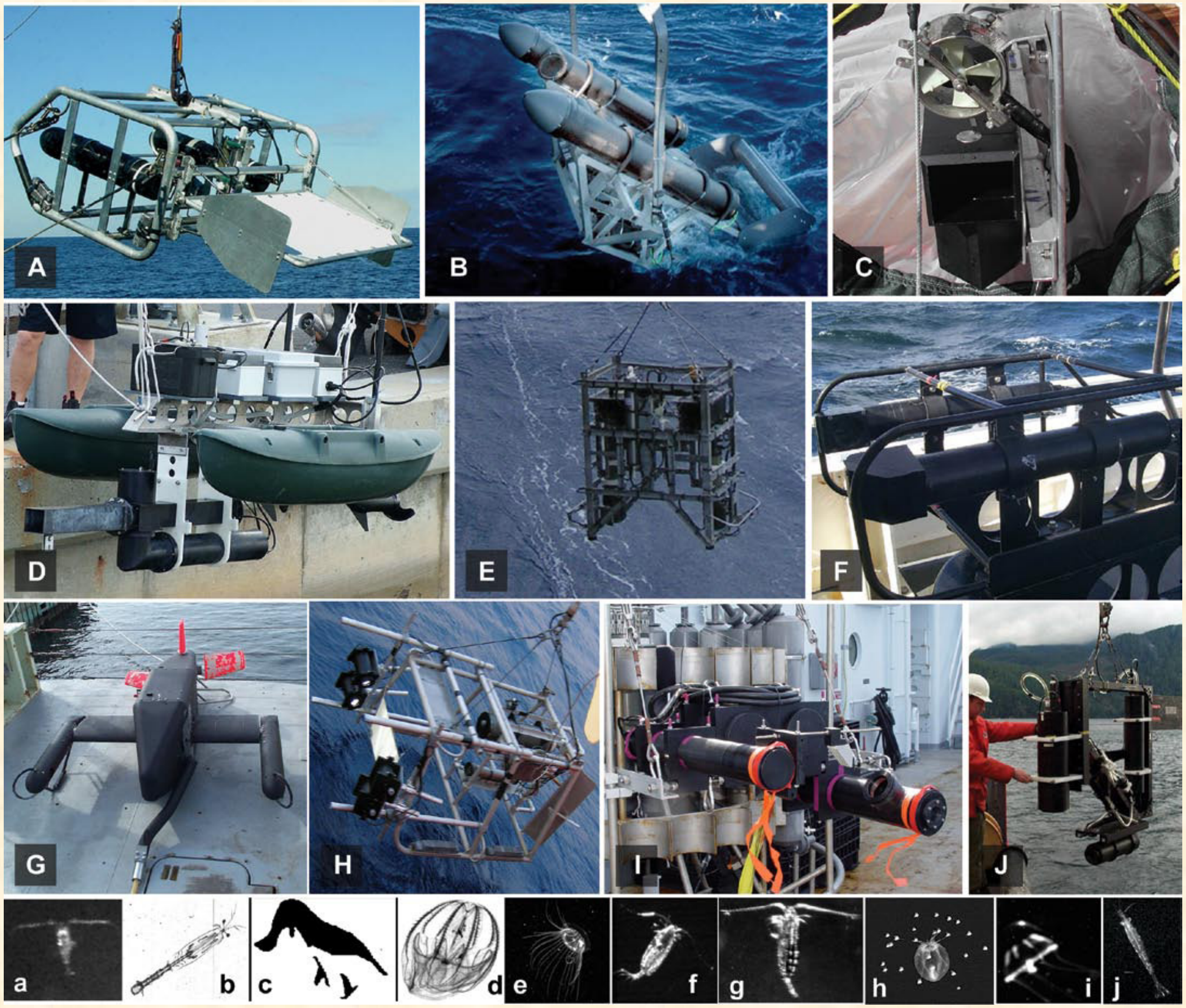


Figure 1 | Distribution and trends in global ocean phytoplankton productivity (NPP) and chlorophyll standing stocks.

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

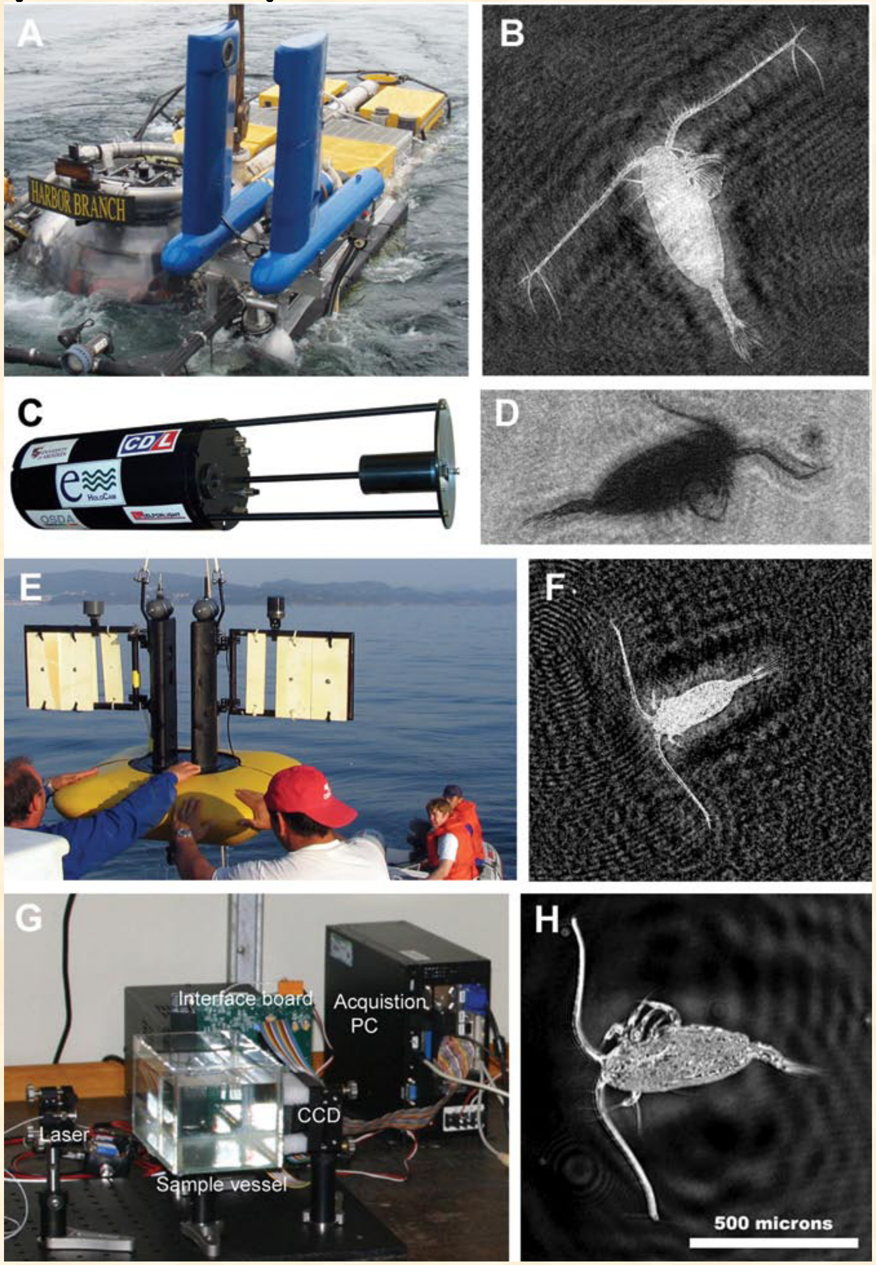


Benfield et al 2007 Oceanography 20 (2), 172-187

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

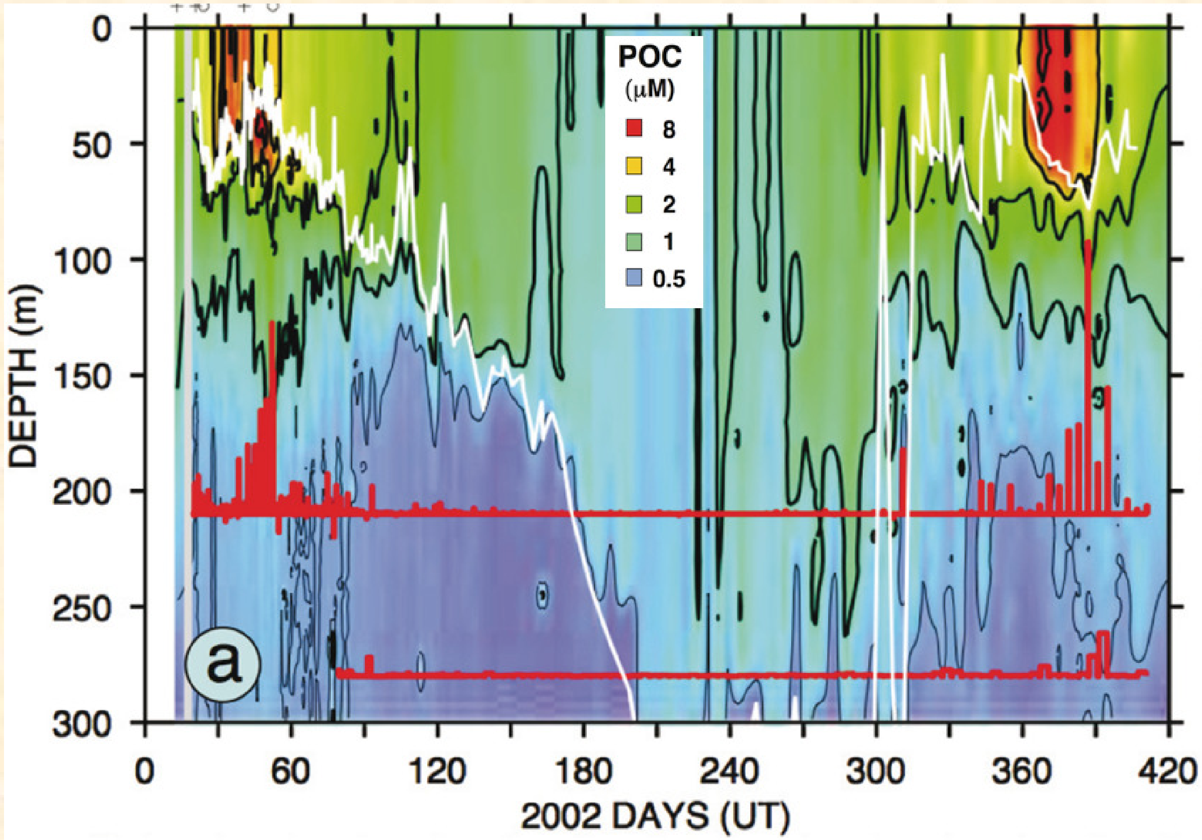


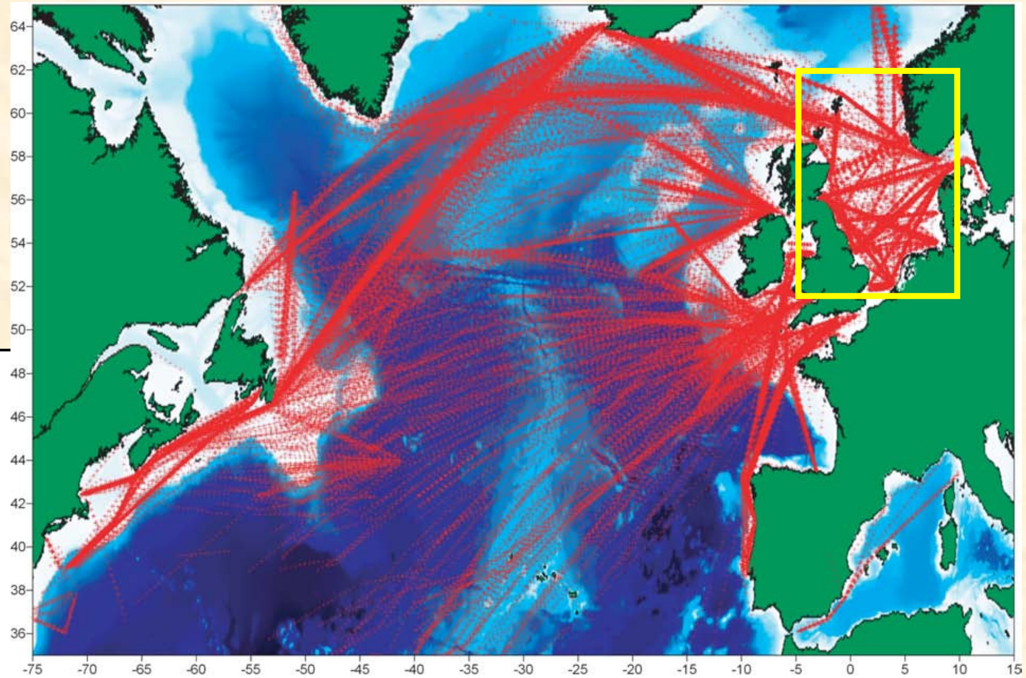
Figure 3. Time series of particulate organic concentration (color plot) and particle flux (red bars, in relative units) in the Southern ocean (around 55°S, 170°W). The data were acquired by the Carbon Explorer float which associates a Solo float to a suite of optical sensors. The reduction of the mixed 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), **GBC, *23*, GB2019.**

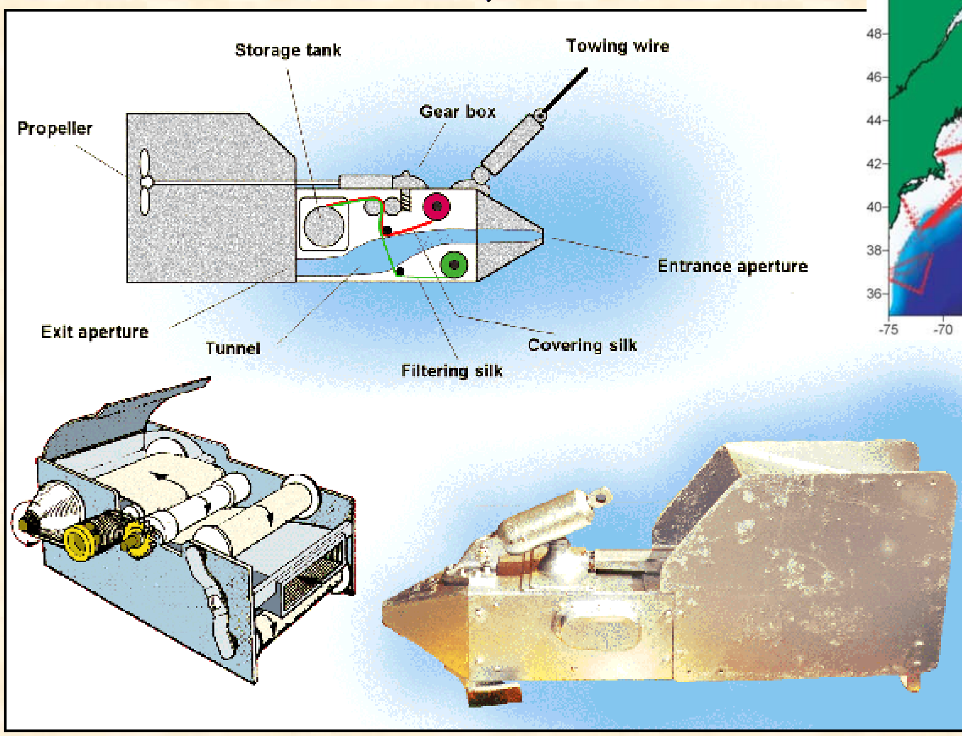
Continuous Plankton Recorder (CPR) Survey:

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

SAHFOS

Thanks: to Peter Burkill and Chris Reid, SAHFOS

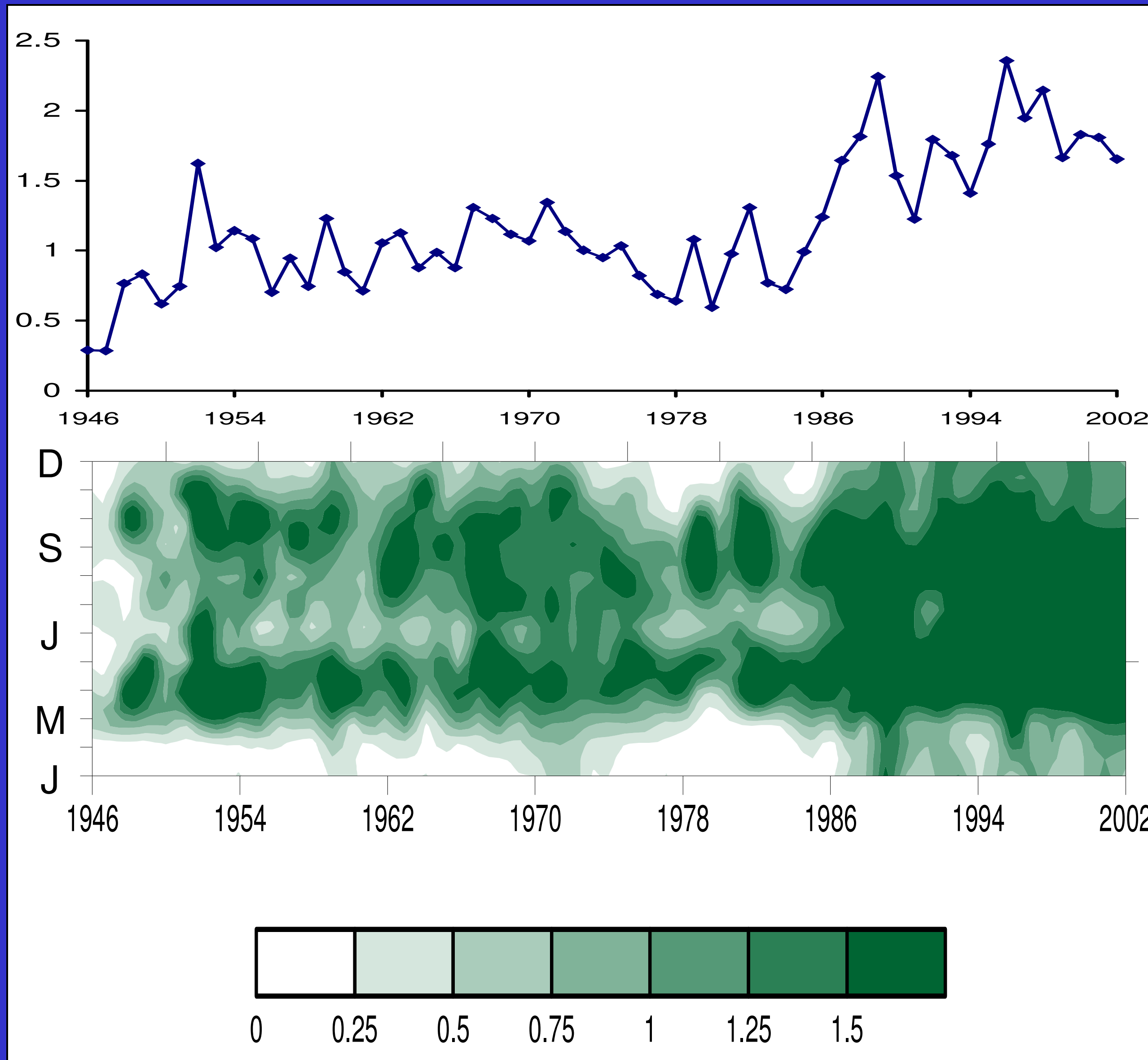




- uses ships of opportunity
- samples caught between 2 rolls of continuously moving silk netting onto roller
- CTDs etc can be added

North Sea Phytoplankton Colour

1946



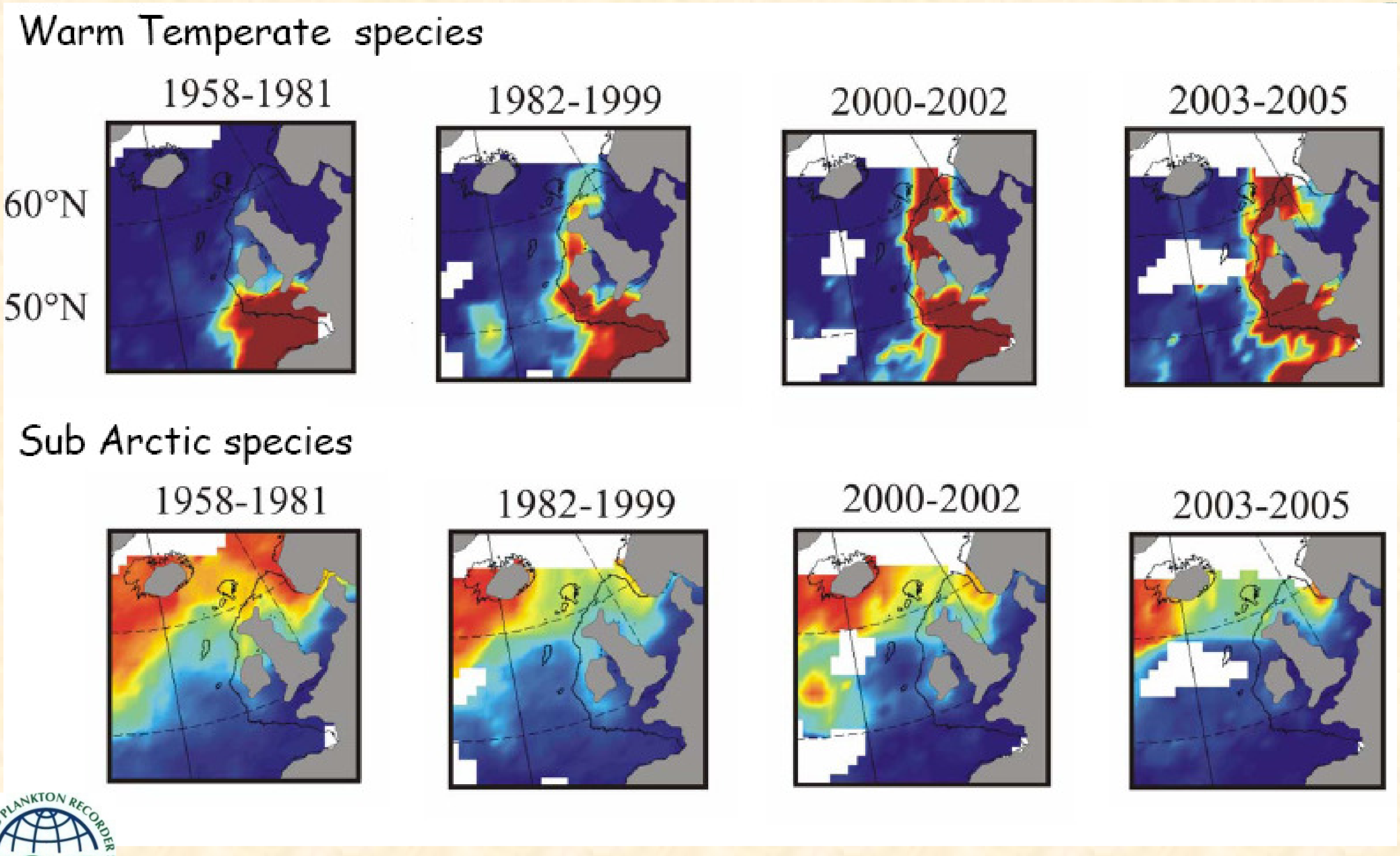
2002

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

SAHFOS

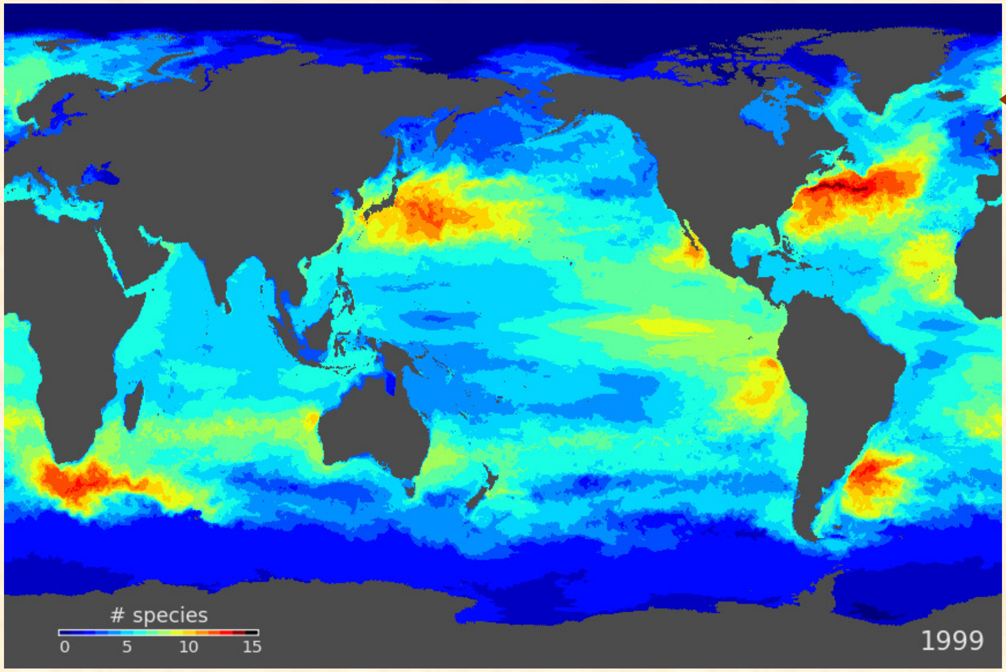
Step changes in regional sea systems: Regime shift

Northerly Shift of Zooplankton



Burkill PP OceanObs09, updated from *Beaugrand et al, 2003, Science 296:1692*

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

Presented at the GLOBEC Open Science Meeting, Victoria, Canada, June 2009

Follows, et al. 2007. Science 315

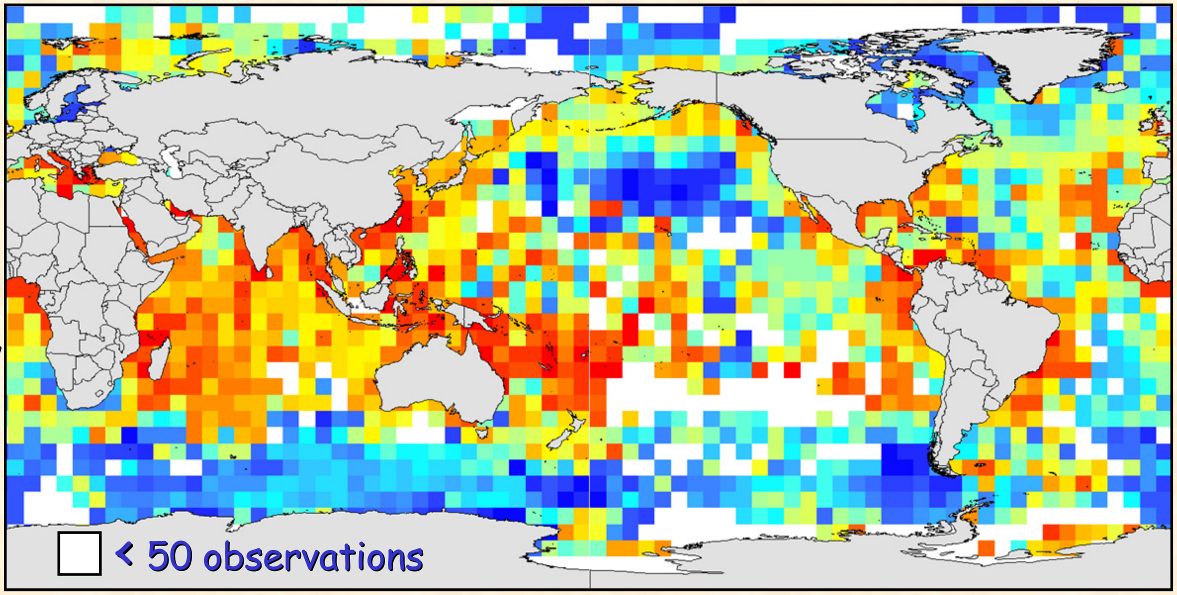
Barton et al. 2010. Science 327

Vanden Berghe et al. Community White Paper, OceanObs09

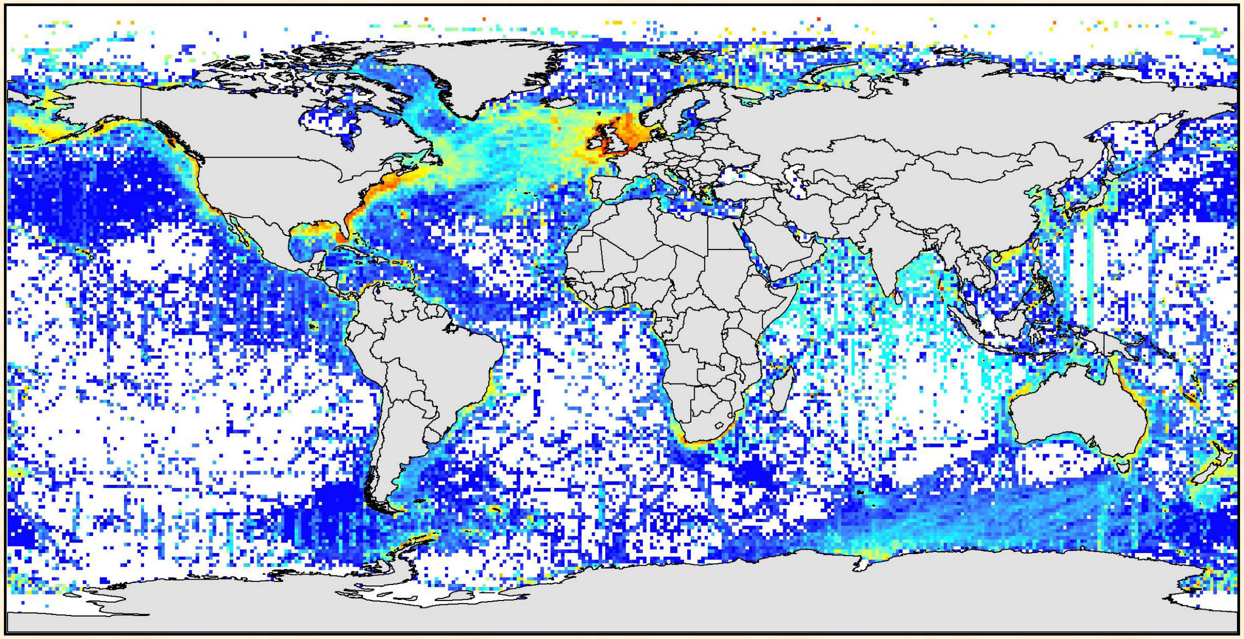
Hurlbert's index of diversity, ES(50): the expected number of distinct species in a random sample of 50 observations of "microbes to whales" calculated on a grid of 5x5 degrees.

See *www.iobis.org*

27.5 M records, 113,000 species (as of 25 May 2010)



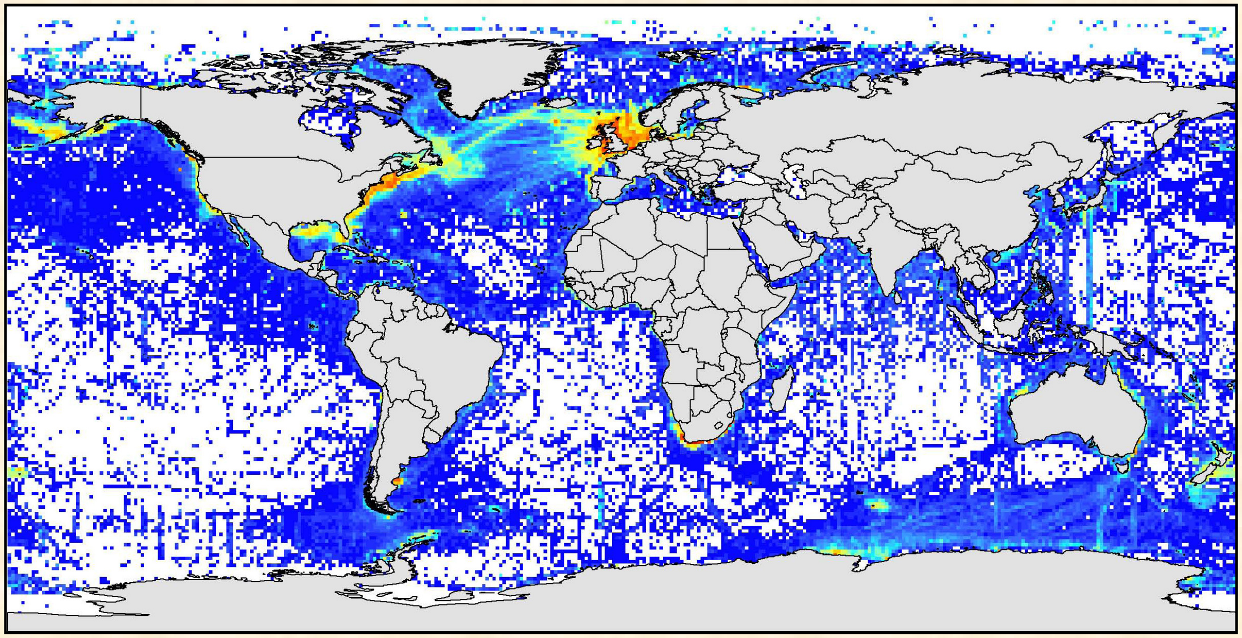
OBIS Database of 27.5 Million Records



Number of species of phytoplankton in each 1° x 1° 'pixel', normalized by area.

Courtesy:

Ed Vanden Berghe
Ocean Biogeographic Information System
Rutgers U., NJ.



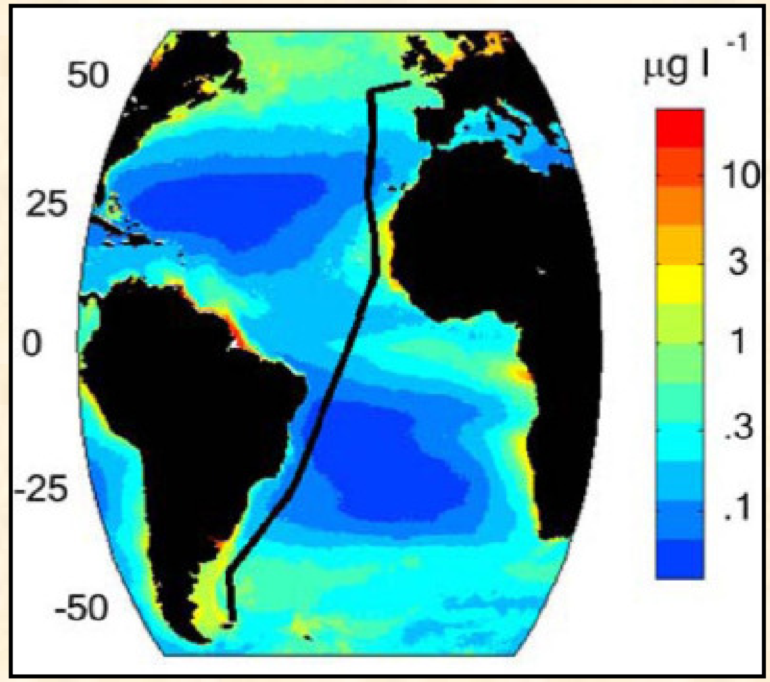
?

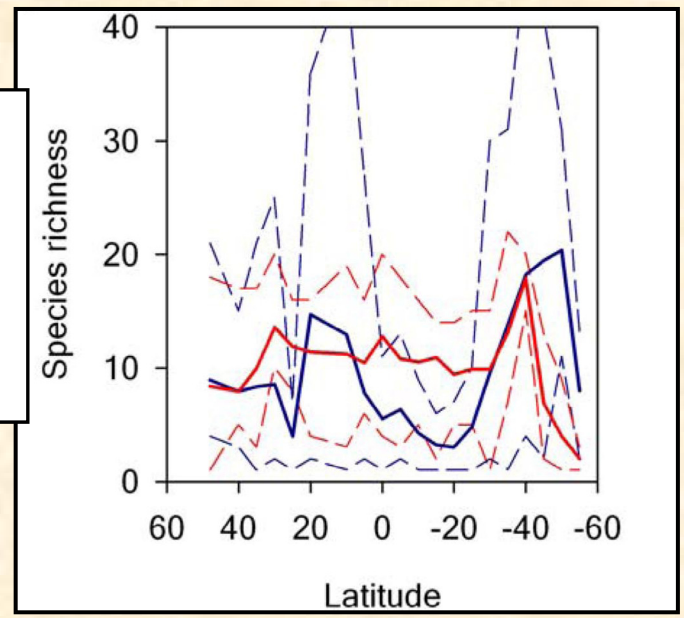
Number of records of phytoplankton species in each 1° x 1° 'pixel', normalized by area.

Four Repeat Sections Along Atlantic Meridonal Transect AMT project

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

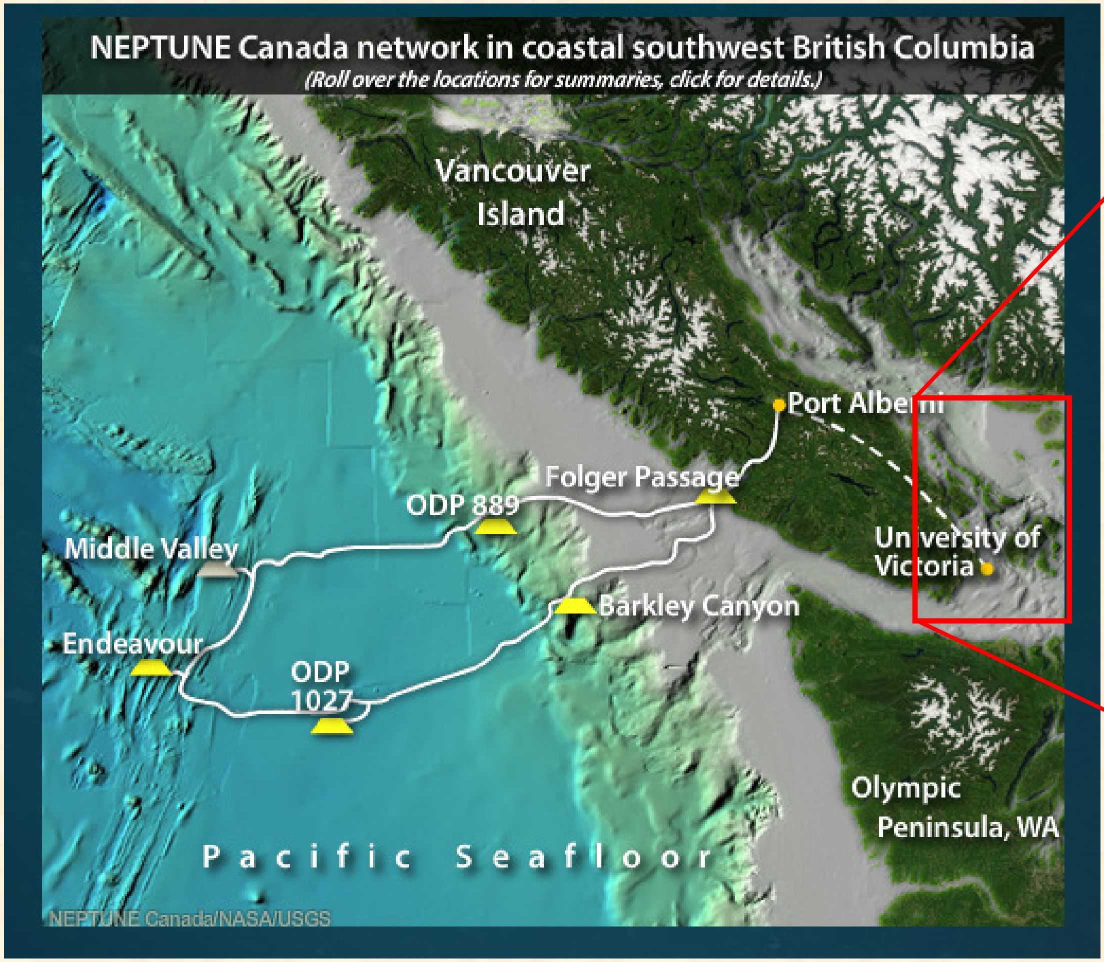
Cermeño et al., 2008. PNAS, 105, 20344-20349.





Diatoms
Coccolithophorids
Mean
Range of data

Ocean Observatories



http://venus.uvic.ca/

www.neptunecanada.com/

http://rucool.marine.rutgers.edu/

OSP: http://www.pmel.noaa.gov/co2/moorings/papa/data_145w_all.htm

Required Improvements

Ocean Physics

- Observations of vertical transport (mixing and advection) processes and rates

Engineering Design

- Instrumentation must be re-engineered: to be robust & reliable, require low power & low maintenance, all at a reasonable cost

Ocean Ecology

- Microbes (anything!) and phytoplankton PFTs
- 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"*

Elements of a Sustained Global Observing System for Ocean Ecosystems

- Satellite remote sensing
- Long term time series stations, e.g. HOT
- Long term Argo-like network of profiling drifters
  - with 'biogeochemical' sensors, e.g. O_2, VPRs, acoustics, …
- Continuous Plankton Recorder survey → go global
- Catalogue of databases
  - linking NODCs, CLIVAR, Argo, SAHFOS, Satellite imagery (e.g.Ocean colour group IOCCG & ChloroGIN), FAO, CDIAC, OBIS/CoML programmes + …
- Coupled ocean ecosystem models and general circulation/climate models
  - 'Optimal state estimation' recognizes uncertainties in models AND in observations

The End

Thanks

ken.denman@ec.gc.ca

And about a class project:

Find Argo floats in N. Pacific with O_2 sensors, plot 'maps' at say 200 and 300m. Compare magnitude and temporal variability with plots of recent O_2 at the different VENUS sites.