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
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’

**Plankton**

- $P_S$
- $N_a$
- $D$
- $P_L$
- $Z_1$
- $Z_2$

**Nekton**

- Salps
- Sea lions
- Seals
- Adult Finfish
- Small Pelagics
- Whales
- Juvenile Finfish
- Humans

Mass Flow

End to End
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.iternet.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*

© I. Grigorov - SOC

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

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]

Station ALOHA 150m

Station K2 150m

Global Change Newsletter No. 73 April 2009
Ecosystem Observation Systems
(modified from Le Quéré et al., CWP)

- Remote sensing – space, acoustics, video (\(\sim 10^6 \text{ m}\))
- Video plankton recorders, shape recognition (\(\sim 10^{-6} \text{ m}\))
- 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


OceanObs09 Sept 15
Regional to Global Derived Time Series


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

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

Thanks: to Peter Burkill and Chris Reid, SAHFOS
North Sea Phytoplankton Colour

Step changes in regional sea systems: Regime shift

Reid et al. 1998, Nature 391, 546 (updated)
Northerly movement of plankton and fish

1960-1963

1996-1999

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]

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.

< 50 observations
Four Repeat Sections Along Atlantic Meridional 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.*

![Graph showing species richness with lines indicating diatoms, coccolithophorids, mean, and range of data.](image)
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, S, Si, P, Fe, etc.*

A Front to Back’ view evolved from focusing on Carbon flows

\[
P_S \quad \text{small phytoplankton}
\]

\[
P_L \quad \text{large phytoplankton i.e diatoms}
\]

\[
N_i \quad \text{nitrate}
\]

\[
N_a \quad \text{ammonium}
\]

\[
D \quad \text{detritus}
\]

\[
Z_1 \quad \text{microzooplankton}
\]

\[
Z_2(t) \quad \text{specified mesozooplankton}
\]

---

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

OceanObs09 Sept
Generic NPZD Model
Scales of Variability

- **Ecological’ scales** for
  - phytoplankton $P$
  - zooplankton $Z$
  - fish $F$

- **Directed motility’ scales**

Modified from Woods (1977) & Steele (1978)

What regulates large-scale patterns of diversity in marine phytoplankton?

Mick Follows, Andrew Barton, Jason Bragg, Stephanie Dutkiewicz, Chris Hill, Oliver Jahn, Glenn Flierl

Presented at the GLOBEC Open Science Meeting, Victoria, Canada, June 2009. Available at [http://web.pml.ac.uk/globec/products/OSM3/wa.htm]
Marine Biodiversity and Ocean Physics (2)

Self-assembling model phytoplankton communities

Many 10s of initialized phytoplankton types
- Stochastically assigned physiological characteristics

Grazers

Global ocean circulation model
N, P, Fe, Si cycles

(Follows et al., 2007; c.f. Pimm and Lawton, 1976)

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