Sverdrup’s (1953) critical depth concept

Important points:
1. $D_c$ and $D_m$ independent
2. $R$ = community respiration
3. Light, not nutrients, limiting
4. Links to papers in Canvas
5. Not the whole story

Hug et al. 2016. *Nature Microbiology*

Traditional view (16SrRNA)

Genomic sequencing

Food-web model (or energy-flow, bottom-up view):

Nutrients, etc. → Phytoplankton → Zooplankton → Fish, Birds, Mammals

Microbes → Microzooplankton

Benthos

Size matters: Microbes in the ocean

A. Who are the microbes and why are they important?
B. Microbial nutrition
C. Microbial Production
D. Microbial consumption and the microbial loop

Take-home message: Microbes rule
**Prokaryotes versus Eukaryotes**

- **Prokaryote**
  - Bacteria and archaea

- **Eukaryote**
  - Eukaryotes (including protozoa)

**How do you study these organisms?**

- Most marine bacteria (> 99%) have never been cultured
- Count bacteria by nuclear staining (DAPI, Acridine orange)
- Count them using flow cytometry
- Determine production using labeled nucleotides or amino acids
- Clone DNA from the ocean and sequence 16S rRNA or genomic DNA
- Perform experiments to determine microbial functions

**Marine microbial genomics**

- Pure culture genomics (right)
  - Get DNA from cultured organisms
- Metagenomics (left)
  - Get DNA from natural communities in seawater
  - Comparisons between culture and seawater DNA allow researchers to infer function

**Roles microbes play in the ocean - food**

- Photoautotrophs – cyanobacteria
  - *Synechococcus*
  - *Trichodesmium* (N-fixer)
  - *Prochlorococcus* (perhaps the most abundant photosynthetic organism in the world, unknown < 1988)
  - Total #: 10^5 cells/ml*10^22 ml in top 50m = 10^27 in ocean
- Photoheterotrophs – cyanobacteria and other bacteria
- Heterophs – bacteria and archaea
- Chemoautotrophs – archaea and bacteria
- Grazers – eukaryotes (microzooplankton)
- Viruses – Control prey populations
Roles microbes play in the ocean - nutrients

- Viruses – Release nutrients from prey via cell lysis
- Nitrogen fixation – cyanobacteria
- Nitrification – bacteria and archaea
- Denitrification – bacteria and archaea

Wild metabolic processes in bacteria & archaea

- Chemoautotrophs: Fe- and Mn-oxidizing, sulfur oxidizing, nitrifying
- Heterotrophs: Aerobic
  Nitrate-reducing
  Iron and manganese reducing
  Sulfate reducing
  Fermentative \( (\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2 \text{CH}_3\text{CH}_2\text{OH} + 2 \text{CO}_2) \)
  Methane-producing

Importance of microbes in the sea: Productivity

Old View: “net phytoplankton” responsible for productivity and zooplankton most important for OM consumption

Newer View:
- “Nanoplankton” (< 60μm) most important for primary production in the open ocean
- Microbes most important for respiration
- Non-living matter (DOC, POC detritus) is an important food resource in the ocean

Sherr and Sherr article

Consumption of microbes and the “Microbial loop”
**Microbial loop: Recovery of DOC by growth and consumption of microbes**

- Major grazers: small (< 5 mm) flagellates
- Minor grazers: larvaceans, pteropods, copepod larvae

How efficient? Is it a carbon “sink” or “link”? Many links in the microbial loop – inefficient (only returns a few percent of carbon to the zooplankton and fish)

But, may stabilize food web during periods of low phytoplankton productivity

Microzooplankton grazing rates as fast or faster than macrozooplankton rates.

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**Fe limitation and phytoplankton blooms**

- Many open ocean areas do not experience spring blooms (Gulf of Alaska, Southern Ocean)
- These areas are dominated by small phytoplankton
- Large diatoms are rare due to Fe limitation (smaller cells take up Fe more efficiently due to large S:V ratio)
- Microzooplankton “keep up” with phytoplankton to prevent blooms
- Microzooplankton do not produce fecal pellets increasing nutrient cycling efficiency